

Science and the Silver Screen

Inside the animation building on the corner of Mickey Avenue and Dopey Drive, Richard Taylor could see that he had a problem. Once a light-show artist for rock bands, Taylor had made a name for himself designing animation for television commercials. Now he was at Disney Studios in Burbank, California, co-supervising the industry's most exciting special effects project of 1981:

the computer movie TRON.

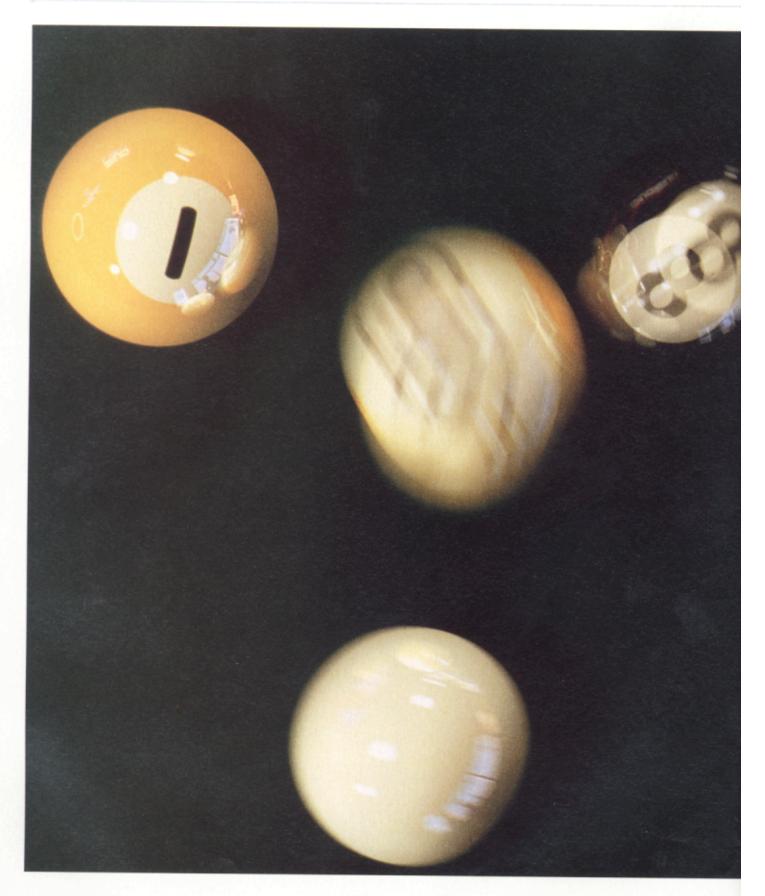
As Taylor and his graphics team sat in the animation building's darkened screening room viewing unedited scenes from the preceding day's work, a projector cast the otherworldly image of an actor kneeling beside a crystal pool. Clothed in a luminous, glowing uniform accented by streaks of bright colors, the figure lay down to drink from the pool—and his stomach disappeared. The room dissolved into laughter, Richard Taylor groaned, and the scene was played over and over while he tried to determine what had gone wrong. Finally, he ordered the sequence to be redone, and the screening continued. Minutes later, more giggles rippled through the audience as the screen displayed several actors descending a staircase, alternately walking on thin air or sinking thigh deep into the steps.

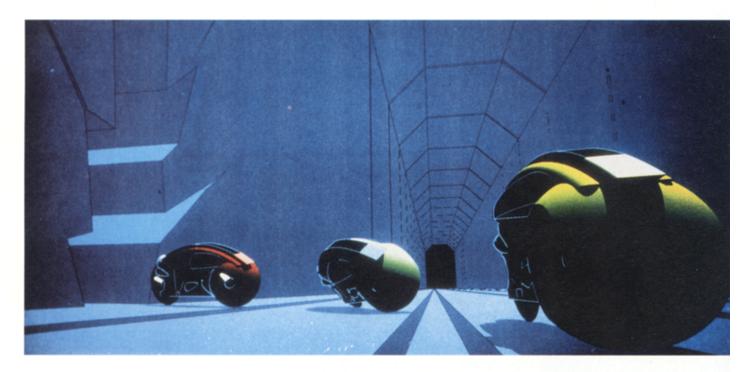
In both cases, a common technique from conventional movies—that of superimposing live action over an artificial background—had misfired. The live characters had been photographed descending real stairs or lying down on real ground; stairs and ground were then replaced by imaginary substitutes created in a computer. But when the real and imaginary images were combined,

the fit was slightly askew.

Although the computer-generated images for TRON were ambitious, Taylor and his colleagues were by no means the first to adapt computers to the making of movies. The earliest such use of computers was to control

This vivid photograph of billiard balls in motion is in fact no such thing: The balls and their green felt background were produced on a computer screen with specialized graphics software. The techniques required for such realism have been developed largely in response to the demands of film makers, who seek a seamless integration of special effects and live-action photography.





the movements of movie cameras. One of the pioneers in this field was inventor John Whitney Sr., whose working studio was the garage at his home in Pacific Palisades, a community approximately 20 miles west of Hollywood. During the 1950s, Whitney had experimented with World War II gun-director mechanisms and analog computers to devise what he called a "technology of the surplus junkyard."

