The authors each dedicate this book, with love, to their parents.

David Fox
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A squadron of spacecraft roaring through a star-filled void, a high speed chase through a canyon of eerie, snowcapped mountains, a man in a tuxedo juggling colorful geometric solids whose finale is a backflip into thin air . . . Are these segments from a George Lucas film or a Disney feature? No, they are scenes created entirely inside a computer using state-of-the-art advances in computer animation.

A small town, a man taking a brisk walk down the street, cars, trees, houses zooming by, a waterfall cascading into a valley, a bird flying across a blue sky, three dozen horses galloping in perfect unison, a forward dive into a channel of kaleidoscopic colors . . . Are these images from the same high tech computers? No, these startling effects actually take place on the screen of a low cost personal computer. They are programmed in BASIC (a popular computer language), and this book will show you how to create them.

Computer Animation Primer is actually two books in one. It is the first book to explain simply the details of the new high-tech computer animation as used in the film and television industry. It is also the first to show BASIC programmers how to create superior animation on a low-cost ATARI Home Computer (400, 800, 600XL, 800XL, 1200XL, and the rest of the XL models). Part I covers the theory and applications behind computer animation, including graphics hardware, software, and programming. Part II contains a tutorial describing animation capabilities of the ATARI Home Computers. In this way, the first half of the book will allow you to become familiar with what the computer animation professionals are doing and how they are doing it, while the second part will provide you with the necessary tools to try out some of these ideas at home.

We have also added special flip book movies to these pages. (Flip books are an old-fashioned way to do animation and are still fun to play with today.) When flipped, these pages will give you a taste of computer animation. You will find a sampling of animated segments from the best animation houses in the United States. They will provide you with a preview of the kinds of special effects that are in vogue today and the impact of computer animation. To see the animation in six films, flip
right-hand pages from the back of the book to the front and left-hand pages from the front of the book to the back. The starting points of the films are as follows: Film 1, "Running Boy," page 393; Film 2, "Vol Libre," page 369; Film 3, "The Juggler," page 201; Film 4, "Panasonic Commercial — Paper Airplane," page 2; Film 5, "Times Square," page 218; Film 6, "Walking Man," page 316.

Throughout the text the illustrations are printed in black and white. Color renditions of most of the photos, Figures 5.20 and 5.21, and nine additional images appear in a 16-page insert located between pages 396 and 397.

The chapters of Part I are organized as follows:

Chapter 1, "Animation Perspectives," discusses the theory behind basic animation, i.e., its mechanics and methods. We describe the general theory and psychology of animation — how the eye and brain may be fooled by the computer to perceive motion and how a computer program does the same thing by flipping frames. The chapter then describes the difference in approaches to animation between high tech and personal computers. We present a concise but intriguing history of animation, followed by a description of the computer applications that animation has made possible. Finally, we tell how YOU can get started in this amazing field.

Chapter 2, "Computer Animation Hardware," covers the computer hardware (the nuts and bolts) that makes computer animation possible. We discuss CRT's, stroke and raster graphics, pixels, gray scale, bit planes, frame buffers, and so on. This information will prepare you for understanding the next chapter and how the software tells the hardware to perform its graphic duties.

Chapter 3, "Computer Animation Software and Applications," covers the interesting secrets and tricks which the animation experts use today for creating their images. Included are descriptions of techniques used for defining objects with programs, transformations, achieving realism, removing hidden lines, shading, and various computer paint systems. We will preview some fancy animation equipment used in the film industry and contrast it with some low cost personal computer-based equipment developed by hobbyists. The making of a computer-animation-based movie (TRON) is highlighted to show you how the hardware and software fit together.

Chapter 4, "Personal Computer Animation Features," describes the 13 key capabilities available in many personal computers that make them suitable for animation. With this chapter, you can learn which features to look for when purchasing a personal computer for animation.

The second part of the book describes in detail how to do your own animation on the ATARI Home Computers. To accomplish this goal, we have included a number of impressive animation demo programs for the ATARI Computers that can be entered immediately into a computer and
run, or just studied. In addition, there are a collection of special "black box" machine language routines that will give the reader the tools to harness some of the ATARI Computer's more advanced features. By black box, we mean that the programmer does not need to understand how the routines work to use them. Just plug a series of values into the routine from BASIC and watch the desired effect on the screen. We encourage people to use these routines in their own software, which they can then market. To make learning really easy and to avoid typing in the source code, all the software examples in the book are available on a diskette from Adventure International.

Here is a description of the chapters in Part II:

Chapter 5, "Character Set Animation," covers the use of character set graphics in animation. We show you how to use the ATARI'S built-in character set for simple animation (such as birds flapping their wings), and how to create your own character sets for animation. This last technique allows us to create a man who gingerly walks across the computer screen. Next, we cover character set flipping, showing how to make 36 horses gallop on the screen at once. Finally, using a multi-colored character set (and a redefined display list), we show how to produce an arcade-like explosion on the screen, complete with sound effects.

Chapter 6, "Color Register Animation," describes the use of ATARI'S color map. This color map is a high-tech feature which allows you to change the color on the screen almost instantly with one instruction and without redrawing the image. We first fill the screen with a hypnotic, ever-changing kaleidoscope of colors. A Star Wars type trench program is then created to demonstrate the effect of motion using color registers. This is followed by a program that displays a beautiful cascading waterfall in a peaceful valley.

In Chapter 7, "Player-Missile Graphics," a distinctly ATARI feature, is covered. Players allow you to move animated objects on the screen without having to worry about erasing parts of the background. We'll provide you with a sample program of a bouncing ball to illustrate how Players work. True to cartoon reality, the ball even flattens when it strikes the floor!

Chapter 8, "Using Machine Language Routines in BASIC Programs," uncovers the secrets of enhancing your animations with our black box machine language routines. These routines (which don't need to be understood to be used) are easy to enter from BASIC and bypass much of the tedious work that is required to animate Players. Players can be instantly moved anywhere on the screen, given a horizontal velocity, and automatically animated (using Vertical Blank Interrupts) with as many frames of information as you desire.

Finally, in Chapter 9, "Creating a Scrolling Background," we will present the powerful techniques of fine scrolling and Display List Inter-
rupts. The ATARI Display List will also be covered in depth. There is a demonstration program here which scrolls an entire suburban background across the screen at various speeds. In this chapter there is an impressive concluding animation demonstration program of a little man walking down the street, head bobbing, arms swinging. In the background, trees and houses with lawns and fences scroll by while numerous cars and trucks with roaring engines pass by in the foreground.

The pushing and shoving that goes on around an arcade game and the willingness of people to feed these machines a steady stream of silver, the millions of low-cost computer games sold for the home, and the popularity of special effects films all attest to the fact that a revolution in the video/graphics/film industry is upon us. It is our belief that graphics-oriented personal computers are forerunners of a new and exciting type of home entertainment. Film quality animation effects, perhaps created remotely and downloaded to your system via cable, will be combined with the arcade capability of your personal computer. The result will give you an interactive experience where you become the dominant player in a world of graphics figures and flashing colors.

This book is intended to inspire the development of high quality, graphics-oriented software for home computers, thus harnessing the animation potential of these marvelous machines and speeding us towards the future.

David Fox
Mitchell Waite

December 24, 1983
Saying that the creation of this book was a large project is a gross understatement. Not only did it require more than a year of work, but it also involved hundreds of hours of consultation, research, telephone calls all over the country, programming, programming, and more programming. In fact this book project had the creative support of more people than all our previous books combined. Therefore we would like to pause and express our sincere gratitude to everyone who contributed time and energy to this project.

First and foremost, we want to thank Annie Fox for her constant support and fantastic editing. Without her help, this book would not have been nearly so interesting and easy to read.

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Part I
Levon Klein knew very little about computer animation. He had heard that many recently produced television commercials and feature films were making use of computer-generated graphics, but he wasn’t really sure what that meant. So computers could be programmed to draw pictures, so what? Being so uninformed on the subject, he couldn’t figure out why his editor had sent him to cover the annual computer graphics conference meeting in his home town this year. He wondered about this as he walked up the auditorium’s steep flight of steps, his press badge fluttering in the wind. In preparation for today’s event, a film showcase of recent computer animation films, he had read everything he could get his hands on. Yet the written word hadn’t been enough to enlighten him as to what all the excitement was about.

The guard at the door glanced at Levon’s badge and with a disinterested nod, let him pass. Once inside the immense room, he began looking around for a place to sit. It was then that the enormity of the event began to sink in. Most of the auditorium’s 10,000 seats were already filled with people. The air crackled with the electricity of excited anticipation. Someone with a staff badge walked up to the slightly stunned reporter and hustled him to a seat towards the front of the room.

Three movie screens occupied the stage. As he impatiently waited for the show to begin, he wondered once again what all the excitement was about. Even without a sense of the technology, the high tech jargon bandied about coupled with the tension in the room brought beads of sweat to Levon’s forehead. At last the overhead lights dimmed, the projector rolled, and Levon took a deep breath as a brave new world unfolded on the screen.

His eyes stared at the screen, unsure about what to make of the images. The position of the camera placed the audience above a human figure standing on a grey checkerboard grid. As the camera floated down towards the ground, Levon noticed that the man on the screen, wearing a black tuxedo and top hat, was juggling three brightly colored objects — a red cone, a blue cube, and a green sphere. One thing that made this unlike any ordinary movie was the colors. They were all of an extraordinary intensity, brighter and purer than any Levon had ever seen on film. The
background sky showed a most beautiful sunset with a bright red tinge at the horizon, blending upward into blue, then darker shades of blue, and finally a star-studded black night. An eclipsed sun flared brightly in the sky, lending an eerie quality to the images. The color was so intense, so surreal, that he felt it was safe not to try to predict anything about what would happen next.

Thus suspending the earth-bound laws of physics, Levon’s gaze returned to the juggler whose face was now coming into view. He saw that this was not a man at all, and in that moment it became clear that these computer people had done something revolutionary.

“What is going on?” Levon wondered out loud, not feeling prepared for what he was experiencing.

The juggler was not alive and yet he moved as if he were. As Levon scrutinized him, he was hard pressed to explain the figure’s origin. His movements were too fluid for any robot, and every detail about him was too flawless to have been hand painted. The man’s face, for example, possessed a manufactured quality, like a clothing store manikin, and appeared android-like, totally devoid of expression, and too perfect to be human.

Levon’s puzzling over the figure was abruptly interrupted when suddenly the scene shifted to a series of television commercials. Levon recalled that he had watched these many times, but now he was amazed to find that these images were all computer generated. Watching them at home, he had just enjoyed their spectacular movements. Now he began to appreciate the technology that had helped to create them.

The juggler appeared again, but this time the entire screen was swimming with brilliantly colored geometric objects. One of them, a red sphere, started flying towards the camera and Levon found himself involuntarily ducking at the last moment. Never had he seen such realism and such unlikely camera angles. He knew that what he was watching had all been created by a computer, and that there was no live actor in a suit, no real objects, no sun, no sky. All the objects and colors he was witnessing were simply cold numbers, datapoints once nestled in the vastness of a computer’s memory banks, now converted to film images for his entertainment. Levon was impressed in spite of, or because of this fact, and the visual experience was absolutely compelling.

Another series of exceptional film segments flashed by, and then the juggler’s three geometric shapes reappeared on the screen. Rainbow colors swirled through the objects as the camera moved to a point above them. The scene suddenly changed, and the three objects became three round dots sitting above three silver I’s. The camera began to fly away from the object, which gradually revealed itself to be a badge on one of the juggler’s lapels. Levon was stunned at the smoothness of motion as the camera continued to retreat. The juggler just stood there blinking. Suddenly yet casually, the juggler did something quite unexpected. The
Figure in the tuxedo simply stretched out his arms, took one brave leap over his own head, and did a back flip, disappearing in a brilliant flash. All that was left above the grey checkerboard was his top hat which promptly tumbled to the ground, rolled around a few times, and came to a stop.¹

The audience burst into spontaneous applause. Levon found himself wildly clapping along with everyone else, joining the roar of appreciation which now echoed across the vast hall. "So this is computer animation," he thought to himself. "How in the world did they do that?"

¹To see the juggler do his disappearing act, flip the pages of the book. (Courtesy of Information International, Inc.)
1.1. WELCOME TO COMPUTER ANIMATION

Definition

An-imation (an'a ma'shan), n. 1. to breath artificial life into images for films or computer-generated displays. 2. a sequence of drawings, each slightly different from the preceding one so that, when filmed and run through a projector or when shown on the computer screen in rapid succession, the resulting figures seem to move, dance, or fly about. 3. a motion picture effect which can elevate otherwise mediocre films to financial success. 4. a technique, when combined with fast action and loud noise, which causes millions of people to drop billions of quarters into strange looking boxes.

This definition points out that we are a species of animation and special effects lovers. This has been the case since the days of the early cave dwellers, when flickering flames inspired a sense of wonder in young hearts. As children, we have always been fascinated with animation. Who cannot recall when hands held in front of lamp light created moving butterfly shadows and scary monsters on the wall?

Today the animation love affair has exploded with such intensity that the stars of movies are no longer actors and actresses, but rather behind-the-scenes complex computers and special effects technicians. To the new producers, the entertainment world has become a high-tech special effects race, with those having the best animation leading the pack. The producer with the fastest and highest performing computer will have the tool to make the flashiest special effects (although without a story to go with it, the film may barely break even). In fact, these days we can no longer go to a film and be sure that what we are seeing ever existed in physical space. As our juggler episode showed, it won’t be long before discriminating between real actors and their computer-generated counterparts will be impossible. An entirely new chapter is being written in the film industry. It includes taking the finest aspects of the cliff-hanging adventure thrillers and science fiction films of old and remaking them using high technology’s special effects. Likewise, the television industry is also utilizing the new products of computer animation. The best of today’s animated television commercials are so well done that you can’t even tell that a computer was involved!

1.2. OUR PREMISE

This is a book about computer animation. We have written it to fill a long existing void. For years, very few people could afford to do
computer animation. Skilled mathematicians and computer scientists were required to operate expensive, megalithic machines, and huge sums of money were needed to produce just a few seconds of animation. Consequently, the knowledge of computer animation remained cloistered, the exclusive domain of a small select body of professionals. This book is designed to change that because it was specifically written for the vast number of personal computer users across the country. Today, anyone who can afford to buy a good stereo system can afford to purchase a computer. With the advent of the microcomputer (a.k.a. personal computer, a.k.a. home computer), the rudiments of animation have suddenly become available to a vast body of consumers.

Therefore, a basic premise of this book is:

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AS BIG COMPUTERS GOETH, SO DOOTH THE SMALL.

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In other words, some of what was being accomplished yesterday on expensive high-tech computers (i.e., highly technical, large, expensive, computers) can be accomplished today on low and moderately priced personal computers. To understand this transition from the few to the many, let’s look at an example.

Today a high-tech computer suitable for animation of quality feature length films has a resolution of $1024 \times 1024$ pixels (dots) and a choice of over 16 million colors for each dot. Such a computer animation system might be based on a minicomputer like the DEC VAX 780, which alone costs more than $160,000.

A typical personal computer, on the other hand, has a resolution of $320 \times 192$ dots, can display as many as 16 colors and costs less than $800. Even though the cost ratio of these two systems is 200 to 1, the performance ratio, as we shall soon see, is much closer. The personal computer is generally much easier to control than the high-tech machine, particularly in the area of real time animation. Before we get too involved with the technical side of computer animation and explain how these two machines differ, we want to tell you how this book is organized and how to best use it.

1.3. ABOUT THE BOOK

We have organized this book into two main sections. Part I covers the theory and applications behind computer animation, including
graphics hardware, software, and programming. Part II contains a tutorial describing animation capabilities of the ATARI Home Computers (although some of the ideas can be implemented on computers which have features similar to the ATARI Home Computer). In this way, the first half of the book will allow you to become familiar with what the "big boys" are doing in the field of animation, while the second part will provide you with what you need to try out some of these ideas at home.

**Flip Book**

We have also added special flip book movies to the pages of this book. Flip books, an old-fashioned way to do animation, are still fun to play with today. On the upper page edges you will find an assembly of computer-animated sequences collected from the best animation houses in the United States. By rapidly flipping through the pages, you can preview the kinds of special effects that are in vogue today and get an idea of the vast power of computer animation. We have also put one of our ATARI animated figures in the flip book so you can see it work without the aid of an ATARI computer.

So now that you have an idea of what this book is about, it's time to plow forward, animated head first, into this exciting world of computer special effects and animation.

1.4. **WHAT IS ANIMATION?**

Animation is the process of creating images that appear to move. Motion pictures don't really move. Anyone that has looked at a piece of film knows that the medium is made up of many still images. From a strictly scientific standpoint, animation relies on the mechanics (and in a way imperfections) of the eye. When things move faster than a certain rate (between 18 and 24 times per second), a physiological phenomenon called persistence of vision comes into play and the motion tends to blur together. This happens because a single image flashed at the eye is retained by the brain longer than it is actually registered on the retina. Thus, if a second image is flashed within a certain minimum time (about 50 milliseconds), the brain still retains the last image and the two images may be combined. When a series of images is flashed in rapid succession, as is accomplished with a movie projector, the brain blends the images together. When these images are only slightly changed one to the next, the end effect is that of continuous motion. This very remarkable illusion is the perceptual foundation of film and television. (You can imagine that if the eye didn't have persistence of vision, the world would appear a strange place indeed.)

Animation can be created in several different ways, as we shall soon see. In each of these approaches, the number of images presented to the
eye in one second determines the "flicker rate" of the scene. Flicker occurs when the eye can detect the individual frames of the picture because the time between frames is too long or the degree of motion within consecutive frames is too great (e.g., a "pan" which moves too rapidly across a landscape). When this happens, the picture appears to strobe uncomfortably. Standard 35 mm film, the kind shown at movie theaters, uses a frame rate of 24 frames per second. This means that every second, 24 frames of information appear on the screen. At this rate, there is usually no visible flicker. In low-cost 8 mm camera film, on the other hand, the 18 frames-per-second rate makes the flicker of these films more noticeable. (A point of information: when a film is shown on television, there is a frame rate discrepancy. Television has a frame rate of 30 frames per second, however a film being broadcast usually was created with the 24 frame-per-second format. This conversion is accomplished by showing every fourth frame twice.)

The speed at which objects appear to move in an animation is a function of the number of drawings used to obtain a movement and the distance between the object's position in successive frames. For example, if we are animating a bouncing ball, the farther the ball has moved in each adjacent frame, the faster the ball will appear to travel across the screen. If there is too much distance between balls in successive frames, the ball will appear to jump from one spot on the screen to another, rather than move smoothly.

One can appreciate that a high frame rate can result in there being many frames. Consider a typical two-hour animated movie: 24 frames in 1 second is equivalent to 1440 frames in 1 minute. An hour's worth of animation, therefore, may have up to 86,400 individual frames. A two-hour animation would then need 172,800 individual frames! Before computers were put to work as animation machines, each of these frames had to be hand drawn, painted, and photographed. It is easy to see why animation is such a laborious task and how computers have opened the door to a whole realm of animation possibilities.²

²Even today's most popular animation computer (VAX from Digital Equipment Corp.) needs around 10 minutes to generate a single frame of animation for a high-resolution moderately complex scene. Thus five minutes of animation can take $5 \times 60 \times 24 = 7,200$ frames $\times 10$ min. $= 72,000$ min. $= 1,200$ hrs. $= 50$ 24-hour days! Very complex scenes might take as much as four hours to generate each frame. By the way, a computer that could do this even faster and is now being used by a few of the really wealthy Hollywood studios is the Cray Research CRAY X-MP, which can do 100 to 200 million floating-point instructions per second and costs a mere $15 to $20 million.
What is an Animator?

Although some people consider an animator to be an individual who merely draws the individual frames of a film, giving some object the illusion of motion, nothing could be farther from the truth. An animator is actually an imparter of emotion (definition thanks to Alvy Ray Smith of Lucasfilm). The really great animators (Preston Blair and Frank Thomas, for example), are much more than great artists. Rather than just capturing the essence of a character in a static picture, they must also breathe life into two-dimensional images. The animator quickly sketches the different parts of the figure in motion using intuitive gifts. Assistants to the animators then convert sketches into final art. Although anyone can do a simple animation, the really great animations from studios such as Disney came from such highly gifted individuals. It is therefore unlikely that a computer will ever be able to automatically produce original animations which possess the depth of character of the classics. A human will probably always need to "start the ball rolling."

1.5. WHAT IS COMPUTER ANIMATION?

Computer animation is the process of creating visual movement through the use of a computer. There are two basic divisions of computer animation covered in this book. One is high-tech computer animation used for making films. The other is the low-cost computer animation used in the personal computer and video game area. The techniques and hardware involved in each of these areas differ greatly and consequently will be explained separately.

High-Tech Computer Animation for Film

Let’s first take a look at how computer animation is used in producing effects on film. You know now that cartoon animation traditionally is done by hand-drawing or painting successive frames of an object, each slightly different than the preceding frame. In computer animation, although the computer may be the one to draw the different frames, in most cases the artist will draw the beginning and ending frames and the computer will produce the in-between drawings. (This is more generally referred to as computer-assisted animation, because the computer is more of a helper than an originator.)

High-Tech Computer Animation Programs

In full computer animation, complex mathematical formulas are used to produce the final picture. These formulas operate on extensive databases of numbers that define the objects as they exist in mathematical space. The database consists of endpoints, color and intensity informa-
tion, and so on. Highly trained professionals are needed to produce such effects, because animation that obtains high degrees of realism involves computer techniques for three-dimensional transformation, shading, curvatures, and so on. (This whole area of database animation will be covered in more detail in Chapter 3.)

High-tech computer animation for film involves very expensive computer systems along with special color "terminals" or "frame buffers." The frame buffer is nothing more than a giant image memory for viewing a single frame. It temporarily holds the image for display on the screen.

A camera can be used to film directly from the computer's display screen, but for the highest quality images possible, expensive film recorders are used. The computer computes the positions, colors, etc. for the figures in the picture and sends this information to the recorder which captures it on film. (Sometimes, though, the images are stored on a large magnetic disk before being sent to the recorder.) Once this process is completed, it is repeated for the next frame. When the entire sequence has been recorded on the film, the film must be developed before the animation can be viewed. If the entire sequence doesn't seem right, the motions must be corrected, recomputed, redisplayed and rerecorded. Obviously, this approach can be very time consuming and expensive. Often, computer animation companies first do motion tests with simple, computer-generated line drawings before setting their computers to the task of calculating the high-resolution, realistic looking images. These low resolution images can often be viewed in motion directly from the computer's screen. When these tests look right, the final scenes are computed with a much higher chance of success.

**Personal Computer Animation**

At the other end of the spectrum is animation done on personal computers. These may be for use in video games or educational programs. These low cost units (such as an Apple or an ATARI) have no frame buffer per se. Instead, their relatively small memory is used to temporarily store the image, and the television screen is used to display the animation.

The major difference between the animation generated on personal computers and that of most high-tech computers is that personal computer animation is presented in *real time*. This means that you see the animation as it is occurring on the screen as opposed to waiting for the filming process to capture all the frames. Real-time animation allows effects to be created and checked out almost instantly, which means that decisions about particular scenes can be made on the spot. On the negative side, since personal computers have fewer available colors and lower screen resolutions than the high tech machines, animations produced on them are lacking in these respects. Even if they had these
features, the lack of fast computing power would make the calculation of three-dimensional, shaded objects highly impractical. Most personal computer animations consist of two-dimensional, cartoon-like figures such as space ships, cars, and people and other simple objects running, bouncing, or flying across the screen. Occasionally, enterprising designers will create games on personal computers that have a third dimension, such as moving through a corridor or around a raceway, but this is the exception rather than the rule.

**Personal Computer Animation Programs**

The programs for doing computer animation on personal computers vary from very simple to extremely complex. A simple program could, for example, be written in BASIC. It might use a statement like \texttt{DRAW 1 AT X, Y} to draw a predefined object. The X and Y coordinates would be changed and the object redrawn at a series of new positions, moving the object across the screen. The next level of animation would be to animate the moving object itself (e.g., flapping a bird’s wings or moving a figure’s legs). This could be accomplished by substituting the object on the screen with a new, slightly different object (\texttt{DRAW 2 AT X, Y}), and then a third object is substituted (\texttt{DRAW 3 AT X, Y}), and so on. This is called real-time animation, and it is essentially the technique used in computer games and video arcades.

For microcomputers, non-real-time animation, the method used by the high-tech animators, is definitely a more complex and expensive approach to animation. As with the large systems, it involves drawing a detailed single frame, photographing it on film, or saving it on disk. This process is repeated until all the frames have been drawn. Ideally, the computer will control the camera so the operator doesn’t need to do it manually over the many hours needed to shoot a short segment. In Chapter 3, we will show how an Apple computer is used for just such a process.

1.6. A LITTLE HISTORY OF ANIMATION

Animation using machines has existed for over 150 years! The first animation device was called the Thaumatrope (pronounced THAW-ma-trope). See Figure 1.1. It was invented by an English doctor, John Paris, in the mid-1820’s. The idea behind it involved using strings to twirl a disc with a different picture on each side. When the disc was twirled, you could see both pictures at the same time. The idea for the Thaumatrope probably originated from a spinning coin. When a coin is spun and viewed from the side, the eye’s persistence of vision phenomenon makes the front and back images appear superimposed on each other. (Of course, if the inventors had an ATARI or Apple they could have filled the entire screen with Thaumatrope images.)
The first device that actually produced animated pictures was the Phenakistoscope (fen-a-KEES-ti-scope, meaning motion shower), which dates back to 1832. (Its inventor, Joseph Plateau, was partially blind from staring at the sun for 20 minutes — he was testing persistence of vision!) This device consists of a notched spinning wheel attached to one end of a handle. The spinning disc contains a series of drawn images, each representing a frame of animation. To view the animations, you held the wheel in front of a mirror, peeked through the notches and spun the wheel. The notches acted like the shutter of a movie projector, letting you see each frame for only a fraction of a second rather than a continuous blur. See Figure 1.2.
The next important animation tool, the Zoetrope, or Wheel of Life, was invented around 1834 by William G. Horner in England where people called it the wheel of the devil (much like some people today think video games are entertainment of the devil). It was redesigned in France by Pierre Desvignes in 1860. The Zoetrope is a revolving drum with images drawn inside. Like the Phenakistoscope, the Zoetrope too has equally spaced slits in the sides. When the drum is spun, the images can be seen when viewed through the slits. A record player can be substituted for the drum.

![Zoetrope image](image)

**Figure 1.3:** Zoetrope — the wheel of the devil. (*Courtesy of Stanford University Museum of Art.*)

Long before movie cameras were invented, a man named Eadweard Muybridge lined up a series of still cameras to photograph a horse as it ran down a racetrack. Muybridge had the camera shutters connected to strings across the track so that the horse’s legs would trip each camera as it passed by. He was hoping to settle an argument between Governor Leland Stanford of California and another millionaire. Stanford claimed that when a horse is galloping it has all four feet off the ground at one time. As you can see in Figure 1.4, the Governor was right!^5

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^5In Chapter 5, we present an ATARI animation program that has three dozen horses galloping on the screen. The images for these horses were based on the original photographs by Muybridge. Imagine that . . . one-hundred-year-old data being used in a twentieth century computer program!
Figure 1.4: The horses of Eadweard Muybridge.

Photo 1.2: Muybridge's Zoopraxiscope. (Courtesy of Kingston-upon-Thames Museum and Art Gallery, Stanford University of Art.)
Later, Muybridge developed the Zoopraxiscop (zoo-o-PRAX-a-scope) to project his motion studies on a screen. He used glass wheels with his images running along the outer edge. The disk spun in a projector showing a repeating cycle of motion. A complete cycle, however, only lasted about half a second.

The Praxinoscope (prak-SIN-a-scope) was a device that replaced the Zoetrope's slits with mirrors. Inventor Emile Reynaud created a version of this device which projected images on a screen. Using long strips of translucent paper with frames drawn on them as film, he eventually went into commercial production and opened the world's first movie theater in Paris in 1892. The show lasted only a short time, but this didn't keep people from flocking to see it. In Chapter 9, we present a show of our own, the Great Movie Cartoon. Because it is programmed in BASIC and uses randomness to create figures, this show never repeats itself. Reynaud would have loved it.

Another popular way to produce animation in the old days was the flip book, technically called the Kineograph (KIN-e-o-graf). With this device you draw animated figures on individual cards, stack them up like a deck, and fasten them together. Flip through the stack with your thumb and watch the action. The flip book was patented in 1868 but was in use long before that. Today you can still find peep shows lined with Mutoscopes, Kinetoscopes, and Kinoras. You can cut out the animation frames in the pages of this book and assemble your own custom Kineograph to impress your friends.
Film animation cartoons were pioneered in 1908 by another Frenchman, Emile Cohl. He put black line drawings on sheets of white paper and photographed them. On the screen he used the negative to show white figures moving on a black background.

Animation techniques began to move forward as methods improved for producing movement and life-like motion. In the next few years a rush of new cartoons were produced, including Gertie the Trained Dinosaur (1909), and in 1917 the first really memorable cartoon character, Felix the Cat, was born.

The following techniques were devised and experimented with prior to the appearance of Felix the Cat:

- Silhouette films. Black cut-out figures were used on plain white backgrounds to create the animation. These figures were easy to draw and move compared to line drawings.
- Phase animation. In this approach, sketches were superimposed on top of each other to save the repeated drawing of a background for different phases in the movement of foreground figures.
- Cel animation. This eliminated phase animation by using transparent celluloid for the foreground and simply superimposing them over an opaque background. Now foreground figures could be moved anywhere on the background and only one photograph was necessary.

In the early 1920s the work of drawing the backgrounds became separate from the main task of the animation movement. Specialists in backgrounds perfected the scenes that the animation people placed their figures upon. In a further division of labor, the time consuming task of taking the outlines of the figures and filling in the color on the transparency or cel was isolated. This separate job is referred to as opaquing or filling.

In 1928, Walt Disney Studios began turning out popular animated cartoons. From the early 1930s to the early 1960s, film animation produced a large number of notable and memorable cartoons that captured the imagination of the public. It became common to expect cartoons to appear at the beginning of every movie. Eventually these cartoons became a main part of television. Among the more popular were: Max Fleischer’s Popeye (1933), Mickey Mouse, Snow White, Pinocchio, Fantasia, Dumbo, Donald Duck (all Walt Disney); Tom and Jerry (MGM); Woody Woodpecker (Walter Lantz); Bugs Bunny and Sylvester (Warner Brothers); Mr. Magoo (UPA).

In the 1960s two scientists from Bell Labs developed the world’s first computer animations. Messrs. Zajac and Knowlton’s achievements were in the area of abstract and texturized patterns. This set the early stages for later high-tech animations on computers by demonstrating that textures could in fact be modeled on a screen. Further research in the use
of computers for graphic output helped progress the field of computer animation. Some of the largest and best funded laboratories developed uses for computer animation including simulation of the flow of viscous fluids (Los Alamos), propagation of shock waves in a solid (Lawrence Livermore National Laboratory), vibration and landing of an aircraft (Boeing Aircraft).

Since the 1970s, computer animation has grown as computers improved and new techniques for manipulating pictures were discovered. Companies specializing in generation of computer animation have been founded across the country, including such names as MAGI, Information International Incorporated, Lucasfilm Ltd., Robert Abel and Associates, Digital Effects, etc. Television advertisers have become primary buyers of animation, using it to grab the viewer’s attention and hopefully to get them to remember “the incredible commercial” they saw on the box. Whether they actually recall the name of the product is another story.

1.7. HOW IS COMPUTER ANIMATION USED TODAY?

Today people are creating hundreds of applications for computer animation. Due to the popularity of the home computer, we are, in fact, in the middle of a revolution in computer animation applications. This low-cost device is driving manufacturers to pursue new techniques for the generation of visual effects. Since we are such a visual culture, the computer screen, the television screen, the photograph, and the movie screen are all blending together. In one study done by Sony Corp., it was discovered that people will more likely trust the validity of an image they see on television over one they see in a photograph or a book! Consequently, Sony is designing all its future products to output to the TV screen.

Applications in the Film Industry

Perhaps the fastest growing use of computer animation is in the film industry. Did you know, for example, that computer animation was used in filming the Death Star simulation at the pilot’s briefing in the film, Star Wars — A New Hope? Although the rest of that movie’s special effects utilized either hand-built models or conventional animation, these will not be the methods of choice for long. One very desirable but not yet fully realized approach is to use computer-generated animation to replace the hand-built models and hand-painted matte backgrounds. (See Photo 1.3 for an example of the kind of incredible realism that is possible today.) Since the resolution provided by computers can now exceed that of film and since a computer-simulated model destroyed by phaser never needs rebuilding, the computer approach promises to improve realism and
lower production costs at the same time. Unfortunately, there is still an important drawback to all of this computer generated animation — it takes a long time to enter all the coordinate information for the model the first time. Luscasfilm, for example, finds that hand built models can be constructed, destroyed and reconstructed faster than a similarly complex model can be entered into the computer database. One potential answer to the database entering problem is to “grow” the model in the computer. If this were possible, we could let the computer create its own database, using brief guidelines set out by the designer of the model.

One movie that used a large amount of computer animation (a full fifteen minutes worth) is TRON from Walt Disney Productions. Although Disney’s Studio was the king of the mountain for many years, the rising labor costs of hand-painted cels made it too expensive to produce full-length feature animation cartoons. With TRON, Disney hoped for a major comeback. As shown in the figure below, TRON takes place inside a giant computer controlled by an evil master control program.

Photo 1.3: This X-Wing Fighter is based on those used in Star Wars films. The realism is so outstanding that the animated fighter can’t be distinguished from a model of “the real thing.” (Courtesy of Information International, Inc.)
Photo 1.4: Light Cycles race through a simulated landscape of TRON. High-tech artist Syd Mead designed the vehicles. MAGI created the images. Notice the good shading effects. (Courtesy of Walt Disney Production. ©MCMLXXXII Walt Disney Production, World Rights Reserved.)

Photo 1.5: a) As we approach a dead, moon-like planet at 100,000 miles per hour, a wall of flames begins spreading over and melting its entire surface from the impact of the Genesis bomb. Four separate programs were used to generate this image. One produced a star field as seen from the star Epsilon Indi using an accurate database, another generated the planet and its texture mapped cratered surface, a third generated the fires, and a fourth composited all the elements together (with no matte lines). b) From the planet's molten surface has arisen fractal mountains (mountains developed from controlled randomness) and beautiful lakes and oceans. The faint blue atmosphere just beginning to form can be seen in the color insert. The once dead planet has turned into an earth-like planet because of the Genesis effect.

Even though TRON used the largest quantity of computer graphics to date, the most sophisticated computer graphics ever put on the big screen appeared in Star Trek II — The Wrath of Khan. The one minute segment showing the Genesis device simulation was produced in a five month period by the computer graphics wizards at Lucasfilm Ltd. Photo 1.5a) and b) show two scenes from this segment.

Although they are revolutionary in their own ways, Star Wars, TRON, and Star Trek II were not the first uses of computers in special
effects movie making. Early science fiction used analog computers (called Scanimates) to produce weird bending and waving, mandala patterns, and other effects. These devices simply distorted the picture signal before it reached the screen.

The advent of the digital computer made it possible to have the picture exist completely inside the computer memory. Mathematical formulas could then be used to manipulate the scene and the result was some very realistic pictures with special qualities. The tradeoffs are that special formulas called transformations are needed (we’ll describe these in Chapter 3) and that mathematically minded programmers must be enlisted. As we mentioned earlier, however, good animation requires artistic talent. As the computer software for doing these animations becomes more user oriented, it will become easier for non-computer oriented animators to create and control them. And who knows, after a while simple animations without much detail may become totally automated.

**Applications of Animation in Space**

In the area of space exploration, computer animation serves a most valuable function. The Pioneer and Voyager space probes launched by the National Aeronautics and Space Administration (NASA) were simulated by James Blinn (with Charles Kohlhase) at the Jet Propulsion Laboratory. (See Photo 1.6.) By putting physical laws of space and motion into the computer, NASA scientists could see what certain trajectories would look like and observe scenes as if they were riding on the vehicle itself! The computer also allows alterations in perspective which can place the observer behind the vehicle, thereby letting him view the entire scene with both vehicle and planet visible. These same simulation techniques were employed with the space shuttle to test its entry into the atmosphere. In addition, with the help of the computer, otherwise devastating errors could be dealt with safely. If, for example, a launch

*Photo 1.6: NASA/JPL “Voyager-2 encounter with Uranus on 1-24-86.” Computer simulation of the space probe as it approaches the planet Uranus in 1986. (Courtesy of James Blinn with Charles Kohlhase of NASA/JPL.)*
orbit was mistakenly calculated, the worst that could happen was that all the dots in the picture turned fiery red as the probe crashed into the planet or shot off the edges of the frame buffer (i.e., into uncharted space).

Medical Research Applications

The use of animation in the medical sciences is becoming important in helping doctors and researchers to visualize the composition of a particular organ or bone structure. In Photo 1.7 we can see several views of the spine as modeled by a computer. The doctor can literally fly about the spine structure as if in a helicopter. Since it’s formed like a wire-frame model, this kind of visual examination actually permits the structure to be viewed more thoroughly. One day doctors might fly around inside our bodies, having first scanned them with whole body scanners to obtain cross sections. The computers would assemble these cross sections into a three-dimensional model, and physicians could then study the resulting computer images on the screen. By storing these images, patients could look at them too, and thereby better understand what the doctor had viewed. With this increased awareness of his body’s disfunctioning, the patient might be better able to help in the healing process.

Photo 1.7: This high-resolution three-dimensional wire frame image of the spine shows two different views. (Courtesy of Digital Effects — Rutgers Medical School, “Spine,” 1981.)
Sports Applications

Animation can be used in the sports world to help athletes improve their performance. Below, for example, we see four frames of a running man. It is possible to simulate a certain runner’s motion, captured by computers and turned into images on the screen. Close examination could reveal imperfections in the runner’s stride and suggest improvements that could make the difference between winning and losing. Similar ideas could apply to the swing of a tennis racquet, golf club, or baseball bat. The computer digitizes the swing or converts it into a form that the computer can manipulate, so it can transform it into a screen image. (We’ll explain that in more detail later.) The trainer utilizing this technique could then modify the actual swing database for a more ideal swing. The athlete would try to mimic the improved version of the swing while the computer monitored. Audio feedback would be provided to indicate the approximation of the athlete’s swing to the ideal. The louder or higher pitch in the tone, the closer the approximation is getting to the ideal programmed case. The use of audio feedback removes the necessity of having to watch the screen at all times.

Photo 1.8: The Running Man shows the kind of detail possible in a frame buffer. Compare this with the Running Boy in the ATARI program in the second part of this book. (Courtesy of Advanced Electronics Design, Inc. (AED)).

Educational Applications

Computer animation has a promising future in the educational fields. Currently however, there hasn’t been too much evidence of its use here. The main reason for this is that software companies with the ability to create impressive animation have not yet been willing to divert their programmers from the lucrative game market to the burgeoning educational market.

Computer animation will most likely be utilized to embellish teaching programs (courseware) on personal computers. To begin with, a classroom computer could be set up in an “attract” mode just like arcade games, presenting a beautiful visual stimulation that entices the student
to try a programmed lesson. Book covers are supposed to serve this function, and a computer screen could do it much better. See Photo 1.9.

Photo 1.9: This is the opening screen from "Juggles’ Rainbow," a program that teaches young children the difference between above and below, left and right. The balls are moving through space as music is played in the background. (Courtesy of Atari, Inc. and The Learning Company.)

Once the student has been lured by animation, more animation could be used to create an exciting lesson. For example, a program that might teach a student geography could simulate a spinning globe on the computer screen in real time, as shown in Photo 1.10. (This sequence was actually taken off the display of an ATARI Home Computer.)

Computer animation could also be used in the physical sciences. In physics, for example, it could effectively simulate motion on the screen. In this way we could plot the course of a comet as it passed by a planet, the flight of a bumblebee landing on a flower, or the path of a baseball as it flew towards the batter. All the vector arrows we see in physics books could be superimposed right on the computer screen, and as the object moved, these arrows would change, reflecting the object’s changes in velocity, inertia, etc. Likewise, in the study of engineering, computer animation could be used to teach how robots walk, or in electronics, to show the flow of electricity in wire. The possibilities for using animation as a teaching tool are limitless.
Photo 1.10: The Spinning Earth, an ATARI animation program, contains 24 frames worth of data (first eight frames shown here) showing the spinning earth. Each frame represents 15 degrees of rotation, so when the entire sequence is animated on the ATARI Home Computer, the effect of a spinning globe is produced. The original data base was on an IBM 370, had a 256 x 256 resolution, and occupied 196 K bytes of data. This program made a transition from the IBM 370 to a CP/M system to a Sorcerer and finally to an ATARI Home Computer. The resolution was lowered, and the pictures were compressed so they would all fit in the ATARI memory at once. Two screen pages were used. When one has been drawn, it is switched on and displayed while the other is being created by decoding the frame data. These photos illustrate the high-resolution effects possible on an ATARI Home Computer. (Courtesy of Robin Ziegler. Created by Robin Ziegler and Bruce Merrit.)
Engineering Applications

Engineering lends itself ideally to the capabilities offered in computer animation. Essentially, animation allows designers and engineers to visualize complex processes and to make better decisions regarding them. For example, animating a complex structure allows viewing from many angles and better understanding on all levels. Consider the three-dimensional wire frame photos below. Because of the transparency of a wire frame structure, the entire shape can be viewed at the same time. In addition, animation enables us to study structures in motion. Complex DNA strands, for example, are difficult to comprehend when viewed from a stationary position. When you see them rotating and spinning on the computer’s screen, however, the underlying structure becomes clear.

In civil engineering, the ability to model a building before it is actually constructed can prevent enormous structural blunders from occurring. For example, a computer animation of the sun rising on an

Photo 1.11: The circular red and yellow wire frame structure (see color insert) is being rotated in three dimensions, showing a good variation of perspective. (Romulus, “Merck Timoptol,” 1981. Courtesy of Digital Effects.)
office complex can be simulated. At the same time, an engineer could take a simulated drive down the road that was to be constructed as an entrance to the new building. The computer could display the precise angle of the sun as reflected off the building. If the subsequent reflection was found to be disturbing and potentially dangerous to oncoming drivers, the angles and position of the building could be adjusted accordingly before anything was committed to concrete and steel.

Air flight simulations on the computer are invaluable to the airframe engineer. (An airframe engineer designs the structural frames of aircraft.) Mathematical storms, wind shear, and icing effects are variables encountered in flight that can be simulated by computer. The airframe engineer can watch the flight path on the screen and judge the performance of the plane as the variables are manipulated.

The advantages of computer animation in engineering are limited only by your imagination and the power of the computer.

![a) b)]](image)

**Photo 1.12:** These two photos show the wire frame output of the NorthStar Advantage personal computer. This special computer has a built-in graphics BASIC (called GBASIC) and graphics calls in the operating system. (Courtesy of NorthStar Computers.)

**Artistic Applications**

The world of art is still a relatively unexplored territory for computer animation. For many years, artists in general shied away from computers as a medium of expression. Today, however, computers and artists are beginning to mix. Now with sophisticated paint systems that are more user-oriented, artists are discovering that a computer which offers a palette of 16 million color combinations opens new realms of visual delights. Once an artist becomes adept at using the new tools, the level of artistic productivity is greatly increased.

In Photo 1.13, an artist is using a computer system to change the appearance of a Victorian home. The house itself was entered into the computer from a photograph, and now that it is stored, the artist can play around with different elements that will alter its external structure. For example, the computer allows the artist to draw in different shrubs to see
how they enhance the house’s image. Also, the computer makes experimenting with different color combinations child’s play. In a matter of seconds, you can completely change the color of the house’s entire facade.

Photo 1.13: Susan Bickford, of Digital Effects, NY, is using a paint system, Video Palette 3, a $125,000 system which includes a DEC 11/34 computer, graphics tablet, and paint software. Susan is using the system to paint a house that was digitized from a black and white photograph. She later added the color and the bushes in front (you can see the hand-drawn quality of the bushes). This system uses a palette of 256 colors, selected from 16 million. It allows you to vary the brush size and type, save images, and repaint these images in a different size and location on the screen. You can zoom in on an object or pan the scene to the right or the left. The menu for this paint system can be seen overlayed on the photo in b). In c) Susan instructed the computer to change the values in the color registers, producing a dramatic “digital effect on the final picture. This photo also shows the high quality of the characters on the screen’s paint menu (see color insert). (Courtesy of Digital Effects.)

Another attractive art-oriented feature of computer animation and graphics is the degree of realism the computer offers over paint. Because the computer has higher resolution than film, visual effects can be produced which were never possible with the standard art media. Shades of color too subtle to be mixed by the unskilled hand can be created and recreated with ease by anyone. Blending of color can be controlled with incredible precision. Note the fantastic realism of the scene in Photo 1.14. Also note the wire frame structure of the paint tubes.
Photo 1.14: Triple I Oil Paint Tubes shows three oil paint tubes on a grid-like floor. From the tube in the foreground a luxurious flow of paint spills out into space. The first tube is represented as a wire frame image, revealing the underlying structure of the shapes used in computer graphics (see color insert). (Courtesy of Information International, Inc.)

Another example of what computer animation offers the artist is shown in Photo 1.15. These are two frames of a computer-generated film called “Carla’s Island.” In the film, the computer was able to simulate completely the sun setting and the water waves lapping at the shore. The light is absolutely perfect because each ray was traced from the viewer’s eye to the object. At this time, the artist would need to have programmer assistance to help create a film of this complexity. In the future, using newly developed tools, however, the artist/animator will be able to create entire films without the aid of the computer programmers.
Photo 1.15: Illustrating reflectance and natural light, these two photos are part of the film "Carla's Island." The film shows a sun setting over ocean waves. The waves are playing on the beach, reflecting the sun's rays perfectly. For every pixel, a ray of light had to be traced from the viewer's eye out to the scene mathematically and further reflected from the water to another part of the scene. This was done using a vectorized ray-tracing algorithm on the extremely powerful Cray 1 computer. The clouds, waves, and islands were all created from mathematical formulas rather than from a data base. Different times of day were created from the same pixel data by changing the values in the color table as the picture was plotted on the Dicom D-48. The sun was added as the picture was drawn. (Courtesy of Nelson Max, Lawrence Livermore National Laboratory.)

Computer animation may be used for other interesting artistic effects. It is possible to have the computer take one picture and convert it into another showing all the in-between stages as it's done. Frames from such a dissolve, or object blend sequence, are shown in Photo 1.16.

Not all artists need to be mathematically inclined to produce an effective animation on computers. The animation called Walking Man located on the page edges of this book was created for us by an artist who simply used cylinders of various sizes and forms to generate the shape of the mechanical man.
Photo 1.16: These three key frames are from an object blend sequence and illustrate how the computer can merge one image into another. The sequence starts out as a detailed bust of a statue and goes through several frames to become two Grecian warriors fighting each other. This sequence is from the award-winning fully animated short entitled “Dilemma” (1981, Educational Film Centre, Great Britain and Computer Creations Inc., South Bend, Indiana).

(VideoCell™ animation courtesy of Computer Creations, South Bend, Indiana.)

Animation in Advertising

Advertising is where the big money is being spent in computer animation today. This is probably because the special effects of computer animation are so novel that even people who don’t like computers are attracted to them. Eventually computer animation may become so commonplace that advertisers will have to try something new to avoid the technocratic, overkill blues. Laser art and three-dimensional television may provide that novelty. Some computer graphics commercials, on the other hand, may not need anything new because they are already so slick; their computer influence is not readily detectable. It is possible that computer animation techniques will be used to produce exceptional graphics effects that would have otherwise required live action film.

One of the oldest uses for computer animation in advertising is the Times Square marquee display. This display is made up of thousands of light bulbs that are controlled by computers housed inside the building. In Photo 1.17 an artist prepares the display for a Timex watch ad.
Photo 1.17: This three-frame sequence shows the famous Times Square display (by Spectacolor, Inc.) in New York. The $40 \times 20$ foot display has a resolution of $64 \times 32$ pixels. Each pixel is a four light bulb cluster (red-blue-green-white). The entire display consists of 8192 bulbs. A computer (a Mark 420 by World-Wide Sign and Indicator Corp.) is used to develop the individual frames that will be animated on the display. In photo a) animator Tom Gemighani is working on an ad for Timex watches. The screen of the computer simulates the resolution of the light bulb display. Tom is working from a storyboard (above the terminal) that tells what each frame of the animation should be like. He has control over each pixel in the display and uses the keyboard to fill in the colors he wants. The final sequence will be displayed at 8 frames per second. Photo b) shows a "big apple" generated on the display, and photo c) is a close-up showing the individual bulbs that comprise the display. Note the "glitches" in the display where bulbs are burned out. (Times Square display courtesy of Spectacolor, Inc.)

The opening sequence of the popular television series, Nova, incorporated some fantastic animation from New York Institute of Technology. This group, located on Long Island, is one of the hotbeds of computer animation research. Photo 1.18 shows the section of the scene where the galaxy that had filled the screen a moment ago begins to shrink leaving the letter "O" (in the word NOVA) to grow and encompass the entire screen.
Photo 1.18: This is a frame from the NYIT-produced opening sequence of Nova, the popular PBS television program. (Courtesy of New York Institute of Technology, Computer Graphics Lab. Graphics by David Geshwind.)

An advertisement for a radio was completely produced with computer animation using a rather old-fashioned yet extremely effective approach (see Photo 1.19). A digital plotter (device for drawing lines on paper under control of a computer) was employed to plot each frame of the ad on paper. The paper images were then photographed through colored filters until the finished ad was created.

Photo 1.19: In this advertisement for a radio, a standard line plotter was used to draw each frame of this sequence with black ink on white paper. (A line plotter is a device that draws lines on a large paper surface in response to commands given to it by a computer.) Various color filters were then used to photograph the image onto film. The filters were placed in front of the line drawings, and then the photographs were overexposed, giving a candy apple neon effect to all the lines. (Separate drawings were created for each color.) The car’s dashboard was painted with conventional techniques and matted in with the computer-generated drawings. What makes this sequence amazing is that the equipment used to create it, an HP Desktop Computer, is quite an affordable machine. (Computer graphics by Colin Cantwell. Courtesy of Marks & Marks.)
State-of-the-Art Computer Animation Center

One of the most prestigious computer graphics houses, where the first computer graphics paint system was developed (more on that soon) and from which many experts got their start, is the New York Institute of Technology (NYIT) Computer Graphics Lab. Manned by a team of over 60 employees, and housed in a pastoral setting, some of the most exciting and realistic computer graphics ever imagined have been created here. Privately funded, the founding fathers of the NYIT system were Ed Catmull, Alvy Ray Smith, Malcolm Blanchard, and David DeFrancisco, who all went on to work at Lucasfilm Ltd.

NYIT probably has the largest and most extensive graphics environment in the world. To display and hold their graphic images, it has over twenty visible frame buffers (frame buffers with a separate processor and video output) and more than fifteen blind frame buffers (large blocks of memory with no video output). NYIT also has an impressive array of large, medium, and small DEC computers. To store the completed images, they have three 2 inch video tape recorders. Connected with a private animation house and video production facility, NYIT is responsible for some of the best video animation yet to appear on a screen. In fact NYIT has produced several computer-animated commercials that are so good that it is impossible to deduce that a computer was on the production payroll. Examples of these are: VW Does It Again, Lincoln Center Live, Nova Opening, Walter Cronkite’s Universe.

Whereas NYIT aims for high-quality video graphics suitable for television (525 line), other computer animation centers, such as Lucasfilm, are geared for super high resolution for film. Towards this end, Lucasfilm is developing a laser printer capable of directly drawing images on film, thereby eliminating the degradation caused by filming off a CRT screen (we’ll explain what a CRT is in Chapter 2 — for now it’s just like a television screen).

Biological Simulation Applications

One growing application of computer animation is in the simulation of how molecules are formed. In most cases, molecular structures are inferred from special x-ray techniques. By shining x-rays on the specimen, a shadow or flat imprint of the internal composition of the molecule is obtained. From this imprint, mathematical relationships between the various parts of the molecule can be generated and fed into a computer. Once the database for the molecule is inside the computer, animation and graphics can be used to draw it on the screen and rotate it to various viewing angles. Photo 1.20 shows a virus that was modeled in the computer. Note the fabulous detail and fine shading that the computer graphics were able to produce.
Photo 1.20: Photo a) is a computer photograph showing a hemisphere of 90 of the full 180 amino acid subunits contained in the protein coat of the tomato bushy stunt virus. X-ray crystallography was used to reveal the basic structure of the virus. Nelson Max then used this information to create the model. Hidden surface computations, which give the outlines of the visible parts of the spheres, were done on the CDC 7600 at the LLNL Computer Center. Color shading and highlights were calculated on a Sperry-Univac V75 minicomputer and then plotted on a Dicom D-48 color film recorder, which uses a high-resolution black and white CRT tube. Color filters were used while transferring the image to film. A special program used to produce the visible surfaces called ATOMLLL was employed. ATOMLLL is adapted from a similar program called ATOMS developed at Bell Labs. Spheres are divided into trapezoids of vertical slices in the ATOMLLL algorithm. Nelson Max added code that allowed shading and light reflection. The shading took five minutes to compute (4096 x 4096 resolution).

Photo b) shows three of the red protein subunits in greater detail. The big red spheres from a) are broken down into greater detail where each smaller sphere represents an individual amino acid. Although the yellow spheres appear in both pictures, it is now apparent that the yellow chains are wrapped around a three-fold helix. The pink regions of the protein extend beyond the shell of the virus and are not indicated in a). (See color insert.) (Courtesy of Nelson Max, Lawrence Livermore National Laboratory.)

Arcade Game Animation

Arcade games found at bars, pizza parlors, and shopping centers are among the most sophisticated examples of real-time animation you can find. Our earlier explanation of computer animation mentioned that personal computers take advantage of displaying action on the screen as it is occurring, rather than using the display and film approach of the high-tech computers. The arcade games utilize very sophisticated microprocessors and computer technology to achieve their effects. Anyone who has played some of the newer high-speed arcade games knows that the action can be so exciting as to actually cause dizziness and elevations in blood pressure.

One car-racing game has the player looking out the front window of a car, steering wheel clutched in sweating palms. While you are in the
driver's seat, you rapidly tear around the corners of the racetrack. Houses and trees zoom by the screen edges at incredible speeds, while other racing cars pass you and smash into your car causing it to careen off the road and crash in a screaming tangle of exploding light and sound. (This is definitely not a game for someone with a weak heart!) Other games have you piloting a jet over complex futuristic terrain while being showered with flack and attacking rockets. The perspective in these games is so engrossingly real that the playing time seems like seconds instead of minutes. Technically, these games are able to achieve real-time animation via custom high-speed circuits and non-standard programming techniques.

1.8. GETTING STARTED IN ANIMATION TODAY

Now that you have seen what can be done with animation you might well be wondering "How do I get started?" The answer depends on what kind of animation you want to explore. There are about four general areas to examine: personal computer animation at home for fun, personal computer animation for profit (i.e., writing games), arcade game animation, and high-tech animation for the film or advertising industry. Let's take a look at each of these.

Personal Computer Animation for Fun

If you wish to simply play with computer animation on your own computer for fun, your task is relatively simple. As we explain in Chapter 4, plenty of home computers will give impressive animation effects without much programming required. You will probably want to do real-time animation; home computers are set up for that. You will also probably want to start by learning a computer language such as BASIC, Pascal, or Logo, because these languages are relatively easy to learn and apply. (Of all three, Logo is the easiest, BASIC next, and then Pascal. However Pascal is probably the most powerful for animation.) Finally, you will want to take a close look at purchasing a computer that has good color capability, has a fast display, has a selection of powerful graphics-oriented languages, and allows custom character set graphics (see Chapter 4).

You could produce non-real-time animation at home on a personal computer too. This will require more investment in hardware (a camera, filters, special motors for turning them, etc. — see Chapter 3) and some knowledge of graphics transformations (which are really not too difficult to understand). Of course, you must have a fundamental knowledge of computer graphics. This book will aid in your understanding of graphics and the use of ATARI products. Computer Graphics Primer by Mitchell Waite (Howard Sams & Co., Indianapolis, IN) will help in your discovery of Apple Computer’s graphics.
Personal Computer Animation for Profit

If you want to write computer games for personal computers that effectively use animation, your task will be a bit tougher. You need to know a high-level computer language such as BASIC or Pascal and probably assembly language (the programming language of the microprocessor). You need to know assembly because good animations must be fast, and BASIC (and sometimes even Pascal) lacks this high speed. You should also look at Forth and C, two high-speed languages that are now available for many personal computers. You will also need to play around with games already on the market and at arcades to get an idea of what people are looking for.

Arcade Game Animation

If you want to do animation on arcade games, you’ll need to learn assembly language for several of the more popular microprocessors. In addition, you will need to be well versed in electronics because these games pull out all the technological stops to obtain an effect. You might also need to understand something called bit-slice microprocessors, as well as the Forth language. Forth is a tricky, powerful, exclusive (bordering on religious) language that is also extremely fast. If you don’t intend to do all of this as an independent agent, it would help to get a position with a company that programs and sells arcade games. A job with an outfit like that might enable you to learn by osmosis.

High-Tech Animation for Film or Advertising

If you wish to get into high-tech computer graphics, such as the kind Lucasfilm uses, then you’ll need to learn the language C and frame buffer technology. Most of the animation houses across the country use large, expensive Digital Equipment VAX or similar minicomputers hooked up to a commercial or custom frame buffer. Some universities have similar computers you could study on. Even if you had access to one of those, most of the software for doing animation on these machines are custom-made, one-of-a-kind products. One solution would be to go to work for a company that makes frame buffers or computer graphics terminals.

The Bottom Line

Obviously there is no right way to get started in computer animation. The best approach is to absorb everything you can about it. You can attend the SIGGRAPH* conventions that occur each year around the end of July and rub shoulders with the computer graphics pros.

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*SIGGRAPH Conference Office, 111 East Wacker Drive, Chicago, Illinois 60601, (312) 644-6610, Telex: 25-4073 SBA.
We'd like to see you get your own computer and start programming away in the haven of your home. In this way you can create a computer animation that may impress someone enough to give you a job or to buy your computer game. Who knows, one day your animations may be viewed across the country either on film or on a computer screen. If you study personal computers in depth, you will be in a position to write special effects that have never been seen before. For example, one student in a computer graphics class wrote an ATARI program that simulates three dimensions just like the old three-dimensional movies, using a pair of red/blue glasses! Good luck and happy animating!

Photo 1.21: Pyramid. (Courtesy of Information International, Inc.)
In the previous chapter we explained the theory of simple animation. We covered the techniques behind hand-drawn animation as used for years in the film industry and (briefly) the differences between high-tech and personal computer animation. Now we are ready to take the next step by examining the hardware (machinery) that is necessary to achieve these animated wonders.

Animation is the most complex and technically sophisticated of all possible computer graphics applications. This being the case, solid grounding in computer graphics hardware is the best way to get started in learning about computer animation. In this chapter we will answer the question “What are the devices that make animation on computers possible?”

Since computer graphics usually starts with a drawing on a computer screen, we will first learn how the hardware of the graphics machine draws on this screen. We will cover the different technologies found in computer graphics (stroke and raster), as well as bits and pixels. We will also be examining how the gray scale works, where color fits in, and how character graphics are done. Finally, we will be presenting material about the purpose and technology of digital frame buffers, the encoding of pictures, video mixing, color in a television, personal computer graphics hardware, and graphics peripherals.

2.1. THE CRT CANVAS

In computer graphics, the most popular “canvas” on which the computer does its painting is called a CRT (cathode ray tube). Although we are no longer in the Flash Gordon Age of Rays, or the Edison Age of

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Footnote:

1 Computers may also draw on paper using special devices called digital plotters. These plotters are very slow devices and therefore less popular than CRTs. They are useful, however, when a hard (tangible) copy of the graphics is needed. (We’ll be discussing them later.)
Tubes, this device persists because as of yet there is no better way to draw with a computer. (Solid-state flat panel displays are still a number of years away.)

As shown in Figure 2.1, the CRT (pronounced C-R-T) is a glass tube-like affair with one large flat end and a long neck. All air is removed, thus the inside of the tube is a vacuum. At the neck end of the CRT is a device that emits billions of electrons. The electrons, like tiny bullets, are shot out towards the flat face end of the tube in a narrow beam, much like squirting water from a hose. The interior side of the CRT’s face is coated with special materials (phosphors) that emit light when struck by electrons at high velocity. (Although this special coating never wears out, too many electrons striking the same spot for a long time can burn the phosphors.) At the point at which the beam of electrons strikes the face of the tube, a tiny spot of light appears. This narrow beam of electrons is the brush with which all images are created on the screen.

**Figure 2.1:** The CRT is revealed.

**Controlling Our Beam “Brush”**

Now that we have a brush (our electron beam) that will draw on the screen, we need a way to control its position. This can be done by putting an electronic field around the neck of the tube at the place where the beam starts its journey.
Just as a magnetic field pulls the needle of a compass, an electric field will bend the electron beam as it travels towards the screen. The goal is to deflect the beam in a predictable manner that can be controlled by external signals. (The problem associated with this is akin to trying to move a hose that is squirting colored water in such a fashion that it draws a picture on the grass.) There are two ways to accomplish the deflection. One is by using metal plates inside the neck of the tube and applying an electric voltage to them. The other involves using wire coils wrapped around the neck and applying electric current to them. The use of coils is the preferred method for televisions and computer graphics CRTs, whereas plates are employed more often for deflection in oscilloscopes. (Oscilloscopes are instruments used by technicians and engineers to study the images of electronic signals. We describe them in this section to help explain the evolution of the graphics computer.)

There are two sets of plates or coils on the tube, one vertical set and one horizontal set. In terms of plates, if we apply a positive voltage to the right horizontal plate, the beam will be pulled (deflected) to the right. Reversing the voltage (positive on left) pulls the beam to the left. A similar effect occurs with the vertical plates, and the beam is deflected up and down. See Figure 2.2.

As the beam moves across the face of the CRT, it also causes the spot of light to move, leaving a trace of light behind it. The trace of light then corresponds to the electric signals that are deflecting the beam. Basically, the position of the spot of light is proportional or analog to the signals controlling it, and consequently we call such signals analog voltages. For example, the greater the amplitude (strength) of the voltages applied to the vertical plates, the higher up the beam (and dot of light) moves on the screen. By applying repetitive voltages to the plates
of the CRT and by varying the amplitude and repetition rates (number of times the voltages change amplitude per second), it is possible to actually see these signals on the face of the CRT. This is the designed purpose of oscilloscopes as a service and research tool, although for many years underground artists used them to generate some beautiful effects by combining special signals on the face of the scope. See Photo 2.1 for an example of this.

![Photo 2.1: Lissajou art pattern on an oscilloscope. (By M. Waite.)](image)

**Drawing on Our CRT with Analog Circuits**

Now that you have an idea of how the beam is deflected and moved about, let's see how we can capitalize on this method to draw an actual shape on the face of the CRT.

Take a look at Figure 2.3. It shows the face of the CRT, the horizontal and vertical deflection plates, and two signals applied to the two sets of plates. The two signals are called waveforms. Each waveform has been carefully produced by special analog signal generation circuits. The signals repeat over and over. One of the signals goes to the electron gun and can turn it on and off. When the signal is steady (indicated by a horizontal line on the waveform), the beam holds its position steady on the screen for that axis. When the signal is ramping (indicated by an angled line going up or down in the waveform), the beam moves from left
to right, or up and down depending on the plate receiving the ramp. In essence, while one signal holds the beam steady on one axis of the screen, the other is moving it in a straight line. By properly coordinating these two signals, we can construct a box shape, the shape of a house as shown in the example, or any shape at all, for that matter. (If you follow the signals and the numbers on the figures you will see how the beam is traced out on the screen.)

![Diagram of beam deflection](image)

**Figure 2.3:** Drawing a house on the CRT with analog circuits.

As you can see from the figure, even drawing a shape as simple as a two-dimensional house requires fairly complex waveforms. As the shape we wish to display increases in complexity, so do the signals needed to create that shape. Although it is a simple matter in electronics to generate symmetrical, repetitive waveforms, the generation of irregular asymmetrical repetitive signals like the kind used in our example is costly and difficult. Sophisticated generation circuits are required, and herein lies the problem. Such circuits are complex, bulky, expensive and unreliable. Because they are analog, they require passive components (resistors, capacitors, etc.) and are sensitive to heat, therefore varying in value with the passage of time. Consequently the display image would be subject to change, requiring repeated trimming (adjusting) of the components. And yet, for many years, despite all of these inherent problems, analog circuits were the only approach in use for generating graphic displays. With the invention of the digital computer, however, a major shift occurred in computer graphics that doomed a lot of expensive analog equipment to the already cluttered closets of the research laboratory.

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For the purposes of the discussion, the waveforms in the figure are actually a distortion from what would be used in a real application.
2.2. STROKE GRAPHICS

Digital computers marked the next logical step in graphics evolution by replacing the analog circuits of the display with digital numbers. Digital numbers are special in that they are made up of several signals. Each signal is very simple and has only one of two possible states, ON or OFF. Since they do not cover the smooth range of values that the analog signals cover, they are not subject to the drift and reliability problems. To create a number with the digital values, several ON-OFF signals must be combined. This is done to represent numbers using the binary numbering system. (Binary is just another way to count. The decimal system counts to ten before creating a new digit; the binary system counts to two before creating a new digit.)

Imagine that each digit of a binary number is a switch. When the switch is ON the digit is called a 1 and when it is OFF, it’s called a 0. The number of binary digits that are used controls the size of the binary value. Below we show some values of a four-digit binary number. On the left are the switch settings, in the middle is the binary representation of these, and on the right are the decimal equivalents of the binary numbers.

<table>
<thead>
<tr>
<th>Switches</th>
<th>Binary</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF OFF OFF OFF</td>
<td>0 0 0 0</td>
<td>0</td>
</tr>
<tr>
<td>OFF OFF OFF ON</td>
<td>0 0 0 1</td>
<td>1</td>
</tr>
<tr>
<td>OFF OFF ON OFF</td>
<td>0 0 1 0</td>
<td>2</td>
</tr>
<tr>
<td>OFF OFF ON ON</td>
<td>0 0 1 1</td>
<td>3</td>
</tr>
<tr>
<td>OFF ON OFF OFF</td>
<td>0 1 0 0</td>
<td>4</td>
</tr>
</tbody>
</table>

Thus, instead of the analog circuits generating complex waveforms, the digital computer manipulates the binary ON-OFF values. The computer works directly with numbers instead of signals and uses mathematics in a more practical fashion. Unfortunately, the use of digital computers created a new problem: they produce binary voltages but the CRT requires analog voltages. Therefore, an additional device called a digital-to-analog convertor (DAC) was installed between the digital output of the computer and the analog input of the CRT. The DACs converted the binary ON-OFF language of the computer into the smooth analog signals needed to bend the electron beam.
In Figure 2.4, we see that a DAC is nothing more than a series of resistors hooked together to sum the various binary values. Each resistor is chosen so that the binary digit attached to it contributes a certain amount of electricity that is proportional to its weight in the number. This means that the topmost significant digits of the binary value have a bigger effect on the final voltage than the lower, least significant digits.

![Figure 2.4: How a digital-to-analog converter works.](image)

(A) THE OLD WAY: STROKE GRAPHICS

IN STROKE GRAPHICS D/A CONVERTERS ARE EXPENSIVE AND SLOW. COMPUTER IS OVERBURDENED WITH REFRESHING DISPLAY, DOESN'T WORK WITH EXISTING TV's, AND SO ON.

(B) STROKE GRAPHICS:

HERE FIVE X,Y POINT PAIRS DEFINE THE SHAPE SO LITTLE MEMORY IS REQUIRED; HOWEVER, EXPENSIVE ANALOG CIRCUITRY RAISES COST.

![Figure 2.5: Stroke graphics using DACs.](image)
Figure 2.5 shows the complete DAC-based graphics computer. Let's see how to draw with it. To begin with, pairs of numbers (in binary) representing the voltage values of the endpoints of the shape's lines are put in the computer's memory. For example, using our previous figure of the house which was painted with the analog circuits, we would set up the binary voltage pairs to correspond to the values in the figure, i.e., the first pair would be $-6/+3$, the next $0/+6$ ($X$ values given first), and so on. (If you're interested in how to do negative binary, see Microcomputer Primer by Mitchell Waite and Michael Pardee, Howard W. Sams and Company, Indianapolis, IN.)

The computer feeds the binary endpoint pairs to the DACs, and they in turn convert the binary values to analog voltages that are sent to the deflection plates. This technique is referred to as stroke graphics because in a single stroke, the beam draws a line from the last point on the screen to the next point. The computer only has to deal with line segments. This stroke approach is also called vector graphics, a vector being a line defined by a start point and an endpoint. The shape drawn with the vector display consists of a list of endpoints defining the shape. To add a new piece to the display, the computer would generate new endpoints and insert them in the list. Moving the shape on the screen requires that some offset value be added or subtracted to all the values in the list. With the development of vector displays, life for the graphics computer user became much easier.

The vector approach ushered in a new era of capability. CRTs and computers began to be used for radar displays, for modeling mathematics, and for revealing the insides of molecules. Although the vector approach allowed dramatic displays and is still in use, it has a serious drawback. Like the analog circuits described earlier, high performance DACs suitable for good quality graphics contain analog circuits that must be adjusted, are temperature sensitive, and relatively unreliable. Therefore DAC-based graphic computers are expensive and utilized only when money is not a primary concern.

2.3. RASTER GRAPHICS

The most popular approach to computer graphics, known as raster graphics, is based on ideas similar to the weaving of rugs. In weaving, an image is created by many strands that all run in lines in one direction. By dividing individual lines into segments of color and coordinating them to coincide with adjacent lines above and below, or right and left, a very beautiful pattern can be formed.

In computer graphics, the CRT beam can be deflected in a similar weaving pattern for drawing on the screen. The weaving pattern is referred to as a raster. In raster scanning, the CRT beam is deflected in a weaving pattern that zig-zags across the screen and down, many times
per second (see Figure 2.6). A standard television also uses raster scanning. The actual lines are visible when you look at the screen at close proximity. For the purpose of the following discussion, when we talk about the raster display, consider that it applies to the television display. (The television has additional components that will be described later in more detail.)

![Diagram of computer, video signal, and television or monitor]

**Figure 2.6**: Raster scanning.

Basically, the graphics computer draws on a raster-scanned screen by keeping track at all times of where the beam is in its scanning field. If it can turn the beam on at the proper location on the raster, a picture can be formed. Because there are a limited number of lines in the display, a closely scrutinized picture will appear to be made up of a series of dots. If there are enough lines and you don’t observe from too close a vantage point, however, the individual picture dots will blend together and a finely detailed image will result.

How does the computer know where to put the dots so as to create the image? And how does it get the raster on the screen in the first place? The answer to these questions is found in the sync circuits and sync pulses.
To get the beam to scan on the screen properly, the raster display contains special vertical and horizontal scanning generators. These are devices that produce a signal which is sent to the deflection plates. The signal is a sawtooth-shaped waveform that, like the signals we saw for driving the oscilloscope, cause the beam to move across the screen, from the top to the bottom and back. The horizontal transit is controlled by the ramping portion of the horizontal sawtooth. During this time the beam can be turned on to display a dot somewhere on the line. The trip back to the beginning of the line happens very quickly by the falling, straight line portion of the sawtooth. At the same time the beam is brought across the screen, a vertical sawtooth signal is driving it downwards.

In standard U.S. video, the beam traces out 525 horizontal lines (actually only 484 plus two half lines are visible). This is done at a rate of about 30 times per second. To decrease the amount of flicker this would produce, the picture is divided into two parts, called fields. Each field contains every other line of the 525 line display. The fields are thus interleaved so that the entire screen is filled with an image 60 times per second. This is called video interlace. Since the weaving pattern is repeated at such a high rate, any dot that is illuminated will appear to the eye to be steady on the display (because of persistence of vision). The 60 cycle rate is called vertical refresh because an entirely new field is scanned (refreshed) 60 times per second.

The scanning generators inside the display device need some way to stay in coordination with the computer, or the computer will not know where the beam is. The solution is that special sync pulses are developed in the computer. These sync pulses are inserted into the main video output that is sent to the display (the information for turning on the beam is in between the pulses). These pulses tell the scan generators when to start scanning a line and when to return the beam to the top of the screen. Circuits in the display strip off and use the pulses to get in step with the computer’s signal. (Without the sync pulses the picture would roll vertically or tear horizontally as you have probably seen it do when it is "out of sync.")

Horizontal sync pulses start the horizontal sweep of the beam, and vertical sync pulses start the vertical trace of the beam. In between these pulses is the video information, also in the form of pulses, that makes up a single horizontal line on the TV. The horizontal lines are like the threads

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3The reason for scanning the picture 60 times per second and not 24 or some other value has to do with the way the United States distributes electricity. In the U.S., all electrical power is alternating at 60 cycles per second (AC). In Europe the rate is 50 Hz. If the vertical refresh rate was anything other than 60, any leakage or ripple from the power line would "beat" with the refresh rate. The result would be a picture that would roll on the screen. By using 60 cycles, we can lock the picture at the same rate as the power line and have a very steady display.
running through the rug, and the video information is like the intensity or color changes on each thread. The sync pulses are the beginnings and endings of the threads.

On a single one of the 525 lines, a large number of dots may be defined, but only a limited number may be displayed due to the mechanics of the display and the limitations of the electronic circuits. An upper limit of about 500 different dots on a line is possible on a black and white display, whereas about 200 are possible on a color display.

![Diagram of raster](image)

**Figure 2.7:** Details of the standard raster.

On a black and white display, video information on each line tells the beam of electrons how intense the dot of light is to be. The light can be controlled from very white to gray to black (no light). In the case of the simplest black and white graphics computers, the video information is represented as a single pulse that indicates whether a dot on a line should be white or black. More sophisticated graphics computers allow the dot
to be one of many shades and are referred to as having gray scale capability.

A computer that is properly synchronized can turn the beam on at any point in the display's X-Y plane, thus forming a dot there. The raster-scanned screen can thus be imagined as a super dense matrix of about 500 dots by 500 lines. If the beam is turned on at specific locations on the screen, we get a shape made of tiny points. This may seem quite a bit more complex than the stroke graphics, but, in fact, raster scanning graphics considerably reduces the cost of the circuits needed for displaying information and leads to a much less expensive computer. The main reason this is true is because the analog circuits of the vector display (the DACs) can be eliminated; also, because the circuitry for televisions is mass produced, it is quite inexpensive.

The negative aspect to the raster graphics approach is that unlike stroke graphics, it must store all the points for the shape being drawn rather than just the endpoints. All these points are stored in the computer's memory. This used to present more of a problem than it does today, since the costs of computer memory devices have been drastically decreased.

Now that you have an idea of what the screen of the computer is all about, let's take a look at how the computer takes its stored pictures from its memory and puts them onto the screen.

**Figure 2.8:** Sync signals.

### 2.4. THE GRAPHICS COMPUTER — A FIRST LOOK

Any graphics computer, whether it's a low cost $99 personal unit (like a Sinclair/Timex ZX-81) or a large expensive mainframe, contains several identically functioning components. (See Figure 2.9.) These are
the central processing unit (CPU), the bus, read/write memory (RAM), read-only memory (ROM), keyboard, graphics input devices, the video I/O section (shown expanded in the figure), and mass storage devices.

The CPU can be thought of as the thinking part of the computer's brain. It is the required intelligence that tells the rest of the computer what to do and how to do it, and is primarily used to interpret the instructions of the computer program. In personal computers the CPU is a microprocessor, a small, mass-produced device, the size of a stick of chewing gum, which contains thousands of transistors. In expensive mainframe
computers, the CPU is usually a complex arrangement of custom devices, each specially designed for the job.

The computer’s bus is where information flows back and forth between the different devices. It is like a high-speed railroad on which signals carrying graphics information can travel. You don’t really need to understand fully how the bus or microprocessor work to do graphics or animation. It is important, however, to be aware of their basic functions in the system.

![Photo 2.2: A typical graphics computer. (Courtesy of Tektronix.)(50 / Computer Animation Hardware)](image)

Let’s continue with our explanation of the standard components of the graphics computer. The computer’s keyboard, which resembles a typewriter, is for entering alphanumeric (letters and numbers) informa-
tion, such as instructions and programs, into the computer.

The RAM is where the instructions and data for the computer are temporarily stored while the computer is doing its processing. The RAM is also where the image of the picture that is on the screen is stored. Screen memory may be either a portion of the RAM memory or a separate RAM memory. Its purpose is to hold the image that will be displayed on the CRT.

The ROM is where special programs and data are kept. When the power is turned off, information in RAM is lost, but information in ROM stays. This special data is always instantly available to the computer.

The graphics input devices are the channel through which graphic information, such as picture and drawings, may be entered into the computer (more on these later). The video scanning circuits are used to take the image in the screen memory and put it on the CRT. You'll learn more about this soon.

Finally, every graphics computer needs a mass storage device. This device functions as a long-term storage of information that has been processed by the computer, i.e., computer programs that will be loaded into the memory, and other data. (Information from the computer can be stored on magnetic material in the same way music is stored on magnetic tape.)

2.5. THE BIT AND THE PIXEL

Earlier we described how pictures could be drawn on a raster-oriented computer screen by having the image composed of tiny dots of light. These dots, which have specific locations on the screen, are called pixels (or pels), which stands for picture element. Pixels become visible by turning on the electron beam at the proper location and proper moment on the screen line.

Where do these pixels come from, and (since timing is crucial to creating animation) what tells them to turn on? They are stored in a special area of the computer’s memory called screen memory or the bit plane. 4 The dots are represented in screen memory as voltage levels using the same binary system we described earlier. A dot that is visible on the screen is stored in memory as an ON voltage, while all invisible dots are stored as OFF voltages. We can consider the ON and OFF voltages as switches that can be on or off. The locations that store these on and off

---
4The remaining portion of memory that is NOT devoted to holding the screen image also contains bits that are on or off. These bits, however, correspond to instructions for the microprocessor or special program data. The versatile computer actually has the ability to store data, pictures, and instructions all in the same memory.
voltages are called bits, an abbreviated way of saying binary digit. Figure 2.10 shows this relationship. In a typical graphics computer there are thousands of these bits devoted to holding our precious image. In our simple example, each bit in the computer’s memory corresponds exactly to a certain pixel location on the screen.

Contained inside the computer are scanning circuits, called multiplexers, that fly through the screen memory synchronized with the scanning of the raster. They are digital devices that very quickly count all the addresses of the memory and read each memory location. The purpose of these scanning circuits is to look at every memory location in the screen memory and decide if a bit is on or off. If it is on, then the video information that is being sent to the display is given a pulse to cause the beam on the screen to turn on (and thus become white and visible). Otherwise, the beam is left off, and black is visible at the location.

(a) HOW BITS LOOK IN 8-BIT WIDE MEMORY

(b) TWO DIMENSIONAL REPRESENTATION

(c) PIXELS ON SCREEN

NOTE 1's CORRESPOND TO DARK DOTS IN PICTURE ON RIGHT

• = 1 ON BIT

O = 0 OFF BIT

(continued)
The correspondence between memory and dots on the screen can tell us the amount of memory bytes needed for a certain desired resolution. For example, suppose the computer is to have a black and white (or black and green) display and that each dot will take up one bit of memory. If the display is to have a resolution of 320 horizontal dots by 200 lines, the result is $320 \times 200$ or 64,000 pixels on the screen. This means that for our example of one bit per pixel, there must also be 64,000 bits in the memory. Since computers usually specify memory storage in terms of bytes ($8 \text{ bits} = 1 \text{ byte}$), we need $64,000/8$ or 8,000 bytes for this particular display. Later we will see how adding color or extra shades to each pixel increases the number of bits per pixel and subsequently the number of bytes needed in memory to hold the image.

**Bit Planes**

Imagine the screen memory for the computer as a two-dimensional plane of bits, with each bit corresponding to a pixel on the screen. (Even though the screen memory is probably organized in bytes, looking at it as a bit plane simplifies our discussion.) Figure 2.11 shows a bit plane for our black and white $320 \times 200$ display.
2.6. ADDING GRAY SCALE

If we wanted to create a picture with some tonal gradations, how could we do it? In other words, how can we add shades of gray to our black and white display? The gray scale can be created by controlling the intensity of the electron beam as it goes through scanning each pixel on the screen. Recall that so far the beam has been either ON (resulting in white), or OFF (resulting in black). Now we are going to add several levels of intensity between white and black.

For example, if we wish eight levels of gray, then eight intensity levels of the beam are required. Where do these intensity levels come from? Simply by adding more bits for each pixel. Remember our binary switches? How many switches are necessary to offer eight different levels? Or, in other words, how many bits are needed to count from 0 to 7 (0 to 7 represents 8 different states)? Three bits are required, as shown in the following table:
<table>
<thead>
<tr>
<th>Switches</th>
<th>Binary</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF OFF OFF</td>
<td>0 0 0</td>
<td>0</td>
</tr>
<tr>
<td>OFF OFF ON</td>
<td>0 0 1</td>
<td>1</td>
</tr>
<tr>
<td>OFF ON OFF</td>
<td>0 1 0</td>
<td>2</td>
</tr>
<tr>
<td>OFF ON ON</td>
<td>0 1 1</td>
<td>3</td>
</tr>
<tr>
<td>ON OFF OFF</td>
<td>1 0 0</td>
<td>4</td>
</tr>
<tr>
<td>ON OFF ON</td>
<td>1 0 1</td>
<td>5</td>
</tr>
<tr>
<td>ON ON OFF</td>
<td>1 1 0</td>
<td>6</td>
</tr>
<tr>
<td>ON ON ON</td>
<td>1 1 1</td>
<td>7</td>
</tr>
</tbody>
</table>

Another way to determine how many bits are required is to use the following formula: $2$ raised to what power equals the desired number? In the example above, we want $2$ raised to a power that equals $8$. We know that $2$ raised to the third power is $8$. So how do we get the extra bits into our image? We simply stack two additional bit planes to our existing plane, as shown in Figure 2.12. Now each pixel on the screen has 3 bits of information. Since we are allowing the amplitude of our video information to take on one of eight different levels, we need to convert the 3 bits of digital pixel information to eight levels of analog information for controlling the beam’s intensity. Again, the DAC comes to the rescue. In this case, we need a DAC with three inputs. The output on the DAC is mixed with the sync pulses and sent to the display. Now it will convert the 3 digital bits in each scanned memory location to the respective voltage level for the amplitude of the beam.

![Figure 2.12](image)

Figure 2.12  Adding gray scale with three bit planes.

Gray scale is one way that high-tech computers accomplish staggering realism. When the number of bits per pixel is increased beyond a certain number (about 8 bits or 256 levels of gray), it is almost impossible to tell the difference between the digital image of a computer and a photograph.
2.7. ADDING COLOR TO THE DISPLAY

Now that we have a gray scale, the next consideration is to add color. As it turns out, this is not as difficult as you might imagine. Before we explain the process, we first must digress a "bit" and see how color is put on the CRT display device in the first place.

The Famous Red Green Blue (RGB) Monitor

Color is obtained on today's high-tech graphics computers by using the Red Green Blue (RGB) direct drive monitor. This is a fairly expensive ($800 to $5,000) CRT that contains three separate electron beams, one for each of the three primary colors of light: red, green, and blue. In addition, this CRT has built-in scanning circuits for moving the beams on the screen. But, unlike the surface of the black and white CRT, which is coated with a smooth layer of white light-emitting phosphor, the surface of the color CRT is coated with three different phosphors arranged in a triad of dots. (See Figure 2.13.) (Note that instead of dot triads some CRTs use bands of the three color phosphors.) A special metal aperture mask is placed inside the CRT directly over the dots. The holes in the mask allow each of three beams to illuminate its corresponding color dots. The beam designed to produce the color red, for example, will only illuminate the red phosphors.

The computer sends a separate video signal to each of the three color guns, each signal representing an intensity of a screen color. The intensity of each beam then determines how much of that primary color is to be mixed at the pixel location. In other words, if the color at a particular location was to be pure blue, we would turn off the red and green guns and turn on the blue gun full force. If the desired color was purple, we would turn off the green gun and turn on the red and the blue. To produce white, we would turn on all three guns. We can fine tune the exact color that gets shown by controlling the amount of each of the primary colors that gets mixed in at each pixel. This is done precisely the same way as we did with shades of gray, i.e., each gun's intensity is controlled by the computer.

The intensity of each color is in turn set by the number of bits representing that color in the bit plane. For example, suppose we allocate 3 bits for each of the three primary colors, so as to get eight intensities (or shades for each color). This would make a total of 9 bits dedicated to each pixel on the display, and we would have 9 bit planes. The 3 bits per primary color means that we can have eight shades per color at each pixel location, for a total of $8 \times 8 \times 8$ or 512 possible colors! Believe it or not, the human eye can actually distinguish many more colors than this.

We now need three separate DACs in our graphics computer, one for each of the primary colors. The circuitry for driving these DACs increases the complexity and cost of the color display, as does the additional screen memory.
2.8. FRAME BUFFERS

Today most high-tech raster-scan displays are based on the use of a large digital memory called a frame buffer. The frame buffer (which we alluded to when we discussed bit planes) is nothing more than all the bit planes, stacked one upon the other and considered as a single entity. The name "frame buffer" comes from the fact that the device is a large memory designed to hold a single frame of a film, graphic picture, etc.

The number of bit planes being used sets the pixel depth of the frame buffer, which in turn sets the number of bits available for the color description of each pixel. The bit depth, in turn, sets the overall cost of the frame buffer. Obviously, the more bits used for each pixel, the greater the color capability of the buffer. Likewise, the number of horizontal and vertical bits in the frame buffer sets the resolution obtainable on the screen. State-of-the-art animation houses, graphics designers, and others use frame buffers with dimensions of $1024 \times 1024$ pixels and a depth of up to 24 bits. (See Figure 2.14.) In a 24-bit deep frame buffer there are usually 8 bits devoted to each of the primary colors. (Later we'll be showing how there are other ways to organize the bit planes.) This results in $256 \times 256 \times 256 = 16,777,216$ different colors. Although it is unlikely that any living creature could differentiate between two adjacent shades, it points out the range of color the high-tech frame buffer allows.
Let’s do a little exercise to see what such a frame buffer might cost. The total number of bits used in the frame buffer is $1024 \times 1024 \times 24$, which is 25,165,824 bits (24 Mbits for short, pronounced Megabits — one Mbit equals one million bits). Today, a 64 K-bit RAM chip costs (in quantity) about $8.50 (price obtained from the classified ads of BYTE magazine). We would need $24 \text{ Mbits} \div 64 \text{ Kbits} = 384$ chips for our frame buffer. At $8.50$ per RAM chip, this comes to $3,264$ just for the memory portion of the frame buffer. This price does not include the
expensive circuits for driving the DACs that are required for each gun.

In general, frame buffers on the market today represent each color gun’s intensity with 1, 2, 4, 8 or more bits of memory. As we saw earlier, 1 bit is sufficient for simple graphics and leads to a low cost display; 2 and 4 bits are useful for solid colors or shades of gray, and 8 bits are required for finely detailed, shaded pictures.

2.9. GETTING THE FRAME BUFFER IMAGE ON FILM

The purpose of the frame buffer is to allow graphics designers to scan their latest work of art on the CRT. This doesn’t, however, solve the problem of getting the image onto 35 mm film, which is the main concern of animation houses. The way this is done is interesting in that it points out the flaws in the color CRT. The most straightforward approach would be to simply display the frame buffer’s image on a high-quality CRT and take a picture of it. This, however, is not the way they usually do it. Remember the dots and the aperture mask used to keep the guns from illuminating adjacent pixels? Well, because the mask and dots cannot be made smaller than a certain measurement, they end up determining the maximum resolution obtainable on the CRT. This is usually much less than what the frame buffer, the computer, or the film is capable of. Therefore, the film will never show a resolution greater than that mask.

The standard solution to the problem of photographing color is to use a device called a film recorder to photograph the images. It contains a very high-quality black and white monitor and three color filters. Since the black and white monitor contains no mask or color dot triads, it can resolve extremely high-resolution images. Here’s how it’s done.

Three color filters are employed, one at a time. The frame buffer is grouped into three primary colors, red, blue, and green, each having eight bits and planes of intensity information. When the red filter, for example, is placed in front of a black and white monitor, the output from the red planes are turned on and the green and blue planes are disabled. Thus the intensity information for the red part of the picture is now on the CRT and the red filter is in front of it. The frame of film is then exposed. Next the blue plane is enabled, the red and green are disabled, a blue filter is placed in front of the CRT, and the photo is taken again without advancing the film. This same process is then repeated for the green plane. The film automatically mixes the three colors for us. This will produce an image with the same resolution as the frame buffer.

Bypassing the Frame Buffer

It is possible, however, to bypass the frame buffer and send to the film recorder much higher resolution images, even higher than the best of today’s film can resolve. This is accomplished by sending the film recorder a single scan line at a time. The computer displays this single
line on its CRT, exposes the film, and then accepts the next scan line, erasing the first from the screen. This is repeated for each scan line of each frame, producing resolutions as high as $6000 \times 4000$ pixels with 9 bits per color.

Unfortunately, even this approach has a major drawback. It can take as long as five to ten minutes to record each frame at high resolutions. To solve this and many other problems, Lucasfilm is developing the ultimate film animation system, called a Pixar. It is a general-purpose picture computer, complete with processors, plenty of memory, and lasers for I/O (input/output) devices. This hardware production instrument can “suck” pictures from film with its lasers, manipulate the images, and spew them back out with another set of lasers onto new film. Lasers are used because they are the most controllable light source available and produce extremely vivid colors. Future Star Wars films should be of an incomparable visual quality.

2.10. ENCODING THE PICTURE IN THE BUFFER

The process of encoding refers to the way the picture information is organized inside the buffer. There are several ways to accomplish this in the frame buffer. Often, bits are divided in some manner to represent the three primary colors. If the pixel depth is only 8 bits, for example, we might allocate 3 bits to red, 3 bits to green, and 2 bits to blue. The reason for the underrepresentation of blue is that the eye is less sensitive to the blue region of the color spectrum, because it has the smallest number of blue receptors. Thus we allocate fewer bits to blue because they would otherwise be wasted. These three components are then fed to the three guns of the color monitor.

2.11. COLOR MAPPING

The trouble with the simple, 8-bit color encoding scheme above is that the range of colors is limited. With 3 bits per primary color we can only have eight shades of that color. In our example of 3-3-2 bits, we can have up to $8 \times 8 \times 4$ or 256 different shades. Although this may seem like a lot, the human eye is capable of resolving many more shades than this. Fortunately, there is a good way to obtain more color shades without utilizing more frame buffer memory. This method, called color mapping, is used by more high-tech frame buffer manufacturers today (and some personal computer manufacturers such as Atari).

With color mapping, the bit values that are normally stored in the frame buffer are interpreted as addresses or pointers into a table of colors, rather than directly as colors. This table may be an area in RAM or a collection of special color registers. This means, for example, that the
8-bit value at a certain pixel location would point to a table address which contained three individual color values, one for each of the primary colors. (See Figure 2.15.)

By using such an approach, an 8-bit per pixel frame buffer can address a color table with a maximum of 256 color values in it. This means that the screen could display 256 different colors at one time. In addition, each of these individual color components can be defined to a high degree of precision, because the bit length of the table can be much greater than the 8 bits per pixel we showed earlier. For example, the table could be 24 bits wide, therefore allowing 8 bits for each primary color, or 256 shades for each color, or a maximum of 16 million shades per pixel!

Keep in mind, though, that only eight bits are required per pixel. (See the box that follows for another explanation of color mapping.)

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**Figure 2.15:** Pixel values indexing into a color map (a & b).
Another, less apparent advantage of the color map is that changing any colors in the color map table changes all associated colors on the screen instantly! This is useful for painting on the screen and for color animation. For example, suppose there were several balloon shapes on the screen. Some are filled with green, some with magenta, and some with yellow. Suppose we wanted to change all the magenta balloons to pink. In a simple color encoding scheme, we would have to change all the magenta pixels to pink pixels. This would prove to be a time-consuming task. Color mapping, however, enables us to simply change the magenta value in the color map table to pink, and instantly all the magenta balloons turn pink. Frequently, the color map table is referred to as color registers, and the entire process is called color register encoding. We will talk more about color register animation in Chapter 6.

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**Color Mapping and the Magic Paint Store**

Here is a simple analogy you can use to understand the idea of color mapping and color registers. Although we will be using an ATARI Home Computer in our example, with its maximum of 128 colors, the analogy holds true for other machines if you assume the appropriate number of available colors.

Imagine a paint store shelf filled with 128 cans of different color paint. In front of you there are nine magic, empty paint buckets, each one labeled with a number from 0 to 8. Each bucket has a brush in it with the same number (the buckets are the color registers and the paint cans are the colors you can put in the registers). A large canvas is before you, begging for a picture. Feeling artistically inspired, you begin by filling the first bucket with one of the 128 colors (a light blue color), pick up the brush, and paint the sky on your canvas. When you have finished with that color, you fill another bucket with your second color selection and paint some more. You continue this process with the remaining seven buckets. Since there are no empty buckets left, you decide to empty Bucket 0 and fill it with a new color, a deep orange, chosen from the paint cans.

This is where the magic comes into play. Lo and behold, as soon as you put the new color in Bucket 0, the sky in your picture, originally painted with Brush 0, immediately changes to orange! In fact, _everything_ that was previously painted with Brush 0 now appears in the new color currently in Bucket 0! When you try this with Bucket 1, the same thing happens with everything previously painted with Brush 1. You have magically changed your painting from a cool mid-afternoon scene to a fiery sunset — and you didn’t even have to use paint thinner to clean out the old color from the bucket before putting in the new. The new color has the property of completely expunging the old color.

The fact that all colors on the screen painted with a certain bucket change color together can be less than desirable at times. For example, if your sun was setting over a blue ocean, you probably wouldn’t be thrilled by having the Caribbean looking like orangeade.
Another potential problem is that the ATARI Home Computer limits you to a maximum of nine different colors on your canvas when using its color registers. Of course, the machine costs only $200 to $800, so you can't really complain.

Photo 2.3 shows an example of color mapping being used to change the primary colors of a graphic display (see color insert).

Photo 2.3: These photos show the effects of color registers. In a) the circles are all red, while in b) they are blue (see color insert). This was done by changing only one byte in the color register. These graphics are done by Jane Veeder, who is using ZGRASS language on a Datamax UV-1 computer. ZGRASS, developed at the University of Chicago, is a very powerful language especially designed for graphics. (Courtesy of Jane Veeder.)

2.12. VIDEO MIXING VIA BIT PLANES

By treating the frame buffer as several bit planes rather than a single unit, each can be made to hold a separate image. For example, an 8-bit per pixel frame buffer can be divided into two images of 4 bits each, four images of 2 bits each, or eight individual black and white images. In
animation, this means several frames of the image can exist in the buffer at the same time. The video from each plane can be turned on and off, and thereby one image part can be faded out while another is merged in. So by having several bits per pixel, we can do more than just represent different colors and intensities. Using this technique, it is possible to have a static background image while another image transverses it. No special logic operations need to be performed for the movement since each bit plane is independent of the other.

2.13. OTHER ENCODING TECHNIQUES

While the frame buffer is an extremely useful innovation, it does have its problems. For one, it does not offer the most compact way of storing graphic images, and therefore the large amount of memory required keeps costs high. Further, since every byte of the image must be changed if the image is to be shifted the smallest amount, the frame buffer is extremely slow in its response time for moving highly detailed images. Finally, when transferring the image in the frame buffer to the disk for permanent storage, much time is required and much space is used up on the disk itself. One solution to this last problem is based on the compacting of the image via encoding techniques.

