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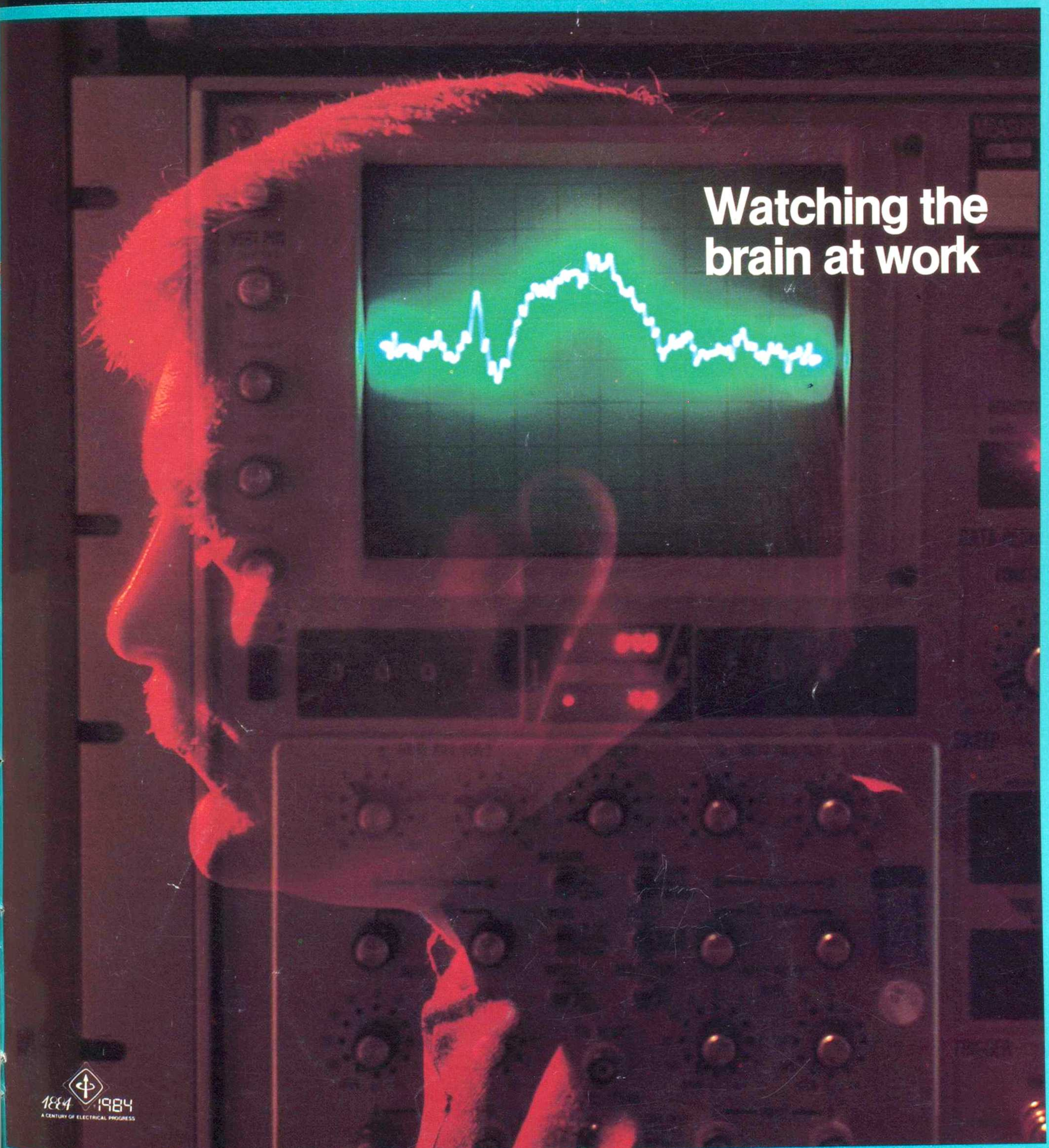
Fiber optics: single-mode vs. multimode