One of Whitney's techniques was to create the illusion of motion by photographing a static painting with a camera that he moved in small increments for each frame. Later the technique was applied to models. An aircraft approaching head on, for example, would appear to bank and fly in the opposite direction if the camera was backed away as the model was simultaneously rotated on its horizontal axis. Controlling the camera with a computer made it possible to repeat such movements precisely, so that a background or a second model photographed on a different strip of film could later be made into a composite without encroaching on the image of the original model. As the practice evolved, techniques like these came to provide most of the special effects for television and science fiction movies.

But the idea of creating a special effect by building and manipulating a model wholly within the computer—computer-generated imagery, or CGI to its practitioners—did not emerge until the early 1970s, when graphics software acquired the versatility necessary to be of use in film and television production. Shortly after that time, in the mid-1970s, *Westworld* and *Futureworld*, two movies about androids escaping from the control of their masters, flirted with computer images to simulate the world as it would be seen through the eyes of a robot.

For Star Wars, released in 1977, director George Lucas had one of his special effects men devote three months to creating a 90-second sequence for a briefing scene before the final battle; the audience sees what appears to be a computerized diagram of the interior levels of the Death Star, the evil Empire's planet headquarters. This was in fact the only authentic sample of computer graphics in the film; the computerized cockpit displays that helped pilots fire on enemy

In this frame from the motion picture *TRON*, a trio of futuristic vehicles called Lightcycles traverse a landscape of grids. Each Lightcycle is composed of 57 geometric forms that have been combined by a solid-modeling program. Because they contain fewer basic elements, the cycles were easier to animate than are models created with polygons.

spacecraft were actually produced with conventional animation drawings. Two years later, Disney Studios' science fiction adventure movie *The Black Hole* included 75 seconds of computer-generated imagery: a vortex-shaped grid that

threatened to suck the heroes' spaceship into its depths.

These modest beginnings were but a child's dabblings compared with the computer graphics envisaged for *TRON*. Sadly for its creators, the movie would not fulfill its box-office expectations, nor would it receive the critical acclaim that had been hoped for. Yet *TRON* would set a standard for the use of computer graphics in movies that later films, as well as special effects for television, would measure themselves against. What is more, even as *TRON* was being assembled, programmers were at work writing sophisticated graphics software that would break new ground in creating both imaginary scenes and realistic images indistinguishable from photographs. And hardware developments would keep pace as well: In a few years, powerful supercomputers would be able to keep track of the millions of bits of digital information that go into generating a computer image, and film printers would be able to match staircases to actors automatically.

A DETERMINED DUO

The two men behind *TRON* were Steven Lisberger, a 31-year-old animator, and Donald Kushner, a lawyer turned theater producer and movie distributor. In 1978, the two had packed up Lisberger's Boston animation shop and moved it to Southern California to complete *Animalympics*, a cartoon takeoff on the Olympic Games to be held in Moscow in 1980. When the United States decided to boycott the Games, a deal between Kushner and the National Broadcasting Company to air the film fell apart.

In the meantime, Lisberger discovered video games and got an idea for a new movie—a fantasy starring live actors as characters in an electronic world and featuring animation done with computers. Lisberger's idea would evolve into *TRON*, a story about a brilliant but erratic programmer who gets sucked into a computer. There he battles to survive in a hostile world populated with deadly tanks, police robots and human-like characters strikingly reminiscent of people

he knew on the outside.

Convinced that financing for TRON would have to come from a major film studio, Kushner and Lisberger prepared a detailed presentation, complete with descriptions of characters, a script and plans for making the movie. The project demanded immense faith. "When we were putting the project together," said Kushner later, "the technology to do the computer art we needed didn't actually exist yet. But we were counting on the fact that computer technology was improving so quickly that by the time we were ready to make the movie, it would exist."

When the presentation document was finished, it filled 300 pages stuffed into a loose-leaf binder, which the partners lugged around Los Angeles in a quest for backing. Disney Studios was far down their list of possible financiers. Because of the Disney tradition of hand-drawn animation, the two film makers considered the studio one of the least likely to adopt the concept. But the company had recently named 29-year-old Tom Wilhite as production chief, and the proposal intrigued him. "It was the most interesting idea I'd seen, an entirely new