Real-Time Scan Conversion

The viability of the frame buffer really deteriorates in terms of compactness of storage when we consider a simple line drawing such as a three-dimensional box. Compared to a stroke graphics display that stores endpoints, the box image could be stored in about 1 percent of the time and 0.2 percent of the memory space as the frame buffer. A solution to this problem is called scan conversion. In scan conversion, the image is stored as geometric descriptions rather than as pixel intensities of the frame buffer. Scan conversion relies on a special display file, which is simply another area of memory for holding endpoint values for an image. A special circuit looks at the display file several times per refresh cycle to generate the image and mathematically determines if a line segment intersects the current scan line being drawn. The image can be easily modified by changing the description in the display file. The problem with this approach is that special hardware is needed to perform the scan conversion at rates of 30 frames per second. Very expensive graphics systems, such as the Link Flight Simulator (a device that allows pilots to be trained in flying new aircraft) uses scan conversion hardware and achieves impressive degrees of realism.

Run-Length Encoding

Another approach to compact storage of images that works on both memory and disk is called run-length encoding. This technique works
best for images involving solid gray or color areas. The approach has been applied even on personal computers such as the Apple and is based on the fact that a typical scan line has pixel values that remain at the same intensity or color for several pixels. This being the case, if we encode the length and intensity of each sequence of identical pixels, we will reduce the amount of memory and disk space required to store the image. Each encoded scan line will then consist of one or more instructions, each of which defines a run length and intensity.

Special hardware can be used in this approach to allow real-time run-length encoding and decoding of the image. It is also possible to design software that will encode and decode the image in non-real time for a savings in memory. Run-length encoding has been employed in some software for the Apple II, when many images need to be stored on the limited space of mini-floppy diskettes. The pictures of the spinning globe from Chapter 1 were encoded in this manner to allow all 24 frames to reside in ATARI's RAM at once.

**Simulation of Resolution with Intensity — Block Pix**

It is possible to simulate a much higher resolution than the X and Y coordinates would imply by using intensity modulation carefully. For example, if you correctly select the color in a single pixel, it is possible to trick the eye into thinking that the resolution is quite high, when, in fact, just the opposite is true.

The series of photographs in Photo 2.4 shows a block pix representation of President Lincoln. Note the marvelous realism the first picture achieves despite the fact that the pixels are relatively large. Shading has greatly affected the way the image is perceived. Note also that when you stand back and squint, the three photos seem very similar. This demonstrates the role of shading and intensity over resolution. A continuing controversy exists among computer graphics experts pertaining to the primary importance of high display resolution versus copious color capability per pixel.

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1 The original block pix picture of Lincoln is a classic by Leon Harmon of Bell Labs done many years ago. These photos are a commercial derivative of the original image.
Photo 2.4: This three frame set (a, b, c) shows a picture of Lincoln evolving through a block pix process where the picture is broken up into fewer and fewer blocks and lower and lower resolution. The intensity and shade of each block, however, is carefully chosen so that the original image can still be recognized, showing that intensity modulation can substitute for absolute resolution.

2.14 ADVANCED GRAPHICS HARDWARE

Thus far, we have limited our discussion to the most fundamental of high-tech graphics hardware. There are much more advanced systems on the market, however, some of which cost in the millions of dollars! A complete understanding of the concepts behind these more advanced devices is not necessary, however, for you to proceed.
2.15. PERSONAL COMPUTER GRAPHICS HARDWARE

Now that you better understand the hardware of the high-tech graphics computer, you are in a good position to tackle the workings of the personal computer hardware used for graphics. We needed to introduce the high-tech hardware first, because, as strange as it may seem, the low-cost color graphics personal computers are actually a bit more complex than their big brothers. This is true for two primary reasons. First, they must work with a color television and consequently a constraint in operation is placed upon them (as you will learn). Second, they must be mass produced and made inexpensively, and this means special tricks are often needed to get the cost low (as you will also soon see).

![Figure 2.16: Personal graphics computer block diagram. This is the same as the previous graphics computer block diagram except for the addition of an RF modulator (as an option).](image)
A block diagram of the personal graphics computer is shown on page 67. It is very similar to the block diagram we showed earlier, except for the inclusion of an RF modulator. The purpose of this is to convert the video information coming from the computer into a high-frequency signal that can be accepted by the television.

Televisions are set up to pull transmitted signals out of airwaves and operate in what is called the radio frequency (RF) spectrum. The RF modulator simply places the computer's video information on an RF wave so it can "ride" into the television. Once the video is inside the TV, usually entering through the antenna terminals, the television strips out the RF, discards it, and merely retains the video portion. From this point, the black and white television works almost identically to the raster-scanning CRT you already learned about. In fact, some of the newer TVs have jacks on the back that allow them to work as direct coupled CRTs!

Getting Color on the Television

When we add color to the personal computer and require it to operate with a standard color television, we have an entirely new ball game. To see how the color computer works, we must first understand how color televisions work.

When color TV was first proposed, it had a major stumbling block to overcome. It had to be compatible with the millions of black and white TVs already on the market. In other words, when a color signal was received it could not interfere with a TV that could only receive black and white. This reality put some real restraints in the design of the color signals. (Had the color television been designed first, things probably would have been much simpler. So much for hindsight.)

Basically like the RGB monitor, the color TV picture tube has three separate intensity-modulated color guns. It also has a shadow mask and a coating of color dot triads (or in some of the newer televisions, stripes) spread over the front interior surface of the tube.

At the transmitting end of television, there are three color signals, often derived live from a camera. The problem is how to get these color signals, which are mixed in with the black and white signal at the transmission end, separated from the black and white signal and finally use them to modulate the three corresponding color guns in a color television.

In 1953, after much head scratching, the television industry came up with the first monochrome (B&W) compatible color transmission method. It is called the National Television System Committee (NTSC) color standard, and it applies to all government-regulated broadcast television systems in the United States and several other countries. The basic underlying principle of the NTSC color standard is the merging of two separate image transmissions, a wide-band signal carrying luminance information and a narrower bandwidth signal containing chromi-
nance information. \textit{(Luminance} is the brightness or intensity of the three colors red, blue, and green. \textit{Chrominance} represents the actual color or hue coming from the three guns.) These signals are derived from mixing the red, blue, and green color signals from the camera (or computer) in a very special way. This special mixing of the color signals and combining for transmission is called NTSC encoding.

After the colors have been mixed in their proper proportions by the encoder, they are used to modulate a high-frequency (3.58 MHz) subcarrier signal. The subcarrier is phase modulated, which means its delay can be varied in different increments. This permits the use of a simple, inexpensive circuit modulator that converts the color bits in the screen memory to phase changes. The carrier is, in turn, mixed in with the waveforms containing the sync signals and sent to the television.

At the television, an NTSC decoder circuit takes apart all the things done by the encoder, thereby separating the colors into their original chrominances. In addition to the color subcarrier signal, a special color burst signal is mixed in with the video signal. This burst contains reference information about the frequency of the color subcarrier and allows the television to “lock” with the original color oscillator.

Another restriction inherent to the functioning of a television is the bandwidth. The television’s bandwidth is the maximum frequency that the television will allow to pass. It sets a limit on the maximum number of color changes possible on a particular line of the screen. Before anything can be received, color signals for the television must fit within the signal bandwidth (4 MHz) of the set. This breaks down the quality of the picture. In addition, all of the encoding and decoding that takes place adds noise to the color signal, further degrading it. At this point we can appreciate why the direct drive RGB monitor gives better quality color than the color television. In a RGB monitor, the bandwidth may be as high as 35 MHz, thus allowing many more color changes to be resolved.

Every personal computer that is designed to work with a color TV has an NTSC color encoding circuit in it. Most personal computers, however, have only the chrominance information encoded. Since the luminance or brightness is fixed, this simplifies the encoding circuits by eliminating the need for a DAC.

2.16. COLOR IN THE PERSONAL COMPUTER

Given that personal computers must keep the cost down, their approach to getting color on the display is more constrained than that of the high-tech graphics machines. For one thing, even though the price of memory is dropping fast, its use must be kept to a minimum, or the computer will be too expensive. The designers of the early personal computers had to invent ways to get color graphics without using up much system RAM. Several methods were used. One was to share
graphics memory with the program memory. For example, in the Apple, ATARI, and in many of today’s new computers, the RAM for the color display is part of the system RAM and is referred to as screen memory. If a program used on such machines is large enough to creep into the area occupied by the screen RAM, high-resolution graphics will not be obtainable. Given this constraint, programmers learned to keep their programs small enough to still use the graphics. (The alternative was forfeiting the graphics and using as much of the RAM as they needed.)

Another way to keep the use of graphics RAM to a minimum is with special encoding techniques that limit the color to certain pixels on the screen. This technique originated with the Apple II’s high-resolution screen and caused programmers many hours of frustration until they finally learned to work around it. In a way, it was a brilliant maneuver by Steve Wozniak, the Apple’s designer, because it allowed the Apple II to be advertised as a system that had $280 \times 192$ resolution in six colors while consuming only 8K bytes of RAM. A little calculating will show this is not possible, as 280 times 192 is 53,760 pixels. Six colors requires about 2½ bits. Two and one half times 53,760 is 134,400 bits. But the Apple’s 8192 byte screen RAM has only 65,536 bits. There is a discrepancy here. The answer is that any color cannot appear in every pixel! Actually you can only have a resolution of $140 \times 192$ on the Apple and get the full 6 colors. To get 280 pixels on a row you have to be willing to accept that every seven pixels only be from one of two color sets. (This is explained in more detail in Chapter 4 in the section pertaining to the Apple II.) Our point here is not to discredit the Apple II, but to show the color limitations of all personal computers.

Newer personal computers, which are following the high-tech machines more closely in their use of graphics, still have some constraints. For example, the IBM Personal Computer has a full 16K bytes of RAM set aside for the graphics and is separate from the program RAM. The IBM PC allows up to 16 colors in a $320 \times 200$ resolution. In reality, however, there are only eight colors and two color sets, one brighter than the other, so that the 16K bytes can handle the full range. Otherwise, 32K bytes would be needed for the graphics RAM.

### 2.17. MEMORY-MAPPED VIDEO AND TEXT STORAGE

In both kinds of raster-scanned systems, the most popular way to display text is to encode the letters, numbers, and special symbols to be displayed into a unique 6- or 7-bit value called an ASCII (ass-key) character. (ASCII stands for American Standard Committee for Information Interchange and is a special set of rules determining what bit patterns are designated for what characters. Almost all computer manufacturers follow the standard.) The ASCII characters are then stored in the computer’s memory.
In order to display the characters, circuits are built that convert the bit patterns stored in the screen memory into dot images. These images are then mixed in with the video and sent to the screen. Usually, a character-generator ROM is used to hold the actual dot images that correspond to the ASCII values stored in memory. There are different kinds of these ROMs, each giving a different style of character on the screen for the ASCII code. The density of the dot matrix for each character that appears on the screen varies from computer to computer. It can have a density ranging from 5 × 7 (the most coarse and not allowing lowercase) to 9 × 12 (the most dense and allowing all symbols of the alphabet as well as special graphic symbols).
In some personal computers, the dot patterns for the characters can be defined in system RAM rather than in a character-generator ROM. This allows the characters to be redefined by the programmer to be whatever is desired. This can include graphics characters, special math symbols, and foreign fonts.

Since the ASCII code is a 7-bit code, there is 1 bit of an 8-bit byte left over. In fact, if only capital letters are used, 6 bits are needed and thus 2 bits are left over. Usually the extra bits of each byte are set up to contain color, intensity, reverse video, or blinking information. In this way, it is possible for each text character to have its own color. In some computers, like the IBM PC, 2 bytes are automatically set aside for each character. One stores the ASCII code and the other stores the attribute for the character, i.e., its foreground and background color, its blinking state, etc.

It should be noted that in many personal computers the screen RAM can simultaneously contain both text characters and graphics. The computer can interpret the byte of screen memory as containing either a ASCII character or several dots of color. In fact, by controlling how many bits make up a pixel and the way in which they are interpreted for color, it is possible to control the amount of color and resolution for several different graphics modes. This is also why you will find that the color graphics personal computers consume different amounts of memory depending on which mode is being used.

2.18. CHARACTER GRAPHICS

Another approach to graphics on personal computers is called character graphics. In this approach, the ASCII text character is replaced by a graphics character, which has been designed by the computer user. In some computers this graphics character may be of several colors and have a density of $8 \times 8$ or larger. By carefully designing several graphics characters, the user can define complex objects that are made up of several of these characters.

In the example below, there are eight distinct graphics characters. The box figure uses nine characters because one character is actually used twice. Had the box been larger, we would have been able to use several of the graphics characters more than once. This graphics character approach to animation is used in several of the sample programs presented in Chapter 5.

With character graphics, we use PRINT statements from BASIC to send the characters to the screen. We draw a figure by PRINTing several parts of it at distinct locations on the screen. We animate by redrawing the figure with new graphics characters that represent the next movement of the figure. One drawback to this technique is the fact that we are limited to the location on the screen where we can start the figure.
Now you know about the part of the graphics computer that creates the image on the screen. But how does one go about getting an original image into the computer to begin with? Unfortunately, the computer is not yet equipped to accept commands like “Draw me a cloud.” Getting objects into the computer is the function of graphics input devices, which we will cover next.

2.19. GRAPHICS PERIPHERALS

How are graphic drawings, paintings, lines, maps, and other images entered into the computer? The keyboard can be used, but it requires the laborious typing of the coordinates of every line, color, and pixel that makes up the image. Instead of entering coordinates, you could use the keyboard’s cursor keys to move a cross-hair cursor on the graphics screen to point to the place where you wanted to draw lines or shapes. If software is set up to allow previously formed graphic objects to be “dragged” into place, the cursor will allow the user to position them anywhere on the screen. In other words, you can use the cross-hair to pick up an object, drag it to some location on the screen, and then paste it in place. Often this dragging is used with paint systems where a selection of preformed objects are displayed at the bottom of the screen.
For the easy manipulation of graphic images, the keyboard leaves much to be desired. There are several graphics peripherals in use today which make manipulation of graphics much easier. These include the joystick, mouse, light pen, and digitizing tablet.

**Joystick**

The joystick is a stick that protrudes out of a small box, like a miniature gearshift lever on an automobile with a standard transmission. The joystick can move in any direction (north-east-south-west), and there are usually two potentiometers connected to the joystick that convert its movements to changes in voltages. These changes, in turn, are converted to digital values for the computer (usually with an analog-to-digital convertor, or ADC, the opposite of the DAC). There are two values, one for the X position of the joystick and one for the Y position of the joystick. Software in the computer can then use the X-Y position information to move a cursor on the X-Y plane of the screen.

The problem with the joystick is that an expensive analog to digital convertor (ADC) is required for movement on high-resolution screens, and, if it is a poorly designed joystick, it will require good coordination to master. By this we mean that it can be tricky to physically relate the stick position to the cursor position on the screen. Joysticks, however, are quite popular for low-cost displays such as those found in personal computers. They are great for games where the user must maneuver a ship or fly an object through a maze.

**Mouse**

The mouse used with a computer is not a furry animal with a long tail. Instead, it is a small box resting on two small wheels whose axes are at right angles to each other. Two or three buttons are on the top of the mouse, and the whole device is rolled around on a flat surface thereby turning the wheels. Shaft encoders (devices that convert mechanical rotation to binary signals) connected to the wheels convert their turning to digital pulses that are sent to the computer. By counting the pulses, the computer can figure out the position of the mouse in the X-Y plane and then use the information to move a screen cursor, like the joystick did.

Mice are becoming quite popular and offer features joysticks lack. They are ideal for positioning objects and can also work well for pointing. (Stanford University did several studies that proved this.) The mouse need not be picked up (like the light pen — see below) to be used. In fact, when it is picked up, the cursor won’t move at all.

Some users don’t care for the mouse because they don’t like having to search for it after using the keyboard in a dark room. Another, more important limitation has to do with the fact that the mouse can’t be used to trace outlines from paper images since a small error in rotation will cause a cumulative mistake in the readings. Another is that the electronic
encoders that are used to translate the information from the turning wheels are expensive. This last problem may be eliminated soon, as several companies are developing low-cost integrated circuits that do the encoding job. With the addition of a microprocessor to these new circuits, this very powerful graphics input device could possibly become more popular than the joystick.

Photo 2.6: The joystick.
The joystick and mouse discussed above are primarily used as positioning devices. They allow us to represent the current position of a cursor or object on the screen and to move it about. A light pen, on the other hand, is a pointing device. When it is pointed at an item right on the screen, its program can identify what item is being indicated.

The light pen is made of a hollow stylus that contains a small lens at one end and a photocell at the other. Whenever the pen is close to the screen, light from the screen enters the pen and falls on the photocell. A switch on the pen allows the user to alert the computer that this is the position to be selected. The output of the photocell goes to a storage device similar to one bit of memory (called a flip-flop). This flip-flop can be triggered when light strikes the pen. It is reset or untriggered when it is read by the computer.

The light pen does not have the X-Y tracking hardware described for the pen and mouse. Instead, it uses software for location of its position. There are two ways to do this: polling and interrupt. In the polling method, as the raster on the screen is being scanned, each individual pixel is being illuminated. In some cases a pair of counters in the computer are constantly updated with the current row and column number of the pixel that is being displayed. In other systems, it is sufficient to simply note that the address of the pixel in the display memory tells us its current
location on the screen. Regardless, the computer can decipher where on the screen the pen is pointing at any time. The computer simply checks the flip-flop after displaying each point to see if it's been triggered. Since the counters contain the X-Y position of the current pixel, when it finds the flip-flop set, it knows exactly where the pen is pointing. This approach may place heavy constraints on the computer, however, since it doesn't have much time to check the flip-flop between plotting each pixel.

In the interrupt approach, as soon as the light pen's switch is pressed, the flip-flop sends a signal to the computer that interrupts whatever it is doing and says "I have a light pen point for you." The computer then simply notes the current X-Y position of the pixel being plotted (assuming the same counters are being used to keep track of the column and row or the address of the pixel in the display RAM), and this is where the pen must be pointing. This method also assumes that the interrupt occurs fast enough so that no more pixels get plotted.

Light pens are not used for drawing on the screen because it is hard to hold them steady on the glass surface of the CRT. They are better for pointing to on-screen menus. Also, there must be light coming from the screen for the light pen to receive. Thus, a cursor has to be sent to every OFF pixel, so that the pen will be noticed when it is pointing to a location that doesn't contain any ON pixels.

**Tablets**

A tablet (or digitizing table) is a flat surface, separate from the display, on which the user may draw with a special stylus or pointer. Using a tablet is much like drawing with pencil and paper, and this explains their popularity.

There are several ways to build a tablet. The most common approach simply embeds into the surface a matrix of tiny wires running at right angles to each other in the X-Y plane. One system, might, for example, contain 1024 x 1024 wires. Each line carries a special digitally coded signal. The stylus contains a sensitive amplifier that picks up the signal and amplifies it. Special decoding circuitry figures out the X-Y position of the stylus. By pressing the pen down on the tablet, a switch inside of the pen allows the user to indicate a selected X-Y position.

Another approach puts a resistive plate on the tablet and applies voltages to it, first horizontally and then vertically. The X-Y position of the pen can be tracked by measuring the voltage of the pen during the times the sheet is being scanned. Still other approaches use strip microphones on the edges of the tablet and let the stylus generate a spark that is then heard by the microphones. Counters record the delay for the sound to reach the microphones and can then compute the position of the stylus.

The tablet is perhaps the most frequently used of the graphics input devices. By placing a sketch on its surface, the stylus can be traced over it.
and the drawing will be transferred directly into the computer. A line drawing can be digitized on the tablet by touching the pen to the intersections of the various lines on the drawings. If three sides of a figure are drawn and digitized, it is possible for the computer to create a three-dimensional model of the figure. Transformation software can then manipulate this information to create three-dimensional movements and perspective drawings on the screen. We will learn more about how these images are manipulated in the next chapter on software and applications.

Photo 2.8: The light pen.
Photo 2.9: The digitizing table.

Photo 2.10: Artist using digitizing table. (Courtesy of Aurora.)
The hardware used today in computer animation is among the most sophisticated you can find. Yet as complex as it is, the computer revolution’s trickle-down effect is making more and more of this sophistication available to the average personal computer user. It is truly remarkable to think that the devices that were once the exclusive domain of rich companies are now being studied and played with in homes across the country. Yet as advanced as the hardware is, hardware alone is not enough. Any computer, from the most expensive Cray-1 (a multimillion dollar computer being used in computer animation) to the almost throw-away $99 Sinclair, needs another half to be worth anything, to do anything useful. This other half is the software program, that marriage partner of the hardware that tells the hardware what to do. In the next chapter we will learn about the programs and software that make animation possible, and we will see how graphics software is a set of rules that tells the hardware what to do with itself. We will learn how the software can make the hardware perform incredible feats of animation and how, over the years, software has become a driving force in computer graphics.
Chapter 3

Computer Animation Software
And Applications

To appreciate the full capability of the graphics hardware, we need to be aware of the hardware’s nebulous marriage partner: the graphics software. This chapter introduces you to techniques for defining graphics objects that the computer hardware can understand and for moving those objects on the screen (transformation). We will also be explaining what clipping and windowing are, how three-dimensional visual realism is achieved with hidden line/surface removal, shading, color use, and more.

You will see how the software breathes life into the computer’s complex circuitry. This will be revealed along with the ways in which software allows lines to be drawn, circles to be plotted, shadows to be cast, and surfaces to be colored, textured, and shaded. In addition, we will also give you insight as to how computer movies are made, revealing the techniques behind the Juggler film (described in Chapter 1), the making of Saturday morning cartoons, and inside production information about TRON, a recent film that relies heavily on computer animation.

3.1. GRAPHICS SOFTWARE — THE BASICS

In most high-powered graphics computers, the hardware will plot (turn ON) a point anywhere in the frame buffer or display memory when that point’s X and Y coordinates are specified. In other words, if, for example, you wish the hardware to turn a pixel ON at X,Y location 100,200, then your program must pass the X coordinate of 100 and the Y coordinate of 200 to the frame buffer hardware. The hardware or software, depending on what machine you are using, will cause the bit in the frame buffer corresponding to the coordinate 100,200 to turn on, and consequently the screen will reflect this with a dot appearing at that location.

Some of the more sophisticated graphics machines have, besides just plotting hardware, built-in line-drawing circuits. With these machines you simply send the beginning and ending coordinates of the line you want on the screen, and presto — the computer draws it for you. If, however, line-drawing hardware is not included in your computer, you
may wonder where line drawing comes from. The answer lies in the software.

Software, as most know by now, is a sequence of computer instructions that creates some end effect. In a graphics computer, the instructions may be in one of several languages, including BASIC (popular with microcomputers), Pascal, or even the more fundamental language of the microprocessor that forms the heart of the computer. You don’t really need to understand all these languages to appreciate that a higher, more complex level of control is operating in the graphics machine as the software steers the hardware to achieve certain effects on the screen. The software can be thought of as the soul of the machine, a higher force that can’t easily be viewed but makes the computer tick, nonetheless. This higher level of control is the sequence of instructions that causes the hardware to plot in certain places and in certain ways.

Let’s look at a simple example to make this clearer. Suppose that all your graphics computer can do is plot points. Say it has only the instructions HPLDT X,Y which plots a point at the location on the screen X,Y. (By the way, this is a graphics statement found in Applesoft BASIC; it is called PLOT in many other BASICS.) How can a line be drawn using just this HPLDT statement? The program in Figure 3.1 shows how. It’s written in BASIC, but could be also written in Pascal, FORTRAN, machine language, or whatever language is at your disposal. In the industry, the program has a name that sort of describes what it does. It’s called a Digital Differential Analyzer (DDA) because it generates lines from their differential equations, another way of saying it uses fancy “incremental” methods of plotting and replotting for drawing a line. It can be used to draw curves as well. If you have a personal computer, you might wish to type this program in and RUN it, otherwise you can follow it on paper, providing you know about BASIC, FOR/NEXT loops, and so on. (If you don’t know BASIC, then skip over it, and realize its purpose is to draw lines when line-drawing hardware is absent.)

In the program in Figure 3.1, entering the endpoints of the line causes the line connecting those points to be drawn automatically. (This particular program is not complete; it will only draw lines with positive startpoints and endpoints.) There are even better algorithms than this one for drawing lines. Bresenham’s Algorithm is one. It is better in the sense that the line will appear cleaner on the screen, and the program will run faster. (These algorithms can be found in Fundamentals of Interactive Computer Graphics by James D. Foley and Andries van Dam (Reading, M.A.: Addison-Wesley, 1982) or Principals of Interactive Computer Graphics by William M. Newman and Robert F. Sproull (New York: McGraw-Hill, 1979).

1You can learn BASIC by reading BASIC Programming Primer by Mitchell Waite and Michael Pardee, Howard W. Sams & Co., Indianapolis, IN, or Armchair BASIC by Annie Fox and David Fox, Osborne/McGraw Hill, Berkeley, CA.
From the primitive capability of just plotting a pixel (HPL0T in Applesoft), we can use software to develop more powerful features such as line drawing or curves, and from these we can draw circles, polygons, three-dimensional figures, and so on.

*Figure 3.1:* This DDA program in BASIC has rather simple instructions (Line 6: HCOLOR = 3) for setting the color of the line to be drawn. In a more sophisticated graphics frame buffer we might have to write additional programs that set the color or shade of the pixel as required.2

```
4 REM SIMPLE DDA SIMULATION FOR APPLE II
5 HGR = 3 : REM puts Apple in the HI resolution mode
6 HCOLOR = 3 : REM sets plotting color to white
100 INPUT "X1,Y1 ";XI,Y1 : REM input the beginning coordinates
110 INPUT "X2,Y2 ";X2,Y2 : REM input the ending coordinates
120 L = INT(ABS(X2 - X1)) : REM L is the "increment"
130 IF ABS(Y2 - Y1) > L THEN L = ABS(Y2 - Y1)
140 XI = (X2 - X1) / L ; Y1 = (Y2 - Y1) / L
150 X = X1 + .5 ; Y = Y1 + .5
160 REM LOOP AND PLOT LINE
170 FOR I = 1 TO L
180 X = X + XI ; Y = Y + YI
190 HPL0T X,Y : REM here's the actual plot
200 NEXT I
210 GOTO 100 : REM Plot another line
```

**Defining Graphics Objects**

Once we can plot points and draw lines on the screen, we have all that is required for drawing simple to complex two- and three-dimensional shapes. This is done by storing the data points for the objects we want displayed (i.e., the X and Y coordinates of the object's

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2In all fairness we should mention that the Apple II does have a line-drawing statement (called HPL0T X1,Y1 TO X2,Y2). However, the above algorithm actually draws a better line than the Apple's statement!
corners). These data points are fed to our line-plotting routines which then draw out the shape. It’s all really quite simple! For example, a rectangle would require four pairs of coordinates, a triangle three pairs, and so on. For three-dimensional objects, a third coordinate describing the depth is needed for each corner. Each of the eight corners of a cube, for example, would contain three numbers, X, Y, and Z, each specifying the location of that corner in three-dimensional space.

3.2. TRANSFORMATIONS

Once we have the capability to draw our shapes on the screen, we will want to move (translate), shrink or expand (scale), and rotate them. This can be accomplished by using the mathematics of transformations. A transformation is a mathematical formula that operates on the coordinate pairs that make up our shape. It takes the various coordinates and changes their values in distinct ways. There are three fundamental transforms in computer graphics, and they are not really as complex as their names imply.

Translation

This transform moves an object to a new location on the screen without affecting its overall shape. It works by simply adding a constant value to each coordinate pair. For example, if you have a shape made up of one point called X,Y (not much of a shape, but good for an example) and want to move it 100 units to the right and 50 units down, you would perform this transformation:

\[ X' = X + 100 \quad Y' = Y + (-50) \]

where \( X', Y' \) are the new coordinates of the point. If this formula is applied to every point in our shape, they will each shift the same distance. (Note that in many personal computers you would not need to put the \(-50\) in parentheses because the Y axis begins at zero at the top of the screen and increases as it travels downward.)

Scaling

In computer graphics, scaling has nothing to do with fish. Rather, it is the graphics industry word for shrinking and expanding an image. Such a transformation is needed when we want to magnify some portion of our shape or to shrink it to allow more of the background to come into focus.
The scaling transform works by simply multiplying each coordinate point by a constant value, as follows:

\[ X' = X \times S1 \quad Y' = Y \times S2 \]

(Note that in computers, the asterisk symbol * represents multiplication.) To expand a shape to twice its current size, all points would be multiplied by 2, as follows:

\[ X' = X \times 2 \quad Y' = Y \times 2 \]

To contract or shrink a point, multiply all the coordinates by a fractional value. For example, to shrink our shape to one half its current size, we would multiply all coordinates by 0.5. (The same results would occur if we divided all coordinates by 2.)

If we change the size of S1 and S2 so they are not equal, then we will create distortion in the X or Y direction. To understand the visual effects of scaling, look at Figure 3.2. It shows the corners of a rectangle centered on the coordinate axis. Note that multiplying each coordinate by 2, moves each corner outward from the center of the axis. If we simply added or subtracted a value from the coordinates, the result would be that the corners would all shift in the same direction (up, down, left, or right). This would result in translation rather than expansion or contraction.

**Figure 3.2:** Example of scaling to magnify a shape.
Rotation

Rotation is the most complex transform because it uses the trigonometric functions sine (SIN) and cosine (COS). These are functions found in most of the high-level computer languages like BASIC and Pascal. When given an angle of a triangle, these functions produce a number that represents the ratio of two of the sides of that triangle. For example, when an angle of 45 degrees is fed to the SIN function, the result is the number .707. To rotate an object by an angle (A), we simply apply these formulas to all points:

\[ X' = X \times \cos(A) + Y \times \sin(A) \]
\[ Y' = -X \times \sin(A) + Y \times \cos(A) \]

The old points are X, Y, and the new points will be X', Y'. The angle used can be from 0 to 360 degrees of rotation. Note we only have to calculate the COS and SIN of the angle once, then it is simply multiplied as shown in the formula. Figure 3.3 was created by laying a piece of grid paper over a drawing and marking coordinates on the grid. These coordinates were then entered into DATA statements in BASIC. Finally, a simple line-drawing algorithm was used to draw the shape. It was rotated by recalculating the points with a certain angle using the above algorithm, and then it was redrawn.

Figure 3.3: Rotation example using da Vinci man. (Courtesy of The Waite Group.)
A mathematical entity called a matrix can be used to assemble several transforms into one neat package. Using a matrix, it is possible to have a single mathematical operation that performs a rotation, a scaling, and a translation in one compact form. Some of the really sophisticated graphics processors perform such matrix operations in hardware!

3.3. CLIPPING AND WINDOWING

Often you see graphics programs that zoom in on some small object in a particular scene, magnifying it until it consumes the entire screen. This zooming is accomplished with the transforms of scaling and translation. But while watching a single object envelope a screen, did you ever wonder what happens to the parts of the scene that are now out of the picture? Are they being drawn on an invisible part of the display? No, they are dealt with by a process known as clipping, which means to eliminate that portion of the scene that will not appear on the display.

The purpose of clipping is to cut off portions of the object that are invisible. This is surprisingly not an entirely trivial task; in fact it is the subject of much scholarly research. In most cases it is not enough to simply determine all points that are not within the screen area and then not plot them. This would be extremely slow, as even in a magnified image there may be millions of pixels that are not displayed. We must attempt to clip larger elements or sections of the picture. This involves the use of clipping algorithms that can determine portions of the picture that are visible and invisible, such as vectors, text characters, and polygons.

To appreciate the problem, consider clipping the triangle that is partly shown on the screen in the figure on page 88. Imagine this as part of a rocket ship, or missile that is moving into the display area. It is no problem to clip lines that are entirely off the screen. It is done by simply throwing them away!

Assume you have line-drawing commands at your disposal. In order to clip the triangle, you must examine all the points that make it up. As you examine these points you look for ones that are off the screen edge. Assume also that your object starts at point A. You immediately discover that point B is off the screen edge. So you must draw a line from point A to a point at the edge of the screen where the line would have intersected the screen edge if it had extended all the way to point B. This requires your software to calculate where the line intersects the screen edge. (A simple algebraic formula exists to do this.) Next you ignore the rest of the shape that is off the screen edge (i.e., from the edge to point B, from B to C, and from C to the edge). You must then draw a second line from the edge of the screen at the point where the line would have intersected had it been drawn from point C to point A.
The problems here are finding the points outside the screen and determining where the intersection points are on the screen edge. Such clipping is usually done with algorithms that involve rejection tests to find parts that lie off the screen and subdivision calculations, which break the line into new parts that lie within the screen boundary.

![Diagram of clipping](image)

**Figure 3.4:** An example of clipping.

### Applesoft Transformation Example

In case you are interested, here is a partial listing of a larger Applesoft BASIC program that can be studied (it can also be modified for other computers). It will help you to understand how the drawing of the rotated figure of the da Vinci Man was produced. The lengthy DATA statements for the program are not included. You can create your own if you wish (use two arrays, one for all the X values and one for all the Y values). Besides demonstrating how to do the rotation, this program also illustrates brute force clipping and scaling transform. To produce more images of the man at different angles on the screen, simply increase the size of the FOR/NEXT loop in line 2020 and change the initial angle in line 2015 and the incremental angle in line 2040.
Main Program:

2000 REM 'Hall of Mirrors' Da Vinci Man rotation example
2005 A = 140: B = 95: GOSUB 21: REM set clipping limits
2006 PI = 3.14159: REM good ol' pi
2007 GOSUB 45: REM clear the screen, draw border
2008 GOSUB 30: REM read the man's data statements into the array
2010 J=2: K=2: GOSUB 40: REM double his size with stretch transform
2015 ANG = -PI/4: REM sets the first angle to -45 degrees
2020 FOR P = 1 TO 2: REM draw first and second man
2030 C = COS (ANG): S = SIN (ANG)
2040 ANG = PI/2: REM sets the incremental angle at 90 degrees
2100 GOSUB 60: REM rotate the man (he's at zero degrees start)
2200 FX = X(0); FY = Y(0): GOSUB 10: REM do clipping (simple)
2205 HPLRT A + FX, B + FY
2210 FOR I = 1 TO N:
         FX = X(I); FY = Y(I): GOSUB 10: REM clip this point first and then....
2220 HPLRT TO A + FX, B + FY: REM finally draw line between points
2230 NEXT I
2235 NEXT P

Subroutines:

10 REM do the clipping
11 IF FX > XH THEN FX = XH
12 IF FX < XL THEN FX = XL
13 IF FY > YH THEN FY = YH
14 IF FY < YL THEN FY = YL
15 RETURN
21 REM set X and Y clipping limits
22 XL = -A: XH = 278 - A: YL = -B: YH = 191 - B:
RETURN

(continued)
30 REM read in the data
   (N=\# of points, F=aspect correction)
31 RESTORE:
   FOR I = 0 TO N:
      READ X(I):
      NEXT I
32 FOR I = 0 TO N:
      READ Y(I):
      Y(I) = -Y(I)/F:
      NEXT I:
      RETURN
40 REM stretch or shrink transform
41 FOR I = 0 TO N:
      X(I) = J * X(I):
      Y(I) = K * Y(I):
      NEXT I :
      RETURN
45 REM clear screen draw border
46 CALL -936; HGR: POKE -16302,0:
      HCOLOR = 3:
      GOSUB 50:
      RETURN
50 HPLOT 0,0 TO 279,0 TO 279,191
      TO 0,191 TO 0,0:
      RETURN
60 REM actual rotation transform
61 FOR I = 0 TO N
62   X1 = C * X(I) + S * Y(I)
63   Y1 = -S * X(I) C * Y(I)
64   X(I) = X1: Y(I) = Y1
65 NEXT I:
      RETURN

Figure 3.5: Applesoft Transformation Example.

Viewing and Windowing Transform

You now know about clipping a picture to remove the invisible parts and transforming a picture to change the scale and orientation of it. One of the immediate advantages we gain from the use of transformations is the ability to define pictures in the coordinate system of our choice. So far we have just used the screen’s limited coordinate system, and in practice this may be quite awkward. For example, what happens when the picture’s coordinates are expressed in floating point (decimal) numbers between ±999,999,999 and the screen coordinates are integers between
0 and 1023 or 0 and 279 (as in personal computers)? We can avoid these problems if we can define our picture in its own coordinate system and then use a transformation to convert it to the screen coordinate system when we are ready to display it. Such a transformation is referred to as a viewing transform.

A viewing transform is simply a combination of clipping, scaling, translation, and rotation that converts all the picture’s coordinates to screen coordinates. (Actually rotation is rare in the viewing transform.) It can be adjusted to allow us to view the picture through a viewing window, a rectangle that surrounds some portion of the picture. In computer graphics, the coordinates for the object or picture we are going to transform are called world coordinates. The world coordinates are the database of points for the picture itself (our large decimal numbers in the above example). These values may be large or small numbers with decimal points, arrays such as game boards, graphs with dates, and so on. Our screen’s coordinates, on the other hand, are usually in integer form (i.e., whole numbers), and are called screen coordinates. It is the purpose of the viewing transform to convert the world coordinates from the picture’s original database of points to fit into the screen coordinates. The viewing transform is particularly useful when we cannot always predict the range of numbers our application will produce. This might be the case, for example, when the data is coming from an experiment or mathematical model.

The window, a rectangular section of the world coordinate system, can specify the viewing transform to be operated on. A window can float around the picture’s database of points and select out just the part we wish to zoom in on, expand, etc. The main use of defining a window is that we can lessen the work that the transform has to perform. It also makes it easy for us to examine other parts of our graph, picture scene, or whatever by simply readjusting the window’s corner limits.

A viewport, in contrast, is a rectangular section of the screen coordinate system to which we can have the output of the viewing transform directed. Often the viewport is smaller than the screen, thereby allowing text menus and system messages to be placed under the picture. There may, in fact, be several viewports on a screen.
3.4. FILLS AND SCAN CONVERSION

We have discussed objects with wire frame construction, i.e., where the shapes are comprised of lines, like the superstructure of a building before the walls are put up. Unfortunately for the graphics designer, the real world is not made up of wire frame models, but rather contains solid areas that give a shape its substance. How does one go about filling in the wire frame outlines that make up a graphics shape? This whole process is an interesting area of study that is just now being pursued with relish in the personal computer field.

Three properties are required to fill an area. First a mask, which defines the pixels that lie inside and outside the area to be filled, is generated. For example, a binary 0 may mean pixels outside and a binary 1 may mean pixels inside. The mask may consist of a list of the corners
(vertices) of the geometric object to be filled. Computing the mask from
the geometric image of the object as it exists on the screen is called scan
converting. Second, there is usually a shading rule that defines what the
intensity of each pixel inside the mask shall be. Different intensities
inside the mask lead to different shading, shadows, colorations, textures,
etc. Third, there is usually a priority assigned to the sides to be filled.
Priority is the property that defines what parts of overlapping areas are
obscured and which are shown. Thus when we do an actual fill we will
know what areas are to cover which.

The process of converting from the geometric representation of an
object (its corner coordinates) to one that can be filled on the screen is
usually not complex when simple shapes are involved. A rectangle, for
example, can be scan converted (filled) with a very simple algorithm that
only plots pixels (or draws lines) between the left and right sides, starting
at the top and finishing at the bottom. But since unadorned rectangles are
uncommon in most graphics scenes, some way must be developed for
scan converting a more general shape such as the polygon. The real
problem of the scan conversion filling is in handling a polygon with
holes, corners, and convoluted nooks and crannies.

**Advanced Fills**

One of the most popular scan conversion approaches for poly-
gons involves extending an imaginary line from some point outside
the polygon to the opposite side of the polygon and counting the
number of boundaries (an edge of the polygon’s perimeter) crossed.
If an odd number of intersections is encountered, the point in ques-
tion must lie inside the shape, otherwise it lies outside.

Using this algorithm, we can plot points on the line while we are
inside the polygon and cease plotting when we are outside the area.
This is a rather slow algorithm, as every point must be tested and
compared with each edge of the polygon. This approach can be
improved; however, by using the concept of coherence, which states
that “if a given pixel is inside the polygon, then adjacent pixels are
likely to be inside as well.” This property suggests that a number of
pixels should be tested together, and the most convenient group to
test is the entire scan line. This leads to the famous YX Algorithm in
which all intersections of scan lines are first found and put in a list.
The list is then sorted so that the various intersections are grouped
by increasing X values. By using the values in this list, we can quickly
plot the entire line between two boundaries, without ever having
to test every point.

Another popular approach to filling involves using the com-
puter’s stack. The stack is an area in the computer’s memory where
we can temporarily place information and quickly retrieve it. It works like the pop-up trays or plates in a cafeteria. With this method, we
scan from top to bottom and left to right filling in pixels as the scan proceeds. When the algorithm discovers that a left or right boundary
changes (due to a corner, for example), it saves the current boundary
coordinates (pushes them onto the stack) so it can later retrieve
them and continue. The algorithm then begins filling in the new area
until it finds the new right boundary and continues until it hits bottom.
Upon finding the bottom, it will restore the old boundary coordinates
(pop them off the stack) and continue the fill from where it left off. In
essence, this algorithm searches for edges until the entire shape is
filled. Such algorithms have been implemented on personal com-
puters such as the Apple and IBM. Microsoft's BASIC for the IBM fills
using the stack approach.

3.5. THREE-DIMENSIONAL REPRESENTATION

Perhaps the most remarkable achievement of computer graphics is
the modeling and displaying of three-dimensional images. Whereas two
dimensions involve X and Y coordinates of width and height, the third
dimension takes us into the realm of depth (the Z coordinate) and
deralism. In two dimensions, our pictures do not require the
subtle qualities of an image seriously attempting to represent reality.
Realism puts an incredible burden on the graphics computer and its
software. For example, since the screen is set up to display two di-
mensions, how is the third dimension of depth to be displayed? And how are
parts of the object that are hidden by the frontal parts to be identified and
removed? In addition, how will lighting, color, shadows, and texture be
added to the display? All of these questions must be answered by those
who employ three-dimensional computer graphics. Let's take a look at
some of the concepts involved.

Achieving Realism

The degree of desired realism in computer graphics depends
on the application. Perfect realism comes at a high price in terms of the
cost of hardware and software, the amount of information stored for the
model, and the time required for computing different views of the
display. Since a three-dimensional scene must be projected onto a two-
dimensional screen, the major stumbling block is depth perception,
sometimes called depth cuing. Many techniques have evolved for provid-
ing depth cues on computer graphics display, as described in the following paragraphs.

**Parallel Projection** Although many different types of projection exist, all are designed to ease the task of generating three-dimensional views of images. Parallel projection is a method by which three views of an object are projected (see Figure 3.7). One application is when an architect draws three parallel projections to illustrate a house, e.g., a front view, a side view and a top view. The viewer must then infer the final shape from the three views. Most people, however, have difficulty inferring the three-dimensional view from parallel projections.

![Figure 3.7: Parallel projection.](image)

**Perspective Projection** This is the most common projection and involves showing the object in three dimensions on the screen, with distant objects smaller than nearer ones (see Figure 3.8). There is a potential problem here if objects are limited in depth, as there may be front/back ambiguity. For example, everyone is familiar with the wire frame cube illusion where the front and the back can change places depending on how you view it or imagine it to be. If we view the image through a wide angle lens and exaggerate the perspective depth, the front/back ambiguity disappears, but undesirable distortion effects take its place.
Intensity Cues  If we use intensity modulation to brighten lines that are in the foreground, we can give the illusion that they are closer to the viewer. When foreground lines are widened, the same effect is achieved. This is a simple way to create depth cues, which requires a gray scale capability in the computer (we covered gray scale in Chapter 2). If the object is very complex, however, or the depth is small, this technique may not work well.

Stereoscopic Views  If separate images are created for the left and right eyes and presented so each eye can only see the image intended for it, a powerful illusion of depth can result. Several methods have been developed for implementing this technique, including flashing shutters, polarized glasses, color filters, and so on.

Kinetic Depth Effect  Watching the movement of an object can help the viewer experience the depth effect. Motion around a vertical axis, for example, can resolve the ambiguity of a simple wire frame object because lines near the viewer move more rapidly than those at a distance. The rotation must be rapid for the effect to work, and this may require special graphics hardware.

Hidden Line Elimination  By removing lines that would not be visible to a viewer, considerable depth cues and realism can be achieved. This is a powerful and much studied technique in computer graphics. For all but the most simple of wire frame objects, it requires large amounts of computing time.
Shading, Surfacing, Texturing  By adding shading, surface texture, and shadow, computer images can achieve a degree of realism that makes them indistinguishable from photographs of real objects. The realism of many of the computer graphics photographs in this book are due to high quality shading, texturing, and surfacing.

Three-Dimensional Coordinate Systems

When dealing with three dimensions, a new axis is added to the standard two-dimensional X-Y coordinate system with which we are familiar. We use the letter Z to represent the new axis which takes on the quantity of depth. The three numbers (X, Y, Z) specify a point in this coordinate space. The choice of the directions of the three axes depends on the application. For computer graphics, it is standard to have the Y axis point up, the X axis to the right and the Z axis point either out from or in to the screen. If the Z axis points out from the screen, we have a right-handed system. If it points in to the screen, we have a left-handed system. (In computer graphics, the most popular orientation is a left-handed system so that as objects get farther away, their Z values increase.) "Handedness" answers the question "Which hand must you wrap around the Z axis so when the thumb points outward along that axis, the fingers on that hand wrap around it in a counterclockwise direction?" You can prove this to yourself on the coordinate system below. (Note in mathematics the Z axis is usually drawn facing upward.)
To generate the view of a three-dimensional scene, three parameters must first be specified. They are viewpoint, viewing direction, and aperture (see Figure 3.11). These parameters are similar to the adjustments a photographer must make when photographing a scene. The viewpoint is the location where the camera must be physically set to take the picture, the viewing direction is the direction in which the camera points, and the aperture is the lens that determines how much of the scene will be included in the picture. These parameters are similar to the window parameters we used for two-dimensional viewing. Note that in this figure the Z axis points upward.

Modeling in Three Dimensions

Before we discuss how curves and surfaces of three dimensions are created, it is important to understand how a three-dimensional object is modeled in the computer. As shown in Figure 3.12, in two dimensions we use polygons, two-dimensional n-sided figures, like rectangles,
trapezoids, pentagons, and hexagons, to model our shapes. In three dimensions we use polyhedrons (as well as polygons) to model objects. Polyhedrons are three-dimensional volumes whose sides are comprised of polygon faces. Some typical polyhedrons are cubes, parallelepipeds, wedges, prisms, etc. (see Figure 3.12).

The polygon face is specified by its vertices and its edges. A vertex is a corner of the polygon. An edge of a polygon is the line connecting two vertices. A polyhedron is also specified by its faces, which in turn are polygons that can be specified by a list of its vertices or edges. This list, referred to as the geometric description, is usually presented in a certain order so we know what vertices connect to what edges.

![Figure 3.12: Polygons and polyhedrons defined.](image)

Since a face has two sides (one inside the object and one facing out), some convention must be chosen for representing these faces to the computer. One way is to list the vertices of the edges in counterclockwise order when the face is viewed from outside.

Table 3.1 shows how a simple cube in the figure is represented mathematically so the computer graphics software can operate on it. Another property of the cube is its topological attributes. Whereas the geometric values give the locations of points in the image (i.e., the coordinate values for each point), the topology gives the underlying structure of the shape. This is done by listing the faces (i.e., F1, F2, etc.)
of the shape. The table may also include auxiliary information about the cube, such as the colors of the various faces, their texture, etc.

Figure 3.13: The three-dimensional cube with vertices indicated.

<table>
<thead>
<tr>
<th>Vertices</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>(1,1,1)</td>
</tr>
<tr>
<td>V2</td>
<td>(1,1,0)</td>
</tr>
<tr>
<td>V3</td>
<td>(1,0,0)</td>
</tr>
<tr>
<td>V4</td>
<td>(1,0,1)</td>
</tr>
<tr>
<td>V5</td>
<td>(0,1,1)</td>
</tr>
<tr>
<td>V6</td>
<td>(0,1,0)</td>
</tr>
<tr>
<td>V7</td>
<td>(0,0,0)</td>
</tr>
<tr>
<td>V8</td>
<td>(0,0,1)</td>
</tr>
</tbody>
</table>

(continued)
## TOPOLOGY

<table>
<thead>
<tr>
<th></th>
<th>Faces</th>
<th>Edges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(list of vertices counterclockwise when viewed from outside)</td>
<td>(can be derived from faces but duplicates are removed)</td>
</tr>
<tr>
<td>F1</td>
<td>V1,V5,V8,V4</td>
<td>V1,V4 V7,V8</td>
</tr>
<tr>
<td>F2</td>
<td>V5,V6,V7,V8</td>
<td>V4,V3 V8,V5</td>
</tr>
<tr>
<td>F3</td>
<td>V6,V2,V3,V7</td>
<td>V3,V2 V5,V1</td>
</tr>
<tr>
<td>F4</td>
<td>V1,V4,V3,V2</td>
<td>V2,V1 V8,V4</td>
</tr>
<tr>
<td>F5</td>
<td>V8,V7,V3,V4</td>
<td>V5,V6 V6,V2</td>
</tr>
<tr>
<td>F6</td>
<td>V6,V5,V1,V2</td>
<td>V6,V7 V7,V3</td>
</tr>
</tbody>
</table>

## AUXILIARY DATA

### Colors

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>(0.4, 0, 0.3)</td>
</tr>
<tr>
<td>F2</td>
<td>(0.3, 0.6, 0.1)</td>
</tr>
</tbody>
</table>

remaining faces repeat F2

Table 3.1: Representing the cube with a data list.

Almost any shape may be created by assembling a group of polyhedrons. As the number of faces of each polyhedron in the shape is increased, very complex objects can be represented. It is beyond the scope of this book to discuss modeling in detail, but it is sufficient to understand that the object to be modeled will be represented as an ordered list of vertices or faces. It is on this list that the transformation, clipping, windowing, and upcoming hidden line removal and surfacing algorithms must operate.

Constructing three-dimensional models is extremely difficult as vast quantities of data must somehow be entered into the computer. The usual method is to make a complex object from more primitive shapes. For example, we might create a three-dimensional ant by making the body from previously defined spheres which were constructed, in turn, from many-sided polyhedrons. We would then only need to add legs which could be made of cylinders, and so on.

### 3.6. CURVES AND SURFACES

One of the most intriguing aspects of three-dimensional graphics is how a curve is made and how surfaces are produced. We have already learned how to represent a three-dimensional object by using many-sided
polyhedrons. Although it would be logical to assume that complex curved surfaces could be modeled by simply increasing the number of polyhedrons and making them smaller, it is often very difficult to modify such shapes because of the number of faces involved. A simple bottle, for example, might be approximated by a single polyhedron with 1000 faces. Changing its diameter would then involve thousands of coordinate points, all of which would have to be altered by the designer.

The need for smooth curves and surfaces is dependent on the actual application. In some applications, such as the design of a simple mechanical part for an engine, for example, constructing the shape from plane face polyhedra may be completely adequate. On the other hand, designing car bodies, where smooth graceful curves are required, calls for more complex shapes and very smooth surfaces. Such shapes are too cumbersome to represent with a finite number of polyhedrons. There must be other ways to modify curves that involve changing only a few parameters thus affecting the curve in a more predictable manner.

There are basically two different methods for describing and creating curves and surfaces: analytic and synthetic. Analytic methods are used to describe shapes that can be measured, i.e., data points exist, and we wish to come up with the curve that is described by these points. Analytic methods are employed when we are trying to achieve a precise fit, to represent a shape in some compact form, and so on. Examples are fitting a curve to a set of data points, fitting a surface to the measured properties of some real object, etc. Synthetic methods, on the other hand, are more often encountered when curves are being created from scratch in the design process. With synthetic methods a designer interacts with a program to create or modify a model of a shape, changing and improving the design until it meets the desired criteria. That model may then be used to create an image of the shape which can be examined.

With synthetic methods we are more concerned with the design process and the exploration of the appearance of new curves and surfaces. Once a curve is created with synthetic methods, the data which describes it can then be used in the analytic methods, allowing measurement of the curve. In this section we will concentrate on the synthetic approach, i.e., interactive shape modeling, and the techniques that we describe for curves can be extrapolated for use with surfaces.

Ordinarily, when a designer is modeling a shape based on curves, there is an interactive program involved. The designer first makes a rough approximation of the shape, then improves it with the program until it more closely resembles the desired shape. A very common way to control the shape of a curve is to locate points through which the curve must pass. These points, called the curve's control points, can be connected by straight lines to make the curve's open polygon. Since the creation of curves is conceptually simple but mathematically complex, we will stick with a visual explanation. (See Figure 3.14.)
By manipulating and moving these control points, it is possible to control the shape of the curve in a predictable way. A complex curve is made up of several curves pieced together end to end. As a designer alters a control point, the curve may change shape only in the region of the control point, or throughout the entire curve. This capability allows the designer to fine tune the curve as desired and is respectively referred to as local and global control.

Control points for a curve or surface may actually be off the curve. One such type of control point altered curve is called Bezier curves (pronounced bay-zee-YAY). A simple Bezier curve with four control points is shown in Figure 3.15. Bezier, a Frenchman who worked for Renault, created a computer modeling program for designing auto body surfaces. The key to his work is special blending functions. These are mathematical functions that represent the influence that each of the control points exerts on the curve. By controlling these blending functions, the designer can change the Bezier curve in very predictable and uniform ways.

Modeling three-dimensional surfaces is merely an extension of control points. Using Bezier curves we can produce a three-dimensional surface by multiplying two curves! Usually a surface is pieced together
from several patches and continuity between them (the places where they connect) is formed with special mathematics. Figure 3.16 shows a Bezier surface and its control points.

![Bezier surface and its control points](image)

**Figure 3.16:** Bezier surface and its control points.

One problem with Bezier curves is that changing the control point can affect more of the curve than the designer wishes. Points that are far from the altered control point, for example, can be affected. Another technique for generating curves that doesn’t suffer from this problem is called the B-spline curve. B-splines allow multiple control points at the same location (i.e., the control points can overlap). This in turn allows good local control of the curve without affecting distant points.

Displaying curves and surfaces on a CRT is more difficult than displaying shapes constructed from straight lines. The simplest technique for displaying curves is using wire frame techniques. In this process, the curve is evaluated using the techniques described above and the points are then connected by many short, straight line segments. Getting depth cues for the display of curves can be tricky too. Often the method of intensity modulation is used for providing a depth impression, but this is not always adequate for complex shapes. Revolving the shape about an axis can help in visualization.

Another approach to visualizing subtle curves in surfaces is by using the hedgehog method. Here small vectors which are normal (perpendicular) to the surface are displayed (see Figure 3.17). Although this technique makes the display look like grass shoots projecting from the surface, its orientation gives the eye a better idea of the general changes the surface will undergo.

Although all of these are valid techniques, shading, which we will discuss soon, is perhaps the best way to visualize curves.
3.7. **HIDDEN LINE AND SURFACE REMOVAL**

Perhaps the greatest challenge facing the computer graphics user is the removal of hidden parts of images from solid objects. In real life we don’t concern ourselves with hidden lines because an object’s solidity automatically blocks light from unviewed parts. (Perhaps there is a survival value for not having X-ray vision like Superman, for had we such an ability we would probably have a difficult time figuring out the front of objects from the back, not to mention the privacy problem.) Given our “limited” visual abilities, we are seldom conscious of what the back side, or inside, or hidden parts of an object look like. When objects are projected on the screen in computer graphics, however, there is no such automatic hidden line removal, and every single part of the object is displayed. To rectify this, special hidden line and hidden surface algorithms have been developed.

In the early 1960s most algorithms centered on hidden line removal because raster displays and surface fills were still in their infancy. We have certainly come a long way since then. Today hidden surface algorithms that utilize hardware can generate views of objects at rates of up to 30 images per second. Although there are many algorithms for hidden line and surface elimination, there is no one best algorithm. Each is ideal for a certain type of scene model or a certain degree of image complexity.

Hidden line and hidden surface algorithms basically work much like the scan converting we discussed earlier. They all use geometric sorting to determine which parts of the shape are visible and which are invisible. Geometric sorting involves finding the objects which are closest to the viewer. Once the near objects are determined, the parts far from the

**Figure 3.17:** Hedgehog method for visualizing subtle curves.
viewer can be tossed in the proverbial garbage can. Geometric sorting is, in reality, much more difficult than it may sound because complex objects do not always fall into simple order. Many algorithms rely on the property of coherence (lines in close proximity are similar) to simplify the determination of lines or surfaces that are hidden.

The most popular form of hidden surface removal is the depth-buffer algorithm. In this method we scan through the object by looking at each of its points in the database. Imagine peering into each pixel with X-ray vision. You would be able to see every surface of every object which falls directly behind that pixel. The Z value of each of these surfaces is checked, and only the one with the lowest value (the closest one in relation to the viewer) is saved. A record is then made of the depth (Z) of this closest surface in a separate array which has the same resolution as the screen. The intensity of this closest surface at that pixel is recorded in another array.

Thus two arrays are used, one for the depth and one for the intensity. When the depth-scanning algorithm is finished, the intensity array contains the image with the hidden surfaces removed. Note that the algorithm only works on objects that have been converted into screen coordinates. Thus if the object is magnified, the entire process will need to be repeated.

The depth-buffer algorithm is not always practical because of the huge size of the depth and intensity arrays. A $400 \times 400$ coordinate system would require two arrays with 160,000 elements each! One way around this is to use smaller arrays and work on individual sections of the picture. This is a good solution since we can throw out the depth array after each pixel is done. The $400 \times 400$ system can be divided into 100 rasters of $40 \times 40$, so only 1600 elements are needed per array.

The process of computing the arrays is still very time consuming and eats up memory like a starving elephant. The way to solve the problem of excessive processing time is to use coherence techniques, as were described earlier, for the scan conversion methods. The need to cut down on processing time has given rise to a class of removal techniques called scan line algorithms that solve the hidden surface problem one scan line at a time. These capitalize on the fact that for each single scan line, short spans of pixels will lie within the same polygon.

Another approach to hidden surface removal involves comparing two polygons to determine which obscures the other. We can compute each polygon's plane equation, which precisely defines the surface of that polygon. This equation allows us to then determine if a particular point in the display scene lies inside or outside the polygon plane. We can also locate all the polygons with back faces (those which cannot be viewed by the observer because they lie on the side of the object facing away from the viewpoint).

Many more advanced algorithms exist for removing hidden sur-
faces, each having characteristics that make it better for one type of object than another. The more available the tools, the better, because as scene complexity grows, hidden surface elimination limits the ability of a computer to process pictures in real time.

3.8. SHADING

Now we come to shading, the one component of graphics processing that does more to help create realism than any other factor. After we have identified the visible surfaces with our hidden surface algorithms, a shading model is used to compute the colors and intensities for the surface. The shading model has two main aspects: properties of the surface and properties of the illumination falling on it. This model attempts to simulate the behavior of light on an object as it would appear in the real world to the eye. To do this, it must simulate the surface properties of the object, such as its reflectance, texture, color, and transparency. Reflectance tells us how much incident light returns to the eye. If the surface is textured, the reflected light will vary with the position of the texture on the surface. If the surface reflection changes for different wavelengths of light, it will appear to be colored. If some light passes through the object then it has transparency.

In addition, the model must simulate the illumination on the object. If the illumination is uniform from all directions it is called diffuse illumination. If the illumination comes from one location it is called a point source. Point source lighting causes highlights to appear on the surface. If the object moves, as it will in animation, the model must change the lighting accordingly. This is a difficult task indeed.

Photo 3.1, below and on the next page, shows a good example of curved objects, hidden surface removal, and shading.
Photo 3.1: Hidden line removal and shading: a) Artist's Table (wireframe) represents one way of previewing an image without incurring the overhead of a full rendering. The color of the wireframe components approximates the colors of the final image. Once the wireframe image is constructed and situated to satisfaction, a solid image with hidden surfaces removed is rendered. b) Artist's Table (with stand-ins) shows the next step in establishing a shot, which is a hidden-surface rendering with "stand-ins," i.e., simpler, less detailed substitutes for the objects to be used in the final image. These stand-ins allow decisions about placement, coloring and lighting to be made and changed more quickly than would be possible with a fully detailed image. c) Artist's Table shows the final still-life, with all the fully detailed parts included in the scene. Spline-based primitive objects, as well as simpler geometric primitive shapes make up the objects in this scene. Light is from two light sources: a white light from over the viewer's left shoulder and a yellow one from the rear left of the scene. These pictures are antialiased, full color, 512 X 512 images (see color insert). They were produced on a PDP 11/44 computer using the UNIX operating system, C programming language, and a DeAnza 6400 frame-buffer. Software and images were produced by Richard Chuang, Glenn Entis, and Carl Rosendahl. (Courtesy of Pacific Data Images.)

Here is how it's done. A mathematical model that takes all the above parameters into account is developed for each pixel of the object in the scene. The model determines the amount of light energy coming from a
point on the display. The model can be broken down into three parts, the contribution from diffuse illumination, contributions from one or more light sources, and a transparency effect. The actual mathematics must utilize the rays of light arriving from different parts of the scene. Each of these effects contributes to the final shading of the object.

An example of a shading formula would be

\[ E(pd) = R(p) \times I(d) \]

where \( E(pd) \) is the energy coming from the point \( P \) due to diffuse illumination, \( I(d) \) is the diffuse illumination falling on the entire scene, and \( R(p) \) is the reflectance coefficient at point \( P \), which ranges from 0 to 1. The actual formulas used for modeling shading use this one as a starting point and expand to be much more complex. Such things as reduction of intensity due to changing angles of incidence (Lambert’s Law), single point source contributions, and transparency must also be included in the formula.

The actual calculations must be performed many times (for each point on the object) to produce a properly shaded image. Thus much of the work in shading involves finding ways to reduce the amount of effort required to evaluate the model. A \( 1024 \times 1024 \) raster, for example, will require that the calculation be performed on over one million pixels. Once again, the concept of coherence is utilized to reduce the amount of calculation required. (Shading coherence relies on the fact that the intensity of adjacent pixels is very nearly identical.)

Two popular algorithms for improving the shading of an object are the Gouraud (pronounced goor-ROE) shading technique and the Phong technique. The Gouraud algorithm involves computing the normal vectors (the perpendiculars) of the numerous surfaces, vertices, and intensities of the shape, and then averaging them. The main advantage to this approach is that it partially eliminates Mach bands, i.e., unwanted intensity ridges that arise from simple shading of the object. On the other hand, the effectiveness of the algorithm is lessened when motion is induced. While the Phong technique eliminates the problems of Gouraud shading, it requires much longer to calculate.

One real problem facing those who use shading is the limitations of the hardware. If the spot size of the electronic beam changes (i.e., the diameter of the beam when it strikes the CRT), the sharpness of the image suffers. If the spot is too small, an array of dots will appear where smooth shading was supposed to show through.

Some of today’s most sophisticated special effects utilize shading techniques. The use of transparency, surface detail, shadows, texture, and reflections are more of an art than a science. Although it is difficult to imagine how these techniques will one day be simplified, it is almost certain that they will. Perhaps LSI chips (large scale integration — the technique used to make microprocessors) will be developed that apply shading algorithms to user-generated scenes.
3.9. **ANTIALIASING LINES**

Antialiasing (pronounced anti-AY-lee-es-sing) is a technique used to remove the jagged staircase effect that occurs on a computer screen when lines are drawn. Since the distance between pixels is not infinitesimal, a staircase effect occurs as the line bounds towards its endpoint. Also known as dejagging, antialiasing involves using intensity modulation to make the line appear a smooth entity, thus minimizing the staircase effect. (See Figure 3.18.)

Ideally, a line on a computer screen would be drawn from one point to another, turning on only that portion of a pixel necessary to represent the line (a). This is not possible since pixels must be either on or off. So the software or hardware that draws the line must take a staircase path from one pixel to the next, approximating the straight line (b). The higher the resolution, the less the staircase (aliasing) effect will be noticed. There is, however, another method besides more resolution to get rid of the "jaggies."

With antialiasing, we can control the intensity of each pixel that the line goes through rather than just turning it on or off. The importance of this capability is apparent when we draw a straight line through the pixels from the start point to the endpoint (c). The line will cut the boxes (pixels) into sections. The antialiasing routine determines what percentage of the box is intersected by the line and uses this to figure the shade of that pixel. For example, if the area above the line is black and the screen is white, then the pixel (1,0) would be a color which was a mixture of 50 percent black and 50 percent white (because half of it is crossed by the line). On the other hand, the pixel (0,0) in the figure would be 85 percent black and 15 percent white (only 15 percent is below the line), and pixel (0,1) would be completely black (none of it is below the line).

If this intersecting line represented the outline of a color filled object, then we would use the same figures to compute the percentages of each color that the pixel should receive. If the color above the line was 100 percent green and the color below the line was 100 percent yellow, then a pixel (1,0) which has the line cutting it exactly in half would be 50 percent green and 50 percent yellow.

Some of the more prominent graphics effects houses, such as Lucasfilm, are staunch supporters of antialiasing and even wear T-shirts with "jaggies forbidden" symbols on them. Personal computer owners must learn to live with jaggies for the time being, given the limited resolution of their machines.
a) Ideal but impossible. Cannot divide a pixel in half.

b) Jaggies: Pixel is either on or off.

c) Antialiasing using mixtures of colors.

Figure 3.18: Antialiasing example.
Photo 3.2: Antialiasing on a CRT: a) Two graphic objects — the one on the left a) is antialiased, the one on the right b) is regular. Note how a) seems smoother. b) Closeup of both objects shows how antialiased a) is made smoother by shading edges of the line. c) Extreme closeup of antialiased object reveals details of shading effect on jaggies. (Courtesy of Advanced Electronic Design, Inc.)

3.10. PERSONAL COMPUTER ANIMATION SOFTWARE

The state of software techniques for personal computers is not nearly as advanced as those used for high-tech machines. The main reason for this is that memory for these machines has purposely been kept below 64K to keep the price realistically within the consumer’s range. Although this is changing with new, large-memory 16-bit personal
computers like the IBM PC and Apple’s Lisa, the software for taking advantage of the larger memory of these machines is still not available. This is not to say, however, that the graphics software on the personal computer has not matured. As we point out in detail in the next chapter, personal computer graphics software offers a large array of new ideas and techniques, especially in the area of real-time animation. You won’t find built-in transformation algorithms, texturing and shading techniques, or shadow mechanisms (at least right now). But you will find automatic movement of simple graphics objects in real time, built-in color fill, special programmable graphics definition languages, circle generation routines, neat graphics languages, numerous text and color modes, page-flipping animation, image array plotting, players, sprites, hardware background scrolling, and more.

We will cover all these concepts in Chapter 4. For now you should be aware that the personal computer is hot on the tail of the high-tech machines, and, as memory capacity grows and programs mature, personal computers will eventually have special software for doing the same complex three-dimensional effects that are seen on the higher memory devices.

3.11. HIGH-TECH DIGITAL PAINT SYSTEMS

To many artists the computerization of painting is nothing less than a mortal sin. This is understandable since the majority of artists eke out a meager existence expressing the more subtle emotions of the heart, delving into rarer forms of meaning, and in general are humanists rather than technocrats. To most of them, digital and all its ramifications is the antithesis of true art. You would be lucky to get one to even consider that a computer could outmaneuver the stroke of a paint brush. The day has come, however, when artists must begin to wake up and see the graphics computer as an entirely new form of artistic expression rather than a device that should be shunned. A graphics computer equipped with good software for drawing can offer extraordinary artistic control. (Using such a system can even save on oil and canvas expenses.)
What Are Paint Systems?

To allow artists to utilize the power of computer graphics, special "paint" software has been developed. These paint systems are programs that can work in conjunction with digital tablets and light pens (described in Chapter 2). They allow the artist to draw on the computer screen by moving the stylus on the tablet, or the light pen on the CRT itself, as if it were a paint brush. The artist usually has a menu presented on part of the computer screen in a viewport (out of the way of the picture) that contains instructions for using the system. (These might include selection boxes for choosing color, brush width, and other parameters.) By using the keyboard along with the menu and the pen, an artist can, for example, select the brush width that draws anything from a very fine line only one pixel wide to a very wide line comprised of many pixels. Some advanced systems even allow the brush to simulate a paint sprayer, sputtering and feathering the edges of the painted line as if there were an aerosol can behind the stylus!

In addition to allowing the selection of paint brush sizes, the paint system that is implemented on a high-tech computer allows the artist to...
choose from a fabulous array of colors. On some systems there may actually be a maximum of 16 million colors to choose from.

With a paint system, an artist can also superimpose multiple images. For example, the artist can create a background scene and then merge it with previously created foreground images. The foreground images can be moved around on the background until they are in the perfect position. Other effects possible for the artist are color cycling (causing certain colors on the screen to change simultaneously to new colors), zooming (magnifying any particular section in a scene so it fills the entire screen), and adding patterns and textures. This last feature, sometimes called rubber stamping, is truly an example of something that computers can easily do that painters cannot. For example, suppose the artist uses the computer paint system to create a brick pattern to be used for a wall. Once a small patch of brick has been made, it can be attached to a brush. Then every time the brush is pressed down on the tablet, the pattern is placed on the screen. In this way the entire wall is rubber stamped on the screen.

**Technical Details**

Technically, such sophisticated paint systems require large frame buffers, powerful computers, and very large hard disks. The software for these systems is very expensive (over $10,000 on the average), and the hardware can easily exceed $50,000. Digitizing tablets with very high resolution are needed. To use this system for video production, a video tape recorder is attached. For film quality images, an expensive film recorder is required for capturing the output onto film.

**Main Applications**

Some of the main uses of paint systems today are in television news, weather reporting, and creating textures for high-tech three-dimensional texture mapping (e.g., the Genesis planet in *Star Trek II*). It is relatively easy, for example, for an artist at the TV station to quickly draw up maps and pictorials on the computer, alter them to fit the news situation and finally capture them on video tape.

Another important use of the paint system is in filling cartoon ‘‘cels’’ with color (we’ll say more about that later). A scan conversion algorithm can evenly fill an enclosed boundary faster and far more accurately than a human artist. The animation field is also utilizing paint systems for creating special effects not possible or not easily made by conventional techniques.

One popular software paint system was AVA. It was based on NYIT’s paint program (written by Alvy Ray Smith) and modified by Tom Porter (who went on to write Lucasfilm’s amazing paint program). AVA ran on a DEC PDP-11 and was designed to be simple to use. However, because it was too sophisticated for its time (it had too many functions for the average user), it was pulled off the market by its owners.
Ampex. The CBS network, however, still uses AVA for many of its news graphics.

Big names in paint systems include Dick Shoup’s Aurora system in San Francisco, Digital Effects in New York, and NYIT’s “Images” system. Microprocessors used frequently in these systems are the DEC LSI 11/23 and the Z80. Popular minicomputers (more expensive but also more powerful) used with paint systems include the HP 1000 and General Nova among others. The principal computer language for paint systems is C. As described at the end of Chapter 2, C is a compiled language that is fast in execution, fairly easy to maintain, and becoming more popular among computer users. Most paint systems require at least 192K of RAM. Most of them store images on disk using the same run-length encoding techniques for compression that were described in Chapter 2.


**Personal Computer Paint Systems**

Today there are several low-cost paint systems designed for personal computers like the Apple and ATARI. (These might actually replace the need for high-tech systems when low-resolution with only a few colors is all that is required.) One particularly fine piece of software can help your Apple emulate a $250,000 graphics system for just $39.95! The package is called Special Effects. It was written by Mark Pelczarski of Penguin Software (830 4th Ave., Geneva, IL 60134) and requires DOS 3.3, 48K of RAM, and a joystick, paddle, or graphics tablet. Special Effects provides 96 different paint brushes that can be moved about the screen. You can load your brush with any of 107 colors or color patterns and move the brush anywhere on the screen. Borders are not required for filling with patterns and colors! Even shading is possible. Brushes and color palette is displayed on screen 2 of the Apple, so it is easy to switch back and forth between your picture and your menu. The package includes a magnify mode which lets you magnify the area around the cursor two or four times so you can see individual pixels. In addition, there is software for taking fonts created with a font generator and merging it into your scene. Mirror image flips and negative image tricks can also be performed (reversing the color of all pixels).

The most impressive aspect of this software is that you can take a rectangular portion of your picture and move it to any other portion of the display. This allows the production of some terrific animation effects. There is also a picture-packing routine for crunching pictures to use less storage space on the disk (just like in the high-tech machines). You can even string several pictures together so they can be quickly and automatically loaded into the display RAM by a BASIC program statement.
Photo 3.4: This pie chart, created on the screen of the Apple III personal computer, has a resolution of 280 x 192. This photo shows the jaggies very clearly. Although few people know it, the Apple has a higher 560 x 192 resolution, but it is only black and white. (Courtesy of Apple Computer Company, Inc.)

Photo 3.5: Scene created on Apple II using “Special Effects” paint system by David Lubar (see color insert). (Courtesy of Penguin Software.)

Of course, the Apple and the Special Effects software lack the high resolution and color capability of the high-tech paint systems. But consider a $3,000, 280 x 192 resolution, six-primary color computer, and $39.95 paint software package versus a $150,000, 1024 x 1024 resolution, 16 million color computer, and $10,000 paint software package. It is easy to see why these low-cost systems are extremely attractive — and it surely won’t be long before their resolution and color capabilities increase to a point where they are rivaling the high-tech machines.
3.12. COMPUTER-ASSISTED AND COMPUTER-GENERATED ANIMATION

Now that you know the basics of graphics software, you are probably anxious to discover how computers are used in professional film animation today. There are two very broad categories of computer animation: computer-assisted animation (also called computer-aided animation) and computer-generated animation, which can be further subdivided into real-time and non-real-time computer-generated animation. Computer-assisted animation is used to aid artists in the production of two-dimensional animation (with paint systems, cel opaquing, etc.) whereas computer-generated animation is the process by which the computer generates a realistic three-dimensional image under the direction of a human-designed database and animation controls. We will explain these in more detail.

A third area outside the realm of computer animation in which computers are being used today in film is called motion control photography. Motion control photography involves using a computer to control the movement of the motion picture camera. The camera has several "stepper" motors that can change its position in almost any direction by very small increments. By doing this, the computer has taken over a laborious task which has previously been relegated to the animator. The camera may be snapping pictures of a spaceship model, for example, while revolving around the model, giving the illusion that the ship is moving. Or it may simply be passing over a long landscape. The computer simplifies the calculations for pans (left to right movement), tilts, rotations, and accelerations.

The movie Dragonslayer used these techniques extensively in addition to a new technique called Go-Motion. The models of the dragon were also provided with stepper motors and connected to an Apple II. Rather than moving the dragon and then taking a picture, as is usually done with stop motion photography, the movie's creators moved the dragon by the computer while the frame was being exposed. This caused each frame to be slightly blurred (as is the case with normally photographed scenes using live actors), resulting in extremely smooth motion. Industrial Light and Magic (a division of Lucasfilm) is a pioneer of such exciting effects.

Computer-Generated Animation

This book primarily focuses on computer-generated animation. As we learned in previous sections, the generation of the original artwork in such animation usually comes from the initial generation of a database of coordinate points that describe the fundamental shape of an object. The method used to enter these points into the computer depends on the object to be animated.
A simple cube that will fly and twist across the screen can be completely generated by mathematics, since its mathematical description is fairly simple and the number of points describing it is minimal. It can thus be entered by a formula, through the digitizing tablet, or with a simple sketch and a digitizing camera. (A digitizing camera is a camera connected to the computer in such a way that anything that appears in front of its lens is scanned and converted to a bit image and stored in the frame buffer.) A three-dimensional image as complex as a person juggling geometric objects might take so long to describe mathematically (given the complex and subtle motions involved) that methods for entering the datapoints which involve shortcuts might be required.

Once the initial coordinates for the image have been entered into the computer, there are several steps that may occur for the production of the final image. In general, they will involve mathematically affecting the image, transforming it, including rotation and scaling, removing hidden lines and surfaces, shading, coloring, texturing, and shadowing. A paint system may be employed for several of the coloring functions.

As always, the actual steps involved are dependent on the particular image and application. In order to get a feel for how an application of computer-generated animation might proceed, we will describe the making of the Juggler film (see Chapter 1). The processes used to produce the Juggler cover the gamut of animation technique, but remember that other animations may take a different approach. The end product is what is important; how it is accomplished is secondary. This sequence is renowned as an excellent example of the realism that can be achieved with computer animation today.

**Making of the Juggler**

If you forgot our description of the Juggler film, now would be a good time to reread it at the beginning of Chapter 1.

The film shows a juggler in a black tuxedo juggling three geometric shapes. Incredible camera angles, smooth realistic body movements, vivid color, and an eerie manikin face, make this film an outstanding example of computer animation. The film was produced by Information International, Inc. (Triple I), a California company which excelled in animation and computer graphics effects. As we explained above, the first step in the production of any computer animation is obtaining the database for the objects.

Triple I had two choices for getting the initial image inside the computer. They could either synthesize the juggler inside the computer using pure mathematics or they could somehow get the coordinate points of a real juggler’s movements inside the computer. Synthesizing their own was almost impossible because there are so many subtle movements of the human body that it would have taken years to describe it mathem-
matically. So they hired a professional juggler named Ken Rosenthal (the computerized juggler is called Adam Powers).

The first step in getting the datapoints into the system was to have Ken dress up in a white leotard and stand on a stage. One camera was placed above him and one directly in front of him. The cameras were synchronized so each frame picked up the exact same movement. The people at Triple I then painted black dots at each joint of Ken's body and connected them with black lines.

With Ken on stage and the camera rolling, they had him juggle three objects for five minutes. The film was then viewed and edited down to one minute of exceptional juggling. After studying the film very carefully, its creators found a simple three second sequence of juggling that could be used for cyclical animation. In other words, this three-second piece of film could be played over and over and it would appear as if Ken (Adam Powers now) were continuously juggling the shapes.

The next step was to rotoscope Ken. Triple I mounted one of the projectors on a device called an animation stand and advanced the three seconds of film one frame at a time, projecting each frame onto a large piece of engineering paper. As each frame was illuminated on the paper, they ignored the other parts of his body and carefully traced onto the paper all the dots at the joints and the black lines connecting them. This process was repeated for the top and front camera views. When they were done, they ended up with 144 frames of data (pieces of paper). This number of frames comes from the fact that the cameras run at 24 frames per second; 24 \times 3 \text{ seconds} = 72 \text{ frames}, and since there were two views, 72 \times 2 gives 144.

Their next task was to get all this data into the computer, so they took their paper frames to a digitizing table and entered the captured points and lines into the computer. (Recall that a digitizing table is a tablet with a special pen. A piece of paper with an image on it is placed flat on the table and is traced over with the pen. The computer is able to follow the pen's motion and record the X and Y coordinates of each pen position.)

They pressed the pen down at a joint to tell the computer it was an endpoint. The two camera views allowed them to track each joint in three dimensions, thereby giving 19 points per frame, for each of the 72 frames. The result was that all the frame information from Ken's juggling was entered into the computer. From this information they formed a database of points for each frame. The precise movements of the juggler were now captured inside of the computer.

The next step was to create the juggler's body parts and make him appear three-dimensional. For this they used a geometric wire frame cylinder for each limb, modeling it mathematically inside the computer, and then attaching it around the limb and joint data already stored in the computer. (See Photo 3.6.) Much experimenting was needed with the
cylinders to get them to correspond properly to the database. Each cylinder was merged with its neighbor in the final filming. The shoes and details of the tuxedo were also added later. Because each cylinder penetrated its neighbor, they decided to make the tux black. This would make the connection points less noticeable.

Once the wire frame image was perfected, the difficult part was completed. At that point a hidden line removal method called Bouknight’s algorithm (a special mathematical method) was used to make the hidden lines disappear. Color was then added by using a cubic patch program and polygon coloring. Shading was accomplished with Lambert’s Cosine Law.

Creating the face presented a unique problem. Two views of a face (front and side) were sketched on four-foot square engineering grid paper. Then they approximated the face using 400 polygons. It was done this way because it is extremely difficult to enter curves into a computer. Triple I wanted the face to be as natural as possible and therefore needed many polygons, because people react negatively to a face with distortions in it.

The next step was to take the engineering paper with the polygons on it and lay it on the digitizing table. The data for the polygon’s locations
was entered in the computer's database by tracing the polygons of the face on the table — thus it "knew" how the face was shaped. Triple I only digitized half the face and then mirrored the image into two pieces and joined them in the computer. Since it looked too perfect, they had to add some imperfections, and did this by moving some of the datapoints around. Finally, they mathematically smoothed the polygons of the face by using the special Gouraud's algorithm we described earlier in this chapter. By the time the entire face was completed, they had used more than 1000 polygons.

Figure 3.19: Human face simulated with polygons. (Courtesy of Henri Gouraud, University of Utah.)
If you’re wondering about the computer that Triple I used, it was not an ATARI or an Apple II. Rather, it was a custom-made computer prototype called a Foonly, designed to be faster than many minicomputers. The resolution at which the Juggler was photographed on 35 mm film was 3000 points by 2400 lines, and that’s 130 times finer than the Apple. On $4 \times 5$ transparencies, Triple I records at a resolution of 6000 points by 4000 lines. When recording on film, the company uses an incredible 9 bits per color, which amounts to over 134 million color levels.

**Real-Time High-Tech Animation**

For real-time animation, the same concepts described throughout this book are used. The only difference is that the speed at which the software processes the images must be much faster. This is usually accomplished by using very high-speed computers that cost in the millions of dollars. (The CRAY X-MP is an example.) These are called vector processors because they deal with real-time computation of vectors. The use of many microprocessors, each representing a certain object or portion of the object in the scene, all running in parallel as they compute, is being considered as an antidote to the cost of the high-speed computer.

Now that you understand a little about the process behind computer-generated animation, let’s investigate computer-assisted animation as it is used in the cartoon industry.

**Computer-Assisted Animation**

To appreciate how much time and effort the computer has saved the cartoonist, consider the six manual steps to creating a cartoon.

**Initial Design** The artist creates a storyboard which is a quick sketch of the main pieces of the entire cartoon from beginning to end, somewhat like a comic strip. It shows all the significant frames of the cartoon, i.e., the important ones that specify a major change in characters or environment.

**Key Frames** The key frames are then drawn in more detail to create significant character positions. Key frames are the frames that hold the peak positions of the figures in the cartoon. They tell the cartoonist the path of the cartoon and where the figures in each motion sequence start and end.

**In-betweening** Many frames *between* peaks of movement in the storyboard are drawn to produce movement. Frames must be eased (also called faired), i.e., properly accelerated from start to rest or jerky movements will result. Usually 24 frames are needed for each second of movement in the final film! Thus just one quarter hour of viewing time of the cartoon requires 21,600 drawings! This is one of the most time-consuming aspects of making an animated cartoon.
Pencil (Line) Testing  The drawings are now photocopied on acetate (called cells) and then filmed on an animation stand to test quality of movements. The animation stand (also called an animation rostrum) is a camera and a platform-like device that allows the drawings to be accurately transferred to film for viewing. If an error is found at this point, then the animator must go back to the drawing and in-betweening and fix it, and the line test is repeated.

Opaquing  Once modifications from the line test are completed, the cells are actually painted in (opaqued) by hand to add color, so characters stand out from backgrounds. This is another expensive, time-consuming step.

Filming  Finally the backgrounds and characters are brought together on the animation stand and filmed by the camera to make the cartoon. Sound is joined with the film at this stage. (Sound is always recorded before the key frame stage since it is easier to make the drawings match the sound than vice versa.)

Computerization of Cartoons

In making cartoons, the computer can help solve many of the time-consuming manual techniques we described above. The following methods are utilized at Hanna Barbera, a company famous for Fred Flintstone and Superfriends.

After the pencil sketch has been created by the artist and cleaned up, it is entered into the computer via a digitizing camera. Because the pencil sketch has gray shades in its outlines, the picture gets automatically antialiased and no special software techniques are needed to obtain smooth non-jaggy edges. Once the picture is inside the computer, a paint system is used to do the opaquing and fill the image with color. With the use of a paint system, the opaquing step only requires the artist to place the cursor in the center of the object, choose the fill color and press the respective button. In a fraction of a second, the interior of the entire shape will be flooded with color.

In such cartoon applications, there are usually 16 shades of 16 colors, allowing a total of 256 different hues. With the various shades the flooding (filling) algorithm blends the colors as they approach the outline of the figure for a smooth, antialiased border.

Of course, once we have the database of points for the figure in the computer, it is relatively simple to rotate and scale the figure in two dimensions. We can make our figures spin, expand, shrink, flip over, mirror, and so on.

Another major contribution of the computer in cartoon applications is in the area of in-betweening. With proper software, the computer can mathematically estimate the in-between positions of two-dimensional
the computer combined swallowed another feature-length tech many independent computer then those time just available may this the selected another, figure's the when ability "hind" actually very two-dimensional beginning the computer is is on the horizon in computer animation.

3.13. THE MAKING OF TRON

Our book would not be complete without mentioning how a high-tech computer is used today in a modern motion picture. TRON, a feature-length film from Disney Studios, is about a programmer whose great computer games are ripped off by the ultimate computer pirate — another computer program. Through the magic of artistic license and computer imagery, our hero gets laser digitized into a patch of pixels and swallowed up by the computer. In his new RAM-based consciousness, he wanders about the frame buffer searching for the villains who stole his best program (called Space Paranoids). When he finds them, a fantastic
battle erupts in the frame buffer. The effectiveness of the film is the result of brilliantly blending computer graphics and old-fashioned animation.

With TRON's release came a new awareness on the part of the public regarding computer animation. Never before have special computer effects been so pronounced. Playing a major role in the making of TRON was Richard Taylor of Triple I and formerly with Robert Abel and Associates (equally famous for candy apple neon 7-Up and Levis Jeans commercials).

The process of making TRON required artist-designers to interact with programmer-technicians, and this presented some interesting problems. The artists were at one end of the country and the programmers at another, further complicating matters. The TRON artists were at Disney studios in Los Angeles, and the programmers were at Mathematics Applications Group, Inc. (MAGI) in New York. When Chromatics terminals were installed at each end, work settled down. Modems were used to send low-resolution motion tests to the director at Disney before committing the images to film.

For example, after MAGI received the storyboards for the vehicular animation from Disney, they took these crude images and plotted them in three views using combinatorial geometry on a 40 × 60 inch Talos digitizing tablet. They then made up flowcharts of the speed and angles of the moving objects for the camera path. The results then went back to Disney for corrections in pacing, staging, and animation. MAGI incorporated these corrections and committed them to film using a high-speed raster system and film recorder.

Photo 3.7 From TRON, a video game tank patrols a dark alleyway. Note the incredible effects of color shading (see color insert). The image is by MAGI. (Courtesy of Walt Disney Production, World Rights Reserved.)
The characters in *TRON* had to be candy apple neon in appearance (i.e., glowing tubes using bright colors, so that they looked like electronic images inside a computer memory). They were done by having the actors wear white costumes and perform in front of a set with just a black backdrop. They were filmed in 70 mm black and white. Then each frame (and that’s thousands of frames) was enlarged for the production of four cells for each frame. Cel painters then came in and applied holdout mattes, masking out unwanted sections, one for the face, another for the costume, one for the eyes and teeth, and a fourth for the glowing circuitry on the front of the costume. A roto-scoping process (combining the four cells into one continuous tone positive film) was then used.

The back-lighting for the film came from the techniques Abel used in the 7-Up commercials. No reflected light is used in the microworld of *TRON*; all light comes from the creatures and objects themselves. Everything glows dimly from within, giving a forbidding and oppressive end effect.

Computer graphics were used throughout the film, often in places that weren’t obvious. Even the scene showing a nighttime landing of a helicopter used computer graphics (the city lights were computer-generated, not the helicopter).

After the computer animation in *TRON* was so well received, we can expect to see its expanded use in future films.
3.14. ANIMATION HOUSE — EXAMPLES

The figures below are from one of the most prolific animation houses in the United States, Robert Abel and Associates. This company is responsible for many television commercials that use computer animation and is perhaps most famous for their Levis commercials, which strangely enough used the computer only to help figure out camera angles (even though it looks very computer-like). The Philips Radio commercial is completely synthetic except for the background, which was airbrushed in. This shows how other media can be mixed in with computer animation.

(continued)
Photo 3.9: These are examples of animation from Robert Abel and Associates. (Courtesy of Robert Abel and Associates.)

a) Levi's Commercial — this commercial won a Cleo Award and great acclaim for Abel. Millions of people loved this when it first appeared on television in 1974. To help plan the commercial, an Evans and Sutherland Picture System 2 was used to calculate the camera moves. The final commercial, however, contains no computer graphics, just live actors and standard animation. (Directed by Robert Abel.)

b) Philips Radio Commercial — the entire scene is synthetic (created with a three-dimensional vector-shading routine) except for the cloud background, which was conventionally painted with an airbrush and then matted in. An Evans and Sutherland Picture System II is used for all of their computer animation work. (Directed by Bill Kovacs.)

c) CBS Evening News Opening — for those of you who watched the evening news on CBS during 1981-1982, you'll recognize this spinning globe with the CBS "eye" symbol indicating the cities. (Directed by Clark Anderson.)

d) AT&T Energy Commercial — this was entirely computer generated. (Directed by Rod Davis.)

3.15. AN APPLE FOR ANIMATION — JAMES LEATHAM

Can a low-cost twentieth century personal computer simulate a high-tech graphics machine from the twenty-first century? Are personal computer users destined to play Space Invaders and Pac Man because they just don't have enough pixels to do anything more significant? Or is there a fantastic animation potential inside your personal computer that's dying to "worm" its way to the surface and do something wonderful?

One person who has answered all these questions with a resounding YES is James Leatham, located in Chester, New York. James is a multitalented programmer and filmmaker who, using a standard Apple II, a SubLogic A2-3D1 Graphics Package (SubLogic Communications Corp., 713 Edgebrook Dr., Champaign, IL 61820), and a special homemade equipment bench, has created fantastic animation scenes for an 8 mm film called Asteroid. The movie concerns space age asteroid belt miners. In the scene that Jim worked on, the ship's computer detects and analyzes a particularly valuable asteroid. The ship's computer creates a simulation of the asteroid and rotates it in three
dimensions. A jagged magnetic field appears to float around the asteroid, rotating with it. The photo below shows another one of James’ creations. This is from the flip movie of a mathematical function. In the movie the two functions appear like colorful wire frame mountains that grow and shrink.

Photo 3.10: Frames from James Leatham’s Calculus Mountains, a good example of how a microcomputer can be used for computer animation. James used a Super-8 camera under the direct control of an Apple II computer. The computer draws a high-resolution picture on the screen, positions a filter from the filter wheel in front of the lens, takes the picture, and draws the next frame with a new color or advances the film as appropriate a) through e): a short sequence of film using three exposures per frame (r-g-b); f): black and white version; g) through i): red, green and blue exposures. (Courtesy of James Leatham.)
James used the SubLogic A2-3D1 package to define a three-dimensional database for the asteroid. It was simple to enter rough coordinates that resembled a round object. Next a control program was written in BASIC to rotate the object in single degree increments on the Apple screen. James devised a special bench for holding the camera and a rotating filter. The control program could move the proper filter in front of the camera and snap the shutter of the camera for each different filter color. The control program and camera mechanism took almost all the labor out of the filming of the animation sequence.

The film was later projected onto the spaceship's CRT at 18 frames per second, which was a speed-up of 180 times over the original rate. Figure 3.20 and Photo 3.12 show James' set up. He uses an Apple II with an Eumig 881 PMA Super-8 movie camera. A black and white monitor is used for maximum resolution, and that explains the reason for all the color filters. The computer can open the camera's shutter and hold it open for as long as required. The computer can also capture the display modes from the text to either of the two high-resolution pages. Each new image is drawn on an alternate graphics page. When it's done, the new page is switched on by the computer program, and the old page (now out of view) is erased. The proper filter is then rotated into place by the stepper motors and the camera shutter is opened for the required time.

James Leatham is one of the first pioneers in the amazing field of home computer animation. His example shows that one can achieve incredible effects on a very small budget. He may be at the forefront of a new phase in computer movies where stick figures and clay models are replaced with data statements and programmed logic.
Photo 3.12: James Leatham's Apple II budget 16 mm animation equipment. This equipment produced the frames in Photo 3.10 as well as animation sequences for a science fiction movie.
Now that you have had a good introduction to computer graphics software, you are in a good position to solve a particular problem using a graphics-oriented computer. You may also be asking yourself, "What is available for a low budget in the way of graphics machines?" Anticipating this, we have prepared the next chapter. It is a survey and analysis of the graphics-oriented personal computers you can purchase today. Although the survey doesn't cover everything on the market, we think our particular sample will whet your appetite. We have not covered the expensive, non-microcomputer-based graphics machines, the S-100 boards, or the most super high-tech computers; we'll leave those for another book.
Now that you know enough about the million dollar, high-technology animation computers to want to own one, it's time to draw up plans for "borrowing" a few bars of gold from Fort Knox. If this isn't quite your style, don't worry, there's another way out. Consider, instead, the more reasonably priced color personal computer.

Given the rapid advances in technology, today's personal computers, once the poor relatives of high-tech machines, are quickly catching up in performance. And even though this is the case, the prices for these marvels (with a single built-in programming language) start at a nominal $99, average $1500, and peak at $3500.

In addition to their attractive low cost, color personal computers offer the animator some other pulses which are lacking in the high-tech machines. To begin with, the personal computer owner will find many books (like this one), which make learning about the machines' capabilities a pleasant task. Likewise, the abundance of add-on hardware products facilitates expanding the system as your needs change. Also, personal computers have a sufficiently large base of owners to support the creation of a wide selection of animation programming tools. A case in point is the easy-to-use machine language animation routines developed as part of this book for use on the ATARI Home Computers; these enable you to design your own animation programs that perform in real time. Due to the projected number of sales for these kinds of programs, their cost is likely to be very reasonable. Therefore, after you've mastered your system and created your own programs, you might wish to sell them to a ready-made market that is eager for all the software it can get.

Because color personal computers offer so much for the money, they are extremely attractive to the consumer on a low budget. As a consumer, the first thing you'll want to know is "What can they do (in terms of graphics and animation), and how can I make them do it?" Answering these questions is the basis of this chapter.
4.1 FORMAT OF THIS CHAPTER

We have identified 13 key features you should be aware of when evaluating a personal computer for graphics animation. These features are:

- BASIC Graphics Statements
- Special Hardware Features
- Graphics and Text Modes
- Graphics Language Statements
  - Mode Selection
  - Color Selection
  - Plotting
  - Line Drawing
  - Shapes, Graphics Definition Language
  - Paint, Fill, Flood
  - Defined Object Statements
  - Image Array Plotting
  - Miscellaneous Statements
- Players/Sprites
- Hardware Scrolling
- Graphics Characters
- Custom Characters
- Color Registers
- Vertical Blank Interrupts
- Display List and Display List Interrupts
- Page Flipping
- Speed of Plotting

The bulk of this chapter will examine each of these features, defining each and explaining its importance to the animator. We will also occasionally make reference to actual personal computers, languages, and products. Our main goal is to expose you to what is important, rather than to endorse a particular machine.

4.2 BASIC GRAPHICS STATEMENTS

BASIC is by far the most popular language for executing graphics on personal computers today. To better understand the things your personal computer can do in the area of graphics, you should examine those BASIC statements that pertain specifically to graphics on the machine(s) in question. In some cases, as in the Apple III, BASIC offers primitives rather than regular statements. Primitives are graphic functions performed when certain character sequences are sent to a special graphics program called a driver. You should understand, however,
before getting involved with graphics primitives, that they are definitely more difficult to use than BASIC statements.

What Language?

Although BASIC is the most common language in use on personal computers and its merits are simplicity of use and immediate feedback, it is not accurate to conclude that it is the only or even the best language for graphics. Another popular language for microcomputer graphics is Pascal, particularly Apple Pascal. Since Pascal is a compiled language, its graphics programs usually execute faster than those written in BASIC. The major drawback with Pascal is that it is a structured language. This means a front-end or preamble of instructions must be first created for your program before you can try an idea. This kind of programming demands much preplanning and is good for long and involved projects but difficult for the "just try it and see" approach.