Microprocessor design case history: Atari's video computer

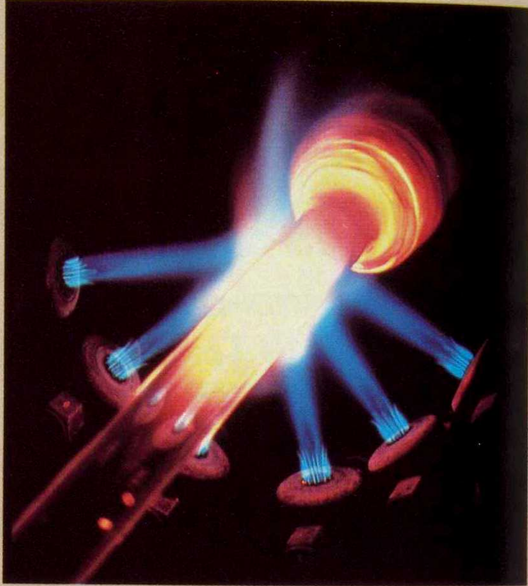
Prospects for nuclear power • The artificial heart

Tubes vs. crystals in early radio detectors



MARCH 1983 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

IEEE
spectrum
VOLUME 20 □ NUMBER 3 MARCH 1983


Corning Glass Works

Single-mode optical fibers have been made in the laboratories of Corning Glass Works, Corning, N.Y., using the inside vapor-deposition process (right). Vapors of silicon tetrachloride and germanium tetrachloride, mixed with oxygen as a neutral carrier, pass through a quartz tube heated by burners. The vapors collect as light soot on the inside walls of the tube, which is continually rotated to ensure even deposition. When enough soot collects to choke the incoming vapors, the furnace temperature is raised to melt the quartz tube and turn the chalky soot into clear glass, called a preform. The preform is then transferred to a drawing tower, where it is stretched into single-mode fiber; the tube becomes the fiber cladding, and the precipitate becomes the core. For manufacturing single-mode fibers, Corning uses outside vapor deposition, a more advanced and efficient process in which vapors collect on the outside surface of a metal rod. Larger preforms can be made, and thus more fiber can be drawn.

Heart surgeons Lyle Joyce (left) and William DeVries (right) concentrate on implanting an artificial heart in patient Barney B. Clark (p. 39). Reflection from the overhead lights surrealistically illuminates the prosthesis as blood flows through a heart-lung bypass machine tube arching over the operating site.

The continuing recovery of Dr. Clark marked the success of the University of Utah's artificial heart system; this first step toward the ultimate implant system is followed by a more compact heart-driving configuration being developed in West Germany. The university has also constructed an electrohydraulic heart in which the heart and its motor would be implanted. The need for smaller, more powerful batteries remains the major obstacle to implanting all components.


Brad Nelson, University of Utah Medical Center

ARTICLES

DEPARTMENTS

THE COVER

As a subject watches images on a CRT screen (not shown) in the human sciences laboratory of the Westinghouse Research and Development Center, Pittsburgh, Pa., his brain's electrical response to the visual stimuli is detected as electric potentials by electrodes on his scalp. Responses from many trials are averaged to find the evoked potential amidst the noise of the ongoing EEG; the result is seen on the oscilloscope superimposed in the photograph. Insights gained may be applied to the design of electronic equipment as discussed in the report beginning on page 52.

IEEE Spectrum (ISSN 0018-9235) published monthly by the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th Street, New York, N.Y. 10017. Send editorial and advertising correspondence to above address. Subscription: $7.00 per year included in member dues. Subscription orders, address changes: IEEE Service Center, 445 Hoes Lane, Piscataway, N.J. 08854. Second-class postage paid at New York, N.Y., and at additional mailing offices.

Design case history: the Atari Video Computer System

By omitting lots of hardware, designers added flexibility and gave video-game programmers room to be creative

In late 1975, sales of devices that made it possible for consumers to play Pong on home television sets were booming. At Atari Inc., which had first introduced Pong as an arcade game and had manufactured one of the most popular home versions of Pong, engineers began looking for the next arcade game to put in consumer hands, anticipating that people would grow tired of two paddles and a ball.

They saw Jet Fighter and Tank, but instead of designing a custom chip for each game, as was done for Pong, they planned a system that would play both games, four-player Pong if anyone was interested, and possibly a few other, as yet unknown games. The system was to be based on a microprocessor.

In a few months, Atari's designers in Grass Valley, Calif., had made a working prototype, and over the next year, designers from Grass Valley and from Sunnyvale, Calif., refined what was to be the Atari Video Computer System (VCS). It was released in 1977, and six years later ranks as one of the most successful microprocessor-based products ever built, with over 12 million sold at about $140 apiece.