Simplifying the Art of Animation

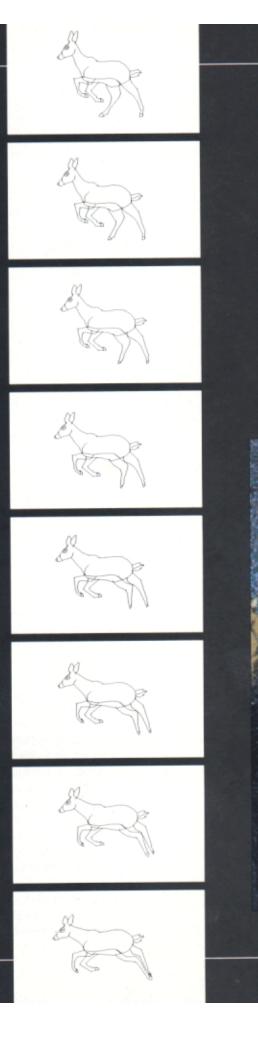
Cartoons, the fleeting delight of youngsters on a Saturday morning, can be tedious labor for the adults who create them. Each brief minute that Mickey Mouse scampers across the movie screen requires 1,440 meticulous drawings to give the illusion of fluid motion. Each drawing must be handpainted on a clear plastic sheet called a cel so that it can later be sandwiched together with background scenery. A 15-minute cartoon might contain 30,000 drawings and take a team of 20 skilled animators, artists, editors and checkers a month or more to produce.

Computers can simplify the animation process and speed it up dramatically. Acting on instructions from a human operator, they can draw and help color as much as 80 percent of the illustrations that go into a cartoon. For example, an artist assisted by a computer can color as many as 500 cels a day instead of the 35 to 40 that could be done by hand. A 15-minute animated movie can be completed in less than a week.

Computer-assisted animation saves an artist time in a number of ways. Once a drawing is entered into the computer, it can be enlarged, reduced or repeated at will. In a process called in-betweening, the computer allows an animator to draw only the key frames of a movement such as that of a bounding deer (right). In doing so, the artist supplies sufficient information for the computer to complete the action by drawing pictures to fit between the key frames.

Coloring the drawings is also more efficient with a computer. By touching a stylus to the screen, an artist can instantly fill an area with a color. If that color proves unsatisfactory, the artist need only press a few keys to replace it with another. To accomplish the same result in coventional animation, the artist must scrape off the old color and repaint with the new.

These eight drawings are part of a 45-frame series that shows a bounding deer. An animator drew the top and bottom pictures—called key frames—by hand, then entered them into a computer, which created the six intervening frames by a process called linear interpolation. In essence, the computer calculated how far the deer's head, body, legs and hoofs would move in each of six equal steps between key frames, then redrew the deer at each stage of the action.





animator has superimposed on one anier five key frames of a deer at various points midair to confirm that the action will not bear disjointed and has tinted them identical-The artist colors only the key frames; the inputer tints the in-between images to match.



What appears to be a herd of deer is actually the gait of a single deer duplicated several times. To keep the herd from seeming to move in unison, the artist can instruct the computer to set the deer and its running cycle at different sizes and locations on the screen, and to stagger the deer's appearances.



d by the computer, the artist combines vibrant colors and a soft, airbrush effect to create a magical setting for the herd of animated deer.

mythology of characters," Wilhite remembered. Moreover, he continued, "we wanted to get back into the risk-taking business at Disney, and TRON looked like the perfect project to do it with."

Wilhite's superiors, concerned that the project was overambitious, were considerably less enthusiastic. Yet they, too, were swayed after seeing a two-minute demonstration film that Lisberger had assembled. It proved that Lisberger, an animator by trade, was capable of directing live action, and it showed the feasibility of mixing actors with computer-generated graphics. In April 1981, Kushner

and Lisberger got a green light from Disney to begin work.

The computer graphics for the demonstration film had been created by three groups: an Elmsford, New York, company called Mathematical Applications Group, Inc., or MAGI; Information International, Inc., or Triple I, of Culver City, California; and a group from the New York Institute of Technology. And it was from Triple I that Richard Taylor was recruited to help supervise special effects for the movie. Originally, Triple I was to have done all of the computer graphics work for *TRON*. But the company had too little computing power to handle the job and balked at buying more. So MAGI was hired to share the load, and two other firms—Digital Effects, Inc., of New York and Robert Abel & Associates, a Los Angeles firm noted for its award-winning graphics on television—would provide titles and a few scenes.

DYNAMISTS AND IMAGISTS

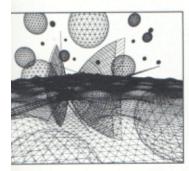
Had Triple I done all the graphics work for *TRON*, the movie would have turned out much differently than it did. For MAGI and Triple I employed radically dissimilar approaches to computer-generated imagery, approaches that spawned two schools of thought. Dynamists, represented by MAGI, value movement above detail, because that is where MAGI's systems excel. Imagists, represented by Triple I, emphasize the texture and smoothness of the image rather than its motion.