Another graphics language which is growing in popularity is Logo. Logo is built around a concept called turtle graphics. Turtle graphics allows the user to see a turtle (with an imaginary drawing pen in its mouth) on the screen. The turtle can be moved with simple commands like TURN and MOVE, and in so doing it leaves a line of color behind it. Children have an easy time drawing with the turtle because its movements are obvious to them and intuitively understood. A simple box, for example, can be drawn in Logo with very few statements (see box on the next page).
Making a Box in Logo and BASIC

TO BOX :SIDE
HOME
REPEAT 4 [FORWARD :SIDE LEFT 90]
END

Figure 4.1: Logo Box Program.

In this program we have previously typed TELL TURTLE to activate the drawing turtle. FORWARD sends the turtle ahead a distance set by the variable SIDE and in any direction on the compass. The turtle starts point straight up (due north). The instruction LEFT 90 turns the turtle 90 degrees. We started the program by typing BOX 10, which made the value of SIDE equal to 10 and then executed the program.

Compare this to the same box done with Applesoft BASIC and decide which is easier to understand. One of the authors was once a devotee of BASIC and worshipped it at every turn. Now after playing with Logo he no longer finds BASIC as friendly as it once was.

100 HGR :REM clear the hi-res screen
110 HCOLOR = 3 :REM set the color
to white
120 XC = 140 : YC = 80 :REM set
the center coordinates
130 INPUT "Enter length of side "; SI:
   REM enter side
140 HPLOT XC,YC TO XC,YC-SI TO
    XC-SI,YC-SI TO XC-SI,YC TO XC,YC
   :REM and draw it
150 END

Figure 4.2: Applesoft BASIC Box Program.

In this program, we must first clear the screen to black, set the drawing color to white, set the center coordinates XC and YC, and request the user to input the length of the sides. Then the HPLOT statement draws the actual box.

Some versions of Logo may, however, hold back the programmer of complex objects because its number crunching ability is more limited than BASIC or Pascal. For example, Apple LOGO has floating point while TI Logo has only integers.

The language C is often used in larger computers for doing graphics. C is similar to Pascal but is easier for creating programs that must manipulate the byte and bits of the microprocessor. It executes faster than Pascal and is just beginning to appear on low-cost personal computers like the ATARI Home Computer (it has been available on CP/M-based computers for some time). With C and the addition of an S-100 graphics
board with a high-resolution bit map, you would have a very powerful, low-cost graphics machine.

You may also want to investigate Forth as a graphics language. Although it is rather difficult to learn, it is a somewhat elegant language and your own graphics instructions are easily added to it. Its advantages include high speed, immediate execution of programs (no compilation like in Pascal and C), ability to define your own commands, and very compact code.

Assembly language is another way to go if you have lots of patience and perseverance. Graphics written in assembly (8080 and 6502 are among the most popular codes) will execute very quickly, allowing the rapid and fluid movement of objects on the screen. One of the authors has created a set of graphics extension routines in 6502 assembly language that enhances Applesoft so you can draw circles, polygons, and fill shapes with color. These routines, however, were very difficult to create, requiring hundreds of programming hours. Rather than attempting to create your own assembly language routines, first check animation aids and products currently available on the market by looking through magazines such as Popular Computing and Byte.

4.3. SPECIAL HARDWARE FEATURES

As a graphics programmer, it may be important to understand how your personal computer works on a hardware level. It all depends on the degree of control you want to have over the graphics effects produced. In the Apple, for example, it doesn’t really matter how the hardware for graphics works if you’re using only BASIC or Pascal. If you want to program your Apple in assembly language though, the hardware is extremely important because you must access bits and bytes in screen memory with a rather complex algorithm. If you are using an ATARI Home Computer with its custom graphics chips and want to have absolute control over the pictures that the machine is capable of creating, then you’ll need an intimate understanding of the built-in hardware.

4.4. GRAPHICS AND TEXT MODES

Every manufacturer has its own way of defining the numerous modes in which a computer can function. A graphics mode (sometimes referred to as a map or pixel mode) sets up the screen for responding to the graphics instructions that are in the language, whereas a text mode screen is set up for displaying words, programs, etc. Usually the text mode is used for program development, and the graphics mode is used for running graphics programs. Text and graphics can often be mixed, but the precise method of doing this varies from machine to machine. For example, when the Apple is in a graphics mode, text can appear only in a window of four lines at the bottom of the graphics screen. On the IBM, on
the other hand, text can be displayed anywhere on the graphics screen. (As a rule, such mixing is more restricted on other computers.) Mixing modes is very important in business graphics where graphs and charts need to be labeled but less critical in animation where objects are simply moved about. Often, as in the case of the Apple, special programs can be purchased that allow the creation of text characters that will appear on the graphics screen. Use of these programs, however, may be a bit complex for the beginner.

Figure 4.3: A typical graphics mode.

Resolution Selection

Mode selection also allows you to choose which resolution you desire. The IBM PC, for example, has a medium- and a high-resolution mode, the difference between the two being the number of pixels and amount of color allowed.
When considering a personal computer for animation, you should not simply assume higher resolution is better. Some lower resolutions offer more color, and careful use of this color can result in brilliant effects.

**How High Is HI Resolution?**

There is an interesting phenomenon about the various resolution modes which is that the terms high, medium, and low resolution have entirely different meanings on different computers. High resolution on the VIC-20, for example, is more like the low resolution of the ATARI Home Computer, and high resolution on the ATARI Home Computer is like medium resolution on the IBM PC. And high resolution on the IBM would be considered low resolution on the large high-tech computers. The ultimate truth in the use of any of these terms lies in the number of horizontal and vertical elements that can be accessed on the screen. For a long time the highest resolution in personal computer graphics was the Apple II’s $280 \times 192$ mode. Then the IBM came out with a $640 \times 200$ mode which they also called high resolution (which it certainly is), even though it does not have color. This gives you an idea of the kinds of problems that consumers face when choosing a computer.

**Mode Color Capability**

Another important item to consider when examining graphics modes is the color capability of each. Here things can get very confusing. There are foreground, background, and border colors. Background colors refer to the color taken on by the entire screen when it is cleared. Foreground colors (called playfield colors on the ATARI computers) are the colors that can be plotted on top of the background color. Border colors are those which can surround the perimeter of the active screen area. In computers that offer these three choices there are usually a certain number of colors that can be used in each area. For example, the IBM PC’s medium resolution mode allows 16 background colors and 3 foreground colors to be chosen from one of two sets. Some computers (Apple) have no user-selectable background colors (although the screen can be filled or plotted with color).

**Maximum Color**

The maximum number of colors allowed in any mode is usually a function of the resolution of the mode. As resolution increases, color capability decreases. This is a consequence of the fact that display pixels are encoded in an area of memory. If memory size is fixed and resolution is increased, then the feature that must suffer is color. This is clearly illustrated with ATARI’s medium-resolution mode ($80 \times 192$), which offers a maximum of 16 colors, and the highest mode which offers only two colors.
Disappearing Colors

As someone interested in computer graphics, you should be aware of the "case of the disappearing colors on a television" problem. A television set has a limited band width, meaning it can respond only to a limited number of changes in electric current per second. Because a computer encodes color information via these changes, there is an upper limit at which the TV cannot recognize a change in color. (If you just use white on a black and white TV, this is not a problem. Also, color RGB monitors have a higher band width than regular televisions so they permit greater color changes on a line.) All this means that there is a limit to the number of color changes that can occur on a horizontal line on the TV. The result is that certain columns are restricted from having certain colors. On the Apple II the problem is further complicated by the way the screen colors are encoded in memory. A drawback like this has not kept people from developing Apple programs, but moving color objects about without having sections of them disappear complicates the programming techniques.

Text Modes

In the text mode we are concerned with several things, including the number of dots per character, the number of characters on a line, and the number of lines on the screen. (These numbers correspond to the degree of resolution in graphics modes.) In reference to the matrix of dots which comprises each character, the more dots the finer the character's detail and the easier it is on the eye. A minimum dot matrix is \(5 \times 7\); a maximum on the computers we are covering is about \(8 \times 8\). The actual number of characters on a line varies from as low as 20 to as high as 80, with 40 as standard for television sets. The final factor in text mode displays is the number of lines on a screen, which varies from 16 to 25, with 24 being the most popular. In most cases the general rule of thumb is "the more characters per line the better"; however, 80 characters per line is very difficult to read due to the television's limited band width problem which we mentioned above. On a black and white monitor and on color RGB monitors, however, 80 characters is very readable.

Many text modes allow you to use color as well. This can be a marvelous benefit in word processing applications or in any application where you want text to stand out. In some computers, such as the IBM PC, there are two horizontal dots for every vertical position in the 40-column text mode. This feature is called double dot and gives the impression of a \(16 \times 8\) matrix, which results in text characters that appear to have serifs! Serifs are the curly ends of characters that give them a certain distinction.
4.5. GRAPHICS LANGUAGE STATEMENTS

Here we present the various features for selecting modes, selecting colors, plotting, drawing lines, creating shapes, filling, defining objects, plotting image arrays, and miscellaneous other uses.

Mode Selection

Computers vary from having no mode selection to having several modes to choose from. A machine might offer mode selection through the use of a single statement (such as Apple’s HGR or TEXT) or, as in IBM’s SCREEN, through the use of a complex statement containing four parameters which the user can set. Some computers, such as the TRS-80 color, have two statements for setting the mode (PMODE and SCREEN).

Pages

The mode statement will usually select the screen’s text or graphics modes. In addition, it may select the page that will be used for display as well as the page that will receive the results of output statements. Pages are sections of memory that can be used for the screen’s contents. Often there exist several of these pages but only one is active at a given time. For example, when the IBM is used in the text mode, it has eight pages, one of which can be made the active page and one the output page. The output page will receive the results of any PRINT statements. The TRS-80 Color Computer allows graphics images to be drawn on the various pages and then flipped into view instantly. The Apple has two pages for high-resolution graphics. The idea behind pages is to allow...
generation of graphics on an output page while the user is viewing an active page. This permits the new picture to be instantly switched on, before the old picture is erased. If we were to erase the old picture and then redraw the new one, the delay in time to draw the new picture would result in an annoying flicker effect. However, because a page can be enabled almost instantly, no flicker effects occur (however there may still be some jerky motion). This method permits the programmer to create animation by letting each page contain one of several frames of, for example, a figure in different positions. The program could then flash through sequential screens to give the effect of movement.

The mode statement may also be used for instantly activating color (color burst) or disabling color in a particular scene. Some computers, such as the ATARI Home Computer, allow changing modes with a very simple statement like Graphics n, where n is the graphics mode number. (By making n equal to 0 the machine will operate in a text mode.)

Color Selection

Colors may be automatically selected by the mode statement or specifically selected with a special color statement. In some computers the color selection statement allows choosing colors for the foreground, background, and border. Computers that feature color registers usually have one statement for selecting which color register will be used to paint a pixel, and a second statement that sets each register's color value. In the ATARI Home Computer the two statements are COLOR and SETCOLOR. When color registers are used, the statement may select the luminance as well as the hue of the color. There may also be a statement for setting the color of any special programmable objects, such as TI's sprites.

Colors Available

The choice of colors on personal computers is very limited compared to the selection available on expensive high-technology computers. In some computers, like the IBM, there are eight colors with two intensities of each (high and low) for a total of sixteen (this is just in the text mode). Most manufacturers include black and white when specifying the number of available colors. In some computers, like the Apple, there are only six colors available. On the other hand, the ATARI user can choose from 128 colors (16 hues, 8 intensities) in most modes and 256 colors in two special modes, but this is the exception rather than the rule.

The names chosen for computer colors follow no standard; one company's aqua may be another's blue-green. Further complicating matters is the fact that the colors that actually appear on the TV depend greatly on the setting of the television color control and the fine tuning.
Some computers thoughtfully present a band of each color next to its name so you can perform this adjustment before using any programs.

**Plotting**

Plotting is the most fundamental graphics function. It consists of using horizontal and vertical coordinates to illuminate a point on the screen. Sometimes the plotting command is referred to as PSET, and sometimes it is simply referred to as PLOT, POINT, or HPLLOT. The plot statement is analogous to a needlepoint stitch done with a certain color yarn. In some cases you may be able to specify the color within the plot statement itself, while in other cases you must first set the color with a color statement. Erasing of plotted points is much simpler than removing a needlepoint stitch. It is done by setting the point color to the background color and replotting. Some computers, like the IBM PC, offer a special erasing command called PRESET X,Y.

Some systems may allow the X,Y coordinates to be relative by use of the word STEP in the plot statement. This means that the new point is plotted X,Y locations away from the last plotted point. Relative coordinates are good for simplifying the coordinate values for a complex object. Although plotting is probably the simplest graphics function to perform on a computer, it is usually too slow for real-time animation in BASIC. With C and Forth, however, point plotting may provide sufficient plotting speed for the animator.

**Line Drawing**

Line drawing is an important graphics instruction, because it allows complex multi-sided objects to be drawn quickly and simply. It eliminates the need to do a repeated PLOT in a loop of some sort. Line-drawing statements can be as simple as Apple’s HPLLOT x1,y1 TO x2,y2 or IBM’s LINE (x1,y1) - (x2,y2) , color, B. The IBM and TRS-80 Color Computer line-drawing statement is unique in that it has a special option that allows a rectangle to be drawn. When the letter B (for BOX) is included in the statement, the x1,y1 and x2,y2 coordinates are taken as diagonal corners of a box. If BF is included, the rectangle gets filled with color (when color is also set in the line statement). Line-drawing statements are often used to put fixed objects on the screen, with DATA statements holding the coordinates of the shape’s numerous corners. Line drawing for real-time animation, unfortunately, is usually too slow from BASIC.

**Shapes and Graphics Definition Language**

Shapes are a feature originated by Apple Computer as part of its famous Apple II’s graphics software. Shapes are ingenious graphics objects composed of tiny vectors, which are small line segments that can be drawn in one of four directions (up, down, right, or left). The
programmer uses simple rules to string these vectors together like tiny arrows connected end to end. A shape can be made from a few vectors or hundreds of them. Once these shapes have been created, they can be drawn on the screen with one very simple statement, like \texttt{DRAW 1 AT X,Y}. There also exists an entire set of additional statements for manipulating these shapes, including ones that scale them in size from 0 to 255, and ones that rotate them from 0 to 360 degrees! These statements make shapes incredibly useful for games and programs where objects fly, sail, spin, or otherwise bounce across the screen. They may be limited for real-time animation however, because the \texttt{BASIC} statements that move them are slow. For non-real-time animation (i.e., when you use film or the disk to store the frames of the picture), they are ideal.

Graphics Definition Language (GDL) is a feature currently found only on the IBM Personal Computer and the TRS-80 Color Computer. GDL is a set of drawing commands that are placed in a string variable (as opposed to being inserted into memory with \texttt{POKE} or \texttt{LOAD} as needed with Apple's shapes). These drawing commands specify the way the line segments are to be drawn on the screen. There is a very complete set of commands including ones that draw up, down, right, left, and diagonal segments, repeat these patterns, move without drawing, rotate, and draw relative to a point. The GDL is too slow for animation when the number of vectors comprising the shape is greater than ten (when this is the case an unacceptable screen flicker occurs). However, for slow moving shapes, complex objects that don't move at all, or non-real-time animation, it is an excellent feature. One problem with the GDL shapes is that there can be vectors in only one of eight directions. This means smooth curves are impossible to draw.

**Paint, Fill, Flood**

These terms all refer to the same thing — filling an enclosed boundary with a particular color. There are different types of fills, the main difference among them being the ability to circumvent corners and fill every nook and cranny of the enclosed area. A fill, or paint, works by the user specifying an \texttt{x,y} location inside an enclosed area and a particular color with which to flood it. Fills are usually slow and do their filling in a method that resembles many bizarre window shades closing at the same time. Because of the way some computer screens are set up (with rules specifying which colors can be positioned next to each other), fills have a tendency to distort the color of adjacent objects.

**Defined Object Statements**

Often it is desirable to draw certain geometric shapes (squares, triangles, polygons) on the screen. This is fairly easy to accomplish using the \texttt{LINE} statement. The procedure, however, is somewhat more complex when curved surfaces are involved. Drawing a simple circle can be
very demanding for the non-mathematically oriented user because we usually need to use complex BASIC programs involving trigonometric functions such as SIN and TAN. One way out of this dilemma is to use the defined object statements that make graphics programming much easier. One such statement is the CIRCLE command (available on the IBM, TRS-80 Color, and VIC-20 Personal Computers), which allows you to draw a circle, ellipse, or arc at any x,y location on the screen. The circle you draw can be of any radius with distortion in either axis and can be used for anything from the petals of a flower to the wheels of a bicycle to complex mandala patterns. CIRCLE permits the drawing of elaborately curved shapes using very little programming code; unfortunately, it is too slow for fast animation, but may work well for slow moving objects.

**Image-Array Plotting**

Image-array plotting is another way to plot complex objects on the screen, and it is a terrific graphics feature. There are two statements involved here: GET and PUT. The GET statement is used to store an object that has already been drawn on the screen in a two-dimensional array (as a matrix of on and off bits/pixels). A pair of x,y coordinates in the GET statement specifies the area on the screen to be stored in the array. These coordinates define the diagonal corners of a rectangle that surround the object on the screen. A corresponding statement, PUT, is then used to draw the object now stored in the array at any x,y (upper left corner of the rectangle) screen location. Since the object is drawn using the bit map stored in the array, an optional action statement can be used to control the way each of the object’s ON bits interacts with the image already on the screen. The action command allows you to AND, OR, or XOR the array contents onto the screen background. In essence, this means you can draw the object on a background without having to erase it! After storing an object with GET, you can use PUT as a specially created paint brush to dab on the screen wherever you wish.

As might be expected, not all BASICS offer GET and PUT. You’ll find it on the IBM and TRS-80 Color Computer. Image-array plotting is too slow for complex animation but can be used effectively when slow movement is desired or when objects are very small or very simple. Apple III’s drawblock command, although cruder, is another example of image-array plotting. It is a graphics primitive and not easily used from within BASIC because up to 20 arguments for it are stored in memory. Even so, it is probably faster in operation than regular array plotting and might work well in animation.

**Miscellaneous Graphics Statements**

Other graphic statements that you will find useful are those designated for clearing the entire screen to a certain color, a width statement
for controlling the number of text columns that can be displayed, and a screen function that returns the ASCII value of a character at a particular row and column. Also useful are the point function for returning the color at a specified location on the screen, a locate statement for positioning the text cursor, a command for setting the viewport (a rectangular window on the screen that graphics drawing is restricted to), and a page copy statement for moving graphics information from one page to another.

4.6. PLAYERS AND_sprites

Players and sprites are graphics objects that can be moved by custom hardware. ATARI calls them players while Texas Instruments refers to them as sprites, but their function is similar in nature. Players solve a major graphics problem — namely, they are separate from the background and don’t require complex erasing to be moved on the screen. They are somewhat easier to update than the normal plotting methods, and they don’t interfere with other objects made from players.

With normal software, the program must keep track of the position of an object, erasing and redrawing it as it moves across the screen. With players, however, you only have to POKE a register with the horizontal value of the object’s screen destination, and the hardware does all the moving for you. For vertical movement, bytes representing the object in a special area of memory must be moved. There are techniques to accomplish this from within BASIC, but a machine language routine makes it simpler. ATARI’s Players have their own color register so they can be a different color than anything else on the screen. You can even combine Players to create larger objects or objects of more than one color.

Sprites function differently from players. A sprite is twice as large as a regular character (16 × 16), whereas the players are 8 bits wide with a maximum height of 256 bits. Sprites are more powerful than players when it comes to moving them on the screen. Once a sprite is put into motion, it keeps moving as directed until told otherwise. The sprite has a large number of special commands for moving it, including a MOTION command for specifying velocity and direction, COINC for detecting sprites coincidence (collision), DISTANCE for telling the distance between two sprites, and MAGNIFY for changing the size of sprites on the screen. You can tell all the sprites to FREEZE and to THAW; you can change colors of any of them at any time, and you can redefine which ones appear on the screen. For some time sprites were available only on the TI 99/4. However, because sprites are generated by a special TI chip that is on the open market, you can now buy a board for the Apple that gives it sprite ability.

It should also be noted that some of the sprite’s manipulation commands are available with ATARI’s players through a direct POKE or
peek to the hardware registers. The collision of a player with another player or specific screen color can be detected, the width of a player can be changed, and the Player’s priority in relation to the screen Playfield colors (non-background screen color) can be controlled. (By priority we mean whether the player passes in front or in back of a screen color.) Each player is also associated with a two-bit wide missile, which can be moved about the screen.

Players and sprites are perfect for animation — they were designed for this purpose. Using them in a program eliminates flicker, update overhead and superfluous, convoluted programming code!

4.7. HARDWARE SCROLLING

Hardware scrolling causes the display screen to move over a screen memory area which is actually larger than the screen. Conventional brute force scrolling, where bytes must be moved one at a time into the display area of memory, results in a visual effect which is slow, wavy, and choppy. With hardware scrolling, the software only needs to change single two-byte pointers to cause the entire screen image to move up or down, right or left, or diagonally, resulting in a very fast and smooth scroll.

There are two distinct kinds of hardware scrolling — coarse and fine. Coarse scrolling moves the screen window many bytes at a time (entire characters), whereas fine scrolling moves the screen on a pixel (dot) basis, allowing a smooth gliding effect. This technique is used in Chapter 9 for moving our program backgrounds.

Although hardware scrolling is perfect for animation background, it is a rare feature usually found only in the most sophisticated computers. The only personal computers currently possessing this feature are the ATARI Home Computers.

4.8. GRAPHICS CHARACTERS

Many personal computers have, in addition to the normal built-in text characters, a set of graphics characters. These are usually tiny shapes such as boxes, line segments, circles, card symbols, smiling faces, Greek characters, and corners. In some quick and dirty types of animations, these graphics characters may be very useful.

4.9. CUSTOM CHARACTERS SETS

A most important feature for animation is the ability to create and manipulate objects which are made from your own custom characters set.
This feature is available on most of today's personal computers. A single custom character usually consists of an $8 \times 8$ matrix of dots. With careful planning, you can create a custom character set that satisfies a variety of purposes. You can create a complex object that can be made up of several of these adjacent custom characters. The Walking Man program (Chapter 5), as well as the trees and houses in Chapter 9, were created using a custom character set.

Some computers, like the Apple, feature special programs that facilitate the creation and use of custom characters. Therefore, if the system lacks the ability to mix text and graphics, as the Apple II does, it is possible to actually create your own character set, as well as graphics characters, and mix them on the screen.

4.10. COLOR REGISTERS

Color registers (see Chapter 2 for more details on these) are a feature just beginning to appear on personal computers. First implemented on the ATARI Home Computer and now found on the VIC-20 color computer as well, color registers provide an indirect way to specify pixel color while giving more power and flexible graphics control. Personal computers use color registers in a manner similar to that of high-tech animation computers, with the exception that they are not as wide, bit-wise (and thus hold fewer colors), nor are they as numerous (nine in the ATARI Home Computer, four in the VIC-20). With enough color registers you can perform animation colors through them. Areas on the screen that reference these registers then change color accordingly. Chapter 6 shows, through program examples, how to use color registers in animation on the ATARI Home Computer.

4.11. VERTICAL BLANK INTERRUPTS

Every 1/60 of a second the entire screen is redrawn. From the time when one screen has been completed and the next one is begun, there is a short period called the vertical blank. If the computer allows it, the microprocessor can be interrupted at this point, and a custom machine language program can be executed. This routine can be used to process animations-in a background mode, which means you can have certain graphics events occur unattended and almost automatically, such as moving an object, playing music, or reading the joystick. The ability to interrupt the microprocessor during the vertical blank period is called a vertical blank interrupt and is another rare feature which is available on the ATARI Home Computer. Vertical blank interrupts are an advanced concept which we thoroughly cover in Chapter 8.
4.12. **DISPLAY LISTS AND DISPLAY LIST INTERRUPTS**

Display lists are popular in high-technology animation computers but rare in personal computers. A display list is a section of memory that contains a set of graphics instructions for a graphics processor. So far, only available on the ATARI Home Computers, the display list controls into which graphics modes the screen is divided. The ATARI screen can be horizontally divided into as many different modes as you wish. Display list interrupts are display list instructions that actually interrupt the microprocessor after a mode line has been drawn on the screen and make it possible to change aspects of the display, such as screen color. Chapter 9 features display list interrupt programming examples.

4.13. **SPEED OF PLOTTING**

A good general test of the speed of your graphics processor is to use the BASIC plotting statement to place a certain number of pixels on the screen using a `FOR/NEXT` loop and see how long it takes to do this. If you subtract the time to do the loop and divide the number of pixels by the number of seconds, you have the number of pixels plotted per second — a good measure of graphics speed.) We created the program below to perform this test. The starting and ending values are adjustable to take into account each computer's particular display format. Here is the benchmark program we used for the IBM. You can modify this program to work with other computers' unique statements.

```basic
100 REM test pixels per second for ibm
110 CLS
120 SCREEN 1: REM sets 320 x 200 mode
130 COLOR 0,1: REM selects background, palette
140 XMIN=1; XMAX=320: REM start and end x
150 NROWS=10: REM enough rows to time it
160 YMIN=1: REM starting y
170 FOR Y=YMIN TO NROWS
180 FOR X=XMIN TO XMAX
190 PSET (X,Y),1
200 NEXT X,Y
210 END
```

**Figure 4.5:** Benchmark Program for testing plotting speed.

Run the above program, and time it with a stopwatch. Calculate the total number of pixels plotted by multiplying `XMAX` by `NROWS`. (`XMAX`
Animation features vary for each computer screen resolution.) After this number is obtained, put a REM statement in front of the plotting command on line 190 (here PSET for the IBM), run the program, and time it again. (In other words line 190 would look like 190 REM PSET (X,Y) +1.) Subtract the difference between the two times and divide the total number of pixels by this difference. The final answer is the number of pixels plotted per second.

As an example of how fast a personal computer can plot, we found that in IBM’s medium- and high-resolution color modes, 320 pixels per second could be PSET to a color.
Part II

Introduction

Earlier you saw what can be done with million dollar computers. Now let's look at the kind of animation that can be created with a personal computer costing only a few hundred dollars. In this half of the book, we will show you how to bring the exciting world of animation into your own home. If you have an ATARI microcomputer (a 400, 800, XL, or equivalent) with ATARI BASIC, you will be able to turn your computer into a fabulous animation machine. If you own something different, read on anyway — some of our examples can be modified for other microcomputers.

This second half of the book is organized differently from the first. This is the hands-on section, and we will be presenting animation program examples that you can type into your computer. We will start out with very simple examples and conclude with a sophisticated demonstration program which uses most of the ATARI's special graphics features.

We assume that you already have some experience with the BASIC programming language. Although we explain the logic behind our animation demonstration programs, we don't cover the meaning of the BASIC keywords (e.g., PRINT, GOTO, GOSUB, etc.). Therefore, if you are new to programming in BASIC, reading a beginning book like BASIC Programming Primer (by Waite and Pardee, Howard W. Sams & Co., Indianapolis, IN) or Armchair BASIC (by Fox and Fox, Osborne/McGraw-Hill, Berkeley, CA) will help you better understand our examples.

You do not need to understand assembly language to use the examples in this book. We have provided you with several black box machine language routines which will give you control over the ATARI features such as Player-Missile graphics, Fine Scrolling, and Display List Interrupts. By black box we mean that you can use these routines without knowing what's inside them — you POKE something into them and the desired result comes out. We have designed them so they are easy to use from within BASIC.

If you have thumbed through this section of the book already, you probably noticed many pages of program listings. To save you the time and trouble of entering all this code, a diskette is available through
Adventure International which contains our major demo programs and all the assembly language routines.

Many of our programming examples are expansions of previous examples. This means that instead of typing an entire program, you will often need only to add new sections to an existing program. Therefore, do not erase the programs you type in — save them on cassette or diskette, you may need them later on. Also, as you enter the examples, it is important to copy them exactly as they are, without changing any line numbers or omitting any lines. Otherwise, when it is time to expand the programs or merge some of them together, you will have quite a bit of difficulty.
In this chapter, we will show you how to use ATARI’s built-in and user-defined character sets to create animated pictures. These techniques can be employed with any computer which allows you to redefine the character set. There are four demonstration programs in this chapter. The first one will produce a flying bird, the next a walking man, the third a screenful of galloping horses, and the last a bomb exploding in brilliant colors.

5.1. BUILT-IN CHARACTER SETS — MAKING DO WITH WHAT YOU HAVE

As we have mentioned earlier, animation is created simply by rapidly displaying a series of pictures which differ only slightly from each other. The brain is fooled into thinking that it is seeing continuous motion rather than individual pictures. The most basic method of implementing animation on a computer is by using PRINT statements to draw a figure on the screen and then using PRINT to go over the figure with a different picture. When these figures are PRINTed in rapid succession, we perceive motion.

To draw our figures, we can use the computer’s built-in characters — the letters of the alphabet, numbers, punctuation, and special graphics characters. (See your ATARI BASIC Manual for the complete ATARI character set.) A graphics character set is made up of straight lines, diagonal lines, corners, squares, and circles. When the imaginative programmer puts these elements together, he or she can create a crude picture. Computers such as the IBM Personal Computer and the Commodore computers (PET, VIC, CBM, Commodore 64) all have built-in graphics character sets. The greater the variety of characters, the more flexibility a budding animator has in creating “living” figures. In our first example, we will use the ATARI’s graphics character set to create a bird in flight on the screen.
Creating the Frames

To produce the effect of animation, you need to create a series of individual pictures that can be rapidly flashed on the screen. Each picture is called a frame. In conventional cel animation, the animator usually draws the key frames first. These are the ones which show the figure in extreme or key positions. With a very short animated motion, there might be two frames: the initial position of the figure (before the action begins) and the final position of the figure. For example, a person waving good-bye could be animated with two key frames. Longer actions, on the other hand, might contain many key frames, each one occurring at every directional shift in the action. An example of this might be a battle between two figures. The key positions are created as the fight is choreographed. This is done by breaking the extended, complicated action into short, simple actions. (In Example 1, our flying bird, we use two key frames, one with the bird’s wings fully raised and one with the wings pointing downwards at the bottom of the flapping cycle.)

The next step is to create the in-between frames, i.e., the ones used between the key frames. The number of in-between frames determines the smoothness of the animation. In Example 1, if we had used only our two key frames, without any in-between frames, the animation would have looked jerky and unnatural. (This jerkiness is called judder and is an indication of lazy animators or tight production budgets.) On the other hand, since the computer can only PRINT a limited number of frames per second, too many in-between frames would result in slow motion. This is because the computer would not be able to flip through the frames fast enough to make the bird flap its wings at the proper speed.

In film animation, frames are flashed on the screen at the rate of 24 per second. The cartoons produced during the golden age of animation used full animation in which each of those 24 frames required a separate drawing. Today’s low-budget cartoons necessitate the reuse of each drawing in consecutive frames. A drawing is placed under the animation camera and photographed two, three, four, or even six times before the next drawing in the sequence is used. This yields a respective animation rate of twelve, eight, six, or four frames per second. Twelve frames per second is tolerable, but anything slower looks painfully crude in comparison to the classics.

In character set animation, the problem of how many frames to display is approached from a different angle. With built-in character sets, we are restricted to the number of in-between frames which can be created with the limited set of characters. In the flying bird example, we could only draw two in-between frames with the available graphics characters, resulting in a total of four unique frames. Even without the restriction of built-in character sets, there is another limiting factor — the computer’s processing speed. How many frames can the computer draw in one second without becoming bogged down? The answer is dependent
upon the complexity (size) of each frame, the number of different objects which must be animated at one time, and the other programmed functions (sound effects, calculations, or joystick inputs) that must be taken care of during the animation cycle.

How do you decide how many frames to use in your animated sequence? After months of creating animation programs we will now pass on our foolproof technique for creating realistic looking animations — it is called “Trial and Error.”

The Art of Trial and Error? Most of the development time for this program was spent deciding which characters to PRINT on the screen to create something that looked like a flying bird. Writing the actual program logic took very little time, which is often the case in creating computer animation. Much time is spent in trial and error, trying to get the figure on the screen to look just right. We had certain prerequisites. Not only must our figure resemble a bird, but when it moved, it had to reflect the image of a bird in flight. If the wings moved too fast, the viewers would see only a blur. If the wings moved too slowly, the effect of motion would be lost.

As you begin to create your own animated figures, you'll begin observing the motion of living things. Another excellent source for learning about animation is by watching cartoons. Notice how simple and limited the animation can be while still conveying the effect of movement. At first you may become frustrated with your results, especially after looking at the video games created by the masters. Don't give up! In time, you'll develop an intuitive feeling for animation and will find that your trials are shorter and the errors farther apart. After all, even masters spend much time throwing away earlier attempts that don't look just right.

One nice thing about computer animation is that the results are visible immediately. You don't have to wait for the film to come back from the lab before discovering that your bird looks like a boomerang with arthritis! With a computer, if you don't like what you see, you can adjust the graphics accordingly.

The Flying Bird Frames

Four individual frames were used to create our flying bird, as shown in Figure 5.1. Notice that only four different graphics characters are used throughout the frames.

[Characters used: CTRL F, CTRL G, CTRL M, CTRL T]
FRAME 1

FRAME 2

FRAME 3

(continued)
Each frame is five characters across and three high. To make the job of animating the bird easier, each frame should be identical in size and shape. To accomplish this, many of the character positions in the frame are filled with spaces.

By taking these four frames and cycling through them in a specific order, the bird flaps its wings. Here is the order of the sequence:

Frame 1  beginning of cycle
Frame 2
Frame 3
Frame 4  midpoint of cycle
Frame 3
Frame 2
Frame 1  end of cycle and beginning of next cycle
Frame 2
Frame 3
Frame 4  midpoint of cycle
Frame 3
etc...

For obvious reasons, this is called cyclic animation. It is relatively easy to implement because the object can be animated for many seconds or minutes by using only a few different frames. In conventional cel animation, each frame would be photographed in order, over and over again. This can be very time consuming. But with a computer, we can use a simple GOTO loop to repeat the cycle. In the upcoming program, Example 1, six frames are displayed before the cycle repeats.
Listing Conventions — How We Represent Those Invisible ATARI Characters

Throughout the listings in this section of the book are many characters which either cannot be printed by our printer or are difficult to find on the ATARI keyboard (e.g., inverse video, cursor control, and graphics characters). To make it easier to enter the programs, we modified the listings so that all special characters are indicated. Inverse video characters are underlined, and all other special characters are surrounded with curly brackets { }. This includes all graphics characters (entered with the CTRL key) and all cursor control characters. When spaces are critical, they are represented as a "b" with a slash through it (b).

You may have noticed that our printed listings look different from programs listed on your screen. We used a special program to print them in a manner which emphasizes their structure, thus making them more easily read and understood. All FOR / NEXT loops are indented so it's easy to see where the loop starts and ends. IF / THEN statements are also indented — you can see exactly what will be executed if the condition is TRUE. Also, the multiple parts of all statements (separated by colons) are printed on a separate line. Of course, when you enter the programs, the structure will disappear; therefore, don't try to maintain it by entering each statement on a separate line!

Although our formatted listings are easier to read, the formatting makes the programs appear to be longer than they really are. Don't let the number of pages it takes to display each program discourage you from entering it. Of course, if you don't want to spend your time typing programs in, you can always purchase them on a disk (see the order card in the back of this book).

Before you try entering the programs, read the complete information in Appendix C, "Listing Conventions."

The listings in this book are in a special format and use special codes. Before you try to enter any of our programs, read the above box and Appendix C, "Listing Conventions."

Some of the listings in Chapters 5 through 9 are rather small and difficult to read. However, the complete listings are printed again, larger, in Appendix A for your reference.
Example 1

Exercise Using the built-in ATARI graphics character set, write a program that draws a flying bird with flapping wings on the screen.

Photo 5.1: Screen photos of the Flying Bird program.
Here is the listing of the Flying Bird program. Look at the lines where the BIRD strings are initialized (lines 120–150). We are using a special convention here to tell you which keys to press to get the appropriate graphics characters. When you see a word or character which is surrounded by curly brackets { }, you must do something special to get the appropriate character into the string. The box called “Listing Conventions” and Appendix C explain how this is done.

How it Works  In line 110, we DIMension the string variables we will be using in this program. The number within the parentheses tells BASIC the maximum number of characters each string may hold. In ATARI BASIC, all strings must be declared in this manner.

The four frame strings, BIRD1$, BIRD2$, BIRD3$, and BIRD4$ (initialized in lines 120–150), contain three different types of characters. They contain:

1. The graphics characters which make up the bird (see Figure 5.1).
2. The cursor control characters which move the cursor before printing a graphics character.
3. Spaces which are used to erase sections of previous frames.

Whenever something is being printed (with PRINT) on the screen, you will see the little white box, called the cursor, following each printed character. The POKE in line 160 turns off the cursor (makes it invisible),
so we don’t see little white boxes swarming around like a bunch of
hornets while each frame is drawn.

The Animation loop (lines 200–270) contains the logic to print each
frame in the correct order. This section is simple and straightforward. We
just have to place the cursor in the middle of the screen with ATARI’s
cursor positioning command (line 220) and print the appropriate frame.
The entire wing-flapping cycle consists of six frames (two of which are
repeated). To accomplish this we use a `FOR/NEXT` loop from 1 to 6 to
step through the frames. An `ON GOSUB` (line 230) uses the current
`FOR/NEXT` value (1) to control which frame is printed. When I equals
1, line 310 is executed and `BIRD 1` gets printed. When I equals 2, line
320 is executed, and so on.

Line 240’s `FOR/NEXT` loop is used to slow down the rate at which
the frames are printed. Try changing the value on this line to see what
happens to the bird. You may like the bird better at a different frame rate.

**Modifications**

Here are a few modifications you can try on
Example 1:

1. Change the program so that more than one bird is flapping its wings on
the screen. This could easily be done by repeating lines 220 and 230
within the main Animation loop and changing the X,Y coordinates of
the `POSITION` statement. You will also have to change the value in
the Pause loop (line 240) to adjust the frame rate of the birds. (You
may be able to gain some animation speed by using separate `PRINT`
statements for each of the three horizontal rows of bird characters per
frame. This will save you from having to use the cursor control
caracters — the fewer characters printed, the faster the program will
run.)

2. Make the bird move around the screen. To do this, just control the
values in line 220’s `POSITION` statement. Be sure to erase the bird
each time you move it or the screen will become wallpapered in birds!
Another point to remember is this: anytime you erase and redraw a
figure, it will appear to *flicker* on the screen (the light from the image
is interrupted by blankness during the instant the image is erased, thus
the flicker). To minimize the flicker, erase the bird immediately
before drawing the next frame — avoid inserting any program logic or
calculations while the bird is erased.

3. Add sound effects. As we will see in later programs, sound effects can
add a great deal of realism to a program.

4. Make the bird look like it is flying away from or closer to you. Add
new frames of the bird which are smaller and frames of a larger bird
which have greater detail. As you display each set of frames in order,
it will look as though the bird is flying towards or away from you.
Summary

Now you have seen how a simple animation program can be put together from start to finish. The result is a crude beginning, but the next technique allows us to produce animated figures with far greater sophistication.

5.2. USER-DEFINED CHARACTER SETS — A BOUNCY WALKING MAN

We must admit that after all that talk about making the bird look like a bird, it takes some imagination on the part of the observer to look at a dot and a bunch of lines and see a flying bird. Using the built-in character set of your computer is very limiting! In this section, we will see how to make use of the ATARI’s capability to redefine the character set. Using the same animation technique as in the first program, we can now sculpture the individual characters into any shapes we wish. In other words, you can create individual characters which can be printed together to make up a larger, perfectly designed shape. Many other computers, such as the IBM Personal Computer,¹ the Apple II,² and the Apple III also have this capability. Now our animated figures can be created with a high degree of detail rather than being limited to the coarseness offered by the built-in character set.

The Character Set

When you first turn on your ATARI computer, you will see a word or words printed on the screen (i.e., READY if you are using your BASIC cartridge). What happens inside your computer to display those words? A series of number codes are placed in an area of RAM called screen memory, one code for each character. These codes are then interpreted in a predetermined way (depending on which graphics mode you are in). In the standard text mode, GRAPHICS 0, the numbers in screen memory are translated as addresses which are used to look up some permanently stored information. This information, stored in ROM (read-only memory) is called a character set.³ Each character in the set is composed of

¹The IBM PC allows you to define characters only in its two graphics modes. Only the top 128 character codes can be redefined.

²The Apple II’s character set is not really redefinable. However, a number of software products now on the market allow you to define a character set that is displayed on the high-resolution graphics screen rather than the standard text screen.

dots in an array that is 8 dots wide and 8 dots high. Each of these 64 dots can be turned on or off, thus defining a character. The information which describes which dots to turn on or off for a character is called the character definition. Figure 5.4 shows the dot array, or character definition, for the letter A.

<table>
<thead>
<tr>
<th>APPEARANCE OF LETTER ON THE SCREEN</th>
<th>THE EIGHT BYTES DEFINING THE CHARACTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>BINARY REPRESENTATION</td>
<td>DECIMAL REPRESENTATION</td>
</tr>
<tr>
<td>00000000</td>
<td>0</td>
</tr>
<tr>
<td>00011000</td>
<td>24</td>
</tr>
<tr>
<td>00111100</td>
<td>60</td>
</tr>
<tr>
<td>01100110</td>
<td>102</td>
</tr>
<tr>
<td>01100110</td>
<td>102</td>
</tr>
<tr>
<td>01111110</td>
<td>126</td>
</tr>
<tr>
<td>01100110</td>
<td>102</td>
</tr>
<tr>
<td>00000000</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 5.3: Character definition for the letter “A.”

Try typing some letters on your screen and see if you can make out the individual dots. If your television set is sharp enough, you will be able to see them.

Photo 5.2: Screen photo — close-up of the letter “A.”

The information in each character definition is stored as a series of 8 bytes, with each byte representing one horizontal row of 8 dots. \(^4\) Since

\(^4\)This is the same as the IBM Personal Computer’s graphics mode.
there are 8 bits in a byte, whether a bit is on will determine whether the
corresponding dot on the screen will be turned on. Each character in the
character set is defined in this manner.

There are 128 distinct characters in the ATARI character set. If we
multiply this number of characters (128) by the number of bytes needed
to define each character in the character set (8), we get 1024, or 1K (128 * 
8 = 1024 bytes). This is the amount of ROM space needed to store the
ATARI built-in character set. Since each character can also be repre-
sented in reverse video, there are a possible 128 * 2 = 256 codes (from 
0 to 255) which can appear in screen memory and be interpreted as
characters. The codes from 0 to 127 represent normal video characters
and the codes from 128 to 255 are reserved for inverse video characters.\(^5\)

![Character Set Animation](image)

In many personal computers, the built-in character set is all you get.
But the ATARI Home Computer has the capability to display user-
defined character sets! As we said, the ROM character set is permanent.
You can’t change any of the character definitions in this ROM. However,
what if we were to create our own set of character definitions and POKE
them into RAM? How would we let the computer know where to find this
customized set of character definitions? The answer is simple — ATARI
has memory location 756 (decimal) reserved for this purpose. This RAM
location always contains the page address of the current character set. (A
page of memory is 256 bytes, therefore to convert a page address to an
actual address, multiply by 256.) When you turn on your computer, press
the SYSTEM RESET button, or change GRAPHICS modes, the value in
756 is automatically initialized to 224 (the page address of the ROM

\(^5\)The IBM PC has a separate byte for each character position to control attributes!
character set; thus we say that 756 points to the character set in ROM). But you can change the value in 756 so it points instead to an address in the computer’s RAM. If you POKE the page address of your customized character set into 756, you “turn on” the new character set. As we shall soon see, the results are instantaneously visible.6

![Diagram](character_set_animation.png)

**Figure 5.5:** Switching between RAM and ROM character sets.

### Turning On Character Sets

Let’s try a simple program to see what happens if we change the value in 756. Try typing in the following short program:

```plaintext
10 GRAPHICS 0
20 FOR I=0 TO 255 STEP 4
30 POKE 756+I: REM Switch character sets
40 NEXT I
50 GOTO 20
```

Now run this program. Don’t worry, your computer isn’t broken! What you will see on your screen is a rapidly changing, finely drawn display which fills the entire screen. Exactly what is happening? Let’s see. When line 10 is executed, the screen is cleared. The ATARI clears its screen by filling screen memory with 0s. These 0s are used to look up the 0th character in the current character set. In the ROM character set,

6On the IBM PC, changing the location of the character definition table affects only future characters to be written, not characters already printed on the screen.
this 0th character is the space. A character set must always begin on a "1 K boundary." This means it can begin at any address which is evenly divisible by 1024. In converting to pages, the value in 756 must be evenly divisible by 4 (there are 4 pages in 1 K). So in line 20, we increment \texttt{I} by four. As we \texttt{POKE} the different values of \texttt{I} into 756, the current character set is changed. Of course, we really aren’t switching to different character sets, just to whatever random information happens to be at that memory location. What we see on the screen is the current character definition for the 0th character (the space character). Whatever happens to occupy the first 8 bytes in each character set (i.e., the character definition for the 0th character) determines how the space character will be displayed. When the first 8 bytes are 0s, the screen goes blank.

Now press \texttt{RESET}, and \texttt{POKE} 756 with 200. The screen immediately becomes a mass of swirling, ever-changing interference patterns. But how could this be — there’s no program running! Ah, but there is. We have discovered an address which is being used by the ATARI operating system. It is changing the contents of the first 8 bytes at machine-language speed.

### Reserving Character Set Memory

After we have designed a character set, we must find a safe place in memory for it. A good location is immediately below screen memory. Where is screen memory? In most computers, screen memory is always located at the same address. However, the ATARI Home Computer automatically reserves space at the very end of RAM for screen memory. This means you’ll find the screen memory at different addresses, depending on how much memory your computer contains and which graphics mode you are using. In \texttt{GRAPHICS 0}, 1 K of memory is used to display the screen.\footnote{Actually \texttt{GRAPHICS 0} uses 960 bytes of screen RAM and 32 bytes for the display list (covered later in this chapter) for a total of 992 bytes.}

The ATARI uses memory location 106 to store the number of pages of memory it thinks it currently has. By taking the value in 106 and subtracting 4 from it for screen memory and another 4 for the size of the character set, we can obtain the page address for our character set (see Figure 5.6).
Creating a Character Set

Now that we know the why and wherefore of user-defined character sets, we can create one of our own. There is a difficult and a not-so-difficult way to create user-defined character sets. The difficult way is to:

1. Photocopy the grid of squares in Figure 5.8 or obtain a sheet of graph paper, preferably 8 squares per inch. (Our grid has been prepared to accurately reflect the true proportions, 7:8, of each character — the vertical side is longer than the horizontal side.)
2. Decide on the size of the character matrix you want your figure to occupy and draw it on your grid of squares.
3. Draw the outline of the figure you wish to represent within the character matrix.
4. Fill in all the little squares which lie more than halfway inside the boundaries of your outline. Use your judgement to improve the appearance of the figure for borderline squares.
5. Calculate the decimal value for each row of each character cell.
6. Enter these byte values into your program.

This method is difficult in that it involves the manual transfer of information from paper to a program. If you only needed to do this once it wouldn’t be so bad. But, as we mentioned earlier, creating an effective animation requires a large degree of trial and error — it’s exceedingly rare to get it right the first time. So once you’ve done all your work, tried the program and discovered that your animated figure looks as if it’s critically ill, you must go through the entire process again.

A more efficient approach is to use one of the commercial font editing programs currently available to consumers. A product like this will allow you to work with your characters in an interactive environment: you can see the characters on the screen as you create and edit

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8The word "font" refers to the style of the characters on the screen. You can design an Olde English font, a computer-like font, a script font, or even a walking-man font.
STEP 2:
2 x 3 MATRIX OF CHARACTERS

STEP 3:
DRAW OUTLINE OF FIGURE

STEP 4:
FILL IN THE SQUARES

STEP 5:
CALCULATE BYTE VALUES FOR CHARACTER DEFINITIONS

(continued)
Figure 5.7: a) Steps to create a character set frame b) using a font editor "INSTEDIT" by Sheldon Leemon, ATARI Program Exchange. Apx 20060.

Figure 5.8: Grid for creating character set figures. A full-size grid appropriate for photocopying can be found in Appendix B.

them. The computer can also take care of the laborious calculations necessary to determine the byte values for each character. You will still spend much time trying and erring, but the computer will handle much of the tedium.

The digitizing tablet is another labor-saving device which facilitates the creation of character sets. As we mentioned in Chapter 2, it consists of a large, flat drawing surface and an electronic pen or pointer. By placing your artwork on the tablet's surface, you can enter information directly into the computer by pressing down on the pen. When you outline the sections you want to transfer, the computer creates an image of your drawing on the screen. Before you rush out and buy a digitizing tablet, though, make sure you can also buy an accompanying program (for your computer) designed to help you create character sets.
Color Artifacts  One thing you should be aware of when creating your character sets is the problem with or capability of (depending on how you look at it) color “artifacts.” You may have noticed that every vertical line in the ATARI built-in character set is at least two dots wide. This is done to make sure the line shows up on a color television screen in the desired color. If a vertical line is only one dot wide, or if every other dot in a row (byte) is turned on, you’ll see a color artifact. For example, instead of appearing white, the character may be blue or some other color. The dictionary defines artifact as an artificially produced changed appearance. In this case, it is a color that is produced by the nature of the color television screen rather than intentionally by the computer. Artifacts can be used to add color to a screen, but these colors may look different on someone else’s ATARI (depending on whether it has a GTIA or a CTIA chip—see Chapter 6). Harry Brown, an ATARI programmer, used artifacts to add extra color to the playing cards of his poker game (see Photo 5.3). The green background was created by filling the screen with quadruple-wide Players and Missiles with holes cut in them for the text and cards (see color insert; see also Chapters 7 and 8 for more on Player-Missile Graphics).

Photo 5.3: Poker game using color artifacts (see color insert). (Courtesy of Harry Brown.)

We will introduce a much better technique for producing extra colors in a character set in Example 4. For more on artifacts, see the box on “Pixels, Dots, and Color Clocks” later in this chapter.

The Walking Man Program

Our next program demonstrates the power of user-defined character sets. We will define a character set that we can use to draw a picture of a little man walking across the screen. Below are the character definitions for our Walking Man character set. Each frame is made up of six characters arranged in a $2 \times 3$ array (see Figure 5.9). We are using five frames for the walking cycle, and each frame is displayed only once during each of his steps. This means that we need only 30 characters ($6$ characters per frame $\times 5$ frames) to animate the man. Actually, we need only 26 characters since 4 of the characters that appear within the frames are blank. To the right of each frame are the byte values we need to PDKE into the character set RAM.
Animation implemented on microcomputers is often considered crude. This is most often because the programmer is usually not an animator or an artist, not because the computer isn’t capable of handling the job. Attention to detail makes animation come alive. Take a look at the position of the man’s head in these five frames. As he walks, his entire body bounces up and down. This is much more realistic than a walking man with moving feet and a stationary head!

To create this character set, Animation, by Preston Blair (published by Walter Foster Art Books, Tustin, CA), a book on conventional animation, was used. This is an excellent yet simple book showing how to draw your own animated characters. We placed graph paper over a set of drawings from the book of a walking man and filled in the appropriate squares. A font editing program (FONTEDIT, from the software package IRIDIS 2 by The Code Works, Goleta, CA) was used to help convert the filled-in squares to character set data. One technique you can try (if you can’t find the figure you wish to animate in an animation book) is to cut out a drawing of your animated character from paper. At each of your figure’s joints (i.e., knees, elbows), use paper clasps or string to create a hinge. Then position your figure for each frame and outline its shape onto graph paper. It will still take some practice to create smooth, realistic motion, but the proportions of each body part will be correct.

Example 2

Exercise Using a user-defined character set, write a program that displays a man walking across the screen. Use the joystick button to control his forward movement. Give him life with a bounce in his step. Include the sounds of his footsteps.
Photo 5.4: Walking Man.
Here is the Walking Man program. There are four main sections: the initialization section, the section which reads in the new character set, the actual character set data, and the animation loop. The complete listing can be found in Appendix A.

```
REM WALKING MAN CHARACTER SET
REM Example 2
REM Demonstration of user-defined character set
REM Copyright 1981 by David Fox and Mitchell White
REM
REM Initialize
10 FRAME$=5 REM Number of frames
20 FRMSZ$=12 REM Characters in frame (including cursor control chars)
30 DIM MAN$,FRMSZ$ ['.FRAME$] (MAN$ is a string register)
40 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
50 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
60 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
70 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
80 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
90 MAN$="%&"DOMECPF:LEFT?):(DOWN?LEFT)?(LEFT)"
100 SMSZE=12; SETCOLOR (CI 0); REM Turn off cursor
110 PRINT "One moment please..."
120 GOSUB 60000 REM Read in Character Set
130 PRINT "Please wait..."
140 SETCOLOR 1
150 SETCOLOR 3;1
160 SETCOLOR 5
170 DRAW "LEFT" (UP):LEFT" (DOWN)
180 PRINT 75;4;1 REM Switch to new Char Set
190 REM
```

**Figure 5.10:** Listing of Example 2—lines 10–250.

**Initialization** Each of the five man frames is made up of six graphics characters and six cursor control characters for a total of twelve characters. The variable FRMSZE (line 120) is set to this value. On line 130 we reserve string space for our frames with the DIMension statement. All of our frames are stored in one string variable, called MAN$, rather than in a series of strings as we did in the Flying Bird program (Example 1). This reduces the size of the program code needed to access a specific frame and makes the program more flexible if we want to use a different set of frame data. We could have initialized MAN$ in one statement, but it would have been much more difficult to understand and enter. The variable FRAME$ will temporarily hold the current frame to make it easier to manipulate.

Make sure you enter lines 140–160 *exactly* as they appear, including the four spaces. Even though you are entering letters of the alphabet now, when you switch over to the new character set, these will be printed as sections of the man.

ERASE$ (line 170) is used to erase the man every time he moves one character position to the right. If this wasn’t used, our friend would leave behind a trail of old body parts as he moved across the screen.

In line 230, the color of the screen background and foreground is changed with the SETCOLOR command. For now, a brief description of it should be enough. The syntax of the command is

```
SETCOLOR  n,hue,lum
```

where *n* selects the *color register* which will receive the new color, *hue* is the hue of the color (a value from 0 to 15; see Table 6.2), and *lum* is the
luminance or brightness of the color (an even value from 0 to 14). The use of color registers is a very important ATARI feature, requiring all of Chapter 6 to cover. The hue we are choosing is gold with the brightness of the man turned to maximum (the 14 in SETCOLOR 1,0,14) and the background set to dark brown (SETCOLOR 2,1,2). We will be covering the SETCOLOR command in depth in Chapter 6.

In line 240, we POKE the address of the new character set into memory location 756. (This is done to turn on the user-defined character set and turn off the built-in ATARI character set).

```
0000 REM Set Up Alternate Character Set
0010 HCHR=B:P'EER(160):E REM Reserve memory space 16(64 bytes) below screen
0020 HCHR=B=HCHR=B+56 REM Peek at start of Character Set
0030 REM Read in data, skip past 97 characters
0040 OFFSET=57482
0050 CHRB=56
0060 READ TOTAL:
0070 TEMP=0
0080 FOR I=CHRBA-OFFSET TO CHRBA+OFFSET+CHAR B=4
0090 NEXT I
0100 IF TOTAL=TEMP THEN
0110 GRAPHICS 01
0120 PRINT "ERROR In Character Set Data"
0130 ENL
0140 REM Clear out first char background
0150 FOR I=CHRBA TO CHRBA+7
0160 POKE L0
0170 NEXT I
0180 RETURN
0190 REM
```

**Figure 5.11:** Listing of Example 2—lines 8000–8160.

**Set Up Alternate Character Set** Here we POKE the new character set into RAM. First, on line 8010, some memory is set aside for our character set. Recall that address 106 is where the ATARI stores the number of pages of memory it thinks are in the computer. We’ve set the variable HCHR (High byte of Character set Base) to the total number of RAM pages in the computer minus eight pages (2 K), four pages for screen memory and four pages for the character set.

In line 8020, the RAM page number in HCHR is converted to an actual RAM address by multiplying it by 256 (number of bytes in a page) and then stored in CHRBA.

The next step is to read in the character set data. The first letter of the character set will replace the lowercase “a,” the second letter, lowercase “b,” etc. In some programs, you may need to copy all or part of the ATARI ROM character set into our RAM character set. You may want to retain the uppercase and numeric characters for use in your screen display. By redefining only the lowercase letters, you would still be able to print text on the screen or read your program when it was listed with the new character set still installed. You could copy the ROM character set into your RAM character set with the statements
100 REMSET=224*256: REM Calculate address of ROM character set
110 FOR I=0 TO 1023:
   POKE CHRBAS+I, Peek(RROMSET+I): NEXT I

where CHRBAS is the RAM address of your new character set. In our
Running Man program, we didn’t need to do this, so it really doesn’t
make any difference whether we redefined the lowercase letters or any
other sequence of characters.

In line 8040, the OFFSET for the lower case “a” (number of bytes
from the beginning of the character set) is calculated, and the number of
characters we are redefining is stored in CHARS.

To assure that the character set data is entered accurately, a check-
sum value is used. All of the bytes in our data statements were added
together to obtain this value. Then this value, which came to 16845, was
placed in a DATA statement on line 20020. This checksum value is
READ into the variable TOTAL (line 8060), and all the bytes in our
DATA statements are added together and stored in TEMP as the character
set is READ and POKEd into RAM (lines 8070–8090). If the checksum
value in TOTAL doesn’t equal the calculated sum in TEMP, an error
message is printed out. If this happens, recheck the values typed into the
character set data statements.

On lines 8120 through 8140 the first character in the character set is
filled with 0’s. As stated before, this is the character definition for the
space character. You already know what kind of designs can appear on
the screen if the space character isn’t a blank!

Figure 5.12: Listing of Example 2—lines 20000–20380.
Character Set Data This is where the data for our Walking Man is stored. As previously mentioned, the first value (16845) is the sum of the rest of data. Each line, starting with 20050, contains one character definition — the 8 bytes which define a single character.

Animation Loop The logic behind this section is similar to the animation loop in the Flying Bird program with the addition of a few new techniques. Since all the frames are stored in one long string, the desired frame can be pointed to directly with the formula in line 330. In ATARI BASIC, a substring (section of a string) can be accessed by indicating the first and last characters:

\[
\text{STRING}(\text{first}, \text{last})
\]

The formula in line 330 allows access to the Ith substring of MAN which is FRMSZE characters long. When I equals 1, the first 12 characters of MAN are stored in FRAME (Frame 1). When I equals 4, the fourth set of 12 characters is stored in FRAME (Frame 4).

On line 340, the cursor (now invisible) is positioned on the screen. ERASE is used to clear away any of the previously drawn man, and then the current frame is drawn.

On lines 350 to 370, the sounds of a footstep are added. The syntax of the SOUND command is

\[
\text{SOUND voice, frequency, distortion, volume}
\]

There are four separate sound registers or voices in the computer, numbered 0 to 3. The frequency can be any number from 0 to 255. It determines how low or high in pitch the sound will be. By changing the
value of the sound’s distortion (even numbers from 0 to 14), anything from a pure tone to a roar can be created. The volume can be any number from 0 (no sound) to 15 (loud sound). By using two different frequency settings in our program, one sound is made when the man’s heel hits the ground and another when the rest of his foot makes contact.

Finally, on line 410 the man’s horizontal position on the screen is incremented if the joystick button is pressed. The screen is cleared when he reaches the right edge of it, and the starting horizontal position (X) in line 310 is reinitialized.

**Running the Program** Before you run the program, plug a joystick into the first joystick port (on the left). Now type RUN, and you’ll see the man walking in place on the left side of the screen. No mistaking him for a bunch of wobbly pick-up sticks — he really looks like a walking man! Adjust the volume on your television set so you can hear the footsteps. When you press the joystick button, the man will begin walking eastward.

**Modification** Make a modification which prints more than one man on the screen at the same time. This could easily be done by adding a few more lines like 340, but changing the vertical position to other values. How many men can you have walking across the screen before they look like they’re walking through a vat of cold molasses? Don’t forget to delete line 380 to gain some speed.

Notice how the walking men seem to be stepping slightly out of sync. This is due to the time it takes for BASIC to move the cursor to the next man’s position and draw a new frame. This modification really shows BASIC’s limitations in animating character set graphics with multiple figures — BASIC just doesn’t PRINT fast enough on the ATARI.

---

**Summary**

By making use of the increased resolution and control gained by user-defined character sets over built-in character sets, your animations can look much more lifelike! The next problem to overcome is that of BASIC’s slowness when it comes to animating more than one figure at the same time. In the next section we will see how this can be accomplished without the use of machine language.
5.3. FLIPPING CHARACTER SETS —
THE GALLOPING HORSE

The next technique overcomes the problem of animating multiple figures with BASIC. The problem relates to the speed at which BASIC can PRINT something on the screen. BASIC can't maintain adequate animation frame rates for the simultaneous display of more than a few separate figures. It can handle one or two simple figures, but then it becomes overloaded, and the result is sluggish and stilted animations. We could use machine language at this point (called from BASIC) to greatly increase the frame rate, but there is a simpler technique — character set flipping. Using this technique in upcoming Example 3, even though the screen will be completely filled with moving figures, the program actually needs to be slowed down to obtain the proper frame rate.

How Does Character Set Flipping Work?

In the last program, one alternate character set was created and then switched on. The animation was created by rapidly PRINTing each frame (made up of characters from that one character set) on the screen. Recall our short introductory program which POKEd a series of numbers into RAM location 756. Do you remember how quickly the display changed? By repeatedly changing the value in 756, we were actually flipping through a series of character sets with random characters. The screen looked like a rapidly changing mess. What would happen if we made use of this flipping technique, but gave it real character sets to flip through? One character set for each frame could be created. Then, rather than redrawing the figure on the screen with PRINT, each of these character sets could be rapidly flipped through! When we PRINT something on the screen, it will be displayed using the character set that is currently being pointed to (by the value in 756). When another character set is pointed to, the image on the screen will immediately change. Each value in a screen location will “index” into the current character set. The frame rate will be determined then by how rapidly we can POKE in the addresses of our different character sets as opposed to how rapidly the computer can PRINT something on the screen.

In our next example, we will borrow from the man who made the first live action movie. As we mentioned in Chapter 1, in 1872 the ex-governor of California, Leland Stanford, and another millionaire horse lover, Fred McCrellish, had an argument about whether a galloping horse ever had all its hooves off the ground at any moment. They hired a

---

This technique will not work for the IBM Personal Computer. Once a character is printed on the screen, its appearance can't be changed by flipping to a different character set.
famous photographer named Eadweard Muybridge to find out. After his first attempts using only one camera failed to produce convincing results, he tried again six years later with 12 cameras. Each of these cameras, equally spaced along a wall, was connected to a trip wire. As the famous trotter Abe Edgington galloped by, it set off each of the cameras in succession. By examining each of the photographs, it was determined that the horse did indeed have all of its feet off the ground at one point during its galloping cycle. Governor Stanford won the argument and had a famous university named after him.

Perhaps more important for us, when Muybridge rapidly flipped through the photographs, the motion of the galloping horse was recreated! He later built the first movie projector (the Zoopraxiscope) and toured North America and Europe, astounding crowned heads on both sides of the Atlantic with the first feature-length (1-2 seconds) films. Five of the frames from his original horse sequence were used to create the character definitions for the next example.\(^\text{10}\)

Figure 5.14 illustrates the character definitions for our galloping horse. Each of the five frames is composed of a $6 \times 4$ array of characters (24 characters).

![Character Set Animation](image_url)
Figure 5.14: Character definitions of the Galloping Horse.

Our thanks to Eadweard Muybridge for taking the original photos, Leland Stanford for hiring him to do so, Charlie Kellner for first digitizing them on the Apple computer, and Tandy Trower for the ATARI conversion of the Galloping Horse character set.
Even though the same number of frames is used here as was used in our last program, these frames employ a larger character array, thus allowing us to create a figure of much greater detail. The drawback, however, is that we have a lot more bytes to enter into our data statements.

Example 3

**Exercise** Using the Galloping Horse character sets, fill the screen with 36 horses, all galloping in unison. Use the technique of character set flipping, and add the sound of hoofbeats. Use paddle 0 to control the animation frame rate.
Here is the Galloping Horse program. The same four main sections are present in this program as in Example 2: initialize, set up alternate character set, character set data, and animation loop. In this program, however, each section is somewhat different.

```plaintext
10 REM GALLOPING HORSE DEMO
20 REM Example using the technique of flipping through multiple character sets
30 REM Copyright ©1982 by David Fox and Mitchell Wate
40 REM Initialize
50 DIM HH(120)
60 REM Fill Screen With Horses
70 FOR Y=0 TO 20 STEP 4
80 FOR X=0 TO 32 STEP 6
90 PRINT "Kabc-
100 PRINT "defgh-
110 PRINT "jWmno-
120 PRINT "pqrstu"
130 NEXT X
140 REM..."....",...
```

Figure 5.15: Listing of Example 3 — lines 10-290.
Rather than dimensioning a string to hold our frames (as we did in the last program), we will dimension an array called \texttt{HICHRB} (line 120) to hold the RAM page address of each of the five character sets. \texttt{HICHRB}(1) will hold the address for character set one (Frame 1), \texttt{HICHRB}(2) for character set two (Frame 2), and so on. This will make it very easy to select the appropriate frame.

The border around the active area of the screen\footnote{This active area is called the Playfield \textemdash more on this later.} is set to the same color as the background in line 180. \texttt{SETCOLOR 2,1,10} sets the background, and \texttt{SETCOLOR 4,1,10} sets the border. \texttt{SETCOLOR 1} sets the brightness of the horses (to dark).

On line 190, the first character set is switched on so when you \texttt{PRINT} the horses on the screen, you’ll see horses and not letters of the alphabet.

Next, on lines 210–280, the screen is filled with horses using two nested \texttt{FOR}/\texttt{NEXT} loops. There will be six horses across and six down for a total of 36 horses — how about that! An instant racing stable!

---

\textbf{Figure 5.16:} Listing of Example 3 — lines 8000–8190.

\textbf{Set Up Alternate Character Set} This time enough room for five character sets plus the screen memory must be reserved. This comes to 24 pages: 4 pages for each of the five character sets (20 pages) plus 4 pages for screen memory. Line 8050 initializes the \texttt{HICHRB} array to point to each of the five character sets. Line 8150 prints out a period after each character set is read, so we have an indicator that the program is still running.
Figure 5.17: Listing of Example 3 — lines 20000–20470.

**Horse Character Set Data** Starting with line 20050, each line contains three character definitions or 24 bytes.

Figure 5.18: Listing of Example 3 — lines 300–370.

**Animation Loop** This section is extremely simple. A FOR/NEXT loop is used to flip through the five frames. On line 330 we turn on the sound effect for a hoof beat on every frame but the third one. Line 340 uses an ATARI game paddle to allow the interactive control of the frame rate of the galloping horses. If you don’t have a paddle, replace the word PADDLE (Ø) with a numeric value — 15 seems about right.
When you run the program, you'll see all 36 horses galloping in perfect synchronization. If you turn your paddle to the fastest speed (or remove line 340), the horses will be moving so fast that their legs will begin to blur (they'd be a sure thing in the Kentucky Derby!). This means that if we used character set flipping in a game, there would be quite a bit of extra processor power to do other things.

5.4. EXPLODING WITH A THREE-COLOR CHARACTER SET

Up until now, it's only been possible to display animated figures on the screen in one color, even though the choice of color is ours. But not for long! The ATARI Home Computer has a graphics mode which allows the display of a custom character set in three colors! We will drop a whistling bomb from the top of the screen and then explode it in a burst of color and sound.

The Display List and Antic Mode 4

Most of today's computers can only operate in two or three different graphics modes. The Apple II, for example, has a text mode, a low-resolution graphics mode, and a high-resolution graphics mode. The ATARI Home Computer is much more flexible than this. In fact, there are twelve\textsuperscript{12} different graphics modes which are supported by the ATARI 400 or 800's operating system\textsuperscript{13} and sixteen modes supported by ATARI's XL Home Computers' operating systems.\textsuperscript{14} These graphics modes can be easily set up from within BASIC using the \texttt{GRAPHICS N} command (where \texttt{N} can be a value from 0–11 on the ATARI 400 and 800, or 0–15 on the ATARI XL Home Computers). Some of them are text (or character) modes, and some are plotted point modes (also called bit mapped or map modes). Most of them can be split screen modes (plotted points on the top part of the screen and four lines of \texttt{GRAPHICS 0} text on the bottom). The exceptions are \texttt{GRAPHICS 0} (the whole screen is a text window) and modes 9, 10, and 11 (GTIA modes — see Chapter 6). The split screen modes can be changed into full screen modes (no text window) by adding 16 to the value of \texttt{N}:

\textsuperscript{12}There are an additional five graphics modes available, including Antic 4, which are not supported by the ATARI 400 or 800 operating system.

\textsuperscript{13}One more mode, Antic 3, isn't supported by the ATARI XL Home Computers' operating system. This mode displays 10 pixel high characters with descenders.

\textsuperscript{14}The operating system is contained within the 10K ROM cartridge in your ATARI 800, or inside the computer if you have an ATARI 400 or XL Home Computer.
GRAPHICS 3  split screen mode 3
(four lines of mode 0 at bottom of screen)
GRAPHICS 3+16  full screen mode 3

Introducing ANTIC  For you ATARI 400 or 800 owners who are feeling jealous that you can’t access the four additional modes the XL Home Computers can access, hold on. Your computer can display anything the XL Home Computer can, it just might be a little more awkward for you to achieve. And for you ATARI XL Home Computer owners who might be feeling a little smug, the following information will help you get the maximum graphics power from your computer.

One of the things which makes the ATARI Home Computers so versatile for creating animation is its custom chip set, the primary thing all ATARI Home Computers have in common. Rather than giving all of the work to the computer’s microprocessor, Atari designed three LSI (large scale integration) chips to help share the load. One of the chips, called Antic, has the responsibility of interpreting the bytes in screen memory into a form which can then be displayed on your television screen (by another custom chip, CTIA or GTIA, depending on the age of your computer). Antic is actually another microprocessor. As with any microprocessor, it has a program (called the display list), data (screen memory), and output (the television picture). Among other things, the display list specifies the graphics mode or modes to be used on the screen. By altering the display list, you can horizontally divide the screen into many strips or ribbons of different graphics modes. This gives the programmer who is able to modify the display list a great deal of flexibility when designing the appearance of the computer’s video output.

When using the GRAPHICS command in a BASIC program, the ATARI’s operating system will automatically set aside the appropriate amount of screen memory for that mode. A low-resolution map mode will take up much less memory than a high-resolution map mode. The OS (operating system) will also create a display list that will tell Antic how to interpret the data (bytes) in screen memory. Should the bytes be interpreted as text characters or as plotted points? How large should each character or pixel (the smallest dot you can plot in the current graphics mode — see box) be displayed on the screen, and what color should it have?

---

Pixels, Dots, and Color Clocks

In many books about computer graphics, there is no distinction between the words pixels, points, and dots. Pixel is derived from the words picture element. It refers to the smallest dot you can access
(directly turn on or off) on the screen. Since the physical size of this
dot is different for each ATARI graphics mode, this could be confusing.
We are modifying the definition of a pixel to be "the smallest
point you can plot in the current graphics mode," and we are using
the word "dot" to mean the smallest point the screen is capable of
displaying (320 × 192 dots). This means that the only time a pixel
and a dot will look the same is in GRAPHICS 8 when there are 320
× 192 pixels on the screen.

Any color of the rainbow can be created by combining varying
amounts of the three primary colors of light, i.e., red, green and blue.
If you look very closely at your color television screen, you will see
vertical stripes of phosphors in these three colors, first red, then
green, and finally blue. (It is hard to see all three phosphors unless
you are looking at a white area on the screen.) The width of each
group of red, green, and blue phosphors is equal to one color clock.
A television term rather than a computer term, a color clock is a unit
of measurement that is related to the maximum number of color
changes possible on one line. There are 227.5 color clocks in each
horizontal scan line, 160 of which are within the active area (for
plotting or printing) of your screen (playfield). To have full control
over the color of a pixel, the pixel must be large enough to have one
of each of the three colored phosphors in it, which means it is at least
one color clock wide. Therefore, in GRAPHICS 8, where each of
the 320 pixels in a line is one half of a color clock wide, you can't
independently control pixel color. You may have wanted the pixel to
look white, but it might appear as blue (only the blue phosphor was
turned on) or orange (both the red and green phosphors were
partially turned on). This is called a color artifact and can be exaggerated
by turning on every other pixel in a horizontal line. Your pixels
will only look white if there are at least two of them horizontally
adjacent to each other, turning on all three phosphors. This is also
true for the pixels that make up each character in GRAPHICS 0 or
for any other graphics mode with pixels that are one half of a color
clock wide.

---

Examining the Screen Look closely at your ATARI's video
picture. You will notice that it is made up of many extremely fine
horizontal lines. There are 192 of these horizontal scan lines in the active
area of your screen (we'll wait if you care to count them). The active area
is that portion of the screen on which you can place text or plot points.
ATARI calls this area the playfield. The playfield is 160 color clocks
wide (see box) and is made up of 320 dots. Surrounding the playfield is a
border which can sometimes be independently colored, depending on the
graphics mode in use.

In GRAPHICS 0, each byte is represented as a character which is
eight dots wide (four color clocks) and eight scan lines high (remember
our character definitions from the last section). This provides us with the
previously mentioned 320 × 192 dots, since there can be 40 characters in
a line (40 × 8 dots per character = 320 dots) and 24 lines of text to a
screen (24 * scan lines per character = 192 scan lines). In GRAPHICS 5, a low-resolution map mode, each pixel (plotted point) is a square which is four dots across (two color clocks) and four scan lines high. This means there are 80 pixels across a line (80 * 4 dots per pixel = 320 dots) and 48 pixels down (48 * 4 scan lines per pixel = 192 scan lines). Figure 5.19 compares the characters, pixels, and bytes in GRAPHICS 0 and GRAPHICS 5.
By modifying the display list, you can access some additional graphics modes which are not supported by the OS. The Exploding Bomb program is compatible with any ATARI Home Computer. (Later on we’ll tell you about a short cut for the ATARI XL Home Computers.) This program uses something called Antic mode 4 (don’t confuse Antic 4 with BASIC’s GRAPHICS 4 — they are totally different). This means that we can’t use a GRAPHICS statement to set it up on an ATARI 400 or 800; we must do so manually by altering the display list. Table 5.1 indicates all the Antic and OS graphics modes. The pixels/column and bytes/screen are calculated for the full screen modes (GRAPHICS N + 16). As you can see, the number of bytes needed for each mode depends on the resolution (number of pixels) and the available number of colors.

Figure 5.19: a) GRAPHICS 0 and b) GRAPHICS 5 on the screen.
**GRAPHIC MODES**

<table>
<thead>
<tr>
<th>Antic Mode</th>
<th>BASIC Mode</th>
<th>Char or Map</th>
<th>Number Colors</th>
<th>Pixels/Line</th>
<th>Pixels/Column</th>
<th>Pixels/Char</th>
<th>Bytes/Line</th>
<th>Bytes/Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>Char</td>
<td>2**</td>
<td>40</td>
<td>24</td>
<td>4</td>
<td>8</td>
<td>40 960</td>
</tr>
<tr>
<td>3</td>
<td>none</td>
<td>Char</td>
<td>2</td>
<td>40</td>
<td>19</td>
<td>4</td>
<td>10</td>
<td>40 760</td>
</tr>
<tr>
<td>4</td>
<td>12*</td>
<td>Char</td>
<td>4</td>
<td>40</td>
<td>24</td>
<td>4</td>
<td>8</td>
<td>40 960</td>
</tr>
<tr>
<td>5</td>
<td>13+</td>
<td>Char</td>
<td>4</td>
<td>40</td>
<td>12</td>
<td>4</td>
<td>16</td>
<td>40 480</td>
</tr>
<tr>
<td>6</td>
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<td>Char</td>
<td>5</td>
<td>20</td>
<td>24</td>
<td>8</td>
<td>8</td>
<td>20 480</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Char</td>
<td>5</td>
<td>20</td>
<td>12</td>
<td>8</td>
<td>16</td>
<td>20 240</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Map</td>
<td>4</td>
<td>40</td>
<td>24</td>
<td>4</td>
<td>8</td>
<td>10 240</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>Map</td>
<td>2</td>
<td>80</td>
<td>48</td>
<td>2</td>
<td>4</td>
<td>10 480</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>Map</td>
<td>4</td>
<td>80</td>
<td>48</td>
<td>2</td>
<td>4</td>
<td>20 960</td>
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<tr>
<td>B</td>
<td>6</td>
<td>Map</td>
<td>2</td>
<td>160</td>
<td>96</td>
<td>1</td>
<td>2</td>
<td>20 1920</td>
</tr>
<tr>
<td>C</td>
<td>14*</td>
<td>Map</td>
<td>2</td>
<td>160</td>
<td>192</td>
<td>1</td>
<td>1</td>
<td>20 3840</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>Map</td>
<td>4</td>
<td>160</td>
<td>96</td>
<td>1</td>
<td>2</td>
<td>40 3840</td>
</tr>
<tr>
<td>E</td>
<td>15*</td>
<td>Map</td>
<td>4</td>
<td>160</td>
<td>192</td>
<td>1</td>
<td>1</td>
<td>40 7680</td>
</tr>
<tr>
<td>F</td>
<td>8</td>
<td>Map</td>
<td>2**</td>
<td>320</td>
<td>192 ½</td>
<td>1</td>
<td>4</td>
<td>40 7680</td>
</tr>
<tr>
<td>F</td>
<td>9†</td>
<td>Map 16***</td>
<td>80</td>
<td>192</td>
<td>2</td>
<td>1</td>
<td>40 7680</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>10†</td>
<td>Map 16‡</td>
<td>80</td>
<td>192</td>
<td>2</td>
<td>1</td>
<td>40 7680</td>
<td></td>
</tr>
</tbody>
</table>

* Memory is also set aside for the display list in each mode. Most modes also have some unused memory reserved (see Appendix H, "Graphics Memory Map Modes").

** One hue, two luminance values.

*** 16 luminance values, one hue.

† All 16 hues, one luminance value.

†† Note: OS Modes 9–11 are GTIA modes. Bits 6 and 7 of PRIOR (location 623) control which mode will be used. See Table 7.5.

* Only supported by the ATARI XL Home Computers' operating systems.

**Table 5.1: Antic and operating system graphics modes.**

Antic 4 uses the same amount of screen RAM as GRAPHICS 0. In fact, it is very similar to GRAPHICS 0 with one exception. Instead of each bit in the character definition representing a dot on the screen (either on or off), the bits in each row are paired. By considering this pair of bits as one pixel, the horizontal resolution is halved so that each character is now four double-wide dots across (instead of eight single-wide dots) and eight horizontal scan lines down (as before). But by losing some horizontal resolution, we gain color information! Because each of the character’s pixels is now a full color clock wide, it can be displayed in any of three colors depending on its bit pattern. If the bit pattern is 01, you can control that pixel’s color with SETCOLOR 0. If the pattern is 11, use SETCOLOR 2. Table 5.2 shows how this works.
SETCOLOR for Antic 4

<table>
<thead>
<tr>
<th>Bit pair in character definition</th>
<th>Use following SETCOLOR value</th>
<th>Color register name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>SETCOLOR 4</td>
<td>COLBAK</td>
</tr>
<tr>
<td>01</td>
<td>SETCOLOR 0</td>
<td>PF0</td>
</tr>
<tr>
<td>10</td>
<td>SETCOLOR 1</td>
<td>PF1</td>
</tr>
<tr>
<td>11</td>
<td>SETCOLOR 2</td>
<td>PF2</td>
</tr>
<tr>
<td>11 (inv. video)</td>
<td>SETCOLOR 3</td>
<td>PF3</td>
</tr>
</tbody>
</table>

Table 5.2: SETCOLOR table for Antic 4.

As the chart indicates, if the character is printed in inverse video (most significant bit is set in screen memory), only the bit pair "11" will be affected. Its color will now be controlled with a SETCOLOR 3. This can give us another color on the screen, but still only three colors within each character. So, let's create a character definition example for Antic 4, since we will soon use it in our falling bomb example.

As you can see, we are filling each of the eight rows with one of the four possible bit patterns. By using the above byte values for our character definition, the above Antic 4 character would be displayed as three horizontal bands of color separated by two thin stripes of the background color.

Now let's set the color registers as follows to color the bands red, blue, and green with a black background:
```
SETCOLOR 4,0,0 : REM Black
SETCOLOR 0,3,6 : REM Red
SETCOLOR 1,7,6 : REM Blue
SETCOLOR 2,12,6 : REM Green
SETCOLOR 3,5,6 : REM Purple
```

We will be covering the SETCOLOR command in greater detail in the next chapter. For now, recall that the syntax of the command is

```
SETCOLOR n,hue,lum
```

If we printed this character in inverse video, only the bottom band of color will change. It would become purple because its color is now controlled by SETCOLOR 3 instead of SETCOLOR 2 (see Table 5.2).

### Explosions and an Antic 4 Character Set

Have you played any games at a video arcade recently? You are flying your spaceship around the universe and suddenly an attacking alien creeps up from behind. Lasers fire and KABRASHH!! Your spaceship vanishes in a brilliant explosion . . . and you lose another quarter. How was that explosion created on the screen? Two basic techniques are used. One shows the exploding object bursting into a mass of dots or debris that rapidly moves outwards towards the corners of the screen. This technique requires a fast machine language algorithm which can directly control each piece of debris. In the other technique, a colorful fireball replaces the destroyed object. Often, you will see flames flick out in different directions as three or four versions of the fireball are rapidly displayed where your spaceship once was. This technique can be easily duplicated using Antic 4 character set animation.

Since you already understand how characters in Antic 4 are displayed, let's look at the character set for our Exploding Bomb program. The actual explosion is created with four frames, each made of a box of four characters arranged in a $2 \times 2$ array. Each frame shows the explosion getting a little larger and in a different shape. By consecutively executing PRINT for each frame at the same screen position, we will see what looks like an expanding explosion. We also need to define a single character for our falling bomb, as shown in Figure 5.21.
Figure 5.21: Character definitions for Exploding Bomb program.
In the above figure, the bit pattern of each character is shown on the left; in the center are the actual characters as they will appear on the screen; on the right are the decimal values needed to define each character. Notice that the pixels that make up each character are now rectangular instead of square. This decreased resolution makes it a little more difficult to represent a detailed figure.

Example 4

Exercise  Randomly drop a whistling bomb from the top of the screen. When it falls to the bottom half of the screen, make it explode in a burst of color and sound. Modify the display list to Antic 4 so that you can use a three-color character set.
Here is the Exploding Bomb program. Before you begin entering it, you'll notice that one section is almost identical to a section in the Walking Man program. To save time, instead of typing this section (lines 8000–8160, Set up alternate character set) from scratch, you can copy it over from the other program.

**Hi-Speed Subroutines** You'll notice that there are three subroutines at the very beginning of the program. These are specifically placed here for a reason. In ATARI BASIC, the closer a section of code is to the beginning of the program, the faster its execution speed will be. (This has to do with the time it takes ATARI BASIC to search through all the line numbers of a program to find the next one it is supposed to execute. The closer the line is to the beginning of a program, the faster it finds it.) One of the subroutines controls the explosion sound effects, another creates a background flash, and the third sets the colors. All these subroutines need to be executed as rapidly as possible, so we placed them at the beginning. In fact, you'll notice that we place most of the initialization subroutines and data towards the end of the program, and the time-critical animation loops towards the beginning.
Line 70 will turn on three of the sound registers (voices) with random explosion-like sounds. Each voice has a different frequency range/distortion combination. Once the registers are on, this line is executed again to randomly change the sound quality of the explosion.

Line 80 rapidly flashes the screen background ten times with random colors. Memory location 712 is where the background color information is stored for this graphics mode. Using SETCOLOR 4 would achieve the same result, but a direct POKE to this location is quite a bit faster. This is because BASIC doesn’t have to take the time to calculate the color value by combining the SETCOLOR hue and lum values together (color value = hue * 16 + lum). The flash is used at the first instant of the explosion.

Line 90 sets the colors of the explosion and is also used to fade out the brightness of the explosion.

**Initialization** The only thing new here is the call to the display list modification subroutine in line 220. We’ll explain this subroutine in just a second.
The lines in the first section (8000–8150) are identical to those in the Walking Man program. The only thing you need to change is the value assigned to CHARS in 8040. The character set data (20000–20290) contains the character definitions for the four frames of the explosion and the bomb character.

Modify Display List

This is the section where we modify the display list to Antic 4. Since GRAPHICS 0 is so close to Antic 4, we need to change only the values in the already existing DL (display list). In line 6010 we find where in memory the DL is. In line 6020, we change the DL instruction that controls the first text line. Don’t worry about this now; we will cover LMS (load memory scan) and display lists in greater depth in Chapter 9.

In line 6030, we change the DL instruction for text lines 2 through 24 when we P&0KE in a 4 (and that’s why it’s called Antic 4). When this subroutine is executed, you will see what looks like a black curtain rapidly descending over your screen as each byte of the DL is modified.

If you have an ATARI XL Home Computer, you can modify this program to let your OS set up the new display list with a GRAPHICS 12 + 16. Because cursor control won’t work in this mode, you will have to PRINT each line of the frames separately on the screen with the PRINT #6 command.
**Falling Bomb** This subroutine displays the falling bomb. The spot on the screen where the bomb will explode is randomly selected (line 620). The vertical coordinate (Y) will always be in the lower half of the screen (because of the +12). A FOR/NEXT loop (lines 630–670) is used to move the bomb down the screen. We are drawing the bomb in its new position and erasing the old bomb with the same PRINT statement. As it falls, sound register 0 is used to create a whistling sound. The whistling sound was split onto two lines, 640 and 660, to create a more even whistle. It smoothly drops two frequency steps for every position of the bomb. One of the SOUND statements could have been omitted, but the change in frequency would have been more choppy.

When the bomb reaches its explosion point, line 680, the screen is cleared and the sound turned off in preparation for the explosion routine in the animation loop.

---

**Film 3**
"The Juggler," Information International, Inc. Here are three segments from "The Juggler" film which we describe in Chapters 1 and 3 (see Photo 1.1 on page 3). (Courtesy of Information International Inc.)
Animation Loop  This is where the entire explosion is orchestrated. After setting the $\text{LUMinance}$ (brightness of the color, used in the subroutine at line 90) and $\text{VOLume}$ levels (used in the subroutine at line 70) to their initial values (310), the bomb is dropped (320). The color registers are reset, the explosion sound turned on, and the background flashed. In a real life explosion, you would see the flash before you heard the sound, but when we tried it that way the effect didn’t seem quite right. The viewer expects to hear noise as soon as something hits so we took the liberty of changing the laws of physics.

The frame loop, lines 360–400, is identical to those in our earlier programs. We didn’t need to erase the explosion after each frame, just write over it. Instead of a pause loop, the sound of the explosion is changed to add the effect of randomness to our pre-dawn graphics.

In lines 410 to 490, the $\text{LUMinance}$ values of the last explosion frame as well as the $\text{VOLume}$ level of the sound registers fade out. This technique of altering the $\text{SETCOLOR}$ values gives the illusion of motion when none is taking place (more on this in the next chapter).

Finally, on line 500 we wait for a random period of time before we drop the next bomb.

Modifications  Here are some modifications to try:

1. Switch the order of the initial sound and flash of light so that the flash comes first. Which do you like better?
2. Use a different set of colors in the explosion. Maybe you can come up with a better or more exciting combination.
3. Run this program with the sound on your television turned off. Notice how much the sound adds to the effect.
4. Try to improve the explosion character set to create a more realistic effect.
5. Program multiple explosions on the screen. What sets the limit to the maximum number?

Commercially Available Software Using Character Sets

The character-set flipping technique is used in a popular ATARI Home Computer game from Automated Simulations, Inc., entitled “Crush, Crumble, and Chomp!” In this game, you control your favorite movie monster on a rampage. The screen can display running people, police cars with flashing lights, helicopters with moving blades, flickering flames, and smoldering ruins all at the same time. The animation uses only two frames and is created by flipping between two character sets. Although the effect is very impressive (especially the flames and ruins), as we have seen, the technique is very simple. Most of the program is written in BASIC, with a number of machine language subroutines to help out (see Chapter 8). To simplify the BASIC portion of the program,
the task of alternating between the character sets is automatically carried out with a Vertical Blank Interrupt routine. (This technique is covered in depth in Chapter 8.) For now, think of it as giving the computer a separate task to do while BASIC is running the main part of the program.

Photo 5.7a and b is from the game’s introduction and shows the two frames which appear on the screen. The two parts [c] and [d] show two consecutive frames from the middle of the game. Notice the position of the flames and the people’s legs. The monster (we chose to be “Mantra” in this game) is made of two adjacent Players. (Players, objects which can be moved anywhere on the screen without changing the background, are covered in Chapter 7.) Even though GRAPHICS 0 is being used, you’ll notice some extra colors on the screen (the green of the trees and light blue on the buildings; see color insert). These extra colors are obtained by turning on every other bit in those characters, resulting in color artifacts (see box on artifacts in next section).
The ATARI Home Computer version of Space Invaders™ (trademark of Taito America Corp.) is another program which makes use of character set animation. This program, however, uses a different technique than the two we've previously introduced. Each of the invading alien types (there are six) is made of two adjacent characters in graphics mode 1. Rather than flipping through entire character sets, it uses machine language to rapidly change the character definitions of each invader. Since each row is made up of the same type of alien, the entire row is animated at once. This doesn't exhaust much processing power since there are only four different frames for each of the six alien types. Three Players were used in this game, one for the large green spaceship on the left of the screen, one for the gun base at the bottom of the screen, and one for the occasional flying saucer which appears at the top of the screen (not pictured). The projectiles being fired by the invaders and the game player are Missiles. Display list interrupts (Chapter 9) were used to add extra colors for the invaders.
Summary

You have learned a powerful and flexible animation technique which can be implemented without any use of machine language. Although defining a new character set can be time consuming, the advantages are well worth the effort in many cases. Using character set animation in GRAPHICS 0 (or the XL Computers' GRAPHICS 12) can provide the same resolution as the ATARI's highest resolution mode (GRAPHICS 8), but with only one-eighth of the memory overhead. By using Antic 4, more colors can be placed on the screen at twice the resolution (and one-fourth the memory overhead) as with GRAPHICS 7. As we will see later, this saving of memory also speeds up the processing speed of the computer for faster animation programs.

Making animated figures roam the screen is exciting, but our programs have been somewhat one dimensional — each character we have animated so far exists in a void, without any background or foreground! In the next chapter, we will explore the advanced graphics feature of color registers and create some beautiful animated backgrounds!
On most personal computers, after you’ve selected a color from a limited number of choices, that color is placed on the screen with PLOT or DRAW statements. The only way to change it is to PLOT again in a new color, and this is very time consuming. In addition, your program must “remember” the screen coordinates of each pixel whose color is to be changed. The ATARI Home Computer, as well as many of the high-tech animation computers, has a feature called the color register, which we first introduced in Chapter 2 when we talked about our “Magic Paint Store.” In this chapter we will see how ATARI’s powerful method of drawing graphics using color registers can be put to work in colorful, action-packed animated scenes. Color register animation will be used to draw a beautiful, ever-changing kaleidoscope of colors, create the illusion that you are rapidly flying through a trench (à la Star Wars), and display the motion of water in a cascading waterfall.

6.1. WHY COLOR REGISTERS?

Color registers were first created to provide the users of professional computer paint systems with a relatively inexpensive way to use a polychromatic (many-colored) palette. Suppose the computer artist wanted sixteen million colors (give or take a few) from which to choose. The expensive technique would be to make each pixel capable of displaying any of these colors so that all sixteen million could appear on the screen at once. Each pixel must then contain 24 bits of information to directly represent any of the sixteen million colors. If the display contained $1024 \times 1024$ pixels, it would represent over three million bytes of screen RAM. That’s why it costs so much.

The less costly method allows the artist to create a palette from a subset of the sixteen million colors, for example, 256 different colors. Instead of storing information at each pixel which describes the color, an 8-bit value is stored which points to a palette (or table or colors) entry, eliminating 16 bits per pixel. The table would contain the 256 different 24-bit descriptions of the sixteen million colors (see Figure 6.1). If the
EXPENSIVE METHOD -
ANY ONE OF 16,777,216 COLORS ON THE SCREEN

SCREEN =
1,048,576 PIXELS x 24 BITS
= 3,145,728 BYTES

LESS EXPENSIVE METHOD -
USES A 256-COLOR PALETTE.
EACH PALETTE COLOR CAN BE
ANY ONE OF 16,777,216 COLORS

SCREEN =
1,048,576 PIXELS x 8 BITS
= 1,048,576 BYTES

TABLE =
256 ENTRIES x 24 BITS
= 768 BYTES

TABLE (PALETTE) OF 256 COLORS
EACH ENTRY HAS 24 BITS
OF COLOR INFORMATION

Figure 6.1: Palette of colors.
value in a pixel was 43, then the computer would look into the forty-third entry of the table. The color value that is contained in this table position is then displayed at that pixel. Screen RAM would only take about one million bytes, and a negligible 768 bytes would be used for the table. This represents a computer hardware investment of about one-third of the price of the previous method! Of course, this way the artist could only display 256 unique colors on the screen at the same time, but this is really not as limiting as it sounds. The artist who plans a picture carefully can create striking scenes with much fewer than 256 different colors.

This second technique of displaying color is called color mapping, and the table of colors is called the color map. When color maps became popular, many advantages other than the lower cost were discovered. An artist could alter colors without having to redraw an entire picture. In the field of computer animation, wonderfully animated scenes could be created without plotting a single pixel simply by moving the colors around the color map! In medical applications, in the analysis of a computer image of an X-ray, formerly unnoticed details could be brought out by assigning contrasting colors to areas which had been depicted with only slight shading differences.

**Color Maps and the ATARI Home Computer**

The ATARI Home Computer is one of the few personal computers that uses this technique to display its colors on the screen. However, there are only 128 possible colors to choose from instead of sixteen million (hope you didn’t get your hopes up!) and only nine entries in the color map, rather than 256. These nine entries are called color registers. Most ATARI graphics modes don’t use all nine color registers. In fact, many use only four or less. Table 6.1 shows most of the different ATARI graphics modes and the color registers which are active for each.