Success did not come without problems. Production problems in the first two years caused Atari losses estimated near $25 million. But once these problems were solved and enough software was developed, the VCS took off.

It is popular today, not because it does an admirable job of playing Jet Fighter and Tank, but because its flexible design also allows it to play chess and baseball, as well as Space Invaders, Pac-Man and many of the other arcade games that have been invented since the VCS came on the market. More than 200 different game cartridges—the read-only memories (ROMs) containing VCS software—are now on the market, manufactured by about 40 companies, and new games are constantly being developed. An estimated 120 million cartridges have been sold at prices from $12 to $35, and the demand is such that, in addition to buying more 6502 microcomputers than anyone else in the world, Atari's purchases of ROMs for its various divisions is greater than that of all other companies in the world combined.

Atari and other video-game companies had been making microprocessor-based arcade games for some time before the VCS was developed, but the cost of then-available processors—$100 or more each—made the idea of a home consumer product based on a microprocessor impractical. Then came Chuck Peddle and the 6502.

Mr. Peddle, who had left Motorola for MOS Technology after designing the MC6800 microprocessor, appeared at Wescon—the annual West Coast electronics show—in September 1975, offering to sell his new microprocessor by the barrel at $8 apiece. "Of course, no one knew that he only had one barrel to his name," recalls Steve Mayer, cofounder of Cyan Engineering, Atari's private consulting company in Grass Valley, and now senior vice president for R&D at Atari.

Mr. Mayer and Ron Milner, his colleague at Cyan, went to see Mr. Peddle at Wescon and found that the 6502 matched precisely the minimum specifications that they had laid out some time before in a blue-sky design for a programmable video game. The three went into the back of the MOS Technology suite, Mr. Mayer recalls, and in an hour the deal was struck. It started a revolution in home video games.

'Trying to survive'

No one saw it that way at the time. "We were just trying to survive," Mr. Mayer told *Spectrum.* Atari had entered the home video market with a one-chip version of its Pong arcade game, and it was developing other home video games, but each was based on a single custom chip that took a year or more and over $100 000 to develop—by the time an arcade game reached the home market, consumers would have forgotten about it. A programmable home video game seemed a desirable alternative.

The key to the design was simplicity: making the software do as much of the work as possible, so that the hardware could be cheaper—silicon was very expensive in those days. The microprocessor was synchronized to the television scan rate and created the display one or two lines at a time. This synchronization reduces memory requirements for the television interface considerably, but the processor must continually update the registers in the interface to get any display at all. The program that feeds information to the video chip (called Stella, after its designer's bicycle) is known as a kernel.

To further reduce memory requirements, Mr. Mayer and Mr. Milner decided to display the background of the screen at relatively low resolution, while displaying moving objects with higher resolution—low-resolution playfield, high-resolution players. They also eliminated any provision for vertical synchronization and gave that task to the programmer. A VCS kernel must count the number of lines displayed on the television screen and must finish displaying a single frame in exactly the same time—15.24 milliseconds—that it takes the TV set's electron gun to make a single top-to-bottom sweep.

Two prototypes of the Stella were built: a functional prototype built by Mr. Milner to test the concept, and a gate-level prototype built by Joe Decuir, who was hired by Cyan in late 1975. The gate-level prototype was designed to mimic as closely as possible the intended final chip, using circuit-design techniques specific to MOS integrated circuits.

One critical MOS-dependent feature was the use of a special counter—called a polynomial counter, or pseudorandom shift register—instead of a true binary counter to determine object positions on the screen. A polynomial counter occupies one-

Tekla S. Perry and **Paul Wallich** Associate Editors

0018-9235/83/0300-0045$00.75©1983 IEEE

fourth the silicon area of an equivalent binary counter, but, unlike a binary counter, it does not count in any simple order [see Fig. 1]. Thus, a programmer cannot calculate a screen position for an object and load it into the position counter.