MAGI had developed an imaging system called SynthaVision that contained a library of 25 preformed solid shapes such as cylinders, spheres, pyramids, cones and doughnuts. SynthaVision's software allowed an artist to link these so-called geometrical primitives (pages 62-63) into elaborate constructions and then to sculpt them electronically into whatever design was required. Larry Elin, head of MAGI's production team, likened the system to having "a box full of little wooden shapes that you can plunk together to make more complex shapes, with the added attraction that you can also subtract a shape or

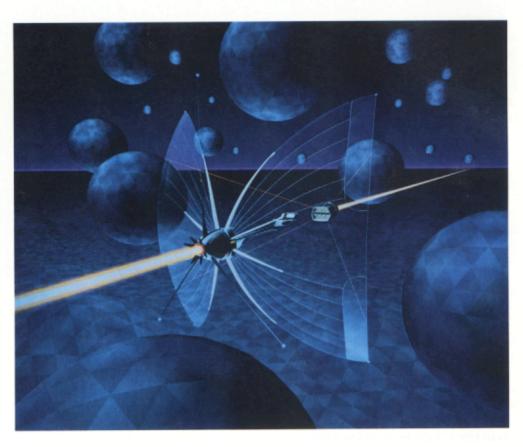
part of a shape."

SynthaVision's building-block approach to generating computer images resulted in smooth, mechanical-looking objects; except for shading, there was little detail to indicate curving surfaces. However, another feature compensated for this lack of realism. SynthaVision required a relatively small data base to describe even a quite complex object. Thus, images could be computed rapidly, and once computed, they could be displayed on the screen at film speed—that is, fast enough to preview and fine-tune the animation as it would eventually appear on film. Using a "director's language" built into the SynthaVision system, an animator could describe the path that an object was to follow, evaluate the results on the computer display, then correct the path





ke TRON's Lightcycles (page 76), ch were made out of simple solid per called primitives, the movie's Soliailer and its environment were leled with a mesh of polygons. Deers first sketched the sailer on grapher, dividing it into triangles, then ed the image on a digitizing tablet nter it into the computer (above). dering programs added color and ding to the finished picture (right), technique allows for greater detail a does solid modeling but requires by more computer memory.



if necessary. This ability to choreograph the movements of objects on the screen suited MAGI's system to the parts of *TRON* that depended on the perfect execution of complex motion. Light cycles—speedy, motorcycle-like vehicles bent on mutual annihilation—could be made to race neck and neck inside one of the movie's "video game arenas." Ominous so-called Recognizer police robots, angular flying arches whose role it was to maintain order, could be made to swoop in formation across *TRON's* computer landscape like mechanical birds of prev.

Triple I's approach to generating images by computer, however, made such choreography difficult. Instead of employing a small number of geometrical primitives to build complex shapes, Triple I artists constructed their images from elaborate linkages of polygons, joined together like tiles in a fine three-dimensional mosaic. Once entered into the computer, the mosaic could be smoothed, shaped, colored, textured and lighted in almost any way that an artist might wish.

The strength of this technique lay in its ability to model details such as distinctive facial features or the parts of imaginary spacecraft (page 81) in a convincing manner. But unlike MAGI's primitive solids, each polygon was unique and had to be entered into the computer by the coordinates that defined each of its corners. Moreover, to give the computer a three-dimensional appreciation of the image, three separate sets of coordinates, representing front, side and top views of the







Procedures for Creating Ethereal Effects

Soft-edged, changeable things such as smoke or water are common in nature but difficult to model on the computer with traditional techniques. But programmers are devising ways to generate such images with simple procedures repeated over and over, often with some random variation built in. The smoke at far left was produced by a program that created sine wave shapes and then broke them up, distorted them and dictated a few points where the background would show through. The urn at top left and its background were given their watery texture through a program that assigned a regular pattern of reflections and shadows to the otherwise smooth models. And the bubble at bottom left was created by a program that modeled the transparent colorful effect produced when light diffracts through a soapy surface.

object, had to be recorded. All told, a single object in a frame of film might require the creation of 15,000 polygons—a herculean task that could take a Triple I artist weeks to complete.

Tracking thousands upon thousands of polygons all but overwhelmed Triple I's computer; the more elaborate pictures, requiring shading or other details, could take more than a minute to appear on the screen. This plodding pace made it impractical to preview motion for the movie *TRON* with the Triple I system.

THE HIGH PRICE OF ONSCREEN DAZZLE

In July 1982, TRON was finally released. Of the film's 105 minutes, about 15 had been generated entirely by computer, and another 15 combined computer graphics with live action. Actors and actresses wearing black and white costumes were photographed against neutral backgrounds, leaving most of each frame blank. Color and computer images were added to these areas later, a tedious and difficult process that could require, for each frame of the film, dozens of handmade masks to block color from some areas and let it through to others. In an attempt to save money, Disney eventually had the work done in Taiwan, but even at that, the movie went overbudget, costing approximately \$20 million to produce.