<table>
<thead>
<tr>
<th>Modes</th>
<th>Default Colors</th>
<th>SETCOLOR POKE</th>
<th>COLOR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAPHICS 0</td>
<td>Lt Blue</td>
<td>709</td>
<td></td>
<td>(Not normally used)</td>
</tr>
<tr>
<td>(text mode and</td>
<td>Blue</td>
<td>710</td>
<td></td>
<td>Char. Lum. (uses bkg color)</td>
</tr>
<tr>
<td>all text windows,</td>
<td></td>
<td></td>
<td></td>
<td>Background</td>
</tr>
<tr>
<td>1 hue,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 luminances)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 12†</td>
<td>Orange</td>
<td>708</td>
<td></td>
<td>(Not Character Pixel</td>
</tr>
<tr>
<td>(Antic 4)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 13†</td>
<td>Lt Green</td>
<td>709</td>
<td></td>
<td>Character Pixel</td>
</tr>
<tr>
<td>(Antic 5)</td>
<td>Blue</td>
<td>710</td>
<td></td>
<td>Character Pixel</td>
</tr>
<tr>
<td>(special text</td>
<td>Red</td>
<td>711</td>
<td></td>
<td>Character Pixel</td>
</tr>
<tr>
<td>modes, 5 colors)</td>
<td>Black</td>
<td>712</td>
<td></td>
<td>Background, Border</td>
</tr>
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</table>

(continued)
<table>
<thead>
<tr>
<th>Modes</th>
<th>Default Colors</th>
<th>SETCOLOR</th>
<th>POKE</th>
<th>COLOR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAPHICS 1 and GRAPHICS 2 (large text modes, 5 colors)</td>
<td>Orange 0 708 (Not Character) Lt Green 1 709 normally used Blue 2 710 Character Red 3 711 Character Black 4 712 Background, Border</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orange 0 708 1 Pixel Lt Green 1 709 2 Pixel Blue 2 710 3 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 3, GRAPHICS 5, GRAPHICS 7 and GRAPHICS 15† (Antic E) (4 colors)</td>
<td>Black 4 712 0 Pixel/Background, Border</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orange 0 708 1 Pixel Lt Green 1 709 2 Pixel Blue 2 710 3 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 4, GRAPHICS 6 and GRAPHICS 14† (Antic C) (2 colors)</td>
<td>Black 4 712 0 Pixel/Background, Border</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 8 (1 hue, 2 luminances)</td>
<td>Lt Blue 1 709 1 Pixel Lum. (uses bkg color) Blue 2 710 0 Pixel/Background</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>GRAPHICS 9 (GTIA mode, 1 hue, 16 luminances)</td>
<td>Black 4 712 0 Pixel/Background, Border</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Change hue with SETCOLOR 4,n,0 or POKE 712,n</td>
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</tr>
<tr>
<td></td>
<td>Dk Gray 4 5 Pixel</td>
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<tr>
<td></td>
<td>Gray 8 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lt Gray 12 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>White 15 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPHICS 10 (GTIA mode, 9 colors)</td>
<td>Black 704 0 Pixel/Background, Border Black 705 1 Pixel Black 706 2 Pixel Black 707 3 Pixel Orange 0 708 4 Pixel Lt Green 1 709 5 Pixel Blue 2 710 6 Pixel Red 3 711 7 Pixel Black 4 712 8 Pixel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(continued)
The Modes column lists the different ATARI graphics modes and the number of colors they support. The Default Colors are the colors set by the OS when the computer is first turned on or reset. The SETCOLOR column gives the active SETCOLOR commands (used to change the color value in the color registers) for that mode. The POKE column lists the corresponding RAM addresses of the color registers for each mode. When you POKE numbers into these addresses, you can bypass the SETCOLOR command for faster color changing. (This is the only way to change some of the registers in mode 10.) The numbers in the COLOR column are the values of the COLOR command that will choose the current color register with which to draw.

The Description column lists which of the three screen elements each color register controls. First there is the screen background. When the screen is cleared, you are looking at background. It is the "canvas" upon which pixels are plotted and text is printed. Next is the border around the background. Although this area sometimes has its own color register, depending on the graphics mode it is really the frame surrounding the canvas and cannot be drawn on. Finally, there are the playfield pixels (any pixel that is plotted with a non-background color register). Each group of plotted pixels using a specific color register is considered to be a separate playfield. For example, look in the table for the section on GRAPHICS 3. Registers 0, 1, and 2 (in the SETCOLOR column) each control the color of playfields 0, 1, and 2 respectively. Register 4
controls the background of the screen and the border. Therefore, in this mode, the background’s color cannot be controlled separately from the border’s color. Notice that register 4 also controls a pixel; however, this is not a playfield pixel. Think of plotting with a background color register as removing the playfield pixels so the background color shows through again.

**Using the Default Colors** At first glance, this table may seem somewhat overwhelming, so let’s look at a few examples. Suppose you want to use GRAPHICS 3. Drawings done in this mode have a very coarse resolution of $40 \times 24$ pixels. Do you remember the buckets of paint in our Magic Paint Store? The store owner (ATARI operating system) was kind enough to fill some of these buckets when he first opened up the store. These are called the default colors and can be selected for drawing with the COLOR command. If you wanted to use only these default colors, then you can ignore the SETCOLOR and POKE columns, because these colors are automatically placed in the color registers when the computer is first turned on or SYSTEM RESET is pressed. To use the table, first choose a color from the default color column—light green, for example. Look across to the COLOR column, and you’ll find a 2. Therefore, the command COLOR 2 selects the bucket filled with light green paint.

To place a light green pixel at 10,8, you would execute the following statements:

```plaintext
10 GRAPHICS 3+16 : REM Full screen mode
20 COLOR 2 : REM Choose your bucket
30 PLOT 10,8
200 GOTO 200 : REM Stay in GRAPHICS 3
```

In line 10, the full screen version of GRAPHICS 3 is used (16 is added to the mode number). This means that there will be no text window at the bottom of the screen. Try temporarily removing line 200 and see what happens when you run this program. The screen flashes to black, the pixel is plotted, and before you get to look at it, the blue GRAPHICS 0 screen has reappeared. At the end of a program which uses a full screen graphics mode, the OS will automatically switch back to GRAPHICS 0. Line 200 is added to prevent this from happening until you press the BREAK button and exit the program.

To draw an orange line across the screen from this light green dot, add the following lines:

```plaintext
40 COLOR 1 : REM Choose another bucket
50 DRAWTO 29,8
```
Now use one more color register available in this mode. This one is filled with blue:

```
60 COLOR 3   : REM One more bucket
70 PLOT 30, 8
```

To erase a pixel, choose the background color (which always happens to be COLOR 0):

```
80 COLOR 0   : REM Select background
90 PLOT 20, 8
```

This screen will now appear as in Photo 6.1.

![Photo 6.1: Default colors of GRAPHICS 3 (see color insert).](image)

Using SETCOLOR

Now that we understand the use of the default colors, let's see what else is available to us. As we've mentioned before, the ATARI Home Computer has 16 different hues from which to choose, and each one can be displayed in any of eight levels of brightness or luminance. As we mentioned earlier, the BASIC command to change a color in a color register is

```
SETCOLOR n, hue, lum
```

where \( n \) is the value from the SETCOLOR column in Table 6.1, \( hue \) is a number from 0 to 15 that controls the hue, and \( lum \) is an even number from 0 to 14 (0, 2, 4, ..., 14) that controls the luminance of the color (the odd \( lum \) values have the same effect as the next lowest even value, e.g., \( lum = 1 \) and \( lum = 0 \) have the same effect). Table 6.2 shows the different hues available on the ATARI Home Computer.
Let’s look at a few examples to see how the luminance value combines with the hue to instantly produce a new color. Try the following SETCOLOR commands while in GRAPHICS Ø to change the color of the border (just type them in direct mode):

<table>
<thead>
<tr>
<th>Command</th>
<th>Hue</th>
<th>Luminance</th>
<th>Color Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SETCOLOR 4,0,14</td>
<td>Gray</td>
<td>14</td>
<td>White</td>
</tr>
<tr>
<td>SETCOLOR 4,0,0</td>
<td>Gray</td>
<td>0</td>
<td>Black</td>
</tr>
<tr>
<td>SETCOLOR 4,1,4</td>
<td>Light Orange</td>
<td>4</td>
<td>Brown</td>
</tr>
<tr>
<td>SETCOLOR 4,1,12</td>
<td>Light Orange</td>
<td>12</td>
<td>Bright Yellow</td>
</tr>
<tr>
<td>SETCOLOR 4,3,4</td>
<td>Red-orange</td>
<td>4</td>
<td>Deep Red</td>
</tr>
<tr>
<td>SETCOLOR 4,3,12</td>
<td>Red-orange</td>
<td>12</td>
<td>Flesh</td>
</tr>
</tbody>
</table>

With a little experimentation, you’ll be able to produce almost any color you wish.
Adjusting Your Color Television

Now would be a good time to make sure the color on your television is set correctly. This is a two-step process which may require you to adjust a hidden control on your computer. First, while in GRAPHICS 0, enter the following statement:

```
SETCOLOR 1,0,0
```

This will change the luminance values of the lettering so it will show up during the next steps. Now enter:

```
SETCOLOR 2,1,10
```

ATARI calls this color light orange, but at this luminance level it is actually a bright yellow. If the color is too green or too orange, then adjust the tint control on your television set until it looks yellow to you. Mark the position of your tint control so you can easily find it again if anyone adjusts your television.

Next, enter the following statement:

```
SETCOLOR 2,14,6
```

This is a strange color called orange-green (a khaki-gold color). After you execute this command, your screen will be filled with this delightful color. If this color doesn't fall exactly halfway between orange and green, you must make an adjustment on your ATARI Home Computer (trying to fix it with the tint control will just throw off the first color you adjusted). There is a small hole at the back of your computer through which you can insert a tiny screwdriver (see Photo 6.2). Inside this hole is the color adjustment control. Insert your screwdriver and turn it very slightly in both directions. You'll find that a very slight adjustment will produce a significant change on the screen. Swing back and forth from orange to green until you find that elusive point which yields a perfect orange-green.

When you have finished, all the other colors will be correctly adjusted as well. To make sure, change the screen to yellow (SETCOLOR 2,1,10) again. It should still be adjusted properly. If not, then go back to step one and try again. (We noticed that the ATARI color adjustment has no effect on this yellow.)

Photo 6.2: Adjusting the color on an ATARI Home Computer.
Now let's have a little fun! Add the following lines to the last program you entered:

```
80 COLOR 1 :REM Choose bucket 1 again
90 PLOT 20,5:
   PLOT 20,6
100 PLOT 19,7:
   DRAWTO 21,7
110 PLOT 19,9:
   DRAWTO 21,9
120 SETCOLOR 1,3,6 : REM Change to Red
130 SETCOLOR 2,12,6 : REM Change to Green
140 FOR I=1 TO 50:
   NEXT I : REM Pause
150 SETCOLOR 1,0,0 : REM Change to Black
160 SETCOLOR 2,0,0 : REM Change to Black
170 FOR I=1 TO 400
180 IF RND(0)*20<1 THEN
   SETCOLOR 4,0,14:
   SETCOLOR 4,0,0: REM Random lightning flash
   NEXT I
190 NEXT I
200 GOTO 120
```

When you execute this program, you will see a crude airplane heading towards you with red and green lights blinking at the tips of its wings. Every so often the background will flash as if the plane were flying through a lightning storm.

Lines 120–130 turn on the wing lights, then after a pause, lines 150–160 turn them off. SETCOLOR 1 changes the color of the pixel plotted with COLOR 2, and SETCOLOR 2 changes the pixel plotted with COLOR 3. This may seem a little confusing, so refer back to Table 6.1 to see the relationship between the SETCOLOR and COLOR commands.

If the value of the random number expression on line 180 is less than 1 (one chance in 20, or 5 percent), the lightning is turned on and off by setting the background color register first to white and then immediately back to black. As you can see in Table 6.1, SETCOLOR 4 controls the screen background.

We could have created the blinking wing lights by replotting the tips with the background color. This technique executes much more slowly than one which just changes the color registers. Although we don't need the speed in this case, the effect would be slightly different. Notice that during the lightning flash the darkened wing lights are silhouetted against
the sky. This effect could not be easily duplicated on a computer without color registers!

**Using POKE to Change Colors**

Referring back to Table 6.1, you’ll notice that there is one more column to cover. Each color register has an address in memory associated with it. The value in the color register can be changed by using POKE to put a new value into this address. In GRAPHICS 10, the only way to change the values in the first four color registers is with the use of a POKE. To obtain the value to POKE into a memory location, take the hue value of the color and multiply by 16, then add in the luminance value.

\( \text{POKE } addr, \text{ hue} \times 16 + \text{luminance} \)

In GRAPHICS 7, for example, the following two statements would be equivalent:

```
SETCOLOR 0, 4, 8  POKE 708, 72
```

To see why, first find the SETCOLOR 0 entry for GRAPHICS 7 in Table 6.1. Then move one column to the right, and you will see the address 708. Multiply the hue in the above SETCOLOR by 16 (4 \* 16 = 64), add the luminance value to it (64 + 8 = 72), and you have your POKE value! In many cases you may want to use a POKE instead of SETCOLOR, because POKE will execute more rapidly. This is because it takes time for BASIC to do the necessary conversion from SETCOLOR’s hue and luminance values to a single value which it then POKEs into the proper address. You speed up the process by precalculating the value while you are **writing** your program and then have BASIC just POKE it in during execution.

This technique was used in the Exploding Bomb program (Chapter 5, Example 4) to flash the background rapidly at the moment of the explosion. Here is that line again:

```
80 FOR I = 1 TO 10:
     POKE 712, RND(0) \* 255:
    NEXT I:
POKE 712, 0:
RETURN: REM Flash
```

This line selects 10 random colors to flash on the background and then resets the background color to black.
Now type in the following short program and see what happens:

10 GRAPHICS 3+16
20 FOR I=0 TO 254 STEP 2 : REM Step through every color
30 POKE 712,I : REM Change background color
50 NEXT I
60 GOTO 20

When you run it, your screen will flash through all the colors so quickly that you will hardly be able to see them. Add the following line to slow it down to human speeds:

40 FOR W=1 TO 50:
      NEXT W

Try doing this trick without color registers!

Summary

Color registers can be used to rapidly change portions of the screen with a simple SETCOLOR or POKE. But what purpose do they serve for animation? In the next section, we will explore the real power of color registers in three amazing demonstration programs.

6.2. CREATING MOTION WITH COLOR REGISTERS

In Chapter 5's Exploding Bomb program, we use color registers to flash the background and then to fade out the explosion on the screen. With careful planning, this ability to instantaneously change the color of a specific area on the screen can be used to create the effect of high-speed motion without resorting to machine language.

To understand how to create motion using color registers, first consider our paint store analogy again. It had nine paint buckets numbered from 0 to 8, each filled with a different color. Now let's add a temporary paint tray called TEMP. We are going to use the nine buckets and the tray to play "pass the colors" (see Figure 6.2). First, empty the paint contained in Bucket 0 into the TEMPorary tray. Then pour Bucket 1's contents into the now emptied Bucket 0. Next, pour the paint in Bucket 2 into Bucket 1. Continue passing the colors until Bucket 8 is emptied into Bucket 7. There are no more buckets left with which to fill Bucket 8. Aha! Stored in TEMP, we still have the paint that first filled...
Bucket 0! So we take the paint in TEMP and empty it into Bucket 8. Then go back to the very first step and empty the paint now in Bucket 0 into TEMP and so on. (This is called a "bucket brigade" in electronics.) We have just created an endless loop of moving colors, which is seen on the screen as a rapidly changing pattern. Depending on what was drawn and how it was organized on the screen, a hypnotically abstract design or an exciting, realistic scene can be produced.

As animators, we must now form the pattern of moving colors into something interesting to look at.
The Moving-Color Curtain Program

Let's see how color register animation actually looks on the screen. In our first program, the screen is filled with vertical bars that have colors rotating through them. We will use GRAPHICS 10, a mode especially suited to color register animation as it allows you to use the full nine ATARI Color Registers (see box).

The GTIA and the CTIA

When the ATARI Computer first came out, it had a special television interface chip called CTIA. Beginning in early 1982, all ATARI's were manufactured with a new and better chip called GTIA. The GTIA supports three additional BASIC graphics modes, 9, 10, and 11, which were not available on the earlier ATARI computers. The resolution on these modes is 80 × 192, yielding the same vertical resolution as GRAPHICS 8 (as well as the same memory consumption). GRAPHICS 9 allows the selection of one hue which can then be simultaneously displayed on the screen with 16 different luminances (see Photo 6.3).

Photo 6.3: Screen photos of GRAPHICS 9.

GRAPHICS 11 allows the placement of up to 16 different hues on the screen, all set to the same luminance value.

Photo 6.4: Screen photo of GRAPHICS 11.

These two modes won't be covered in this book since they can't be used for color register animation. We will be discussing GRAPHICS 10, however, which allows you to chose any nine colors from the ATARI palette of 128 colors!
To tell whether your ATARI Home Computer has the CTIA or the GTIA chip, enter and run the following program:

```
10 GRAPHICS 10
20 GOTO 20
```

If your screen first flashes black and then returns to blue, you have the CTIA. The program will still be running, but the CTIA will not be able to properly display a GRAPHICS 10 screen. If your screen stays black, congratulations! You have the GTIA and may run our GTIA examples. You may get your computer upgraded to the GTIA chip for a small fee. If you haven't already done so, you will be missing out on many new ATARI programs which require this chip.

---

**Using the Amazing GRAPHICS 10**

GRAPHICS 10 has a rather strangely shaped pixel. Each pixel is about four times as wide as it is high, with a screen resolution of $80 \times 192$. This doesn't present a problem in Example 5, but it is awkward to use when drawing curved surfaces. As you can see in the following figure, lines that are almost horizontal show very fine resolution, and those that approach vertical are extremely coarse.

---

![Figure 6.3: GRAPHICS 10 pixels.](image)
To change the values in the color registers for the standard CTIA graphics modes (0 through 8), you can use the BASIC SETCOLOR command. However, ATARI BASIC isn't fully set up for the GTIA graphics modes. The only way to change the colors in the first four color registers (see Table 6.3) is to POKE them directly into the color register's RAM address. The following table shows the relationship between this RAM address and the SETCOLOR command. Even though BASIC's SETCOLOR isn't adequate in GRAPHICS 10, BASIC's COLOR command can be used to choose any of the registers for painting. For example, to draw an orange (hue 2, luminance 8) pixel on the GRAPHICS 10 screen with register 1, use the statements:

POKE 705, 0 : REM Fill register 1 with orange (hue=2, lum=8)
COLOR 1 : REM Select register 1 for drawing
PLOT X, Y : REM Place an orange pixel at X, Y

To draw with register 6, you could use either the SETCOLOR command or a direct POKE:

SETCOLOR 2, 2, 8 or POKE 710, 4

Here is the GRAPHICS 10 section of Table 6.1 for easy reference:

<table>
<thead>
<tr>
<th>Modes</th>
<th>Default Colors</th>
<th>SETCOLOR</th>
<th>POKE</th>
<th>COLOR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAPHICS 10 (GTIA mode, nine colors)</td>
<td>Black</td>
<td>—</td>
<td>704</td>
<td>0</td>
<td>Pixel/Background, Border</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>—</td>
<td>705</td>
<td>1</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>—</td>
<td>706</td>
<td>2</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>—</td>
<td>707</td>
<td>3</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Orange</td>
<td>0</td>
<td>708</td>
<td>4</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Lt Green</td>
<td>1</td>
<td>709</td>
<td>5</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>2</td>
<td>710</td>
<td>6</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>3</td>
<td>711</td>
<td>7</td>
<td>Pixel</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>4</td>
<td>712</td>
<td>8</td>
<td>Pixel</td>
</tr>
</tbody>
</table>

Table 6.3: GRAPHICS 10 — color registers and COLOR command.

Even though we have nine color registers to play with on a GTIA ATARI, we seldom use all of them for color rotations in an animated scene. In the next example, we use the eight color registers that color the
playfields (all colors except the background) and leave the screen background register (register 0) alone.

Example 5

Exercise Create a beautiful kaleidoscopic pattern by filling the screen with vertical bars drawn with all eight of GRAPHICS 10’s playfield color registers. Divide the screen in half so that when you rotate colors through the registers, both the left and right halves of the screen move towards the center. Leave the background black.

![Screen photos of moving color curtain program](image)

There are three sections to this program: the initialization section, the section which draws the bars on the screen, and the section which animates the picture by rotating the colors. You’ll notice that this last section was placed at the beginning of the program. It makes use of the previously discussed fact that statements towards the beginning of an ATARI BASIC program execute at a faster rate than those at the end.

```
200 REM Initialize
210 GRAPHICS 10 REM GTIA Mode - 80 x 192 with 9 color registers
220 COL=11
230 LUM=8 REM Set starting COLOR Register & LUMinance values
240 rem
250 POKE 704,01 REM Background to black
260 FOR I=1 TO 16 REM Other registers to different colors
270 POKE 704+I,16*I+LUM
280 NEXT I
290 REM
```

Figure 6.4: Listing of Example 5 — lines 200-290.

Initialize First, GRAPHICS 10 is turned on. Even though the ATARI operating system fully supports GRAPHICS 10, BASIC doesn’t. Since the normal SETCOLOR command to control the first four
registers can't be used, we will directly POKE in the initial colors (lines 250–280).

```
200 REM Draw Bars, Increment COLOR
300 FOR I=0 TO 79
310 COLOR COL
320 PLOT I,O;
330 DRAWTO
340 IF K=0 THEN
350 COL=COL-1;
360 IF COL=0 THEN
370 COL=8
380 IF I=10 THEN
390 COL=COL+1
400 IF COL=9 THEN
410 COL=1
420 END: GOTO 30
```

Figure 6.5: Listing of Example 5 — lines 300–370.

**Draw Bars, Increment Color** This is the section of a color register animation program which requires the most work, i.e., drawing the picture on the screen. The color register is set to the value in C, then this color is used to draw a vertical bar. (The values from 0 to 8 can be used in the COLOR command without any problems.) After each bar is drawn, the value in C is changed so the next bar will be drawn using a different color register. On the left half of the screen, we are decrementing through the color registers. On the right half, we are incrementing through them and continue to draw bars until the screen is completely filled. Again, notice that the background register, COLOR 0, is not used.

```
10 REM *** MOVING COLOR CURTAIN ***
20 REM Example 5
30 REM
40 REM Program to demonstrate Color Register Animation in GRAPHICS 10
50 REM 6512A chip required
60 REM Copyright © 1982 by David Fox and Mitchell Muite
70 REM
80 GOTO 200
90 REM
100 REM Rotate Color Registers
110 TEMP=PEEK(705)
120 FOR I=705 TO 711
130 POKE观赏+18
140 NEXT I
150 POKE 712,TEMP
160 GOTO 110
170 END
```

Figure 6.6: Listing of Example 5 — lines 10–140.

**Rotate the Color Registers** Now that the scene is drawn, it can be animated. We play our game of "pass the colors" with eight of the registers, using a FOR/NEXT loop for simplicity, even though it slows the execution speed a bit. Listing out each POKE in the color rotation sequence (as we do in Example 6) would increase the program's execution speed.
When this program is executed, the colors are seen moving from each half of the screen towards the middle.

**Modifications** For variety, try the following changes:
1. Use a different initial set of colors and/or a different luminance value.
2. Change line 110 to the following:

```
110 TEMP = PEEK(705)+16:
   IF TEMP > 255 THEN
      TEMP = LUM: REM Add a new color
```

This will change the color stored in TEMP to the next color in the ATARI rainbow of colors. This will cause the colors displayed on the screen to circulate constantly through the 16 different hues as they move towards the center of the screen.
3. For those who like surprises, change line 110 to the following:

```
110 TEMP = RND(1)*256: REM Pick random color
```

4. Change the program so the background color is rotated.

---

**Summary**

Creating kaleidoscopes is fun, but what about some real action! In the next section, we will use the same technique and apply it to the beginnings of a space game.

---

### 6.3. THE TRENCH PROGRAM

Everyone who saw *Star Wars* remembers the flight through the Death Star’s trench. In the next program, Example 6, we will use color register animation to create this effect. We will be using GRAPHICS 7 (available on all ATARI Home Computers) which will give us fewer registers to play with (GRAPHICS 7 has a resolution of 160 × 96 and uses four color registers). This program can be the core of an exciting game.

The theory behind the Trench program is the same as that in Example 5. The main difference is that we will rotate colors through only three registers. This will almost triple the speed of the color rotation loop. Also, the size of the sections on the screen that will be animated are much larger than those in Example 5. This will so exaggerate the effect of motion that there will be more than enough processing time left for sound effects and major improvements to the program.
Example 6

**Exercise**    Draw a trench on the screen in GRAPHICS 7 in such a way that the viewer will have the experience of rapidly traveling through it when color register rotation is used. Make the trench U-shaped, with two vertical sides and a horizontal bottom. Using a game paddle, give the viewer control of speed through the trench and forward/reverse motion. Make the roar of the engines change as the velocity changes.

![Screen photos of the Trench program.](image)

This program has three main sections: the initialization section, the section which draws the trench on the screen, and the section which animates the picture by rotating the colors and reading the game paddle. The drawing section was difficult to write. It took quite a while to create a formula that could simulate the perspective of the trench. We could have drawn the trench on graph paper and just translated the plotting coordinates to the program, but that would have used much more memory (and would have been much more boring).

### Figure 6.7: Listing of Example 6 — lines 200–220.
**Initialize** The initial values are set along with the colors to be drawn. Notice that two of the registers are set to the same color. Even though we are using three color registers in our animation sequence, only two colors will be passed through them. This yields a smoother animation effect (see Figure 6.8). The three boxes, A, B, and C, show the progression of the two colors through the three registers. Even though the width of the moving color is two bars wide, the step size of the movement is only one bar wide.

![Color Register Animation](image)

**Figure 6.8:** Using two colors and three registers.
If only two colors and two registers were used (boxes D, E, F), the viewer would just see the two colors alternating places. There wouldn’t be any illusion of movement, just a flickering effect. With three colors and three registers, there would be too many colors in the trench and the effect would be spoiled. (Darth in a candy-striped trench?)

**Figure 6.9:** Listing of Example 6 — lines 300–440.

**Draw Trench on Screen** This section draws the trench on the screen using the appropriate color register. We start near the horizon, draw the three sides of the trench, then move out towards the edges of the screen. The algorithms used here were all arrived at through the scientific method of trial and error. Line 370 increments the value of C in smaller and smaller steps as X (the horizontal position of our lines) increases. This creates the illusion of perspective — the closer the different colored panels are to the viewer, the wider they appear.

**Figure 6.10:** Listing of Example 6 — lines 10–190.
**Loop to Rotate the Colors**  
This program calls for sound effects and an element of interaction. Sound register 3 is used to give us a constant background roar (line 110). The game paddle is used to control the speed through the trench (line 150) and to reverse the direction we are traveling (line 130). If the paddle button is pressed, we move backwards (line 140). To gain as much execution speed as possible, each POKE in lines 130–140 is written out rather than using FOR/NEXT loops. In line 160, the position of the game paddle is also used to control the pitch of the other three sound registers. To add to the realism, the whine of the engine rises in pitch as velocity increases. Line 170 takes the paddle value and uses it to control a pause loop.

If you don’t have game paddles, use a joystick to change the value in PDL — if you push forward, increment PDL; if you pull back, decrement PDL.

**Modifications**  
The following are modifications for you to try:

1. You may want to modify this program to use GRAPHICS 10 instead of GRAPHICS 7. This will give you some extra registers for stars and other objects.
2. Turn this program into a game. After reading the next chapter on player-missile graphics, see if you can create the target spacecraft in front of you as well as a movable gunsight.

---

**Summary**

Moving from the excitement of outer space, we will visit a sylvan scene of the wilderness. In the next section the same techniques are used to animate only a single portion of a scene.

---

**6.4. AUTUMN WATERFALL PROGRAM**

The tranquility of this program is for those of you who don’t enjoy roaring through a narrow trench at almost the speed of light. GRAPHICS 10 will be used to draw an autumnal landscape complete with trees casting long shadows from an early morning sun. The scene is brought to life by a foaming waterfall cascading down a steep cliff and across a green valley.

We are not introducing any new animation techniques, just expanding on earlier ones. Because of the complexity of the scene on the screen, this program is quite a bit longer than some of our previous examples. The section which actually animates the scene, however, is only three lines long! This reveals that much of our ATARI animation involves set up while the actual motion code is simple.

Only four color registers will be used for the program’s animation. The other five registers will be used to draw the landscape. This takes
some planning, as there is an interdependency between what we want to include in the picture and how many colors can be used. One way to plan the picture is to keep adding details as long as there are colors left. That's the method we used. The background register was used for the sky, another register for the brown cliffs, and a third for the grass covering the top of the cliff and the valley floor. That left two unused registers, so we planted trees across the valley. The brown of the cliffs was recycled for the tree trunks, and the tree tops were painted orange-red to add some color. Finally, a darker shade of green was used in the last register for tree shadows. The foam at the base of the waterfall was drawn with the sky's color rather than one of the waterfall’s colors, since we didn’t want its color to change at all. There were no more registers left for new colors, so the scene was completed!

Using Fill

To make it easier to color large areas of the screen rapidly, the ATARI operating system’s built-in Fill routine is used. Unfortunately, this Fill is not the same as the Fill or Flood used in professional computer paint systems. ATARI’s Fill will not seek out all the adjacent nooks and crannies within the area to be filled. Since it’s more of a box fill, it just draws a series of horizontal lines towards the right of the screen. Each line is completed when it hits a non-background color. Even worse than its inadequacy is the fact that there doesn’t even exist a simple ATARI BASIC statement to implement the OS’s Fill (although there is a FILL in ATARI Microsoft BASIC). Instead, we must use a special call to the OS to activate Fill after setting up the screen in a particular way. This makes it very inconvenient to use, but it’s still better than nothing.

Photo 6.7 shows how Fill works. The left boundary of the area being filled is created as Fill is at work. This outline was drawn in a color different from the filled-in area to make it easier to see precisely how Fill operates. The steps are further described in the text that follows.
Photo 6.7: The Fill routine in action.
Since Fill is an OS routine and not directly supported by BASIC, it must be accessed through BASIC’s XI0 command. This is a general input/output statement used for special operations which, in addition to Fill, can be used to perform special disk operations like Rename, Delete, Lock. (For more information on XI0, see your ATARI BASIC manual.)

Here are the steps you need to go through to use Fill:

1. Using the COLOR command, select the outline color of the area to be filled.
2. Select the color for Fill with a POKE of the appropriate COLOR value into RAM location 765.
3. Make sure there is a right edge to the area you want to fill. If there isn’t one, then draw it in.
4. There are two ways to mark the starting point of the fill (see Photo 6.7). One, you can draw a horizontal line from step 3’s right edge to the starting point of the Fill. Fill doesn’t actually begin until the next line (up or down) towards the end point (X2, Y2 in step 5). Two, you can indicate the starting point with a PLOT X1, Y1. In this case, the first horizontal line will again begin on the next line towards X2, Y2 and will end when it reaches the right edge of step 3. However, with this method a pixel will be left out in the open at X1, Y1. This is fine when you are filling in an area by sections and this pixel blends into the previous section. We used this second method in our Waterfall Program.
5. Indicate the ending point with a POSITION X2, Y2. This is where the final horizontal line will begin. It too will end when it reaches the right edge of step 3.
6. Call the Fill routine with the XI0 function (XI0 1B + #6 0 0 "S:" ). This will fill in the defined area with the color set in step 2. Note that the borders may be in a different color than the filled area (see above photos).

Example 7

Exercise Create a practical example of motion using color registers. Draw a peaceful scene on your computer’s screen with a waterfall roaring over the edge of a cliff onto a valley floor. Draw some trees using the colors of autumn. Use color register animation to create the motion of the water in the river and the falls. Use four registers for the moving water and the remaining five registers for the scenery.
There are three main parts to this program: initialize, draw the scene, and animate the scene. However, because the program is longer than the earlier ones, we divided the draw-the-scene portion of the program into several smaller sections.

**Initialize**  Set up the palette of colors we will be using.
**Draw Grass and Cliff**

As in oil painting, we must first paint in the large background areas, then the details. We are using ATARI's built-in Fill routine to rapidly color these large areas. To make this process simpler, a subroutine on lines 1300–1310 is used. It carries out Fill steps 4–6 as described earlier.
Draw the Falls and River  In our scene, the water is the only thing which is animated. Four color registers are used to animate the moving water. The water is drawn in three sections: the river on top of the cliff (lines 510–600), the waterfall (lines 610–720), and the river on the valley floor (lines 730–820). The water consists of a series of parallel strips. To give some randomness to these strips, a subroutine (lines 1500–1530) is called which chooses the starting color register for each strip of water, making sure that no two adjacent strips will be identical.

On lines 710–720 some grass and dirt are added around the falls to depict the natural forces of erosion.
Figure 6.14: Listing of Example 7 — lines 900–1080, 2000–2010.

**Draw the Trees** This section draws 11 identical trees. The X and Y base coordinates for the trees are stored on line 2010. An X,Y coordinates pair is READ and a new tree is drawn at that location. Lines 980–1010 add a great deal of realism by creating a shadow in a darker shade of green. Lines 1020–1060 create some randomness by scattering 15 leaves about the base of each tree.

Figure 6.15: Listing of Example 7 — lines 1100–1210.

**Draw the Foam** As the water hits the base of the falls, white foam is created. Since there are no color registers left for white foam, the sky color is reused.
**Figure 6.16:** Listing of Example 7 — lines 1250–1280.

**Turn on the Sound** All the sound registers are used to create the roar of the waterfall. The sound is constant and does not need to be changed anywhere else in the program.

**Figure 6.17:** Listing of Example 7 — lines 10–140.

**Rotate the Colors** This section is similar to the corresponding sections in the other programs of this chapter. Of course, we only need to rotate the color registers for the four colors of the water.

**Modifications** Try the following modifications:
1. Simulate a sunset by gradually changing the sky color to orange, pink, and purple and by decreasing the luminance values of each of the color registers. Then, after a period of time, reverse the process for a sunrise.
2. Change this program into a representation of the different seasons of the year. Simply by changing the colors in the appropriate registers, you can turn this into a summer scene (turn the treetops green). By altering the color of the grass and treetops to white, the sky to grey, and slowing or stopping the flow of the river, you can create a winter scene.

**Commercially Available Games Using Color Register Animation**

After scouring the marketplace, we could find not a single example of color register animation being used in a current game. What untapped potential!
Summary

Color register animation is a wonderful tool for creating a background scene with some life to it. Very little computer processing power is needed to create fantastic effects. Using color registers, it’s a simple matter to create an entrancing picture. It would be somewhat difficult, however, to combine this technique with character set animation for two reasons.

One, color register animation is more suited for map modes than for text modes. In GRAPHICS 0, there aren’t enough registers available to do color register animation. In ANTIC 4, where there are enough registers available, it would be difficult to design the picture to be animated.

Two, GRAPHIC modes can’t be mixed at the same location on the screen — only in horizontal bands. It would be possible to carefully lay out your screen so that your animated character set figure only stayed in its own band and the rest of the screen was a beautiful animated scene. Although this technique would be more than adequate for many well thought-out programs, it is somewhat limiting because the figure could only stay in this horizontal band and not move freely about the screen.

Fortunately there is a solution to this problem. It’s possible to move animated figures over complex backgrounds without having to worry about erasing anything! This feature is called player-missile graphics, and we will cover it in the next chapter.
Chapter 7

Player-Missile Graphics

In advertisements for many ATARI games you’ll see the words “... uses ATARI player-missile graphics!” What are player-missile graphics, you may have wondered, especially if the game has nothing to do with war or fighting? In this chapter, you will be introduced to this powerful feature through a Bouncing Ball program. Even though this sounds like a trivial example, it reveals the fundamental method behind animating players on the ATARI Home Computer. You will be able to control the ball’s initial velocity and how much “bounce” it has — from a bowling ball dropped into a vat of mud to a ball which gains energy every time it hits the ground. To move the ball on the screen, the untapped power of ATARI BASIC string manipulations will be used. All of the upcoming examples from Chapters 8 and 9 build on this program, using much of the same program code, so save each program to avoid endless retyping.

7.1. WHY PLAYER-MISSILE GRAPHICS?

In Chapter 5 some lively animated figures are created, and in Chapter 6 some spellbinding backgrounds are produced. Unfortunately, it is somewhat difficult to combine these two elements because every time a figure is moved from one part of the screen to another, the old figure must be erased before the new one is drawn. This is a simple procedure when the figure is moving across a blank screen. A number of problems arise, however, if our little man were to stroll through a forest or down a city street. The first difficulty results from the computer’s inability to mix different graphics modes on the same horizontal line. By altering the display list, the screen can contain different graphic modes, but only in horizontal bands stacked one on top of another. A character set walking man can’t traverse a map mode screen!

There are several apparent solutions to this first problem. If the man can be restricted to a horizontal band on the screen, and this band can be created in a solid background color, then the technique of altering the display list could work. Even though the rest of the screen contains a
colorful scene, the man could only walk over a solid background, and the techniques of Chapter 5 would apply. This approach takes quite a bit of planning and is still very confining.

Another solution is to make sure the animated figure and the entire background are created in the same graphics mode. This is done either by producing the background out of character sets so it matches the man, or making the man out of plotted points to match the background. This solution, however, presents the second problem. Let's assume you painstakingly construct a beautiful scene using an Antic 4 character set (difficult but not impossible). What happens when you want the man to walk across the scene? As you erase him from the old position, a portion of the background is also erased. By the time the man reaches the other side, he has ripped a long hole in the background scenery and done more damage than an ambitious strip mining operation. In order for this technique to work properly, the man must be erased by precisely redrawning the background over his old position. Although techniques to accomplish this feat are available, they are awkward to implement and require machine language's quick calculation power.

Fortunately, ATARI had a better idea! Rather than relying on complicated software routines to mix animated figures and complex backgrounds, they gave the task to two of their custom chips, Antic and GTIA (or CTIA). Now, you can create an animated figure, move it quickly to any part of a screen consisting of any mixture of graphics modes, and not worry about erasing the existing background! This capability is called player-missile (PM) graphics.

What Are Player-Missile Graphics?

A player is actually a section of RAM, totally separate from normal screen memory, which controls a vertical bar on the screen. This bar, consisting of a stack of bytes, can be horizontally positioned anywhere on the screen. Defining a player is very similar to defining a character (see Chapter 5). Just turn on the appropriate bits of the appropriate bytes. On the first screen in Figure 7.1, every bit in the player has been turned on.
(each byte in the stack has the value of 255). This results in a solid vertical bar. On the second screen, a round ball has been defined by turning on some of the bits in five adjacent bytes only. The player is invisible where bits are turned off. Moving the object vertically is a simple matter of moving its byte image up and down within the vertical bar.

Since there are 8 bits in a byte, a player has a horizontal resolution of eight pixels. The vertical resolution of a player can either be one or two horizontal scan lines, depending on how you set up PM (player-missile) graphics. There are 128 bytes in the stack of a double-line resolution player and 256 bytes in a single-line resolution player (it takes twice as many bytes to display the increased resolution). All examples in this book use the double-line resolution mode. A player pixel in this mode is one color clock wide and two scan lines high, exactly the same size as a pixel in GRAPHICS 7, and four times as large (twice as wide and twice as high) as a GRAPHICS 0 character set pixel. Figure 7.2 shows how a ball might be represented as both double- and single-line resolution players. Even though these close-ups exaggerate the pixel steps, the single-line resolution ball still looks rounder.

![Figure 7.2: Player in double-line resolution.](image)
Even though players are larger than characters, the proportions of their pixels are identical. This means that you can use all the tools for creating user-defined character sets to help make players, including a font-editing program or our character grid (Figure 5.8). Also watch for software tools designed especially for creating players.

A total of four players is available in the ATARI Home Computer, and each one can be independently controlled. Each has its own color, width, and area of RAM and can be moved separately from the others (see the section in this chapter on player parameters). In addition, each of the four players has a missile. A missile is similar to a player except that it is only 2 bits wide instead of 8. Each player-missile pair shares the same color. It is possible to combine the four missiles into a fifth independent player. (None of our demonstration programs use missiles.)

Figure 7.3: The four players and their missiles.

Figure 7.4 is a memory map of PM RAM. PMBASE, the address where PM RAM begins, must be on a 1 K address boundary for double-line resolution (a RAM address which is evenly divisible by 1024) or a 2 K boundary for single line resolution (evenly divisible by 2048). Notice that there is some wasted memory at the beginning of the PM RAM area. This RAM can be used for other purposes (e.g., storing frame information).
7.2. PLAYER MOTION

Each player can be moved independently in a horizontal, vertical, or diagonal direction. Horizontal movement is the easiest. How much easier is it to move a player than to move an object using other techniques? Let's find out.

Moving a Player Horizontally

It is extremely simple to move a player across the screen from left to right (or from right to left). Each player (and each missile) has its own address called a horizontal position register. To move a player to any horizontal position, simply POKE the proper value into the player's horizontal position register and the player immediately appears at its new position! Table 7.1 lists the locations of these registers for each player and missile.
Addresses

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Hex</th>
<th>Name for it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player 0</td>
<td>53248</td>
<td>D000</td>
</tr>
<tr>
<td>Player 1</td>
<td>53249</td>
<td>D001</td>
</tr>
<tr>
<td>Player 2</td>
<td>53250</td>
<td>D002</td>
</tr>
<tr>
<td>Player 3</td>
<td>53251</td>
<td>D003</td>
</tr>
<tr>
<td>Missile 0</td>
<td>53252</td>
<td>D004</td>
</tr>
<tr>
<td>Missile 1</td>
<td>53253</td>
<td>D005</td>
</tr>
<tr>
<td>Missile 2</td>
<td>53254</td>
<td>D006</td>
</tr>
<tr>
<td>Missile 3</td>
<td>53255</td>
<td>D007</td>
</tr>
</tbody>
</table>

Table 7.1: Player-missile horizontal position registers.

The value you POKE into the horizontal position registers is in color clocks (see Chapter 5). Each horizontal scan line is 227.5 color clocks wide, but because of overscan (television manufacturers adjust their sets so that part of the picture overflows the screen and is lost), each end of the scan line is off the screen. So, although you can POKE a value from 0 to 255 into any of these registers, a player positioned with the low and high values will not be visible. Depending on your television set, the values less than 20–60 will be off the left edge and the values greater than 200–245 will be off the right edge. Therefore, to make a player vanish, all you have to do is POKE its horizontal position register with a 0. It will immediately disappear from the screen. Actually, it is hiding off the left edge of the screen, waiting for your next command.

Hardware Registers and Shadow Registers

Try the following experiment — press SYSTEM RESET on your ATARI, POKE a value into 53248 (the horizontal position register for player 0), and then immediately PEEK into this address to see what's there:

```
POKE 53248,50
PRINT PEEK(53248)
0
```

The ATARI printed this.

No there isn't anything wrong with your computer. No matter what value you POKE into 53248, you won't be able to alter the value you find when you PRINT its contents! This is because any address in the ATARI from 53248 to 55295 (D0000-D7FF Hex) is
not really a RAM address; it is a **hardware register**. These addresses are mapped to locations in the ATARI special chip set, which gives direct access to the power of the computer (see Figure 7.5). In this case, Antic, which is tied to location 53248, receives your value and immediately put it to use. If PM graphics were enabled (turned on), you would see Player 0 move to the indicated position, but you wouldn't be able to verify this by a **PEEK** into the register. This is called a *write-only register*

<table>
<thead>
<tr>
<th>ADDRESSES</th>
<th>DECIMAL</th>
<th>HEX</th>
<th>FUNCTION</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>65535</td>
<td>FFFF</td>
<td></td>
<td>OPERATING SYSTEM AND MATH ROUTINES</td>
<td>10K</td>
</tr>
<tr>
<td>55296</td>
<td>0D800</td>
<td></td>
<td>HARDWARE REGISTERS</td>
<td>2K</td>
</tr>
<tr>
<td>55295</td>
<td>0D7FF</td>
<td>D000</td>
<td>RESERVED FOR FUTURE OPERATING SYSTEM EXPANSION</td>
<td>4K</td>
</tr>
<tr>
<td>53247</td>
<td>0CFFF</td>
<td></td>
<td>BASIC CARTRIDGE OR RAM (IN 48K SYSTEM WITH NO CARTRIDGES)</td>
<td>16K</td>
</tr>
<tr>
<td>49152</td>
<td>0BFFF</td>
<td></td>
<td>RAM (IN ATARI WITH 40K OR MORE MEMORY)</td>
<td>16K</td>
</tr>
<tr>
<td>49151</td>
<td>0A000</td>
<td></td>
<td>RAM (IN ATARI WITH 32K OR MORE MEMORY)</td>
<td>16K</td>
</tr>
<tr>
<td>40960</td>
<td>0FFF</td>
<td>16384</td>
<td>RAM (IN ATARI WITH 16K OR MORE MEMORY)</td>
<td>16K</td>
</tr>
<tr>
<td>40959</td>
<td>9FFF</td>
<td>16383</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32768</td>
<td>8000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32767</td>
<td>7FFF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16384</td>
<td>4000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16383</td>
<td>3FFF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7.5:** Memory map showing hardware registers and RAM.

There is a limited number of addresses set aside for this purpose, so ATARI has them doing double duty. The address 53248, for example, has a split personality. In addition to its function as the write-only horizontal position register for Player 0, it is also tied to a
read-only GTIA register that is used for collision detection. You can PEEK into this address to find out if Missile 0 has collided with a playfield (see the upcoming section on collision detection). The 0 that you just PRINTed on the screen means that no collisions of this nature have occurred.

What about color registers? They do not follow our description of hardware registers in two ways. They don't fall within the specified hardware register addresses, and we were able to PEEK at their contents and POKE them with color information. Certain hardware registers have "scratch pad" RAM locations associated with them called shadow registers. A shadow register is a normal RAM location. Every sixtieth of a second, the computer looks into its shadow registers, grabs their values, and places them into the corresponding hardware registers (or, with some registers, the information is transferred from the hardware register to the shadow register). This is necessary when a register controls some aspects of the screen display. For example, if the gathering of color information were not synchronized with the display (which is also being refreshed every sixtieth of a second), you would see the color change on the screen at random horizontal positions resulting in an annoying flicker (see the sections on the vertical blank in the next chapter). So, the color registers we have been using are really shadow registers of the hardware color registers. The use of shadow registers made the color register animation programs from the last chapter as simple to implement as they are!

When a shadow register is available for a specific hardware register, we will only give you that shadow register address. If you try to POKE information (from within BASIC) into a hardware register that is shadowed, it will be set back to its shadowed value during the next sixtieth of a second. Some amazing things can be accomplished, however, by directly accessing these shadowed hardware registers through machine language as we will see in Chapter 9. (Appendix G furnishes a list of ATARI hardware and shadow registers.)

---

Moving a Player Vertically with BASIC

Vertical player movement is slightly more difficult to accomplish than its horizontal counterpart. Since there is no vertical position register, the only way to move a player up and down is to actually move its bit pattern through player RAM. To do this effectively, machine language speed is required. There is a technique, however, by which we can trick BASIC into helping us with this problem through the use of string manipulations.

Background on Strings As you enter a BASIC program line which contains string variables, some information is stored in two tables. One table, called the variable name table, keeps a list of all variable
names, and another, called the variable value table, has information as to where in memory each string's data will be stored. (This table also has information about numeric arrays, which we won't be covering here.) The location of the table can be discovered from within BASIC by checking a pair of memory locations called VVTP (variable value table pointer). The value of VVTP is calculated like this:

\[ \text{VVTP} = \text{PEEK}(134) + \text{PEEK}(135) \times 256 \]

Suppose, for example, you had a program which started like this:

10 DIM A$(25), B$(256)
20 A$ = "This is a test"
30 B$ = "done"

Here is how the beginning of the variable table would look if we PEEKed into the contents of RAM starting at VVTP. All of the values are given in decimal:

<table>
<thead>
<tr>
<th>Byte Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>String (DIMensioned)</td>
</tr>
<tr>
<td>(unDIMensioned)</td>
</tr>
<tr>
<td>Entry for A$</td>
</tr>
<tr>
<td>Entry for B$</td>
</tr>
</tbody>
</table>

Table 7.2: Variable value table.

Each variable’s entry in the table is 8 bytes long. Byte 1 indicates whether the variable has been DIMensioned yet (a 129 is stored here if it has and a 128 if it hasn't). The second byte indicates the variable's position in the variable name table. It is important to note that this number represents the order in which the variables were entered (time-wise) into the program, not the order in which they occur in the listing. In our example above, another string variable now added at line 5 would be the third variable in the program. This order is maintained even when the program is saved on disk (or cassette), and even variables which have been deleted from the program remain in the table. The only way to reorder the variables in the table (or to purge old variables) is to LIST the program to disk (or cassette), type NEW, and then use ENTER to bring the program back into memory. As far as BASIC is concerned, the
program is being entered by hand for the first time. This information is important to remember for Examples 8 and 9 in which the string manipulation is used.

The next 6 bytes in the table are paired as low and high bytes. This means the second byte is multiplied by 256 and added to the first byte to get the proper (16 bit) value. Bytes 3 and 4 in the table give the "offset" from the beginning of the string/array area (where the string data and array data are actually stored). This area, located elsewhere in memory, can be pinpointed by a PEEK into a pair of memory locations called STARP (for string/array pointer):

\[
\text{STARP} = \text{PEEK}(140) + \text{PEEK}(141) \times 256
\]

Offset refers to the number of bytes from the beginning of the string/array area to where the string's data is stored. A$'s contents are at the beginning of this area, and B$'s contents have an offset of 25 (which also happens to be the reserved length for A$ when A$ is DIMensioned). This offset value is what will give us vertical control over our players!

Bytes 5 and 6 contain the current length of the string, and bytes 7 and 8 contain the DIMentioned values for the string, or the number of bytes reserved for the string in the string/array area.

By changing the offset value in bytes 3 and 4, we can switch the area in RAM where the data for a specific string will be stored. In our next program, this offset value for the first entry in the variable value table is changed so the first string coincides with the RAM for Player 0. This means if something is stored in this relocated string, it will appear on the screen as a player! If we fill the string with zeroes (ATASCII 0), the image in the player will be erased! By using normal string manipulation techniques, BASIC is forced to move the player image up and down at machine language speeds! Later, in the next chapter, we will introduce some machine language routines to do the same thing a little more efficiently.

Moving an Object Through a String

Once the string is relocated over the player RAM, how is an object or character moved up and down? The technique used in upcoming Example 8 allows the player to jump from one vertical position to any other in one move. This ability is essential for fast action games. A temporary string buffer (BUFFER$) is used which is the same size (in bytes) as the RAM for one player (128 bytes). Another string of the same length (BLANK$) contains 128 blank characters (ATASCII 0, not space characters). PLR0$ is the string which has been moved to player RAM. There are four steps executed each time the player is moved vertically:

1. Obtain the player’s new vertical position in a variable called YPOS.
2. Fill BUFFER$ with blanks:

\[ \text{BUFFER$} = \text{BLANK$} \]

3. Move the player image, stored in FRAME$, into the proper vertical position in BUFFER$. FRMSIZE is the number of bytes contained in FRAME$:

\[ \text{BUFFER$} (\text{YPOS}, \text{YPOS} + \text{FRMSIZE} - 1) = \text{FRAME$} \]

4. Move BUFFER$ to the player RAM area where its contents will be immediately displayed. This step also erases the old player sinceBUFFER$ is filled with blanks as well as the player image:

\[ \text{PLRO$} = \text{BUFFER$} \]

This isn't the only possible method of player movement that uses string manipulation, but it has a number of advantages over the others. By employing the two 128-character strings, BUFFER$ and BLANK$, we give up 256 bytes of memory and gain animation speed. Storing blanks in BLANK$ saves time when erasing the old frame information in BUFFER$ (step 2), and thus a manual clearing of BUFFER$ isn't necessary. Since the old player is automatically erased at the same time the new player is moved to the screen (step 4), there is no screen flicker and the computer doesn't have to remember the player's old position.

This method also makes it very simple to add another step which stores new frame information in FRAME$. This provides a rapid means of animating a figure.

If the program you are designing only required the player to be moved up and down in single steps rather than in random jumps, it would be possible to eliminate step 2 and combine steps 3 and 4 so FRAME$ is moved directly into PLRO$:

\[ \text{PLRO$} (\text{YPOS}, \text{YPOS} = \text{FRMSIZE} - 1) = \text{FRAME$} \]

It would be necessary to include one blank space at the beginning of the frame and one at the end so the player would erase itself as it moved. Otherwise, a vertical trail of player pieces would be seen as the frame is moved up and down the screen.

**Moving a Player Diagonally**

Diagonal motion is simple once horizontal and vertical player motion is understood. It is achieved by combining a number of horizontal
and vertical moves. One horizontal move to the left and one vertical move up results in a diagonal move towards the upper left.

7.3. PLAYER PARAMETERS

Each player has a number of parameters which can be independently controlled. In addition to its motion, the player’s color and width can be specified. Also, a player can be given a priority to determine whether it will be displayed in front of or behind a specific playfield. Lastly, there is a way to easily determine when a player has a collision with another player or a playfield!

Selecting Player Color

The color of each player can be independently controlled through the use of its own color register. To change a player’s color, just POKE the color value directly into the appropriate RAM location (704–707 — see Table 7.3). Recall from the last chapter that the color is determined by multiplying the selected hue by 16 and adding in the luminance value:

\[
\text{color} = \text{hue} \times 16 + \text{luminance}
\]

Notice in the following table that each player and its missile share the same color (except when combined to make a fifth player — see upcoming section on Using Five Players).

<table>
<thead>
<tr>
<th>Addresses</th>
<th>ATARI’s Name for it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player-Missile 0</td>
<td>704</td>
</tr>
<tr>
<td>Player-Missile 1</td>
<td>705</td>
</tr>
<tr>
<td>Player-Missile 2</td>
<td>706</td>
</tr>
<tr>
<td>Player-Missile 3</td>
<td>707</td>
</tr>
</tbody>
</table>

Table 7.3: Player-missile color registers (shadow registers.)

These same color registers are also used in GRAPHICS 10 to color the background and three of the playfields. If you use PM graphics in GRAPHICS 10, you will have to be careful that the player doesn’t rest on one of these colors, or it will seem to disappear! However, in
Graphics 9 and 11, you will be able to display 20 different colors on the screen at once when using PM graphics.

Unfortunately, unless special machine language routines are used (along with display list interrupts — see Chapter 9), each player can only be shown in one color. Although PM graphics greatly increases animation speed and simplicity, there is a loss of color detail, and this is its major drawback. (See the section on Enabling Multiple Color Players.)

Selecting Player Width

Each player can appear on the screen in one of three sizes: single width, double width, and quadruple width. In double width, for example, each bit in the player definition controls two adjacent pixels instead of one. In the following figure, you can see how our player ball would look in these different sizes.

![Figure 7.6: Example of different player widths.](image)

Table 7.4 show the addresses of the four player width registers.

<table>
<thead>
<tr>
<th>Player 0</th>
<th>53256</th>
<th>D00B</th>
<th>SIZEP0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player 1</td>
<td>53257</td>
<td>D009</td>
<td>SIZEP1</td>
</tr>
<tr>
<td>Player 2</td>
<td>53258</td>
<td>D00A</td>
<td>SIZEP2</td>
</tr>
<tr>
<td>Player 3</td>
<td>53259</td>
<td>D00B</td>
<td>SIZEP3</td>
</tr>
<tr>
<td>All Missiles</td>
<td>53260</td>
<td>D00C</td>
<td>SIZEM</td>
</tr>
</tbody>
</table>

*Table 7.4: Player-missile width registers.*
To change Player 2 to double width, execute the following statement:

POKE 53258,1

To change Player 3 to quadruple width, execute

POKE 53259,3

To restore Player 2 to single width (the default when the computer is turned on or SYSTEM RESET is pressed), execute either of the following statements:

POKE 53258,0
POKE 53258,2

**Priority Control**

In most cases, you probably will want your players to appear on top of the background scenery. When this happens, the scenery, which is made up of all the different available playfields and the background color, is always obscured by a passing player. Other effects, however, are possible. For example, the playfields (not the background color) can take precedence over the players. The trees of a dark and dangerous forest could be drawn using playfields. When the walking man then moved across the screen, he would appear to move behind the trees. Or you could make a figure enter a house and watch it pass by the windows. For different effects, a combination of the above could be used. The available priority settings are listed in the following table, where a Pn (as in PO) represents Player n and PFn means Playfield n. To change a priority setting, just POKE the indicated value into memory location 623 (26F Hex), which is called GPRIOR.

---

1Recall that each color register controls the color of a different playfield, e.g., pixels plotted with Color Register 2 are considered to be Playfield 2. This means that in each graphics mode, the number of playfields available is the same as the number of active color registers for pixel plotting (not counting the background register).
<table>
<thead>
<tr>
<th>Bit Number:</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>128</td>
<td>64</td>
<td>32</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Priorities

Set only one of these four bits

1

Fifth Player Enable

Multiple Color Players

1

CTIA modes

0 0

GTIA modes:

GRAPHICS 9 0 1
GRAPHICS 10 1 0
GRAPHICS 11 1 1

<table>
<thead>
<tr>
<th>Value in 623</th>
<th>Priorities of Players and Playfields</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P0 P1 P2 P3 All Playfields</td>
</tr>
<tr>
<td>2</td>
<td>P0 P1 All playfields P2 P3</td>
</tr>
<tr>
<td>4</td>
<td>All Playfields P0 P1 P2 P3</td>
</tr>
<tr>
<td>8</td>
<td>PF0 PF1 P0 P1 P2 P3 PF2 PF3</td>
</tr>
</tbody>
</table>

Table 7.5: Bit values for GPRIOR.

Using Five Players  If you don’t need any missiles but could use an extra player, add a 16 to the value in 623 (if we don’t say Hex, we always mean mean decimal). This will enable a fifth player by assigning all the missiles the same color, which is obtained from Playfield 3 (SETCOLOR 3 or address 711). Note that this mode affects only the color of the missiles — to move this new player horizontally, you must change all the missile registers together (53252 to 53255). Vertical motion can be achieved in the same manner as with the other players.

Enabling Multiple Color Players  Although each Player can have only one color, you can create the appearance of players with two colors by creating a single figure made up of two players. For example, a two-tone tree could be created by making the brown trunk out of one player and the leafy green top out of another (see Example 12 in the next chapter).

A third color can be obtained by enabling a special multicolor player mode. This is accomplished by adding a 32 to the chosen priority value.
from the above table. Now, where Player 0 overlaps with Player 1, their colors will blend to form a third new color — voilà, a three-color figure! The same blending will occur where Player 2 overlaps Player 3. Also note that the top two bits in GPRIOR enable GTIA modes.

**Collision Detection**

When using PM graphics in a game, it might be important to know when one player rams into a wall, or when a missile strikes the opponent’s player. The ATARI Home Computer provides us with a series of 16 Collision Registers that are automatically set when any such collision occurs. These registers are updated every sixtieth of a second, and all collision information remains there until it is cleared by your program.

<table>
<thead>
<tr>
<th>Function</th>
<th>Addresses</th>
<th>ATARI’s Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player 0 to Playfield</td>
<td>53252 D004</td>
<td>POPF</td>
</tr>
<tr>
<td>Player 0 to Player</td>
<td>53260 D00C</td>
<td>POPL</td>
</tr>
<tr>
<td>Player 1 to Playfield</td>
<td>53253 D005</td>
<td>P1PF</td>
</tr>
<tr>
<td>Player 1 to Player</td>
<td>53261 D00D</td>
<td>P1PL</td>
</tr>
<tr>
<td>Player 2 to Playfield</td>
<td>53254 D006</td>
<td>P2PF</td>
</tr>
<tr>
<td>Player 2 to Player</td>
<td>53262 D00E</td>
<td>P2PL</td>
</tr>
<tr>
<td>Player 3 to Playfield</td>
<td>53255 D007</td>
<td>P3PF</td>
</tr>
<tr>
<td>Player 3 to Player</td>
<td>53263 D00F</td>
<td>P3PL</td>
</tr>
<tr>
<td>Missile 0 to Playfield</td>
<td>53248 D000</td>
<td>M0PF</td>
</tr>
<tr>
<td>Missile 0 to Player</td>
<td>53256 D008</td>
<td>M0PL</td>
</tr>
<tr>
<td>Missile 1 to Playfield</td>
<td>53249 D001</td>
<td>M1PF</td>
</tr>
<tr>
<td>Missile 1 to Player</td>
<td>53257 D009</td>
<td>M1PL</td>
</tr>
<tr>
<td>Missile 2 to Playfield</td>
<td>53250 D002</td>
<td>M2PF</td>
</tr>
<tr>
<td>Missile 2 to Player</td>
<td>53258 D00A</td>
<td>M2PL</td>
</tr>
<tr>
<td>Missile 3 to Playfield</td>
<td>53251 D003</td>
<td>M3PF</td>
</tr>
<tr>
<td>Missile 3 to Player</td>
<td>53259 D00B</td>
<td>M3PL</td>
</tr>
</tbody>
</table>

**Table 7.6:** Collision registers for players and missiles.

To determine whether there was a collision, just PEEK into the appropriate collision register. You will have to perform some checks on the value obtained to see what type of collision (if any) occurred. The four right-most bits of the value are used to discover which player or playfield was hit (see Figure 7.7).
Discovering which collisions happened is awkward from within ATARI BASIC since there is no easy way to check selected bits of a byte (no masking of bits). To see if Player 1 collided with Playfield 2, use Table 7.6 to find out which collision register keeps track of all Player 1 collisions with any playfield (it’s 53253). Then use the following statement:

\[ \text{HIT} = \text{PEEK}(53253) \]

If the value in HIT is 4, then the anticipated collision occurred. If the value is 5, then there was a collision with Playfield 2 and Playfield 0 (bits 4 + 1 = 5). The following short program shows how BASIC can be used to translate the value in HIT to collision information. This program will only give accurate results for values of 15 or less.

```basic
10 PRINT "Enter value in HIT: ";
20 INPUT BYTE
30 BIT=8 : 'REM Start with bit 3
40 PRINT "P/PF 3 2 1 0" : PRINT "XXXXOOOO";
50 IF BYTE>=BIT THEN
      BYTE=BYTE-BIT:
      PRINT "1" : GOTO 70 : 'REM Bit is on, print '1'
60 PRINT "0" : 'REM Bit is off, print '0'
70 BIT=BIT/2 : 'REM Next bit
80 IF BIT<1 THEN
      PRINT:
      PRINT:
      GOTO 10
90 GOTO 50
```
Here is a sample run of this program:

```
Enter value in HIT: 5
POKE 3 2 1 0
 0 1 0 1
```

So a value of 5 obtained from a Player-1-to-playfield collision register means that the Player collided with Playfields 2 and 0 since the last time the registers were cleared.

**Clearing the Collision Register**  Some of the addresses for the Collision Registers might look familiar to you. For example, 53248 (Missile 0 to playfield) is also the horizontal position register for Player 0, as we explained earlier. There is really no RAM at the other end of these addresses, however. The RAM addresses just provide an easy way to pass the information back and forth. The custom ATARI chips are designed so they directly receive the information intended for them and will directly provide requested data. They know when the request was in the form of a POKE or a PEEK and respond accordingly, never allowing information to move in the wrong direction. This means you can read (PEEK) information from the collision registers, but the POKE information is always routed to the horizontal position registers. Likewise, you can’t discover the horizontal location of your player by a PEEK into its horizontal position register, or its width by a PEEK into its size register! Furthermore, once a collision value is set, it can’t be cleared by a POKE of zero into the register. The only way to clear a collision register is to POKE any value into RAM location 53278 (called HITCLR):

```
POKE 53278,0
```

All the collision registers will now be cleared to 0.

**Summary**  
Okay — enough theory and explanation. Let’s put this information to use. In the next section we present our Bouncing Ball program, which uses player-missile graphics. With this program as a foundation, you can go on to make dazzling programs using this flexible ATARI feature.

7.4. WATCH THE BOUNCING BALL — USING PM GRAPHICS

Now that you understand how PM graphics work, let’s explore its applications. Example 8 will simulate a bouncing ball. You will be able to enter the initial velocity of the ball and its elasticity coefficient — how
bouncy it will be. The ball (made out of a player) will not only bounce, but will also be displayed using three different frames to give it some added life and allow it to “squash” when it hits.

Graphics Mode and Execution Speed

In many of our player examples, we use GRAPHICS 3 even though PM graphics will work in any graphics mode. You may wonder, “Why GRAPHICS 3? It has such a coarse resolution.” That is exactly why we chose it — coarse graphics means low memory overhead. In fact, no ATARI graphics mode uses less memory than GRAPHICS 3. Okay, you say, but these programs aren’t that long — why conserve memory? Ah . . . do you remember how it’s Antic’s responsibility to gather display information to update the screen? Well, only one microprocessor can use the address and data buses of the computer at any time. So during this update process Antic halts the 6502 CPU and takes control of the buses for its direct memory access (DMA) once for each byte of screen memory. At this time, the 6502 is asleep and can’t do anything, including BASIC program execution or calculations. The more screen RAM used in a particular graphics mode, the more often Antic halts the CPU, and the longer it takes the CPU to do its chores. This entire update process must happen 60 times a second! So, GRAPHICS 3 (or GRAPHICS 2 which uses the same amount of RAM) yields the fastest execution time for a BASIC program, or a program written in any other language, including assembly language.

The same 6502 slowdown occurs when PM graphics are enabled. Antic must fetch information from PM RAM for display. Once enabled, Antic grabs every byte of PM memory during each update of the screen (60 times a second), even if PM graphics are no longer being used. This amounts to 76,800 wasted machine cycles each second — processing cycles during which the 6502 could be doing something better than sleeping! So, remember to disable PM graphics if you no longer need them in your program but do need the increased CPU speed which this can provide (see the next section).

Initializing Player-Missile Graphics

After setting aside a section of RAM for player-missile memory, there are three POKEs which must be executed to turn on player-missile graphics. The first one tells Antic where to find PM RAM. POKE address 54279 with the memory page where PM RAM begins:

POKE 54279, PMPAGE

Next, Antic must be told that it should begin grabbing information from PM memory. This is done through address 559 (22F Hex). ATARI
calls this address SDMCTL (Shadow for Direct Memory Access Control). SDMCTL affects not only PM graphics, but the entire screen display as well. Different bits are used for different purposes as shown in Table 7.7.

<table>
<thead>
<tr>
<th>SDMCTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Number:</td>
</tr>
<tr>
<td>Bit Value:</td>
</tr>
<tr>
<td>Enable Screen DMA</td>
</tr>
<tr>
<td>PM Resolution</td>
</tr>
<tr>
<td>Enable Player DMA</td>
</tr>
<tr>
<td>Enable Missile DMA</td>
</tr>
<tr>
<td>Playfield Width</td>
</tr>
</tbody>
</table>

**Examples**

<table>
<thead>
<tr>
<th>POKE Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Screen, PM graphics off</td>
<td>1 0 0 0 1 0 = 34</td>
</tr>
<tr>
<td>Normal Screen, 2-line PM graphics, Player DMA enabled</td>
<td>1 0 1 0 1 0 = 42</td>
</tr>
<tr>
<td>Normal Screen, 2-line PM graphics, Player DMA enabled, Missile DMA enabled</td>
<td>1 0 1 1 1 0 = 46</td>
</tr>
<tr>
<td>Normal Screen, 1-line PM graphics, Player DMA enabled, Missile DMA enabled</td>
<td>1 1 1 1 1 0 = 62</td>
</tr>
</tbody>
</table>

**Table 7.7:** Bit control of SDMCTL.

Bit 5 enables the direct memory access (DMA) using the display list. This bit is normally on (1). But if you turn it off (0), Antic stops fetching display RAM, the screen displays only the background, and the 6502 is no longer halted by Antic for screen updating. This technique can be used if you need to do some extra number crunching and don’t mind if the computer looks like it’s “out to lunch.” Bit 4 controls whether a one- or two-line PM display is to be used: one-line if the bit is on (1); two-line if the bit is off (0). Bit 3 (when on) enables DMA from Player RAM. Bit 2 (when on) enables DMA from Missile RAM. This means that either players or missiles or both can be used by selecting a combination of bits 2 and 3. Bits 1 and 0 control the width of the Playfield. We will discuss the three playfield widths in Chapter 9. For now, note that bit 1 should be on and bit 0 off for a normal playfield.
Therefore, a POKE of 42 into 559 will leave us with a normal screen, a two-line PM display, and an enabled Player DMA:

\[ \text{POKE} \ 559, 42 \]

Since missiles are not being used, this is the value which is used in all PM programs in this book. It would also be all right to enable missile DMA by a POKE of 46 instead of 42, but this would cause Antic to unnecessarily grab an extra 128 bytes of memory every sixtieth of a second, thus slowing the 6502 just a bit more.

The third POKE gives Antic the go ahead to begin sending player-missile information to GTIA so it can be displayed on the screen. Address 53277 (DD1D Hex), called GRACTL (Graphics Control) by ATARI, uses the bits as indicated in Table 7.8.

<table>
<thead>
<tr>
<th>Bit Number</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>(X = not used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latch Joystick button</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable Player data transfer</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable Missile data transfer</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examples</th>
<th>POKE Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable Players</td>
<td>0 1 0 = 2</td>
</tr>
<tr>
<td>Enable Players, Enable Missiles</td>
<td>0 1 1 = 3</td>
</tr>
</tbody>
</table>

Table 7.8: Bit control of GRACTL.

Bit 2 isn’t used for PM graphics. It causes the joystick buttons (TRIG0-TRIG3) to be latched when this bit is on. This means that the button will act as if it is still being pressed even after you have released it. This is useful in interactive programs — normally, if you don’t happen to check the button at the instant the operator is pressing it, there is no way to tell if it has been pressed. When latched, the button can be checked later and then released by turning off this bit. Bit 1 is used to enable the transfer of player information to GTIA. Bit 0 is used to enable the transfer of missile information to GTIA. Again, you can choose to use either
players or missiles or both. Since missiles aren’t being used in our programs, the value of 2 will be used:

```
POKE 53277,2
```

Player graphics are now enabled and ready to go. Disabling them takes an extra step, however. If there is a player on the screen, setting SDMCTL and GRACTL back to their original values may not make it vanish. (This is because even though no new player information will be sent to GTIA for display, it still has the old player information.) You will need to first move the player off the screen by a POKE of 0 into its horizontal position register, then disabling PM graphics:

```
POKE 53248,0 : REM Move Player 0 to left of screen
POKE 559,34 : REM Disable PM DMA, normal screen display
POKE 53277,0 : REM Disable PM information to GTIA
```

Creating the Frames

Have you ever noticed how cartoons tend to exaggerate life? When a coyote falls off a cliff, he flattens out at the bottom as if he were made of clay. When a rabbit is going to jump over a wall, it will squash down in anticipation of its feat, then stretch out during the jump, and finally flatten when it hits the ground again. These overcompensation techniques add a degree of realism to simple two-dimensional drawings by making them seem more alive. Well, we can do the same thing with a bouncing ball by using three frames: a round ball — for most of the ball’s flight; a vertically elongated ball — immediately before and after impact; and a flattened ball — at impact. (See Figure 7.8.) Don’t laugh at frames two and three until you have seen this program in action. They look silly but they really work as part of the sequence!
Example 8

Exercise  Using player-missile graphics and string manipulation, create a simulation of a bouncing rubber ball. Allow the user to enter values from the keyboard for initial velocity and elasticity to see what will happen. Have the program calculate the positions of the ball using the formula for gravity. Use exaggerated animation to create three different frames. Create a sound effect for the bounce of the ball.
Overview  As with some of our previous examples (and all of
our subsequent examples), most of the code in this program sets every-
thing up for the relatively short main animation loop. You will notice that
we skipped large blocks of line numbers throughout the program; for exa-
mp le, one section is numbered 5000, 5100, 5120, 5130, 5170, 5360.
This was intentional, and in later examples every "skipped" line number
will be filled in as our programs become more complex. For this reason,
it is essential that you enter every line with its given line number in the
remainder of our example programs. Otherwise, there may be a line
numbering conflict and the programs in later chapters may not run
correctly. For the same reason, don't add extra lines, even if they are
REMARKS, into these programs unless their line numbers don't end in 0.

![Figure 7.9: Listing of Example 8 — lines 10–130.](image)

Heading and High/Low Byte Calculation  First look at line
70. This is where the first entry into the variable value table is made with
string variable PLR0$. This line must be entered before entering any
other line containing variables or the program will not work properly.
Later, the location of the data for this variable will be moved to coincide
with the RAM for Player 0.

The subroutine on lines 100–130 is called when the value of a 16-bit
number, X, needs to be separated into high and low bytes. This is
necessary when the HIBYTE and/or LOBYTE will be put into memory
address by a POKE.

![Figure 7.10: Listing of Example 8 — lines 140–330.](image)
**Initialize**  This section initializes the program’s variables and sends the computer off into four initializing subroutines. On line 150, three variables are DIMensioned — BLANK$ will be used to clear a temporary player buffer; PLR(n) will hold the RAM address of the four players; and HPLR(n) will be set to the address of the horizontal position registers for the four players.

On line 160, an ATARI BASIC trick is used to fill BLANK$ with 128 ATASCII 0 (ATARI ASCII) characters. After the first and last characters of BLANK$ are initialized to CHR$(0), the magic begins with the statement

```
BLANK$(2) = BLANK$
```

destination string  source string

BASIC copies the first character of the source string into the second character of the destination string, then the second character of the source string into the third character of the destination string, and so on. In this way, each character of the string will be copied from the one before until the string is filled! Try this out — it really works!

Line 170 sets the screen to GRAPHICS 3, turns off the cursor and PRINTs a message on the screen. Lines 180–240 call some special set-up subroutines that we will cover next. Lines 300–320 PRINT information on the screen and set the initial VElocity and ELASTICity values. By elasticity, we mean the percentage of the ball’s current velocity which remains when it hits the ground. An elasticity of 0.5 (50 percent) means that the ball maintains half its current velocity and loses the other half every time it bounces. An elasticity of 1.0 (100 percent) is a perfect bouncing ball. It never loses any energy and will bounce forever. The closest to perfect we have seen is about 0.85 (85 percent) for a toy super ball. An elasticity of 0 (0 percent) is a ball that will not bounce at all — it just hits the ground and dies.

**Figure 7.11:** Listing of Example 8 — lines 5000–5370, 20000–20060.
Set Up Memory Locations  

This subroutine reserves memory space (in the form of strings) for the frame data. Line 5100 reads the number of frames used in the sequence (FRAMES = 3), the size of each frame in bytes (FRMSIZE = 7), and the number of players used in this program (NUMPLRS = 1). The data is located on line 20060. On 5120, the variable PLRFRMEM (PLAYER FRAME MEMORY) is set to the total number of bytes necessary to store the frames for each player. Line 5130 sets FRAMEMEM (FRAME MEMORY) to the total number of frame bytes needed for all players.

On line 5170, string memory is reserved for three variables. BUFFER$ is the temporary buffer used in vertical player movement (see earlier explanation in section on vertical player movement). FRAME$ will hold the current frame to be displayed and FRAMEMEM$ holds all frames for every player.

7000 REM Initialize Player-Missile Graphics
7010 TEMP=HEX1040; REM Set side Player-Missile area
7020 PMBASE=54279; TEMP: REM Tell ANTIC where PM RAM is
7030 PMBASE=75406; TEMP: REM Find PM Base address
7040 FOR I=3 TO 3
7050 PLR0=PMBASE+12H*I:512; REM Set addresses for Players
7060 XPLR=50240H: REM Horizontal Player Position registers
7070 NEQ 7
7080 POKE 359402; REM Set PM 0 line resolution, Players enabled
7090 POKE 7541H:161+HI; REM Color ball green
7100 POKE 50377;31 REM Enable Player display
7120 RETURN
7120 REM

Figure 7.12: Listing of Example 8 — lines 7000–7130.

Initialize Player-Missile Graphics  

In this section, memory is reserved for the players, and PM graphics are enabled. As we mentioned before, it takes extra work on Antic's part to move the information in player RAM to GTIA for display on the screen. When PM graphics are turned on, the 6502 is slowed down just a bit more.

Line 7010 reserves four pages of memory for the player and four pages for the screen. GRAPHICS 3 only occupies 240 bytes of memory so why use four pages for screen RAM when only one is necessary? Recall that PM RAM must begin on an even 1 K boundary (in double-line mode). If necessary, the wasted memory could be used for storage of frame information or other data.

Line 7020 tells Antic where to find PM RAM by placing the starting memory page number (TEMP) in 54279 (D407 Hex). The actual RAM address of PM RAM is calculated and stored in PMBASE in line 7030.

In lines 7040–7070, two arrays are initialized. PLR (I) holds the RAM address for Players 0 through 3 (see Figure 7.4). HPLR (I) holds the address of the horizontal position register for each player.

In line 7080, SDMCTL, address 559 is initialized and Antic begins DMA (direct memory access) from player RAM. A POKE of 42 into 559
leaves us with a normal screen, a two-line PM display, and enabled player DMA (but no missiles).

In line 7100, Antic starts sending player information to GTIA so it can be displayed on the screen when GRACL., 53277, is POKEd with a 2.

Figure 7.13: Listing of Example 8 — lines 9000–9080.

**Point PLRO$ to Player 0 RAM** Here is where BASIC is tricked into moving a string variable to coincide with Player 0 RAM. In lines 9010–9020 the locations of the string/array area and the variable value table are calculated. In 9030 the number of bytes from the beginning of the string/array area to the start of Player 0 RAM is stored in OFFSET. Line 9040 uses the HI/LO byte subroutine on OFFSET so these values can be POKEd into the variable value table and the first variable in the program is now relocated! See the earlier section “Moving a Player Vertically With BASIC” for more information on this technique.

Figure 7.14: Listing of Example 8 — lines 10000–10140, 21000–21060.

**Read in Frame Data** This loop reads the frame data for the bouncing ball into the string FRAMEMEM$. Each BYTE is converted to a character with CHR$. 

```plaintext
9000 REM Point PLRO$ to Player 0 RAM
9010 START=PEEK(144)+PEEK(145)+1554 REM Start of String Array area
9020 VTTY=PEEK(146)+PEEK(147)+256 REM Start of Variable Value Table
9030 OFFSET=TTY-START REM Calculate offset from String Area to Player 0
9040 X=OFFSET: GO TO 110 REM
9050 POKE VTTY+2,LO BYTIE REM Poke offset of string into Variable Value Table
9060 POKE VTTY+3,HI BYTIE REM This points the first string (PLRO$) to PL00
9070 RETURN
9080 REM
```

```plaintext
10000 REM Read in Frame Data
10010 FOR J=0 TO LENGTH
10020 READ BYTE
10030 FRAMEMEM$=FRAMEMEM$+CHR$ (BYTE)
10040 NEXT J
10050 RETURN
10060 REM
```

```plaintext
21000 REM Frame Data for Bouncing Ball
21010 DATA 0,0,128,128,0
21020 DATA 256,256,64,128,0
21030 DATA 64,0,128,128,0
```

```plaintext
21040 DATA 0,0,128,255,128,0
```
**Move Player 0 to Left of Screen**  This subroutine will move Player 0 off the left side of the screen. This routine will be expanded in later programs.

**Main Animation Loop**  This section controls the movement of the ball on the screen. There is some mathematics involved to calculate the positions of the ball as it is being affected by gravity and its elasticity, but don’t worry about them if you aren’t a math person. Just skim the parts you don’t understand; we promise not to test you later.

On line 410 four constants are initialized. **BOTTOM** is the lowest vertical screen position to which the ball will go and is analogous to the floor. **XPOS** is the starting horizontal position of the ball (off the screen to the left). **TIME** holds the elapsed time from the moment the ball is launched or bounced. **HORIZ** holds the horizontal velocity. This value is constant until the ball begins to roll.

The ball is moved to the left of the screen in 420, and the value of **ELASTIC** is checked in 430. Later, when input is accepted from the keyboard, this line makes sure that if the elasticity is very low, there is at least one bouncing noise when the ball hits the ground.

The important loop begins at 440 with the gravity calculation. The
effect gravity has on the motion of an object can be represented by the formula

\[-16 \times \text{TIME}^2\]

or

\[-16 \times \text{TIME} \times \text{TIME}\]

This shows the acceleration of gravity over time. \(\text{TIME} \times \text{TIME}\) is used rather than the exponent function (\(^\)\) to increase calculation speed. By subtracting the above value from the current velocity (VEL) multiplied by \(\text{TIME}\), the current height of the ball off the ground is obtained:

\[\text{VEL} \times \text{TIME} - 16 \times \text{TIME} \times \text{TIME}\]

This must be subtracted from the value of the ground (BOTTOM) to convert the number to screen coordinates:

\[\text{YPOS} = \text{BOTTOM} - (\text{VEL} \times \text{TIME} - 16 \times \text{TIME} \times \text{TIME})\]

FRMNO, the number of the current frame to be displayed, is set to 1 (the round ball).

In line 450 the YPOS and VEL are checked; if the ball is near the ground and the velocity is high enough, the vertically elongated ball frame is chosen to exaggerate the vertical motion.

Line 460 checks for contact with the ground. If the ball has hit (YPOS will be greater than or equal to BOTTOM), the ball’s VElocity is recalculated by multiplying the current VElocity by ELASTIC. With the initial ELASTICity of 0.8, 80 percent of the current velocity will be conserved and 20 percent lost. \(\text{TIME}\) is set to 0 since as far as gravity is concerned, the ball is first starting out and was thrown by the ground. The frame number is set to 1 unless the velocity is high enough to cause the ball to flatten, at which time it is set to 3.

Line 470 checks to see if the ball is still on the screen. If not, the animation loop is exited, and new values can be entered from the routine starting at 600.

Now that all the values are calculated, the ball will be positioned on the screen. The horizontal position of the player is set in line 480. On 490 the correct frame is transferred from FRAMEMEM$ (where all three frames are kept) to FRAME$. This is the same technique used in the Walking Man program (Example 2) from Chapter 5. Lines 500–520 position FRAME$ at the proper vertical position in player RAM as
described in a previous section, "Moving a Player Vertically With BASIC." The ball is now in place.

In line 530 the horizontal position of the ball (XPOS) is incremented. Line 540 turns on the bounce sound if the ball has just struck bottom and the velocity is high enough. If SNDLAG was set in line 430 (low elasticity), the sound will be heard on the first bounce.

In line 550, TIME is incremented by 0.15 and the loop continues at line 440 if the velocity is greater than 0.5. A different value can be substituted for the 0.15 to simulate the ball bouncing in slow or fast motion. Use a smaller TIME increment to make the ball move in tinier increments (slow motion).

Finally, line 560 will be reached if the velocity of the ball is so slow that it can only roll rather than bounce. HORIZ is decremented to simulate the effect of friction on the ball's horizontal velocity. If the ball is still rolling (HORIZ will be greater than 0), frame 1 is selected, and the program jumps to 470 since the bouncing calculations of 440–460 are no longer needed. If the ball has stopped rolling, the program will fall through to the routine at 600.

```
400 REM Get Parameters for Ball
410 GOSUB 700
420 POKE 75210, REM Turn on cursor
430 PRINT "CLEAR!"; Enter initial velocity: "
440 TRAP 400
450 INPUT VEL
460 PRINT "Enter the ball's elasticity (a number)"
470 PRINT "Enter from 0-9 for more Hit!"
480 INPUT ELASTIC
490 POKE 75211
500 PRINT "!" REM Turn off cursor
520 TRAP 40000
530 GOTO 400
540 REM
```

**Figure 7.17:** Listing of Example 8 — lines 600–690.

**Get Parameters for Ball** This section of the program is executed after every ball finishes bouncing to allow you to enter your own velocity and elasticity values. The ball is moved off the screen in line 610. The TRAP command is used in line 640 to trap any INPUT errors which may occur. If there are any, the program will jump to line 630 and the values can be reentered. In line 670, after executing the "cursor off" POKE, at least one character must be PRINTed before the cursor vanishes. Line 680 turns off error trapping by setting TRAP to a nonexistent line number, and the animation loop is restarted.

**Modifications** Try the following modifications:

1. Experiment with different velocities and elasticities. Try a velocity of 1 and an elasticity greater than 1.0. Did you ever see the Walt Disney movie, *The Absent-Minded Professor*, which is about an amazing
substance called Flubber? This flying rubber gained velocity every time it bounced.

2. Change the constant (16) in the gravity equation (line 440) to simulate a ball falling on a different planet with stronger or weaker gravity.

3. Modify the program so there is a ceiling as well as a floor off which the ball can bounce. Will the ball speed up if you use an elasticity greater than or equal to 1.0?

Commercially Available Games and
Player-Missile Graphics

Almost every action game now appearing on the market includes the use of player-missile graphics. The only exceptions are those games which are straight conversions from computers which don’t have players or sprites (e.g., the Apple II). The use of players usually results in extra color and much smoother action. The game Threshold (by Warren Schwader and Ken Williams of On-Line Systems) is an example of an Apple conversion which doesn’t use PM graphics. As do most conversions, it uses GRAPHICS 8, the closest mode to the Apple’s 280 × 192 screen. The object of the game is to destroy the endless waves of attacking aliens. The first wave is made up of bird-like creatures. The flapping of their wings is achieved with four different frames, much like our Example 1. The motion of the figures and their animation is done with a technique called byte move (or playfield animation). Rather than plotting individual pixels on the screen, entire bytes (8 pixels wide) are rapidly moved into screen memory to create the effect. All the color on the screen is a result of artifacts. Even though the only special ATARI feature used is sound, the game still plays well with more than enough action.

Photo 7.2: These frames are from the game Threshold. (Copyright (c) 1982 by On-Line Systems.)
Another game, Apple Panic (by Olaf Lubeck of Broderbund Software, Inc.), uses a combination of PM graphics and map mode graphics. The object of the game is to avoid and destroy the apples. This is accomplished by pounding holes in the bricks. When an apple walks by, it falls into your trap. Then you must pound the apple on its head with the hammer, driving it into oblivion. The little man is made up of all four players in the single-line resolution mode (thus the different colors). The game uses graphics mode Antic E (also affectionately known as GRAPHICS 7 1/2 by ATARI 400 and 800 programmers). Known as GRAPHICS 15 on the ATARI XL Home Computers, it has the same number of colors (four) and horizontal resolution as GRAPHICS 7 but twice the vertical resolution (160 × 192). The wandering apples were drawn with a technique similar to the one used in Threshold using playfield animation. Each time an apple moves, it is Exclusive ORed (XOR) with the background. When one passes in front of a ladder, rather than temporarily erasing the background, the ladder shows through the apple in the color of the bricks. With this technique, it is not necessary to remember what the background looked like when it needs to be restored.

Photo 7.3: A frame from the game Apple Panic. (Copyright (c) 1982 by Broderbund Software, Inc.)

In ATARI’s PAC-MAN™, each ghost is the chomping PAC-MAN as well as a player. This was accomplished by combining the four missiles into a fifth player. Notice the two lines of GRAPHICS 0 text at the top of the screen.
Summary

ATARI player-missile graphics can be an extremely powerful animation tool. Although somewhat awkward to set up, once implemented in your program, they are capable of effects that would be much more difficult to achieve by other means.

Up to this point in our examples, everything can be accomplished using BASIC programming. In the next chapter, we introduce you to three of our black box machine language routines which enable us to use the ATARI Home Computer’s special features most effectively. Don’t let the words “machine language” scare you away from trying out these examples! Remember, you do not need to understand anything about assembly language or machine language to use our routines. Black box means that all you see are the results without seeing the mechanics of production.
Chapter 8

Using Machine Language Routines In BASIC Programs

We have come about as far as we can with pure BASIC programs, so in this chapter a modification is made to the previous program, Example 8, by adding two machine language routines to it. Wait! Don’t go away! We know we’re talking about something that is terrifying to many BASIC programmers, but believe it or not, machine language routines are not monsters waiting to confuse and befuddle you or erase programs from your disks! We will first introduce you to a couple of very friendly machine language routines that are going to change your attitude permanently. For those of you who speak “assembly,” complete listings of the assembly language source code for these routines are included in Appendix F. As for the rest of you, don’t worry; it’s going to be painless because all of our machine language routines are like black box machines — you don’t need to understand their inner workings to take advantage of them. We will show you how to coax them into your programs and how to feed them parameters so they will do your bidding. In essence, these machine language routines will expand ATARI BASIC by adding new statements that will allow control over some of the most powerful but elusive ATARI features.

Four separate routines are introduced in this chapter, and another two are introduced in Chapter 9. The simplest routine will rapidly fill any portion of memory with a selected byte value. Then we’ll provide you with a routine to move the players to any point on the screen, one to automatically move frame information into the players at a selected rate, and one to assign a horizontal velocity to the players.

8.1. WHAT IS MACHINE LANGUAGE?

Machine language is a series of number codes and memory addresses that the CPU understands as a program. Each code, actually a byte, will cause the CPU to do one tiny task. Because these tasks are so small (it requires a lot of them for anything interesting to happen), machine language is called a low-level language. BASIC, which is really a large machine language program, is called a high-level language because each
of its commands causes the CPU to execute a flurry of its tiny tasks. The main advantage of machine language is its speed of execution. This is essential for fast-action game and graphics. Machine language’s main disadvantage is the amount of effort the programmer must put forth to produce the finished product.

To make it easier for us humans to produce the byte codes of machine language, assembly language was invented. This allows the programmer to write programs using short words called mnemonics, which have more meaning for us than a bunch of numbers would. When the assembly language programmer has completed writing this program, called the source code, it is processed by another program called an assembler. The assembler checks the mnemonics for errors and produces the final product by assembling all the information in the source code into the numbers which the CPU can understand. These number bytes are called the object code, machine code, or machine language and can be directly executed by the CPU when stored in the computer’s memory. Routines, then, are originally a list of letters and numbers that get boiled down to just plain numbers.

Using Our Black Box Machine Language Routines

We keep on stressing how easy it is to use our machine language routines and that they have been designed for programmers who don’t necessarily know assembly language. Once they have been entered into memory, most of our routines use a reserved section of RAM for a parameter table. To talk to the routines or check on their progress, use BASIC PEEK and POKE statements to access this table. To make it easier to remember which table locations do what, their memory locations are assigned to BASIC variable names, and in some cases, to arrays (e.g., to control the horizontal position of Players 0 through 3, we POKE values into table locations stored in array variables HPLR (0) through HPLR (3)).

All of our routines are designed to be as flexible as possible rather than specific to our demonstration programs. This means they will be somewhat longer than other less versatile routines designed for a single application. Our routines do, however, have some limitations — there are bound to be some features which we didn’t include that would be perfect for your dream program. Just think of our routines as some important programming tools to add to your ATARI workshop.

If you are an assembly language programmer, feel free to either modify our routines or to use them as guides for creating your own. The complete source code listings for our routines are found in Appendix F and are also included on our program diskette.
Entering the Routines Into Memory

There are different methods for getting the machine language program into memory. Programs which are pure machine code can be stored in cartridges, diskettes, or cassettes. They are simply loaded in and executed. We will be using a mixture of BASIC and machine language, so two different types of program information must get into memory. For disk owners, it would be a simple task for the BASIC program to pull the machine language routine off the disk and into a reserved section of memory. But what about those cassette recorder owners who aren’t so fortunate? One solution would be to store the machine code bytes as DATA statements in your BASIC program. This way everything is loaded at the same time from disk or cassette. The BASIC program would then POKE each number into consecutive memory locations. There are two disadvantages to this method. If the routine is long, it could take quite a while to POKE each byte into RAM. A more serious problem is that the machine language routine will be occupying precious memory space two times — once as DATA statements (where each number actually takes up seven bytes) and once in its reserved RAM.

ATARI BASIC provides a simple solution. The routine bytes can be stored in strings! Each byte has a value from 0 to 255 and can be converted to a character representation using the CHR$ function. By using the ATARI BASIC ADR function (which returns the address of a string’s data), the machine language routine can be located and executed. The above problems are solved with this technique. The routines are moved into the strings at machine language speed when the strings are initialized, and a byte stored as a character only takes up one byte of RAM rather than seven. In addition, memory for the routines is automatically reserved by BASIC when the string is DIMensioned.

Now, how do we get those bytes into strings? We have written a String Loader BASIC program for you which will read bytes from DATA statements and then stuff them into strings. These strings, complete with line numbers, can be outputted to disk, cassette, or even the screen. It’s a simple task then to merge these saved strings into your BASIC programs. The only real difficulty is that some of the routines are long — the longest two contain about 300 bytes each! There are a few ways to get around entering all these bytes into DATA statements: enter and assemble the source code yourself, talk a quick-typing friend into entering the DATA, or purchase the program diskette from Adventure International.

The listing and explanation of our String Loader program is found in Appendix D. Now would be a good time to enter it so you can convert our first machine language routine, MFILL, into a string. (The data bytes for MFILL are included in the String Loader listing.) MFILL will allow you to rapidly fill a section of RAM of any size with the byte value of your choice. MFILL is used in the rest of our program examples as a utility program, a program designed to make some frequently used function
easier and more efficient. This routine could be replaced with some simple BASIC code, but then it would execute much more slowly.

**Flashing with Memory Fill**

Now for some fun! We will use MFILL in a program called Flash to create some wonderful patterns on your screen. Type NEW and enter the MFILL routine string (created by the String Loader Program, Appendix D) into memory. Use the following commands depending on whether you used the String Loader program to save it on disk or cassette:

ENTER "D:MFILL.STR" (disk)
ENTER "C:" (cassette)

Next, enter the following statements (of course, lines 11610–11620 containing the MFILL string will have just been entered). Since it isn’t necessary to represent the routine’s string characters (line 11620) in our listings, we will indicate where they belong with the phrase "<<Routine String goes here >>" in this and all subsequent programs.

```
REM --- FLASH ---
20 REM Program to demonstrate the Memory Fill Machine Language Routine
40 REM
50 REM Copyright © 1992 by David Fox and Mitchell W. Haite
60 REM
100 REM Initialize
110 GRAPHICS 9
120 GOSUB 1100: REM Store routine
130 SCREEN$=PEEK$(8)+PEEK$(9)+PEEK$(10): REM Address for start of screen memory
140 REM
200 REM Main Loop
210 FOR I=0 TO 255
220 TEMP$=MFILL$SCREEN$: REM Call routine
230 NEXT I
240 GOTO 210
250 REM
14600 REM Routine
14610 REM MFILL$(41)
14620 MFILL$(41): <<<Routine String goes here>>>"
14630 MFILL$=ADR(MFILL$): REM Find address of routine
14640 RETURN
```

**Figure 8.1:** Listing of FLASH.

Go ahead and run the program. Phew! What’s happening? The entire screen immediately begins flashing through all of the characters,
first in normal and then in inverse video. The characters fill the screen so rapidly that it’s difficult to make out each one. Let’s look at the listing and find out why. After the graphics mode in line 110 is chosen, the sub-routine at 11600–11640 is called. This initializes the memory fill routine and discovers its location in RAM by using the ADR function. This address is then saved in the variable MFILL (named after guess what).

In line 130, the address of screen RAM is calculated. This address will correspond to the first byte of screen memory or the upper left corner of the screen. To check this, stop your program and clear the screen. Then POKE a value into SCREEN and watch the corner:

```plaintext
POKE SCREEN, 33
```

You’ll see an ‘A’ appear in that corner because 33 is the position in the ROM character set for ‘A’ (see Chapter 5 on user-defined character sets).

In lines 210–230, a FOR/NEXT loop is used to cycle through all the possible byte values. Line 220 calls the machine language routine and passes it the needed information (parameters). Here is the syntax for using MFILL:

```plaintext
TEMP = USR(MFILL, start, length, byte)
```

The variable TEMP is necessary for proper syntax of the USR function; however, in this case it is a dummy variable (although a value could be passed to BASIC from a routine, we aren’t doing so here). USR is the BASIC function which allows the use of machine language routines. The first value within the parentheses is the address of the routine (MFILL). When USR is used, there must always be an address here. The next three parameters tell MFILL where in memory the filling should start, how many bytes should be filled (length), and what byte value should be used to fill memory. Any parameters after the first one have been established by the routine’s programmer. Here is line 220 again:

```plaintext
220 TEMP = USR(MFILL, SCREEN, 960, I)
    REM Call routine
```

The address of the first byte to be filled is SCREEN, the beginning of screen memory. Since the entire screen is to be filled, the length parameter must equal the number of bytes in screen RAM. By checking Table 5.1, we discover that there are 960 bytes in a GRAPHICS 0 screen. The byte value (I) will be controlled by the FOR/NEXT loop and will cycle through all the possible values. So, this line says “call the machine language routine located at address MFILL and fill the 960 bytes starting at SCREEN with the value in I.” Once the FOR/NEXT loop is completed, it starts over again with 0.
Flashing in Other Graphics Modes  Since GRAPHICS 0 is being used, the values which are filling the screen are interpreted as characters. If you use a different GRAPHICS mode (change line 110), some beautiful and colorful patterns will appear. Use Table 5.1 to determine the number of bytes in screen memory for the mode you are using. Notice that with the higher resolution graphics modes, the screen takes much longer to fill — you can actually see a "curtain" of new colors fall from the top of the screen.