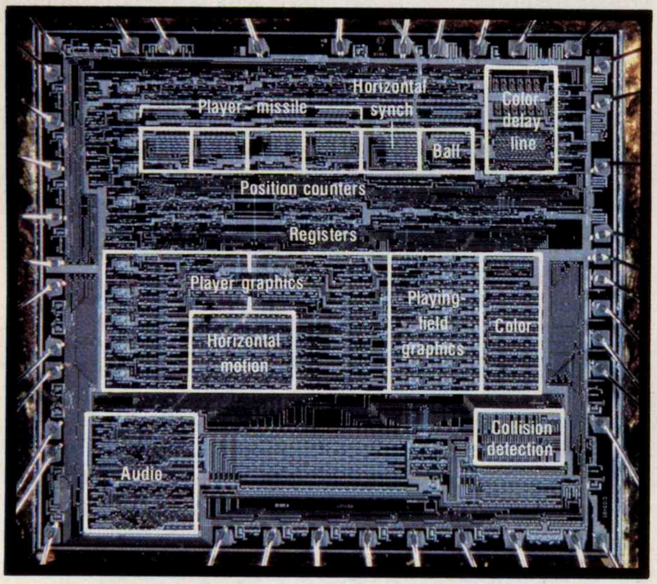
The original Stella prototype had only one signal to the position counter: a reset that would trigger the immediate display of an object. Mr. Decuir and Jay Miner, who designed the production version of the Stella chip, used this same concept in their design. As a result, displaying an object in a given position on the screen requires that the programmer count the number of clock cycles taken by a given set of instructions, figure out how far across the screen the electron beam would be after the instructions had been executed, and act accordingly. Once the position counter for an object is reset at the proper point, it continues to display the object at that spot on succeeding lines.

To move objects, the prototype blocked out four clock pulses from the position counters during the vertical blanking interval; a programmer could then add pulses to move an object left or right—four pulses had to be added to keep the object in the same place. Mr. Miner added a set of motion registers, which add or subtract pulses automatically when a signal—called H-move—is sent by the microprocessor. The H-move can be sent during the vertical blanking interval, or during the horizontal blanking interval at the beginning of each line.

"This seemed innocuous enough," said Larry Kaplan, the first software designer hired to develop games for the Stella project. "But I discovered early that it was possible to reposition player objects during a screen [a frame of the TV picture], though that was not a consideration of the design."

So Mr. Kaplan designed Air-Sea Battle, which has horizontal bands of player objects, a technique used in countless VCS games, including Space Invaders, Freeway, Asteroids, and Football. "Without that single strobe, H-move, the VCS would have died a quick death five years ago," said Mr. Kaplan, now vice president of product development at Atari.

H-move and a feature that allowed two or three copies of an object to be placed on the screen let another VCS programmer,



The Video Computer System television interface adapter measures 180 by 160 mils. Much of the layout uses mirror symmetry, such as the position counters across the top, the player graphics, and the horizontal motion registers in the center. The collision detectors at lower right sample the output of all graphics registers to determine whether screen objects are colliding.

Rick Mauer, design a home version of the arcade hit, Space Invaders. That game hit the arcades in 1979, when the VCS was going downhill after losing money in 1977 and 1978.

"The VCS was not doing that well—there were only a few million in the field, and it looked like it was dying—then Space Invaders came out, and bam! it exploded," Mr. Kaplan said. Space Invaders was the most popular game in the arcades, and the VCS, with rows of six objects across the screen (two player-objects, copied three times each) could recreate it in the home.

Another hardware feature, one that actually cost a fair amount of silicon, was vertical delay, or VDEL. The VCS writes two television lines at a time, explained Mr. Miner, but shifting objects by two lines between frames leads to jerky motion. A way had to be found to shift objects by only one line, and that way was VDEL. Two registers are used to hold the graphics information for each player-object, and VDEL selects which register will be displayed on the screen.

The sequence of events is as follows: information sent to the display registers for one player object is loaded into its primary register; when information is written to the other player object, the contents of the primary register for the first object are automatically duplicated in its secondary register; if information for each player object is written every other scan line, the secondary register selected by VDEL will display the same shape as the primary register, but one line later [see Fig. 1C]. This technique is now being used to load different information into the primary and secondary registers of each player object, thus yielding single-line resolution and other unintended bonuses.

In addition to being able to determine the shape of an object, programmers can also determine its color and luminance. The decision to go with both color and luminance registers probably would not have been made but for the simplicity of the color control. Television color is determined by the difference in phase between the color signal and a reference signal, or color burst, that is transmitted at the beginning of each line. The VCS's phase shifter is nothing more than a delay line tapped at appropriate intervals, and so it occupies fairly little chip space.