This expense played a major role in giving TRON a black mark in Hollywood. A project that goes overbudget can bring a smile to a producer's lips if it turns out to be a smash hit at the box office. But TRON, though dazzling on the screen, was cursed with a weak plot and dull characters. "The story and art for TRON developed together," Lisberger said later. "In my mind that was always a crucial thing about the movie. Since we were cooking up this fantasy world from scratch, we relied on the visuals to tell us the story. If somebody did some sketches for a character or an environment that worked from a design standpoint, they went into the script." This dominance of technology over story line, or form over substance, may have been TRON's fatal flaw as a motion picture.

When it became clear that the movie had bombed at the box office, Holly-wood adopted a wait-and-see attitude toward computer graphics techniques, a disappointing setback for the small but passionate community of computer graphics experts who had counted on the film to throw open studio gates to computer imaging. Instead, the gates almost swung shut. Triple I sold its computer graphics operation, and other graphics outfits went back to television, where advertisers were entranced by CGI and stations were eager to display flashy, computer-generated logos.

HARNESSING A SUPERMACHINE

But TRON had "made the crack in the wall," Richard Taylor later remarked. It was, as he put it, "the beginning of a technical renaissance in the film industry."

Two men who found the crack and slipped through were John Whitney Jr., son of the special effects pioneer, and master programmer Gary Demos. Both had worked for Triple I but had quit before production began on *TRON* to found their own company, Digital Productions. As members of the imagist school of CGI, Digital Productions would harness the world's fastest calculating machines—first a Cray = 1/S supercomputer and then its successor, the Cray X-MP—to fashion images that would be as much as 700 times more complex than the most ambitious of *TRON's* computer-generated objects.

Whitney had been discussing such a film since 1981 with his friend Miguel Tejeda-Flores, vice president for film development and acquisition at Lorimar, Inc., the television and movie production studio. But no script then making the rounds in Hollywood had the right mix of story line, space setting and broad audience appeal that the two thought would make a movie suitable for the

special effects Whitney had in mind.

Digital Productions had scarcely hung out its shingle when Tejeda-Flores called Whitney to say that a script reader at Lorimar had come across something that seemed made to order. Called *The Last Starfighter*, it told the story of a young video gamesman who is recruited by aliens to save an embattled federation of planets from imminent destruction. Whitney and Demos started negotiations with the studio even before their first computer was installed.

Although the computer images were an important reason for doing the movie, Whitney was determined not to make the same mistake that Lisberger had made with TRON. In The Last Starfighter, the story came first: "The special effects are there to serve the purpose of furthering that story," Whitney said later. "They were not meant to stand alone as special effects, but to present outer space in as acceptable a way and as easy a way as location photography does."

The centerpiece was a space fighter called the Gunstar. The first step in creating the craft was to make a detailed drawing on graph paper to facilitate encoding it for the VAX 11/782 mainframe used for the initial phases of production. "In the early stages," said Digital Productions' designer Ron Cobb, "we were kind of handicapped in that I had to use geometric primitives to a certain extent." But gradually, Cobb and the crew of computer encoders became more skilled in their work. As the project advanced, Demos—a programming genius if ever one lived—improved the graphics software he had masterminded, and the Gunstar became increasingly detailed. The final version

of the craft, which had begun as a sample of Digital Productions' work for Lorimar's approval, comprised 750,000 polygons and took Digital's team of encoders, which at times had as many as 30 members, almost three months to

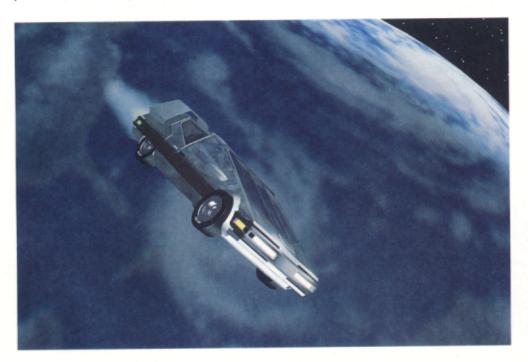
feed into the computer.

"When we have the images encoded," Whitney explained afterward, "the next step is to put them onstage." To begin with, a computer-generated model of the ship was displayed on a vector graphics monitor as a wire-frame outline of polygons that could be moved around the screen with great facility. This allowed Cobb to preview motion on the screen much as MAGI had been able to do with TRON. "The technology intervenes or interferes very little," Cobb said. "Instead it's extremely helpful. There's no end of subtlety; you can add to the action because you have full control over the movement of the object."