Summary

Now that you have successfully implemented a machine language routine in a program, we can proceed to much more useful and powerful applications. Notice that you never had to understand exactly how the machine language routine worked! Our next goal is to make ATARI's player graphics more accessible and controllable from within BASIC.

8.2. MOVING PLAYERS WITH PMOVER

In this section we will introduce a machine language routine to move a player or players to specific positions on the screen. Since we have already successfully moved players without machine language, you may be wondering, "Why bother?" This routine, the first part of an integrated set of machine language routines, can accomplish certain tasks more rapidly than BASIC and automatically carry them out while your program is executing BASIC statements. The power this places at your disposal will soon become apparent.

Synchronizing the Screen

Aside from all this, a number of other advantages are gained with the use of our next routine, called PMOVER. In the Bouncing Ball program (Example 8), a single, very small player was moved on the screen. When a large player (or even worse, several large players) moves horizontally across the screen, a tearing effect is sometimes observed. This is caused by a synchronization problem between the player's movement and the updating of the screen. To understand how this works, let's talk about how the screen is updated. As we mentioned in Chapter 2, the television picture is actually painted by an electronic beam. The beam starts in the upper left corner of the screen and paints one horizontal scan line to the right. Then it's turned off and returned to the left side of the screen where it paints the second horizontal scan line. There are actually 262 horizontal lines on the screen which need to be painted, 192 of which make up the ATARI playfield. After the 262nd line is painted, the electron beam must return to the upper left corner in preparation for painting the next complete screen. This entire process happens 60 times a
second, which means it takes one-sixtieth of a second to paint each screen frame! (See Figure 8.2.)

Imagine a very tall player being moved horizontally from left to right across the screen. What would happen if this player was moved while the screen was being updated (redrawn by the electron beam)? It is possible that the top half of the player will be in the original position while the bottom half is updated in the new position. Of course, when the beam gets to the top of the screen, the top half of the player will also be updated. But if this happens over and over as the player is moved, it will look like the player is being torn in half (see Figure 8.3).

**Figure 8.2:** Screen updating cycle.

**Figure 8.3:** Tearing of a player during horizontal motion.
Vertical Interrupts

The problem intensifies when two or more players have been combined into one larger player for increased color or resolution. The combined player must appear to move as one player, or it may risk losing its solidity as some parts try to catch up with others. This will happen if we attempt to use BASIC to move them simultaneously. BASIC just isn’t fast enough to allow the perfectly synchronized movement of players. That’s the problem, and here comes our machine language routine to the rescue! The first part of the solution is to execute all horizontal player movements during the period of time (about 1400 microseconds) when the electron beam is returning from the bottom of the screen to the upper corner, called the vertical blank or vertical retrace period. In this way, the players will never move horizontally during a screen update, and the problem of tearing is solved. The second part of the solution is to have the machine language routine move all desired players vertically with one call to the routine rather than a separate call for each player. All players will appear to arrive at their new vertical positions together. Since there is no tearing problem with vertical player movement, the VBLANK (vertical blank) isn’t needed and vertical movement can be executed immediately.

Fortunately, the people who designed the ATARI Home Computer made the first part of this solution easy to implement through the use of the vertical blank interrupt (VBI). During vertical blank, the 6502 is interrupted with whatever it is doing (e.g., calculating the number of peanuts which will fit in a Volkswagen), and the ATARI OS performs all of its updating of hardware registers by grabbing information from shadow registers, reading joysticks and paddles, incrementing the real-time clock, etc. It is possible to add in our own program, which will be executed after the OS does its updating tasks.

In PMOVER we created eight new shadow registers (see Chapter 7 for an explanation on shadow registers), one for the horizontal and vertical position of each player. By POKEing information into these locations, PMOVER is told where to move the players. These shadow registers, however, are ignored until all POKEs have been completed. At that time, PMOVER is called (activated) and told which player or players are to be moved. There are actually two separate programs in PMOVER. One is a normal machine language routine which vertically moves each player to its new position. The other is a vertical blank interrupt routine which will fetch the horizontal position from our shadow register during the next VBLANK and store it in the appropriate player’s horizontal position register. All this happens so rapidly that all the players seem to appear at their new screen locations. In addition to eliminating horizontal tearing, BASIC’s inherent lack of speed is bypassed by avoiding a series
of consecutive calls to the routine to move each player separately. The call to the routine looks like this:

```
TEMP=USR(PMOVER,FLAG)
```

The value in `FLAG` determines which player or players will be moved during the next `VBLANK`. The table below lists the addresses which `PMOVER` uses and the bit values indicating which players are to be moved.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMBASE</td>
<td>0</td>
<td>1024</td>
<td>Start of Parameter area</td>
</tr>
<tr>
<td>PMBAS</td>
<td>0</td>
<td>1024</td>
<td>Page address of Player 0 (hi byte)</td>
</tr>
<tr>
<td>PMBUF</td>
<td>1</td>
<td>1025,1026</td>
<td>Low and High bytes of Player Buffer</td>
</tr>
<tr>
<td>HPLR(0)</td>
<td>6</td>
<td>1030</td>
<td>Player 0 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(1)</td>
<td>7</td>
<td>1031</td>
<td>Player 1 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(2)</td>
<td>8</td>
<td>1032</td>
<td>Player 2 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(3)</td>
<td>9</td>
<td>1033</td>
<td>Player 3 Horizontal Shadow Register</td>
</tr>
<tr>
<td>VPLR(0)</td>
<td>10</td>
<td>1034</td>
<td>Player 0 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(1)</td>
<td>11</td>
<td>1035</td>
<td>Player 1 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(2)</td>
<td>12</td>
<td>1036</td>
<td>Player 2 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(3)</td>
<td>13</td>
<td>1037</td>
<td>Player 3 Vertical Shadow Register</td>
</tr>
</tbody>
</table>

**Bits of FLAG byte**

<table>
<thead>
<tr>
<th>Bit Number:</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>(X = not used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>(X = not used)</td>
</tr>
</tbody>
</table>

**FLAG for Player #:**

<table>
<thead>
<tr>
<th>Examples</th>
<th>FLAG Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move Player 1 only</td>
<td>0 0 1 0 = 2</td>
</tr>
<tr>
<td>Move Players 0, 2 &amp; 3</td>
<td>1 1 0 1 = 13</td>
</tr>
<tr>
<td>Move all Players</td>
<td>1 1 1 1 = 15</td>
</tr>
</tbody>
</table>

Table 8.1: Parameters for `PMOVER`.

All of our machine language routines will be utilizing a parameter table starting at 1024 for shadow registers and to hold temporary values. This memory is normally used by the OS when reading or writing to a cassette recorder (you can’t use your recorder during the execution of these programs). The above table shows only the parameter table entries used by `PMOVER`. The first column contains the variable names we
assigned to each parameter table address. The first three addresses listed in the table are used only during the initialization selection of a program. PARAMBASE is set to the base address of the parameter table (1024), PMBASE will hold the page address (high byte) of Player 0 so PMOVVER knows where the players are, and PMBUF will hold the two byte address of the temporary player buffer. This buffer will be used in much the same way as BUFFER$ in the Bouncing Ball program. When a player is to be moved vertically, all 128 bytes of it are copied into this buffer. Then, using the information in its vertical position shadow register, it is copied back into Player RAM with the appropriate vertical offset. This is the fastest method when the player needs to jump around the screen. Each vertical relocation requires moving 256 bytes of RAM (128 into the buffer from player RAM and 128 out of the buffer back into player RAM). See Figure 8.4.

Figure 8.4: Two methods for moving a player.
An alternate method would be to slide or rotate all of the player's RAM up or down a byte at a time directly within the player's RAM (no buffer). Each vertical step would require the movement of 128 bytes of RAM as each byte moves one position up or down. As a result, this technique executes more rapidly when the player needs to move up or down only one vertical increment. The farther the player must move, the longer it will take, since the player must occupy every intermediate position between its starting location and its destination. The player will appear to slide smoothly to its new position rather than just materializing there. This technique would not work in our Bouncing Ball program, however, as it would take too long for the player to arrive at each new position, and the sliding effect isn’t appropriate.

These two methods are excellent as general-purpose player movers, where the height of the player may not be known. When sliding the player is acceptable and you know exactly how tall the player is, a third technique, mentioned in the last chapter, may be more efficient. This would be to include a blank byte immediately above and below the player object as part of the object. Then, when the object is moved in single steps either up or down, this blank space would erase the object in the original position. We used a similar technique with the falling bomb in Example 4 when the bomb erased itself as it moved down the screen.

The array HPLR(n) holds the addresses of the shadow registers for the horizontal position of Player n and the array VPLR(n) holds the vertical position shadow register for Player n. Here is an example of how PMOVER might be used. If you wanted to move both Players 0 and 1 together, you would add the following to your program (assuming the variables have already been initialized):

```
100 POKE HPLR(0),100
110 POKE HPLR(1),108 : REM Player 1 is adjacent to Player 0
120 POKE VPLR(0),50
130 POKE VPLR(1),50
140 TEMP=USR(PMOVED,3) : REM Move Players 0 and 1
```

Notice that the position of Player 1 is eight steps over from Player 0. Since the players in normal width are eight pixels wide, this will place them adjacent to each other. The two players would appear in their new positions on the next updated screen.
Setting Up Vertical Blank Interrupts

After our routine is in memory, its VBI (vertical blank interrupt) section must be connected to the "plumbing" of the existing ATARI VBI routines. The program flow during the vertical blank period is similar to the flow of water through pipes. To connect additional "fixtures" to the existing pipes, a special sequence of steps must be followed to avoid an accident (water on the floor). Figure 8.5 shows the process of installing our VBI routine into the normal path of the operating system's VBI routines.

Normally, once the OS has completed the updating process, the VBI program goes through a vector (direction sign) called VVBLKD (deferred vertical blank vector), which is located at address 548 and 549 (0224 Hex). (This is indicated in part a) of Figure 8.5.) VVBLKD contains the address of XITVBV (exit vertical blank interrupt, E462 Hex), where there is a simple interrupt termination routine. By placing the address of the VBI section of PMOVED into VVBLKD, the program flow gets rerouted through our program (the new plumbing fixture). When PMOVED has finished its job, it returns the flow to XITVBV (part c) of Figure 8.5.

There is one potential problem at this point. Since we must POKE a two-byte address into VVBLKD, it is possible that a VBI may occur after the POKE of the first byte but before the POKE of the second. This will cause the interrupt routine to shoot off to some unknown part of memory and the computer will crash! As any amateur plumber knows, you must turn off the water or detour it before disconnecting any pipes. ATARI has provided us with a "detour valve" precisely for this purpose. It is called CRITICAL and is found at location 06. Before changing the values in VVBLKD to connect PMOVED, we POKE al into CRITICAL to open the detour pathway (part b) of Figure 8.5). Then, after the connections (POKEs) are completed, CRITICAL is closed by a POKE of 0:

\[13010 \text{POKE CRITICAL, 1: REM Open CRITICAL "value", set up detour}\]

(connect PMOVED to the ATARI VBI routine at this point)

\[13170 \text{POKE CRITICAL, 0: REM Close CRITICAL value, routine installed}\]

Stuffing the PMOVED String

The next step in implementing PMOVED is to enter its byte values into DATA statements, and then run our String Loader program to convert these values into a string. Load the String Loader program into
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Figure 8.5: Vertical blank interrupt pathway.
memory, making sure that the DATA statements from MFILL are deleted. Then add the lines shown in Figure 8.6.

```
26000 REM Player Move Routine DATA
26010 DATA PMOVER,11300,1186,22177
26020 DATA 189,0,167,76,522,2,187,30,4,157,0,2,202,1,287,4,240,1,181,223,157,60
26030 DATA 4,220,208,206,164,184,222,166,5,227,173,326,172,4,4,2,2,2,162,142,4,14,70,224,144,6
26040 DATA 189,0,157,38,4,222,24,4,226,24,4,224,160,4,4,162,0,24,224,172,6,4,153,226,173,1
26050 DATA 4,133,228,172,3,2,133,229,172,3,4,133,226,142,3,4,70,227,176,20,165,223,13,103
26060 DATA 224,200,2,226,225,240,4,208,237,165,226,141,4,4,232,189,84,4,149,224,202,16,248,96
26070 DATA 189,6,4,157,38,4,232,224,4,208,241,140,4,4,162,0,134,224,173,0,4,133,229,173,1
26080 DATA 4,133,228,173,2,4,133,229,173,3,4,133,226,142,3,4,70,227,176,20,165,223,13,103
26090 DATA 224,200,2,226,225,240,4,208,237,165,226,141,4,4,232,189,84,4,149,224,202,16,248,96
```

Figure 8.6: Listing of DATA statements for PMOVER.

Now run the program to create the routine string. We are now ready to use PMOVER in a program.

**Example 9**

**Exercise** Create a version of the previous Bouncing Ball program that uses the machine language routine PMOVER to place the ball at its horizontal and vertical position on the screen. Everything else in this program will remain the same as before.

The Bouncing Ball program, Example 8, will be modified to use PMOVER, so load that program into memory and delete the following lines:

```
160 500 510 7060
```

We will now present the sections of this program which have new or modified lines. Just add to your program the lines which are highlighted. Refer to Figure 8.7.

```
10 REM *** BOUNCING BALL 2 PROGRAM *** Example 9
20 REM
30 REM
40 REM Program to demonstrate Player-Missile Graphics with Machine Language routine to move players
50 REM Copyright © 1982 by David Fox and Mitchell Waite
60 REM
70 REM Initialize
80 GRAPHICS 3
90 POKE 752,210
100 PRINT "One moment please..." REM Turn off cursor, print message
110 GOSUB 11000: REM Initialize Routine strings
120 GOSUB 10000: REM Set up memory locations
130 GOSUB 70000: REM Set up Player area
140 GOSUB 90000: REM Point PLN0 to Player 0 RAM
150 GOSUB 100000: REM Read frames into RAM
160 GOSUB 120000: REM Set up parameter addresses
170 GOSUB 130000: REM Turn on interrupts
180 PRINT "CLEAR***BUNNCINGBALL100000***"
```

Figure 8.7: Listing of Example 9 — lines 10–60, 140–300
**Initialize** Line 150 eliminates the DIMensioning of BLANK $(no longer needed) and adds VPLR (3) for the parameter table entry of the players’ vertical position. Lines 180, 280, and 290 call the added subroutines to initialize, install, and turn on PMOVER.

```
470 IF XPOS>220 OR YPOS=1 THEN 600
480 POKE HPLR(0),YPOS
   POKE VPLR(0),YPOS
490 FRAME=FRAMEMIN+FRAME-1+FRMNO+FRMSIZE:REM Select correct frame
500 PMGR=FRAME:REM Move new frame into Player 0
510 YPOS=YPOS/HORI
520 IF YPOS>BOTTOM AND (VEL+XDFLAG)=0.5 THEN
   SOUND 1,250,10,140:
   SNDXPLAD=0
   SOUND 1,500
```

**Figure 8.8:** Listing of Example 9 — lines 470–540.

**Main Animation Loop** In line 480, the horizontal and vertical positions for the ball are POKEd into PMOVER’s shadow registers and then PMOVER is called. PMOVER is passed the value in P0, which is a 1, to move only Player 0. Since the player has already been positioned by PMOVER, the current frame can be placed directly over the old frame in line 520 without fear of leaving multiple balls in player RAM.

```
700 REM Move Player 0 to Left of Screen
710 POKE HPLR(0)
720 PQMGR=VPLR(0):
730 RETURN
740 REM
```

**Figure 8.9:** Listing of Example 9 — lines 700–740.

**Move Player 0 to Left of Screen** Line 720 calls PMOVER to move the ball off the screen to the left.

```
5000 REM Set Up Memory Locations
5090 READ FRAME,BUFFER+JUMPLOLURES
5100 FRAMEMIN=FRAMES+FRMSIZE
5120 FRAMES=FRAME+FRMSIZE
5130 FRAMES=FRAME+FRMSIZE
5140 DIM BUFFER(128),FRAME+FRMSIZE,FRAME+FRAME
5270 PMOVER=ADRPMOVER
5300 MIFILL=ADR(MIFILL)
5310 BUFFER=ADR(BUFFER)
5340 RETURN
5350 REM
```

**Figure 8.10:** Listing of Example 9 — lines 5000–5350.

**Set Up Memory Locations** Lines 5270–5310 use ADR to find the address of the two machine language routines and the temporary player buffer.
Using Machine Language Routines in BASIC Programs

7000 REM Initialize Player-Missile Graphics
7010 TEMP=PEEK(106)+8 REM Set aside Player-Missile area
7020 POKE 54379,TEMP REM Tell TM AIA where PM RAM is
7030 PMBASE=256*TEMP REM Find PM Base address
7040 FOR I=0 TO 3
7050 PM(I)=FMBASE+'28*It512 REM Set addresses of Player-Missile registers
7070 NEXT I
7080 POKE 559,42 REM Set PM 2 line resolution, Players enabled
7090 POKE 704,12+8*TEMP REM Color ball green
7100 POKE 53277,2 REM Enable Player display
7120 RETURN

Figure 8.1: Listing of Example 9 — lines 7000–7130.

Initialize Player-Missile Graphics

Line 7110 is added to clear out Player RAM with zeroes. Notice that 7060, the line which stored the addresses of the horizontal position registers, has been deleted. The equivalent line appears in a later section.

11000 REM INITIALIZE ROUTINE STRINGS
11100 REM Set PMOVER routine
11110 DIM PMOVER(136>
11120 PMOVER(0)="<Routine String goes here>
11130 PMOVER(9)="<Routine String goes here>
11140 PMOVER(18)="<Routine String goes here>
11150 RETURN
11160 REM Set MFILL routine
11170 DIM MFILL(41)
11180 MFILL(0)="<Routine String goes here>
11190 RETURN
11200 REM

Figure 8.12: Listing of Example 9 — lines 11000–11660.

Initialize Routine Strings

The next three sections are all new to this program. This subroutine places the routine strings into RAM. First, ENTER the saved routine strings for PMOVER and MFILL, then add the lines which are highlighted.

12000 REM Set Parameters for Routines
12100 PARAMBASE=1024 REM Parameter Base address
12120 PMBUF=PARAMBASE+16 REM Address of a 128 byte buffer
12130 FOR I=0 TO 3
12140 BPLRI=PARAMBASE+I REM Player horizontal "shadow" registers
12190 VPLRI=PARAMBASE+I REM Player vertical "shadow" registers
12200 NEXT I
12210 VVELK=540 REM Deferred Vertical Blank Interrupt Vector
12220 CRITICAL=9d REM Critical Flag
12230 PM=41
12240 P1=21
12250 POKE 1104 REM Control bits for the four Players
12260 TEMP=10000000 REM Set aside Player-Missile area
12270 POKE PMBUF.HIBYTE REM Set PM Buf of Player 0 into PMBUF
12280 POKE 53127,2 REM Player display enable
12300 FOR I=0 TO 3
12310 POKE PMBUF.I+512,0 REM Clear parameter area
12320 NEXT I
12330 RETURN
12340 REM

Figure 8.13: Listing of Example 9 — lines 12000–12540.
Set Parameters for Routines  This section initializes the values necessary to support our machine language routines. As we said before, \texttt{PARAMBASE} is the starting address of the memory reserved for the shadow registers and other parameters used by all of our routines. The routines look into \texttt{PMBAS} to learn where Player 0 RAM begins and into \texttt{PMBUF} for the address of the temporary player buffer. In lines 12070–12130, the addresses of the horizontal and vertical shadow registers are initialized. In line 12210, a bit value is assigned to variables \texttt{P0}–\texttt{P3} to make it easier to pass parameters to \texttt{PMOVER}. When \texttt{PMOVER} is called, it is only necessary to include the appropriate \texttt{P} variable:

\begin{align*}
\text{TEMP} &= \text{USR(PMOVER}, \texttt{P0}+\texttt{P1}) \\
\text{TEMP} &= \text{USR(PMOVER}, \texttt{P2}+\texttt{P3}) \\
\text{TEMP} &= \text{USR(PMOVER}, \texttt{P0}+\texttt{P1}+\texttt{P2}+\texttt{P3})
\end{align*}

Line 12240 uses \texttt{MFILL} to clear the entire parameter area to zeroes. If this isn’t done, then the random values in the parameter area could cause the computer to crash.

Line 12250 uses the subroutine at \texttt{110} to calculate the high byte of Player 0’s RAM address and then \texttt{POKES} it into \texttt{PMBAS}. Lines 12260 and 12270 \texttt{POKE} the high and low bytes of the temporary buffer into \texttt{PMBUF}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{example9.png}
\caption{Listing of Example 9 — lines 13000–13210.}
\end{figure}

Install Interrupt Routine  This is the section in which the \texttt{VBI} portion of \texttt{PMOVER} gets patched into the operating system’s vertical blank routines. Notice that in line 13080 the address which is \texttt{POKED} into \texttt{VUBLKD} is actually \texttt{PMOVER+6} and not the starting address of \texttt{PMOVER}. This is to link the \texttt{VBI} portion of \texttt{PMOVER} and not the section which vertically moves the players.

\textbf{Important:}  \textit{You can stop this program with the \texttt{BREAK} key, but make sure you use the \texttt{SYSTEM RESET} button before you try to \texttt{rerun it or list it}!!!} Otherwise, the computer will lock up and will have to be momentarily turned off (thus fully resetting the computer) before it can be used again. The same procedure must be followed for any other program that uses \texttt{VBIs}!
When you run this program, it will look nearly the same as Example 9. Then why all this work if no apparent improvement has been gained? Rather than giving you all of our machine language routines at once, we are allowing you to test each one separately in a program to make sure it works properly! This road testing is a necessary step for the more advanced programs to come.

**Modifications** Try these variations:

1. Turn the Trench program (Example 6) into a real game by adding PM graphics to it and using PMOVER to move the players. Create a crosshairs (gun sight) from one player and an enemy ship from another. Use the joystick to move the crosshairs around the screen.

2. Add some players to the Waterfall program (Example 7). How about a bird or two flying across the sky or a deer drinking from the river?

**Summary**

With the first two machine language routines successfully implemented, we are ready to move on to more exciting applications. In the next section, the power of VBI’s will be put to use to automatically flip through the different frames of an animation sequence for us — a change from the slow and inefficient BASIC loop.

### 8.3. AUTOMATIC ANIMATION WITH ANIMATE

In all of our previous animation programs that included the transfer of frame information from a string to the screen, the current frame had to be calculated and displayed from within BASIC. The frame rates (number of frames per second) that could be achieved with this method are adequate for demonstration programs, but fast-action games might require the rapid transfer of frames for all four players in addition to a variety of other computer activities. It would be nice to be able to turn over this frame flipping task to a background machine language routine while more complicated things were being orchestrated by BASIC. (A background routine is one which is executing independently while the computer is running another program, e.g., BASIC or another machine language routine.) By patching a routine into the vertical blank interrupt routines, a program can be made to automatically carry out a task (like flipping frames) as fast as every sixtieth of a second. This is exactly what our next machine language routine, ANIMATE, can do!

**Revisited by Our Walking Man**

Before explaining how to use ANIMATE, let’s take a look at our subject matter. In the next example, we will borrow our Walking Man from Example 2 and animate him using players. A two-by-three array of characters was needed to represent the man on the screen. This provided
16 bits of horizontal resolution and 24 bits of vertical resolution. Since a player only has 8 bits of horizontal resolution, two players are placed side by side to give us the required 16 bits. However, only 19 of the 24 bits of vertical resolution are used in the character set man, and the remaining 5 are left blank. This wasted space is avoided when converting to players, which can be any number from 1 to 128 pixels (in double-line mode) high. Recall that each player pixel is twice as wide and twice as high as a character set pixel, so a walking man made of players will be four times as large (and four times as coarse) as a character set man.

Below is the frame data for our Walking Man character set. The numbers are the same, but there are now two long strips rather than six small boxes, so the organization of these numbers in a program will be
different. Unfortunately, this means that you will have to type in this data once again when we reach Example 10.

**How ANIMATE Works**

ANIMATE was designed for cyclic animation, animation such as in our Walking Man and Galloping Horse programs which repeat a few frames in a specific order. However, the cycle can be much greater than four or five frames long. Very complex sequences can be produced with much longer cycles. For example, an entire dance could be choreographed using only 20–25 unique frames that are put together in an imaginative sequence. An excellent example of this technique is found in Leo Christopherson’s TRS-80 program called Dancing Demon. In this program, the user can program the demon’s dance to original music by choosing from a selection of 26 tap dance steps. Each of these steps is composed of a few frames from a pool of twenty-two unique frames (see Figure 8.16a). The genius of this program is in the creation of these twenty-two frames — the demon is always unbelievably life-like. Using ANIMATE, the same level of animation can be achieved on the ATARI Home Computer.

![Figure 8.16a](https://example.com/figure816a.png)

*Figure 8.16a: Three of the twenty-two frames for Leo Christopherson’s “Dancing Demon” program. (Copyright © 1979 by Leo Christopherson and 80-NW Publishing Co.*)
Frame Data  ANIMATE requires two types of information. The first is the actual Frame Data (the bytes which define the shape of the figure) and is stored in a string. This data is stored in the manner shown in Figure 8.16b.

![Frame Data Diagram](image)

b)  

**Figure 8.16b:** Frame data for ANIMATE.

Two sets of frame data are represented in Figure 8.6b, set A and set B. A set contains data for all the frames of a figure for one player. In reference to the frame data in Figure 8.15, one set would be the entire left vertical column (all five frames) for Player 0, and another set would be the right column for Player 1. At the beginning of each set of data is stored the frame size of the following frames in that set (19 for our Walking Man data). Each frame of a set must contain exactly that number of bytes. There can be as many sets of frame data in the string as you wish.

Frame List  We call the second type of information a frame list. This is an ordered list of the frames which are to be moved into a player. Figure 8.17 illustrates how frame lists are stored in memory.
The first two bytes of a frame list contain the address of the frame data that is to be used. Then follows the order in which the frames are to be displayed (their animation cycle). For example, our Walking Man uses five frames numbered 1 through 5. The frame list for the man would look like this:

Lo Byte
Hi Byte
1
2
3
4
5
0 (end of list, return to beginning)

The two-byte address points to the first byte of the frame data that will be used for this player. The numbers from 1 to 5 tell ANIMATE the order of the frames to be grabbed from the frame data. There must always be a 0 at the end of each frame list. This tells ANIMATE to return to the first frame indicated in the list (see Figure 8.18).

**Passing Information to ANIMATE**

Unlike PMOVER (which accepts parameters through the USER function and the parameter table), there is only one road through which
ANIMATE receives its parameters — the parameter table. The ANIMATE table entries as well as four read-only addresses are listed in Table 8.2.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITANIMATE</td>
<td>3</td>
<td>1027</td>
<td>Flag to initialize ANIMATE</td>
</tr>
<tr>
<td>RATE (0)</td>
<td>14</td>
<td>1038</td>
<td>Player 0 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE (1)</td>
<td>15</td>
<td>1039</td>
<td>Player 1 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE (2)</td>
<td>16</td>
<td>1040</td>
<td>Player 2 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE (3)</td>
<td>17</td>
<td>1041</td>
<td>Player 3 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>FRMLSTPTR(0)</td>
<td>18</td>
<td>1042,1043</td>
<td>Player 0 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(1)</td>
<td>20</td>
<td>1044,1045</td>
<td>Player 1 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(2)</td>
<td>22</td>
<td>1046,1047</td>
<td>Player 2 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(3)</td>
<td>24</td>
<td>1048,1049</td>
<td>Player 3 Pointer to Frame List</td>
</tr>
</tbody>
</table>

The following addresses are read-only addresses — don’t change their values:

<table>
<thead>
<tr>
<th>Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1086</td>
<td>Player 0 Frame List Position</td>
</tr>
<tr>
<td>1087</td>
<td>Player 1 Frame List Position</td>
</tr>
<tr>
<td>1088</td>
<td>Player 2 Frame List Position</td>
</tr>
<tr>
<td>1089</td>
<td>Player 3 Frame List Position</td>
</tr>
</tbody>
</table>

Table 8.2: Parameters for ANIMATE.

The RATE parameters set the duration in “jiffies” or sixtieths of a second which each frame will remain on the screen. Each player’s frame rate can be changed independently of the others. A POKE of 4 into RATE (0) means that a new frame will automatically be moved into Player 0 every four jiffies (4/60 second, or 15 times a second).

The frame list pointer (FRMLSTPTR) contains the RAM address of the frame list that is to be used for that player. It’s possible to have a large number of frame lists stored in RAM describing various types of motion. Any one of these can be selected simply by a POKE of its address into FRMLSTPTR (n).

INITANIMATE is the address which alerts ANIMATE to change its parameters. The values in RATE(n) and FRMLSTPTR(n) are ignored until all values have been POKEd in. In the meantime, ANIMATE checks the contents of INITANIMATE for your “ready” signal every jiffy. As soon as ANIMATE sees your signal value in INITANIMATE, it goes to work.

The value you POKE into INITANIMATE tells ANIMATE what to do. Table 8.3 contains the bit information for INITANIMATE.
Using Machine Language Routines in BASIC Programs

Begin Animation, Players 0 & 1 = 3
Modify Frame Rate only Players 2 & 3 = 28
Halt All Animation = 0
Resume All Animation = 128

Table 8.3 Bit values for INITANIMATE ready signal.

As in PMOVE, the player or players to be affected are indicated by turning on the appropriate bits (0–3). To tell ANIMATE that it must begin animation with a new frame list, these bit values are used by themselves. Once ANIMATE is happily flipping frames, you may want to change only the frame rate. Using the player bit value by itself will not only change the rate but also will begin the frame sequence from the first one on the list. Adding a 16 (bit 4) to the player bit value will change only the rate. To halt animation for all players, POKE INITANIMATE with a 0. To continue the animation where it left off, POKE INITANIMATE with a 128 (bit 7). To stop a specific player’s animation, POKE its RATE with a 0, then POKE INITANIMATE with 16 plus the player’s bit value:

POKE RATE(1),0 : REM Halt Player 1 only
POKE INITANIMATE,18 : REM Ready Flag - 16+2

ANIMATE is a state machine, a program which looks at its status (value in INITANIMATE) to find out what its supposed to be doing. By a PEEK into INITANIMATE, we can tell whether it has received our new information yet. When ANIMATE has accepted any non-zero information from INITANIMATE, it changes the value in INITANIMATE to 128. When making rapid changes in the parameter table values (RATE and FRMLSTPTR), you should first check the value of INITANIMATE. Problems can appear in a loop with very little or no code between successive table changes. For example, if after a
POKE of 18 (see above) into INITANIMATE, we still find an 18 there (rather than a 128), ANIMATE has not yet received our new parameter table information (or even the message to retrieve that information). If the values in RATE (n) are changed before ANIMATE has a chance to grab them, a synchronization problem could occur between the player's frame rates. (See Example 10, line 710.)

Finally, in most of our programs, we need to discover what frame is currently being displayed in a player. This can be accomplished by a PEEK into FLPO$0 through FLPO$3. Do not POKE information into these locations or ANIMATE will lose track of what frame it's on!

**The ANIMATE Chain of Command**

Now that you have all of the pieces of ANIMATE, let's pull it all together. Figure 8.18 shows how ANIMATE would operate on the Walking Man.

![Diagram](image)

**Figure 8.18:** ANIMATE in action.
During the initialization process in the program, the frame data is POKEd in, making sure that the first byte of each set of player data is the frame size (19 in this case). Then the frame lists are constructed, setting the address of the appropriate set of frame data into the first two bytes of the list. Now, to turn on the Walking Man, all we need to do is:

POKE RATE(0),4 : REM Set Frame Rates
POKE RATE(1),4
POKE FRMLSTPTR(0),POINTER(0) : REM Point to Frame Lists
POKE FRMLSTPTR(1),POINTER(1)
POKE INITANIMATE,3 : REM Begin Animation of Players 0 & 1

The initial frame rate is set to four jiffies per frame, and ANIMATE is given the addresses of the two frame lists which will be used — their addresses are stored in POINTER (0) and POINTER (1). Then the ready flag is set with a 3 (INITANIMATE), and the animation begins!

Even though the frame data is stored in the same sequence as the number of the frame lists, this is not at all necessary. For example, by changing the numbers in the frame list to

5
4
3
2
1
0 (end of list, return to beginning)

the man would appear to be walking backwards! It would be a simple matter to maintain this information in an additional frame list that could then be switched on simply by pointing the frame list pointers (FRMLSTPTR) to it and POKEing INITANIMATE with a 3! This flexibility can save a tremendous amount of program development time.

Installing ANIMATE

As with PMOVER, ANIMATE must also be installed into the ATARI vertical blank interrupt routines. Each of our VBI routines can be joined together in any order, very much like a set of Leggo interlocking blocks. Recall that when PMOVER has completed its tasks, it returns control to the exit point of the ATARI VBI routine. This exit address, XITVBV, is stored in the fifth and sixth bytes (starting address + 4, starting address + 5) of each of our VBI routines. All that is necessary to
patch in another of our VBI routines is to change this exit value from XITVBV to the entry point of the next routine, which is always the seventh byte (starting address + 6). Figure 8.19 shows how ANIMATE is patched in.

![Diagram showing VBLK, PMOVER, ANIMATE connections](image)

**Figure 8.19:** Connecting our VBI routines together.

To patch in another routine after ANIMATE simply POKE its address into the fifth and sixth bytes of ANIMATE.

**Stuffing the ANIMATE String**

Now it’s time to enter the bytes of ANIMATE into the String Loader program so a routine string can be created. Before you begin entering this information, it would be a good idea to LIST the DATA statements from PMOVER into a separate file. To do this, use one of the following commands:

```
LIST "D:PMOVER.DAT",26000,26070  (for disk)
LIST "C:\",26000,26070         (for cassette)
```
Now delete the PMOVER DATA and enter the lines indicated in Figure 8.20. After you have RUN String Loader, we can go on to the next example!

Figure 8.20: Listing of DATA statements for ANIMATE.

**Example 10**

**Exercise** Write a program which uses players to animate our Walking Man from Example 2. Use the ANIMATE routine to automatically flip through the five frames. Accept keyboard entry to control his walking speed: pressing a number from 1 through 9 for the number of jiffies per frame. Single step the man when 0 is pressed.

Again, much of this program is the same as the previous program (Example 9), so load it into memory, and away we go. First, all the lines controlling the Bouncing Ball, relocating a string, and miscellaneous others must be deleted. Delete the following lines.

```
```

In the following sections you’ll only need to enter the lines that are highlighted.

Figure 8.21: Listing of Example 10 — lines 10–80, lines 140–150.
**Initialize** The old line 70 has been replaced because the technique to move frame information into player RAM is being taken over by ANIMATE. Some of the new parameters are DIMensioned in line 150.

```
3000 REM Set Up Memory Locations
3090 READ FRAMES,FRMLIST,FROMFILES
5110 PI=FRAME$=FRAME$+FRMSIZE
5120 FRMLIST$=FRMLIST$+FRMSIZE+BUFFER
5130 TOTFRMLIST$=TOTFRMLIST$+BUFFER
5140 DIM BUFFER$[26][FRMLIST$+(FRMLIST$+TOTFRMLIST$)]
5270 MOVES=ADDR(MOVES)
5300 ANIMATE=ADDR(ANIMATE)
5330 FD$=ADDR(FD$)
5330 FRMLIST$=ADDR(FRMLIST$)
5340 RETURN
5350 REM
```

**Figure 8.22:** Listing of Example 10 — lines 5000–5350.

**Set Up Memory Locations** In line 5110, 1 is added to the value to create space for the frame size byte. In line 5130, the size of one frame list is calculated. In addition to the number of frames, two bytes are needed for the address of the frame data, and one byte is needed for the terminating 0. Line 5140 calculates the total frame list size by multiplying the size of one frame list by the number of players. The string variables for the temporary player buffer, frame data memory (FRAME$) and the frame list memory (FRMLIST$) are DIMensioned in line 5160. In lines 5280, 5320, and 5330, the addresses for the new string variables are determined.

```
7040 FOR H=0 TO 2
7050 PLRI$=PMBASE+128+1+S12: REM Set addresses of Players
7060 POKE 704+H,1616+101: REM Color him peach
7070 NEXT H
```

**Figure 8.23:** Listing of Example 10 — lines 7040–7070.

**Initialize Player-Missile Graphics** Line 7060 is the only new line here. It sets the players to a peach color. Actually the color of Players 2 and 3 are also being set here — that’s fine since they never appear on the screen.

```
10000 REM Read in Frame Data
10010 OFFSET$=0
10020 FRAME$=FRMLIST$+OFFSET$
10030 PPO=1 TO BUFFER
10040 PI=FRAME$+PI
10050 POKE PI,FRAME$+PI
10060 POKE FRAME$+PI,FRAME$+PI
10070 FOR H=1 TO PLRFAMES: REM Frame size at beginning of each set of frame data
10080 FOR H=1 TO FRAMES: REM Frame size at beginning of each set of frame data
10090 FOR H=1 TO FRAMES: REM Frame size at beginning of each set of frame data
10100 FOR H=1 TO FRAMES: REM Frame size at beginning of each set of frame data
10110 FOR H=1 TO FRAMES: REM Frame size at beginning of each set of frame data
10120 NEXT J
10130 NEXT I
10140 RETURN
10150 REM
```

**Figure 8.24:** Listing of Example 10 — lines 10000–10140.
Read In Frame Data

This section has been modified so it begins the frame list set up and POKEs in the frame size at the beginning of each set of frame data. In line 10010, OFFSET2 is a temporary variable, which helps calculate the beginning of the next set of frame data. Line 10030 sets the variable FRAMELIST to the beginning of frame list memory.

The FOR/NEXT loop beginning at 10050 sets up the frame data. FRMDATA(I) in line 10060 points to the beginning of each set of frame data. Later in the program, these values will be used when constructing the frame lists. OFFSET2 is set to point to the beginning of the next set of frame data in line 10070. The frame size is POKEd into the beginning of each set of frame data in line 10080.

Finally, the actual DATA bytes are POKEd into RAM in lines 10090–10110. Notice that in line 10110 a different technique is being implemented than in the last program where the following statement was used:

10110 FRAMEMEM$(J,J) = CHR$(BYTE)

Both lines accomplish exactly the same thing; only the current version executes almost 50 percent faster.

Initialize Routine Strings

Now is the time to ENTER the ANIMATE routine strings from your storage device.
Set Parameters For Routines  In this section the new ANIMATE variables must be initialized (INITANIMATE, RATE(I), FRMLSTPTR(I)). In line 12220, a variable is set to the bit value that will control the first two players (FST2P). This saves having to do this addition in a section where calculation speed is critical.

Figure 8.27: Listing of Example 10 — lines 12390–12520.

Set Up Frame Lists  This new section creates the two frame lists needed in this program. In line 12410, the variable that will hold the beginning address of each frame list (POINTER) is DIMensioned. Lines 12430–12520 create a frame list for each player in use. Line 12440 calculates the beginning addresses of each frame list. (Make sure you use the LET in front of the variable POINTER since it contains the ATARI BASIC reserved work POINT.) The high and low bytes of the beginning of each set of the frame data are obtained (12450) and POKEd into the beginning of the appropriate frame list (12460–12470). Lines 12480–12500 POKE in the frame numbers (1 through 5 in this case), and the terminating 0 is POKEd in on line 12510.

Figure 8.28: Listing of Example 10 — lines 13000–13210.

Install Interrupt Routines  Lines 13110–13130 have been added to point the exit vector of PMOVER to the entry point to ANIMATE (see Figure 8.19).
Figure 8.29: Listing of Example 10 — lines 20000–21200.

**Frame DATA** This section contains the frame data for the Walking Man. Each DATA line contains one 19-byte frame for a single player.

Figure 8.30: Listing of Example 10 — lines 1500–1570.

**Put Frame List Addresses in Parameter Table** This subroutine transfers the addresses in the POINTER array into the appropriate parameter table addresses (FRMLSTPTR(I)).

Figure 8.31: Listing of Example 10 — lines 1000–1090.

**Parameters For Players** This subroutine positions the man on the screen at coordinates PX, PY. First, the subroutine at 1500, which
puts the frame list addresses in the parameter table is called. Then the vertical and horizontal coordinates are POKEd in. On line 1050, the players are set next to each other with Player 0 on the left. Line 1070 calls PMOVE to position the players.

Figure 8.32: Listing of Example 10 — lines 700–790.

Set Frame Rate  This subroutine sets all the frame rates to the value in SPEED. Line 710 checks to make sure ANIMATE has received its last set of information before giving it new information (the value in INITANIMATE is set to 128 when it is finished). Line 760 changes only the frame rate (+ 16).

Figure 8.33: Listing of Example 10 — lines 300–390.

Initialize Revisited  This section prepares the final parameters and variables before entering the main animation loop. The horizontal (PX) and vertical (PY) player coordinates are set in line 330. The subroutine at line 1000 (called in 340) places the man on the screen at this position and calls the 1500 subroutine, which puts the frame list addresses in the parameter table. Line 350 sets a variable (SFLAG, sound flag) to its initial value. This variable is used in the main animation loop to determine during which frames a footstep will be heard. Line 360 initializes ANIMATE, and line 370 sets the frame rates to 4.

In order to accept keyboard information without using an INPUT, the keyboard is opened as a device in 380. Location 754 is an ATARI location used as a key ready flag — if there is anything other than a 255 in it when checked later on, then a key has been pressed.
Main Animation Loop

This section keeps track of the frames so the sound of footsteps can be added. It also enables the computer to accept frame rate information from the keyboard. As we mentioned earlier, parameter table locations FLP0S0–FLP0S3 (RAM locations 1086–1089) are scratch pad addresses used by ANIMATE. They contain the current frame number being displayed for each of the players. By checking the value in 1086 (FLP0S0), we can synchronize the man’s actions with footstep sounds. When frame 2 is being displayed, a heel sound is created and when frame 3 appears, a sole sound is turned on. The variable SFLAG is used so the sound only occurs once during each of the appropriate frames. Otherwise, you would hear a continuous buzz during the slower frame rates (or single stepping) as the sound was constantly being turned on and off. Line 480 checks for a keypress. If the value in 754 is anything other than what we set it to (255), then the following lines are executed. Line 490 accepts the BYTE value of the key which was pressed, converts it to a number from 0 to 9, and location 754 is reset to 255. Then the value in SPEED is checked for low and high error values and corrected. Line 510 calls the subroutine which implements the new frame rate, and the cycle repeats.

Before you run this program, make sure it has been saved to disk or cassette! Now go ahead and run it. At the fastest frame rate (one frame per jiffy), the man is walking so fast that his feet become a blur! While the man is walking along, stop the BASIC program with the BREAK key. Wait a second! The man keeps on chugging away as if nothing happened. This is because our VBI routines are still active and executing. Press SYSTEM RESET before typing anything else, or the computer may lock up requiring you to turn it off and on again.

Modifications

1. Play around with the frame lists. Implement one for a backwards walk.
2. Store both the normal and backwards frame lists in RAM. Modify the
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program so pressing a special key will alternate from a forwards and backwards walk.
3. Use PMOVER to make the man walk across the screen rather than walking in place.
4. Starting with the same BASIC program, create a new set of frame data for a flying bird. After you have successfully gotten the bird to fly in place, use PMOVER to make it fly around the screen. Since the frame flipping is now on automatic, this should not be too difficult. You could even increase the flapping rate as the bird flies upwards and decrease it as it soars towards the ground.

Summary
You now have some very powerful animation tools at your disposal. The drudgery of moving the frames into Player RAM is now a thing of the past. In the next section, one final player machine language routine will be added. This will liberate even more BASIC processing power.

8.4. SETTING A HORIZONTAL VELOCITY WITH AUTOMOVE
The last machine language routine of this chapter, AUTOMOVE, allows us to assign a horizontal velocity to a player. Once this velocity is set, the player will continue to move to the right or left until we stop it or it goes off the screen. To show off this routine, a new four-player-wide animated character, Running Boy, will be introduced.

How AUTOMOVE Works
AUTOMOVE is a fairly simple routine to use. Each player has its own velocity shadow register, MOVERTA(1), and there is a ready flag location called INITAUTOMOVE which is similar in purpose to INITANIMATE. In addition to these addresses, there are four more locations which can be used to discover the current horizontal position of a player (PLR0X-PLR3X), which can also be used for PMOVER. Here are the addresses for AUTOMOVE:
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<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTOMOVE</td>
<td>4</td>
<td>1028</td>
<td>Flag to Initialize AUTOMOVE</td>
</tr>
<tr>
<td>MOVERATE(0)</td>
<td>32</td>
<td>1056</td>
<td>Player 0 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(1)</td>
<td>33</td>
<td>1057</td>
<td>Player 1 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(2)</td>
<td>34</td>
<td>1058</td>
<td>Player 2 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(3)</td>
<td>35</td>
<td>1059</td>
<td>Player 3 Horizontal Velocity</td>
</tr>
</tbody>
</table>

The following addresses are read-only addresses — don’t change their values:

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLRX</td>
<td>38</td>
<td>1062</td>
<td>Player 0 Horizontal Position</td>
</tr>
<tr>
<td>PLR1X</td>
<td>39</td>
<td>1063</td>
<td>Player 1 Horizontal Position</td>
</tr>
<tr>
<td>PLR2X</td>
<td>40</td>
<td>1064</td>
<td>Player 2 Horizontal Position</td>
</tr>
<tr>
<td>PLR3X</td>
<td>41</td>
<td>1065</td>
<td>Player 3 Horizontal Position</td>
</tr>
</tbody>
</table>

Table 8.4: Parameter table for AUTOMOVE.

The velocity is entered as horizontal steps per jiffy, a step being the minimum horizontal distance which a player can be moved (one color clock). If you want the player to move to the right, use a positive number. Use a negative number for movement to the left, and a 0 for no movement. Because you can’t POKE in negative values, add 128 to all velocities (called a bias). This means a value of 127 is 1 horizontal step per jiffy to the left, 128 is stopped, and 129 is 1 horizontal step per jiffy to the right. Here are some more examples:

```basic
POKE MOVERATE(0),128+3 : REM Player 0 moves 3 steps/jiffy to the right
POKE MOVERATE(3),128-5 : REM Player 3 moves 5 steps/jiffy to the left
POKE MOVERATE(1),128 : REM Player 1 is halted
```

Once the values are POKEd in, tell AUTOMOVE you are ready by POKEing INITAUTOMOVE with the bit numbers of the players you wish to move (see Table 8.5).
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<table>
<thead>
<tr>
<th>Bits of FLAG Byte</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bit Number:</strong></td>
</tr>
<tr>
<td><strong>Bit Value:</strong></td>
</tr>
<tr>
<td>Resume Player Motion</td>
</tr>
<tr>
<td>FLAG for Player #1</td>
</tr>
</tbody>
</table>

**Examples**

<table>
<thead>
<tr>
<th><strong>Begin Player Motion</strong></th>
<th><strong>FLAG Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Players 0 &amp; 1</td>
<td>0 0 0 1 1 = 3</td>
</tr>
<tr>
<td>Halt All Motion</td>
<td>0 0 0 0 0 = 0</td>
</tr>
<tr>
<td>Resume All Motion</td>
<td>1 0 0 0 0 = 128</td>
</tr>
</tbody>
</table>

**Table 8.5:** Bit values for INITAUTOMOVE ready signal.

A **POKE** of 0 into INITAUTOMOVE will halt the horizontal motion of all players; a **POKE** of 128 will resume player motion at the last initialized rates:

**POKE** MOV2ERATE(2),131 : REM Player 2 moves 3 steps/jiffy to right
**POKE** INITAUTOMOVE,1 : REM Begin movement with current velocities
**POKE** INITAUTOMOVE,0 : REM Halt all Player movement
**POKE** INITAUTOMOVE,128 : REM Resume movement at old velocity

In practice, a **POKE** of 128 into INITAUTOMOVE is seldom used. The only difference between using a 128 and using the player bit values is that these bit values cause AUTOMOVE to grab new data from the appropriate MOV2ERATE addresses. The 128 option does not check the MOV2ERATE addresses but uses the last values grabbed by AUTOMOVE. It is important to always use the player bits the first time AUTOMOVE is used, so some values are transferred from the MOV2ERATE addresses. As with ANIMATE, you can check the value in INITAUTOMOVE to see whether it has received your last read message. If its value is 128, it has; otherwise wait as we did for INITANI-MATE in line 710 of Example 10.

Note that if PMOVER is called while AUTOMOVE is moving a player, the player will continue its travels from its new horizontal and vertical position. Once a player reaches position 255 or position 0, its velocity and its PLRnX value are both set to 0.

**IMPORTANT:** AUTOMOVE requires PMOVER to be in memory for it to work. AUTOMOVE uses PMOVER to reposition the players on the screen.
Stuffing the AUTOMOVE String

Figure 8.35 shows the DATA statements for AUTOMOVE. Follow the earlier procedure of Listing the DATA for ANIMATE onto a disk or cassette before deleting it.

The Running Boy DATA

Before we go on to the program, here is the player information for the Running Boy. He is 31 bytes high and 32 bits (four players) wide and uses four frames. See Figure 8.36.

![Frame 1 and Frame 2 images]
(continued)
It's difficult to tell from the static pictures, but as the boy runs, his hair bounces up and down. The book *Animation*, by Preston Blair (published by Walter Foster Art Books, Tustin, California), was used again to help create these frames.

**Example 11**

**Exercise** Modify the last program, Example 10, to create a four-player-wide Running Boy. Use AUTOMOVE to smoothly move him across the screen. As before, create the sound of his footsteps and accept frame rate information from the keyboard.

This program is very close to Example 10, so there are no lines to delete and not too many new lines to enter.
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Photo 8.1: Screen photos of Running Boy.

```
10 REM *** RUNNING BOY PLAYER DEMO ***
20 REM
30 REM Program to introduce the AUTOMOVE Machine Language routine and the running boy
40 REM Copyright © 1982 by David Fox and Mitchell Kaitz
50 REM
150 DIM FRAMES,FRMSIZE,NUMFRAMES

Figure 8.37: Listing of Example 11 — lines 10–60, 150.

Initialize Line 150 has some new variables. You already know about MOVEMENT, but MSPEED is new. It will contain the proper horizontal velocity for each frame rate that is entered from the keyboard. If the boy’s feet are moving too fast or too slow for his horizontal velocity, it will look like he’s running on the ice because his feet will be slipping and sliding in relation to the floor. These velocities were determined through trial and error until the boy’s running looked as realistic as possible.

5000 REM Set Up Memory Locations
5010 READ FRAMES,FRMSIZE,NUMFRAMES
5110 FRLSTMEM=FRAMEMEM+FRAMES-1
5120 FRAMESIZE=FRAMEMEM+FRAMES-2
5130 TOTFRMLSTSIZE=FRAMESIZE+3
5140 FRMLSTMEM=FRAMEMEM+FRAMESIZE+3
5160 DIM BUFFER(128),FRAMEMEM,FRMLSTMEM,TOTFRMLSTSIZE
5270 MOVEMENT=ADR(PMOVEMENT)
5300 ANIMATE=ADR(PANIMATE)
5290 AUTOMOVE=ADDR(AUTOMOVE)
5300 NFILL=ADDR(NFILL)

Figure 8.38: Listing of Example 11 — lines 5000–5300.

Set Up Memory Locations Line 5290 assigns the location of AUTOMOVE to the variable of the same name.

11500 REM Set AUTOMOVE routine
11510 DIM AUTOMOVE(74)
11520 AUTOMOVE(0)=<<(Routine string goes here)>>

Figure 8.39: Listing of Example 11 — lines 11500–11520.
**Initialize Routine Strings**  
This is where you can enter the **AUTOMOVE** string into the program from your disk or cassette.

```
12000 REM Set Parameters For Routines
12010 PARAMBASE=1024: REM Parameter Base address
12020 PMBASE=PARAMBASE: REM Hi Byte of PMO Location goes here
12030 PMBASE+PARAMBASE+1: REM Address of a 129 byte buffer
12040 INITKINATE=PARAMBASE+2: REM Initialize Frame Animate routine
12050 INITAUTOMOVE=PARAMBASE+4: REM Initialize Player Automove routine
12070 FOR I=0 TO 3
12080 HPLSR=PARAMBASE+4: REM Player horizontal "shadow" registers
12090 VPLSR=PARAMBASE+5: REM Player vertical "shadow" registers
12100 RATEP=PARAMBASE+14: REM Animate rate "shadow" registers
12110 PMIOSPR=PARAMBASE+16: REM Pointer to Frame List
12120 MOVESX=PARAMBASE+32: REM Horizontal movement for AUTOMOVE
12130 NEXT I
12140 CRITICAL=PARAMBASE: REM Critical Interrupt Vector
12150 PMOVER=PARAMBASE: REM Move Flag
12160 ANIMATE=PARAMBASE: REM Animate Flag
12170 FOR I=0 TO 3
12180 CRITICAL=CRITICAL: REM Close Critical routine
12190 RETURN
```

**Figure 8.40:** Listing of Example 11 — lines 12000–12230.

**Set Parameters For Routines**  
Lines 12050 and 12120 set up the parameter table entries for **AUTOMOVE**. Line 12230 provides us with a single variable which can be used to represent the bit values of all the players for **PMOVER** and **ANIMATE**.

```
13000 REM Install Interrupt Routines
13010 POKE CRITICAL: REM Open CRITICAL "valve", set up detour
13020 POKE PMOVER+4: CUE
13040 POKE VVBLKD+1: REM Set VBLANK vector to PMOVER
13100 POKE VVBLKD+1: REM Set VBLANK vector to PMOVER
13110 POKE ANIMATE+4: CUE
13120 POKE PMOVER+4: CUE
13130 POKE ANIMATE+4: CUE
13140 POKE AUTOMOVE+4: CUE
13150 POKE PMOVER+4: CUE
13160 POKE ANIMATE+4: CUE
13170 POKE CRITICAL: REM Close CRITICAL "valve", routines installed
13200 RETURN
```

**Figure 8.41:** Listing of Example 11 — lines 13000–13200.

**Install Interrupt Routines**  
**AUTOMOVE** is installed by pointing the exit vector in **ANIMATE** to **AUTOMOVE**'s entry address (see Figure 8.19).
Frame Data

Here is the frame data for the Running Boy. Each frame takes up two DATA lines. The first one has 16 bytes and the second has 15.

Figure 8.42: Listing of Example 11 — lines 20000–21490.

Figure 8.43: Listing of Example 11 — lines 1000–1090.
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Film 6

“Walking Man,” MAGI (Mathematical Applications Group, Inc.). This is an example of cyclic animation — these frames of a walking mechanical man can be endlessly repeated to show a continuous walk.

The images, created by artist Chris Wedge, were computed with the MAGI SynthaVision 3-D computer animation system on a Perkin-Elmer 3240 super-minicomputer. The output was filmed on a CELCO CFR 4000 Color Film Recorder. Resolution is 1680 points per line by 1200 lines. Dynamic range is 256 grey levels for each of the red, green, and blue components of the pictures. (Courtesy of MAGI/SynthaVision.)

Parameters For Players

This subroutine POKEs the initial parameter table values for PMOVE. Line 1070 moves all the players to their starting position.

```
300 PRINT "CLEAR:9=RIGHT+H=RUNNING BOY DOWN+T=STOP"
310 PRINT "Press a number from 1 to 9 to control his speed or 0's to single step."
320 FOR I=1 TO 9 STEP 11
330 FOR 1+I TO 6 STEP -11
340 READ TEMP
350 MSPEED=TEMP
360 FOR I=0 TO 255
370 POKE 724+I,255
380 NEXT I
390 NEXT I
```

Figure 8.44: Listing of Example 11 — lines 300–390, 30000–30010.

More Initialize

Line 320 reads the MSPEED DATA into the array. The intermediate variable, TEMP, is used because in ATARI BASIC you can’t directly READ DATA into an array. Line 330 has new PX and PY values because of the boy’s large size. In line 360, ANIMATE is initialized for all the players. Line 370 sets a new initial SPEED.

```
700 REM Set Velocities and Frame Rates
710 IF.peek INIT ANIMATE=128 THEN 710
720 FOR I=0 TO WINDLES-1
730 POKE MPOS=I,128+MSPEED(SPEED)
740 POKE RATE=1+MSPEED
750 NEXT I
760 POKE INIT ANIMATE=16
770 POKE INIT AUTOMOVE=16
780 RETURN
790 REM
```

Figure 8.45: Listing of Example 11 — lines 700–790.

Set Velocities and Frame Rates

This subroutine now sets the new horizontal velocities for each player in addition to their frame rates. Line 730 POKEs the correct value of MSPEED into the MOVE-RATE addresses. Line 760 resets the frame rate for all the players, and line 770 starts them moving across the screen.
Main Animation Loop The only change to this section is line 460, which makes sure the boy is still on the screen. If the horizontal position of Player 0 (determined through parameter table address 1062) is less than the value in PX (10, off screen right), then AUTOMOVE is reactivated by POKEing ALLP into INITAUTOMOVE (the values currently in the MоворАTE registers are used again), and the boy is returned to his starting position with PMOVER.

A rather exotic bug would appear if PMOVER were called before AUTOMOVE on this line; it’s possible to cause the boy to split in half as a separation appears between the four players. This would happen if a key is pressed to change the speed at the proper instant — for example, after Player 1, 2, and 3 have reached position 255 and been sent to 0, but before Player 0 reaches 255. All the players would be given the new velocity. Then, after Player 0 reaches 255 and its velocity is stopped when it gets sent to 0, the other players will still be moving from the recent speed change. PMOVER would then properly position all the players, but three of them will keep moving while Player 0 waits the fraction of a second for AUTOMOVE to be called on the same line. The solution is to write the line as we did with AUTOMOVE before PMOVER.

Go ahead and run the program now. Entering the frame data for the boy was a lot of work, but now you’ll see it was worth it!

If you press the BREAK key while the boy is still on the screen, he will continue running but will not reappear. That’s because line 460 needs to be executed for him to reappear from the left side, and the BASIC program has been stopped.

Modifications
1. Implement AUTOMOVE using the Walking Man data. You’ll have to create a new set of MSPEED values to create realistic motion in relation to his frame rate.
2. Make the boy run backwards. Change the frame lists and the velocity. Don’t forget to make his starting position on the right side of the screen.

Summary

You now have all of our tools to make player graphics easier to use. In the final section of this chapter, we will take these tools and create the animated foreground for our climactic program, the Great Movie Cartoon.

8.5. PLAYER FOREGROUND FOR THE GREAT MOVIE CARTOON

Imagine you own an ion-powered train which can cruise at sub-light speeds or stop on a dime. While traveling through the undeveloped outskirts of a major metropolis, you see cars and trucks speeding by, large green trees, and an occasional resident out for a stroll. Sometimes you choose to stop your train to watch everything move by; other times you enjoy matching the velocities of the inhabitants, or “dragging” with the local automobiles.

![Frame 1 Player 2 Player 3 Data](image)

![Frame 1 Player 2 Player 3 Data](image)

Figure 8.47: Player frame data for cars, trucks, and trees.
In this section we will take everything we know about players and put it together into one program. This program will make use of multi-colored players, double- and quadruple-width players, player priorities, sound effects, keyboard control, and all of the machine language routines introduced so far. This program of foreground objects will later be combined with a background program for the next chapter’s Great Movie Cartoon.

The Cast of Players

In addition to the walking man, this program must display cars, trucks, and trees. Each object will use two players: the cars use two adjacent double-wide players of the same randomly selected color, the trucks use one double-wide player for the cab and a quadruple-wide player for the trailer (both in different colors). Finally, the trees use a brown single-wide player for the trunk and a green quadruple-wide player for the leafy top. However, unlike the walking man, each of these objects has only one frame. Their only form of animation will be their motion across the screen. The frame data for these new objects is in Figure 8.47.
You may be wondering how we can display four objects on the screen, each of which uses two players — don’t we really need eight players? That would be nice, but it’s not necessary. The trick is: never allow more than two objects on the screen at once. Players 0 and 1 are permanently reserved by the Walking Man. Players 2 and 3 are used for the rest of the objects. When a tree is passing by, the street is suspiciously free of cars and trucks. When a truck hogs the road, not a car or tree is in sight. The little man, however, comes and goes as he pleases, regardless of the traffic or foliage.

Overview of the Player Foreground Demo

To understand this program, take the point of view that we are looking out of a window of a moving vehicle. The only thing we can control is our own velocity in relation to the scene on the screen. From time to time, cars, trucks, and trees appear to pass in front of our window. Our point of view can be moved parallel to these objects at different speeds, but always towards the right (the same direction the man is walking). Each object has its own intrinsic velocity in relation to the ground. To simulate this on the screen, our velocity is subtracted from the object’s velocity, and this value is passed to AUTOMOVE for that object. When our velocity is 0, the man (whose velocity is 1) walks past us across the screen. When our velocity is 1, we are moving at the same rate as the man, and he stays framed in our window. This is because our two velocities cancel each other out \((1 - 1 = 0)\). When we increase our velocity beyond 1, the man moves off the screen to the left as we seem to leave him behind.

Trees, on the other hand, have no velocity of their own (of course), so unless our velocity is 0, we pass them by. The velocity of a tree (in relation to our point of view) is calculated by multiplying our velocity by 2 and subtracting the result from the tree’s 0 velocity. This won’t make much sense until the background is added in the next chapter. For now, just accept that this exaggerated velocity will look realistic in the final program.

When a car occasionally appears on the screen, it is also moving in the same direction as we are, but at a velocity of 4. This means that if we are moving at a velocity less than 4, the car will pass us by. Trucks move in the other direction (from right to left) with a velocity of \(-3\). The higher our velocity, the faster the trucks seem to roar across the screen.

Most of the work in this program is handled by our black box

---

1 By using display list interrupts (see next chapter), it would be possible to cause a player to appear on the screen in more than one incarnation at the same time. Different figures would be stacked within a single player, restricting each to a separate horizontal band on the screen.
Using machine language routines. BASIC's job is to handle the orchestration of the program — which object should appear next, calculating the object's velocity in relation to our own, watching when an object leaves the screen, accepting keyboard input, and controlling the sound effects. BASIC is also responsible for setting up the frame lists and POKEing the frame data into memory. Much of the program code has been taken from the previous examples to make it easier for you to enter and understand.

**Example 12**

**Exercise** Using your knowledge of players in conjunction with our machine language routines, create a program which simulates a window looking onto a scene that contains a walking man, tall trees, and roaring cars and trucks. We, as observers, can only change our own velocity in relation to the scene by entering numbers from the keyboard.

![Photo 8.2: Screen photos of man, tree, car, and truck.](image)

First, load the Walking Man program, Example 10, into memory. Then save the DATA statements, lines 20050–21200, onto disk or cassette:

```
LIST "D:MAN.DAT",20050,21200 (disk)
LIST "C:",20050,21200 (cassette)
```
You will add this data into the program later on. Next, load the Running Boy program, Example 11, and delete the following lines:

780  21210–30010

Many of the lines in Example 12 are similar but not identical to lines in Example 11. Others are completely new. We will indicate when a line requires only modification, rather than a total retyping, by placing an asterisk (*) before its line number, in addition to highlighting it.

```
10 REM *** PLAYER FOREGROUND DEMO ***
20 REM
30 REM
40 REM Program using all four Players to create animated foreground
50 REM Copyright © 1982 by David Fox and Mitchell Ware
60 REM
70 GOTO 140
80 REM
90 REM III/Lo Byte Calculation
100 HIBYTE=INT(X/256); REM Calculate High Byte
110 LOBYTE=X-HIBYTE*256; REM Calculate Low Byte
120 RETURN
130 REM Initialize
140 REM

150 DIM PMR[1:16],PLRM[1:16],PMWS[1:3],FRMST[1:3],PLRFHMMEM[1:3],POKEDATA
170 GRAPHICS 3
POKE 756,11
PRINT "One moment please..." REM Turn off cursor, print message
```

Figure 8.48: Listing of Example 12 — lines 10–170.

**Initialize** Some new arrays are introduced in line 150. PMWIDTH contains the addresses of the player width registers. FRMDATA is now DIMensioned in line 5070.

```
5000 REM Set Up Memory Locations
6060 READ OBJI
5070 DIM FRMDATA(OBJI),FRMDATA[1:OBJI],PMWS[1:3],PLRFHMMEM[1:3],POKEDATA
5080 FOR I=1 TO OBJI
5090 READ TEMP; TEMP
5100 FRMS[I]=TEMP
5101 FRMSL[I]=TEMP
5102 KMLBSG[I]=TEMP
5110 POKEDATA[I]=FRMS[I]+FRMSL[I]+KMLBSG[I]""
5120 PMW[1:3]=PMW[I]
5130 PLRFHMMEM[1:3]=PMW[I]
5140 PMW[I]=FRMSL[I]
5150 NEXT I
5160 DIM BUFFER[120],FRMMEM[1:3],FRMST[1:3],TOTFRMLST[1:3]
```

Figure 8.49: Listing of Example 12 — lines 5000–5160.

**Set Up Memory Locations** Line 5060 READs the number of objects being displayed in the program (OBJI). (The tree is considered to be two objects, trunk and top, so there will be a total of five objects.) In line 5070, a number of familiar variables has been converted to arrays, so information on each object can be individually maintained. FRMDATA,
which contains the addresses of the frame data, is now a two-dimensional array. The first dimension, 5, refers to the number of objects, and the second refers to the player numbers (0 to 3) which make up those objects. This reflects a change from Example 11 where there was only one object to animate (the boy). Now FRMDATA can point to the frame data for each player of each object.

The loop from 5080 to 5150 reserves frame data and frame list memory for each of the objects. The Temporary variables in lines 5090 and 5100 are needed because ATARI BASIC can’t directly READ data into an array. Lines 5110-5130 have been modified to include the subscripts (I).

**Initialize Player-Missile Graphics**  
Line 7060 saves the addresses of the player width registers, and 7090 sets the player priority so the players will appear in front of a playfield (see Table 7.5).

**Read in Frame Data**  
The main change in this section is the added K FOR/NEXT loop to read in data for all the objects. Line 10010 initializes OFFSET which will be used to calculate the beginning address of the next frame list. FRAMELIST is turned into an array to maintain the beginning address of the frame lists for each object.
Line 10040 calculates the size of the frame list for object K and adds it to OFFSET.

```
12210 P=1:1
12220 P2=4: P5=8: REM Control lists for the four Players
12230 P=4: P5=8: REM Control lists for the four Players
12240 P=4: P5=8: REM Control lists for the four Players
12250 P=4: P5=8: REM Control lists for the four Players
```

Figure 8.52: Listing of Example 12 — lines 12210–12230.

**Set Parameters For Routines**  The variable LST2P has been added to make it easier to control the last two players (2 and 3).

```
12400 REM Set Up Frame Lists
12410 DIM POINTER(51)
12420 FOR K=1 TO OBJS
12430 FOR I=1 TO FRAMES(K)+1
12440 LET POINTERS(I)=FRAMELIST(K)+1: REM Points to start of each Frame List
12450 LET POINTER(I)=FRAMELIST(K)+1: REM Points to start of each Frame List
12460 LET FRAME(K)=K: REM Frame number
12470 LET FRAME(K)=K: REM Frame number
12480 LET FRAME(K)=K: REM Frame number
12490 LET FRAME(K)=K: REM Frame number
```

Figure 8.53: Listing of Example 12 — lines 12400–12530.

**Set Up Frame Lists**  Again, the main change to this section is the addition of a K FOR/NEXT loop to cover all the objects. In line 12410, POINTERS, the variable which holds the addresses of each frame list, is turned into a two-dimensional array. The first dimension is the number of objects, and the second dimension is the number of players. Since none of the objects use more than two players, a 1 is used for the second number (for values 0 and 1).

```
20000 REM FRAME DATA
20010 REM Number of objects
20020 DATA 5
20030 REM
20040 REM Number of Frames, Frame Size, Number of Players
20050 REM (Walking Man)
20060 DATA 5,4,2
20070 REM (Walking Man)
20080 DATA 1,5,1
20090 REM (Tree Top)
20100 DATA 1,4,1
20110 REM (Tree Top)
20120 DATA 1,3,2
20130 REM (Car)
20140 DATA 1,3,2
20150 REM (Car)
21000 REM Frame data for Walking Man
21010 REM Frame 1, Player 0
21020 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
21030 REM Frame 2, Player 0
21040 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
21050 REM Frame 3, Player 0
21060 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

(continued)
Using Machine Language Routines in BASIC Programs

**Frame Data**
This section has all the frame data of our objects. Now is the time to ENTER the earlier saved data of the man:

ENTER "D:MAN.DAT" (disk)
ENTER "C:" (cassette)

Then go ahead and enter the rest of the lines (the ones which are highlighted). There are no more than 20 sets of numbers on any of the lines. Look at lines 20070–20100, and you'll see why we separated the tree into two objects. Each player in an object must have the same number of bytes for our routines to work properly. Since the trunk has twice as many bytes (52) as the top (26), it would have been necessary to pad the tree top with an extra 26 zero bytes (bytes with a value of 0) to make them equal.

**Figure 8.54:** Listing of Example 12 — lines 20000–22240.
Parameters For Players  This section consists of four subroutines, one to initialize the player information for the men, trees, trucks, and cars. The color, vertical (VPLR) and horizontal (HPLR) starting position, and player width must be set for each object.

Let’s look at the Man subroutine first (lines 1010–1090). After the color is set, another subroutine is called in line 1030, placing the appropriate frame list information into the parameter table. This routine (at 1500) requires two pieces of information: the first player (0 to 3) in which to place the frame data (FRSTPLR) and the number of the OBJECT which is to be used. The first player that the man will occupy is Player 0 (FRSTPLR = 0) and the man is object number one (OBJECT = 1). Line 1040 sets the vertical position for the man. Line
1050 checks to see if the current velocity (SPEED) is 1. If so, then the horizontal position doesn’t need to be set (in line 1060). Since the man also walks at a velocity of one, he will never appear on the screen when we are traveling at this velocity. If he is already on the screen, then line 1060 doesn’t need to be executed again. Line 1060 will position the man either off screen left or right, depending on the current value of SPEED. If our SPEED is 0, the man will pass by our window from the left to the right. If we are moving greater than 1, we will seem to pass the man by and he will move from the right edge to the left. In 1070 a flag is set that will keep the man from appearing on the screen for a random period of time.

The tree section (lines 1100–1190) is very similar. In line 1110, the SPEED is checked for a value of 0. If the tree objects are selected to make their appearance while our velocity is 0, this line sends the program back for another selection. This is because if we are stopped when the tree objects are selected, nothing will happen until we begin moving again. Since the tree has no velocity of its own, it would just stand patiently off screen right until we pass by it. As we mentioned before, only one non-man object can be on the screen at a time, so the stationary tree would keep the cars and trucks away.

Line 1150 calls the subroutine at 1500 twice, once for each of the tree’s objects. The width of the tree players are set in line 1160 with the tree top set to quadruple width. Line 1170 sets a volume flag (VF) so the main animation section will know whether to make a sound or not. We don’t want a roaring tree, so VF is set to 0.

The truck section (line 1200–1280) adds a few variations. In line 1210, the trailer of the truck is assigned a random hue (with a luminance of 10). The cab is always orange to avoid some awful color combinations. In line 1220, notice that the difference between the horizontal position of the two players is 16 rather than 8 as in earlier programs. This is because the cab of the truck will be set to double width (in line 1250). As with the tree, the truck will always emerge from the right side of the screen. In line 1260, the volume flag is turned on (VF = 1), and the pitch of the truck’s roar is set by the sound constant (SCDNS = 180).

Finally, take a look at the car section (lines 1300–1390). In line 1310, the velocity is checked to see if it matches the car’s velocity of 4. If they do match, the two velocities will cancel each other out, and the situation described for the tree with a velocity of 0 will occur. In line 1320, a random color from 0 to 15 is selected along with a random luminosity of either 4 or 8. This is to make sure that in the final program, when the car is traveling over a background with a luminance of 6, the car won’t seem to vanish into the street if the luminance and color values happen to match. In lines 1330 and 1340, the initial horizontal position of the car is set based on the current SPEED to make sure the car appears from the correct side of the screen. In line 1380, the volume flag is turned
on and the sound constant value is set to 40. This will create a higher pitched roar than that of the truck.

```
300 REM Put Frame List Address in Param Table
310 FOR J = 0 TO NUMOBJECT-1
320 POKE FORMS+1+J,FIRSTPLR=J+1
330 NEXT J
340 POKE FORMS+1+FIRSTPLR=J+1
350 RETURN
360 REM
```

Figure 8.56: Listing of Example 12 — lines 1500–1570.

**Put Frame List Address in Parameter Table** This is the subroutine that is called whenever we want to move new objects into the players. As we said before, **OBJECT** selects which object will be used, and **FIRSTPLR** points to the first player that will be filled. The values in the **NUMPLRS** array controls how many players the selected object uses.

```
300 PRINT "CLEAR RIGHT";44 PLAYER FOREGROUND DEMO ***"
310 FOR J = 0 TO 11
320 POKE RATERA+J
330 NEXT J
340 REM Frame rate for walking man
350 POKE RATERA+1: REM Temporary start up condition
360 GOSUB 10001
370 GOSUB 10002
380 SPEED=-1: REM Temporary start up condition
390 SPEED=1
400 TSMO=SUBPLOT,ALLP
410 POKE INTIMATE,ALLP
420 GOSUB 700
430 OPEN #2:"<E":
440 POKE 754,255
450 REM
```

Figure 8.57: Listing of Example 12 — lines 300–390.

**More Initializing** This section finishes the initialization process. Line 310 places the frame rate for the man players into the parameter table. Note that the frame rate for Players 2 and 3 are still set to 0, as they will be throughout this program. **ANIMATE** will therefore be used for two purposes: to automatically animate the man and to move new frame information into the other players. In line 320, **SPEED** is temporarily set to -1. This will allow us to set the parameters for both the man and the tree (the first object to pass by our window) in line 330 (remember that both the man and tree parameter-setting subroutines check for "legal" values of **SPEED**). In line 340 the **SPEED** is set to 1, the starting velocity for the program. Line 350 positions all the players to their starting positions, and 360 moves the frames into player memory and starts the man walking (although he is still off the screen). Then the subroutine (starting at line 700) is called, starting the players across the screen.
Set Horizontal Velocities  This part of the program calculates the proper velocities for each of the objects. This routine is called whenever a new object has been selected or when a key is pressed to change the SPEED. Line 710 calculates the new speed (NSPD) for the trees, line 720 for the trucks, and 730 for the cars. As we mentioned earlier, these velocities are obtained by subtracting our velocity from the object’s inherent velocity.

Line 740 places NSPD into the parameter table and sets TEMP to LST2P (last 2 players). The velocity of the man is POKEd into the table in line 750, and then the value of WALK is checked. If it has been set to −1 in the main animation loop, then the man can appear on the screen and TEMP is reset to include the man players. Then, in line 760, AUTOMOVE is started for the players represented in TEMP. An alternate method would be to POKE INITAUTOMOVE once for the man in line 750 and again for the other object in 760. It would then be necessary to add a line 755 to keep checking the value in INITAUTOMOVE until it equaled 128. This would prevent AUTOMOVE from taking the information from line 760 before it was finished with line 750:

755 IF PEEK(INITAUTOMOVE)<>128 THEN 755

The method we chose insures that the velocity of all players will be changed simultaneously.
**Select a New Object**  
This routine randomly selects one of the non-man objects to appear on the screen. It is called whenever the main animation loop discovers that one of these objects has exited the screen. In line 610 and 620, the current VOL une level of the last object to zoom across the screen is checked. If a sound is still turned on (VOL > 0), then it will be gradually faded out. Line 630 uses the _FMILL_ routine to clear out Players 2 and 3 before they receive their new objects. Since the _ANIMATE_ frame rates for these two players is 0, _ANIMATE_ isn’t constantly updating them with new information. If the frame rates were non-zero, _ANIMATE_ would refill the players as soon as they were cleared. In line 640, _FLAG_ receives a number from 1 to 6 which will be used to choose the next object. Yes, we know there are only three possible choices, and we’ll explain what we’re doing in a moment. Line 650 sets _OBJECT_ to 0, so we can use this variable as a flag to indicate whether an object was successfully selected. Line 660 directs the program to the selected subroutine. Notice that the first three line numbers are 1100 (the tree). This means that 3 out of 6 times (50 percent) a tree will be selected. Likewise, the truck will be selected 1 out of 6 times (16.7 percent) and the car 2 out of 6 times (33.3 percent). By changing this line and line 640, a different mix of objects could be created. You could reduce the number of cars and trucks to a very small percentage if you prefer a more rural setting.

If _OBJECT_ is still set to 0 after the selected subroutine has been executed, this subroutine is exited. Otherwise, line 670 moves the new object to its starting position in line 670, and line 680 transfers the appropriate frames into the players. The program then falls through to the routine beginning at line 700 to set the velocities.

```
410 REM Main Animation Loop
420 IF TF THEN
430 IF MATE THEN
440 IF KALE THEN
450 IF PECK THEN
460 IF PECK THEN
470 IF PECK THEN
480 IF PECK THEN
490 GOSUB 700
510 GOSUB 410
530 REM
```

**Figure 8.50:** Listing of Example 12 — lines 400–530.
Main Animation Loop  
Now we come to the main controlling section of the program. This section creates the sound effects, watches to see when an object leaves the screen, and accepts keyboard input for velocity changes. Line 410 sets the value of two sound variables, SND and SND2, using the horizontal position of Player 2 (location 1063). As an object moves across the screen, the value in TEMP decreases from 128 to 0 (at midpoint) and back to 128. This value can be used to raise the pitch of the passing cars and trucks and then lower it again as they go off the screen. Line 420 controls the VOLUME in a similar manner — it increases towards midpoint and fades as the vehicle leaves the screen. Notice that the sound is only turned on if the volume flag (VF) is set to 1.

Line 430 checks the value of WALK, the wait flag which gets set to a random number in line 1070. If WALK is still greater than 0 and SPEED is not 1, WALK is decremented and the program jumps to line 470, skipping the selection that creates the footstep sounds for the man. As soon as WALK becomes equal to 0 and the man can appear on the screen (SPEED < 1), line 440 starts the man moving across the screen, making sure he starts from the proper position, and sets WALK to −1 so this line isn’t executed again until the next man arrives.

Line 450 checks the current frame number of Player 0 to synchronize a footstep to the man’s feet. Line 460 checks the position of the man. If he has moved off the screen on either side, the man is reinitialized starting at line 1050.

If one of the other objects leaves the screen (line 470), a new object is selected in the subroutine beginning at line 600.

Now you may run this program. Have some fun trying to keep up with the man or drag racing with the car. Notice how the truck seems to get shorter as your velocity increases (theory of relativity at work?).

Modifications
1. Animate some of the objects (other than the man) by creating additional frames for them. Try to make the wheels turn, or place a flashing light on top of the car.
2. Add some additional objects — how about a bird, a plane, a differently shaped tree, or a motorcycle?

Commercially Available Software
Using Players and VBI

In addition to player-missile graphics, many commercial games use the vertical blank interrupt to gain more control of the computer. Jaw Breaker, by John Harris of On-Line Systems, uses the VBI to play the game’s musical interludes and to redefine the character set. The object of this game is to move your set of teeth around the maze, munching lifesavers and avoiding the bullies who will knock your teeth out if they
catch you. Eating one of the colorful jawbreakers in the corner will turn the bad guys blue — then you can catch them.

John used ATARI's Music Composer cartridge to create the music, then converted the final music file into data for a VBI routine that plays the notes in a background mode while the action is occurring on the screen. GRAPHICS 0 is used for the playfield, with each lifesaver being a redefined character. The constant redefining of the jawbreaker character during VBLANK means that the colors (artifacts) are always changing in perfect unison. The teeth are made of the four missiles combined into a fifth player. If you manage to eat all the lifesavers, a giant toothbrush will appear to clean your teeth for another round. The toothbrush is made of one quadruple-wide player (the red handle) and one single-wide player (the bristles).

One of the features of this game that makes it stand out from the others in the PAC-MAN genre is the wonderful animations John added to the four bullies (each made of a player in single-line resolution mode). Each one has its own sequence of frames to go through. One's eyes bounce and mouth changes shape (five frames); one spins like a top (eight frames); one rolls like a coin on its edge (eighteen frames); and one flips upside down (twenty-four frames). The frame changing is not under VBI control, but is part of the main program — every time one of the objects moves, a new frame is placed into the player.

Photo 8.3: Screen photo of Jawbreakers. (Copyright (c) 1981 by On-Line Systems.)

In another game, Mouskattack (On-Line Systems), John Harris uses similar techniques. In this game, you are a plumber who must lay pipes in the dreaded Rat Alley. The rats are constantly trying to destroy you and your work, so you must move fast. In this game, there can be two people playing at the same time. The plumber or plumbers, represented as a hard hat(s), and the rodents are made of players. The inadequate mouse traps that you can lay, the pipes, and your two timid helper cats are made of GRAPHICS 0 redefined characters. The animation isn't quite as clever
as in Jawbreakers. The rats stomp their feet up and down as they run after you, and, when a rat gets you, your hat floats to the ground (using five frames). John did, however, do a splendid job with the sound effect of laying the pipes. The clank sound, and all other sounds, are under VBI control.

Summary

You have now graduated from player-missile graphics class and are ready to tackle some exciting games. However, before you go too far, there are two more special ATARI features we'll be introducing you to in Chapter 9, fine scrolling and display list interrupts. Using these techniques, you'll be able to create a moving background that would be the envy of any cartoon animator! Then, all the techniques discussed in this book will be combined into our grand finale, the Great Movie Cartoon.
Creating A Scrolling Background

In the golden years of film animation, companies like Walt Disney Productions perfected the art of fluid and realistic motion for their characters and paid painstaking attention to the quality of the background scenery for their cartoons as well. The results were imaginary worlds which irresistibly pulled us in to share in their fantasies. To achieve this level of reality, Disney invented a large machine called a *multiplane*. This enabled artists to create complicated backgrounds consisting of up to six layers, each positioned at a different distance from the camera. As the characters in the foreground moved along, the backgrounds were scrolled behind them, each layer at a different rate, with the furthermost ones moving the most slowly as governed by the laws of perspective. The multiplane produced breathtaking results, but the dozen operators necessary to run it plus the tremendous production costs required to feed it multilevel backgrounds caused this marvel of technology to finally take up residence in the museum.

In today's cartoons, backgrounds usually consist of only one level which is moved behind the characters as they walk or drive along. This succeeds in creating the feeling of movement, but through a very flat, two-dimensional world. In this chapter, we will create a moving background for our foreground players of Example 12, bringing back the feeling of depth to animation. Our background has not one, but two levels, and when combined with the three levels of the foreground players in the final program of this book (the Great Movie Cartoon), provides a five-level scene with enough realism to bring on motion sickness if you have a weak stomach!

To give motion to our background, the ATARI feature of fine scrolling will be used. To color the screen with more colors than is normally possible, another feature called display list interrupts is utilized. Both features are implemented through our old friend, the ATARI display list.

9.1. **THE DISPLAY LIST REVISED**

In Chapter 5, we introduced you to the Exploding Bomb program (Example 4), which uses a graphics mode that is only accessible (in the
Creating a Scrolling Background

ATARI 400/800) by modifying the display list (DL). Recall that the DL is actually a program for Antic, the display processor chip. The DL specifies how the screen memory is to be interpreted; what graphics mode is in effect for each horizontal scan line. This enables us to create a screen made up of many different graphics modes. Although that is the primary purpose of the DL, there are some other important features that it can provide.

A GRAPHICS 0 Display List

Besides the specific graphics modes to be used, the display list tells Antic where to find screen RAM and whether to implement fine scrolling or display list interrupts. Different values for each DL instruction specify which functions are in effect. Let's start by taking a look at a normal, no frills display list. Enter and run the following program. It will print out the entire display list for a GRAPHICS 0 screen:

```plaintext
10 GRAPHICS 0
20 DLIST=PEEK(560)+PEEK(561)*256
30 FOR I=0 TO 31
40 PRINT I,PEEK(DLIST+I)
50 NEXT I
```

In Figure 9.1 are the numbers that will be printed out by this program, plus the description of each display list instruction and a picture of the screen showing which mode lines (horizontal band of scan lines which make up one graphics mode line) are controlled by each instruction.

As we explore the function of each of these bytes, refer to Table 9.1. It shows which bits of a display list instruction are used to control the graphics mode that will be in effect and which bits enable the different display list functions.

<table>
<thead>
<tr>
<th>Bit Number:</th>
<th>7 6 5 4 3 2 1 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>128 64 32 16 8 4 2 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Fine Scrolling</td>
</tr>
<tr>
<td>Vertical Fine Scrolling</td>
</tr>
<tr>
<td>Load Memory Scan</td>
</tr>
<tr>
<td>Display List Interrupt</td>
</tr>
</tbody>
</table>

Table 9.1: Display list control bits.
Figure 9.1: GRAPHICS 0 display list.
Because more than one display list function can be implemented with each instruction, calculating the correct value can be confusing. Table 9.2 can be used to figure out what byte value the display list instruction should have. It gives the decimal byte value for all possible mode/function combinations for creating a custom DL. Don’t be overwhelmed by the table’s size; it’s really very simple to use. Just look in the top section (with all the Xs) to find the column which has the combination of features you want to implement, then follow that column down to the bottom section until you find the graphics mode you want to use. The number found at that intersection is the value to use in your display list. Note that some DL instructions are always followed by a two-byte address.

Let’s use this table to decipher the sample display list in Figure 9.1. Starting at the top of the DL, the first byte is a 112. Now, look at the first number column (on the left) in Table 9.2 (pages 342—343). The eighth entry from the top is also a 112. The table’s description says that this instruction creates eight blank horizontal scan lines. Why tell ANTIC to create blank lines? This is to compensate for vertical overscan and to center the playfield on the screen. Look at your GRAPHICS 0 screen, and you’ll notice a black border at the top. These blank lines are displayed on the screen in the current border color. Since the next two instructions in the display list are also 112’s, this border is made up of a total of 24 blank lines (8 blank lines * 3 instructions = 24), which is the standard followed in all display lists. Notice there is also a bottom border. The size of this border is determined by what screen space is left over after all the mode lines have been displayed.

Try the following experiment:

```
10 GRAPHICS 0
20 DLIST=PEEK(560)+PEEK(561)*256
30 REM Change the number of blank scan lines at top of screen
40 FOR I=0 TO 112 STEP 16
50 POKE DLIST,I
60 GOSUB 500
70 NEXT I
80 GOTO 40
90 REM
500 REM Pause loop
510 FOR W=1 TO 10: NEXT W
520 RETURN
```
When this program is RUN, the entire screen will seem to bounce up and down! This is because we are changing the top margin of the screen by changing the value of the first byte of the DL (line 50 in the program). As you can see in Table 9.2, a value of 0 creates one blank scan line, a value of 16 creates two, a value of 32 creates three, etc. Thus a POKE of 0 into this address will decrease the original 24-scan line top border to 17 \((1 + 8 + 8)\). As different numbers are POKEd into the first DL byte, the border will enlarge by one scan line at a time until it is back at 24. Then, the program will loop back to a 17-scan line top border. The remainder of the display list is not changed, so the remainder of the screen that it controls will move up and down in one block. The bottom border will become larger as the top becomes smaller, since the total number of scan lines on the screen always remains constant.

**Coarse Scrolling**

The next byte (number 3) in the DL of Figure 9.1 serves two purposes. First, it alerts Antic that the following two bytes will contain the starting address of screen RAM. This function is called load memory scan (LMS) because it tells Antic to load the address where the scanning of display memory will begin. This byte also tells Antic to display one GRAPHICS 0 mode line. As you can tell from the two tables, a 64 is added to the value of the mode line (a value of 2) to enable LMS. By having more than one LMS instruction in a DL, it is possible to use RAM from totally different parts of memory to make up one screen.

Try the following program:

```
10 GRAPHICS 0
20 DLIST=PEEK(5G0)+PEEK(5G1)*256
30 LMSLO=DLIST+4 : REM Load Memory Scan Low byte
40 LMSHI=DLIST+5 : REM Load Memory Scan High byte
50 SCRNLO=0:
   SCRNHI=0
60 REM Take a Scroll Through Memory
70 POKE LMSLO,SCRNLO : REM Point to new screen
80 POKE LMSHI,SCRNHI
90 SCRNLO=SCRNLO+40 : REM Increment by number of bytes/line
100 IF SCRNLO>255 THEN
   SCRNLO=SCRNLO-256:
   SCRNHI=SCRNHI+1
```

(continued)
When this program is executed, you will see a rapid, vertically scrolling display of numbers and letters. This is called coarse scrolling. When we increment the address of screen memory by 40 (the number of bytes in a line in the current graphics mode), we are constantly changing where in RAM the screen memory is located in increments of one horizontal line of text. You have just taken a visual tour through the entire memory space of your computer! (Use \texttt{GRAPHICS 7+16} instead of \texttt{GRAPHICS 0}, and the moving patterns will become more apparent.)

The visual effect produced by this example will remind you of a \texttt{L1ST} of a \texttt{BASIC} program. However, with a \texttt{L1ST}, the brute force method of moving 960 bytes of information \texttt{through} screen memory is used while coarse scrolling changes two bytes to move the screen window \texttt{over} the information.

This ability to redefine the location of screen RAM is a very powerful feature. By only changing two bytes, we were able to move full screens of text or graphics by our "window into memory." Compare this to the microprocessor intensive method of moving \texttt{each of thousands of bytes of memory} into a fixed screen area! And with a little more effort, we could scroll horizontally instead of vertically. However, coarse scrolling by itself doesn't compare to the beauty of fine scrolling, which we will look at in the next section.

With a slight modification of the above technique, it is possible to have several different screens set aside at once, each with a different animation frame on it. To flip through the frames, just change the fourth and fifth bytes in your display list, and the new screen instantly appears!

\textbf{Stereoscopic ATARI}

Joe Vierra, a student at California State University, Hayward, decided to undertake the task of creating a stereoscopic view on his ATARI. He wrote a Vertical Blank Interrupt routine which flipped between two pages of screen memory every jiffy. He conserved memory by using \texttt{GRAPHICS 6}, a 160 by 96 mode that only uses one Playfield color, which he also changes from red to blue during \texttt{VBLANK}. To draw the two cubes, he used \texttt{BASIC}, which slowed down the process too much for animation. With assembly language, however, it wouldn't be too difficult to create a \textit{spinning} three dimensional object! Following is a screen photo showing his stereo cube.
Notice that where the red and blue lines meet, it appears to be purple. When viewed with red/blue glasses (left eye red, right eye blue), the image takes on real depth (see color insert).

Photo 9.1: Stereoscopic cube by Joe Vierra (see color insert).

Jump on Vertical Blank After the two-byte address indicating the beginning of screen memory comes the rest of the mode line instructions. Since there are 24 text lines in a GRAPHICS 0 screen, we need 23 more GRAPHICS 0 mode instructions (2). Remember that the mode instruction for the first screen line was combined with the LMS instruction.

The last three bytes (numbers 29–31) consist of a special jump instruction (similar to the BASIC GOTO command) plus the beginning address of the DL. This is a jump on vertical blank (JVB) instruction. It tells Antic to wait until the vertical blank period, then jump to the beginning of the display list and continue processing display information. This assures that the processing of the DL will be synchronized with the television display. The address following the JVB instruction (which points to the beginning of the DL) is ignored under normal circumstances. This is because during the VBI, the OS takes the address stored in 560,561 and feeds it to Antic as the start of the next display list. By disabling the OS VBI routines, however, it is possible to jump to a completely different DL to create a rapid flipping between two screens. This technique could be used to create a stereo display by showing the left eye view on the first screen in red lines and the right eye on the other in blue lines. The user would see a relatively flicker free three-dimensional
Creating a Scrolling Background

<table>
<thead>
<tr>
<th>DISPLAY LIST INSTRUCTION CALCULATION AID</th>
</tr>
</thead>
<tbody>
<tr>
<td>H SCROLL (+16)</td>
</tr>
<tr>
<td>V SCROLL (+32)</td>
</tr>
<tr>
<td>LMS (+64)</td>
</tr>
<tr>
<td>DLI (+128)</td>
</tr>
<tr>
<td>Blank 1 Line</td>
</tr>
<tr>
<td>Blank 2 Lines</td>
</tr>
<tr>
<td>Blank 3 Lines</td>
</tr>
<tr>
<td>Blank 4 Lines</td>
</tr>
<tr>
<td>Blank 5 Lines</td>
</tr>
<tr>
<td>Blank 6 Lines</td>
</tr>
<tr>
<td>Blank 7 Lines</td>
</tr>
<tr>
<td>Blank 8 Lines</td>
</tr>
<tr>
<td>Jump</td>
</tr>
<tr>
<td>Jump Vrt Blnk</td>
</tr>
<tr>
<td>GRAPHICS 0</td>
</tr>
<tr>
<td>Antic 3</td>
</tr>
<tr>
<td>Antic 4(^1)</td>
</tr>
<tr>
<td>Antic 5(^2)</td>
</tr>
<tr>
<td>GRAPHICS 1</td>
</tr>
<tr>
<td>GRAPHICS 2</td>
</tr>
<tr>
<td>GRAPHICS 3</td>
</tr>
<tr>
<td>GRAPHICS 4</td>
</tr>
<tr>
<td>GRAPHICS 5</td>
</tr>
<tr>
<td>GRAPHICS 6</td>
</tr>
<tr>
<td>Antic C(^3)</td>
</tr>
<tr>
<td>GRAPHICS 7</td>
</tr>
<tr>
<td>Antic E(^4)</td>
</tr>
<tr>
<td>GRAPHICS 8</td>
</tr>
</tbody>
</table>

All values are in decimal.
An X means the optional function is turned on.

\(^1\)GRAPHICS 12 on the ATARI XL Computers
\(^2\)GRAPHICS 13 on the ATARI XL Computers
\(^3\)GRAPHICS 14 on the ATARI XL Computers
\(^4\)GRAPHICS 15 on the ATARI XL Computers

NOTE: GTIA makes 9, 10 and 11 use GRAPHICS 12 values as controlled by GPRIOR (623) — see Table 7.5.

### Table 9.2: Display list instruction calculation aid.
<table>
<thead>
<tr>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>Horizontal Scrolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Vertical Scrolling</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Load Memory Scan (3-byte instr)</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Display List Interrupt</td>
</tr>
</tbody>
</table>

- Blank Horizontal
- Scan Lines for
- Top Border

<table>
<thead>
<tr>
<th>Jump (3-byte instruction)</th>
<th>Jump &amp; wait for Vertical Blank (3-byte instruction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>146 162 178 194 210 226 242</td>
<td>Character Mode Instructions</td>
</tr>
<tr>
<td>147 163 179 195 211 227 243</td>
<td></td>
</tr>
<tr>
<td>148 164 180 196 212 228 244</td>
<td></td>
</tr>
<tr>
<td>149 165 181 197 213 229 245</td>
<td></td>
</tr>
<tr>
<td>150 166 182 198 214 230 246</td>
<td></td>
</tr>
<tr>
<td>151 167 183 199 215 231 247</td>
<td></td>
</tr>
<tr>
<td>152 168 184 200 216 232 248</td>
<td></td>
</tr>
<tr>
<td>153 169 185 201 217 233 249</td>
<td></td>
</tr>
<tr>
<td>154 170 186 202 218 234 250</td>
<td>Map Mode (Pixel) Instructions</td>
</tr>
<tr>
<td>155 171 187 203 219 235 251</td>
<td></td>
</tr>
<tr>
<td>156 172 188 204 220 236 252</td>
<td></td>
</tr>
<tr>
<td>157 173 189 205 221 237 253</td>
<td></td>
</tr>
<tr>
<td>158 174 190 206 222 238 254</td>
<td></td>
</tr>
<tr>
<td>159 175 191 207 223 239 255</td>
<td></td>
</tr>
</tbody>
</table>
display by viewing the screen with a pair of red/blue glasses (see box). Of course, there’s no reason to stop with only two screens — the second DL could jump to a third DL (which could jump to a fourth, etc.) before returning to the beginning of the first one to close the loop.