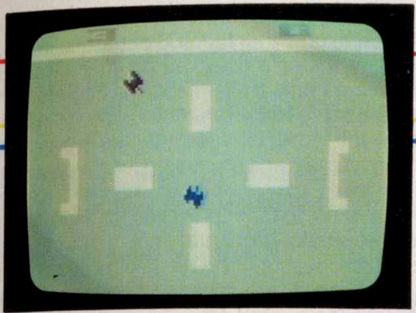
An example of extensive color manipulation is a subroutine developed by Mr. Decuir to avoid burning game patterns onto the TV screen if the VCS is left unattended. The routine, which cycled through all possible color-luminance combinations, used only a dozen bytes, a great advantage in early game cartridges, which held only 2 kilobytes of ROM. "In 2K, you barely have room to brush your teeth," Mr. Decuir said.

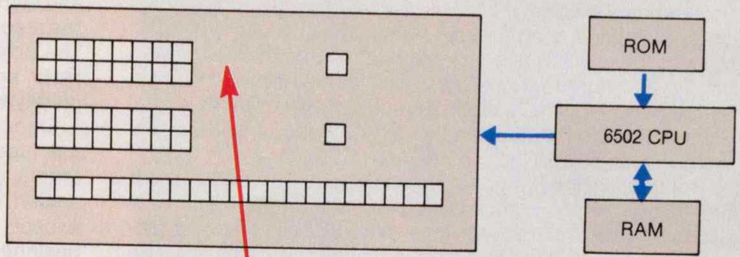
A similar variety of effects was produced with a minimum of chip space in the sound generator; it contains simply a few dividers and polynomial counters that can be interconnected in a number of ways under program control. A 5-bit polynomial counter, Mr. Decuir noted, produces a low, grumbling sound (used in Tank), and a 9-bit counter produces a whooshing sound (used in Jet Fighter). The rest of the sounds that the programmers have made the VCS produce come essentially free, and they have been extensive—Mr. Mayer said he has even heard the VCS reproduce the words "E.T. phone home."

Exploiting the hardware

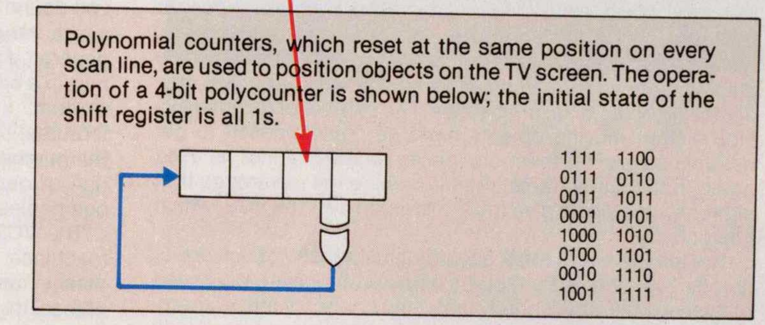
Because the VCS hardware does so little on its own, a heavy burden is placed on the programmer. But though programming is arduous, few walls hold back software creativity.

"Writing the kernels that make up the game programs," Mr. Mayer said, "is like solving acrostic puzzles with lots and lots of possibilities. There's a certain class of programmer that can deal in the microcode like that. If it were easier to program, we wouldn't have these programmers, because they'd be bored. The

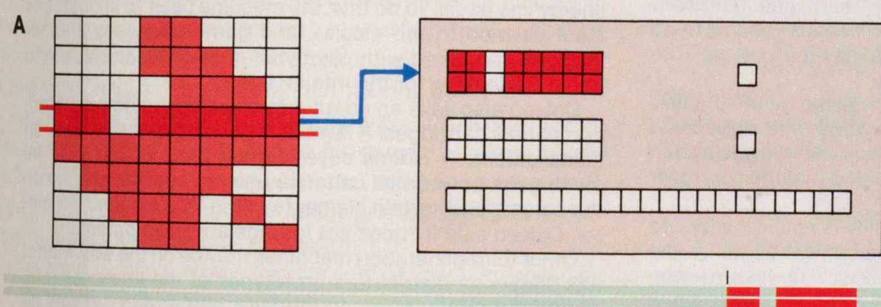




[1] The Video Computer System consists of ROM in cartridges, 128 bytes of RAM, a 6502 microprocessor, and the television interface adapter (TIA). The 6502 sends information to the TIA to form a display; the TIA can hold a maximum of two lines worth of information at a time. A frame of Tank is shown above; the steps for creating it are depicted below. (For clarity, only the left half of the image is illustrated.)