The ship could be enlarged or reduced in size at will, and—more significant—it could be easily replicated. The original Gunstar may have taken about six months to create from start to finish, but a hangar scene with 14 such ships—10.5 million polygons altogether—required only a few minutes to bring to the screen. But there were problems, nonetheless. Because these images were transparent wire-frame outlines, it was not always possible to tell foreground from background or, in the case of a ship in the distance, even the direction it faced. "We had a few funny instances like that when we had ships passing through

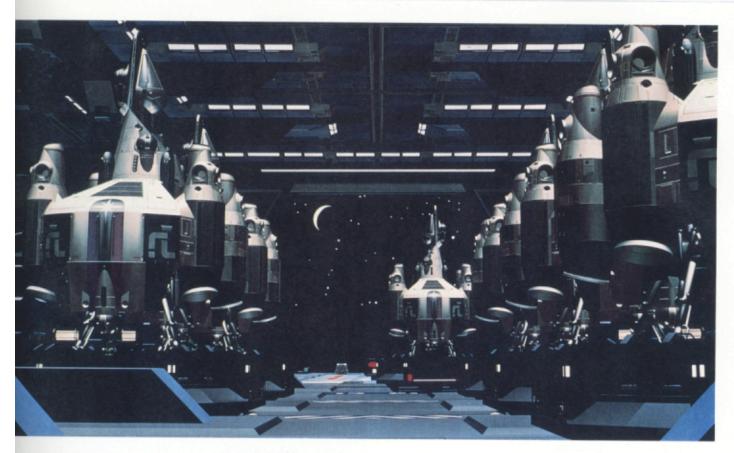
things or flying backwards," Cobb recalled.

But all of these details were clarified in the next phase of development, when Digital brought in its heavy hitter: The Cray X-MP. Now Cobb's team could color the surfaces of the wire-frame renditions of the Gunstar at workstations equipped with very-high-resolution raster monitors (pages 22-23). This made it possible, for example, to introduce dents and other blemishes on the spacecraft



A crucial test of realistic computer simulation comes in this scene (left) from The Last Starfighter, in which the Starcar takes off from earth. Programmers had to craft an image with such high resolution and detail that viewers could not tell the difference when it was combined in the film with footage of an actual car (below).





ristling with exotic spacecraft, this omputer-generated hangar from The ast Starfighter vividly demonstrates the dvantages of a graphic data base. Using onventional special effects, different ips would have been built at great exense as separate models. With a comuter, a designer builds only one image feach kind of ship and then repeats it cross the screen as often as necessary.

to keep the ships from looking too much like clones of the original. Digital's software permitted a technical editor to choose from nearly 70 billion colors. Although the human eye cannot distinguish so many shades, without them, changes in surface tones—the subtle gradation from sunlight to shadow, for example—can result in stripes that rob the object of its realism. To further the illusion, the technical editor assigned a given surface type for each group of polygons, creating the sheen of metal or the dullness of wall paint. Finally, much as a stage may be lighted with a spotlight, the Gunstar could be placed in a physical context by telling the computer where to position how many light sources and how bright each should be.

The lights themselves could not be seen, of course, but the effects brought the spacecraft to life. Having established these details for the first frame of film for a scene, the director relied on the computer to apply them to the remaining frames. Each movement of the Gunstar caused its appearance to change as if the fighter were a real object, illuminated by the flash of explosions as

it battled through space.

Such realism did not come cheap. To assign a color and a surface to each polygon in an image, and to set the lighting, required the computer to perform between 24 and 72 billion calculations for each frame of the scene. On average, a VAX computer would have needed more than 16 hours to construct each frame of the movie on a workstation monitor—an impossibly unwieldy process for a film that would eventually contain about 36,000 frames of computer-generated imagery. The Cray X-MP accomplished the same task in two and a half minutes.

The Gunstar was so believable the technical director had no qualms about its passing for real on the screen. A far more challenging test of photographic realism

The Complexity of Human Movement

Producing realistic models of the human body in motion is one of the hardest tasks facing computer animators today. A typical human activity—walking, for instance—is a synthesis of hundreds of subtly coordinated movements that include complex rotations of joints, the flexing of muscles from head to toe and reactions to surroundings. The softness and flexibility of the human form are also obstacles for graphics software because of the difficulty of describing such irregularities mathematically.

But many aspects of human motion have been closely studied in such fields as biomechanics and robotics, and data from this research has been used to create animation soft-

(a)

- 1. RIGHT STANCE LMP/LEFT SWING LMP
- 2. RIGHT STANCE LMP/LEFT STANCE LMP
- 3. RIGHT SWING LMP/LEFT STANCE LMP
- 4. RIGHT STANCE LMP/LEFT STANCE LMP

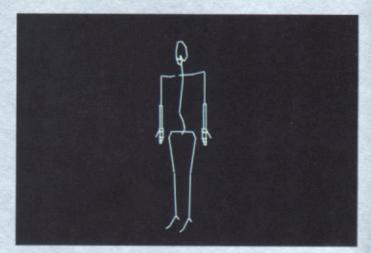
(b)

- 1. HIP FLEXION, KNEE FLEXION, ANKLE FLEXION
- 2. HIP FLEXION, KNEE EXTENSION, ANKLE FLEXION
- 3. HIP EXTENSION, KNEE EXTENSION, ANKLE EXTENSION