That’s all there is to a GRAPHICS 0 display list! When constructing your own, there are a few rules you must follow. See the following box.

Rules for Creating a Display List

The following three rules must be followed when you create your custom display lists:

1. A display list cannot cross a 1 K boundary, which means they are not fully relocatable. In the rare cases when you must cross a boundary, use the DL JMP instruction (01) and the address of the first byte on the other side of the boundary just before you reach it:

   RAM Address | DL
   ------------------
   . .        . .
   20475  4
   20476  4
   20477  1  JMP over boundary
   20478  0  Low byte
   20479  80 High byte
   20480  1 K boundary
   20481  4  Resume DL
   . .        . .

2. Screen memory cannot cross a 4 K boundary. When using the higher resolution modes, for example GRAPHICS 8 which takes up almost 8 K, this is impossible to avoid. You must include a second LMS instruction in the DL pointing to the second 4 K of screen RAM. Here is an example using GRAPHICS 8:

   20475  4
   20476  4
   20477  1  JMP over boundary
   20478  0  Low byte
   20479  80 High byte
   20480  1 K boundary
   20481  4  Resume DL
   . .        . .

3. When creating a display list, ensure that it does not exceed the 64K boundary. If it does, you must divide the list into smaller segments that can fit within the boundary limits.
Creating a Scrolling Background

<table>
<thead>
<tr>
<th>DL Byte #</th>
<th>DL Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>15 GRAPHICS 8</td>
</tr>
<tr>
<td>98</td>
<td>15 GRAPHICS 8</td>
</tr>
<tr>
<td>99</td>
<td>79 GRAPHICS 8 +LMS</td>
</tr>
<tr>
<td>100</td>
<td>0 Low byte - Next 4 K of screen RAM</td>
</tr>
<tr>
<td>101</td>
<td>144 High byte</td>
</tr>
<tr>
<td>102</td>
<td>15 Resume GRAPHICS 8 DL</td>
</tr>
<tr>
<td>103</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. No more than 192 horizontal scan lines can be displayed in the playfield (although fewer are okay). When creating a custom DL, you must count the number of scan lines used in all of your mode lines to make sure their total doesn't exceed 192. Otherwise, it may take too much time to display them; Antic will no longer be synchronized with the screen, and the display may roll or break up.

——

Fine Scrolling

The ATARI feature called fine scrolling allows you to move the mode lines smoothly in any direction. Whereas coarse scrolling moves the image past the screen in whole byte or mode line increments, fine scrolling vertically moves the image by horizontal scan lines or horizontally moves it by color clocks (see Figure 9.2.).

Horizontal Fine Scrolling

To see what we are talking about, enter and execute the program in Figure 9.3.
Figure 9.2: Comparing coarse and fine scrolling.

```plaintext
10 REM HORIZONTAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCRL=24376
50 DLIST=PEEK(56)+PEEK(56)+256: REM Find Display List
60 POKE DLIST+H,181: REM Turn horizontal scroll bit (2+16)
70 POSITION 1,0: REM Print "This is a demo of horizontal scrolling."
80 FOR I=0 TO 15
90 POKE HSCRL,I
100 NEXT I
110 GDUB 500
120 NEXT I
130 FOR I=15 TO 0 STEP -1
140 POKE HSCRL,I
150 NEXT I
160 GDUB 500
170 GOTO 90
180 FOR N=1 TO 5:
190 NEXT N
200 RETURN
```

Figure 9.3: Listing of horizontal fine scrolling demo.
You will see the sentence that was PRINTed by line 80 ("This is a demo of horizontal scrolling!") smoothly sliding back and forth horizontally on the screen. Notice that scrolling is being used to display more information than will fit on one line. When part of the first word ("This") moves off the screen to the left, the cursor will appear on the right. This is one of the major advantages of scrolling — to control a window which peers into a much larger amount of data than will appear on the screen at once.

To use horizontal fine scrolling, just two steps are required. First, enable it by adding 16 to the value of the DL instruction (line 70). Then, all you have to do is POKE a value from 0 to 15 into the special hardware register called HSCROL (54276 Decimal, D404 Hex). The value you POKE determines how many color clocks the line will be moved to the right. Since each GRAPHICS 0 text character is four color clocks wide, this program will slide the sentence four characters over (16 increments/4 color clocks per character = 4 characters).

Now press the BREAK key, and LIST the program. What happened?! The screen looks disorganized, but this is only a temporary condition (either press RESET or type GRAPHICS 0). When horizontal fine scrolling is turned on, Antic automatically grabs extra bytes (20 percent more) for that line, throwing off the rest of the display. This is to provide a scrolling buffer. When one character is halfway off the screen on the left, then half of one should be appearing on the right. This means that more than 40 characters will appear on the line at once. The extra characters are taken from the next line down, causing the remainder of the screen to be shifted to the left by eight characters.

**Vertical Fine Scrolling**

To show off vertical fine scrolling, modify the previous example as follows. The lines with an asterisk in front just need to be altered rather than added.

```
10 REM VERTICAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCROL=54276
50 VSCROL=54276
60 LIST=PEEX=16=PEEK(5)=1=PEEK(6)=1=PEEK(7)=1=PEEK(8)=1 REM Find Display List
* 70 POKE DLIST+15,34 REM Turn vertical scroll bit on
* 80 POSITION 1,1
* 90 PRINT "This is a demo of vertical scrolling!"
* 100 POKE VSCROL
110 GOUB 500
120 NEXT I
* 130 FOR I=1 TO 0 STEP -1
* 140 POKE VSCROL
150 GOUB 500
160 NEXT I
170 GOTO 90
500 FOR W=1 TO 5:
NEXT W
510 RETURN
```

**Figure 9.4:** Listing of vertical fine scrolling demo.
Now the line of text slips up and down in horizontal scan line increments. Since the GRAPHICS 0 mode line is only eight scan lines high, we are using values from 0 to 7 to scroll the sentence up one line. Notice that it seems to vanish as it moves up. Add the following line to the program:

```
75 POKE DLIST+14,34
```

Now when you run the program, the entire line remains on the screen as it hops up and down. This is because two adjacent mode lines are now being scrolled rather than one.

Vertical fine scrolling is enabled (activated) by adding a 32 to the DL instruction. Then, values (from 0 to 7) are POKEed into the VSCROL register (54277 Decimal, D405 Hex).

**Diagonal Fine Scrolling**  
Sorry — there is no diagonal fine scrolling register. To achieve diagonal scrolling, just combine horizontal and vertical motion as indicated in the following program. Delete line 75 from the last example and then modify the asterisked lines:

```
10 REM  DIAGONAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCLRL=54276
50 VSCROL=54277
60 DLIST=PEEK(564)+PEEK(565)+256 REM Find Display List
70 POKE DLIST+14,128 REM Turn horizontal and vertical scroll bits (14+32)
80 POSITION 3,10
90 PRINT **This is a demo of diagonal scrolling** "
100 FOR I=1 TO 7
110 POKE VSCROL+I
120 NEXT I
130 FOR I=7 TO 0 STEP -1
140 POKE VSCROL+I
150 NEXT I
160 GOSUB 500
170 NEXT I
180 GOTO 90
500 FOR H=1 TO 31
510 NEXT H
520 RETURN
```

**Figure 9.5:** Listing of diagonal fine scrolling demo.

**Mixing Coarse and Fine Scrolling**

All this smooth motion is nice, but if you ran these programs you may have noticed that fine scrolling can only be implemented over a short distance. What if you want to slide the line *more* than one line up or down (or more than 16 color clocks to the right)? The solution is to combine fine scrolling with coarse scrolling. Look at Figure 9.6 to see how this works.
Figure 9.6: Combining fine scrolling and coarse scrolling.
The trick is to use coarse scrolling to move in one-byte increments (in GRAPHICS 0, each byte represents one character) and use fine scrolling to smooth out the steps between each byte. Using animation terms, think of coarse scrolling as the key positions and fine scrolling as the in-between positions. First, the character (or pixel) is fine scrolled for just enough scan lines or color clocks to reposition it one increment short of the next character’s original position. Then, it is reset to its starting position, and coarse scrolling takes over to move the display on a byte level by one increment. The process then repeats “forever.” The last step must be executed during vertical blank so the jump is never seen on the screen. In fact, a machine language routine should be used for fine scrolling over any distance. (Of course, we will be introducing just such a routine later in this chapter.) You may have noticed some occasional screen glitches (picture “break-ups” that last for a fraction of a second) during our fine scrolling demo programs. This is caused by changing an Antic display register while the screen is being drawn. The glitch problem and any jumpiness is totally avoided with a vertical blank interrupt machine language routine.

Applications  Fine scrolling is used in conjunction with coarse scrolling to allow you to access a much larger area of screen memory than is normally available to open a window in RAM. The ATARI game, Eastern Front (1941) by Chris Crawford, uses this technique to present a large map of Russia, which is actually about ten screenfuls large, on the display. With a joystick, the user can fly across the entire terrain at will. For more information on this program and some screen photos, see the end of this chapter.

For another application, imagine a word processing program that allows you to fine scroll through your entire document, either horizontally (for lines wider than the screen width) or vertically. This would be much easier on the eyes than moving around in huge jumps.

Display List Interrupts

The last option which can be implemented with display lists is called the display list interrupt (DLI). We have already talked about vertical blank, the period of time when the television’s electron beam has finished painting the screen, turns off, and then moves from the lower right corner of the screen to the top left corner in preparation to turn on and repeat the update process. There is also something called the horizontal blank. This is the period of time after a horizontal scan line is drawn when the beam shuts off and moves from the end of one scan line to the beginning of the next. Vertical blank lasts about 1400 microseconds, and horizontal blank lasts about 14 microseconds. We know that there is not much we humans can do in 14 (or even 1400) microseconds, but the computer is somewhat faster than we are. By setting the DLI bit on a display list instruction
(adding 128 to the instruction’s value), the 6502 can be interrupted at a specific point in time in relation to the screen updating process (i.e., just before that mode line has been fully displayed). All sorts of interesting things can be accomplished when the CPU is directed to a special DLI routine. For example, the DLI routine could change the hardware color registers to increase the number of colors that are displayed on the screen, move a player horizontally so it appears to be in two or more places at the same time, or change a player’s size.

We will not go into much detail on the inner workings of DLI’s, as they are beyond the scope of this book. For an excellent discussion on DLI’s, see the ATARI publication, De Re Atari (product number APX-90008). We will be introducing a black box DLI routine later in this chapter. For now, all you need to know is that the display list instruction gets its DLI bit set for the mode line just preceding the place where the desired change is to go into effect. Again, to set the DLI bit, just add 128 to the display list instruction:

<table>
<thead>
<tr>
<th>DL Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>.</td>
</tr>
<tr>
<td>.</td>
</tr>
<tr>
<td>7 GRAPHICS 2</td>
</tr>
<tr>
<td>7 GRAPHICS 2</td>
</tr>
<tr>
<td>135 GRAPHICS 2 with DLI bit set (7+128)</td>
</tr>
<tr>
<td>7 GRAPHICS 2 — Color change will be seen on this line</td>
</tr>
<tr>
<td>7 GRAPHICS 2</td>
</tr>
<tr>
<td>.</td>
</tr>
<tr>
<td>.</td>
</tr>
<tr>
<td>.</td>
</tr>
</tbody>
</table>

**Summary**

You now have a fundamental understanding of the power of the display list, coarse and fine scrolling, and DLI’s. No other personal computer now on the market can give you the flexibility that the DL provides. By combining all of its features, you can create some exciting effects. In the next section, we will lay the foundation for our scrolling background program using the display list’s capabilities.

### 9.2 THE SCROLLING BACKGROUND PROGRAM

As you look out the window of your ion-powered train, the scene suddenly changes. Gone are the noisy cars and trucks. It’s early Sunday morning, and all the people are inside their homes. The sky, a peaceful shade of blue, has cotton clouds in it. “I must have arrived in the
suburbs, you think as row upon row of nicely kept cottages, homes, and large apartment buildings pass by. The lawns are bright green, the shrubs and trees well groomed, the pink and yellow buildings immaculate. "What a nice day for a drive," you decide.

Now that you have glimpsed the world of fine scrolling, we'll show you how to incorporate it into a program by presenting our scrolling street scene example. What we want to create is a long horizontal strip of scenery which can pass across the window of our super train. If the strip is long enough, we won't notice it repeating. One technique would be to use map graphics, for example, GRAPHICS 7, to create the background. However, if we made a long strip in this mode, it would eat up quite a bit of memory. A solution is to create a special character set and use GRAPHICS 2. A full screen in this mode takes up only 240 bytes, whereas a GRAPHICS 7 screen is 3840 bytes long! Furthermore, the working resolution of both modes is identical, and GRAPHICS 2 provides us with one extra color! (By working resolution we are referring to the pixel size within each GRAPHICS 2 character.)

The only major drawbacks to this technique are the development time required to define a new character set and the limitation to the number of characters we can define without resorting to special tricks. Fortunately, for you, we have already solved these problems by creating a custom character set. This set is used to create houses and trees of random shapes, sizes, and colors. Every time the program is executed, a new street scene will be produced out of our characters.

The Street Character Set

To add some originality to the street scene, we designed a series of shapes that fit together to produce a wide variety of houses, cottages, apartment buildings, shrubs, bushes, and trees. The computer is given the task of putting these building blocks together along certain guidelines. Should the house have a fence, a TV antenna, a chimney? How many stories high and how wide should it be? How many windows should the house have, and what color should it be painted? By allowing the program to choose the features for each house, we saved the time it would have taken us to try to think of all the possible combinations, and then lay them out in a random order. Another advantage to our computer-designed street is that the street can be of any length — from two screenfuls wide to twenty. The computer will continue building houses and growing foliage until the allocated space has been filled.

Color Selection In GRAPHICS 2  GRAPHICS 2 allows for four playfield colors and one background color. We are using pink and yellow for the houses, brown for the roofs, fences and tree trunks, and dark green for the tree tops and shrubs. Extra color will be provided with the help of DLI's. We will add white and gray clouds (also made of characters), blue sky, light green grass, sidewalks, and a gray street.
When using either GRAPHICS 1 or GRAPHICS 2, the 128 characters normally available in the ATARI built-in character set are reduced to 64. This is because the upper two bits of each byte in screen memory that were used to help select a character (or activate inverse video) in GRAPHICS 0 have been reassigned for color selection. Try the following experiment. (Notice that the second two A’s and the second 123 are in inverse video.)

10 GRAPHICS 2
20 PRINT #6;"AaAz123123"

When this program is RUN, you will see four capital A’s in four different colors and ‘123’ in two different colors. The #6 means PRINT to the graphics screen device that was opened with the GRAPHICS 2 statement. Now type in the following statement:

POKE 756,226

The four capital A’s are now four lowercase a’s. The 123’s have turned into strange lines, and the background is filled with orange hearts instead of black background. You have switched to the other half of the standard character set (remember from Chapter 5 that location 756 contains the high byte of the current character set’s address). The first half contains numbers and uppercase letters, and the second half contains the graphics characters and lowercase letters. To switch back, type the following:

POKE 756,224

This means that you can’t mix uppercase and lowercase letters when using these graphics modes unless you resort to redefining the character set.

Displaying the four possible colors for a letter is simple, but what about numbers or graphics characters? There is no such thing as an uppercase or lowercase ‘2.’ The first complication is that the byte information stored in screen memory to display a specific character may not match that character’s ATASCII code. The screen bytes refer to the order of the character set in ROM (or RAM), not to their ATASCII value. The order of the character set was created so it could easily be divided for GRAPHICS 1 and 2 displays. For example, the ATASCII value of the number 2 is 50. However its screen value is 18, as it occupies the eighteenth position in the character set. Table 9.3 gives the positional value of each character in the ATARI ROM character set.
### Table 9.3: The order of the ATARI character set.

Columns 1 and 2 show the characters available when `GRAPHICS 1` and `2` are first initialized. Columns 3 and 4 hold the characters accessible when location 756 is `POKE`d with a 226. Notice the position of the heart-shaped character (64) in relation to the space character (0). Both occupy the first location in their half of the table. This explains why the background character shows up as hearts when the second half is used.

Try the following experiment:

```
10 GRAPHICS 2
20 SCREEN=PEEK(88)+PEEK(89)*256
30 POKE SCREEN,18
40 POKE SCREEN+1,18+64
50 POKE SCREEN+2,18+128
60 POKE SCREEN+3,18+64+128
```

When you `RUN` this program, you will see the number 2 displayed in four different colors. In lines 40–60, the upper two bits that control the color are being switched on.

---

1. From the ATARI BASIC manual.
To accomplish the same thing with PRINT statements, you must use the above table. First find 2 on the table. Then, jump over to the other half of the table, and locate the character in the corresponding position. This is the graphics character obtained by typing control-®. Let’s try it out by adding the following statement. Remember that the curly brackets mean to hold down the CTRL key, and underline means to print in inverse video.

```
70 POSITION 0,1
80 PRINT #6:"2(R)2(R)"
```

You will see a second line of colorful 2’s below the first line. The entire process becomes much more difficult when the screen control characters are to be displayed. You can’t directly PRINT an “inverse cursor down” by using the inverse key, for example. However, an inverse down arrow can be displayed on the screen by pressing a combination of keys, ESC Shift INSERT (use the ATASCII table in Appendix B). The semicolon can appear in only three of its color incarnations, because the fourth corresponds to the EOL (RETURN) code and can’t be displayed. Our solution is to avoid redefining characters that cannot be displayed in all their incarnations.

**Our Street Characters Definitions** Here are the character definitions for the street character set. We are using 35 characters out of the 64. By a change of color, some do double duty as cloud tops and tree tops, others as sections of roofs or walls of houses, and one character is used in clouds, tree tops, houses, and roofs!
Figure 9.7: Character definitions for street scene.
Creating a Scrolling Background
Laying Out the Screen

In the beginning of this chapter we mentioned that our background will consist of two levels. The farthest level is made up of the sky and clouds which are so far away that they will remain stationary no matter how fast we are moving. The second level consists of the houses, trees, and a street. Although the background is in two levels, the screen will actually be split into three sections (see Figure 9.8). The center section with the houses and trees is the only section that will be scrolled. The top cloud isn’t moved (must be a windless day), and the bottom section, consisting of the grass, sidewalks, and street, doesn’t need to be moved, because it doesn’t contain any details. There is no way to tell whether it is actually moving or stationary by looking at it. The illusion of movement will be created, since the viewer assumes the foreground must be connected to the center section.

Notice how wide the strip of street is in relation to the screen. To set this up in the display list, eight LMS instructions must be used. There is one for line 1 to establish the beginning of screen memory. Lines 3 through 8 each use one, so coarse scrolling can be used by changing the byte addresses following the LMS instruction. (The horizontal fine scrolling bit is also activated for these lines.) Line 9 also needs one to establish the address for the remainder of the screen.

Creating an Endless Street Now, how can this long horizontal strip be turned into a loop which endlessly scrolls across the screen? When the end of the strip is reached, it must be reset to the beginning for another pass. Doing this would cause an unpleasant jump, and the entire screen would change. To avoid a potentially jarring experience we copy the first screenful of information onto the area of the strip which contains the last screenful. Then, when that last screen is being displayed, reset all the LMS bytes of the scrolling section back to the starting screen during the vertical blank period (see Figure 9.9). The result is a smooth, invisible transition to the next pass of the strip across the screen window.
Figure 9.8: Three sections of street scene.
Playfield Width  

In Chapter 7, we mentioned that there were three playfield widths from which to choose — wide, normal, and narrow. These widths control the number of bytes of information to be fetched for each line of the screen. The playfield width is controlled by the lower two bits of SDMCTL (559 Decimal, 22F Hex). This register also controls player-missile DMA and display list DMA (see Table 7.7). Try the following POKEs on a GRAPHICS 0 screen. [Bit 5 (+32) turns on the DMA for the display list.]

POKE 559,33 : REM Narrow Playfield  
(bits 5 and 0 on)

POKE 559,34 : REM Normal Playfield  
(bits 5 and 1 on)

POKE 559,35 : REM Wide Playfield  
(bits 5, 1 and 0 on)
Notice the size of the side borders for each playfield width. The screen is all jumbled up for narrow and wide modes, because the display list is still set up for a normal playfield. Table 9.4 shows the number of bytes fetched for each mode line in GRAPHICS 0 and 2.

### Bytes per Mode Line in GRAPHICS 0 and 2

<table>
<thead>
<tr>
<th>PLAYFIELD WIDTH</th>
<th>Narrow</th>
<th>Normal</th>
<th>Wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAPHICS 0</td>
<td>32</td>
<td>40</td>
<td>48</td>
</tr>
<tr>
<td>GRAPHICS 2</td>
<td>16</td>
<td>20</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 9.4: Bytes per mode line using different playfield widths.
The wide playfield option will be used in our Street Scene program to eliminate the side borders. Using a normal playfield in this program would cause the houses to appear from the void of the border, rather than from the edge of the television screen.

The actual length of the scrolling strip is controllable within the program. It must be at least wide enough to contain two screenfuls — 48 bytes wide (2 screens * 24 bytes per line). This would cause the same screenful of houses to continuously scroll by since the first and last screens are identical.

Adding Extra Color With DLIs

The five colors with which GRAPHICS 2 provides aren’t enough to create a realistic scene. Display list interrupts are used to add additional colors. Figure 9.10 shows where DLIs are set and the colors that they affect.

As you can see from Figure 9.10, five DLIs are used on the screen. During each of these interrupts, our DLI routine is designed to change only three of the five color registers available in GRAPHICS 2 (registers 2, 3 and 4). The brown for the roofs and tree trunks and the green tree tops are left alone. Initially, the background (register 4) is set to the color of the sky, and registers 2 and 3 are set for two different shades of white for the clouds. The DLI set on mode line 2 changes the cloud colors to pink and yellow for the houses. Again, the color change doesn’t go into effect until the line following the DLI line, line 3 in this case. On line 5, the background register is changed to light green for the grass. This creates a horizon on line 6. On line 8, a house color is changed to the sidewalk color. The background grass color is changed to the gray color for the pavement of the street on line 10. (The light gray distant sidewalk is made from a character, not the screen background.) Finally, on line 12, the background (actually the bottom border) is changed to the near sidewalk.
The SCROLL Routine

The black box machine language routine that horizontally scrolls the strip of street is appropriately called SCROLL. It is extremely easy to use. Once it knows where to find the section of screen memory that is to be scrolled, all you need to do is give it a scroll rate. In Table 9.5 are the parameter table entries used by SCROLL.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCRLINIT</td>
<td>5</td>
<td>1029</td>
<td>POKEd 1 to turn on routine, 0 off</td>
</tr>
<tr>
<td>SCRLADR</td>
<td>26</td>
<td>1050,1051</td>
<td>Lo and Hi bytes of scrolling window</td>
</tr>
<tr>
<td>SCRLLEN</td>
<td>28</td>
<td>1052,1053</td>
<td>Width of scrolling window in bytes</td>
</tr>
<tr>
<td>SCRLCLK</td>
<td>30</td>
<td>1054</td>
<td>Color clocks per mode line byte -1</td>
</tr>
<tr>
<td>SCRLSTEP</td>
<td>31</td>
<td>1055</td>
<td>Step size to scroll each jiffy</td>
</tr>
</tbody>
</table>

Table 9.5: Parameters for SCROLL.

To set up for SCROLL, POKEd the two-byte address that points to the beginning of the scrolling window into SCRLADR. This is the upper left corner of the section that will be scrolled, not the first byte of screen memory (unless the first mode line is to be scrolled too). In our scrolling street scene program, this is the same two-byte address that follows the LMS instruction for line 3 of the screen. Then POKEd the width of the scrolling window into SCRLLEN. This is a two-byte value so SCROLL can accept very long window lengths. The next parameter, SCRLCLK, controls the number of fine scrolling steps that will be performed before a coarse scroll. This is based on how wide (in color clocks) the bytes in your mode lines are. GRAPHICS 2 bytes are eight color clocks wide so a 7 will be POKEd into this address. When using a 40-bytes-per-line graphics mode, use the value 3; with a 10-bytes-per-line mode, POKEd in a 15.

When all these parameters are POKEd in, SCROLL is turned on by a POKEd 1 into SCRLINIT. (The fifth parameter, SCRLSTEP, need not be set until after SCROLL is activated in this way.) At every sixtieth of a second, the routine will look into SCRLSTEP to determine how quickly to scroll the screen. To begin the movement, just POKEd in the rate you want the street to scroll, and the scrolling window will immediately begin to move. The step size is in color clocks per jiffy and can be any value from 0 to 255. A step size of 1 yields the slowest rate — the scene moves one color clock every jiffy (1/60 of a second). A POKEd of 2 will double the rate to two color clocks per jiffy. To pause the display, POKEd SCRLSTEP with a 0, then POKEd in a new step size to start it again.
If you wish to reset the display to its starting position, POKE SCRLINIT with a 1. It will immediately begin again from the original starting position at the rate currently in SCRLSTEP. (As with our earlier routines, when SCROLL has received the 1 that was POKEd into SCRLINIT, it replaces it with a 128.)

SCROLL will work in any GRAPHICS mode with any number of adjacent scrolling lines. The routine looks for the first display list LMS instruction with the horizontal fine scrolling bit set and defines that mode line as the top of the scrolling window. It continues incrementing all the address bytes following the DL instructions with these two bits set until it reaches the end of the DL. Even if the scrolling lines are not adjacent, they will still be scrolled, but the display will become jumbled.

Note that SCROLL only moves the scrolling window from the right to the left.

**Entering SCROLL**

Here are the bytes for SCROLL that are entered with the same method as shown in Chapter 8 (with the String Loader program).

![Figure 9.11: Listing of DATA statements for SCROLL.](image)

**The Display List Interrupt Routine (DLIROUT)**

We made it! We have finally come to the last machine language program in the book. This routine, called DLIROUT, is used to add the extra colors on the screen as described earlier in this chapter. DLIROUT changes the values in the hardware color registers, not the shadow registers that we have been accessing from within BASIC (see Table 9.6). A color value sent to a hardware color register goes into effect immediately, whereas a shadow register alteration doesn’t take effect until the next vertical blank. This means that all the mode lines prior to (and including) the line containing the first DLI instruction take their color values from the shadow color registers. During vertical blank, all the hardware color registers are reset once again to the shadow register values.
<table>
<thead>
<tr>
<th>COLOR REGISTER #</th>
<th>COLOR REGISTER NAME</th>
<th>HARDWARE ADDRESS</th>
<th>SHADOW ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dec</td>
<td>Hex</td>
<td>Dec</td>
</tr>
<tr>
<td>0</td>
<td>COLPF0</td>
<td>53270</td>
<td>0016</td>
</tr>
<tr>
<td>1</td>
<td>COLPF1</td>
<td>53271</td>
<td>0017</td>
</tr>
<tr>
<td>2</td>
<td>COLPF2</td>
<td>53272*</td>
<td>0018</td>
</tr>
<tr>
<td>3</td>
<td>COLPF3</td>
<td>53273*</td>
<td>0019</td>
</tr>
<tr>
<td>4</td>
<td>COLBK</td>
<td>53274*</td>
<td>001A</td>
</tr>
</tbody>
</table>

* The three hardware color registers controlled by DLIROUT

Table 9.6: Hardware and shadow color registers.

DLIROUT uses one parameter table location to store the address of a table of color values. This color table contains the new color values for each DL instruction with the DLI bit set (see Table 9.7).

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Offset From PARAMBASE</th>
<th>Address (Decimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLIAOR</td>
<td>36</td>
<td>1060,1061</td>
<td>Low and High bytes of DLI color table</td>
</tr>
</tbody>
</table>

Table 9.7: Parameters for DLIROUT.

As we said before, this routine changes the color of registers 2, 3, and 4. The size of its table is determined by the number of display list instructions that have the DLI bit set. For each DLI bit that is set, three table entries are required, one for each of the three color registers to be changed. Since our program uses five DLI instructions, its DLI table is 15 bytes long (5 DLI’s * 3 entries per DLI). See Figure 9.12.
Look at the color values for the first DLI instruction. Even though we wanted to change the color of only the first two registers (from cloud colors to house colors), the third register had to be reassigned its original sky color. Each of the three registers must have a table entry for each DLI instruction, even if there is no color change for that register and even if that register isn’t being used. In the last set of table entries, registers 2 and 3 are not used, but a value (any value) still needs to be stored in the table for them.

Using DLIROUT To use DLIROUT, first create a table and fill it with the desired color values. Turn on the DLI bit (+128) in the appropriate display list instructions. The OS must then be told where the DLI routine is located in memory. This is accomplished by a POKE of the address (low and high bytes) of the routine into locations 512 and 513 (200, 201 Hex). DLIROUT must next be told where your table is stored by a POKE of its address into the parameter table:

```
POKE DLIADR, TABLELO
POKE DLIADR+1, TABLEHI
```

As with our previous machine language routines, DLIROUT has a section of code that is executed during vertical blank and must be linked to the VBI vectors (see lines 13000–13210 in upcoming Example 13). Finally, display list interrupts must be turned on by a POKE of 192 into 54286 (NMIEN, non-maskable interrupt enable, D40E Hex). That’s all there is to it; the rest is automatically carried out by DLIROUT.
Even though we are using this routine with SCROLL, there is no reason why either of them could not be implemented by themselves. (However, AUTOMOVE requires PMOVER for its execution.)

**Entering DLIROUT**

The lines containing the DATA statement for DLIROUT follow. Again, use the string loader program to stuff the bytes into strings.

![Figure 9.13: Listing of DATA statements for DLIROUT.](image)

**Entering the Scrolling Street Scene Program**

You have now been fully briefed on the Scrolling Street Scene program and are ready to enter it into the computer. When you have finished entering this program, it will be combined with the Player Foreground Demo (Example 12) to produce the book's final program.

Most of this program is new and must be entered from the keyboard. For those lazy disk owners who would rather make the poor ATARI do some extra work, we offer the following program to transfer 41 lines from Example 12 to Example 13. To use the Copy program, first load Example 12 into memory, and then LIST the entire program to disk or a cassette:

```
LIST "D:PLAYERS.TXT"   (disk)
LIST "C:"               (cassette)
```

Then enter and execute the following program. It will copy the common lines to a file called SCROLL.BAS. (Note that there are 15 numbers on each DATA statement but the last.)
Now that this program has finished its task, type NEW, and ENTER the newly created file into memory:

```
ENTER "D:SCROLL.BAS"  (disk)
ENTER "C:"  (cassette)
```

**Example 13**

**Exercise** Create a scrolling scene filled with houses, trees, and shrubs of different shapes and sizes. Design a custom character set to build these objects, and use GRAPHICS 2 to display them. Use SCROLL to move the scene across the screen and DLIROUT to add extra color. Set up the program so it can later be merged with the Player Foreground Demo.
Creating a Scrolling Background

Film 2
"Vol Libre," Loren Carpenter.
The landscape images from this excerpt are constructed from hundreds of thousands of triangles, created by fractal splitting of only 100 or so original triangles. Fractals are a convenient method for representing natural randomness. The pictures were computed in 15 to 40 minutes each on a DEC VAX 11/780, and are a full 24 bits per pixel, 512 by 512 resolution. No antialiasing was done. (Courtesy of Loren Carpenter.)

Photo 9.3: Screen photos showing several different types of houses and trees.

As before, the lines which are new to this program are highlighted. If you don’t use the above Copy Program, just enter all the lines, highlighted or not.

```plaintext
10 REM *** SCROLLING STREET SCENE ***
20 REM
30 REM Program demonstrating Horizontal Fine Scrolling and Display List Interrupts
40 REM Copyright © 1982 by David Fox and Mitchell Waite
50 REM
60 REM
70 GOTO 140
80 REM
90 REM Hi/Lo Byte Calculation
100 HIBYTE=INT(X/256): REM Calculate High Byte
110 LOBYTE=X-HIBYTE*256: REM Calculate Low Byte
120 RETURN
130 REM Initialize
140 REM
150 REM CLEAR=CHR$(0), CLRI(24), CLRI(32), CLRI(40)
160 REM CLRI(24)=CHR$194)
170 REM CLRI(1)=CHR$(124)
180 REM CLRI(1)=CHR$(124)
190 REM GOSUB 5000: REM Set-up memory locations
200 REM GOSUB 6000: REM Set-up Display List
210 REM GOSUB 2600: REM Clear screen
220 REM GOSUB 8000: REM Load in Character Set
230 POKE 1781,#7:REM Switch to Street character set
240 POKE 557,751:REM Turn screen DNA on again, Hide Playfield
250 REM GOSUB 3000: REM Create a street
260 POKE 12000: REM Set up parameter addresses
270 GOSUB 13000: REM Turn on interrupts
280 SPEED=41
290 POKE 13818,CHR$(1)
300 REM
310 REM
320 REM Figure 9.15: Listing of Example 13 — lines 10–390.
```
**Initialize**  
This section of the program calls all the subroutines that set up the screen and machine language routines. To speed up the initialization time, screen DMA has been turned off (line 6020) and must be turned on again so the picture will show. The statement on line 260 turns on the screen and sets the playfield to wide. Line 340 starts the display scrolling.

---

**Initialize Routine Strings**  
This section initializes the routines and creates the DLI color table for DLIROUT. Enter your SCROLL and DLIROUT strings at this time.

Lines 11200–11270 create the DLI table. Each byte is read in and stored into the string DLITABLE$.

---

**Figure 9.16:** Listing of Example 13 — lines 11000–11660, 25500–25510.

**Figure 9.17:** Listing of Example 13 — lines 5000–5350.
Set Up Memory Locations  This section reserves the memory space for the screen and display list. D1F (line 5010) is used to determine the number of memory pages needed to hold the screen. Line 5040 calculates the number of bytes needed for the screen. Note that there are six wide playfield lines of 24 bytes each and six scrolling lines of LINELEN bytes each.

In line 5170, the number of pages of memory needed to hold the screen plus the DL is calculated. The DL will come first, then the screen RAM. Since the DL must not cross a 1 K boundary (four pages), D1F is incremented by 4 each time. When D1F's value is large enough, the high and low bytes of the DL are calculated (lines 5180-5190). The address of the screen (SCRN, line 5210) is determined by adding the length of the DL (DLSZE) to the DL's beginning address (DLBASE).

In line 5240, the address of the scrolling window is found by adding the number of bytes in the first two lines (24*2) to the beginning of screen memory.

Figure 9.18: Listing of Example 13 — lines 6000–6340.
**Set Up the Display List** Here is the section that creates the display list. First, line 6010 tells the OS that the computer will be operating a full-screen graphics mode. This is not necessary for the operation of the program since a custom DL has already been created. However, because the OS thinks we’re using a full-screen mode, it will immediately return the screen to a normal GRAPHICS 0 mode if an error occurs in the program or if **BREAK** is pressed. On the next line, 6020, screen DMA is turned off to increase the processor speed during the initialization process and to keep the screen from jumping or glitching when we switch over to the new display list. The only drawback is that if the initialization process is too long, the user may think the computer has passed away. It might be a good idea first to display a message stating how long the screen will be blank before turning off the DMA.

Next, the top border of the screen is created by blanking 24 scan lines (6030–6050). The instruction for the first mode line (+7 for GRAPHICS 2) with the LMS bit set (+64) indicates the beginning of screen memory (lines 6060–6080). On line 6090, the second mode line gets its DLI bit set.

Lines 6100–6190 create the DL instructions for mode lines 3 through 9. **WINDOW** is a temporary variable that holds the beginning memory address for each mode line. The lines get the LMS bit (+64), horizontal fine scroll bit (+16), and mode bits (+7) for a value of 87. Mode lines 5 and 8 (line 6130) also receive a DLI bit. Mode line 9 (line 6140) begins the section of the screen immediately under the scrolling window so its horizontal scroll bit remains unset.

Lines 6230–6250 tell Antic to note that the end of the display list has been reached and to return to the beginning.

The OS receives the address of DL TR:00 in lines 6260–6280 so it knows where to send the CPU during a DLI. The new DL is then switched on by a **POKE** of its location into 560 and 561.

Finally, the color registers are set for the top section of the screen (before the first DLI). Even though the screen DMA is turned off, the background color is still controlled by color register 4 so the screen will turn from black to light blue at this point. This suggests a technique to keep DMA off during program set up but will still show that the computer is alive and functioning — from time to time, just change the color of the screen background.

```
2600 REM Clear the Screen -- Fill the Screen With 0
2610 TEMP=$0000
2615 SCRN=SCREEN
2620 FILL=SCRN
2625 SCREEN
2630 REM
```

*Figure 9.19:* Listing of Example 13 — lines 2600–2630.
Clear the Screen  

MFILL is used to clear all of display memory by filling it with 0’s.

```
0000 REM Set Up Alternate Character Set
0010 NICHRB=REETR(16) H savings in data, skip first 20 characters
0020 CHRBAS=HICHRB+256 REM Find start of Character Set
0030 REM Read in data, skip first 20 characters
0040 OFFSET=2040
0050 CLEAR=95
0060 READ TOTAL:
0070 TEMP=0
0080 FOR I=CHRBAS+OFFSET TO CHRBAS+OFFSET+CHARBS-1
0090 POKE I,CHR:
0100 TEMP=TEMP+BYTE
0110 NEXT I
0120 IF TOTAL=TEMP THEN
0130 GRAPHICS 01:
0140 PRINT "ERROR In Character Set Data!": END
0150 REM Clear out first char *background
0160 FOR I=CHRBAS TO CHRBAS+7
0170 POKE I,100: NEXT I
0180 RETURN
0190 REM
```
Figure 9.20: Listing of Example 13 — lines 8000–8160.

Set Up Alternate Character Set  

This subroutine READS in the character definitions for the street character set and POKEs them into memory. This section was stolen from Example 2, the Walking Man Character Set program, with only a few changes (you may want to transfer it over to save some typing). Line 8010 places the beginning of the character set two pages below the display list (remember, only 512 bytes are required for a GRAPHICS 2 character set).

```
23000 REM Character Set Data
23010 DATA 38936
23020 DATA 5,9,15,31,63,63,127,127
23030 DATA 6,193,240,246,252,254,254
23040 DATA 127,127,127,63,63,127,127
23050 DATA 254,254,254,254,254,254
23060 DATA 4,201,4,31,4,201
23070 DATA 8010,8010,8010,8010
23080 DATA 254,254,254,254,254,254
23090 DATA 254,254,254,254,254,254
23100 DATA 1,63,7,15,240,240,240
23110 DATA 2,201,3,15,63,63,63
23120 DATA 8193,240,240,240,240,240
23130 DATA 63,63,512,512,512,512
23140 DATA 255,255,255,255,255,255
23150 DATA 255,255,255,255,255,255
23160 DATA 128,192,244,246,252,254,255
23170 DATA 5,31,15,5,5,5,5
23180 DATA 3,3,15,6,6,6,6
23190 DATA 63,63,63,63,63,63,63
23200 DATA 128,192,244,246,252,254,255
23210 DATA 128,192,192,224,224,224,224
23220 DATA 224,224,224,224,224,224,224
23230 DATA 224,224,224,224,224,224,224
23240 DATA 224,224,224,224,224,224,224
23250 DATA 224,224,224,224,224,224,224
23260 DATA 224,224,224,224,224,224,224
23270 DATA 224,224,224,224,224,224,224
23280 DATA 224,224,224,224,224,224,224
23290 DATA 224,224,224,224,224,224,224
23300 DATA 255,255,255,255,255,255,255
23310 DATA 255,255,255,255,255,255,255
23320 DATA 31,31,63,63,127,127,255
23340 DATA 254,254,254,254,254,254,254
23350 DATA 254,254,254,254,254,254,254
23360 DATA 254,254,254,254,254,254,254
23370 REM
```
Figure 9.21: Listing of Example 13 — lines 23000–23370.
**Character Set Data**  Here are the character definitions for the street scene’s houses, trees, etc. Each line contains the eight numbers necessary to define one character. (The first line is the checksum value.)

```
2800 REM Put in Clouds and Sidewalk
2810 SEG$="COLD<SKY""
   CLOUD1:
   PTR=4:
   HEIGHT=1:
   WIDTH=7:
   GOSUB 2000
2820 SEG$="COLD<SKY""
   CLOUD2:
   PTR=PTR+5:
   WIDTH=5:
   GOSUB 2000
2830 SEG$="COLD<SKY""
   CLOUD3:
   PTR=PTR+5:
   WIDTH=4:
   GOSUB 2000
2840 RETURN
```

**Put in Clouds and Sidewalk**  We have now come to the first part of the program, which fills the screen memory with scenery. This section places the clouds and the sidewalk on the screen. The technique we have chosen places the appropriate characters into a string called **SEG$** (for segment). Each object to be displayed is stuffed into **SEG$** and then a subroutine at line 2000 is called that **POKE**s the information into memory. Even though this is a text screen, its unusual dimensions would make it very difficult to **PRINT** the strings to the screen.

Line 2810 has a number of parameters that instruct the subroutine at 2000 how and where to place the information on the screen. **CLOUD** is a flag that alerts the subroutine that this is a cloud. **PTR** gives the string’s horizontal screen position as an offset from the left edge of the screen. **HEIGHT** informs the routine how many mode lines tall (less 1) the shape in the string is. (A height of 1 means 2 mode lines; a height of 0 means 1 mode line.) **WIDTH** says how many bytes wide the shape is. This means that there will be **HEIGHT*WIDTH** characters in the string. This line will send two light gray clouds to the screen.

Line 2820 creates another cloud, which will be positioned 3 bytes over from the previous one. Line 2830 then creates the sidewalk string.

```
2000 REM Send Info to Screen
2010 L=LENGTHSEG$:
   IF L<10 THEN
   SEG$=SEG$+″\n″
2020 IF FENCE THEN
   PTR=PTR+1:
2030 FOR I=0 TO HEIGHT
2040 IF FENCE THEN
   GOSUB 2200
2050 FOR J=1 TO WIDTH
2060 P=I(WIDTH+J):
   CHAR=ASC(SEG$(P))
   PRINT CHAR
```

(continued)
Send Information to Screen  After SEG$ has been filled with characters defining an object, this subroutine is called. The object's HEIGHT, WIDTH, and horizontal placement (PTR) are passed to this routine as well as flags that indicate special objects. FENCE means that a fence is to be placed around the house. SPCFLAG is used to increase the space between objects. CLOUD and GRND cause the object to be placed in special locations outside the scrolling window.

Line 2010 makes sure the string is at least 24 characters long by padding short strings with blanks contained in CL$.

Line 2060 obtains the ATASCII value for the individual character to be transferred to the screen. A subroutine at 1900 converts this value to the proper byte value so it will be correctly displayed.

After the string has been POKEd into memory, line 2150 increments PTR for the next object, and line 2170 finds out how much room is left on the line for more objects.

Convert to Screen Value  As we mentioned earlier, the ATASCII value of a character doesn't always match its screen value. This routine makes a conversion which enables the character to be POKEd into the screen. We won't explain lines 1920–1930, but we'll guarantee they'll work! Line 1940 changes the house color to pink or yellow, depending on the value of PAINT.
Figure 9.25: Listing of Example 13 — lines 2200–2280.

Put in Fence This routine is called by line 2040 if a fence is to be placed around the house (a random event). The variable I gives the current mode line being filled (from the loop in the routine at 2000). If I is less than 4, we’re too high up so the routine is exited. Otherwise, the side fence pieces are POKEd in. The front bottom section of the fence is contained in SEG$.

Figure 9.26: Listing of Example 13 — lines 3000–3140.

Create Random Display This is the master controller section for building the houses and planting the greenery. It makes the random choices that will control many of the features of the street scene. In this city, a tree or shrub is planted between each pair of buildings. The size of the plant depends on the care and feeding provided by a later program section.
Line 3040 selects a random house width. There is an equal chance for the house to be 2, 3, or 4 bytes wide. Lines 3050–3070 select the number of stories tall the house will be. Given a large enough street, 45 percent will be a two-story house, 35 percent will be a three-story house, and 20 percent will be a four-story house. These percentages could be changed if you want to modify the ambience of your street.

Line 3080 decides whether a chimney can be built on the house. However, since not all houses can receive building permits for chimneys (depending on roof shape), the actual percentage will be lower than 60 percent.

Line 3090 gives a 40 percent chance for a fence around the house only if a shrub wasn’t first planted next door.

How many houses have antennas and how many opted for cable? This important decision is made on line 3110. Again, the actual percentage will be different as either a chimney or a flat roof is a prerequisite for “free TV.”

Line 3120 chooses the paint color for the house, half yellow and half pink. If you have a preference of one color over the other (or wish a different two-tone town), feel free to make the change.

Line 3130 clears the string and calls the contractor that specializes in building houses of the specified width. After the string is stuffed and transferred to the screen, line 3140 checks for the number of bytes left on the line. If there is no room left for a plant (the next section), then the routine 2400 is called and copies the first screen to the last (see Figure 9.9).

```
3500 REM Width 2
3510 IF STORY=0 THEN
3520 STORY=0
3530 IF STORY=0 THEN
3540 IF CHIMNEY THEN
            SEG1047=1025
            GOTO 3560
3550 SEG1047=1025
3560 BT=BT+4
3570 FOR I=1 TO BT+4+STORY-2+2 STEP 2
3575 IF RND(I)<0.5 THEN
            SEG1047="TE"
            GOTO 3570
3580 SEG1047="EP"
3590 NEXT I
3600 SEG1079="CT"
3610 IF FENCE THEN 3640
3620 IF RND(I)<0.5 THEN
            SEG1047="MN"
            GOTO 3640
3630 SEG1047="EP"
3640 RETURN
3650 REM
```

Figure 9.27: Listing of Example 13 — lines 3500–3650.
Width 2  This subroutine builds the small "get away" cottages. To ensure coziness, line 3510 restricts the number of stories to these houses to three. In line 3520, BT, a byte pointer used in the creation of the strings, is set to 1. If there are only two stories (rather than three) for this house, then BT is set to 3 (remember, this is a two-byte wide house). First the roof is built (the contractors we hired are very strange — they believe in a top-down approach). If a chimney has been requested, line 3540 obliges; otherwise 3550 takes over. BT is incremented, and a loop is entered that fills in the third and second stories. Notice the randomness being added. Then line 3600 builds a door, and lines 3620–3630 build a fence, if requested.

Figure 9.28: Listing of Example 13 — lines 3700–3820.

Width 3  This section is very similar to the previous one. The main difference, other than the width, is that the antenna is an option and the chimney isn't (those bigger houses just aren't as romantic).
**Width 4** The wide body house is assembled in this section. There are actually two different possible versions. If the house has more than two stories, is adjacent to a shrub, or is just lucky (33 percent chance), the house gets normal outer walls (decided in line 3930). Otherwise, it is branded an ODDHOUSE and gets the narrower set of walls. Because of these indented walls, a fence or shrub placed next to it would sit a distance away from the house, so they aren’t permitted.

In line 4010, the house can receive both an antenna and a chimney, otherwise, the normal house is not any different than its skinnier cousins.
Plant Some Foliage  

Here is where the gardeners reside. After a house is built, they come in and plant something before the next house is plunked down. There are basically two types of plants: shrubs and trees. A shrub is a quarter of a tree top which rests next to the outer wall of a house. Shrubs only come in pairs, so when one house gets a shrub, its soon-to-be neighbor gets one too. Trees are vertical plants which may or may not have a trunk. By selecting different heights for the tree and deciding how much of that will be leafy green, you can create a wide selection of trees.

First, line 3170 checks whether a shrub is possible. It must be a normal house without a fence with enough room next to it for another house to follow. If a shrub is eligible after these tests, it has a 30 percent chance of appearing; otherwise, a tree is planted. All trees have a width of 2. Their height can range from 2 to 6 bytes (3200–3250). Then, the height of the trunk (3260) and the height of the tree top (3270) are determined. In lines 3280–3340, the tree top is grown first (clever gardeners!), then the trunk (3360–3380), and finally a base is spliced onto half of the trees (3390). Then lines 3400–3430 add random spacing next to either (or neither) side of the tree.

Lines 3440–3460 create the shrubs. They can either have a width of 2 or 3 bytes. If the width is three, then a blank space is inserted between them.

Finally, the amount of room left on the screen is checked. If it isn’t enough for a house, line 3140 checks if another plant can be grown instead.

**Figure 9.30**: Listing of Example 13 — lines 3150–3490.

**Figure 9.31**: Listing of Example 13 — lines 2400–2470.
**Copy First Page Onto Last Page**  
Once the available space in the scrolling window has been filled with houses and trees, the first screen page must be copied to the last to allow for a smooth transition when the screen is reset to its starting position. This loop copies the first 24 bytes of each of the six scrolling lines to the last 24 bytes of each line.

```
12000 REM Set Parameters For Routines
12010 PARAMBASE=1024: REM Parameter Base address
12020 SCRINT=PARAMBASE+: REM Page a 1 to initialize the scroll routine
12030 SCRLIN=PARAMBASE+: REM Address of scrolling window
12040 SCRLLE=PARAMBASE+: REM Line length of scrolling window
12050 SCRLCN=PARAMBASE+: REM Number of Color Clocks per screen byte
12060 SCRLSE=PARAMBASE+: REM Step size of scroll each jiffy
12070 DLIADD=PARAMBASE+: REM Address of DLI table
12080 VBLKED=54H: REM Deferred Vertical Blank Interrupt Vector
12090 CRITICAL=66: REM Critical Flag
12100 TEMT=05H:PARAMBASE,PAIR
12110 REM IMPORTANT: Clear out parameter area
12120 GOSUB 110
12130 POKE SCRLDIR,LETTE
12140 POKE SCRLDIR,LETTE
12150 X=LINEL:
12160 GOSUB 110
12170 POKE SCRLPEN,LETTE
12180 POKE SCRLPEN,LETTE
12190 POKE SCRLCN,LETTE
12200 POKE SCRLSE,LETTE
12210 X=DLITABLE:
12220 GOSUB 110
12230 POKE DLIAN,LETTE
12240 POKE DLIAN,LETTE
12250 POKE DLIAN,LETTE
12260 RETURN
12270 REM
```

Figure 9.32: Listing of Example 13 — lines 12000–12540.

**Set Parameters For Routines**  
This subroutine sets up the parameter table for the machine language routines. All the parameters for SCROLL are POKEd in except SCRLSTEP. SCRLINIT isn’t set until the VBLANK routines are in place.

```
13000 REM Install Interrupt Routines
13010 POKE CRITICAL,1: REM Open CRITICAL "value", set up detour
13020 X=SCROLL+1
13030 GOSUB 110
13040 POKE VBLKED,LETTE: REM Set VBLANCE vector to SCROLL
13050 POKE VBLKED,LETTE
13060 X=DLIROUT+1
13070 GOSUB 110
13080 POKE DLIROUT+1: REM Points SCROLL to DLIROUT
13090 POKE SCROLL,LETTE
13100 POKE SCROLL,LETTE
13110 POKE CRITICAL,0: REM Close CRITICAL "value", routines installed
13120 POKE SCRLINIT
13130 POKE 51200,192: REM Enable DLI’s
13140 RETURN
13150 REM
```

Figure 9.33: Listing of Example 13 — lines 13000–13210.

**Install Interrupt Routines**  
SCROLL and DLIROUT are installed into the vertical blank routines, SCROLL is turned on (line 13180), and the DLI’s are enabled (13190).
Main Animation Loop  We have reached the last section of this program. All it does is watch the keyboard, accept SPEED values, and POKE them into SCRLSTEP.

Before running this program, make sure you have saved it on disk or cassette! We wouldn’t want you to lose all that work! For the first run, set LINELEN (in line 5030) to 48. You won’t get much variety in houses, but you won’t have to wait as long to see your results. The screen will flash to black for a few seconds, then to light blue for about 15 seconds. Appearing next will be the clouds, the sidewalk, and then the first house and tree, on the far left side of the screen. After the visible screen is covered, it will be copied over to the end of the scrolling window. Don’t be alarmed when the houses first appear in gray and white and there is no grass or street — the interrupts aren’t turned on until the entire street has been completed. The screen will then spring into full color and start rolling by! Press RESET when you have finished admiring your work, and set up a longer scrolling window (160 is a good number to use). Just remember that the wider it is, the longer you’ll have to wait for the action to begin.

Try changing the speed. Notice that when you press down on a key, there is sometimes a slight jump at the color border between DLI. This is because the computer’s interior speaker interferes with the DLI timing. The only way to avoid it is by not acknowledging keyboard input (don’t use the GET command), or avoid using the keyboard as the input device.

Modifications
1. Use the paddles to change the speed rather than the keyboard. This will eliminate the DLI jump upon keypress.
2. To save memory space and set-up time, save the entire screen to disk. Then, replace the street drawing code with a routine to read that disk file back into screen memory.
3. Experiment with creating a scrolling window in a different graphics mode. Be sure to set SCRLCLK to the correct color value.
4. The scrolling background would make a perfect backdrop for many arcade type games (e.g., Defender or racing-type games). Think of the current crop of games, and see if you can come up with any ideas of your own.

Figure 9.34: Listing of Example 13 — lines 400-530.
Summary

You have now successfully implemented two more very powerful ATARI features into a program. We are about to enter the last stage of this book, combining all the best features into one climactic program, the Great Movie Cartoon.

9.3. THE GREAT MOVIE CARTOON

As you continue your trip through the Sunday morning suburbs you suddenly notice a few very large trees passing by. They are on the curb so they seem to pass faster than the houses in the background. Then the sound of traffic reaches your ears. When you realize that you are going very slowly, you triple your speed. Occasionally, a man appears, walking on the sidewalk. It seems the town has awakened.

Well, this is it — the moment you have been waiting for. It is now time to merge Examples 12 and 13 to create the final program in this book, the Great Movie Cartoon. This process is really very simple. Just delete six lines, modify fourteen lines and add one! That's all!

Example 14

Exercise  Merge the last two program examples, 12 (Player Foreground Demo) and 13 (Scrolling Street Scene) into one program. Use the same keyboard routine to change the speed of the display.
There are just ten simple steps you must follow to merge Examples 12 and 13. For everything to work properly, it is essential that all the lines and line numbers were entered exactly as given in the book.

As we mentioned in Chapter 7, every time a variable is entered into a program, it takes up residence in the variable name table. This wouldn’t be much of a problem except for two facts: 1) There can be no more than 128 different variable names in an ATARI BASIC program, and 2) the Great Movie Cartoon has exactly 128 different variable names. If there is one extra variable name in the table, you will get an error (ERROR 4) while trying to merge Examples 12 and 13. An extra variable may have sneaked its way in while you were entering the programs. If you mistyped any of the variable names and pressed RETURN, that name would remain
in the variable table. The method to clear the extra entries from the variable name table is to LIST the program to disk or cassette, type NEW, and ENTER the program back into memory. Here are the steps to follow to create Example 14:

1. Load Example 13 into memory.
2. Delete the following lines:
   
   ```
   340  480  500  520
   ```

3. LIST the program into a temporary file:
   
   ```
   LIST "D:TEMP" for disk
   LIST "C:" for cassette
   ```

4. Load Example 12 into memory.
5. LIST the program onto disk or cassette as in step 3, but use a different file:
   
   ```
   LIST "D:EX12" for disk
   LIST "C:" for cassette
   ```

6. Type NEW, and ENTER the program back into memory:
   
   ```
   ENTER "D:EX12" for disk
   ENTER "C:" for cassette
   ```

7. Delete the following lines:
   
   ```
   300  7080
   ```

8. Merge the temporary file into the program in memory:
   
   ```
   ENTER "D:TEMP" for disk
   ENTER "C:" for cassette
   ```

9. Modify the following highlighted lines:

   ```
   260 POKE 756,HCHR! REM Switch to Street character set
   270 POKE 559.47! i^H Turn screen DMA back on, Hide Playfield, PM 2 line resolution, Players enabled
   270 GOSUB 38000 REM Create a street
   ```

Figure 9.35: Listing of Example 14 — lines 10–50, 250–270.

Line 260 now enables PM graphics as well as turning the screen DMA back on and setting it to a wide playfield.
These lines reset the vertical position for the four objects: the man, the trees, the trucks, and the cars. They must now be positioned properly on the sidewalk, the street, or the grass.

The \texttt{RESTORE} must be added to line 5060 to \texttt{READ} information on the players.

Line 7010 is changed so player RAM resides in the 1 K section of memory directly below screen memory. Recall that the players use the upper two pages (512 bytes) of this 1 K section and that the missiles use part of the second page. Since we are not using missiles, the first two pages can be used to store the character set (line 8010), which also requires only 512 bytes.
The `RESTORE 21000` statement is added to line 10010 to again reset the READ pointers.

```
13000 REM Install Interrupt Routines
13010 POKE CRITICAL,11 REM Open CRITICAL "valve", set up detour
13020 X=SCROLL+4!
13030 GOSUB 110
13040 POKE VVBLKD,LOBYTE: REM Set VBLANK vector to SCROLL
13050 POKE VVBLKD+1,USBYTE
13060 X=DLIROUT+4!
13070 GOSUB 110
13080 POKE DLIROUT+4,LOBYTE: REM Points DLIROUT to DLIROUT
13090 POKE DLIROUT+5,USBYTE
13100 X=ANIMATE+4!
13110 GOSUB 110
13120 POKE PMOVER+4,LOBYTE: REM Points PMOVER to ANIMATE
13130 POKE PMOVER+5,USBYTE
13140 X=AUTOMOVE+4!
13150 GOSUB 110
13160 POKE ANIMATE+4,LOBYTE: REM Points ANIMATE to AUTOMOVE
13170 POKE CRITICAL+11: REM Close CRITICAL "valve", routines installed
13180 POKE CRITICAL,11 REM Close CRITICAL "valve", routines installed
13190 POKE S428&=173 REM Enable DLI's
13200 RETURN
```

Figure 9.40: Listing of Example 14 — lines 13000–13200.

PMOVER must now be connected to the previous routine, DLIROUT, rather than VVBLKD. Now all the routines are chained together.

10. Add the following new line:

```
700 REM Set Horizontal Velocities
710 IF OBJECT=3 THEN
    NSPD=120-SPEED!120
    GOTO 740: REM Tree
720 IF OBJECT=4 THEN
    NSPD=125-SPEED!
    GOTO 740: REM Truck
730 NSPD=120-SPEED!120 REM Car
740 POKE MOVERATE(0),NSPD
    POKE MOVERATE(1),NSPD
    TEMP=LASTP
750 POKE MOVERATE(0)+29,SPEED!
    POKE MOVERATE(1)+29,SPEED!
    IF WALK=-1 THEN
    TEMP=ALLP
760 POKE INITAUTOMOVE+TEMP
770 POKE SCRLSTEP,SPEED
780 RETURN
790 REM
```

Figure 9.41: Listing of Example 14 — lines 700–790.

In line 770, SCROLL receives the new SPEED by POKEing it into SCRLSTEP.

Are you ready to run the culmination of all that code entry? Make sure you have saved the program first and that LINELEN is a small
value to start. Then RUN the program and sit back and enjoy. Remember that there is quite a bit more initialization than before, so don’t panic. The screen will remain light blue for about 40 seconds before the first cloud appears on the horizon. May it be a cloud of joy.

Commercially Available Software — Scrolling and DLIs

There are currently two main uses for scrolling in games. One is to create a playing area or map that is much larger than the screen. Then the television screen becomes a moving window into this larger universe. The games Match Racer, The Adventures of Farnsworth, Caverns of Mars, and Eastern Front use scrolling in this manner. The second technique is to move a band of figures across the screen (usually in a horizontal direction). This method is used in Embargo, Chicken, and all the Frogger look alikes.

In Match Racer (by Bill Hooper, Solitaire Group, distributed by Gebelli Software, Inc.), the background consists of a race track with a number of obstacles. There are a total of eight different track sections that are randomly combined to make a continuous race track. A GRAPHICS 2 redefined character set is used for these backgrounds. Racing on the tracks are two cars (when two people are playing the game), each of which is made of two players. The priority control (GPRIOR) is set to allow multi-colored players (see Chapter 7 on priority control), so each car has three colors (the third being a result of the combination of each player’s color). The odometer numbers at the bottom of the screen are created with redefined GRAPHICS 0 characters. Also at the bottom of the screen, all four missiles are used to display the current speed. The collision registers are used to determine when a race car collides with a wall or other object.
Creating a Scrolling Background / 399

A perfect application for scrolling is in an adventure game. The entire game universe fits into memory, and the explorer can view only a portion of it at any time. This is the technique used in The Adventures of Farnsworth (by Doctor Goodcode, Gebelli Software, Inc.). You get to control Farnsworth, the little man with the red hat, moving him around the castle and adjoining maze as he fights off evil characters and bats, while searching for treasures. The background is made of a GRAPHICS 2 character set. All the figures are made of players.

Photo 9.5: Screen photos of Match Racer. (Copyright (c) 1981 by Gebelli Software, Inc.)

Photo 9.6: Screen photos of The Adventures of Farnsworth. (Copyright (c) 1982 by Gebelli Software, Inc.)
In **Caverns of Mars** (by Greg Christensen, ATARI, Inc., CX8130), the scrolling background was created in **GRAPHICS 7**. The object of this game is to make it through a number of levels of the Martian cavern defense system to activate a fusion bomb, leveling Martian Headquarters. Your fighter ship is a player and your laser torpedoes are missiles.

![Photo 9.7: Screen photo of Caverns of Mars. (Copyright (c) 1982 by ATARI, Inc.).](image)

We mentioned the game **Eastern Front (1941)** (by Chris Crawford, ATARI cartridge RX8039) earlier in this chapter. It was one of the first games to make use of fine scrolling on the ATARI Home Computer. (Chris probably knows more about how to push the ATARI Home Computer to its limits than any other programmer.) This game is a simulation of Operation Barbarossa, the German invasion of Russia towards the beginning of World War II. You control the German troops and the computer controls the Russians. The map of Russia (about ten screens large) was created entirely in **GRAPHICS 2** with two separate character sets. The second character set (as well as some new colors) is enabled during a DLI. This was rather difficult, since the mode line on which to make this switch changes as the map is scrolled up and down. Players are used for the cursor (the large pink square), the cross, and pointers (arrows, not pictured here). As you move the cursor to one of the edges of the screen, the entire map scrolls to reveal other portions. As the seasons change, so does the background — from brown (summer) to gray (muddy fall) to white (winter). Chris used vertical blank interrupts in a most ingenious way — to have the computer calculate its next move. The computer starts off with a rough guess and then refines it during each successive VBI until the human finally presses the **START** key. The longer the human takes to make a decision, the more time the computer gets to perfect its strategy!
The second use of fine scrolling makes a number of playfield objects fly across the screen. The game Embargo (by Bill Hooper, Solitaire Group, distributed by Gebelli Software, Inc.) has a beautifully laid out screen with four bands of Antic 4 ships that move horizontally across the screen. The object of the game is to fly your light blue ship (a player) past the blockade, pick up supplies (a player) on the ground, and then transport them to your mother ship (upper left of screen, Antic 4). To make things more difficult, a small brown enemy ship (another player) flies around trying to shoot you. The ships at the very bottom of the screen that show how many turns are left are also players. As many as nine players can appear on the screen simultaneously using DLI’s to move them to a new position. All the objects on the ground are made from map mode Antic E. DLI’s are also used to obtain the extra colors on the screen.
Finally, there is the delightful game called Chicken (by Mike Potter, Synapse Software). The object of the game is to catch in your wheelbarrow all the eggs that the fox is throwing down at you (the chicken). If you miss an egg, it breaks open and a chick pops out. Then, if you are clumsy enough to step on a chick, the farmer runs out and kicks you off the screen. The sifter is made of three bars of GRAPHICS 0 characters using artifacts for the color. Each bar randomly scrolls back and forth, sifting the eggs down. The fox (standing on top of the sifter), the chicken, the red of the wheelbarrow, the blue of the wheelbarrow, and the farmer are all players. The eggs and chicks are redefined GRAPHICS 0 characters.
Photo 9.10: Screen photo of Chicken. (Copyright (c) 1982 by Synapse Software.)

Film 1
This is the Running Boy from our ATARI program, Example 11.

Summary

Congratulations! You are now a graduate of our course on Personal Computer Animation. The programs in this book are intended as a jumping off place, and we would be thrilled if you will take what you have learned and apply it in some heretofore unseen examples of extraordinary animation. Part of our reason for doing this book was indeed selfish. As more of you can implement animation on a personal computer, two things will happen: 1) Fabulous new games will begin emerging on the computers that exist today, and 2) there will be a demand on the manufacturers of microcomputers to continue making rapid technological advances in their products until they match the power of today's ten million dollar real-time simulation computers. In the meantime, enjoy your personal animation machine!
Complete Listings of BASIC Program Examples

The following is a compilation of all listings from Chapters 5 through 9, reproduced in larger detail for easier reference.

```
10 REM *** FLYING BIRD ***
20 REM Example 1
30 REM
40 REM Demonstration of Character Set Animation using Atari's built-in graphics characters
50 REM Copyright (C) 1982 by David Fox and Mitchell Waite
60 REM
100 REM Initialize
110 DIM BIRD1$(17),BIRD2$(17),BIRD3$(16),BIRD4$(16)
120 BIRD1$="(DOWN)(F)(T)(G)(DOWN)(5 LEFT)(F)KK(K)"
130 BIRD2$="(DOWN)(F)(M)(T)(G)(DOWN)(5 LEFT)BBBBB"
140 BIRD3$="(S)(DOW)(5 LEFT)(2 M)(T)(2 M)"
150 BIRD4$="(S)(DOW)(5 LEFT)(M)(T)(M)"
160 POKE 752,1
170 PRINT "(CLEAR)"
180 REM
200 REM Animation Loop
210 FOR I=1 TO 6
220  ON I GOSUB 310,320,330,340,330,320
230  FOR W=1 TO 25:
240  NEXT W: REM Pause
250 NEXT I
260 GOTO 210
270 REM
300 REM Draw Frame
310 PRINT BIRD1$;
320 RETURN
330 PRINT BIRD2$;
340 RETURN
350 PRINT BIRD3$;
360 RETURN
370 PRINT BIRD4$;
380 RETURN

10 REM WALKING MAN CHARACTER SET
20 REM Example 2
30 REM
40 REM Demonstration of user-defined character set
50 REM Copyright (C) 1982 by David Fox and Mitchell Waite
60 REM
```
REM Initialize
FRAMES=5: REM Number of frames
FRMSIZE=12: REM Characters in frame (including cursor control chars)
DIM MAN$(FRAMES*FRMSIZE),FRAMES$(FRMSIZE),ERASE$(7)
MAN$(25)="k(DOWN)<2 LEFT>OdDOWN)<2 LEFT>(DOWN)<2 LEFT>ij"
MAN$(25)="w(LEFT)<2 DOWN><2 LEFT>OdDOWN)<2 LEFT>rs(LEFT)<2 LEFT)h"
MAN$(49)="uv(LEFT)<2 DOWN><2 LEFT>OdDOWN)<2 LEFT>rs(LEFT)<2 DOWN>xy" ERASE$="k(LEFT)<UP>k(LEFT)<UP>k"
REM Ini-tialis FRAMES=5; REM Number of frames
FRMSIZE=12! REM Characters in frame (including cursor control chars)
DIM MAN$(FRAMES*FRMSIZE),FRAMES$(FRMSIZE),ERASE$(7)
MAN$(25)="k(DOWN)<2 LEFT>OdDOWN)<2 LEFT>ij"
MAN$(25)="w(LEFT)<2 DOWN><2 LEFT>OdDOWN)<2 LEFT>rs(LEFT)<2 LEFT)h"
MAN$(49)="uv(LEFT)<2 DOWN><2 LEFT>OdDOWN)<2 LEFT>rs(LEFT)<2 DOWN>xy" ERASE$="k(LEFT)<UP>k(LEFT)<UP>k"

GRAPHICS 0
POKE 752,1: REM Turn off cursor
PRINT "One moment please..."
GOSUB 8000: REM Read in Character Set
PRINT "CLEARJ"
SETCOLOR 1,0,14;
SETCOLOR 2,1,2
POKE 756,HICHRB!
REM Switch to new Char Set
REM Animation Loop
X=3: REM Set starting horizontal position of Man
FOR I=1 TO FRAMES
FRAMES$=MAN$(I#FRMSIZE-(FRMSIZE-1),I#FRMSIZE)
POSITION X,14!
PRINT ERASE$;FRAME$;
IF I=1 THEN SOUND 1,0,0,14: REM Footsteps
IF I=2 THEN SOUND 1,24,0,14
SOUND 1,0,0,0: REM Turn off sound
FOR W=1 TO 10!
NEXT W!
REM Slow him down a little
NEXT I
REM Walk man across screen if Joystick button is down
IF STRIG(0)=0 THEN X=X+1!
IF X=36 THEN PRINT "CLEARJ"!
GOTO 310
GOTO 320
REM
REM Set Up Alternate Character Set
HICHRB=PEEK(106)-8: REM Reserve memory space (1024 bytes) below screen
CHRBAS=HICHRB«256!
REM Find start of Character Set
READ TOTAL!
TEMP=0
FOR I=CHRBAS+OFFSET TO CHRBAS+OFFSET+CHARS*3-1
READ BYTE!
POKE I,BYTE!
TEMP=TEMP+BYTE
NEXT I
IF TOTAL<>TEMP THEN
GRAPHICS 0:
PRINT "ERROR In Character Set Data": END
REM Clear out first char (background)
FOR I=CHRBAS TO CHRBAS+7
POKE I,0
NEXT I
RETURN
REM Character Set Data
10 REM  GALLOPING HORSE DEMO  Example 3
20 REM
30 REM  Example using the technique of flipping through multiple character sets
40 REM  Copyright (C) 1982 by David Fox and Mitchell Waite
50 REM
60 REM
100 REM  Initialize
110 FRAMES=5: REM Number of frames
120 DIM HICHRB(FRAMES)
130 GRAPHICS 0
140 POKE 752,11 REM Turn off cursor
150 PRINT "One moment please..."'
160 GOSUB 60000 REM Read in Character Set
170 PRINT "CLEAR"
180 SETCOLOR 1,0,21
190 SETCOLOR 2,1101
200 SETCOLOR 4,1110
210 POKE 756,HICHRB(1): REM Switch to Frame 1 Char Set
220 REM  Fill Screen With Horses
230 FOR Y=0 TO 20 STEP 4
240 FOR X=2 TO 32 STEP 6
250 POSITION X,Y:
260 PRINT "wwwabc"
240 POSITION X,Y+1:
PRINT "deghit"
250 POSITION X,Y+2:
PRINT "jklmno"
260 POSITION X,Y+3:
PRINT "pqrsu"!
270 NEXT X
280 NEXT Y
290 REM
300 REM Animation Loop
310 FOR I=1 TO FRAMES
320 POKE 756,HICHRB(I)
330 IF I=3 THEN
SOUND 0,0,8,10!
SOUND 0,0,0,0: REM Hoof Beats
340 FOR W=1 TO PADDLE(0): NEXT W: REM Use 15 if you don't have paddles
350 NEXT I
360 GOTO 310
370 REM
8000 REM Set Up Alternate Character Set
8010 HICHRB=PEEK(106)-24: REM Reserve mem space (5 X 1024 bytes) below screen
8020 OFFSET=97*8:
CHARS=21
8030 READ TOTAL:
TEMP=0
8040 FOR J=1 TO FRAMES
8050 HICHRB(J)=HICHRB+4*(J-1): REM Find start of Character Sets
8060 REM Read in data, skip first 97 characters
8070 CHRBA8=HICHRB(J)+256
8080 FOR I=CHRBA8+OFFSET TO CHRBA8+OFFSET+CHARS*8-1
8090 READ BYTE:
POKE I,BYTE:
TEMP=TEMP+BYTE
8100 NEXT I
8110 REM Clear out first char (background)
8120 FOR I=CHRBA8 TO CHRBA8+7
8130 POKE I,0
8140 NEXT I
8150 PRINT ",,"
8160 NEXT J
8170 IF TOTAL>TEMP THEN
GRAPHICS 0!
PRINT "ERROR In Character Set Data!"
END
8180 RETURN
8190 REM
20000 REM Horse Character Set Data
20010 REM :Checksum
20020 DATA 46921
20030 REM
20040 REM Frame 1
20050 DATA 0,0,0,0,1,1,6,15,0,0,0,6,118,155,127,247,231,0,0,0,128,192,32,136
20060 DATA 0,0,0,3,14,29,5,0,0,0,3,232,188,14,11,11,0,0,255,31,0,24,31,157
20070 DATA 59,15,254,192,0,0,0,240,135,14,60,124,12,8,6,56,196,204,48,0,0,0,0
20080 DATA 0,0,0,0,0,0,0,0,15,5,126,127,97,99,103,99,207,223,243,224,192,192,128
20090 DATA 292,191,223,127,3,1,11,11,12,248,254,142,232,248,128,128,0,0,0,0,0,0
20100 DATA 1,1,0,0,0,0,0,193,128,0,0,0,0,0,192,224,112,24,28,0,0
20110 DATA 1,1,1,0,0,0,0,0,128,192,224,48,56,0,0,0,0,0,0,0,0
20120 REM
20130 REM Frame 2
20140 DATA 0,0,0,1,5,6,59,87,0,0,12,190,121,248,252,191,0,0,0,0,128,32,208
20150 DATA 0,0,0,3,7,15,29,0,0,0,7,252,208,151,31,31,15,0,255,32,32,108,255,255,255
10 REM *** EXPLODING BOMB PROGRAM ***
20 REM
30 REM Program to demonstrate the three color text mode - ANTI 4
40 REM Copyright (C) 1982 by David Fox and Mitchell Waite
50 GOTO 110
60 REM Hi-speed Subroutines
70 SOUND 0,RND(0)*150+30,0,VOL:
80 SOUND 1,RND(0)#80+175,2,VOL:
90 SOUND 2,RND(0)*150+30,8,VOL:
100 RETURN : REM Sound
110 FOR I=1 TO 10!
120 POKE 712,RND(0)*255:
130 NEXT I:
140 POKE 712,0:
150 RETURN : REM Flash
160 SETCOLOR 0,4,LUM(0):
170 SETCOLOR 1,2,LUM(1):
180 SETCOLOR 2,1,LUM(2):
190 RETURN : REM Color
200 REM Initialize
210 FRMSIZE=4: REM Number of frames
220 FRMSET=7: REM Characters in frame (including cursor control chars)
230 DIM EXPL(4*FRMSIZE),FRMSIZE,FRMSET,LUM(2)
240 EXPL="ab\DON(2 LEFT)ddef\DON(2 LEFT)ghij\DON(2 LEFT)klmn\DON(2 LEFT)op"
250 GRAPHICS 0
260 POKE 752,11: REM Turn off cursor
270 PRINT "One moment please...";
280 GOSUB 8000: REM Read in Character Set
290 PRINT "CLEAR"
400 / Appendix A

220 GOSUB 6000: REM Alter Display List
230 POKE 756, HICHRB: REM Switch to new Char Set
240 REM
250 REM Animation Loop
260 LUM(0)=61
270 LUM(1)=61
280 LUM(2)=12:
290 VOL=14
300 REM (n*w) Char Sat
310 LOM(0)=6J
320 LUM(1)=8:
330 LUM(2)=12:
340 GOSUB 600: REM Falling Bomb
350 GOSUB 70: REM Set colors
360 FOR I=1 TO FRAMES
370 FRAME$=EXP$(I*FRMSZE-(FRMSZE-1)*I*FRMSZE)
380 POSITION X,Y:
390 PRINT FRAME$;
400 NEXT I
410 FOR J=0 TO 2: REM Fade out explosion
420 LUM(J)=LUM(J)-2
430 IF LUM(J)<0 THEN
440 LUM(J)=0
450 NEXT J
460 GOSUB 90:
470 IF LUM(2)=0 THEN 410
480 IF VOL>0 THEN
490 VOL=VOL-1:
500 GOSUB 70: REM Fade sound off
510 NEXT W: REM Random pause
520 GOTO 310
530 REM
540 REM Falling Bomb
550 SETCOLOR 0,3,8:
560 SETCOLOR 1,7,6:
570 SETCOLOR 2,5,6
580 X=INT(RND)*36+2:
590 Y=INT(RND)*10+12:
600 FOR I=0 TO Y-1:
610 SOUND 0,1+2*16,10,8
620 POSITION X,1:
630 PRINT "<DOWN><LEFT>q";
640 SOUND 0,1+2*17,10,8
650 NEXT I
660 PRINT "<CLEAR>";
670 SOUND 0,0,0,0
680 RETURN
690 REM
700 REM
710 REM Modify Display List
720 DLIST=PEEK(560)+PEEK(561)*256: REM Find Display List
730 POKE DLIST+3,68:
740 FOR I=6 TO 28:
750 POKE DLIST+I,4:
760 NEXT I: REM Lines 2 through 24
770 RETURN
780 REM
790 REM Set Up Alternate Character Set
800 HICHRB=PEEK(106)+8: REM Reserve memory space (1024 bytes) below screen
810 CHRBB=HICHRB+256: REM Find start of Character Set
8030 REM Read in data, skip first 97 characters
8040 OFFSET=97*8!
8050 CHAR=$17
8060 READ TOTAL:
8070 FOR I=CHR$+OFFSET TO CHR$+OFFSET+CHAR$-1
8080 READ BYTE:
8090 POKE I,BYTE:
8100 NEXT I
8110 IF TOTAL=TEMP THEN
8120 GRAPHICS 0!
8130 PRINT "ERROR In Character Set Data"
8140 END
8150 NEXT I
8160 REM
20000 REM Character Set Data
20010 REM . Checksum
20020 DATA 8264
20030 REM
20040 REM . Frame 1
20050 DATA 0,0,0,0,3,50,10,2
20060 DATA 0,0,0,0,16,128,128,176
20070 DATA 58,10,1,3,0,0,0,0
20080 DATA 160,172,196,64,0,0,0,0
20090 REM
20100 REM . Frame 2
20110 DATA 0,0,0,8,2,43,11,3
20120 DATA 0,0,0,0,32,180,192,224
20130 DATA 11,3,15,24,32,64,0,0
20140 DATA 232,192,48,32,16,0,0,0
20150 REM
20160 REM . Frame 3
20170 DATA 0,0,0,65,17,34,43,11
20180 DATA 0,0,16,32,128,208,228,249
20190 DATA 27,91,26,2,10,8,24,0
20200 DATA 228,208,192,160,16,4,4,0
20210 REM
20220 REM . Frame 4
20230 DATA 64,80,20,25,26,10,91,27
20240 DATA 135,132,152,168,16,228,229,245
20250 DATA 11,27,106,86,2,10,5,4
20260 DATA 228,208,164,182,165,32,20,4
20270 REM
20280 REM . Bomb
20290 DATA 20,215,215,60,60,60,40,40

10 REM *** MOVING COLOR CURTAIN ***
20 REM
30 REM
40 REM Program to demonstrate Color Register Animation in GRAPHICS 10
50 REM (GTIA chip required)
60 REM Copyright (C) 1982 by David Fox and Mitchell Waite
70 REM
80 GOTO 200
90 REM
100 REM Rotate Color Registers
110 TEMP=PEEK(705)
120 FOR I=705 TO 711:
   POKE I,PEEK(I+1):
NEXT I: REM Rotate colors
130 POKE 712,TEMP:
GOTO 110
140 REM
200 REM Initialize
210 GRAPHICS 10: REM GTIA Mode - 80 X 192 with 9 color registers
220 COL=11
   LUM=8: REM Set starting COLOR Register & LUMinance values
230 REM
240 REM Set initial colors
250 POKE 704,0: REM Background to black
260 FOR I=1 TO 8: REM Other registers to different colors
270 POKE 704+I,I*16+LUM
280 NEXT I
290 REM
300 REM Draw Bars, Increment COLOR
310 FOR I=0 TO 79
320   COLOR COL
330   PLOT I,0
340   DRAWTO L191
340   IF I<40 THEN
350     COL=COL-11
360     IF COL=0 THEN
370       COL=8
380     IF I>40 THEN
390       COL=COL+11
400     IF COL=9 THEN
410       COL=1
420 NEXT I
430 GOTO 100
10 REM *** THE TRENCH ***
20 REM
30 REM Example 6
40 REM Program to create the illusion of flying through a trench by rotating
50 REM the Color Registers in GRAPHICS 7
60 REM Copyright (C) 1982 by David Fox and Mitchell Waite
70 REM
80 GOTO 200
90 REM
100 REM Rotate the Colors
110 SOUND 3,255,0,8: REM Background roar (always on)
120 REM If the trigger on PADDLE 0 is pressed, reverse the direction
130 IF PTRIG(0)=1 THEN
135   TEMP=PEEK(710):
140   POKE 710,PEEK(709):
145   POKE 709,PEEK(708):
150   POKE 708,TEMP:
155 GOTO 150: REM Not pressed
160 TEMP=PEEK(708):
165 POKE 708,PEEK(709):
170 POKE 709,PEEK(710):
175 POKE 710,TEMP: REM Pressed
180 PDL=PADDLE(0)/5: REM Speed and sound controlled by PADDLE 0
190 FOR PAUSE=1 TO PDL:
195 IF PAUSE=1 THEN
197 FOR I=0 TO 79:
200   POKE 704+I,I*16+LUM:
205 NEXT I
210 GOTO 120
220 NEXT PAUSE
190 REM
200 REM Initialize
210 COL=1;  
   Y1=45;  
   Y2=49  
220 REM
300 REM Draw Trench on Screen
310 GRAPHICS 7+16: REM Full screen graphics
320 SETCOLOR 0,3;8: REM Set Color Register values
330 SETCOLOR 1,3;8
340 SETCOLOR 2,3;4
350 FOR X=2 TO 79: REM Increment horizontal coordinates
360   COLOR INT(COL+0.5): REM Choose which Color Register to draw with
370   PLOT X+80,Y1:  
   DRAWTO X+80,Y2:  
   DRAWTO 79-X,Y2:  
   DRAWTO 79-X,Y1
380   Y1=Y1-0.6;  
   Y2=Y2+0.6: REM Increase vertical line length
390 IF Y1<0 THEN  
   Y1=0: REM Prevent overflow
400 IF Y2>95 THEN  
   Y2=95
410   COL=COL+(79-X)/160: REM Increment Color Register
420 IF COL+0.5>=4 THEN  
   COL=C0L-3
430 NEXT X
440 GOTO 100

10 REM *** FALL WATERFALL ***
20 REM Example 7
30 REM
40 REM Demonstration of animating a scene by rotating the Color Registers
50 REM (Uses GRAPHICS 10 - GTIA is needed)
60 REM Copyright (C) 1982 by David Fox and Mitchell Waite
70 REM
80 GOTO 200
90 REM
100 REM Rotate the Colors
110 TEMP=PEEK(705);  
   POKE 705,PEEK(706);  
   POKE 706,PEEK(707);  
   POKE 707,PEEK(708);  
   POKE 708,TEMP
120 FOR WT=1 TO 5:  
   NEXT WT
130 GOTO 110
140 REM
200 REM Initialize
210 FILL=1300
220 GRAPHICS 10
230 POKE 704,9*16+10: REM Sky - COLOR 0
240 POKE 705,8*16+10: REM Water - COLOR 1
250 POKE 706,8*16+8: REM Water - COLOR 2
260 POKE 707,8*16+6: REM Water - COLOR 3
270 SETCOLOR 0,6;4: REM Water - COLOR 4
280 SETCOLOR 1,12;4: REM Tree shadow - COLOR 5
290 SETCOLOR 2,2;4: REM Cliff & tree trunks - COLOR 6
300 SETCOLOR 3,12;6: REM Grass - COLOR 7
310 SETCOLOR 4,3;6: REM Treetops - COLOR 8
320 REM
400 REM Draw Grass and Cliff
COLOR 7:
POKE 765,7: REM The grass
PLOT 79,10:
DRAWTO 79,45:
X1=78:
Y1=10:
X2=66:
Y2=15:
GOSUB FILL

X1=65:
Y1=15:
X2=61:
Y2=18:
GOSUB FILL:
X1=60:
Y1=18:
X2=56:
Y2=25:
GOSUB FILL

X1=56:
Y1=25:
X2=65:
Y2=35:
GOSUB FILL:
X1=66:
Y1=35:
X2=78:
Y2=45:
GOSUB FILL

COLOR 6:
POKE 765,6: REM The cliff
PLOT 79,46:
DRAWTO 79,145:
X1=-56:
Y1=26:
X2=56:
Y2=117:
GOSUB FILL

Y1=117:
X2=68:
Y2=132:
GOSUB FILL:
X1=68:
Y1=132:
X2=78:
Y2=145:
GOSUB FILL

COLOR 7:
POKE 765,7: REM More grass
PLOT 6,191:
DRAWTO 79,191:
DRAWTO 79,146:
X1=0:
Y1=191:
X2=0:
Y2=91:
GOSUB FILL

REM Draw the Falls and River
FALL=58:
CFLAG=0: REM Draw the river on top of the cliff
FOR Y=25 TO 34
GOSUB 1500
FOR X=79 TO FALL STEP -1
COLOR COL
PLOT X,Y
COL=COL-1:
    IF COL=0 THEN
        COL=4
NEXT X
FALL=FALL+1
NEXT Y
FALL=0:
    CFLAG=-1: REM Draw the falls
FOR X=58 TO 66
    FALL=FALL+1
    GOSUB 1500
    PLOT X,25+FALL
    FOR Y=30 TO 120 STEP 4
        COLOR COL
        DRAWTO X,Y+FALL
        COL=COL-1:
        IF COL=0 THEN
            COL=4
    NEXT Y
NEXT X
COLOR 6:
    PLOT 59,26:
    DRAWTO 60,25:
    DRAWTO 60,25:
    PLOT 65,36:
    DRAWTO 66,129: REM Cleanup
COLOR 7:
    PLOT 73,33:
    DRAWTO 79,33:
    PLOT 78,34:
    DRAWTO 79,34
FALL=57:
    CFLAG=1: REM Draw the river on the valley floor
FOR Y=121 TO 128
    GOSUB 1500
    FOR X=FALL TO 0 STEP -1
        COLOR COL
        PLOT X,Y
        COL=COL-1:
        IF COL=0 THEN
            COL=4
    NEXT X
NEXT Y
FALL=FALL+1
NEXT X
NEXT Y
REM Draw the Trees
FOR T=1 TO 11
READ X,Y
COLOR 8: REM Treetop
FOR I=0 TO 2:
    PLOT X-I,Y-40+2*I:
    DRAWTO X-I,Y-20-2*I:
NEXT I
FOR I=-2 TO -1:
    PLOT X-I,Y-40-2*I:
    DRAWTO X-I,Y-20+2*I:
NEXT I
COLOR 6: REM Tree trunk
PLOT X,Y:
DRAWTO X,Y-21
COLOR 5: REM Shadow of tree
Appendix A

406 PLOT X,Y+1
  DRAWTO X+7,Y+4
  PLOT X+8,Y+3
  DRAWTO X+9,Y+6
1000 DRAWTO X+9,Y+3
  DRAWTO X+10,Y+3
  DRAWTO X+9,Y+7
1010 PLOT X+11,Y+7
  DRAWTO X+11,Y+4
  DRAWTO X+12,Y+3
  DRAWTO X+12,Y+7
1020 COLOR 8! REM Fallen leaves around tree trunk
1030 FOR I=1 TO 15
1040 RX=X+INT(RND(1)*7)-3
  IF RX=X THEN 1040
1050 RY=Y+INT(RND(1)*8)-3
  PLOT RX,RY
1060 NEXT I
1070 NEXT T
1080 REM
1100 REM Draw the Foam
1110 COLOR 0! REM Same color as the sky
1120 PLOT 57,114!
  DRAWTO 65,122
1130 PLOT 57,115!
  DRAWTO 65,123
1140 PLOT 57,116!
  DRAWTO 65,124
1150 PLOT 56,114!
  DRAWTO 65,125
1160 PLOT 56,117!
  DRAWTO 65,126
1170 PLOT 56,118!
  DRAWTO 65,127
1180 PLOT 56,119!
  DRAWTO 65,128
1190 PLOT 55,119!
  DRAWTO 64,128
1200 PLOT 55,120!
  DRAWTO 63,128
1210 REM
1220 REM Turn on the Sound
1230 FOR I=0 TO 3!
  SOUND 1,1*50,0,8!
  NEXT I
1240 GOTO 100
1250 REM
1260 REM Fill Subroutine
1270 PLOT X1,Y1!
  POSITION X2,Y2!
  X IO 16,#6,0,0,"S!"
1280 RETURN
1290 REM
1300 REM Choose Color
1310 COL=INT(RND(1)*4)+1!
  IF COL=STARTCOL THEN 1510! REM No two adjacent strips with same color pattern
1320 STARTCOL=COL+CFLAG! REM Calculate next starting color to avoid
1330 IF STARTCOL=0 THEN
1340 STARTCOL=4
1350 IF STARTCOL=5 THEN
1360 STARTCOL=1
1370 RETURN
Appendix A

1560 REM
2000 REM Data for Location of Trees
2010 DATA 7,106,13,96,30,100,40,112,47,145,7,179,15,155,27,164,35,173,60,181,66,174

10 REM *** BOUNCING BALL 1 PROGRAM ***
20 REM Example 8
30 REM
40 REM Program to demonstrate Player-Missile Graphics using string manipulation
50 REM Copyright (C) 1982 by David Fox and Mitchell Haite
60 REM
70 DIM PLR0$(128);
80 REM This MUST be the first variable in the program
90 REM
100 REM Hi/Lo Byte Calculation
110 HIBYTE=INT(X/256); REM Calculate High Byte
120 LOBYTE=X-HIBYTE*256; REM Calculate Low Byte
130 RETURN
140 REM Initialize
150 DIM BLANK$(128), PLR(3), HPLR(3)
160 BLANK$(1)=CHR$(0);
170 BLANK$(128)=CHR$(0);
180 BLANK$(2)=BLANK$(1); REM Fill with blanks
190 GRAPHICS 3;
200 POKE 752,11;
210 PRINT "One moment please..."; REM Turn off cursor, print message
220 GO SUB 5000; REM Set up memory locations
230 GO SUB 7000; REM Set up Player area
240 GO SUB 9000; REM Point PLR0$ to Player 0 RAM
250 GO SUB 10000; REM Read frames into RAM
260 PRINT "***********BOUNCING BALL DEMO***********"
270 VEL=70;
280 ELASTIC=0.8
290 PRINT "Initial velocity: "VEL;
300 PRINT "Elasticity: "ELASTIC;
310 REM
320 REM Main Animation Loop
330 BOTTOM=91;
340 XP08=40;
350 TIME=.5;
360 HORIZ=0.75
370 GO SUB 7000; REM Move Player off screen
380 IF ELASTIC<0.1 THEN
390 SNDFLAG=1
400 YPOS=BOTTOM-(VEL*TIME-16*TIME*TIME);
410 FRMNO=1
420 IF YPOS<82 AND VEL>30 THEN
430 FRMNO=2
440 IF YPOS>BOTTOM THEN
450 YPOS=BOTTOM;
460 VEL=VEL*ELASTIC;
470 TIME=0;
480 FRMNO=1;
490 IF VEL>14 THEN
500 FRMNO=3
510 IF XP08>220 OR YPOS<1 THEN 600
520 POKE HPLR(0),XP08
530 FRAME=FRAME+1; REM Select correct frame
540 BUFFER=BLANK$(1); REM Fill buffer with blanks
550 BUFFER=YPOS,YPOS,FRAME$(1); REM Move current frame into buffer
560 PLR0$=BUFFER$; REM Move buffer into Player 0 RAM
570 XP08=XP08+HORIZ
540 IF YPOS=0 AND (VEL+SNDFLAG>0.5) THEN
    SOUND 1,250,10,14;
    SNDFLAG=0;
7000 REM Set Up Memory Locations
7100 READ FRAMES,FRMSIZE,NUMPLRS
7200 PLRFRMMEM=FRAMES*FRMSIZE
7300 FRAMEMEM=PLRFRMMEM*NUMPLRS
7400 DIM BUFFER$(128),FRAME$(FRMSIZE),FRAMEMEM#(FRAMEMEM)
7500 RETURN
7600 REM
7700 REM Point PLR0$ to Player 0 RAM
7800 STARP=PEEK(140)+PEEK(141)*256:REM Start of String Array area
7900 VVTP=PEEK(134)+PEEK(135)*256:REM Start of Variable Value Table
8000 OFFSET=PLR(0)-STARP:REM Calculate offset from String Array to Player 0
8100 X=OFFSET:
8200 GOSUB 110
8300 POKE VVTP+2,LOBYTE:REM Poke offset of string into Variable Value Table
8400 POKE VVTP+3,HIBYTE:REM This points the first string (PLR0$) to PLR(0)
8500 RETURN
8600 REM
8700 REM Read in Frame Data
8800 FOR J=1 TO PLRFRMMEM
8900 READ BYTE
REM *** Bouncing Ball 2 Program ***

Example 9

REM Program to demonstrate Player-Missile Graphics with Machine Language routine to move players
REM Copyright (C) 1982 by David Fox and Mitchell Waite