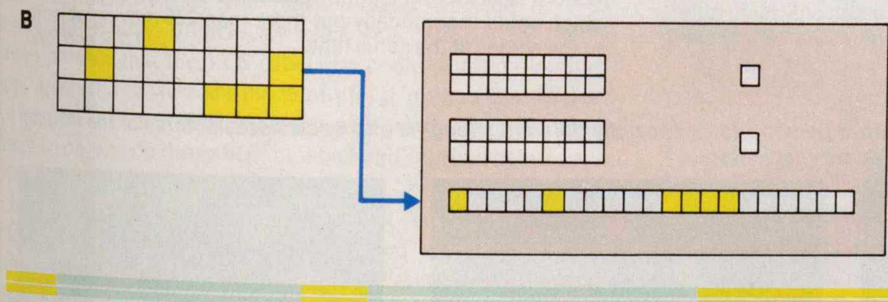


A



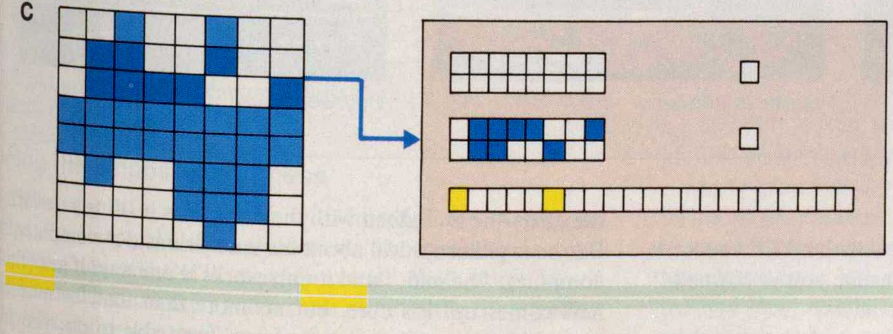
To display a line of the first player object, a tank on the screen, the 6502 loads its pattern from the section of graphics containing ROM into the corresponding register of the TIA. When the position counter resets, the top member of the register pair is scanned out onto the screen.

B



To display any given line of playfield, the 6502 loads it from ROM into the playfield register. Playfield is scanned onto the screen four times more slowly than player graphics, yielding pixels four times as wide. Playfield for the right half of this screen is a mirror image of the left.

C



The second player object's graphics are displayed on the screen using vertical delay. This means that the first scan line uses the second register of the pair, whose contents were copied from the line above, while the second line uses information newly placed in the first register.

Comparing the hardware

Many companies have tried to market programmable video-game machines, starting with Fairchild's Channel F in 1976. Most of these machines—including the Fairchild—have sold poorly. The four programmable video-game units currently in demand are Atari Inc.'s Video Computer System (VCS), Mattel Electronics' Intellivision, Magnavox's Odyssey 2, and Coleco-Vision, from Coleco Industries.

The Intellivision is the VCS's major competitor. Because it has far more random-access memory than the VCS, it can display an entire television frame without help from its processor—in fact, it must do so, because the processor can communicate with the video chip only during the vertical blanking interval.

The Intellivision display has a background made up of a 20-by-12-"card" array, with the cards' content specified by the programmer. With a "character set" of different shapes, a designer can build up quite detailed scenes. However, because the processor cannot talk to the video chip while the display is being formed, line-by-line changes of background or moving objects are impossible. Two or more of the Intellevision's eight moving objects must be superimposed to get multiple colors. Furthermore, player objects cannot be used again in the same frame, thus lessening the advantage that eight player objects give the Intellivision over the VCS, which has only two.

The Intellivision's forte, according to industry observers, is games with detailed but static displays. However, the speed of moving objects is entirely under the control of the programmer, since the hardware supports fast motion as least as well as the VCS.

"Mattel is the victim of realism," said one hardware designer at Mattel. "Its games are slow because people try to make them like the real world, and it takes time to move from one end of a football field to the other."

Sports and strategy games are well served by the Intellivision controller, which combines a keypad with directional controls and action buttons, as opposed to Atari's one-button joystick. On the other hand, some contend that the controller may be difficult to use.