(c)

- DOWNWARD PELVIC CORONAL ROTATION ABOUT SUPPORT HIP, HIP EXTENSION, KNEE FLEXION, ANKLE EXTENSION, SUPPORT ROTATION ABOUT HEEL
- UPWARD PELVIC CORONAL ROTATION ABOUT SUPPORT HIP, FORWARD TRANSVERSE ROTATION ABOUT SUPPORT HIP, HIP EXTENSION, KNEE FLEXION, ANKLE FLEXION
- UPWARD PELVIC CORONAL ROTATION ABOUT SUPPORT HIP, FORWARD PELVIC TRANSVERSE ROTATION ABOUT SUPPORT HIP, HIP EXTENSION, KNEE EXTENSION, ANKLE FLEXION
- FORWARD PELVIC TRANSVERSE ROTATION ABOUT SUP-PORT HIP, HIP EXTENSION, KNEE FLEXION, ANKLE EX-TENSION, SUPPORT ROTATION ABOUT BALL OF FOOT
- HIP FLEXION, KNEE FLEXION, ANKLE EXTENSION
 (d)
- 1. ELBOW FLEXION, SHOULDER FLEXION
- 1. ELBOW EXTENSION, SHOULDER EXTENSION

Some of the complex elements of a walking sequence are revealed in this list of motions from the skeleton animation cycle. Section (a) details the local motor programs, or LMPs, that go into the overall walk control program. The leg swing LMP is shown in (b), lower body stance LMP in (c), forward arm swing LMP in (d) and rearward arm swing LMP in (e).



To refine motion control in an animated sequence before rendering a fully shaded raster version, the programmer calls up a stick figure version on a vector monitor and puts it through a series of tests.

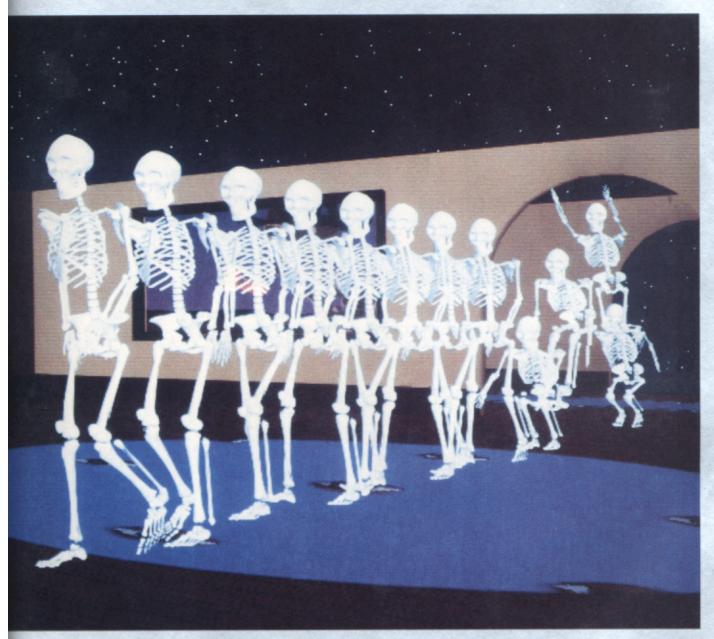


After the sequence passes the stick figure test, it is rendered in color on a raster monitor. This composite image shows 12 frames—one for each skeleton—from a film depicting the skeleton's response to uneven terrain.

re such as the walking skeleton system shown on these ges. Here, the programmer chose to avoid the difficuls of working with fully fleshed figures by using a model nsisting of rigid segments. The problems of coordinating multitude of motions were dealt with by organizing the ograms in three levels. At the top level is the task maner, which, after receiving a description of the task to be rformed—say, "crouch, jump and walk forward"—will eak the action down into a sequence of skills. The second rel controls the programs for each skill—the motions inlived in crouching, for example. The third level consists local motor programs, each of which controls a set of

joints for one motion, such as bending knee, hip and ankle during crouching. As the programs are executed, they update the skeleton data base so that each new movement starts from the correct position.

The ability to produce accurate models of bodies in action holds great promise, not only for film makers but for doctors, athletes, dancers and others concerned with the movement of the human form. But even with the most sophisticated equipment, the complexities of programming a realistic human figure to execute even a simple dance step can make the modeling of a starship battle in outer space look easy.



is composite picture shows every fourth frame from the animation of a broad jump and transition to a full stride.



The personalities of the snobbish Snoot (right) and the roguish Muttly (left), characters in a computeranimated film, are revealed by the way the two birds move. Complex programs govern the articulation and distinctive motions of each figure's eyes, head, neck, body, leg joints and tail.

in a computer image was the Starcar, an automobile in the movie that converted into a spaceship. According to Demos, after the car was designed, it was actually "built" in the computer first. Then the real car, a drivable mock-up, was constructed from the same plans by a Modesto, California, custom builder, using a Volkswagen van chassis stretched 14 inches.