DIM PLR0(128)
GOTO 1401 REM This MUST be the first variable in the program

REM Hi/Lo Byte Calculation

HIBYTE=INT(X/256) REM Calculate High Byte
410 / Appendix A

120 LOBYTE=X-HIBYTE*256: REM Calculate Low Byte
130 RETURN
140 REM Initialize
150 DIM PLR(3),HPLR(3),VPLR(3)
170 GRAPHICS 3:
POKE 752,11
  PRINT "One moment please...": REM Turn off cursor, print message
180 GOSUB 11000: REM Initialize Routine strings
190 GOSUB 50001: REM Set up memory locations
220 GOSUB 70001: REM Set up Player area
230 GOSUB 90001: REM Point PLR0% to Player 0 RAM
240 GOSUB 100001: REM Read frames into RAM
280 GOSUB 1200001: REM Set up parameter addresses
290 GOSUB 1300001: REM Turn on interrupts
300 PRINT "*CLEAR**********BouncingBallDemo**"*
310 VEL=70:
320 PRINT "Initial velocity: "VEL;
330 PRINT "Elasticity: "ELASTIC;
340 REM
350 REM Main Animation Loop
360 BOTTOM=911:
  XPOS=401:
  TIME=0.51:
  HORIZ=0.75:
370 GOSUB 70001: REM Move Player off screen
380 IF ELASTIC<=0.1 THEN
  SNDFLAG=1
390 YPOS=BOTTOM-(VEL*TIME-16*TIME**TIME):
  FRMNO=1
400 IF YPOS>82 AND VEL>3 THEN
  FRMNO=2
410 IF YPOS>=BOTTOM THEN
  YPOS=BOTTOM:
  VEL=VEL*ELASTIC:
  TIME=0:
  FRMNO=1:
  IF VEL>14 THEN
    FRMNO=3
420 IF XPOS>220 OR YPOS<=1 THEN 600
430 POKE HPLR(0),XPOS:
  POKE VPLR(0),YPOS:
  TEMP=USR(PMOVER,PO)
440 FRAME=FRAMEMEM{(FRMNO-1)*FRMSIZE+1,FRMNO*FRMSIZE}:
  REM Select correct frame
450 PLR0(YPOS)=FRAME:
  REM Move new frame into Player 0
460 XPOS=XPOS+HORIZ:
470 IF VEL>0.5 THEN TIME=TIME+0.15:
  GOTO 440
480 HORIZ=HORIZ-0.01:
  IF HORIZ<0 THEN
    FRMNO=1:
    GOTO 470
500 REM
510 REM Get Parameters for Ball
520 GOSSUB 7001:
530 POKE 752,01: REM Turn on cursor
540 PRINT "*CLEAR>Enter initial velocity!: "";
640 TRAP 630!
   INPUT VEL
650 PRINT "Enter the ball's elasticity (a number)";
   PRINT "from 0-1 for more)";
660 INPUT ELASTIC
670 POKE 752,1!
   PRINT "Turn off cursor"
680 TRAP 40000!
   GOTO 400
690 REM
700 REM Move Player 0 to Left of Screen
710 POKE HPLR(0),0
720 TEMP=USR(PMOVER,0)
730 RETURN
740 REM
5000 REM Set Up Memory Locations
5090 READ FRAMES,FRMSIZE,NUMPLRS
5110 PLRFRMMEM=FRAMES*FRMSIZE
5120 FRAMEMEM=PLRFRMMEM*NUNMPLRS
5160 DIM BUFFER$(128),FRAME$(FRMSIZE),FRAMEMEM$(FRAMEEMEM)
5270 PMOVER=ADR(PMOVER*)
5300 MFILL=ADR(MFILL*)
5310 BUFFER=ADR(BUFFER*)
5340 RETURN
5350 REM
7000 REM Initialize Player-Missile Graphics
7010 TEMP=PEEK(106)-8; REM Set aside Player-Missile area
7020 POKE 54279,TEMP; REM Tell ANTIC where PM RAM is
7030 PMBASE=256*TEMP; REM Find PM Base address
7040 FOR I=0 TO 3
7050 PLR(I)=PMBASE+128*I+512; REM Set addresses of Players
7060 NEXT I
7070 NEXT I
7080 POKE 559,42; REM Set PM 2 line resolution, Players enabled
7090 POKE 704,12+6; REM Color ball green
7100 POKE 53277,2; REM Enable Player display
7110 TEMP=USR(MFILL,PLR(0),512,0); REM Use memory fill routine to clear Players
7120 RETURN
7130 REM
9000 REM Point PLR$ to Player 0 RAM
9010 STARP=PEEK(140)+PEEK(141)*256; REM Start of String Array area
9020 VVTP=PEEK(134)+PEEK(135)*256; REM Start of Variable Value Table
9030 OFFSET=PLR(0)-STARP; REM Calculate offset from String Array to Player 0
9040 X=OFFSET:
9050 POKE VVTP+2,LOBYTE; REM Poke offset of string into Variable Value Table
9060 POKE VVTP+3,HIبت.; REM This points the first string (PLR$) to PLR(0)
9070 RETURN
9080 REM
10000 REM Read In Frame Data
10090 FOR J=1 TO PLRFRMMEM
10100 READ BYTE
10110 FRAMEEMEM$(J,J)=CHR$(BYTE)
10120 NEXT J
10130 RETURN
10140 REM
11000 REM INITIALIZE ROUTINE STRINGS
11300 REM Set PMOVER routine
11310 DIM PMOVER$(186)
11320 PMOVER$(1)="<<Routine String goes here>>"
11330 PMOVER$(19)="<<Routine String goes here>>"
11340 PMOVER$(181)="<<Routine String goes here>>"
11600 REM Set MFILL routine
11610 DIM MFILL$(41)
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<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>11620</td>
<td>\texttt{MFILL(1)=&quot;&lt;&lt;&lt;Routine String goes here&gt;&gt;&gt;&quot;}</td>
</tr>
<tr>
<td>11650</td>
<td>\texttt{RETURN}</td>
</tr>
<tr>
<td>11660</td>
<td>\texttt{REM}</td>
</tr>
<tr>
<td>12000</td>
<td>\texttt{REM Set Parameters for Routines}</td>
</tr>
<tr>
<td>12010</td>
<td>\texttt{PARAMBASE=1024: \texttt{REM Parameter Base address}}</td>
</tr>
<tr>
<td>12020</td>
<td>\texttt{PMBASE=PARAMBASE: \texttt{REM Hi Byte of PLR0 Location goes here}}</td>
</tr>
<tr>
<td>12030</td>
<td>\texttt{PMBUF=PARAMBASE+1: \texttt{REM Address of a 128 byte buffer}}</td>
</tr>
<tr>
<td>12070</td>
<td>\texttt{FOR I=0 TO 3}</td>
</tr>
<tr>
<td>12080</td>
<td>\texttt{HPLRI=PARAMBASE+4+I: \texttt{REM Player horizontal &quot;shadow&quot; registers}}</td>
</tr>
<tr>
<td>12090</td>
<td>\texttt{VPLRI=PARAMBASE+10+I: \texttt{REM Player vertical &quot;shadow&quot; registers}}</td>
</tr>
<tr>
<td>12100</td>
<td>\texttt{NEXT I}</td>
</tr>
<tr>
<td>12190</td>
<td>\texttt{VVBLKD=548: \texttt{REM Deferred Vertical Blank Interrupt Vector}}</td>
</tr>
<tr>
<td>12200</td>
<td>\texttt{CRITICAL=66: \texttt{REM Critical Flag}}</td>
</tr>
<tr>
<td>12210</td>
<td>\texttt{PO=1;}</td>
</tr>
<tr>
<td>12220</td>
<td>\texttt{PI=2;}</td>
</tr>
<tr>
<td>12230</td>
<td>\texttt{P2=4;}</td>
</tr>
<tr>
<td>12240</td>
<td>\texttt{P3=8;}</td>
</tr>
<tr>
<td>12250</td>
<td>\texttt{TEMP=USR(MFILL,PARAMBASE,94,0):}</td>
</tr>
<tr>
<td>12260</td>
<td>\texttt{X=PLR(0): \texttt{GO}_SUB \texttt{110!} \texttt{POKE PMBASE,HIBYTE: \texttt{REM Poke Hi Byte of Bayer 0 into PMBASE}}</td>
</tr>
<tr>
<td>12270</td>
<td>\texttt{X=BUFFER: \texttt{GO}_SUB \texttt{110!} \texttt{POKE PMBUF,LOBYTE: \texttt{REM Poke address of buffer}}</td>
</tr>
<tr>
<td>12280</td>
<td>\texttt{POKE PMBUF+1,HIBYTE:}</td>
</tr>
<tr>
<td>12290</td>
<td>\texttt{RETURN}</td>
</tr>
<tr>
<td>12520</td>
<td>\texttt{RETURN}</td>
</tr>
<tr>
<td>12540</td>
<td>\texttt{REM}</td>
</tr>
<tr>
<td>13000</td>
<td>\texttt{REM Install Interrupt Routine}</td>
</tr>
<tr>
<td>13500</td>
<td>\texttt{POKE CRITICAL+1: \texttt{REM Open CRITICAL &quot;valve&quot;, set up detour}}</td>
</tr>
<tr>
<td>13580</td>
<td>\texttt{X=PMOVER+6:}</td>
</tr>
<tr>
<td>13590</td>
<td>\texttt{GO}_SUB \texttt{110}</td>
</tr>
<tr>
<td>13600</td>
<td>\texttt{POKE VVBLKD,LOBYTE: \texttt{REM Set VBLANK vector to PMOVER}}</td>
</tr>
<tr>
<td>13610</td>
<td>\texttt{POKE VVBLKD+1,HIBYTE:}</td>
</tr>
<tr>
<td>13620</td>
<td>\texttt{RETURN}</td>
</tr>
<tr>
<td>13710</td>
<td>\texttt{FRAME DATA}</td>
</tr>
<tr>
<td>20040</td>
<td>\texttt{REM Number of Frames, Frame Size, Number of Players}</td>
</tr>
<tr>
<td>20050</td>
<td>\texttt{REM {Bouncing Ball}}</td>
</tr>
<tr>
<td>20060</td>
<td>\texttt{DATA 3,7,1}</td>
</tr>
<tr>
<td>21010</td>
<td>\texttt{REM Frame data for Bouncing Ball}</td>
</tr>
<tr>
<td>21020</td>
<td>\texttt{DATA 0,60,126,126,126,60,0}</td>
</tr>
<tr>
<td>21030</td>
<td>\texttt{DATA 0,60,126,126,126,60,0}</td>
</tr>
<tr>
<td>21040</td>
<td>\texttt{DATA 24,60,60,60,60,24}</td>
</tr>
<tr>
<td>21050</td>
<td>\texttt{DATA 0,60,126,126,60,0}</td>
</tr>
<tr>
<td>27000</td>
<td>\texttt{REM \texttt{ANIMATE,11410,294,34779}}</td>
</tr>
<tr>
<td>27030</td>
<td>\texttt{DATA 184,80,3,76,98,228,216,162,3,181,224,157,89,4,202,16,248,173,3,4,240,237,48,72,10}</td>
</tr>
<tr>
<td>27040</td>
<td>\texttt{DATA 10,141,80,4,162,0,78,5,4,176,16,144,3,240,128,157,141,3}</td>
</tr>
<tr>
<td>27050</td>
<td>\texttt{DATA 4,200,8,189,1,4,208,2,169,255,157,46,4,138,10,168,155,18,4,153,50,4,185,19,4}</td>
</tr>
<tr>
<td>27060</td>
<td>\texttt{DATA 153,51,4,173,80,4,4,214,189,14,4,157,55,4,159,1,157,62,0,4,208,201,169,0,133,224}</td>
</tr>
<tr>
<td>27070</td>
<td>\texttt{DATA 173,0,4,133,225,162,0,189,46,4,240,9,201,255,240,37,222,58,4,240,25,165,224,73,128}</td>
</tr>
<tr>
<td>27080</td>
<td>\texttt{DATA 133,224,208,2,230,225,232,224,4,208,227,169,88,4,149,223,202,208,248,240,149,189,46,4,201}</td>
</tr>
<tr>
<td>27090</td>
<td>\texttt{DATA 255,208,2,169,1,157,58,4,138,10,168,155,50,4,133,226,185,54,1,133,227,354,62,4,189}</td>
</tr>
<tr>
<td>27100</td>
<td>\texttt{DATA 6,2,168,177,226,208,9,169,2,157,62,4,208,244,80,186,141,80,4,206,80,4,160,0,177}</td>
</tr>
<tr>
<td>27110</td>
<td>\texttt{DATA 220,72,200,177,226,133,227,104,133,226,136,177,226,141,81,4,169,0,160,8,78,80,4,144,4}</td>
</tr>
<tr>
<td>27120</td>
<td>\texttt{DATA 24,109,81,4,174,110,82,4,136,208,240,168,173,82,2,156,101,226,139,226,152,101,227,133,227}</td>
</tr>
<tr>
<td>27130</td>
<td>\texttt{DATA 142,80,4,189,42,4,168,162,0,140,82,4,138,168,177,226,172,82,4,145,224,200,232,236,81}</td>
</tr>
<tr>
<td>27140</td>
<td>\texttt{DATA 4,208,237,174,80,4,189,46,4,201,255,208,3,254,46,4,184,80,151}</td>
</tr>
</tbody>
</table>
REM *** WALKING MAN PLAYER DEMO ***
Example 10
REM Program to introduce the Animate Machine Language routine with the walking man
REM Copyright (C) 1982 by David Fox and Mitchell Waite
REM
GOTO 140
REM
REM Hi/Lo Byte Calculation
HIBYTE=INT(X/256) REM Calculate High Byte
LOBYTE=X-HIBYTE*256 REM Calculate Low Byte
RETURN
REM Initialize
DIM PLR(3),HPLR(3),VPLR(3),RATE(3),FRML8TPTR(3),FRMDATA(3)
GRAPHICS 3:
POKE 752, i:
PRINT "One moment please..." REM Turn off cursor, print message
GOSUB 11000: REM Initialize Routine strings
GOSUB 5000: REM Set up memory locations
GOSUB 7000: REM Set up Player area
GOSUB 10000: REM Read frames into RAM
GOSUB 12000: REM Set up parameter addresses
GOSUB 13000: REM Turn on interrupts
PRINT "CLEAR! RIGHT!!! WALKING MAN DEMO!!!"
PRINT "Press a number from 1 to 9 to control his speed or 0's to single step."
PX=120:
PY=77
GOSUB 1000
SFLAG=2
POKE INITANIMATE,FST2P
SPEED=4:
GOSUB 700
OPEN #2,4,0,"K"
POKE 754, 255
REM
REM Main Animation Loop
IF PEEK(1086)=SFLAG THEN
SOUND 0,0,0,101: SFLAG=3 REM Footsteps
SPEED=2: REM Footsteps
GOSUB 700
FOR I=0 TO NUMPLR8-1
POKE RATE(I), SPEED
NEXT I
IF SPEED<0 THEN SPEED=0
GOTO 410
SOUND 0,0,0,0
IF PEEK(754)=255 THEN 410
GET #2, BYTE!
SPEED=BYTE+48:
POKE 754, 255:
IF SPEED<0 THEN SPEED=0
GOTO 500
SOUND 0,0,0,0
IF PEEK(INITANIMATE)=128 THEN 710
FOR I=0 TO NUMPLR8-1
POKE RATE(I),SPEED
NEXT I
POKE INITANIMATE,FST2P+16
RETURN
REM Parameters For Players
1010 REM Man
1020 GOSUB 1500: REM Point to Frame Lists
1030 FOR I=0 TO NUMPLRS-1
1040 POKE VPLR(I),PY
1050 POKE HPLR(I),PX+I*8
1060 NEXT I
1070 TEMP=USR(PMOVER,FST2P)
1080 RETURN
1090 REM
1100 REM Put Frame List Address in Param Table
1110 FOR I=0 TO NUMPLRS-1
1120 X=POINTER(I)
1130 GOSUB 110
1140 POKE FRMLSTPtr(I),LOBYTE
1150 POKE FRMLSTPtr(I)+1,HIBYTE
1160 NEXT I
1170 TEMP¬USR(PMOVER,FST2P)
1180 RETURN
1190 REM
1200 REM Set Up Memory Locations
1210 READ FRAMES,FRMSIZE,NUMPLRS
1220 PLRFRMMEM=FRAMES*FRMSIZE+1
1230 FRAMEMEM=PLRFRMMEM*NUMPLRS
1240 FRMLSTSIZE=FRAMES+3
1250 TOTFRMLSTSIE=FRMLSTSIZE*NUMPLRS
1260 DIM BUFFER$(128),FRAMEMEM$(FRAMES*FRMSIZE+NUMPLRS)
1270 PMOVER=ADR(PMOVER)
1280 ANIMATE=ADR(ANIMATE$)
1290 MFill=ADR(MFILL$)
1300 BUFFER=ADR(BUFFER$)
1310 PLRFRAMES=ADR(FRAMEMEM$)
1320 FRMLSTMEM=ADR(FRMLSTMEM$)
1330 RETURN
1340 REM
1350 REM Initialize Player-Missile Graphics
1360 TEMP=PEEK(106)-8: REM Set aside Player-Missile area
1370 POKE 54279,TEMP: REM Tell ANTIC where PM RAM is
1380 PMBASE=256*TEMP: REM Find PM Base address
1390 FOR I=0 TO 3
1400 FOR J=0 TO 128*I+512: REM Set addresses of Players
1410 POKE 704+I,3*16+10: REM Color him peach
1420 NEXT I
1430 NEXT J
1440 POKE 559,42: REM Set PM 2 line resolution, Players enabled
1450 REM
1460 REM
1470 POKE 53277,2: REM Enable Player display
1480 TEMP=USR(MFill,PLR(0),512,0): REM Use memory fill routine to clear Players
1490 RETURN
1500 RETURN
1510 REM
1520 REM Read in Frame Data
1530 OFFSET2=0
1540 FRMLIST=FRMLSTMEM
1550 FOR I=0 TO NUMPLRS-1
1560 FRMDATA(I)=PLRFRAMES+OFFSET2: REM Store addresses of frame data
1570 OFFSET2=OFFSET2+PLRFRMEM
1580 FOR J=1 TO PLRFRMEM-1
1590 READ BYTE
1600 POKE FRMDATA(I),BYTE
1610 NEXT J
1620 NEXT I
1630 RETURN
1640 REM
1650 REM INITIALIZE ROUTINE STRINGS
1660 REM Set PMOVER routine
DIM PMOVER#(186)
PMOVER#(1)=" <<Routine String goes here>> "
PMOVER#(91)=" <<Routine String goes here>> "
PMOVER#(91)=" <<Routine String goes here>> "
DIM ANIMATE#(294)
ANIMATE#(1)=" <<Routine String goes here>> "
ANIMATE#(91)=" <<Routine String goes here>> "
ANIMATE#(191)=" <<Routine String goes here>> "
ANIMATE#(271)=" <<Routine String goes here>> "
DIM MFILL#(41)
MFILL#(1)=" <<Routine String goes here>> "
RETURN
REM Set Parameters For Routines
PARAMBASE=1024: REM Parameter Base address
PMBASE=PARAMBASE: REM Hi Byte of PLR0 Location goes here
PMBUF=PARAMBASE+11: REM Address of a 128 byte buffer
INITANIMATE=PARAMBASE+31: REM Initialize Frame Animate routine
FOR I=0 TO 3
HPLR(I)=PARAMBASE+4+I: REM Player horizontal "shadow" registers
VPLR(I)=PARAMBASE+10+I: REM Player vertical "shadow" registers
RATE(I)=PARAMBASE+14+I: REM Animate rate "shadow" registers
FRMLSTPTR(I)=PARAMBASE+18+I: REM Pointer to Frame Lists
NEXT I
VVBLKD=548: REM Deferred Vertical Blank Interrupt Vector
CRITICAL=661: REM Critical Flag
PO=1:
P1=2:
P2=4:
P3=8: REM Control bits for the four Players
FST2P=F0+P1
TEMP=USR(MFILL,PARAMBASE,94,0): REM IMPORTANT! Clear out parameter area
X=PLR0
GOSUB 110
POKE P0BASE,HIBYTE: REM Poke Hi Byte of Player 0 into PBASE
POKE P0BASE+1,LOBYTE: REM Poke address of buffer
POKE P0BASE+2,HIBYTE
RETC
X=POINTER+4
GOSUB 110
POKE POINTER,LOBYTE: REM Put in address of Frame Data
POKE POINTER+1,HIBYTE
FOR J=1 TO FRAMES: REM Make up a Frame List (numbers 1 thru FRAMES)
POKE POINTER+J+1,J
NEXT J
POKE POINTER+FRAMES+2,0: REM End of frame list marker
NEXT I
RETURN
REM Install Interrupt Routine
POKE CRITICAL,1: REM Open CRITICAL "valve", set up detour
X=P0VER+61
GOSUB 110
POKE VVBLKD,LOBYTE: REM Set VBLANK vector to PMOVER
POKE VVBLKD+1,HIBYTE
13110 X=ANIMATE+61
GOSUB 110
13120 POKE PMOVER+4,LOBYTE: REM Points PMOVER to ANIMATE
13130 POKE PMOVER+5,HIBYTE
13170 POKE CRITICAL,0: REM Close CRITICAL "value", routine installed
13200 RETURN
13210 REM
20000 REM FRAME DATA
20030 REM
20040 REM Number of Frames, Frame Size, Number of Players
20050 REM .Walking Man
20060 DATA 5,19,2
21000 REM Frame Data For Walking Man
21010 REM Frame 1, Player 0
21020 DATA 0,0,0,0,0,0,15,29,59,51,7,7,15,252,224,112,48
21030 REM Frame 2, Player 0
21040 DATA 0,0,0,0,0,0,1,7,15,31,55,55,7,111,125,248,192,193
21050 REM Frame 3, Player 0
21060 DATA 0,0,0,0,0,0,3,7,15,31,31,31,31,222,254,251,231,206,15
21070 REM Frame 4, Player 0
21080 DATA 1,3,5,3,1,7,15,31,30,62,62,63,63,60,124,120,112,112,252
21090 REM Frame 5, Player 0
21100 DATA 0,0,1,1,1,0,7,31,31,31,31,31,15,15,13,31,123,112,124
21110 REM Frame 1, Player 1
21130 REM Frame 2, Player 1
21140 DATA 0,56,124,124,124,56,224,224,224,224,246,254,192,128,224,224,248
21150 REM Frame 3, Player 1
21160 DATA 0,112,248,248,248,112,192,192,128,128,128,224,224,0,0,0,0,128
21170 REM Frame 4, Player 1
21180 DATA 192,224,224,224,192,0,0,0,0,0,0,0,0,0,0,0,0,0
21190 REM Frame 5, Player 1
21200 DATA 0,224,240,240,240,240,128,128,128,128,128,128,176,240,0,128,192,128,192,0
28000 REM Automove Routine DATA
28010 REM DATA AUTOMOVE,11510,74,6564
28020 DATA 194,80,3,76,228,216,173,4,240,247,48,23,162,0,78,4,4,144,6,189,32,4,157
28030 DATA 71,4,222,224,4,208,240,169,128,141,4,4,162,3,189,71,4,73,128,8,24,125,38,4,144
28040 DATA 1,40,48,12,16,3,40,16,7,169,128,157,71,4,169,0,157,38,4,202,16,223,49,185
10 REM *** RUNNING BOY PLAYER DEMO ***
20 REM Example 11
30 REM
40 REM Program to introduce the AUTOMOVE Machine Language routine and the running boy
50 REM Copyright (C) 1982 by David Fox and Mitchell Waite
60 REM
70 GOTO 140
80 REM
100 REM Hi/Lo Byte Calculation
110 HIBYTE=INT(X/256): REM Calculate High Byte
120 LOBYTE=MOD(X,HIBYTE)*256: REM Calculate Low Byte
130 RETURN
140 REM Initialize
150 DIM PLR(3),HPLR(3),VPLR(3),RATE(3),FRMLSTPTR(3),FRMDATA(3),MOVERATE(3),MSPEED(9)
170 GRAPHICS 3:
POKE 752,11:
PRINT "One moment please...",! REM Turn off cursor, print message
180 GOSUB 11000: REM Initialize Routine strings
190 GOSUB 5000: REM Set up memory locations
220 GOSUB 7000: REM Set up Player area
240 GOSUB 10000: REM Read frames into RAM
280 GOSUB 12000: REM Set up parameter addresses
290 GOSUB 13000: REM Turn on interrupts
300 PRINT "(CLEAR)(6 RIGHT)** RUNNING BOY DEMO ***"
310 PRINT "Press a number from 1 to 9 to control his speed or 0's to single step."
320 FOR I=9 TO 0 STEP -1
325 READ TEMP
330 MSPEED(I)=TEMP
335 NEXT I
330 PX=10!
340 FY=64
340 GOSUB 1000
350 SFAL=2
360 POKE INITANIMATE,ALLP
370 SPEED=6!
380 GOSUB 700
390 OPEN #2,4,0,"K:"
400 POKE 754,255
410 REM
420 REM Main Animation Loop
430 IF PEEK(1086)=SFLAG THEN
440 SOUND 0,0,0,10!
450 SFAL=31 REM Footsteps
460 IF PEEK(1086)=SFLAG THEN
470 SOUND 0,24,0,10!
480 SFAL=2
490 IF PEEK(1062)<PX THEN
500 POKE INITAUTOMOVE,ALLP:
510 TEMP=USR(PMOVER,ALLP): REM Reset Boy
520 IF PEEK(754)>255 THEN 410
530 GET #2,BYTE!
540 SPEED=BYTE-48!
550 IF SPEED<0 THEN SPEED=0
560 IF SPEED>9 THEN SPEED=9
570 GOSUB 700
580 GOTO 410
590 REM
600 REM Set Velocities and Frame Rates
610 IF PEEK(INITANIMATE)>128 THEN 710
620 FOR I=0 TO NUMPLRS-1
630 POKE MOVERATE(I),128+MSPEED(SPEED)
640 POKE RATE(I),SPEED
650 NEXT I
660 POKE INITANIMATE,ALLP+16
670 POKE INITAUTOMOVE,ALLP
680 RETURN
690 REM
700 REM PARAMETERS FOR PLAYERS
710 REM Boy
720 GOSUB 1500: REM Point to Frame List
730 FOR I=0 TO NUMPLRS-1
740 POKE VPLR(I),PY
750 POKE HPLR(I),PX+I*8
760 NEXT I
770 TEMP=USR(PMOVER,ALLP)
780 RETURN
790 REM
800 REM Put Frame List Address in Param Table
810 FOR I=0 TO NUMPLRS-1
820 X=POINTER(I)
830 GOSUB 110
840 POKE FRMLSTPTR(I),LOBYTE
1540  POKE FRMLSTPTR+i, HIBYTE
1550  NEXT I
1560  RETURN
1570  REM

5000 REM Set Up Memory Locations
5090 READ FRAMES, FRMSIZE, NUMFRMS
5110 PLFRMMEM = FRAMES*FRMSIZE+1
5120 FRAMEMEM = PLFRMMEM*NUMFRMS
5130 FRMLSTMEM = FRAMES+3
5140 TOTFRMLSTMEM = FRMLSTSIZE*NUMFRMS
5160 DIM FRMSIZE(128), FRAMEMEM(1, FRAMEMEM(1), FRMLSTMEM(1), TOTFRMLSTMEM)
5270 PMOVER = ADR(PMOVED)
5280 ANIMATE = ADR(ANIMATE)
5290 AUTOMOVE = ADR(AUTOMOVE)
5300 MFILL = ADR(MFILL)
5310 BUFFER = ADR(BUFFER)
5320 PLFRAMES = ADR(PLFRAMES)
5330 FRMLSTMEM = ADR(FRMLSTMEM)
5340 RETURN
5350 REM

7000 REM Initialize Player-Missile Graphics
7010 TEMP = PEEK(1, 100) 81 REM Set aside Player-Missile area
7020 POKE 54279, TEMP 81 REM Tell ANTIC where FM RAM is
7030 PMBASE = 256+TEMP 81 REM Find FM Base address
7040 FOR I = 0 TO 3
7050  PLRI = PMBASE+120+I+512 81 REM Set addresses of Players
7060  POKE 704+I, 13+I+101 REM Color him peach
7070  NEXT I
7080 POKE 559,42 81 REM Set FM 2 line resolution, Players enabled
7090 POKE 53277,21 81 REM Enable Player display
7100 TEMP = USR(MFILL, PLR(0), 512, 0) 81 REM Use memory fill routine to clear Players
7120 RETURN
7130 REM

10000 REM Read In Frame Data
10010 OFFSET2 = 0
10030 FRAMELIST = FRMLSTMEM
10050 FOR I = 0 TO NUMFRMS-1
10060  FRMDATA(I) = PLFRAMES+OFFSET2 81 REM Store addresses of frame data
10070  OFFSET2 = OFFSET2+PLFRMMEM
10080 POKE FRMDATA(I), FRMSIZE 81 REM Frame size at beginning of each set of frame data
10090 FOR J = 1 TO PLFRMMEM-1
10100 READ BYTE
10110 POKE FRMDATA(I)+J, BYTE
10120  NEXT J!
10130 RETURN
10140 REM

11000 REM INITIALIZE ROUTINE STRINGS
11300 REM Set PMOVER routine
11310 DIM PMOVER(136)
11320 PMOVER(1) = "<<<Routine String goes here>>> "
11330 PMOVER(91) = "<<<Routine String goes here>>> "
11340 PMOVER(181) = "<<<Routine String goes here>>> "
11400 REM Set ANIMATE routine
11410 DIM ANIMATE (274)
11420 ANIMATE(1) = "<<<Routine String goes here>>> "
11430 ANIMATE(91) = "<<<Routine String goes here>>> "
11440 ANIMATE(181) = "<<<Routine String goes here>>> "
11450 ANIMATE(271) = "<<<Routine String goes here>>> "
11500 REM Set AUTOMOVE routine
11510 DIM AUTOMOVE(174)
11520 AUTOMOVE(1) = "<<<Routine String goes here>>> "
11600 REM Set MFILL routine
DIM MFILL$(41)
MFILL$(1)="<<<Routine String goes here>>>"
RETURN

REM Set Parameters For Routines
PARAMBASE=1024: REM Parameter Base address
PMBAS=PARAMBASE+1: REM Hi Byte of PLR0 Location goes here
PMBUF=PARAMBASE+11: REM Address of a 128 byte buffer
INITANIMATE=PARAMBASE+3: REM Initialize Frame Animate routine
INITAUTOMOVE=PARAMBASE+4: REM Initialize Player Automove routine
FOR I=0 TO 3
HPLR(I)=PARAMBASE+6+I: REM Horizontal "shadow" registers
VPLR(I)=PARAMBASE+10+I: REM Vertical "shadow" registers
RATE(I)=PARAMBASE+14+I: REM Animate rate "shadow" registers
FRMLSTPTR(I)=PARAMBASE+18+I: REM Pointer to Frame Lists
MOVERATE(I)=PARAMBASE+32+I: REM Horizontal movement for AUTOMOVE
NEXT I
VVBLKD=548: REM Deferred Vertical Blank Interrupt Vector
CRITICAL=66: REM Critical Flag
P0=1: P1=2: P2=4: P3=8: REM Control bits for the four Players
FST2P=P0+P1
ALLP=P0+P2+P3
TEMPbUSR(MFILL,PARAMBASE,94,0): REM IMPORTANT! Clear out parameter area
POKE PMBA5,HIBYTE: REM Poke Hi Byte of Player 0 into PMBAS
POKE PMBUF,HIBYTE: REM Poke address of buffer
POKE PMBUF+1,HIBYTE
DIM POINTER(NUMPLRS-1)
FOR I=0 TO NUMPLRS-1
POINTER(I)=FRAMELIST+I*FRMLSTSIZE: REM Points to start of each Frame List
X=FRMDATA(I)
GOSUB 110
POKE PMOVER+6,L0BYTE: REM Poke a Frame Data
POKE PMOVER+6,HIBYTE
POKE PMOVER+4,L0BYTE: REM Point to Frame Lists
POKE PMOVER+4,HIBYTE
POKE PMOVER+8,L0BYTE: REM Set VBANK vector to PMOVER
POKE PMOVER+8,HIBYTE
X=ANIMATE+6: REM Open ANIMATE "valve" and set up detour
GOSUB 110
POKE VVBLKD,HIBYTE: REM Set VBANK vector to PMOVER
POKE VVBLKD+1,HIBYTE
X=ANIMATE+6: REM Set ANIMATE to AUTOMOVE
GOSUB 110
POKE PMOVER+4,L0BYTE: REM Points PMOVER to ANIMATE
POKE PMOVER+5,HIBYTE
X=AUTOMOVE+6: REM Points ANIMATE to AUTOMOVE
GOSUB 110
POKE ANIMATE+4,L0BYTE: REM Points ANIMATE to AUTOMOVE
POKE ANIMATE+5,HIBYTE
POKE CRITICAL,0: REM Close CRITICAL "valve", routines installed

RETURN

REM FRAME DATA

REM Number of Frames, Frame Size, Number of Players

REM: (Running Boy)

DATA 4,31,4

REM Frame data for Running Boy

DATA 20000

REM Frame 1; Player 0

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20010

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20020

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20030

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20040

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20050

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20060

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20070

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20080

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 20090

DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

DATA 21000

DATA 21010

DATA 21020

DATA 21030

DATA 21040

DATA 21050

DATA 21060

DATA 21070

DATA 21080

DATA 21090

DATA 21100

DATA 21110

DATA 21120

DATA 21130

DATA 21140

DATA 21150

DATA 21160

DATA 21170

DATA 21180

DATA 21190

DATA 21200

DATA 21210

DATA 21220

DATA 21230

DATA 21240

DATA 21250

DATA 21260

DATA 21270

DATA 21280

DATA 21290

DATA 21300

DATA 21310

DATA 21320

DATA 21330

DATA 21340

DATA 21350

DATA 21360

DATA 21370

DATA 21380

DATA 21390

DATA 21400

DATA 21410

DATA 21420

DATA 21430

DATA 21440

DATA 21450

DATA 21460

DATA 21470

DATA 21480

DATA 21490

DATA 30000

DATA 30010
**Example 12**

Program using all four Players to create animated foreground

**Hi/Lo Byte Calculation**

```plaintext
110 HIBYTE=INT(X/256) REM Calculate High Byte
120 LOBYTE=X-HIBYTE*256 REM Calculate Low Byte
130 RETURN
```

**Initialize**

```plaintext
150 DIM PLR(3),HPLR(3),VPLR(3),RATE(3),PMWIDTH(3),FRMLSTPTR(3),MOVERATE(3)
170 GRAPHICS 3:
   PRINT "One moment please..." REM Turn off cursor, print message
180 GOSUB 11000 REM Initialize Routine strings
190 GOSUB 5000 REM Set up memory locations
200 GOSUB 7000 REM Set up Player area
210 GOSUB 10000 REM Read frames into RAM
220 GOSUB 12000 REM Set up parameter addresses
230 GOSUB 13000 REM Turn on interrupts
300 PRINT "(CLEAR)(< RIGHT)*** PLAYER FOREGROUND DEMO ***"
310 FOR I=0 TO 1!
   POKE RATE(I),4:
NEXT I: REM Frame rate for walking man
320 SPEED=1 REM Temporary start up condition
330 GOSUB 1000
GOSUB 1100
340 SPEED=1
350 TEMP=USR(PMOV,ALLP)
360 POKE INITANIMATE,ALLP
370 GOSUB 700
380 OPEN $2,4,0, 所
   POKE 754,255
390 REM
```

**Main Animation Loop**

```plaintext
410 TEMP=ABS(PEEK(1064)-128)
   SND=TEMP/5!
   SND2=SN=SCONS
   IF VF THEN
      VOL=128-TEMP)/9!
      SOUND 1,SND,6,VOL!
      SOUND 2,SND2,2,VOL
430 IF WALK>0 THEN
      WALK=WALK-(SPEED-1)
   GOTO 470
440 IF WALK=0 THEN
      POKE INITAUTOMOVE,FST2P:
      TEMP=USR(PMOV,FST2P):
      WALK=-1
450 IF PEEK(1066)>2 THEN
      SOUND 0,10,4,10!
      SOUND 0,0,0,0: REM Footsteps
460 IF PEEK(1062)>218 OR PEEK(1062)<20 THEN
      GOSUB 10500 REM Reset Man
470 IF PEEK(1064)<220 OR PEEK(1065)<16 THEN
      GOSUB 6000 REM Reset other players
480 IF PEEK(754)=255 THEN 410
```
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490 GET #2, BYTE;
SPEED = BYTE - 48;
POKE 754, 255;
IF SPEED < 0 THEN
SPEED = 0
510 GOSUB 700
520 GOTO 410
530 REM
600 REM Select a New Object
610 IF VOL THEN
  VOL = INT(VOL);
  IF VOL = 0 THEN
    VOL = 1
620 IF VOL THEN
  VOL = VOL - 0.5;
  SOUND 1, SND, 6, VOL;
  SOUND 2, SND2, 2, VOL;
  GOTO 620
630 TEMP = USR(MFILL, PLR(2), 256, 0); REM Use memory fill routine to clear Players 2 & 3
640 FLAG = INT(RND(1) * 5 + 1); REM Which object to display (if possible)
650 OBJECT = 0; REM No object selected yet
660 ON FLAG GOSUB 1100, 1100, 1100, 1200, 1300, 1300;
IF OBJECT = 0 THEN
  RETURN
670 TEMP = USR(MOVER, LST2P)
680 POKE INITANIMATE, LST2P
690 REM
700 REM Set Horizontal Velocities
710 IF OBJECT = 3 THEN
  NSPD = 128 - SPEED * 2;
  GOTO 740; REM Tree
720 IF OBJECT = 4 THEN
  NSPD = 125 - SPEED;
  GOTO 740; REM Truck
730 NSPD = 132 - SPEED; REM Car
740 POKE MOVERATE(2), NSPD;
POKE MOVERATE(3), NSPD;
TEMP = LST2P
750 POKE MOVERATE(0), 129 - SPEED;
POKE MOVERATE(1), 129 - SPEED;
IF WALK = -1 THEN
  TEMP = ALLP
760 POKE INITAUTOMOVE, TEMP
780 RETURN
790 REM
1000 REM PARAMETERS FOR PLAYERS
1010 REM Man
1020 POKE 704, 3 * 16 + 10;
POKE 705, 3 * 16 + 10; REM Set color to peach
1030 FRSTPLR = 0;
OBJECT = 1;
GOSUB 1500; REM Point to proper Frame List
1040 POKE VPLR(0), 77;
POKE VPLR(1), 77
1050 IF SPEED = 1 THEN 1070
1060 POKE HPLR(0), 20;
POKE HPLR(1), 28;
IF SPEED > 1 THEN
  POKE HPLR(0), 218;
  POKE HPLR(1), 226
1070 WALK = INT(RND(1) * 100 + 20)
1080 RETURN
1090 REM
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1100 REM Tree
1110 IF SPEED=0 THEN
1114 RETURN
1115 POKE 706,14#16+4;
1116 POKE 707,13#16+6;
1117 REM Brown trunk and green leaves
1118 POKE HPLR(2),229;
1119 POKE HPLR(3),217
1120 POKE VPLR(2),32;
1121 POKE VPLR(3),18
1122 FRSTPLR=2;
1123 OBJECT=2;
1124 GOSUB 1500;
1125 FRSTPLR=3;
1126 OBJECT=3;
1127 GOSUB 1500; REM Point to proper Frame List
1128 POKE PMWIDTH(2),0;
1129 POKE PMWIDTH(3),3
1130 VF=0
1131 RETURN
1132 REM
1133 REM Truck
1134 POKE 706,3#16+6;
1135 POKE 707,INT(RND(1)#16)#16+10
1136 POKE HPLR(2),217;
1137 POKE HPLR(3),233
1138 POKE VPLR(2),57;
1139 POKE VPLR(3),57
1140 FRSTPLR=2;
1141 OBJECT=4;
1142 GOSUB 1500; REM Point to proper Frame List
1143 POKE PMWIDTH(2),1;
1144 POKE PMWIDTH(3),3
1145 VF=1;
1146 SCONS=180
1147 RETURN
1148 REM
1149 REM Car
1150 IF SPEED=4 THEN
1151 RETURN
1152 C=INT(RND(1)#16); L=8=INT(RND(1)#2)#4;
1153 TEMP=C#16+L;
1154 POKE 706,TEMP;
1155 POKE 707,TEMP
1156 POKE HPLR(2),0;
1157 POKE HPLR(3),16
1158 IF SPEED>4 THEN
1159 POKE HPLR(2),216;
1160 POKE HPLR(3),232
1161 POKE VPLR(2),76;
1162 POKE VPLR(3),76
1163 FRSTPLR=2;
1164 OBJECT=5;
1165 GOSUB 1500; REM Point to proper Frame List
1166 POKE PMWIDTH(2),1;
1167 POKE PMWIDTH(3),1
1168 VF=1;
1169 SCONS=40
1170 RETURN
1171 REM
1172 REM Put Frame List Address in Param Table
1173 FOR I=0 TO NUMFLRS(OBJECT)-1
X=POINTER(OBJECT,I);
GOSUB 110
POKE FRMLSTPTR(I+FRSTPLR),LOBYTE
POKE FRMLSTPTR(I+FRSTPLR)+1,HIBYTE
NEXT I
RETURN
REM

DIM FRMDATA(OBJS,3)
DIM FRAMES(OBJS),FRMSIZE(OBJS),NUMPLRS(OBJS),PLRFRMMEM(OBJS),FRMLSTSIZE(OBJS)
FOR I=1 TO OBJS
READ TEMP1,TEMP2,TEMP3
FRAMES(I)=TEMP1;
FRMSIZE(I)=TEMP2;
NUMPLRS(I)=TEMP3
PLRFRMMEM(I)=FRAMES(I)+1
FRAMEMEM=FRAMEMEM+PLRFRMMEM(I)+NUMPLRS(I)
FRMLSTSIZE(I)=FRAMES(I)+3
TOTFRMLSTSIZE=TOTFRMLSTSIZE+FRMLSTSIZE(I)+NUMPLRS(I)
NEXT I
DIM BUFFER(128),FRAMEMEM(0BJS),FRMLSTMEM(TOTFRMLSTSIZE)
PMOVER=ADR(PMOVER);
ANIMATE=ADR(ANIMATE);
AUTOMOVE=ADR(AUTOMOVE);
MFILL=ADR(MFILL);
BUFFER=ADR(BUFFER);
PLRFRAMES=ADR(FRAMEMEM);
FRMLSTMEM=ADR(FRMLSTMEM);
RETURN
REM

TEMP=PEEK(106)+8: REM Set aside Player-Missile area
POKE 54279,TEMP: REM Tell ANTIC where PM RAM is
PMBASE=256*TEMP: REM Find FM Base address
FOR I=0 TO 3
PLR(I)=PMBASE+128*I+512: REM Set addresses of Players
PMWIDTH(I)=53256+I: REM Set addresses of Player Widths
NEXT I
POKE 559,42: REM Set FM 2 line resolution, Players enabled
POKE 623,11: REM Set priority - Players in front
POKE 53277,2: REM Enable Player display
TEMP=USR(MFILL,PLR(0),512,0): REM Use memory fill routine to clear Players
RETURN
REM

OFFSET=0;
OFFSET2=0;
DIM FRAMELIST(OBJS)
FOR K=1 TO OBJS
FRAMELIST(K)=FRMLSTMEM+OFFSET
OFFSET=OFFSET+FRAMES(K)+3*NUMPLRS(K)
FOR I=0 TO NUMPLRS(K)-1
FRMDATA(K,I)=PLRFRAMES+OFFSET2: REM Store addresses of frame data
OFFSET2=OFFSET2+PLRFRMMEM(K)
POKE FRMDATA(K,I),FRMSIZE(K): REM Poke Frame size at beginning of each set of frame data
FOR J=1 TO PLRFRMMEM(K)-1
READ BYTE
POKE FRMDATA(K,I)+J,BYTE
NEXT J;
NEXT K;
RETURN
REM INITIALIZE ROUTINE STRINGS
DIM PMOVER*(186)
PMOVER$(1)=" <<Routine String goes here>> "
PMOVER$(91)=" <<Routine String goes here>> "
PMOVER$(181)=" <<Routine String goes here>> "
REM Set ANIMATE routine
DIM ANIMATE*(294)
ANIMATE$(1)=" <<Routine String goes here>> "
ANIMATE$(91)=" <<Routine String goes here>> "
ANIMATE$(181)=" <<Routine String goes here>> "
ANIMATE$(271)=" <<Routine String goes here>> "
REM Set AUTOMOVE routine
DIM AUTOMOVE*(74)
AUTOMOVE$(1)=" <<Routine String goes here>> "
REM Set Mfill routine
DIM MFILL*(41)
MFILL$(1)=" <<Routine String goes here>> "
RETURN
REM Set Parameters For Routines
PARAMBASE=1024: REM Parameter Base address
PMBASE=PARAMBASE: REM Hi Byte of LR0 Location goes here
DIM P0INTER(OBJ8,1)
FOR K=1 TO OBJ8
FOR I=0 TO 3
HPLR(I)=PARAMBASE+6+I: REM Player horizontal "shadow" registers
VPLR(I)=PARAMBASE+10+I: REM Player vertical "shadow" registers
RATE(I)=PARAMBASE+14+I: REM Animate rate "shadow" registers
FRMLSTPTR(I)=PARAMBASE+18+I: REM Pointer to Frame Lists
FOR I=0 TO 3
HIBYTE: REM Poke Hi Byte of Player 0 into PMBAS
POKE PMBUF+1,LOBYTE: REM Poke address of buffer
POKE PMBUF+1,HIBYTE: REM Point to Frame List
POKE PMBUF+1,HIBYTE: REM Set up Frame Lists
DIM POINTER(OBJ8,1)
FOR K=1 TO OBJ8
LET POINTER(K,I)=FRAMELIST(K)+I*FRMLSTSIZE(K): REM Points to start of each Frame List
POKE POINTER(K,I),X:REM Points to start of each Frame List
POKE POINTER(K,I),X:REM Put in address of Frame Data
FOR J=1 TO FRAMES(K): REM Make up a Frame List (numbers 1 thru FRAMES)
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12500 NEXT J
12510 POKE POINTER(K,1)+FRAMES(K)+2,01 REM End of frame list marker
12520 NEXT K
12530 RETURN
12540 REM
13000 REM Install Interrupt Routines
13010 POKE CRITICAL,11 REM Open CRITICAL "valve", set up detour
13008 X=POINTER+6
13090 POKE VVBLKD,LOBYTE REM Set VBLANK vector to PMOVER
13100 POKE VVBLKD+1,HIBYTE REM Set VBLAMK vector to PMOVER
13110 X=ANIMATE+6
13140 X=ANIMATE+6
13200 RETURN
13210 REM
20000 REM FRAME DATA
20010 REM Number of objects
20020 DATA 5
20030 REM
20040 REM Number of Frames, Frame Size, Number of Players
20050 REM , (Walking Man)
20060 DATA 5,19,2
20070 REM , (Tree Trunk)
20080 DATA 1,52,1
20090 REM , (Tree Top)
20100 DATA 1,26,1
20110 REM , (Truck)
20120 DATA 1,29,2
20130 REM , (Car)
20140 DATA 1,15,2
20150 REM
21000 REM Frame data for Walking Man
21010 REM Frame 1, Player 0
21020 DATA 0,0,0,0,0,0,0,3,15,29,59,51,7,7,15,252,224,112,48
21030 REM Frame 2, Player 0
21040 DATA 0,0,0,0,0,0,0,1,17,15,31,55,55,7,11,125,248,192,193
21050 REM Frame 3, Player 0
21060 DATA 0,0,0,0,0,0,0,3,7,15,31,31,31,222,254,251,231,206,15
21070 REM Frame 4, Player 0
21080 DATA 1,3,3,3,1,7,15,31,30,62,62,62,63,63,60,124,120,112,112,252
21090 REM Frame 5, Player 0
21100 DATA 0,0,1,1,1,0,7,31,31,31,31,31,15,15,15,13,31,123,112,124
21110 REM Frame 1, Player 1
21130 REM Frame 2, Player 1
21140 DATA 0,0,56,124,124,124,56,224,224,224,224,224,224,224,224,224,224,248
21150 REM Frame 3, Player 1
21160 DATA 0,112,248,248,248,112,112,248,224,224,224,224,224,224,224,224,224,224
21170 REM Frame 4, Player 1
21180 DATA 192,224,224,224,192,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
21190 REM Frame 5, Player 1
21200 DATA 0,224,240,240,240,240,128,128,128,128,176,240,0,128,192,192,192,0,0
21210 REM
22000 REM Frame data for Tree
22010 REM Player 2, Tree Trunk
10 REM *** SCROLLING STREET SCENE *** 
Example 13

20 REM 

30 REM 

40 REM Program demonstrating Horizontal Fine Scrolling and Display List Interrupts

50 REM Copyright (C) 1982 by David Fox and Mitchell Waite

60 REM 

70 GOTO 140

80 REM 

100 REM Hi/Lo Byte Calculation

110 HIBYTE=INT(X/256) REM Calculate High Byte

120 LOBYTE=X-HIBYTE*256 REM Calculate Low Byte

130 RETURN 

140 REM Initialize 

160 DIM CL$(24),SEG$(24),TEMP$(8)

170 CL$(1)=CHR$(0) REM Fill with ASCII 0

180 CL$(24)=CHR$(0)

190 CL$(2)=CHR$(0) REM Fill with ASCII 0

200 GOSUB 11000 REM Initialize Routine strings

210 GOSUB 5000 REM Set up memory locations

220 GOSUB 6000 REM Set up Display List

230 GOSUB 2600 REM Clear screen

240 GOSUB 8000 REM Load in Character Set

250 POKE 756,HIBYTE REM Switch to Street character set

260 POKE 559,LOBYTE REM Turn screen DMA on again, Wide Playfield

270 GOSUB 2800 

280 GOSUB 12000 REM Create a street

290 GOSUB 13000 REM Set up parameter addresses

300 GOSUB 13000 REM Turn on interrupts

310 SPEED=11 

320 POKE SCRLSTEP,SPEED

330 OPEN #2,4,0,“K”! REM Set up parameter addresses

340 IF PEEK(754)=255 THEN 480

350 REM 

400 REM Main Animation Loop

410 IF PEEK(754)<>255 THEN 320

420 GET #2,BYTE: 

430 SPEED=BYTE-48 REM Set up parameter addresses

440 IF SPEED<0 THEN 

450 SPEED=0

460 POKE SCRLSTEP,SPEED
520 GOTO 480
530 REM
1900 REM Convert to Screen Value
1910 CFLAG=0
1920 IF CHAR>127 THEN
   CHAR=CHAR-128
   CFLAG=128
1930 IF CHAR<96 THEN
   CHAR=CHAR-32
   IF CHAR<0 THEN
   CHAR=CHAR+96
1940 IF CFLAG THEN
   CHAR=CHAR+CFLAG+PAINT*64
1950 RETURN
1960 REM
2000 REM Send Info to Screen
2010 LN=LEN(SEG$)
   IF LNC24 THEN
      SEG$(LN+1)=CL$
2020 IF FENCE THEN
   PTR=PTR+1
2030 FOR I=0 TO HEIGHT
2040 IF FENCE THEN
   GOSUB 2200
2050 FOR J=1 TO WIDTH
2060   P=I*WIDTH+J:
   CHAR=ASC(SEG$(P,P))
2070   GOSUB 1900
2080 IF ORND THEN
   POKE SCRLMIN+6*LINELEN+J+23,CHAR
   GOTO 2130
2090 IF CLOUD=0 THEN 2120
2100 IF CLOUD=2 THEN
   CHAR=CHAR+64
2110 POKE SCRN+PTR+I*24+J-1,CHAR
   GOTO 2130
2120 POKE SCRLWIN+PTR+J*LINELEN+J-1,CHAR
2130 NEXT J
2140 NEXT I
2150 PTR=PTR+WIDTH+ABS(FENCE)+SPCFLAG
2160 SPCFLAG=0
2170 ROOMLEFT=LINELEN-25-PTR
2180 RETURN
2190 REM
2200 REM Put In Fence
2210 IF I4 THEN 2240
2220 IF I=4 THEN
   CHAR=ASC("Q")
   GOSUB 1900:
   P=-1
   GOSUB 2250:
   CHAR=ASC("E")
   GOSUB 1900:
   P=WIDTH:
   GOSUB 2250:
   GOTO 2240
2230 CHAR=ASC("A")
   GOSUB 1900:
   P=-1
   GOSUB 2250:
   CHAR=ASC("D")
   GOSUB 1900:
   P=WIDTH:
GOSUB 2250
2240 RETURN
2250 REM Poke In Data
2260 POKE SCRLWIN+PTR+I*LINELEN+P,CHAR
2270 RETURN
2280 REM
2400 REM Copy First Page Onto Last Page
2410 FOR I=0 TO 5
2420 FOR J=0 TO 24
2430 POKE SCRLWIN+I*LINELEN+LINELEN-25+J,PEEK(SCRLWIN+I*LINELEN+J)
2440 NEXT J
2450 NEXT I
2460 RETURN
2470 REM
2600 REM Clear the Screen — Fill the Screen With 0
2610 TEMP=USR(MFILL,SCRN,SCRNSZE,0)
2620 RETURN
2630 REM
2800 REM Put In Clouds and Sidewalk
2810 SEG$="<T<CT=\|\|\|\|\|\|\|"
   CLOUD=11
   PTR=4:
   HEIGHT=7:
   GOSUB 2000
2820 SEG$="<T<CT=\|\|\|"
   CLOUD=2:
   PTR=PTR+3:
   WIDTH=5:
   GOSUB 2000
2830 SEG$="-----------------------------"
   ORND=11
   HEIGHT=0:
   WIDTH=24:
   GOSUB 2000
2840 RETURN
2850 REM
3000 REM CREATE RANDOM DISPLAY
3010 PTR=0: REM Initialize Pointer to Scroll Window
3020 HEIGHT=5: REM How tall is the window
3030 CLOUD=0: ORND=0
3040 WIDTH=INT(RND(1)*3+2): REM From 2-4
3050 IF RND(1)>0.75 THEN
   GOTO 3080: IF RND<0.55 THEN
   STORY=21
3060 IF RND(1)>0.55 THEN
   STORY=3
   GOTO 3080: IF RND<0.5 THEN
   STORY=3
3070 IF RND<0.3 THEN
   GOTO 3080: IF RND<0.2 THEN
   CHIMNEY=RND(1)<0.6
   REM 60% chance
3090 IF SHRUB=0 THEN
   FENCE=RND(1)<0.4
   REM 40% chance (only if no shrub)
3100 IF ROOMLEFT<6 THEN
   FENCE=1: REM Not enough room left for a fence
3110 IF RND(1)<0.5 THEN
   REM 50% chance
3120 IF RND<0.5 THEN
   REM 50% yellow, 50% pink
3130 IF RND<0.5 THEN
   ON WIDTH-1 GOSUB 3500,3700,3900
   GOSUB 2000
3140 IF ROOMLEFT<2 THEN
   GOSUB 2400:
   RETURN : REM No room for tree, exit routine
3150 REM Plant Some Foilage
3160 SHRUB=0
3170 TREE=0
3180 REM Make a tree
3190 WIDTH=2
SEG#=CL
3200 REM Find height of tree
3210 IF RND(1)>10<1 THEN
   TREE=2!
   GOTO 3260
3220 IF RND(1)>9<2 THEN
   TREE=3:
   GOTO 3260
3230 IF RND(1)>8<4 THEN
   TREE=4:
   GOTO 3260
3240 IF RND(1)>3<2 THEN
   TREE=5:
   GOTO 3260
3250 TREE=6: REM 10%
3260 TRUNK=INT(RND(1)*(TREE-2)+1)
   IF TREE=2 THEN
      TRUNK=0
3270 TREETOP=TREE-TRUNK
   IF TREETOP=4 THEN
      TRUNK=TREE-4:
      TREETOP=4
3280 BT=(6-TREE)*2+1
3290 SEG#(BT)="(UP)(DOWN)"
3300 IF TREETOP=2 THEN 3340
3310 FOR I=1 TO TREETOP-2
3320 BT=BT+2
   SEG#(BT)="tt"
3330 NEXT I
3340 BT=BT+2:
   SEG#(BT)=(LEFT)(RIGHT)"
3350 IF TRUNK=1 THEN 3390
3360 FOR I=1 TO TRUNK-1
3370 BT=BT+2
   SEG#(BT)="BV"
3380 NEXT I
3390 IF RND(1)>0.5 THEN
   SEG#(BT+2)="KL"
3400 REM Add random spacing on side of tree
3410 TEMP=INT(RND(1)*3+1)
   IF TEMP=3 OR ROOMLEFT<3 THEN 3470
3420 IF TEMP=1 THEN
   PTR=PTR+11
   GOTO 3470
3430 SPCFLAG=1:
   GOTO 3470
3440 REM Make a shrub
3450 WIDTH=INT(RND(1)*2+2)
SEG#=CL
   IF WIDTH=2 THEN
   SEG#(9)="(DOWN)(UP)"
   GOTO 3470
3460 SEG#(13)="(DOWN)(UP)"
3470 ODDHOUSE=01
FENCE=01
GOSUB 2000
3480 IF ROOMLEFT<4 THEN 3140 REM Add another tree if not enough room for a house
3490 GOTO 3040
3500 REM Width 2
3510 IF STORY=3 THEN
STORY=3
3520 BT=1
3530 IF STORY=2 THEN
BT=3
3540 IF CHIMNEY THEN
SEG*(BT)="INZU":
GOTO 3560
3550 IF STORY=2 THEN
SEG*(BT)="IOXX"
3560 BT=BT+4:
FOR I=BT TO BT+(STORY-2)*2 STEP 2
3570 IF RND(1)<0.5 THEN
SEG*(I)="TP"
GOTO 3590
3580 NEXT I
3590 IF RND(1)<0.5 THEN
SEG*(I)="TP"
3600 IF FENCE=0 THEN 3640
3610 IF RND(1)<0.5 THEN
SEG*(I)="WW"
GOTO 3640
3620 IF FENCE=0 THEN
SEG*(I)="EQ"
3630 RETURN
3640 REM
3650 REM Width 3
3660 BT=(4-STORY)*3+1
3670 IF ANTENNA AND STORY<4 THEN
SEG*(BT-3)="(,(,),,"*"
3680 SEG*(BT)="ITX"
3690 IF RND(1)<0.5 THEN
TEMP=*"FG"
3700 GOTO 3760
3710 IF RND(1)<0.5 THEN
SEG*(I)="FG"
3720 NEXT I
3730 IF FENCE THEN
SEG*(I)="WW"
3740 RETURN
3750 REM
3760 REM Width 4
3770 BT=(4-STORY)*4+1
3780 IF STORY<4 THEN
SEG*(BT)="HTJ":
GOTO 4050
3790 IF STORY<2 OR SHRUB OR RND(1)<0.3333 THEN 4000 REM Which type house?
3800 REM Create Odd House type
3810 ODDHOUSE=1
3820 IF CHIMNEY THEN
SEG*(I)="(,)IN(2)"*
GOTO 3990
3830 SEG*(I)="(,)IOC2 ,IOX,"
3840 IF FENCE=0 THEN
SEG*(9)="ITTOBEPVTCT"!
GOTO 4100
4000 REM Create Normal House type
4010 IF ANTENNA AND CHIMNEY THEN
        SEG*(BT-4)="(\J)(\J)(\Y)(T)(T)"
        GOTO 4050
4020 SEG*(BT-4)="(\J)(\J)(\Y)(T)(T)"
        IF CHIMNEY=0 THEN
        SEG*(BT)="HTTJ"
        GOTO 4050
4030 IF RND(1)<0.5 THEN
        SEG*(BT)="YTTJ"
        GOTO 4050
4040 SEG*(BT)="HTTM"
4050 BT=BT+4:
        FOR I=BT TO BT+(STORY-2)*4 STEP 4
        4060 IF RND(1)<=0.25 THEN
                SEG*(I)="F(S)G"  GOTO 4080
4070 SEG*(I)="E(S)G"
4080 NEXT I
        4090 SEG*(21)="MEG0"  GOTO 4100
4100 RETURN
4120 REM
5000 REM Set Up Memory Locations
5010 DIF=0
5020 DLSZE=34: REM Display List size
5030 LINELEN=48: REM Horizontal length of scrolling window
5040 SCRLSZ=6x24+LINELEN=64: REM Screen size
5050 MEM=DLSZE+SCRLSZ: REM MEMORY to reserve for DL and Screen
5170 DIF=DIF+4:
        IF DIF<256<MEM THEN 5170
5180 HIBASE=PEEK(106)-DIF:
4390 LOBASE=0
5200 DLBASE=HIBASE*256+LOBASE
5210 SCRNL=DLBASE+DLSIZE: REM Starting address of Screen RAM
5220 X*SCRNL:
        GOSUB 110
5230 SCRNL=HIBYTE:
        SCRNL=LOBYTE:
4340 SCRNL+SCRLW=48: REM Beginning of Scroll window
5250 SCROLL=ADR(SCROLL+)
5260 DLIROUT=ADR(DLIROUT+)
5270 MFILL=ADR(MFILL+)
5280 RETURN
5350 REM
6000 REM Set up the Display List
6010 GRAPHICS 2+16: REM Set flags to Graphics mode 2
6020 POKE 559,01 REM Turn off screen DMA
6030 POKE DLBASE,112 REM Set up top border, 24 scan lines
6040 POKE DLBASE+1,112
6050 POKE DLBASE+2,112
6060 POKE DLBASE+3,711: REM LMS for line 1
6070 POKE DLBASE+4,SCRNL
6080 POKE DLBASE+5,SCRNL
6090 POKE DLBASE+6,7+128: REM Line 2 (w/ DLI)
6100 FOR I=0 TO 61 REM Loop for lines 3-9
6110 WINDOW=SCRNL+1*LINELEN
6120 BYTE=67: REM LMS and HSCRL
6130 IF I=2 OR I=3 THEN
        BYTE=87+128: REM DLI, LMS and HSCRL for lines 5 and 8
6140 IF I=6 THEN
        BYTE=71: REM No scroll for line 9
POKE DLBASE+7+3*I, BYTE; REM LMS and HSCRL
X=WINDOW:
GOSUB 110
POKE DLBASE+8+3*I, LOBYTE
POKE DLBASE+9+3*I, HIBYTE
NEXT I
POKE DLBASE+28, 7+128; REM Last 3 lines
POKE DLBASE+29, 7
POKE DLBASE+30, 7+128
POKE DLBASE-t-31; REM Jump on VBLANK to beginning of DL
POKE DLBASE+32, LOBASE
POKE DLBASE-t-33, HIBASE
X=DILIROUT;
GOSUB 110
POKE DLBASE+33, HIBASE
REM Address of DL for DLI handling routine
POKE 512, LOBYTE
POKE 513, HIBYTE
REM Tell AMTIC where the DL is
POKE 560, LOBASE
POKE 561, HIBASE
SETCOLOR 0, 15, 4;
SETCOLOR 1, 12, 4;
SETCOLOR 2, 0, 10;
SETCOLOR 3, 0, 12;
SETCOLOR 4, 9, 8; REM Brn, grn, wht, wht, blue
RETURN
REM
8000 REM Set Up Alternate Character Set
HICHRB=PEEK(106)-DIF-2; REM Reserve space (512 bytes)
CHRBA=HICHRB*256; REM Find start of Character Set
REM Read in data, skip first 28 characters
OFFSET=28+8;
CHARS=35
RESTORE 23000
READ TOTAL!
TEMP=0
FOR I=CHRBA+OFFSET TO CHRBA+OFFSET+CHARS*8-1
READ BYTE;
POKE I, BYTE;
TEMP=TEMP+BYTE
NEXT I
IF TOTAL<TEMP THEN
PRINT "Error in Character Set Data!":
END
REM Clear out first char (background)
FOR I=CHRBA TO CHRBA+7
POKE I, 0
NEXT I
RETURN
REM
11000 REM INITIALIZE ROUTINE STRINGS
11010 REM Set SCROLL routine
11020 DIM SCROLL$(316)
11030 SCROLL$(1)=" <<<Routine String goes here>>> "
11040 SCROLL$(91)=" <<<Routine String goes here>>> "
11050 SCROLL$(181)=" <<<Routine String goes here>>> "
11060 SCROLL$(271)=" <<<Routine String goes here>>> "
11070 REM Set DLI routine
11080 DIM DILIROUT$(94)
11090 DILIROUT$(1)=" <<<Routine String goes here>>> "
11091 DILIROUT$(91)=" <<<Routine String goes here>>> "
11100 REM Read Color Values Into DLI Table
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DLITBLSZE=15
RESTORE 25510
DIM DLITABLE$(DLITBLSZE)
DLITABLE=ADR(DLITABLE$)
FOR I=0 TO DLITBLSZE-1
READ BYTE
POKE DLITABLE$+I,BYTE
NEXT I
REM Set MFILL routine
DIM MFILL$(41)
MFill$(1)=" <<Routine String goes here>> "
RETURN
REM Set Parameters For Routines
PARAMBASE=1024: REM Parameter Base address
SCRLIN=PARAMBASE+5: REM Line length of scrolling window
SCRLCLK=PARAMBASE+30: REM Number of Color Clocks per screen byte
SCRLSTEP=PARAMBASE+31: REM Step size of scroll each jiffy
DLIADR=PARAMBASE+36: REM Address of DLI table
VVBULD=548: REM Deferred Vertical Blank Interrupt Vector
CRITICAL=66: REM Critical Flag
TEMP=USR(MFILL$,PARAMBASE,94,0): REM IMPORTANT! Clear out parameter area
x=SCRLWIN:
GOSUB 110
POKE SCRLADR$,LOBYTE
POKE SCRLADR$+1,HIBYTE
x=LINELEN:
GOSUB 110
POKE SCRLLEN$,LOBYTE
POKE SCRLLEN$+1,HIBYTE
POKE SCRLCLK,7: REM Set to 8 color clocks per byte
x=DFunABLE$:
RETURN
REM Install Interrupt Routines
POKE CRITICAL,11: REM Open CRITICAL "valve", set up detour
X=SCROLL$+6:
GOSUB 110
POKE VVBULD,LOBYTE: REM Set VBLANK vector to SCROLL
POKE VVBULD$+1,HIBYTE
X=DLIROUT$+6:
GOSUB 110
POKE SCROLL$+4,LOBYTE: REM Points SCROLL to DLiROUT
POKE SCROLL$+5,HIBYTE
POKE CRITICAL,01: REM Close CRITICAL "valve", routines installed
POKE SCRLINIT,1
POKE 54286,1921: REM Enable DLI's
RETURN
REM Character Set Data
DATA 38646
DATA 0,3,15,31,63,63,127,127
DATA 0,192,240,248,252,252,254,254
DATA 127,127,127,63,63,31,15,7
DATA 254,254,254,252,252,248,240,224
DATA 4,3,3,3,3,3,3,3
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23110  DATA 0,0,0,252,108,108,108,108
23120  DATA 128,192,224,240,248,252,254,255
23130  DATA 3,3,7,7,15,0,0,0
23140  DATA 192,192,224,224,240,0,0,0
23150  DATA 156,220,252,252,252,252,254,255
23160  DATA 128,128,192,192,224,224,243,243
23170  DATA 3,3,7,7,15,0,0,0
23180  DATA 128,128,192,192,224,224,254,255
23190  DATA 1,3,7,15,31,63,127,255
23200  DATA 1,1,3,3,7,7,15,15
23220  DATA 192,192,192,192,192,192,192,192
23230  DATA 3,3,7,7,15,0,0,0
23240  DATA 192,192,192,192,192,0,0,0
23250  DATA 156,220,252,252,252,252,254,255
23260  DATA 128,128,192,192,224,224,240,240
23270  DATA 255,255,255,255,255,255,255,255
23280  DATA 251,251,255,252,254,254,255,255
23290  DATA 255,255,255,255,255,255,255,255
23300  DATA 251,192,224,224,240,240,255,255
23310  DATA 255,255,255,255,255,255,255,255
23320  DATA 254,254,254,254,252,252,120,0
23330  DATA 255,255,255,0,0,0,0,0
23340  DATA 255,255,255,255,255,255,255,255
23350  DATA 255,255,255,0,0,0,0,0
23360  DATA 255,255,255,255,255,255,255,255
23370  REM
25500  REM DLI Color Values
25510  DATA 234,90,152,234,90,198,0,0,6,0,0,0,0,10

10 REM *** THE GREAT MOVIE CARTOON ***
20 REM  Example 14
30 REM
40 REM Program putting it all together - PM Graphics, Fine Scrolling, & Display List Interrupts
50 REM Copyright (C) 1982 by David Fox and Mitchell Waite
60 REM
70 GOTO 140
80 REM
90 REM
100 REM Hi/Lo Byte Calculation
110 HIBYTE=INT(X/256) REM Calculate High Byte
120 LOBYTE=X-HIBYTE*256: REM Calculate Low Byte
130 RETURN
140 REM Initialize
150 DIM PLR(3),HPLR(3),VPLR(3),RATE(3),PMWIDTH(3),FRMLSTPTR(3),MOVERATE(3)
160 DIM CL$(24),SEG$(24),TEMP$(8)
170 CL$(1)=CHR$(0): CL$(2)=CHR$(0):
180 CL$(24)=CHR$(0):
190 REM Fill with ASCII 0
200 GOSUB 11000: REM Initialize Routine strings
210 GOSUB 5000: REM Set up memory locations
220 GOSUB 6000: REM Set up Display List
230 GOSUB 2600: REM Clear screen
240 GOSUB 7000: REM Set up Player area
250 GOSUB 8000: REM Load in Character Set
260 GOSUB 10000: REM Read frames into RAM
270 POKE 76,CHR$(0): REM Switch to Street character set
280 REM Turn screen DMA on again, Wide Playfield, PM 2 line resolution, Players enabled
290 GOSUB 2800: REM Create a street
300 GOSUB 12000: REM Set up parameter addresses
GOSUB 13000: REM Turn on interrupts
FOR I=0 TO 11:
  POKE RATE(I),4:
NEXT I: REM Frame rate for walking man
SPEED=-11 REM Temporary start up condition
GOSUB 1000:
GOSUB 1100:
SPEED=1
TEMP=USR(PMOVER,ALLP)
POKE INITANIMATE,ALLP
GOSUB 700:
OPEN #2,4,0,"K"
POKE 754,255
REM
REM Main Animation Loop
TEMP=ABS(PEEK(1064)-128):
SND=TEMP/5:
SND2=SND*4
IF VP THEN
  VOL=(128-TEMP)/9:
  SOUND 1,SND,8,VOL:
  SOUND 2,SND2,2,VOL:
IF WALK>0 THEN
  WALK=WALK-(SPEED<>1):
GOTO 470:
IF WALK<0 THEN
  POKE INITAUTOMOVE,FST2P:
  TEMP=USR(PMOVER,FST2P):
  WALK=-1:
IF PEEK(1064)=2 THEN
  SOUND 0,10,4,10:
  SOUND 0,0,0,0: REM Footsteps
IF PEEK(1062)>218 OR PEEK(1062)<20 THEN
  GOSUB 1050 REM Reset Man
IF PEEK(1064)>229 OR PEEK(1063)<16 THEN
  GOSUB 600 REM Reset other players
IF PEEK(754)=255 THEN 410:
GET #2,BYTE:
SPEED=BYTE-48:
POKE 754,255:
IF SPEED<0 THEN
  SPEED=0:
GOTO 410:
REM Select a New Object
IF VOL THEN
  VOL=INT(VOL):
IF VOL<0 THEN
  VOL=0:
IF VOL THEN
  VOL=VOL-0.5:
  SOUND 1,SND,8,VOL:
  SOUND 2,SND2,2,VOL:
GOTO 620:
TEMP=USR(FILL,FLR(2),256,0): REM Use memory fill routine to clear Players 2 & 3
FLAG=INT(RND(1)+6+1): REM Which object to display (if possible)
OBJECT=0: REM No object selected yet
ON FLAG GOSUB 1100,1100,1100,1200,1300,1300:
IF OBJECT=0 THEN
  RETURN:
TEMP=USR(PMOTHER,LST2P)
POKE INITANIMATE,LST2P:
REM
700 REM Set Horizontal Velocities
710 IF OBJECT=3 THEN
   NSPD=128-SPEED*2:
   GOTO 740: REM Tree
720 IF OBJECT=4 THEN
   NSPD=125-SPEED:
   GOTO 740: REM Truck
730 NSPD=132-SPEED: REM Car
740 POKE MOVERATE(2),NSPD:
   POKE MOVERATE(3),NSPD:
   TEMP=LST2P
750 POKE MOVERATE(0),129-SPEED:
   POKE MOVERATE(1),129-SPEED:
   IF WALK=-1 THEN
      TEMP=ALLP
760 POKE INITAUTOMOVE,TEMP
770 POKE SCRLSTEP,SPEED
780 RETURN
790 REM
1000 REM PARAMETERS FOR PLAYERS
1010 REM Man
1020 POKE 704,3*16+10:
1030 POKE 705,3*16+10: REM Set color to peach
1040 IF SPEED=1 THEN
1050 IF SPEED=1 THEN 1070
1060 POKE HPLR(0),20:
1070 IF SPEED>1 THEN
   POKE HPLR(0),218:
   POKE HPLR(1),226
1080 RETURN
1090 REM
1100 REM Tree
1110 IF SPEED=0 THEN
1120 RETURN
1130 POKE 706,14*16+4:
1140 POKE 707,13*16+6: REM Brown trunk and green leaves
1150 POKE HPLR(2),229:
1160 POKE HPLR(3),217
1170 POKE VPLR(2),42:
1180 POKE VPLR(3),28
1190 FRSTPLR=2:
1200 OBJECT=2:
1210 IF SPEED=0 THEN
   RETURN
1220 OBJECT=2:
1230 GOSUB 1500: REM Point to proper Frame List
1240 POKE PMWIDTH(2),0:
1250 POKE PMWIDTH(3),3
1260 VF=0
1270 RETURN
1280 REM
1290 REM Truck
1300 POKE 706,3*16+6:
1310 POKE 707,INT(RND(1)*16)*16+10
1320 POKE HPLR(2),217:
1330 POKE HPLR(3),233
1340 POKE VPLR(2),77:
1350 POKE VPLR(3),77
FRSTPLR=2:
OBJECT=4:
GOSUB 1500: REM Point to proper Frame List
POKE PMWIDTH(2),1:
POKE PMWIDTH(3),3
VF=1:
SCONS=180
RETURN
REM
REM Car
IF SPEED=4 THEN
RETURN
C=INT(RND(1)*16):
L=8-INT(RND(1)*2)+4:
TEMP=C*16+L:
POKE 706,TEMP:
POKE 707,TEMP
POKE HPLR(2),0:
POKE HPLR(3),16
IF SPEED>4 THEN
POKE HPLR(2),21:
POKE HPLR(3),23:
POKE VPLR(2),96:
POKE VPLR(3),96
FRSTPLR=2:
OBJECT=5:
GOSUB 1500: REM Point to proper Frame List
POKE PMWIDTH(2),11:
POKE PMWIDTH(3),1
VF=1:
SCONS=40
RETURN
REM
REM Put Frame List Address in Param Table
FOR I=0 TO NUMPLRS(OBJECT)-1
X=POINTER(OBJECT,I);
GOSUB 110
POKE FRMLSTPTR(I+FRSTPLR),LOBYTE
POKE FRMLSTPTR(I+FRSTPLR)+1,HIBYTE
NEXT I
RETURN
REM
REM Convert to Screen Value
CFLAG=0
IF CHAR>127 THEN
CHAR=CHAR-128:
CFLAG=128
IF CHAR<96 THEN
CHAR=CHAR-32:
IF CHAR<0 THEN
CHAR=CHAR+96
IF CFLAG THEN
CHAR=CHAR+CFLAG+PAINT*64
RETURN
REM
REM Send Info to Screen
LN=LEN(SEG#)
IF LN<24 THEN
SEG#(LN+1)=CL#
IF FENCE THEN
PTR=PTR+1
FOR I=0 TO HEIGHT
IF FENCE THEN
   GOSUB 2200
FOR J=1 TO WIDTH
   P=P+WIDTH+J1
   CHAR=ASC(SCR$6(P,P))
GOSUB 1900
IF GRND THEN
   POKE SCRLWIN+6*LINELEN+J+23,CHAR
   GOTO 2130
IF CLOUD=0 THEN 2120
IF CLOUD=2 THEN
   CHAR=CHAR+64
   POKE SCRN+PTR+I*24+J-1,CHAR
   GOTO 2130
   POKE SCRLWIN+PTR+I*LINELEN+J-1,CHAR
NEXT J
NEXT I
PTR=PTR+WIDTH+ABS(FENCE)+SPCFLAG
SPCFLAG=0
ROOMLEFT=LINELEN-25-PTR
RETURN
REM Put In Fence
IF I=4 THEN 2240
IF I=4 THEN
   CHAR=ASC("Q")
   GOSUB 1900:
   P=P-1:
   GOSUB 2250:
   CHAR=ASC("E")
   GOSUB 1900:
   P=P=WIDTH:
   GOSUB 2250:
   GOTO 2240
CHAR=ASC("A")
GOSUB 1900:
P=P-1:
GOSUB 2250:
CHAR=ASC("D")
GOSUB 1900:
P=P=WIDTH:
GOSUB 2250
RETURN
REM Poke In Data
POKE SCRLWIN+PTR+I*LINELEN+P,CHAR
RETURN
REM Copy First Page Onto Last Page
FOR I=0 TO 5
   FOR J=0 TO 24
      POKE SCRLWIN+I*LINELEN+LINELEN-25+J,P,P,EK(SCRLWIN+I*LINELEN+J)
   NEXT J
NEXT I
RETURN
REM Clear the Screen — Fill the Screen With 0
TEMP=USR(MFILL,SCRN,SCRNSIZE,0)
RETURN
REM Put in Clouds and Sidewalk
2810 SEG*="\T<\T|\|``"!
   CLOUD=1!
   PTR=4!
   HEIGHT=1!
   WIDTH=7!
   GOSUB 2000
2820 SEG*="\T<\T|```````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````````
3240 IF RND(1)*3<2 THEN
    TREE=5;
    GOTO 3260; REM 20%
3250 TREE=6; REM 10%
3260 TRUNK=INT(RND(1)*(TREE-2)+1);
    IF TREE=2 THEN
        TRUNK=0
3270 TREETOP=TREE-TRUNK;
    IF TREETOP<4 THEN
        TRUNK=TREE-4;
        TREETOP=4
3280 BT=(6-TREE)+2+1
3290 SEG$(BT)="(UP)<DOWN)"
3300 IF TREETOP=2 THEN 3340
3310 FOR I=1 TO TREETOP-2
3320 BT=BT+2;
    SEG$(BT)="tt"
3330 NEXT I
3340 BT=BT+2;
    SEG$(BT)="(LEFT)<RIGHT)"
3350 IF TRUNK=1 THEN 3390
3360 FOR I=1 TO TRUNK-1
3370 BT=BT+2;
    SEG$(BT)="BV"
3380 NEXT I
3390 IF RND(1)>0.5 THEN
    SEG$(BT+2)="KL"
3400 REM Add random spacing on side of tree
3410 TEMP=INT(RND(1)*3+1);
    IF TEMP=3 OR ROOMLEFT<3 THEN 3470
3420 IF TEMP=1 THEN
    PTR=PTR+1;
    GOTO 3470
3430 SPCL=1!
    GOTO 3470
3440 REM Make a shrub
3450 WIDTH=INT(RND(1)*2+2);
    SEG$="CL";
    IF WIDTH=2 THEN
    SEG$="(DOWN)<UP)"
    GOTO 3470
3460 IF ROOMLEFT<4 THEN 3140; REM Add another tree if not enough room for a house
3470 GOTO 3040
3500 REM Width 2
3510 IF STORY>3 THEN
    STORY=3
3520 BT=1
3530 IF STORY=2 THEN
    BT=3
3540 IF CHIMNEY THEN
    SEG$(BT)="INIU"
    GOTO 3560
3550 SEG$(BT)="IOIX"
3560 BT=BT+4;
    FOR I=BT TO BT+STORY-2 STEP 2
3570 IF RND(1)>0.5 THEN
    SEG$(I)="TF"
    GOTO 3590
3580 SEG$(I)="TP"
3590 NEXT I
3600 SEG$(9)="CT"
3610 IF FENCE=0 THEN 3640
3620 IF RND(1)<=0.5 THEN  
    SEG$(1)="WN"
    GOTO 3640
3630 SEG$(11)="EQ"
3640 RETURN
3650 REM
3670 REM Width 3
3671 BT=(4-STORY)+3+1
3672 IF RND(1)<=0.5 THEN  
    SEG$(11)="WW"
    GOTO 3640
3680 SEG$(n)="EQ"
3690 RETURN
3700 REM Width 4
3710 BT=(4-STORY)+4+1
3720 IF RND(1)<=0.5 THEN  
    TEMP$="FFG"
    GOTO 3750
3730 TEMP$="FRG"
3740 BT=BT+3:
    FOR I=BT TO BT+(STORY-2)*3 STEP 3  
    SEG$(I)="FRG"
    NEXT I
3750 SEG$(13)="FCG"
3760 IF FENCE THEN  
    SEG$(16)="WMW"
    RETURN
3770 SEG$(0)=TEMP$  
    NEXT I
3780 IF RND(1)<>0.5 THEN  
    TEMP$="FPG"
    GOTO 3760
3790 IF RND(1)<>0.5 THEN  
    TEMP$="FRO"
3800 BT=BT+3:
    FOR I=BT TO BT+(STORY-2)*3 STEP 3  
    SEG$(I)="FRG"
    NEXT I
3810 RETURN
3820 REM
3830 REM Width 4
3840 BT=(4-STORY)+4+1
3850 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3860 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3870 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3880 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3890 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3900 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3910 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3920 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3930 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3940 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3950 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3960 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3970 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3980 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
3990 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
4000 REM Create Odd House type
4010 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
4020 SEG$(BT-4)="HTTJ"
    GOTO 4050
4030 IF RND(1)<=0.5 THEN  
    SEG$(BT-4)="HTTJ"
    GOTO 4050
4040 SEG$(BT)="HTTM"
4050 IF RND(1)<=0.5 THEN  
    SEG$(BT)="HTTM"
    GOTO 4050
4060 IF RND(1)<=0.5 THEN  
    SEG$(BT)="HTTM"
    GOTO 4050
4070 IF RND(1)<=0.5 THEN  
    SEG$(BT)="HTTM"
    GOTO 4050
4080 NEXT I
4090 SEG$(17)="FTCG"
0410 IF FENCE THEN
   SEG*(21)="WEGW"
0411 RETURN
0412 REM
0500 REM Set Up Memory Locations
0510 DIF=0
0520 DLSIZE=34: REM Display List size
0530 LINELEN=160: REM Horizontal length of scrolling window
0540 SCRNSIZE=6*24+LINELEN*6: REM Screen size
0550 MEM=DLSIZE+SCRNSIZE: REM Memory to reserve for DL and Screen
0560 RESTORE:
   READ OJS
0570 DIM FRMDATA(OJS,3),FRAMES(OJS),NUMPLRS(OJS),PLRFRMEM(OJS),FRMLSTSIZE(OJS)
0580 FOR I=1 TO OJS
0590  READ TEMP1,TEMP2,TEMP3
0600   FRAMES(I)=TEMP1
0610   FRMSIZE(I)=TEMP2
0620   NUMPLRS(I)=TEMP3
0630   PLRFRMEM(I)=FRAMES(I),FRMSIZE(I)+1
0640   FRMLSTSIZE(I)=FRAMES(I)+3
0650   TOTFRMLSTSIZE(I)=FRMLSTSIZE(I)+NUMPLRS(I)
0660 NEXT I
0670 DIM BUFFER$(128),FRAMEMEM$(FRAMES),FRMLSTMEM$(TOTFRMLSTSIZE)
0680 IF DIF*256<MEM THEN
0690   X=X+4
0700 HIBASE=FEEK(106)-DIF:
0710   LOBASE=0
0720 DLBASE=HIBASE*256+LOBASE
0730 S=SCRN+48: REM Starting address of Screen RAM
0740 X=S
0750 GOSUB 110
0760 SCRNL=LOBYTE: REM Find Screen Hi and Lo bytes
0770 SCRLWIN=LOBYTE: REM Beginning of Scroll window
0780 SCROLL=ADR(SCROLL$)
0790 DLIROUT=ADR(DLIROUT$)
0800 PMOVER=ADR(PMOVER$)
0810 ANIMATE=ADR(ANIMATE$)
0820 AUTOMOVE=ADR(AUTOMOVE$)
0830 MFILL=ADR(MFILL$)
0840 BUFFER=ADR(BUFFER$)
0850 PLRFRAME=ADR(PLRFRAME$)
0860 FRMLSTMEM=ADR(FRMLSTMEM$)
0870 RETURN
0880 REM
0890 REM Set Up the Display List
0900 GRAPHICS 2+16: REM Set flags to Graphics mode 2
0910 POKE 559,0: REM Turn off screen DMA
0920 POKE DLBASE,112: REM Set top border, 24 scan lines
0930 POKE DLBASE+1,112
0940 POKE DLBASE+2,112
0950 POKE DLBASE+3,71: REM LMS for line 1
0960 POKE DLBASE+4,SCRNL
0970 POKE DLBASE+5,SCRNL
0980 POKE DLBASE+6,7+128: REM Line 2 (w/ DLI)
0990 FOR I=0 TO 6: REM Loop for lines 3-9
1000 WINDOW=SCRNL+I+LINELEN
1010 BYTE=87: REM LMS and HSCRL
1020 IF I<2 OR I=5 THEN
1030   BYTE=87+128: REM DL, LMS and HSCRL for lines 5 and 8
1040 IF I<6 THEN
BYTE=71: REM No scroll for line 9
6150  POKE DLBASE+7+3*I,BYTE: REM LMS and HSCRL
6160  X=WINDOW:
6170  GOSUB 110
6180  POKE DLBASE+8+3*I,LOBYTE
6190  NEXT I
6200  POKE DLBASE+28,7+128: REM Last 3 lines
6210  POKE DLBASE+29,7
6220  POKE DLBASE+30,7+128
6230  POKE DLBASE+31,65: REM Jump on VBLANK to beginning of DL
6240  POKE DLBASE+32,LOBASE
6250  POKE DLBASE+33,HIBASE
6260  X=DLIR0UT5
6270  POKE 512,LOBYTE: REM Address of DL for DLI handling routine
6280  POKE 513,HIBYTE
6290  REM Tell ANTIC where the DL is
6300  POKE 560,LOBASE
6310  POKE 561,HIBASE
6320  SETCOLOR 0,15,4!
6330  SETCOLOR 1,12,4!
6340  SETCOLOR 2,0,10!
6350  SETCOLOR 3,0,12!
6360  SETCOLOR 4,9,8: REM Brn, grn, wht, wht, blue
6370  RETURN
6380  REM Initialize Player-Missile Graphics
6390  POKE 54279,TEMP!
6400  PMBASE=256*TEMP:
6410  FOR I=0 TO 3
6420    PLR(I)=PMBASE+128*I+512: REM Set addresses of Players
6430  PMWIDTH(I)=53256+I: REM Set addresses of Player Widths
6440  NEXT I
6450  POKE 53277,2: REM Enable Player display
6460  TEMP=USR(MFILL,PLR(0),512,0): REM Use memory fill routine to clear Players
6470  RETURN
6480  REM Set Up Alternate Character Set
6490  HICHRB=PEEK(106)-DIF-4: REM Reserve space (512 bytes)
6500  CHRBAS=HICHRB+256: REM Find start of Character Set
6510  FOR I=CHRBAS+OFFSET TO CHRBAS+OFFSET+CHARS#8-1
6520    READ BYTE!
6530    POKE 1,BYTE!
6540    TEMP=TEMP+BYTE
6550  NEXT I
6560  IF TOTAL=TEMP THEN
6570    GRAPHICS 0:
6580    PRINT "ERROR In Character Set Data"
6590  END
6600  RESTORE 23000
6610  READ TOTAL:
6620  FOR I=CHRBAS+OFFSET TO CHRBAS+OFFSET+CHARS#8-1
6630    READ BYTE!
6640    POKE 1,BYTE!
6650    TEMP=TEMP+BYTE
6660  NEXT I
6670  REM Clear out first char (background)
6680  FOR I=CHRBAS TO CHRBAS+7
6690  POKE I,0
6700  NEXT I
6710  RETURN
REM
10000 REM Read in Frame Data
10010 OFFSET=0: OFFSET2=0:
10020 FOR K=1 TO OBJ5
10030 FRAMELIST(K)=FRMLSTMEM+OFFSET
10040 OFFSET=OFFSET+(FRAMES(K)+3)*NUMPLRS(K)
10050 FOR I=0 TO NUMPLRS(K)-1
10060 FMDDATA(K,I)=FRMLSTMEM+OFFSET
10070 RESTORE 21000
10080 FOR I=0 TO NtJMPLRS(K)-1
10090 FOR J=1 TO PLRFRMMEM(K)
10100 READ BYTE
10110 POKE FMDDATA(K,I)+J,BYTE
10120 NEXT J
10130 NEXT I
10140 NEXT K
10150 RETURN
10160 REM INITIALIZE ROUTINE STRINGS
10170 REM Set SCROLL routine
10180 DIM SCROLL$(316)
10190 SCROLL$(1)=" «Routine String goes here»"
10200 SCROLL$(91)=" «Routine String goes here»"
10210 SCROLL$(181)=" «Routine String goes here»"
10220 SCROLL$(271)=" «Routine String goes here»"
10230 REM Set DLI routine
10240 DIM DLIROUT$(94)
10250 DLIROUT$(1)=" «Routine String goes here»"
10260 DLIROUT$(91)=" «Routine String goes here»"
10270 REM Read Color Values Into DLI Table
10280 DLITBLSIZE=15:
10290 RESTORE 25510
10300 DIM DLITABLE$(DLITBLSIZE)
10310 DLITABLE$=ADR(DLITABLE$)
10320 FOR I=0 TO DLITBLSIZE-1
10330 READ BYTE
10340 POKE DLITABLE$+I,BYTE
10350 NEXT I
10360 REM Set PMOVER routine
10370 DIM PMOVER$(186)
10380 PMOVER$(1)=" «Routine String goes here»"
10390 PMOVER$(91)=" «Routine String goes here»"
10400 PMOVER$(181)=" «Routine String goes here»"
10410 REM Set ANIMATE routine
10420 DIM ANIMATE$(294)
10430 ANIMATE$(1)=" «Routine String goes here»"
10440 ANIMATE$(91)=" «Routine String goes here»"
10450 ANIMATE$(181)=" «Routine String goes here»"
10460 REM Set AUTOMOVE routine
10470 DIM AUTOMOVE$(74)
10480 AUTOMOVE$(1)=" «Routine String goes here»"
10490 REM Set MFILL routine
10500 DIM MFILL$(41)
10510 MFILL$(1)=" «Routine String goes here»"
10520 RETURN
10530 REM Set Parameters For Routines
10540 PARAMBASE=1024: REM Parameter Base address
10550 PMBAD=PARAMBASE: REM Hi Byte of PLR0 Location goes here
PMBUF=PARAMBASE+i:  REM Address of a 128 byte buffer

INITANIMATE=PARAMBASE+3:  REM Initialize Frame Animate routine

INITAUTOMOVE=PARAMBASE+4:  REM Initialize Player Automove routine

SCRLIMIT=PARAMBASE+5:  REM Poke a 1 to initialize the scroll routine

FOR I=0 TO 3

HPLR(I)=PARAMBASE+6+I:  REM Player horizontal "shadow" registers

VPLR(I)=PARAMBASE+10+I:  REM Player vertical "shadow" registers

RATE(I)=PARAMBASE+14+I:  REM Animate rate "shadow" registers

FRMLSTPTR(I)=PARAMBASE+18+I:  REM Pointer to Frame Lists

MOVERATE(I)=PARAMBASE+32+I:  REM Horizontal movement for AUTOMOVE

NEXT I

SCRLADR=PARAMBASE+26:  REM Address of scrolling window

SCRLLEN=PARAMBASE+28:  REM Line length of scrolling window

SCRLCLK=PARAMBASE+30:  REM Number of Color Clocks per screen byte

SCRLSTEP=PARAMBASE+30:  REM Step size of scroll each jiffy

DLIADR=PARAMBASE+36:  REM Address of DLI table

VVBLKD=548:  REM Deferred Vertical Blank Interrupt Vector

CRITICAL=66:  REM Critical Flag

PO=i:

PI=2:

P2=4:

P3=8:

REM Control bits for the four Players

FST2P=P0+P1

LST2P=P2+P3

ALLP=P0+P1+P2+P3

DIM POINTER(OBJS,l)

POKESMBAS,HIBYTE:  REM Poke Hi Byte of Player 0 into PMBAS

X=BUFFER:

POKE POKERL,LOBYTE:  REM Poke address of buffer

POKE POKERL+1,HIBYTE

X=SCRWIN:

GOSUB 110

POKE SCRADR,LOBYTE

POKE SCRadr+1,HIBYTE

X=LIGEN:

GOSUB 110

POKE SCRLEN,LOBYTE

POKE SCRLEN+1,HIBYTE

POKE SCRCLK,7:  REM Set to 7 color clocks per byte

X=DITABLE:

GOSUB 110

POKE DLRADR,LOBYTE

POKE DLRadr+1,HIBYTE

RETRn

REM Set Up Frame Lists

DIM POINTER(OBJS,1)

FOR K=1 TO OBJS

LET POINTER(K,J)=FRAMELIST(K)+I*FRMLSIZE(K):  REM Points to start of each Frame List

X=FRMDATA(K,I):

GOSUB 110

POKE POINTER(K,J),LOBYTE:  REM Put in address of Frame Data

POKE POINTER(K,J,1),HIBYTE

FOR J=1 TO FRAMES(K):  REM Make up a Frame List (numbers 1 thru FRAMES)

POKE POINTER(K,J+1,J):

NEXT J

POKE POINTER(K,J)+FRAMES(K)2,0:  REM End of frame list marker

NEXT K

RETURN
12540 REM
13000 REM Install Interrupt Routines
13010 POKE CRITICAL,1: REM Open CRITICAL "valve", set up detour
13020 X=SCROLL+8: GOSUB 110
13030 POKE VVBLKD, LOBYTE: REM Set VBLANK vector to SCROLL
13040 POKE VVBLKD+1, HIBYTE
13050 X=DLIROUT+6: GOSUB 110
13060 POKE SCROLL+4, LOBYTE
13070 POKE SCROLL+5, HIBYTE
13080 X=PMOVER+6: GOSUB 110
13090 POKE DLIROUT+4, LOBYTE
13100 POKE DLIROUT+5, HIBYTE
13110 X=ANIMATE+6: GOSUB 110
13120 POKE PMOVER+4, LOBYTE
13130 POKE PMOVER+5, HIBYTE
13140 X=AUTOMOVE+6: GOSUB 110
13150 POKE ANIMATE+4, LOBYTE
13160 POKE ANIMATE+5, HIBYTE
13170 POKE CRITICAL,0: REM Close CRITICAL "valve", routines installed
13180 POKE SCRLINIT,1
13190 POKE 54286, 192: REM Enable DLI's
13200 RETURN
13210 REM
20000 REM FRAME DATA
20010 REM Number of objects
20020 DATA 5
20030 REM
20040 REM Number of Frames, Frame Size, Number of Players
20050 REM (Walking Man)
20060 DATA 5, 19, 2
20070 REM (Tree Trunk)
20080 DATA 1, 52, 1
20090 REM (Tree Top)
20100 DATA 1, 26, 1
20110 REM (Truck)
20120 DATA 1, 25, 2
20130 REM (Car)
20140 DATA 1, 13, 2
20150 REM
21000 REM Frame data for Walking Man
21010 REM Frame 1, Player 0
21020 DATA 0, 0, 0, 0, 0, 0, 3, 15, 29, 59, 51, 7, 7, 15, 152, 224, 112, 48
21030 REM Frame 2, Player 0
21040 DATA 0, 0, 0, 0, 0, 0, 1, 7, 15, 31, 55, 55, 7, 11, 125, 248, 192, 193
21050 REM Frame 3, Player 0
21060 DATA 0, 0, 0, 0, 0, 3, 7, 15, 31, 31, 31, 31, 31, 31, 31, 224, 254, 251, 231, 206, 15
21070 REM Frame 4, Player 0
21090 REM Frame 5, Player 0
21100 DATA 0, 0, 0, 0, 0, 3, 7, 31, 31, 31, 31, 31, 31, 31, 15, 15, 15, 15, 13, 31, 123, 112, 124
21110 REM Frame 1, Player 1
21130 REM Frame 2, Player 1
21150 REM Frame 3, Player 1
21160 DATA 0, 112, 248, 248, 248, 248, 112, 192, 192, 192, 192, 128, 128, 128, 224, 224, 0, 0, 0, 0, 0, 128
21170 REM Frame 4, Player 1
21180 DATA 192, 224, 224, 224, 192, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
21190 REM Frame 5, Player 1
21200 DATA 0,224,240,240,224,224,128,128,128,128,128,176,240,0,128,192,128,192,0,0
21210 REM
22000 REM Frame data for Tree
22010 REM Player 2, Tree Trunk
22020 DATA 2,2,132,128,64,0,149,165,210,211,219,251,255,254,126,126,126,126,126
22030 DATA 126,126,126,126,126,126,126,126,126,126,126,126,126,126,126,126
22040 DATA 126,126,126,126,126,126,126,126,126,126,126,126,126,126,126,126
22050 REM Player 3, Tree Top
22060 DATA 24,24,60,60,126,126,65,210,211,219,251,255,254,264,264,264,264
22070 DATA 126,126,126,126,126,126,126,126,126,126,126,126,126,126,126,126
22080 DATA 126,126,126,126,126,126,126,126,126,126,126,126,126,126,126,126
22090 DATA 126,126,126,126,126,126,126,126,126,126,126,126,126,126,126,126
22100 REM Frame data for Truck
22110 REM Player 2, Truck Cab
22120 DATA 0,0,0,0,15,25,17,17,31,63,17,17,31,31,255,255,255,255,255,255
22130 DATA 255,255,255,28,28
22140 REM Player 3, Truck Body
22160 DATA 255,255,255,12,12
22170 REM
22200 REM Frame data for Car
22210 REM Player 2, Car back
22220 DATA 7,9,17,17,17,31,63,127,255,255,255,56,16
22230 REM Player 3, Car front
22240 DATA 192,64,32,32,16,248,255,255,255,254,255,28,8
23000 REM Character Set Data
23010 DATA 38646
23020 DATA 0,3,15,31,63,63,127,127
23030 DATA 0,192,240,248,252,252,254,254
23040 DATA 127,127,127,63,63,31,15,7
23050 DATA 254,254,254,252,252,248,240,224
23060 DATA 4,31,4,31,4,4,4,4
23070 DATA 48,48,48,63,54,54,54,54
23080 DATA 3,3,3,3,3,3,3,3
23110 DATA 0,0,252,108,108,108,108
23130 DATA 254,254,254,254,254,254,254,254
23140 DATA 1,3,7,15,31,63,127,255
23150 DATA 1,1,3,7,7,15,15
23160 DATA 128,192,224,240,248,252,254,255
23170 DATA 3,3,7,7,15,0,0,0
23180 DATA 192,192,224,240,240,0,0,0
23190 DATA 156,220,252,252,252,252,254,255
23200 DATA 128,128,192,192,224,224,243,243
23210 DATA 128,128,192,192,224,224,240,240
23220 DATA 255,255,39,39,255,39,39,255
23230 DATA 0,0,63,54,54,54,54,54
23240 DATA 255,255,228,228,255,228,228,228
23250 DATA 255,24,24,24,255,24,24,24
23260 DATA 255,255,255,255,255,255,255,255
23270 DATA 251,251,255,252,254,254,254,255
23280 DATA 192,192,192,192,192,192,192,192
23290 DATA 0,0,255,102,102,102,102,102
23300 DATA 248,248,252,252,254,254,254,255
23310 DATA 57,59,63,63,63,127,255
23320 DATA 31,31,63,63,127,127,255,255
23330 DATA 127,127,127,127,63,63,30,0
23340 DATA 255,255,255,255,255,254,124,0
23350 DATA 254,254,254,254,252,252,120,0
23360 DATA 255,255,255,0,0,0,0,0
23370 REM
DATA 234,90,152,234,90,198,10,0,198,0,0,6,0,0,10

10 REM HORIZONTAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCROL=54276
50 VSCROL=54277
60 DLIST=PEEK(560)+PEEK(561)*256: REM Find Display List
70 POKE DLIST+15,18: REM Turn horizontal scroll bit (2+16)
80 POSITION 1,10:
   PRINT "This is a demo of horizontal scrolling!"
90 FOR I=0 TO 15
100    POKE HSCROL,I
110    GOSUB 500
120    NEXT I
130 FOR I=15 TO 0 STEP -1
140    POKE HSCROL,I
150    GOSUB 500
160    NEXT I
170 GOTO 90
500 FOR W=1 TO 5:
   NEXT W
510 RETURN

10 REM VERTICAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCROL=54276
50 VSCROL=54277
60 DLIST=PEEK(560)+PEEK(561)*256: REM Find Display List
70 POKE DLIST+15,34: REM Turn vertical scroll bit (2+32)
80 POSITION 1,10:
   PRINT "This is a demo of vertical scrolling!"
90 FOR I=0 TO 7
100    POKE VSCROL,I
110    GOSUB 500
120    NEXT I
130 FOR I=7 TO 0 STEP -1
140    POKE VSCROL,I
150    GOSUB 500
160    NEXT I
170 GOTO 90
500 FOR W=1 TO 5:
   NEXT W
510 RETURN

10 REM DIAGONAL FINE SCROLLING
20 REM
30 GRAPHICS 0
40 HSCROL=54276
50 VSCROL=54277
60 DLIST=PEEK(560)+PEEK(561)*256: REM Find Display List
70 POKE DLIST+15,50: REM Turn horizontal and vertical scroll bits (2+16+32)
80 POSITION 3,10:
   PRINT "This is a demo of diagonal scrolling!"
90 FOR I=0 TO 7
100    POKE HSCROL,I
110    POKE VSCROL,I
120    GOSUB 500
120 NEXT I
130  FOR I=7 TO 0 STEP -1
140    POKE HSCROL,I:
141    POKE VSCROL,I
150  GOSUB 500
160 NEXT I
170 GOTO 90
500 FOR W=1 TO 5:
510 RETURN
24000 REM SCROLL Routine DATA
24010 DATA SCROLL,11020,316,29349
24020 DATA 184,80,3,76,98,228,216,173,5,4,240,247,16,72,165,224,141,89,4,165,225,141,90,4,173
24030 DATA 48,2,133,224,173,49,2,133,225,173,30,4,141,80,4,169,192,141,81,4,173,31,4,1^,0,0
24040 DATA 78,80,4,144,7,74,78,81,4,200,208,244,141,80,4,173,36,4,29,349
24050 DATA 205,30,4,240,14,144,12,176,4,80,173,208,89,238,80,4,45,30,4,141,70,4,77,30,4
24060 DATA 141,4,212,173,80,4,24,109,70,4,169,0,141,68,4,173,26,4,141,66,4,173,27,4,141,69,4,173
24070 DATA 68,4,144,3,238,69,4,173,68,4,56,109,81,4
24080 DATA 30,169,0,141,68,4,141,69,4,141,80,4,173,26,4,141,66,4,173,27,4,141,67,4,184
24090 DATA 80,19,208,103,80,159,173,68,4,24,237,81,4,141,68,4,176,3,206,69,4,173,66,4,24
24100 DATA 109,80,4,141,66,4,141,82,4,144,3,238,67,4,173,67,4,141,83,4,160,3,177,224,201
24110 DATA 65,240,41,41,80,240,32,4,15,240,26,200,173,82,4,145,224,24,109,28,4,141,82,4,200
24120 DATA 173,83,4,145,224,109,29,4,141,83,4,173,200,200,200,208,211,80,166,173,89,4,133,224,173
24130 DATA 90,4,133,225,184,80,153,169,128,141,5,4,173,30,4,141,70,4,169,0,141,68,4,141,69
24140 DATA 4,173,26,4,141,66,4,173,27,4,141,67,4,184,80,207
25000 REM DLI Routine DATA
25010 DATA DLIROUT,11110,4,12803
25020 DATA 184,80,10,76,98,228,169,0,141,75,5,4,240,246,72,138,72,152,72,165,224,141,93,4,165,225
25030 DATA 141,94,4,173,36,4,133,224,173,37,4,133,225,172,75,4,177,224,72,200,177,224,170,200,177
25040 DATA 224,200,140,75,4,168,104,234,234,234,234,234,234,234,234,234,141,10,212,141,24,208,142,25,208
25050 DATA 140,26,208,173,93,4,133,224,173,94,4,133,225,104,168,104,170,104,64
10 REM COPY PROGRAM
20 REM Program to transfer duplicate lines from PLAYER program to SCROLL
30 REM
40 DIM LN$(120)
50 OPEN 1,4,0,"DPLAYERS.TXT"
60 OPEN 2,8,0,"DSCROLL.BAS"
70 FOR I=1 TO 41
80 READ LNNUM
90 INPUT #1,LN$:
100 IF VAL(LN$)=LNNUM THEN 90
100 PRINT #2,LN$:
101 PRINT LN$
110 NEXT I
120 CLOSE #1:
120 CLOSE #2
130 REM
200 REM Lines To Copy
220 DATA 30,50,60,70,80,100,110,120,130,140,180,190,290,290,380
230 DATA 390,400,490,530,5000,5300,5340,5350,11000,11600,11610,11620,11650,11660,12000
240 DATA 12010,12190,12200,12240,12530,12540,13000,13010,13170,13200,13210
Character Set Grid/
ATARI ROM Character Set

Figure B.1: Grid for creating character set figures. See also Chapter 5.
<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>CHR</td>
<td>#</td>
<td>CHR</td>
</tr>
<tr>
<td>0</td>
<td>Space</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>!</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>#</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>$</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>%</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>&amp;</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>'</td>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>(</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>)</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>26</td>
<td>:</td>
</tr>
<tr>
<td>11</td>
<td>+</td>
<td>27</td>
<td>;</td>
</tr>
<tr>
<td>12</td>
<td>,</td>
<td>28</td>
<td>&lt;</td>
</tr>
<tr>
<td>13</td>
<td>-</td>
<td>29</td>
<td>=</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>30</td>
<td>&gt;</td>
</tr>
<tr>
<td>15</td>
<td>?</td>
<td>31</td>
<td>?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CHR</th>
<th>#</th>
<th>CHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Space</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>!</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>#</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>$</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>%</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>&amp;</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>'</td>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>(</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>)</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>26</td>
<td>:</td>
</tr>
<tr>
<td>11</td>
<td>+</td>
<td>27</td>
<td>;</td>
</tr>
<tr>
<td>12</td>
<td>,</td>
<td>28</td>
<td>&lt;</td>
</tr>
<tr>
<td>13</td>
<td>-</td>
<td>29</td>
<td>=</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>30</td>
<td>&gt;</td>
</tr>
<tr>
<td>15</td>
<td>?</td>
<td>31</td>
<td>?</td>
</tr>
</tbody>
</table>

Figure B.2: The order of the ATARI character set in ROM. (Reproduced with permission of ATARI, Inc.)
Listing Conventions

HOW WE REPRESENT THOSE INVISIBLE ATARI CHARACTERS

Throughout the listings in this section are many characters that either can’t be printed by our printer or are hard to find on the ATARI keyboard (because they’re not obviously indicated). To make it easier to enter the programs, we will use the following conventions:

1. All inverse video characters (characters entered after pressing the "ATARI Key" — light background and dark letters instead of dark background and light letters) will be underlined. In the following example, the letters C, E, and F should be entered in inverse video:

   \[ S\$ = "ABCDEFGHIJKLMNOPQRSTUVWXYZ\$" \]

   \[ S\$ = "\>_BCDEFGHIEJ" \]

2. Control characters (those entered while the control button is depressed) will be surrounded by curly brackets \{ \}. All of the ATARI's graphics characters are accessed while depressing the control (CTRL on the keyboard) button. In the following example, the letters B, G, and H are control characters:

   \[ C\$ = "A\{B\}CDEFG\{G\}\{H\}I\{J\}" \]

3. Special cursor and screen keys will be represented by printing the name or description of the key within curly brackets \{ \}. To enter these special keys into a string, you will need to press the ESC key first. This puts the code for the key into the string instead of actually carrying out the action. In the following example, we want to clear the screen on line 100. To do this, first tap the ESC key, then hold the shift key down and press the key with the word CLEAR on it (it has < on it). When the line is executed, the screen will clear:

   \[ 100 \text{ PRINT } "\{\text{CLEAR}\}" \]
In the next example, the cursor key with the arrow pointing down is used. When this line is executed, the computer will print the word HI, move the cursor down one line, and then print BYE. To enter this character, first press the ESC key, then hold the CTRL key down and press the key with the down arrow and = on it:

110 PRINT "HI{DOWN}BYE"

When executed, you will see the following on your screen:

HI
   BYE

4. When a number appears before a curly bracketed word, it means we want you to enter that character the indicated number of times. In the following example, we want you to enter the letters "ABCDE," then one cursor down, then five cursors left, and finally the letters "FGHIJ":

120 PRINT "ABCDE{DOWN}{5 LEFT}FGHIJ"

When this line is executed, you will see the following on the screen:

ABCDE
   FGHIJ

This technique of embedding the cursor characters enables us to create a block of characters which can be PRINTed with one statement.

5. When spaces are important to an animation, as they are in the programs in Chapter 5, we will represent a space with a lowercase b that has a slash through it:

b

This will enable you to enter the correct number of spaces. As before, if the b character is underlined, enter the space as an inverse video character.

6. In Chapters 8 and 9, our black box machine language routines are presented. Since it would be too confusing to present the actual representations for the routines in the listings, the lines containing the routines will contain the message:

<<<Routine String goes here>>>
MORE ABOUT THE LISTINGS — HOW THEY WERE CREATED

You may have noticed that our printed listings are formatted differently from programs listed on your screen. We used a special program\(^1\) to print them in a manner which emphasizes their structure, thus making them more readable and easier to understand. All `FOR/NE\^X\,T` loops are indented so that it’s easy to see where the loop starts and ends. `IF/THEN` statements are indented so that you can see exactly what will be executed if the condition is `TRUE`. Also, the multiple parts of all statements (separated by colons) are printed on a separate line. Of course, when you enter the programs, the structure will disappear — *don’t* try to enter each statement on a separate line!

One disadvantage to this method is that our stretched-out listings make the programs appear to be longer than they really are. Don’t let the number of pages it takes to display each program discourage you from entering them!

---

\(^1\)Our listing program was based on the ATARI Program Exchange product called *BLIS—BASIC Program Lister* by Image Marketing, Inc. (APX-20049). We modified the program so it would print the special codes for spaces and cursor and screen control keys, and also so it would use the ATARI 825 Printer’s proportionally spaced font.
The String Loader Program

HOW TO STORE MACHINE LANGUAGE ROUTINES IN STRINGS

As mentioned in Chapter 8 when we first introduced programs containing machine language routines, loading the bytes of the routine into a string is an excellent storage method when using ATARI BASIC. Here is the String Loader program along with the DATA for MFILL, the first machine language routine we introduced.

```
10 REM *** STRING LOADER ***
20 REM Program to convert data to strings
30 REM Copyright (C) 1982 by David Fox and Mitchell Waite
40 GOTO 110
50 REM Prepare Control Characters for Screen
60 IF (BYTE>26 AND BYTE<32) OR (BYTE>124 AND BYTE<128) OR (BYTE>155 AND BYTE<160) OR (BYTE>252) THEN 80
70 RETURN
80 CHAR*(1,1)="(ESC)";
   CHAR*(2,2)=CHR*(BYTE);
   RETURN
90 REM
100 REM Initialize
110 DIM DEV$(15),STRNAME$(8),QUOTE(10),EOL(10),QUOTE$(1),CHAR*(2)
120 QUOTE$=CHR$(34)
130 GTECNTR=0:
   EOLCNTR=0:
   STRPNTR=1:
   START=0:
   BYTETOT=0
140 READ STRNAME$,LINE,SIZE,ERRCHECK
150 GOSUB 800: REM Open Output Device
160 REM Begin Printout
170 PRINT #1;LINE:" DIM "STRNAME$"*"$("SIZE")"
180 STRSTART=STRPNTR:
   STRENDR=STRENDR+89:
   IF STRSTART>SIZE THEN 400
190 LINE=LINE+10
200 PRINT #1;LINE; ""STRNAME$"*"$(STRENDR)=""QUOTE$;
210 FOR I=STRSTART TO STRENDR
220 START=START+1:
   IF START>SIZE THEN 300
```
READ BYTE:
BYTETOT=BYTETOT+BYTE!
IF BYTE=34 OR BYTE=155 THEN 260
CHAR*=CHR$(BYTE!)
IF DEV*(1,1)="E" THEN
GOSUB 60
250 PRINT #1;CHAR*;
GOTO 280
260 PRINT #1;":"
IF BYTE=34 THEN
QUOTE$=QUOTE$+QUOTE$(I)
QUOTE$=QUOTE$+QUOTE$(I)+""
GOTO 280
270 EOL$=EOL$+EOL$(I)
EOLNTR=EOLNTR+1
280 NEXT I
290 PRINT #1;QUOTE$;
STRPNTR=STRPNTR+90;
GOTO 180
300 PRINT #1;QUOTE$
310 REM
400 REM Verify Accuracy of Data
410 IF BYTETOT=ERRCHECK THEN
PRINT "CLEAR ERROR - Please recheck your data."
PRINT "I get ":BYTETOT:
GOTO 700
420 REM
500 REM Insert Quotes
510 IF QTECNTR=0 THEN 610
520 FOR I=0 TO QTECNTR-1
530 LINE=LINE+10
540 PRINT #1;LINE: "\";QUOTE$(I);"";QUOTE$(I);"="CHR$(34)"
550 NEXT I
560 REM
600 REM Insert End of Line Character
610 IF EOLNTR=0 THEN 700
620 FOR I=0 TO EOLNTR-1
630 LINE=LINE+10
640 PRINT #1;LINE: "\";QUOTE$(I);"";EOL$(I);"";EOL$(I);"="CHR$(155)"
650 NEXT I
700 END
800 REM Choose and Open Output Device
810 PRINT "CLEAR) STRING MAKER"
820 PRINT "4 DOWN) Please the enter storage device: DOWN"
830 PRINT "E = Screen Editor"
840 PRINT "D = Disk (D, D2)"
850 PRINT "C = Cassette"
860 POSITION 4,11;
PRINT "SHIFT-DELETE (E,D,C): "
INPUT DEV$";
870 TRAP 960
880 LN=LEN(DEV$)
890 DEV$(LN+1)="!
900 DEV$(LN+2)=STRNAME$
910 DEV$(LEN(DEV$)+1)=".STR"
920 OPEN #1,8,0,DEV$";
930 TRAP 40000
Once you have entered this program, you may re-use it for all our subsequent machine language routines just by deleting the old DATA statements for MFILE and entering the new ones for the next routine you want to use. The program will read the name of the routine, its starting line number, how long it is, check whether it was entered correctly, and then save the finished “routine string” on the storage device of your choice. All this is taken care of automatically.

**Initialize (lines 100–150)** This section sets all the variables to their initial values. In line 110, the string and array variables are DIMENSIONED. DEV$ will contain the name of the device on which you will store your routine strings (disk, cassette, or screen editor), and STRNAME$ will hold the name of the routine string. There are two byte values which cannot be represented in a string and must be handled separately: quotation marks (ATASCII 34), which would prematurely end a string, and the end-of-line character (ATASCII 155), which would end the statement line. These characters are singled out and their positions in the string are stored respectively in the arrays QUOTE and EOL. QUOTE$ is set to the quotation mark character and CHAR$ temporarily holds the character representation of the current byte.

In line 140, the name of the string, the routine’s starting line number and size, and a checksum value (ERRCHECK, to make sure the DATA was accurately entered) are read in from the DATA statements.

**Choose and Open Output Device (lines 800–960)** This section asks you on which storage device you want to store your routine strings. Once stored on either disk or cassette, they can be merged into any program with the ENTER command. If you have a disk drive, type D (or D2 if you want to use your second drive), and type C if you want to use your cassette recorder. If the E option is selected, the screen will clear and the routine will be printed on the screen. If you enter a non-existent device, you will have another chance to input a valid response.
Begin Printout (lines 160–310) This is where all the work is done. On line 170, the first line which contains the DIM statement for the string is printed out. In line 180, STRSTART (String Start) is set to the position of the next open string character as saved in STRPNTR (String Pointer). STRENDF (String End) points to the last string character on the next line which is 89 characters later (there are a maximum of 90 characters per line). A check is made to see whether STRSTART is larger than the number of bytes in the routine (SIZE). Then the LINE number is incremented by 10 (line 190) and the heading for the first string line is printed (line 200).

Next, the loop is started. START keeps track of the number of bytes read. BYTETOT keeps a running total of all bytes read to make sure that the final sum matches the value stored in ERRCHECK. If the user wants to display the strings on the screen, a subroutine at lines 50–80 is called. It checks for cursor or screen control characters and, if any are found, causes the ESCape character to be printed on the screen first (delayed mode). (Note: to enter the ESC character into the string in line 80, you must press the ESC key twice.)

Lines 260–270 set the position of quotes and end-of-line characters for later printout. If one of these characters has been discovered, a space is temporarily stored in the proper position of the string. Line 290 sends the program back for the next line of characters.

Verify Accuracy of Data (lines 400–410) These lines check for any errors which may have been made during entry. If you receive an error message here, all DATA must be rechecked. First count the number of bytes in each DATA statement to make sure it’s correct. If you get an ERRORS, then you left out some bytes.

Insert Quotes and End-Of-Line Character (lines 500–650) These lines will print out any special characters found using the CHR$ function. For example, if the thirty-first byte was a 34 (quotation mark) then the following line might be printed to the output device:

11730 ROUTINE$(31,31) = CHR$(34)

As it turned out, none of our routines contain either a 34 or a 155.

Memory Fill Routine Data (lines 29000–29030) This is where we placed the byte data for the MFILL routine. Line 29010 contains the name of the routine, its starting line number, the number of bytes the routine contains, and the checksum value. Each line which follows receives 25 byte values until there are no bytes left. If the program tells you that you have made a mistake in entering this data, this makes it easier to check that each line contains the correct number of bytes.
Using the Program  The operation of this program is very simple. If you have a disk drive, type D (or D2 if you want to use your second drive). The section of program code will be written to your disk and automatically named (with the routine’s name). When you are ready to merge the routine into a BASIC program, first load your program into memory (or type NEW if starting from scratch), and then type:

\textbf{ENTER "D: \textit{name}.STR"}

where \textit{name} is the string name of your routine, MFL L in this case. The ENTER command tells the computer that information will be coming into memory from the following device instead of from the keyboard.

To use with a cassette recorder, press C when prompted. You will hear two beeps from the computer. This means you are to press the PLAY and RECORD buttons on your recorder and then press RETURN. You will hear a high pitched tone from your television speaker, then some distorted sounds (the routine). To merge the routine into a program, use the command:

\textbf{ENTER "C:"

Programs aren’t stored with names on cassette so you must keep track of their location with the tape counter.

If you want to use the screen option, either to watch the routine being written out or because you don’t want to use a disk or cassette, choose option E. The screen will clear and you will see the lines being formed. By positioning your cursor over the first line, and pressing RETURN for each statement, you can enter each line into a BASIC program. If you haven’t first typed \texttt{NEW}, these lines will be merged into the String Loader program currently in memory.

Here are screen photos of a sample run of this program using the E option for screen output.

\includegraphics[width=\textwidth]{sample_run.png}

(a) (continued)
Figure D.2: Screen photos of String Loader program sample run.
## Complete List of Parameter Table Entries for Black Box Routines

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>OFFSET FROM PARAMBASE</th>
<th>ADDRESS (DECIMAL)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMBASE</td>
<td></td>
<td>1024</td>
<td>Start of Parameter area</td>
</tr>
<tr>
<td>PMBAS</td>
<td>0</td>
<td>1024</td>
<td>Page address of Player 0 (hi byte)</td>
</tr>
<tr>
<td>PMBUF</td>
<td>1</td>
<td>1025,1026</td>
<td>Low and High bytes of Player Buffer</td>
</tr>
<tr>
<td>INITANIMATE</td>
<td>3</td>
<td>1027</td>
<td>Flag to initialize ANIMATE</td>
</tr>
<tr>
<td>INITAUTOMOVE</td>
<td>4</td>
<td>1028</td>
<td>Flag to initialize AUTOMOVE</td>
</tr>
<tr>
<td>SCRLINIT</td>
<td>5</td>
<td>1029</td>
<td>POKE 1 to turn on routine, 0 off</td>
</tr>
<tr>
<td>HPLR(0)</td>
<td>6</td>
<td>1030</td>
<td>Player 0 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(1)</td>
<td>7</td>
<td>1031</td>
<td>Player 1 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(2)</td>
<td>8</td>
<td>1032</td>
<td>Player 2 Horizontal Shadow Register</td>
</tr>
<tr>
<td>HPLR(3)</td>
<td>9</td>
<td>1033</td>
<td>Player 3 Horizontal Shadow Register</td>
</tr>
<tr>
<td>VPLR(0)</td>
<td>10</td>
<td>1034</td>
<td>Player 0 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(1)</td>
<td>11</td>
<td>1035</td>
<td>Player 1 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(2)</td>
<td>12</td>
<td>1036</td>
<td>Player 2 Vertical Shadow Register</td>
</tr>
<tr>
<td>VPLR(3)</td>
<td>13</td>
<td>1037</td>
<td>Player 3 Vertical Shadow Register</td>
</tr>
<tr>
<td>RATE(0)</td>
<td>14</td>
<td>1038</td>
<td>Player 0 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE(1)</td>
<td>15</td>
<td>1039</td>
<td>Player 1 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE(2)</td>
<td>16</td>
<td>1040</td>
<td>Player 2 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>RATE(3)</td>
<td>17</td>
<td>1041</td>
<td>Player 3 Animation Rate Shadow Reg.</td>
</tr>
<tr>
<td>FRMLSTPTR(0)</td>
<td>18</td>
<td>1042,1043</td>
<td>Player 0 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(1)</td>
<td>20</td>
<td>1044,1045</td>
<td>Player 1 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(2)</td>
<td>22</td>
<td>1046,1047</td>
<td>Player 2 Pointer to Frame List</td>
</tr>
<tr>
<td>FRMLSTPTR(3)</td>
<td>24</td>
<td>1048,1049</td>
<td>Player 3 Pointer to Frame List</td>
</tr>
<tr>
<td>SCRLADR</td>
<td>26</td>
<td>1050,1051</td>
<td>Low and High bytes of scrolling window</td>
</tr>
<tr>
<td>SCRLLEN</td>
<td>28</td>
<td>1052,1053</td>
<td>Widths of scrolling window in bytes</td>
</tr>
<tr>
<td>SCRLCLK</td>
<td>30</td>
<td>1054</td>
<td>Color clocks per mode line byte − 1</td>
</tr>
<tr>
<td>SCRLSTEP</td>
<td>31</td>
<td>1055</td>
<td>Step size to scroll each jiffy</td>
</tr>
<tr>
<td>MOVERATE(0)</td>
<td>32</td>
<td>1056</td>
<td>Player 0 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(1)</td>
<td>33</td>
<td>1057</td>
<td>Player 1 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(2)</td>
<td>34</td>
<td>1058</td>
<td>Player 2 Horizontal Velocity</td>
</tr>
<tr>
<td>MOVERATE(3)</td>
<td>35</td>
<td>1059</td>
<td>Player 3 Horizontal Velocity</td>
</tr>
<tr>
<td>DLIADR</td>
<td>36</td>
<td>1060,1061</td>
<td>Low and High bytes of DLI color table</td>
</tr>
</tbody>
</table>
The following addresses are read-only addresses — don’t change their values:

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLRX</td>
<td>38</td>
<td>Player 0 Horizontal Position</td>
</tr>
<tr>
<td>PLRY</td>
<td>39</td>
<td>Player 1 Horizontal Position</td>
</tr>
<tr>
<td>PLRZ</td>
<td>40</td>
<td>Player 2 Horizontal Position</td>
</tr>
<tr>
<td>PLR0</td>
<td>41</td>
<td>Player 3 Horizontal Position</td>
</tr>
<tr>
<td>FLPOS0</td>
<td>62</td>
<td>Player 0 Frame List Position</td>
</tr>
<tr>
<td>FLPOS1</td>
<td>63</td>
<td>Player 1 Frame List Position</td>
</tr>
<tr>
<td>FLPOS2</td>
<td>64</td>
<td>Player 2 Frame List Position</td>
</tr>
<tr>
<td>FLPOS3</td>
<td>65</td>
<td>Player 3 Frame List Position</td>
</tr>
</tbody>
</table>

**CONTROL BITS FOR ROUTINES**

In the following tables, X means that bit is not used.

**PMOVER**

Used when routine is called: \( \text{TEMP} = \text{USR(POVER, FLAG)} \)

<table>
<thead>
<tr>
<th>Bit Number</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAG for Player #:</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EXAMPLES**

- Move Player 1 only
  - FLAG VALUE = 2
- Move Players 0, 2 & 3
  - FLAG VALUE = 13
- Move all Players
  - FLAG VALUE = 15

**ANIMATE**

Used to POKE into INITANIMATE for "Ready" signal

<table>
<thead>
<tr>
<th>Bit Number:</th>
<th>7</th>
<th>X</th>
<th>X</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>128</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resume Animation</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modify Frame Rate only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAG for Player #:</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EXAMPLES**

- Begin Animation, Players 0 & 1
  - FLAG VALUE = 3
- Modify Frame Rate, Players 2 & 3
  - FLAG VALUE = 28
- Halt All Animation
  - FLAG VALUE = 0
- Resume All Animation
  - FLAG VALUE = 128
AUTOMOVE

Used to POKE into INITAUTOMOVE for “Ready” signal

<table>
<thead>
<tr>
<th>Bit Number:</th>
<th>7</th>
<th>X</th>
<th>X</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Value:</td>
<td>128</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Resume Player Motion
FLAG for Player #:

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>FLAG VALUE</th>
</tr>
</thead>
</table>
| Begin Player Motion | F
| Players 0 & 1 | 0 0 0 1 1 = 3 |
| Halt All Motion | 0 0 0 0 0 = 0 |
| Resume All Motion | 1 0 0 0 0 = 128 |
For those Assembly Language programmers among our readers, we have included the complete source listings of our "black box" routines. They contain enough comments to make them fairly clear. Feel free to use all or part of them in your own Assembly Language programs.

Notice that there are two versions of MFILL. Version 1 was written for ATARI BASIC and is the one included in all of our programs. Version 2 will work for either ATARI BASIC or ATARI Microsoft BASIC. To use with Microsoft BASIC, just change the value in line 280 from 1 to 0.

All the other routines will work with either BASIC. In PMOVER, change the value in line 670 from 1 to 0 for Microsoft BASIC. The rest will run in Microsoft without any changes.

```
10 ; MFILL ver. 1
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL HAITE
40 ;
0000 0100 ;TITLE "CLK-MFILL1,ASM;v01.00,B10907-B20407"
0000 0110 ;PAGE "Memory Fill Routine"
0120 ;
0130 ; BY COREY L. KOSAK
0140 ;
0150 ; Called from BASIC with TEMP=USR(MFILL,START,LEN,BYTE)
0160 ;
0170 ; THIS IS THE ATARI BASIC VERSION (USE ver.2 WITH MBASIC)
0000 0180 x= $600
00CB 0190 L0 = $4C8 ;POINTER TO DATA
00CC 0200 HI = $4C9
00CD 0210 LENLO = $4CD ;LENGTH IN BYTES
00CE 0220 LENHI = $4CE
0600 68 0230 MFILL PLA ;REMOVE STACK BIAS
0601 68 0240 PLA ;ADDRESS...
0602 85CC 0250 STA HI ;HI
0604 68 0260 PLA
0605 85CB 0270 STA LO ;LO
0607 68 0280 PLA ;LENGTH...
0608 85CE 0290 STA LENHI ;HI
```
10 ; MFILL ver. 2
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL HAITE
40 ;

0000 0100 .TITLE "CLK-MFILL.ASM;v02.00,810907-810907"
0000 0110 .PAGE "Memory Fill Routine"
0120 ;
0130 ; BY COREY L. KOSAK
0140 ;
0150 ; This version will work in both MBASIC and Atari BASIC. To use,
0160 ; execute the following lines from within BASIC where START is
0170 ; the first address to fill:
0180 ; POKE START,LENLO :REM Low byte of length (number of bytes to fill)
0190 ; POKE START+1,LENHI :REM High byte of length
0200 ; POKE START+2,BYTE :REM Byte value to fill
0210 ; TEMP=USR(MFILL,START) ;REM Call routine
0220 ;
0230 ;
0240 ; B=4000,FREL
0250 ;

4000 0260 BASE = $4000
0270 ;
0001 0280 ABASIC = 1 ;0=MBASIC, 1=ATARI BASIC
0290 ;
0000 0300 MEDU .IF ABASIC @AEDU
0310 ;
0320 ARG=$E3
0330 LEN=$E0
0340 ;
0000 0350 AEDU .IF 1-ABASIC @PROG
0360 ;
00CB 0370 ARG = $CB ; TEMP
06FE 0360 LEN = $6FE
0390 ;
0000 0480 PROC X= BASE
0410 ;
0420 START
0430 , IF 1=ABASIC @NOSAVE
0400 68 0440 PLA
0401 68 0450 PLA
0402 05CC 0460 STA ARG+1
0404 68 0470 PLA
0405 05CB 0480 STA ARG
0490 ;
0500 NOSAVE
0407 A002 0510 LDY #002
0520 LOOP2
0409 B1CB 0530 LDA (ARG),Y
0408 PF06 0540 STA LEN-1,Y
040E 68 0550 DEY
040F D1F8 0560 BNE LOOP2
0411 B1CB 0570 LDA (ARG),Y
0560 ;
0590 LOOP
0413 91CB 0600 STA (ARG),Y
0415 AA 0610 TAX
CLK-MFILL.ASM;v02.00,B10907-B10907
Memory Fill Routine
4016 A6FE06 0620 LDA LEN
4017 D003 0630 BNE OK
4018 CEFF06 0640 DEC LEN+1
0650 OK
401E CEFE06 0660 DEC LEN
4021 ADFF06 0670 LDA LEN
4024 00FF06 0680 ORA LEN+1
4027 F008 0690 BEQ DONE
4029 8A 0700 TXA
402A 8B 0710 INY
402B D0E6 0720 BNE LOOP
402D 06CC 0730 INC ARG+1
402E D0E2 0740 BNE LOOP
0750 ;
0760 DONE
4031 68 0770 RTS
0780 ;
4032 0790 .END

10 ; PMOVER
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL WALTER
40 ;
0000 0100 .TITLE "CLK-PMOVED.ASM;v02.10-B10713,B28628"
0000 0110 .PAGE "Player Mover Routine"
0120 ;
0130 ;BY COREY L. KOSAK
0140 ;
0150 JB=#4808,FREL
0160 ;
4000 0170 BASE  =  $4000
0180 ;
0000 0190  x=  $400
0200 ;
0210 \CASBUF DATABASE EQUATES
0220 ;
0400 0230 PMBASE  x=  x+1  ;BYTE OF PLAYER MISSILE AREA (LOBYTE EQUALS 0)
0401 0240 PMBUF  x=  x+2  ;ADDRESS OF 128 BYTE BUFFER (FOR PMOVER)
0403 0250 ANIMINIT  x=  x+1  ;INIT LOCATION FOR ANIMATE
0404 0260 AUTOINIT  x=  x+1  ;INIT LOCATION FOR AUTOMOVE
0405 0270 SCRINIT  x=  x+1  ;INIT LOCATION FOR SCROLLER
0406 0280 HPLK  x=  x+4  ;PLAYERS 0-3 X COORDINATE (FOR PMOVER)
040A 0290 VPLK  x=  x+4  ;PLRS 0-3 Y COORD (FOR PMOVER)
040E 0300 RATE  x=  x+4  ;PLRS 0-3 RATE (FOR ANIMATE)
0412 0310 FLSTPTR  x=  x+4  ;PLRS 0-3 FRAME LIST POINTERS (FOR ANIMATE)
041A 0320 SCRADR  x=  x+2  ;SCREEN ADDRESS (FOR SCROLL)
041C 0330 SCRLLEN  x=  x+2  ;LENGTH OF SCROLLED AREA (FOR SCROLL)
041E 0340 SCROLLK  x=  x+1  ;COLOR CLOCKS IN SCREEN BYTE (FOR SCROLL)
041F 0350 SCRLSTEP  x=  x+1  ;SCROLL STEP (FOR SCROLL)
0420 0360 MOVESIZE  x=  x+4  ;PLRS 0-3 HORIZONTAL STEP (FOR AUTOMOVE)
0424 0370 DLTRDR  x=  x+2  ;ADDRESS OF COLOR TABLE
0380 ;
0390 \XLOCALX DATABASE EQUATES
0400 ; THESE LOCATIONS ARE \XLOCALX TO THE ROUTINES
0410 ; AND SHOULD \NOTX BE MODIFIED BY THE HOST PROGRAM
0420 ;
0426 0430 OX  x=  x+4  ;PLRS 0-3 X COORDINATE
042A 0440 OY  x=  x+4  ;PLRS 0-3 Y COORD
042E 0450 ORATE0  x=  x+4  ;PLRS 0-3 FRAME CHANGE RATE
0432 0460 OAR0  x=  x+3  ;PLRS 0-3 FRAME LIST ADDRESS
043A 0470 TMR0  x=  x+4  ;PLRS 0-3 COUNTDOWN TIMERS (HOW MANY JIFFIES UNTIL FRAME CHANGE)
043E 0480 POS0  x=  x+4  ;PLRS 0-3 FRAME LIST POSITION
0442 0490 OASGR  x=  x+2  ;SCREEN ADDRESS FOR SCROLLER
0444 0500 CFPOS  x=  x+2  ;COARSE SCROLL POSITION FOR SCROLLER (0-LINELEN)
0446 0510 FPOS  x=  x+1  ;FINE SCROLL POSITION (0-7)
0447 0520 DXSTEPF  x=  x+4  ;PLRS 0-3 HORIZONTAL STEP
044B 0530 DLIPOS  x=  x+1  ;CURRENT POSITION IN COLOR TABLE
044C 0540 PM1  x=  x+1  ;14 LOCATIONS RESERVED FOR PMOVER
044D 0550 PM2  x=  x+1
044E 0560 PM3  x=  x+1
044F 0570 PM4  x=  x+1
0450 0580 EX1  x=  x+1  ;14 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND MFILL
0451 0590 EX2  x=  x+1
0452 0600 EX3  x=  x+1
0453 0610 EX4  x=  x+1
CLK-PMOVER.ASM;v02,10-81713,820620
Player Mover Routine

0454 0460 FMSAVE  x=  x+5  ;ZERO PAGE SAVE AREA FOR PMOVER
0459 0630 ZSAVE  x=  x+4  ;ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
D000 0650 HPOSP0 = $D000
E562 0660 XITBV = $E562
0001 0670 ABASIC = 1 ;1=ATARI BASIC, 0=HBASIC
0680 ;
00E0 0690 ZERO = $E0
00E4 0700 ONE = $E4
00E8 0710 ARG = $E8
00E2 0720 TEMP = $E2
0730 ;
0450 0740 X= BASE
0750 ;
0760 START
4000 E0 0770 CLV
4001 5010 0780 BVC START1 ;SKIP OVER GENUS EXIT ROUTINE
0790 ;
0800 EXIT
4003 4C62E4 0810 JMP XITBV ;RETURN FROM INTERRUPT
0820 ;
0830 VEINT
4006 A203 0840 LDX #03 ;MOVE PLAYER X COORDINATES
0850 LOOP4
4008 B02604 0860 LDA 00X,X ;INTO
4009 900000 0870 STA HPOSP0,X ;HARDWARE REGISTERS
400C 0880 DEX
400F 0890 BPL LOOP4
4011 30F0 0900 BMI EXIT ;LEAVE.
0910 ;
0920 START1
4013 0940 .IF 1=ABASIC @NOSAVE
4013 A206 0940 LDX #06 ;SAVE ZERO PAGE LOCATIONS (NOT NECESSARY FOR MBASIC)
0950 LOOP6
4015 B0DF 0960 LDA ZERO-1,X
4017 905304 0970 STA PMSAVE-1,X
401A 0980 DEX
401B D0F8 0990 BNE LOOP6
401D 68 1000 PLA ;NUMBER OF PARAMS (MUST BE 1)
401E 68 1010 PLA ;HI BYTE - DISCARD
401F 68 1020 PLA ;LO BYTE
4028 B0E3 1030 STA ARG ;PUT IN 'ARG'
1040 NOSAVE
1050 ;
4022 A0E3 1060 LDA ARG
4024 B0E2 1070 STA TEMP
4026 A004 1080 LDY AUTOINIT ;SAVE OLD PARAMETER
4029 A200 1090 LDX #00
402B B0404 1100 STX AUTOINIT ;DISABLE AUTOMOVE SO PLAYERS AREN'T MOVED OUT OF SYNC
402E 46E2 1110 LOOP7
4030 9006 1120 BCC NOMOVE
4032 B08680 1130 LDA HPLR,X
CLK-PHIXER.ASM;v02.10-B10713,B2B620
Player Mover Routine
4035 902604 1140 STA 00X,X
1150 NOMOVE

4038 EB 1160 INX
4039 E04 1170 CPX #04
403B D0F1 1180 BNE LOOP7
403D BD04 1190 STY AUTOINIT ;RE-ENABLE AUTOMOVE
  1160 ;
4040 A200 1210 LDX #00
4042 86E6 1220 STX ZERO ;'ZERO' IS A POINTER TO
4044 A000 1230 LDA PMBRAS ;PLAYER 0
4047 C5E1 1240 STA ZERO+1
4049 A010 1250 LDA PMBUF ;'ONE' IS A POINTER
404C B5E5 1260 STA ONE ;TO HOST PROGRAM'S
404E A020 1270 LDA PMBUF+1 ;TEMPORARY BUFFER
4051 B3E5 1280 STA ONE+1
  1290 ; HERE WE DISABLE ANIMATE SO IT DOESN'T DO BIZARRE
  1310 ; THINGS TO OUR PLAYERS WHILE WE'RE MOVING THEM
  1320 ;
4053 A030 1330 LDA AN2INIT ;REMEMBER ANIMATE'S STATUS
4056 B5E5 1340 STA TEMP ;STORE IN TEMP
4058 BD03 1350 STX ANIMINIT ;TELL ANIMATE TO HALT (X STILL EQUALS 0)
  1360 ;
  1370 LOOP
405B A5E3 1380 LSR ARG ;GET NEXT PLAYER'S BIT INTO CARRY
405D B01E 1390 BCS DOIT ;IF IT'S A ONE, MOVE PLAYER
  1400 NEXT
405F C5E6 1410 LDA ZERO ;ADD #80 TO 'ZERO' TO
4061 49B0 1420 EOR #80 ;MOVE TO NEXT PLAYER
4063 B5E5 1430 STA ZERO
4065 D002 1440 BNE INC
4067 E6E1 1450 INC ZERO+1
  1460 INC
4069 EB 1470 INX ;INCREMENT PLAYER NUMBER
406A E004 1480 CPX #04 ;DONE WITH ALL 4 PLAYERS?
406C D0ED 1490 BNE LOOP ;NO, LOOP
406E 85E2 1500 LDA TEMP ;RESTORE ANIMINIT BYTE TO
4070 BD03 1510 STA ANIMINIT ;WHAT IT WAS ORIGINALLY
4073 EB 1520 INX ;SET X TO 5
  1530 LOOP5
4074 1540 ;IF 1-ABASIC #ROEST
4074 BD5A 1550 LDA PHSAVEX ;RESTORE ZERO PAGE TEMPORARIES
4077 95E0 1560 STA ZERO+X
4079 CA 1570 DEX
407A 10F8 1580 BPL LOOP5
  1590 MOST
407C 60 1600 RTS ;BACK TO BASIC
  1610 ;
  1620 DOIT
407D A7F 1630 LDY #7F ;MOVE PLAYER INTO TEMPORARY BUFFER
407F 81E0 1650 LDA (ZERO),Y
CLK-PM0VER.ASM;v02.10-B10713,820620
Player Mover Routine

4081 91E4 1660 STA (ONE),Y ;NEXT BYTE, ARE WE DONE?
4083 88 1670 DEY ;NO, LOOP.
4084 10F9 1680 BPL LOOP2 ;THE "DESTINATION" COORDINATE IN THE
4086 BE4C04 1690 STX PH1 ;THIS WRANGLE MESS OF CODE ENDS UP WITH
4089 B0A04 1700 LDA (000),X ;THE "SOURCE" Y COORD IN
408D 80A04 1720 LDA VPL,X ;X-REG, THE "SOURCE" Y COORD IN
4090 92A04 1730 STA O0Y,X ;THE Y-REG, AND MOVES THE DESTINATION
4093 A0 1740 TAY ;Y COORD INTO THE SOURCE Y
4094 68 1750 PLA ;COORDINATE LOCATION
4095 AA 1760 TXA ;TRANSFER X-REG TO Y-REG
4096 BE4D04 1770 STX PH2 ;SAVE Y-REG
4099 B3E04 1799 STY PH3 ;SET DATA BACK FROM BUFFER
409C 8A 1800 TXA ;TRANSFER X-REG TO Y-REG
409D 80 1810 TAY ;RESTORE Y-REG
409E B1E4 1820 LDA (ONE),Y ;STORE DATA IN PLAYER IN NEW SPOT
40A0 AC4E04 1830 LDY PH3 ;DID THE Y-REG HIT #$00?
40A3 91E0 1840 STA (ZERO),Y ;NEXT BYTE
40A6 1002 1850 BPL OK ;GET DATA BACK FROM BUFFER
40AB 8A00 1870 LDY #$000 ;STORE DATA IN PLAYER IN NEW SPOT
40AF EC4D04 1890 CPX PH2 ;RETURN TO "NEXT" TO
40B2 80E5 1900 BNE LOOP3 ;MOVE ANOTHER PLAYER
128 ;
40B7 8B 1910 CLV ;NO, COPY MORE
40B9 50A5 1920 CPX PM2 ;DO WE HAVE COPIED ALL 128 BYTES?
1930 ;
40BA 9000 1940 BNE LOOP3 ;NO, COPY MORE
40BF 9000 1950 LDX PH1 ;RESTORE X-REG
40C7 88 1960 CLV ;BRANCH BACK TO 'NEXT' TO
40C8 58A5 1970 BVC NEXT ;MOVE ANOTHER PLAYER
1980 ;
40CA 1990 .END

10 ; ANIMATE
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL WAITE
40 ;
0000 0100 .TITLE "CLK-ANIMATE.ASM;v01.05-B10714,820619"
0000 0110 .PAGE "Interrupt-driven Player Animator"
0000 0120 ;
0000 0130 ; BY COREY L. KOSAK
0000 0140 ;
0000 0150 ; B=$4000,FREL
0000 0160 ;
0000 0170 BASE = $4000
0000 0180 ;
0000 0190 x= $400
0200 ;
CASEF DATABASE EQUATES
0210 ;BASE
0220 ;

0400 0230 PMHAS = x+1 \(1\)Byte of Player Missile Area (LOBYTE Equals 0)
0401 0240 PMBUF = x+2 \(1\)Address of 128 Byte Buffer (For PHOVER)
0403 0250 ANINIT = x+1 \(1\)INIT Location for ANIMATE
0404 0260 AUTOINIT = x+1 \(1\)INIT Location for AUTOMOVE
0405 0270 SCRINIT = x+1 \(1\)INIT Location for SCROLLER
0406 0280 HPLR = x+4 \(1\)Players 0-3 X Coordinate (For PHOVER)
040A 0290 VPLR = x+4 \(1\)Players 0-3 Y Coordinate (For PHOVER)
040E 0300 RATE = x+4 \(1\)Players 0-3 Rate (For ANIMATE)
0412 0310 FLSTPTR = x+8 \(1\)Players 0-3 Frame List Pointers (For ANIMATE)
041A 0320 SCRLADR = x+2 \(1\)Screen Address for SCROLL
041C 0330 SCRLLEN = x+2 \(1\)Line Length of Scrolled Area (For SCROLL)
041E 0340 SCRLCLK = x+4 \(1\)Color Clocks in Screen Byte (For SCROLL)
0420 0350 SCRLSTEP = x+1 \(1\)Scroll Step (For SCROLL)
0424 0360 NOVERATE = x+4 \(1\)Players 0-3 Horizontal Step (For AUTOMOVE)
0428 0370 DLADDR = x+2 \(1\)Address of Color Table
0380 ;
0390 \%LOCAL\% DATABASE EQUATES
0400 \%These Locations are \%LOCAL\% to the Routines
0410 \%And Should Not Be Modified by the Host Program
0420 ;

0426 0430 DX = x+4 \(1\)Players 0-3 X Coordinate
042A 0440 DY = x+4 \(1\)Players 0-3 Y Coordinate
042E 0450 ORATE = x+4 \(1\)Players 0-3 Frame Change Rate
0432 0460 ORADR = x+8 \(1\)Players 0-3 Frame Address
043A 0470 ONR = x+4 \(1\)Players 0-3 Countdown Timers (How Many Jiffies Until Frame Change)
043E 0480 POS0 = x+4 \(1\)Players 0-3 Frame List Position
0442 0490 OSADR = x+2 \(1\)Screen Address for SCROLL
0444 0500 CPDS = x+2 \(1\)Coarse Scroll Position for SCROLLER (0-LINELEN)
0446 0510 FPDS = x+1 \(1\)Fine Scroll Position (0-7)
0447 0520 DXSTEP = x+4 \(1\)Players 0-3 Horizontal Step
044B 0530 DLPOS = x+4 \(1\)Current Position in Color Table
044C 0540 PM1 = x+1 \(1\)Locations Reserved for PHOVER
044D 0550 PM2 = x+1
044E 0560 PM3 = x+1
044F 0570 PM4 = x+1
0450 0580 EX1 = x+1 \(1\)Locations Reserved for ANIMATE, AUTOMOVE, SCROLL, AND MFILL
0451 0590 EX2 = x+1
0452 0600 EX3 = x+1
0453 0610 EX4 = x+1

CLI-ANIMATE.ASM;v01.05-210719,820619
Interrupt-driven Player Animator

0454 0620 PMSAVE = x+5 \(1\)Zero Page Save Area for PHOVER
0459 0630 ZSAVE = x+4 \(1\)Zero Page Save Area for All Other Routines
0640 ;
0650 0650 HPOS0 = #0000
E462 0660 XTV5V = %E462
0670 ;
00E0 0680 ZERO = %E0
00E2 0690 ONE = %E2
0700 ;
045D 0710 x = BASE
interrupt-driven Player Animator

Internet-driven Player Animator
1230  ;
403F BA 1240  TXA  ;MULTIPLY X BY 2
4040 BA 1250  ASL A
4041 AB 1260  TAY  ;AND PUT INTO Y
4042 E91204 1270  LDA FLSTPTR,Y  ;MOVE ADR INTO LOCAL AREA
4045 993204 1280  STA QAOR,Y
4048 E91304 1290  LDA FLSTPTR+1,Y
404B 993304 1300  STA QAOR+1,Y
404E AD5004 1310  LDA EX1  ;HAS '16' BIT SET?
4051 30D6 1320  BKI NEXT  ;YES, DON'T INITIALIZE FRAME #
4053 BD0E04 1330  LDA RATE,X
4056 903A04 1340  STA TIMRO,X
4059 A901 1350  LDA #01
405B 9D3E04 1360  STA POS+X
405E D0C9 1370  BNE NEXT  ;UNCOND, BRANCH
        1380  ;
4060 A900 1400  LDA #00  ;'ZERO' POINTS TO CURRENT
4062 C5E0 1410  STA ZERO  ;PLAYER
4064 AD0004 1420  LDA PNBAS
4067 B0E1 1430  STA ZERO+1
        1440  ;
4069 A200 1450  LDX #00  ;START WITH PLAYER #0
        1460 LOOP2
406B BD0E04 1470  LDA ORATE,,X  ;IS THIS A SPECIAL
406E F009 1480  BEQ NEXT2  ;YES, FILL PLAYER
4070 C9FF 1490  CMP #FF  ;'RATE=0' PLAYER?
4072 F025 1500  BEQ CHANGE2  ;YES, CHANGE FRAME
        1510  ;
        1520 NOTZERO
4074 DE3A04 1530  DEC TIMRO,X  ;HAS TIME RUN OUT FOR THIS PLAYER?
4077 F019 1540  BEQ CHANGEIT  ;YES, CHANGE FRAME
        1550  ;
        1560 NEXT2
4079 A5E0 1570  LDA ZERO  ;POINT TO NEXT PLAYER
407B 4980 1580  EOR #80
407D B5E0 1590  STA ZERO
407F D002 1600  BNE INC
4081 E0E1 1610  INC ZERO+1
        1620  ;
        1630 INC
4083 EB 1640  INX  ;MOVE TO NEXT PLAYER
4084 E004 1650  CPX #04  ;LAST PLAYER?
CLK-ANIMATE,ASM;v01.05-810711,820619
Interrupt-driven Player Animator
        1660 LOOP2  ;INO, LOOP
        1670  ;
4088 B05004 1690  LDA ZSAVE-1,X  ;RESTORE ZERO PAGE LOCS
408B 950F 1700  STA ZERO-1,X
408D CA 1710  DEX
408E D0FB 1720  BNE LOOP5
4090 F095 1730  BEQ BSEXIT  ;UNCOND, BRANCH TO EXIT
; 1740 
; 1750 CHANGE1
492 B02E04 1760 LDA ORATE0,X ;RESET TIMER
495 C9FF 1770 CMP $FF
497 D002 1780 BNE NOSPECIAL
; 1790 CHANGE2
499 A001 1800 LDA #$01
1810 NOSPECIAL
49B 903A04 1820 STA TIM0,X
49E 0A 1830 TXA ;SET Y=X^2
49F 0A 1840 ASL A
4AB 0A 1850 TAY
4A1 B93204 1860 LDA DA0R0,Y ;MOVE PLR ADDRESS
4A4 B3E2 1870 STA ONE ;INTO 'ONE'
4A6 B93304 1880 LDA DA0R0+1,Y
4A9 B3E3 1890 STA ONE+1
4AB FE3E04 1910 INC POS0,X ;INCREMENT POSITION IN TABLE
4Ae B03E04 1920 LDA POS0,X
1930 ZAPPO
4B1 0A 1940 TAY
4B2 B1E2 1950 LDA (ONE),Y ;GET FRAME #
4B8 D009 1960 BNE OK ;IF IT'S NON-ZERO, JUMP TO 'OK'
4B9 A002 1970 LDA #$02 ;RESET FRAME POSITION
4BB 903E04 1980 STA POS0,X
4BB D0F4 1990 BNE UNCOND. BRANCH TO ZAPPO
2000 BNEXT2
4BD 5AB0 2010 BVC NEXT2 ;BUCKET-BRIGADE
2020 ;
2030 OK
4BF 850B04 2040 STA EX1 ;STORE FRAME # HONUS ONE.
4C2 CE5004 2050 DEC EX1
4C5 A000 2060 LDY #$00
4C7 B1E2 2070 LDA (ONE),Y ;PUT ADDRESS OF
4C9 0B 2080 PHA ;FRAME DATA
4CA CB 2090 INY ;INTO 'ONE'
4CB B1E2 2100 LDA (ONE),Y
4CD B3E3 2110 STA ONE+1 ;STORE IT
4CF 6B 2120 PLA
4D0 B3E2 2130 STA ONE
4D2 80 2140 DEY ;SET Y TO ZERO
4D3 B1E2 2150 LDA (ONE),Y ;STORE FRAME HEIGHT
4D5 BD5014 2160 STA EX2 ;FRAME HEIGHT
2170 ;
CLK-ANIMATE.ASM:v0.05-810714,820619
Interrupt-driven Player Animator

2180 ;PERFORM:
2190 ;FRAMENUMBER TIMES HEIGHT + FRAME ADDRESS + 1
2200 ;
4098 A900 2210 LDA #$00 ;THIS MULTIPLIES (FRAMENUMBER-1)*HEIGHT
409A A008 2220 LDY #$08
2230 NEXTBIT
40C 4E5004 2240 LSR EX1 ;FRAMENUMBER
40DF 9004 2250          BCC  ALIGN
40E1 1B 2260          CLC
40E2 605104 2270         ADC EX2
                          2280 ;
                          2290 ALIGN
40E5 4A 2300          LSR A
40E6 6E5204 2310        ROR EX3
40E9 BB 2320       DEY
40EA 00F0 2330       BNE NEXTBIT
40E9 AB 2340       TAY ;HIBYTE OF RESULT INTO Y
                          2350 ;
40ED A05204 2360       LDA EX3 ;LOBYTE OF RESULT IN A-REG
40F0 3B 2370          SEC ;+ 1
40F1 6E52 2380       ADC ONE ;+ FRAME ADDRESS
40F3 8E52 2390     STA ONE
40F5 9B 2400       TYA ;NOW ADD THE HIBYTES
40F6 6E53 2410       ADC ONE+1
40F8 8E53 2420     STA ONE+1
40FA BE5004 2430       STX EX1 ;SAVE X
40FD 002A04 2440       LDA 00Y,X ;GET PLAYER Y COORD
4100 AB 2450       TAY ;PUT IN Y-REG
4101 A200 2460       LDX ##80
                          2470 ;
                          2480 LOOP3
4103 BC5204 2490       STY EX3 ;SAVE Y
4106 BA 2500       TXA ;MOVE X INTO Y
4107 AB 2510       TAY
4108 B1E2 2520       LDA (ONE),Y ;MOVE FRAME INTO PLAYER
410A AC5204 2530       LDY EX3 ;RESTORE Y
410C 91E0 2540       STA (ZERO),Y
410F CB 2550       INY
4110 EB 2560       INX
4111 EC5104 2570       CPX EX2 ;HAVE WE COPIED ALL BYTES?
4114 D0ED 2580          BNE LOOP3 ;NO, LOOP
                          2590 ;
4116 AE5004 2600       LDX EX1 ;RESTORE X
4119 BD2E04 2610          LDA ORATE0,X
411C CPFF 2620      CMP ##FF ;IS RATE=FF?
411E D003 2630          BNE NOTFF
4120 FE2E04 2640          INC ORATE0,X ;YES, SET RATE=0
                          2650 NOTFF
4123 BB 2660       CLV
4124 5097 2670       BVC BNEXT2
                          2680 ;
4126 2690       .END

10 ;    AUTOMOVE
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL WAITE
40 ;
0000   0100   .TITLE "CLK-AUTOMOVE.ASM\v01.04-810724,820619"
0000   0110   .PAGE "Automatic Player Mover"
0130 ;BY COREY L. KOSAK
0140 ;
0150 ;B=$4000,FREL
0160 ;
0170 BASE = $4000
0180 ;
0190 x = $400
0200 ;
0210 ;CASEBUF DATABASE EQUATES
0220 ;
0230 PMDR = x+1 ;HIGH BYTE OF PLAYER MISSILE AREA (LOBYTE EQUALS 0)
0240 PMBF = x+2 ;ADDRESS OF 128 BYTE BUFFER (FOR PHOVER)
0250 ANXX = x+1 ;INIT LOCATION FOR ANIMATE
0260 AUTOINIT = x+1 ;INIT LOCATION FOR AUTOMOVE
0270 SCRLINIT = x+1 ;INIT LOCATION FOR SCROLLER
0280 HPLR = x+4 ;PLAYERS 0-3 X COORDINATE (FOR PHOVER)
0290 VPLR = x+4 ;PLAYERS 0-3 Y COORD (FOR PHOVER)
0300 RATE = x+4 ;PLAYERS 0-3 RATE (FOR ANIMATE)
0310 FLSTPTR = x+4 ;PLAYERS 0-3 FRAME LIST POINTERS FOR ANIMATE
0320 SCRLADR = x+2 ;SCREEN ADDRESS (FOR SCROLL)
0330 SCRLLEN = x+2 ;LINE LENGTH OF SCROLLED AREA (FOR SCROLL)
0340 SCRLCLK = x+2 ;COLOR CLOCKS IN SCREEN BYTE (FOR SCROLL)
0350 SCRLSTEP = x+1 ;SCROLL STEP (FOR SCROLL)
0360 MOVERATE = x+4 ;PLAYERS 0-3 HORIZONTAL STEP (FOR AUTOMOVE)
0370 DLADR = x+2 ;ADDRESS OF COLOR TABLE
0380 ;
0390 ;LOCAL* DATABASE EQUATES
0400 ; THESE LOCATIONS ARE *LOCAL* TO THE ROUTINES
0410 ; AND SHOULD NOT BE MODIFIED BY THE HOST PROGRAM
0420 ;
0430 OAK = x+4 ;PLAYERS 0-3 X COORDINATE
0440 OAY = x+4 ;PLAYERS 0-3 Y COORD
0450 ORATE0 = x+4 ;PLAYERS 0-3 FRAME CHANGE RATE
0460 OADR0 = x+8 ;PLAYERS 0-3 FRAME LIST ADDRESS
0470 TIMR0 = x+4 ;PLAYERS 0-3 COUNTDOWN TIMERS (HOW MANY JIFFIES UNTIL FRAME CHANGE)
0480 POS0 = x+4 ;PLAYERS 0-3 FRAME LIST POSITION
0490 OADR = x+2 ;SCREEN ADDRESS FOR SCROLLER
0500 CPSR = x+2 ;COARSE SCROLL POSITION FOR SCROLLER (0-LINELEN)
0510 FPOS = x+4 ;FINE SCROLL POSITION (0-7)
0520 OXSTEP0 = x+4 ;PLAYERS 0-3 HORIZONTAL STEP
0530 DLPOS = x+1 ;CURRENT POSITION IN COLOR TABLE
0540 PH1 = x+1 ;4 LOCATIONS RESERVED FOR PHOVER
0550 PH2 = x+1
0560 PH3 = x+1
0570 PH4 = x+1
0580 EX1 = x+1 ;4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND MFILL
0590 EX2 = x+1
0600 EX3 = x+1
0610 EX4 = x+1
0620 PMSAVE = x+5 ;ZERO PAGE SAVE AREA FOR PHOVER
0630 ZSAVE = x+4 ;ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
0640 ;
E462 0650 XITBV = $E462
0660 ;
00E0 0670 ZERO = $E0
00E2 0680 ONE = $E2
0690 ;
045D 0700 X= BASE
0710 ;
0720 START
4000 BB 0730 CLV
4001 5003 0740 BVC START1
0750 ;
0760 EXIT
4003 4C62E4 0770 JMP XITBV
0780 ;
0790 START1
4006 BB 0800 CLD ;CLEAR DECIMAL MODE!!!
4007 AD0404 0810 LDA AUTOINIT ;INIT BYTE SET?
400A FO7F 0820 BEQ EXIT ;NO, LEAVE
400C 3017 0830 BNE MOVETHEN ;NORMAL OPERATION IF >127
0840 ;
400E A200 0850 LDX #000 ;START WITH PLAYER #0
0860 LOOP
4010 E40404 0870 LSR AUTOINIT ;IS THE BIT FOR THIS PLAYER SET?
4013 9006 0880 BCC NEXT ;NO, SKIP OVER UPDATE
4015 BD2004 0890 LDA MOVEPOS,X ;MOVE PARAMS INTO LOCAL LOCATIONS
4018 9D4704 0900 STA OXSTEP0,X
0910 NEXT
401B EB 0920 INX
401C E004 0930 CPX @#04 ;ARE WE ALL DONE?
401E 00F0 0940 BNE LOOP ;NO, SO LOOP
4020 A980 0950 LDA #080
4022 BD0404 0960 STA AUTOINIT ;SET INIT BYTE TO #80
0970 ;
0980 MOVETHEN
4023 A203 0990 LDX #003 ;START WITH PLAYER #3
1000 LOOP2
4027 BD4704 1010 LDA OXSTEP0,X ;READ STEP
402A 99B0 1020 EOR @#80 ;REVERSE SIGN
402C 0B 1030 PHP
402D 1B 1040 CLC
402E 702A40 1050 ADC OX,X ;ADD STEP TO OLD XCOORD
4031 9005 1060 BCC CLEARD
1070 ;
4033 2B 1080 PLP
4034 300C 1090 BMI OK ;CARRY SET IS OK, IF STEP IS NEGATIVE
4036 1003 1100 BPL BAD
1101 ;
1110 CLC
1120 CLEARD
4039 2B 1130 PLP
CLK-AUTOMOVE.ASM;v1.04-010724-820619
Automatic Player Move
4039 1007 1140 RPL OK ;CARRY CLEAR IS OK, IF STEP IS POSITIVE
1150    ;
1160    BWD
1170    LDA #80    ;ZERO THE STEP. (STOP MOTION FOR THIS PLAYER)
1180    STA OXSTEP,X ;STORE XCOORD OF THIS PLAYER
1190    LDA #00    ;ZERO THE XCOORD. OF THIS PLAYER
1200    ;
1210    OK
1220    STA OXX,X ;STORE XCOORD
1230    DEX ;DO NEXT PLAYER
1240    BPL LOOP2 ;LAST PLAYER? NO, LOOP
1250    BMI EXIT ;YES, LEAVE.
1260  .END

10 ; SCROLL
20 ;
30 ; COPYRIGHT (C) 1982 BY DAVID FOX AND MITCHELL WAITE
40 ;
0000 0100    ;TITLE "CLK-SCROLL.ASM\v01.09-010719,820619"
0000 0110    ;PAGE "Interrupt-driven Screen Scroller"
0120 ;
0130 ; BY COREY L. KOSAK
0140 ;
0150 ; E=#4000,FREL
0160 ;
4000 0170 BASE = $4000
0180 ;
0000 0190 x = $400
0200 ;
0210 ; CASEBUF DATABASE EQUATES
0220 ;
0400 0230 PHNAS x = x+1 ;HIBYTE OF PLAYER MISSILE AREA (LOBYTE EQUALS 0)
0401 0240 PHNBF x = x+2 ;ADDRESS OF 128 BYTE BUFFER (FOR PSMOVE)
0403 0250 ANIMX x = x+1 ;INIT LOCATION FOR ANIMATE
0404 0260 AUTOMIT x = x+1 ;INIT LOCATION FOR AUTOMOVE
0405 0270 SCRDLIT x = x+1 ;INIT LOCATION FOR SCROLLER
0406 0280 HLR x = x+4 ;PLAYERS 0-3 X COORDINATE (FOR PSMOVE)
040A 0290 VLR x = x+4 ;PLRS 0-3 Y COORD (FOR PSMOVE)
040E 0300 RATE x = x+4 ;PLRS 0-3 RATE (FOR ANIMATE)
0412 0310 FLSTPTR x = x+8 ;PLRS 0-3 FRAME LIST POINTERS (FOR ANIMATE)
041A 0320 SCRADR x = x+2 ;SCREEN ADDRESS (FOR SCROLL)
041C 0330 SCRLEN x = x+2 ;LINE LENGTH OF SCROLLED AREA (FOR SCROLL)
041E 0340 SCCLK x = x+1 ;COLOR CLOCKS IN SCREEN BYTE (FOR SCROLL)
041F 0350 SCSTEP x = x+1 ;SCROLL STEP (FOR SCROLL)
0420 0360 MOVSTEP x = x+4 ;PLRS 0-3 HORIZONTAL STEP (FOR AUTOMOVE)
0424 0370 0380 ;
0390 ;LOCAL# DATABASE EQUATES
0400 ; THESE LOCATIONS ARE LOCAL# TO THE ROUTINES
0410 ; AND SHOULD NOT# BE MODIFIED BY THE HOST PROGRAM
0420 ;
0426 0430 OX x = x+4 ;PLRS 0-3 X COORDINATE
042A 0440 OY x = x+4 ;PLRS 0-3 Y COORD
042E 0450 ORATE x = x+4 ;PLRS 0-3 FRAME CHANGE RATE
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0432 0460 DMOR0  =  x+6  ;PLRS 0-3 FRAME LIST ADDRESS
0434 0470 TDMR0  =  x+4  ;PLRS 0-3 COUNTDOWN TimERS (HOW MANY Jiffies UNTIL FRAME CHANGE)
043E 0480 POS0  =  x+4  ;PLRS 0-3 FRAME LIST POSITION
0442 0490 OSADR  =  x+2  ;SCREEN ADDRESS FOR SCROLLER
0444 0500 CPBS  =  x+2  ;COARSE SCROLL POSITION FOR SCROLLER (0- SCROLLLEN)
0446 0510 FPBS  =  x+1  ;FINE SCROLL POSITION (0-7)
0447 0520 DXSTEP0 =  x+4  ;PLRS 0-3 HORIZONTAL STEP
044B 0530 DLSTEP0 =  x+1  ;CURRENT POSITION IN COLOR TABLE
044C 0540 PM1  =  x+1  ;4 LOCATIONS RESERVED FOR PMOVER
044D 0550 PM2  =  x+1
044E 0560 PM3  =  x+1
044F 0570 PM4  =  x+1
0450 0580 EX1  =  x+1  ;4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND MFILL
0451 0590 EX2  =  x+1
0452 0600 EX3  =  x+1
0453 0610 EX4  =  x+1

CLK-SCROLL.ASM:v01.09-B18719,828619
Interrupt-driven Screen Scroller

0454 0620 PHSAVE  =  x+5  ;ZERO PAGE SAVE AREA FOR PMOVER
0459 0630 ZSAVE  =  x+4  ;ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
0460 ;
0462 0650 XITBV9 = $E462
0464 0660 HSCROLL = $0464
0230 0670 SOLSTL = $230
0680 ;
00E0 0690 ZERO  =  $00
00E2 0700 ONE  =  $02
0710 ;
045D 0720  =  BASE
0730 ;
0740 START
4000 DB 0750 CLV
4001 5003 0760 BVC START1 ;SKIP OVER VBLANK EXIT ROUTINE
0770 ;
0780 EXIT
4003 4C62E4 0790 JMP XITBV9
0800 ;
0810 START1
4006 DB 0820 CLD ;CLEAR DECIMAL MODE FOR ATARI BASIC!
4007 AD0504 0830 LDA SCRLINIT ;IS THE INIT BYTE SET?
400A F0F7 0840 BEQ EXIT ;NO, LEAVE
400C 104B 0850 BPL BSINIT2 ;YES, INIT EVERYTHING
0860 ;
400E 8570 0870 LDA ZERO ;SAVE ZERO PAGE TEMPS
4010 805904 0880 STA ZSAVE
4013 85E1 0890 LDA ZERO+1
4015 805004 08A0 STA ZSAVE+1
4018 AD3802 08B0 LDA SOLSTL ;MOVE DISPLAY LIST POINTER
401B 85E0 08C0 STA ZERO ;INTO TEMPORARY POINTER
401D AD3102 08D0 LDA SOLSTL+1
4020 85E1 08E0 STA ZERO+1
0950 ;
0960 ; HOW WE SPLIT SCRLSTEP INTO A COARSE
Interrupt-driven Screen Scroller

0970 ; AND FINE STEP, AND ALSO COMPUTE, VIA
0980 ; SCRLCLK, THE NUMBER OF BYTES PER SCREEN LINE (IN MODE PLAYFIELD)
0990 ;
2022 A01E04 1000 LDA SCRLCLK   ;MOVE CLOCK VALUE TO EX1
2025 BD5004 1010 STA EX1
2028 A9C0 1020 LDA @C0   ;BYTES PER MODE LINE
202A BD5104 1030 STA EX2
202D A01F04 1040 LDA SCRLSTEP   ;SHIFT OUT FINE SCROLL
2030 AD00 1050 LDY @D00   ;OFFSET IN SCREEN BYTE TABLE
2032 AE5004 1060 LSR EX1  ;SHIFT RIGHT CLOCK VALUE
2033 9007 1070 BCC CO01E   ;ANY BITS LEFT?
2037 4A 1080 LSR A   ;YES, SHIFT SCROLL VALUE
2038 AE5104 1090 LSR EX2  ;DIVIDE MODE LINE LENGTH BY 2
203B CB 1100 INY   ;AND BUMP POINTER
203C D0F4 1110 BNE CLOOP  ;ALWAYS TAKEN
203E D05004 1120 STA EX1   ;STORE COARSE STEP
2137 1B 1130 CLC
203F 60A40 1200 ADC FP0S   ;ADD CURRENT FINE SCROLL VALUE
2040 D01E04 1210 CMP SCRLCLK   ;DID IT GO OVER CLOCK VALUE?
2044 F00E 1220 BEQ OK   ;NOPE.
2050 900C 1230 BCC OK   ;NOPE.
2052 B004 1240 BCS INCIT  ;SKIP OVER BUCKET-BRIGADES
2125 1260 BSEXIT2
2054 58A0 1270 BVC EXIT
2128 BSEXIT2
2056 D059 1290 BNE BINIT   ;STORE IN CURRENT SCROLL VALUE
2130 ;
2136 INCIT
2058 EE5004 1320 INC EX1  ;YES, INCREMENT COARSE STEP
205B 201E04 1330 AND SCRLCLK  ;AND PUT FINE STEP IN RANGE
213D 1340 ;
213D 1350 OK
205E BD4604 1360 STA FP0S   ;STORE IN CURRENT SCROLL VALUE
2061 DA0E04 1370 EOR SCRLCLK   ;SCROLL REGISTER IS
2064 BD4004 1380 STA HSCROLL   ;BACKWARDS'
213D 1390 ;
2067 AD5004 1400 LDA EX1  ;GET COARSE SCROLL STEP
206A 18 1410 CLC
2068 BD4404 1420 ADC CP0S   ;ADD CURRENT SCROLL VALUE
206B BD4404 1430 STA CP0S   ;AND STORE BACK
2071 9003 1440 BCC DK4
2073 EE4504 1450 INC CP0S+1   ;
2146 1460 ;
2147 1470 DK4
Interrupt-driven Screen Scroller

4076  AD4404  1460  LDA  CPOS  ;ADD EX2+1 TO BEGINNING OF
4079  38  1490  BEC  END OF SCREEN
407A  605104  1500  ADD  EX2
407D  BD4404  1510  STA  CPOS
4088  9003  1520  BCC  OK5
4082  EE4504  1530  INI  CPOS+1
1540  OK5
4085  AD5404  1550  LDA  CPOS+1
4088  CD1D04  1560  CMP  SCRLLEN+1 ;HAVE WE SCROLLED TO EDGE OF SCREEN?
408B  9028  1570  BCC  OK2 ;NO, WE'RE OK
408D  D008  1580  BNE  RESET ;YES, BET BACK TO BEGINNING
408F  AD4404  1590  LDA  CPOS ;MAYBE?
4092  CD1C04  1600  CMP  SCRLLEN
4095  901E  1610  BCC  OK2 ;NO, WE'RE OK
1620  RESET
4097  A900  1630  LDA  #000 ;SET POINTERS TO BEGINNING OF
409F  BD4404  1640  STA  CPOS ;SCREEN LINE
409C  BD4504  1650  STA  CPOS+1

CLK-SCROLL.ASH;v01.09-810719,820619

MOVE START ADDRESS

1670  STA  SCRLADR

1680  STA  OSADR ;OF SCROLL WINDOW

1690  LDA  SCRLADR+1 ;INTO LOCAL AREA

1700  STA  OSADR+1

1710  CLV

1720  BVC  OK6 ;AND DON'T SUBTRACT EX2

1730 ;

1740  BEXIT

1750  BNE  INIT

1760  BEXIT

1770  BVC  BEXIT2

1780 ;

1790  OK2

4085  AD4404  1800  LDA  CPOS ;SUBTRACT THE EX2 WE ADDED EARLIER

4088  18  1810  CLC

4089  ED5104  1820  SBC  EX2

408C  BD4404  1830  STA  CPOS

408F  B003  1840  BCS  OK6

40C1  CE4504  1850  DEC  CPOS+1

1860  OK6

40C4  CD4204  1870  LDA  OSADR

40C7  18  1880  CLC

40CB  6D5004  1890  ADD  EX1 ;ADD STEP TO SCREEN ADDRESS
40CB  BD4204  1900  STA  OSADR ;AND MOVE INTO EX3 AND EX4
40CE  BD5204  1910  STA  EX3
40D1  9003  1920  BCC  OK3
40D3  EE4304  1930  INC  OSADR+1
1940 ;

1950  OK3

40D6  AD4304  1960  LDA  OSADR+1

40DF  BD5304  1970  STA  EX4

40DC  A003  1980  LDY  #003 ;SKIP OVER FIRST THREE DL INSTRUCTIONS
Appendix 

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1990 LOOP
400E B1E0 2000 LDA (ZERO),Y ;GET BYTE IN DISPLAY LIST
400E C941 2010 CMP #41 ;MB? (END OF DLIST?)
400E F029 2020 BNE DONE ;YES, QUIT
4030 ;
404E 2950 2040 AND #50 ;MSROLL OR LSB BITS SET?
404E F920 2050 BNE NOCHANGE ;NO, FORGET IT
404E 2910 2060 AND #10 ;MSROLL SET?
404E F01A 2070 BNE NSROLL ;NO, SKIP OVER NEXT TWO BYTES
404E CB 2080 INY ;NEXT 2 BYTES ARE MEMORY ADDRESS OF CURRENT LINE
404E AD5204 2090 LDA EX3 ;MOVE SCREEN ADDRESS
4050 91E0 2100 STA (ZERO),Y ;INTO DISPLAY LIST
4050 18 2110 CLC
4050 601C04 2120 ADC SCRLLEN ;AND ADD SCRLLENGTH
4050 805301 2130 STA EX3
4050 C8 2140 INY
4050 AD5300 2150 LDA EX4 ;DO KBYTE
4050 91E0 2160 STA (ZERO),Y
4050 FF 601D04 2170 ADC SCRLLEN+1
CLK-SCROLL.ASM:01.09-810719,820619
Interrupt-driven Screen Scroller

4102 805304 2180 STA EX4
4100 18 2190 ;
4105 AD 2200 .BYTE #40 ;"LDA ABSOLUTE" OPCODE SKIPS NEXT 2 BYTES
4106 CB 2220 NSROLL
4107 CB 2230 INY
4107 CB 2240 ;
4108 CB 2250 ;
4108 CB 2260 NOCHANGE
4109 D0D3 2270 INY ;ALWAYS (DISPLAY LIST MUSTN’T BE LONGER THAN 256 BYTES)
410B 5A66 2280 BNE LOOP
410D 5A66 2290 ;
4110 B8EX3 2300 BNE LOOP
4110 5A66 2310 BVC B8EXIT
4110 2320 ;
4110 2330 DONE
4110 AD5904 2340 LDA ZSAVE ;RESTORE ZERO PAGE TEMPS
4111 8SE0 2350 STA ZERO
4112 AD5A04 2360 LDA ZSAVE+1
4115 8SE1 2370 STA ZERO+1
4117 B8 2380 CLV
4118 5099 2390 ;
4118 2400 ;
4118 2410 INIT
411A 9B00 2420 LDA #80 ;
411C BD5004 2430 STA SCRLINIT ;SET INIT BYTE TO "ON"
411F AD1E04 2440 LDA SCRLCLK ;SET SCROLL POINTERS TO LEFT OF SCREEN
4122 BD4804 2450 STA FP0S
4125 A900 2460 LDA #00 ;
4127 BD4504 2470 STA CP0S
412A BD4404 2480 STA CP0S+1
412D AD1A04 2490 LDA SCRLADR ;MOVE SCREEN ADDRESS TO LOCAL AREA
; DLIROUT

$0400 0238 PMHAS = x+1 ; HIGH OF PLAYER MISSLE AREA (LOBYTE EQUALS 0)
$0401 0240 PMBUF = x+2 ; ADDRESS OF 128 BYTE BUFFER (FOR PHOVER)
$0403 0250 ANINIT = x+1 ; INIT LOCATION FOR ANIMATE
$0404 0260 AUTOINIT = x+1 ; INIT LOCATION FOR AUTOMOVE
$0405 0270 SCRLINIT = x+1 ; INIT LOCATION FOR SCROLLER
$0406 0280 HPLR = x+4 ; PLAYERS 0-3 X COORDINATE (FOR PHOVER)
$040A 0290 VPLR = x+4 ; PLRS 0-3 Y COORD (FOR PHOVER)
$040E 0300 RATE = x+4 ; PLRS 0-3 RATE (FOR ANIMATE)
$0412 0310 FLSTPTR = x+8 ; PLRS 0-3 FRAME LIST POINTERS (FOR ANIMATE)
$041A 0320 SCRLADR = x+2 ; SCREEN ADDRESS (FOR SCROLL)
$041C 0330 SCRLLEN = x+2 ; LINE LENGTH OF SCROLLED AREA (FOR SCROLL)
$041E 0340 SCROLCK = x+1 ; COLOR CLOCKS IN SCREEN BYTE (FOR SCROLL)
$041F 0350 SCRLSTEP = x+1 ; SCROLL STEP (FOR SCROLL)
$0420 0360 MOVEHRT = x+4 ; PLRS 0-3 HORIZONTAL STEP (FOR AUTOMOVE)
$0424 0370 DLJADR = x+2 ; ADDRESS OF COLOR TABLE

$0380 ;
$0390 ; LOCAL# DATABASE EQUATES
$0400 ; THESE LOCATIONS ARE #LOCAL# TO THE ROUTINES
$0410 ; AND SHOULD #NOT# BE MODIFIED BY THE HOST PROGRAM

$0426 0438 ODX = x+4 ; PLRS 0-3 X COORDINATE
$042A 0440 ODY = x+4 ; PLRS 0-3 Y COORD
$042E 0450 ODRATE = x+4 ; PLRS 0-3 FRAME CHANGE RATE
$0432 0460 OADR0 = x+8 ; PLRS 0-3 FRAME LIST ADDRESS
$043A 0470 TDHR = x+4 ; PLRS 0-3 COUNTDOWN TIMERS (HOW MANY JIFFIES UNTIL FRAME CHANGE)
$043E 0480 POS0 = x+4 ; PLRS 0-3 FRAME LIST POSITION
$0442 0490 OSAOR = x+2 ; SCREEN ADDRESS FOR SCROLLER
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1444 0500 CPOS \( x = x+2 \) :COARSE SCROLL POSITION FOR SCROLLER (O-LINELEN)
1446 0510 FPPOS \( x = x+1 \) :FINE SCROLL POSITION (0-7)
1447 0520 DXSTEP \( x = x+4 \) :PLUS 0-3 HORIZONTAL STEP
1448 0530 DLPOS \( x = x+1 \) :CURRENT POSITION IN COLOR TABLE
1449 0540 PH1 \( x = x+1 \) :4 LOCATIONS RESERVED FOR PHM0W
1450 0550 PH2 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1451 0560 PH3 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1452 0570 PH4 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1453 0580 EX1 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1454 0590 EX2 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1455 0600 EX3 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL
1456 0610 EX4 \( x = x+1 \) :4 LOCATIONS RESERVED FOR ANIMATE, AUTOMOVE, SCROLL, AND NFILL

CLK-DLIROUT.ASM:v01.06-810806,820819
DLI Color Changer

0454 0620 PMSAVE \( x = x+5 \) :ZERO PAGE SAVE AREA FOR PHM0W
0459 0630 ZSAVE \( x = x+4 \) :ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
045D 0640 DLI1 \( x = x+1 \) :ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
045E 0650 DLI2 \( x = x+1 \) :ZERO PAGE SAVE AREA FOR ALL OTHER ROUTINES
0660 ;
0618 0670 COLPF2 = \#0018
0619 0680 COLPF3 = \#0019
061A 0690 COLBAK = \#001A
0462 0700 XITVBV = \#0462
046A 0710 MSYNC = \#046A
0720 ;
06E0 0730 ZERO = \#00
0740 ;
045F 0750 \( x = BASE \)
0760 ;
0770 START
4000 88 0780 CLV
4001 508A 0790 BVC DLIIO \( ;(\)SKIP OVER VBLANK EXIT ROUTINE
0800 ;
0810 EXIT
4003 4C62E4 0820 JMP XITVBV
0830 ;
0849 VBLINT
4006 A900 0850 LDA \#0000 \( ;ON VBLANK, ZERO THE COLOR TABLE POINTER
4008 8D480A 0860 STA DLIPOS
4010 50F6 0870 BEQ EXIT \( ;\)LEAVE
0880 ;
0899 DLIIO
4010 48 0900 PHA \( ;S\)AVE A,X, & Y ON STACK
401E 8A 0910 TXA
401F 48 0920 PHA
4010 98 0930 TYA
4011 48 0940 PHA
0950 ;
4012 A5E1 0960 LDA ZERO \( ;\)SAVE ZERO PAGE LOCs
4014 8D5D04 0970 STA DLI1
4017 A5E1 0980 LDA ZERO+1
4019 8D5E04 0990 STA DLI2
488 / Appendix F

```
401C AD2404 1000  LDA DLIADR  ;MOVE ADDRESS OF COLOR TABLE
401F B5E0 1010  STA ZERO  ;INTO POINTER
4021 AD2504 1020  LDA DLIADR+1
4024 B5E1 1030  STA ZERO+1
4026 AC4B04 1050  LDY DLIPOS  ;GET COLOR TABLE POINTER INTO Y-REG
4029 B1E0 1060  LDA (ZERO),Y  ;GET COLOR
402B 4B 1070  PHA  ;A=COLPF2
1080 ;
402C C8 1090  INY  ;GET THE NEXT COLOR
402D B1E0 1100  LDA (ZERO),Y
402F AA 1110  TAX  ;X=COLPF3
1120 ;
4030 C8 1130  INY  ;AND THE NEXT
CLK-DLIROUT.ASM:v01.06-B10086,B20619

DLI Color Changer

4031 B1E0 1140  LDA (ZERO),Y
4033 C8 1150  INY
4034 8C4B04 1160  STY DLIPOS  ;STORE NEW COLOR TABLE POINTER
4037 AB 1170  TAY  ;Y=COLBALK
4038 6B 1180  PLA  ;A=COLPF2
4039 EA 1190  NOP  ;PUT 18 CYCLE DELAY IN FOR
403A EA 1200  NOP  ;TIMING PROBLEM
403B EA 1210  NOP
403C EA 1220  NOP
403D EA 1230  NOP
403E EA 1240  NOP
403F EA 1250  NOP
4040 EA 1260  NOP
4041 EA 1270  NOP
1280 ;
4042 8D0A04 1290  STA HSYNC  ;WAIT FOR HORIZONTAL SYNC
4045 8D1E00 1300  STA COLPF2  ;QUICK! STORE THOSE COLORS!
4048 8E1900 1310  STX COLPF3
404B 8C1A00 1320  STY COLBALK
1330 ;
404E AD5004 1340  LDA DLI1  ;RESTORE ZERO PAGE LOCS
4051 B5E0 1350  STA ZERO
4053 AD5E04 1360  LDA DLI2
4055 B5E1 1370  STA ZERO+1
1380 ;
4058 6B 1390  PLA  ;AND REGISTERS FROM STACK
4059 AB 1400  TAY
405A 6B 1410  PLA
405B AA 1420  TAX
405C 6B 1430  PLA
405D 10 1440  RTI  ;AND RETURN FROM WHENCE.
1450 ;
405E 1460  .END
```
### Appendix G (Courtesy of ATARI)

#### ATARI Hardware and Shadow Registers

<table>
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<td>COLOR2</td>
<td>2C6</td>
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<td>Character Base Address</td>
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Set to $40 by IRQ code
write to by NMI code
read by NMI code
Set to $3C by IRQ Code
Set to $3C by IRQ Code

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<td>Sizes for all missiles</td>
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| SIZEP0 | Size of Player 0 | D008 | 53256 |        |      |      |
| SIZEP1 | Size of Player 1 | D009 | 53257 |        |      |      |
| SIZEP2 | Size of Player 2 | D00A | 53258 |        |      |      |
| SIZEP3 | Size of Player 3 | D00B | 53259 |        |      |      |
| SKCTL  | Serial Port Control | D20F | 53775 | SSKCTL | 232  | 562  |

| SKREST | Reset Serial Port Status (SKSTAT) | D20A | 53770 |        |      |      |
| SKSTAT | Serial Port Status | D20F | 53775 |        |      |      |
| STIMER | Start Timer | D209 | 53769 |        |      |      |
| TRIGO  | Joystick Controller Trigger 0 | D010 | 53264 | STRIG0 | 284  | 644  |
| TRIG1  | Joystick Controller Trigger 1 | D011 | 53265 | STRIG1 | 285  | 645  |
| TRIG2  | Joystick Controller Trigger 2 | D012 | 53266 | STRIG2 | 286  | 646  |
| TRIG3  | Joystick Controller Trigger 3 | D013 | 53267 | STRIG3 | 287  | 647  |
| VCOUNT | Vertical Line Counter | D40B | 54283 |        |      |      |
| VDELAY | Vertical Delay | D01C | 53276 |        |      |      |
| VSCROL | Vertical Scroll | D405 | 54277 |        |      |      |
| WSYNC  | Wait for Horizontal Sync | D40A | 54282 | Used by keyboard click routine |
Appendix H

Graphics Memory Map Modes

(Figure continues)
Figure H.1: Graphics memory map modes.
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A
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More BYTE Books Coauthored by Mitchell Waite
This is just one of four books coauthored by Mitchell Waite and published by BYTE/McGraw-Hill. You’ll find the same friendly, easy-to-follow style and user-centered approach in each of the titles listed below. If you enjoyed and learned from this book, you’ll certainly find the others in the Waite series equally helpful.

APPLE BACKPACK: Humanized Programming in BASIC, by Scot Kamins and Mitchell Waite. This book aids all computer users by establishing the “user-friendly” approach to programming in BASIC. The authors present concrete methods for developing programs that are not only easy to use, but also hard to misuse. Specific topics include clear screen formatting, crashproofing programs, developing built-in verifications and validations, presenting directions on the video display, and writing helpful, thorough documentation. Appendices feature an educational game program embodying the authors’ user-centered approach and a humanized telephone-message-recording program with model documentation, both with complete Applesoft BASIC listings.

8086/8088 16-bit Microprocessor Primer, by Christopher Morgan and Mitchell Waite. The new, vastly more powerful 16-bit microprocessors are destined to become the basis for the next generation of personal computers, and this book provides the understanding you need to harness this remarkable advance in technology. Using a comfortable, down-to-earth approach, the authors detail the design and capabilities of the Intel 8086/8088 16-bit microprocessor. Also examined are two 16-bit “coprocessors,” the 8087 Numeric Data Processor and the 8089 I/O Processor. In addition, the authors survey the current scene in 16-bit technology, reviewing software and products such as the new 8088-based IBM Personal Computer.

Word Processing Primer, by Mitchell Waite and Julie Arca. The first book of its kind, Word Processing Primer focuses on the newly available microcomputer-based text-editing programs. The authors begin with a review of the field, giving a working knowledge of the equipment and programs that make text editors work. A section on text formatting shows you how to control the final appearance of your printed copy, and a review of ancillary software, such as programs that check grammar or spelling and those that generate indexes or personalized form letters, shows the potential for customized applications. The book goes on to tell you what to look for when choosing a word processor, and a mini-catalog compares features, capabilities, limitations, and prices of many of the most popular pieces of software and equipment.
ANIMATION MAGIC

Programs From COMPUTER ANIMATION PRIMER

Animation Magic is a two-sided diskette containing all of the animation demonstration programs and Assembly Language Source code from Part Two of this book. The programs are an excellent collection which illustrates the power of the ATARI Home Computer. Included are the examples covering Character Set Animation, Color Register Animation, Player-Missile Graphics, Fine Scrolling, and Display List Interrupts.

Many of the programs make use of special “black box” machine language routines. By black box, we mean that it is not necessary to understand how the routines work. Just plug in the values and call the routine to move Players across the screen, scroll a background scene, or allow the use of many extra colors on the display.

Animation Magic is ideal for the programmer who doesn’t have the time or inclination to enter the pages of BASIC listings into the computer. The source code for the black box routines, developed with the ATARI Assembler-Editor cartridge, can be modified for custom applications. Any of the programs or routines can be incorporated into your own programs which can then be marketed. Only an acknowledgment at the beginning of the program and in the documentation is required.

When the programs on the disk are used in conjunction with this book’s clear and thorough explanations, they form an excellent tutorial. We think you will find the programs an interesting and efficient way to learn how to maximize the use of your ATARI Home Computer.

To order Animation Magic, simply use the form on this page. You may send a check or money order for $19.95 plus $3.00 shipping and handling payable to Adventure International, or you may use your VISA or MasterCard. Mail to:

Adventure International
P.O. Box 3435
Longwood, FL 32750

or you may order directly by calling Adventure International toll free at 1-800-327-7172 (in Florida call 1-862-6917). Ask for Animation Magic, catalog number 52-0223.
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Photo 1.15b, page 28. (Courtesy of Nelson Max, Lawrence Livermore National Laboratory.)
Frame from "Vol Libre," Loren Carpenter. (Flip through the book to see this film in motion.) (Courtesy of Lucasfilm Ltd.)

Frame from "Panasonic Commercial — Paper Airplane." (Flip through the book to see this film in motion.) (Courtesy of Robert Abel and Associates.)
Frame from "Times Square," Digital Effects Inc.: Rosebash, Kleiser, Leich, Cox, Loen, Prins, Deas, and Cohen, 1979. (Flip through the book to see the film in motion.) (Courtesy of Digital Effects Inc.)

Frame from "Walking Man," Mathematical Applications Group, Inc. (Flip through the book to see the film in motion.) (Courtesy of MAGI/SynthaVision.)
"Pt. Reyes" — Lucasfilm Ltd., April 1983. This landscape was defined using patches, polygons, fractals, particle systems, and a variety of procedural models. The various elements were rendered separately and later composited. The piece is very much a team effort, a one-frame movie, produced by Loren Carpenter, Rob Cook, Tom Porter, Bill Reeves, David Salesin, and Alvy Ray Smith.

"Maxfield" — Lucasfilm Ltd., December 1983. The upper half of the picture contains computer-generated aspen and spruce trees by Bill Reeves. They are 3-dimensional and fully antialiased. The color scheme is inspired by Maxfield Parrish paintings. The lower half is handpainted using a computer painting program. The picture composition and painting are by John Lasseter; the paint program is by Tom Porter.


Pacific Data Images, Inc. "Test Flight — Approach." This spaceship is modeled from various superquadrics. The green terrain under the ship is a fractal landscape.

Pacific Data Images, Inc. "Test Flight — Orbit." Another superquadric spaceship. It is in orbit around a planet made by texture mapping an image of Jupiter's surface onto a sphere.

Photo 2.3a,b, page 63. (Courtesy of Jane Veeder.)

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Photo 2.5, page 71.
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Photo 3.1a, page 107.
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Photo 3.2a, b, c, page 112.
(Courtesy of Advanced Electronics Design, Inc.)

Photo 3.3a, b, c, pages 113-114.
(Courtesy of Aurora Systems; Damon Rarey — artist.)

Photo 3.3c, page 114.
(Courtesy of Digital Effects Inc., Mark Lindquist — artist.)
<table>
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<th>BYTE VALUE</th>
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<th>INVERSE</th>
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Figure 5.20, page 194.

Photo 5.7c, “Crash, Crumble, and Chomp!” page 204. (Copyright 1981 Automated Simulations, Inc.)

Figure 5.21, page 196.

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Photo 6.8, page 233.
Computer Animation Primer

This is the book for those who want real action on their computer screens! Popular computer authors Mitchell Waite and David Fox introduce you to the exciting world of computer animated graphics and present the tools and techniques for creating original animated displays on personal computers.

The first part of Computer Animation Primer fills you in with an overview of the field, describing the theory of animation, basic hardware and software concepts, and the potential of various products for animation. A vivid look at state-of-the-art computer-generated animated movies and flip book computer animation will fascinate and inspire you. Given this background, you're ready for the actual programming techniques used in personal computer animation, including character sets, plotting, player-missile, and scrolling graphics.

Computer Animation Primer features complete listings of Atari BASIC animation programs, such as the Great Movie Cartoon and Walking Man. Although the authors chose to work solely with the Atari computer because of its unique potential for graphics and animation, users of other personal computers will find much inspiration and valuable technical information in these pages.

Enhanced by many colorful illustrations, this enticing new book shows you all you need to know to create your own galloping horses, exploding bombs, flying spaceships, and dancing figures.

David Fox has been a member of the Computer Games Project at Lucasfilm Ltd. since 1982 and was the project leader for one of their first games, Rescue on Fractalus! Prior to joining Lucasfilm, he and his wife, Annie, co-founded the world's first public access microcomputer center. Since it opened in 1977, the center has been a prototype for bringing today's technology to the public. David Fox made his first 8 mm cartoon when he was eleven years old and has been fascinated with animation ever since. He studied engineering at UCLA and Humanistic Psychology at California State University at Sonoma, where he received his bachelor's degree. He is the co-author of the best-selling books Armchair BASIC and Pascal Primer as well as the software package Apple Spice. When not playing with computers, he enjoys science fiction, good films, photography, hiking, and tennis with Annie and their daughter, Jessica.

The Waite Group is a San Rafael, California-based producer of high-quality books on personal computing. Acknowledged as a leader in the industry, the Waite Group has written and produced over thirty titles, including such best sellers as Unix Primer Plus, Graphics Primer for the IBM PC, 8088/8086 16-Bit Microprocessor Primer, Apple BackPack, CP/M Primer, and Seal of CP/M. Internationally known and award-winning, Waite Group books are distributed worldwide and have been repackaged with the products of such major companies as Epson, Wang, Xerox, Tandy, Radio Shack, NCR, and Exxon Office Systems. Mitchell Waite, President of the Waite Group, has been involved in the computer industry since 1976 when he bought his first Apple I computer from Steve Jobs.

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