Demos recalled the widespread concern that the physical model and the computer model would compare unfavorably when the film cut from one to the other—and the relief when the project turned out all right: "We took a bunch of photographs of the simulated one and the real one and we showed them to Ron Cobb, who had designed the car, and he couldn't tell which was which. To be quite honest, I couldn't tell which was which, either, and I knew we were in pretty good shape when things like that started to happen."

The last phase of making the movie was to transfer the computer images to film. Each frame was photographed with a high-resolution film recorder (pages 28-29), a process that took from two and a half to five minutes per frame. The Cray could perform this task with virtually no human intervention, so the machine was used for various other operations during the day and left to do the filming at night, with only one person standing by. This phase took six to eight months, and at first kept the supercomputer occupied eight hours a night weekdays and 24 hours a day on weekends; toward the end, it was busy around the clock.

The Last Starfighter was not a blockbuster by Hollywood standards—it cost \$14 million to make and grossed only \$21 million in its first 31 days—but it

earned enough to be considered a success. Perhaps most important, the film demonstrated that computer images could hold their own in a movie that made frequent transitions between real and simulated scenes. "At least a third of the effects in the film attain photorealism," said Cobb. "They are almost flawless. The average filmgoer who is not terribly concerned with the techniques behind the film will probably just assume that these dynamic, interesting images are models—which is extraordinary."

FIGHTING HOLLYWOOD'S SKEPTICS

The success of *The Last Starfighter*, while welcome, did not suddenly turn CGI into a movie industry darling. Both the cost of photographic realism and the skepticism of film studios remained high. Television was another matter. For one thing, titles for network specials and the like last only a few seconds, and most commercials are on the screen for no more than 30 seconds. More significant, the low-resolution television screen demands far fewer calculations than the movie screen. Thus, even if the goal is an image as believable as a photograph, such an image can be produced for television in a fraction of the time—and for a small percentage of the cost—required to create the same image for a film.

One who refused to give up on CGI for the movies was George Lucas, head of Lucasfilm, Ltd., and creator of the wildly successful series of *Star Wars* movies. In 1979, Lucas had formed a computer division within Lucasfilm, with a mandate to "bring high technology into the film industry." For starters, he raided the computer graphics laboratory of the prestigious New York Institute of Technology, hiring the four men who had set up the school's computer graphics lab in 1974: Edwin Catmull, Alvy Ray Smith, Malcolm Blanchard and David Di-Francesco. The results were impressive.



This realistic forest scene is a backdrop for the computer-animated film The Adventures of André & Wally B., featuring an android and a bee. Trees, grass and flowers were all generated with particle systems (page 64) employing random variables that introduced atural-looking irregularities. A shading program dappled the trees with sunight and cast tree shadows on the grass. Among other accomplishments, the group created a computer-animated short subject to showcase at the 1984 International Animation Festival in Toronto. The film, titled *The Adventures of André & Wally B.*, recounted the adventures of an android named André and a bumblebee named Wally B. living deep in a Disneystyle forest executed in such detail that the audience could pick out individual leaves on trees. So voluminous were the graphics calculations for the forest and for the two characters' actions that to produce the film required the power of six Cray central processing units, as well as 15 smaller machines. The finished movie lasted only a minute and a half on the screen.

Then, in the spring of 1985, the Lucasfilm computer whizzes unveiled a graphics computer of their own, which promised to reduce drastically the cost of lifelike computer images. Called the Pixar, the machine consists of four processors for the display, one each to control red, green and blue, and the fourth to control text. Each processor is capable of handling 10 million instructions per second. But the key to Pixar's sophistication and power is its software—intricate

algorithms for generating the forms and textures of real life.

The Pixar's graphics abilities, and its relatively low cost—around \$100,000, compared with the \$10- to \$15-million Cray X-MP—make it attractive outside the film industry as well. Hospitals see in it the potential to increase radically the quality of the images produced by CT and PET scanners (page 46). Gas- and oil-exploration companies, which would benefit by clearer pictures of information yielded by seismic soundings of the earth's crust, are also interested in the machine.

As good as the Pixar is, it could not represent the state of the art in computer graphics for long. Indeed, no sooner had Lucas' organization completed work on the Pixar than it announced an even more capable machine for 1986, the Reyes. The special-purpose graphics machine has complex algorithms built into its hardware, making it as much as 1,000 times faster than either the Pixar or the Cray X-MP. Thus the acronym the Lucas team fondly attached to Reyes: Renders Everything You Ever Saw. In time, as computer graphics specialists adapt advances in computer hardware to CGI, it is reasonable to expect speed to increase as prices fall. Ultimately the work that once required a Cray might be accomplished just as quickly with a small computer sitting on a desktop.