Although the Intellivision's inflexibility is counterbalanced by its great power, the Odyssey 2 does not fare as well in the estimation of those who have examined it: "It is weak in everything," said Robert Ogden, president of Action Graphics, a freelance game company in Carey, Ill. David Johnson, an Imagic game designer who works with the Odyssey 2, said that it was a more primitive game machine. It has only eight colors, compared with Intellivision's 16 and the VCS's 128 (16 colors and eight luminances). Its four movable objects have only half the resolution of objects on either the VCS or the Intellivision. The objects have only a single color, as do Intellivision objects, and can be reused only if the display is blanked completely while they are being rewritten.

One advantage that the Odyssey 2 has over other machines is its full keyboard and character generator, so that letters or parts of them can be placed anywhere on the screen. However, it makes no other provision for background, except for a very low-resolution grid, not used by most designers. The microprocessor, an 8048, is described by Mr. Johnson as not well suited to video games because it is slow and has an inefficient instruction set.

Sound generation is very difficult on the Odyssey 2, and very crude, since it has only one sound channel. The VCS has two sound channels, which programmers have pushed to get a wide variety of sounds. And far more complex sound can be generated with the Intellivision, which has three sound channels in a separate, programmable chip. The overall Odyssey 2 system, said Mr. Johnson, "has a number of unusual features, almost all of them disadvantageous." However, a fair number of the machines have been sold, and the production of games for the Odyssey 2 by independent software companies indicates that the machine is established.

The VCS and Odyssey 2 are considered first-generation machines, the Intellivision a second-generation unit. Coleco-Vision marks the third generation of programmable video games. Its background display has better resolution than do the moving objects of the other systems and both objects and background can change color on a pixel-by-pixel as well as line-by-line basis. To do this, the machine uses 16 kilobytes of RAM devoted to the display, and game play uses another kilobyte, compared with 128 bytes of RAM for the VCS and about 3 kilobytes for the Intellivision.

Coleco also sells an adapter to allow its unit to play Atari-compatible cartridges. A lawsuit is pending over this, as Atari holds patents it claims cover certain parts of the VCS, including the polynomial counters used to position players on the screen, and certain elements of the VCS's sound generator. Coleco said it "does not infringe any valid patent."

Other third-generation machines may be on the way. Mattel has shown its distributors prototypes of the Intellivision III, which has vastly improved graphics and sound, as well as wireless controllers that use infrared-emitting diodes. Commodore is still promising to release its Max game machine, which could theoretically put more than 256 moving objects on the screen at the same time. —*T.S.P. and P.W.*

Three different versions of Imagic Corp.'s Demon Attack show the differing strengths and weaknesses of three of the leading game machines. (Photographs supplied by Imagic Corp.)

Atari VCS

Mattel Intellivision

Odyssey 2

VCS is an absolute challenge."

"Another way of saying it is that to deal with a VCS you have to unlearn every good programming practice you've learned," said Mr. Mauer, who designed Space Invaders.

Bob Whitehead, senior designer and cofounder of Activision Inc. in Mountain View, Calif., may be the most innovative VCS designer—he is credited with the most firsts in using a new trick. But he is philosophical about his innovations. "A computer is a computer," he said, "and it only works in one way. If something new comes up, it's cute, but no more than that, because it's something the computer has always been able to do; you just didn't discover it before. It's like finding a penny under the couch—it's always been there, but it's cute to discover."

Once a trick is discovered and is implemented in a game, it becomes obvious to experienced VCS programmers, Mr. Whitehead noted, and soon the trick is copied in other games. Less experienced programmers look at a program listing or pick up tricks by word of mouth.

Today, however, designers estimate that the hardware has been 70 to 80 percent exploited. "More and more the cute things aren't showing up," Mr. Whitehead said, "but then every time we discover something new, we think that it is the last thing."

Changing displays 'on the fly'

The first trick popped up when Mr. Whitehead designed Blackjack, and it is now used in nearly every VCS game. It is the capability to rewrite player objects "on the fly." Because the microprocessor must feed information every line to the "Stella" chip to make a display, it can change the information even during a line to change the appearance of objects. The hardware can produce multiple copies of a player object—a feature added so that groups of biplanes could fight each other—and Mr. Whitehead discovered that he could change the displayed player object between copies. Instead of putting up three copies of the same object, the VCS then displays three different objects: three different cards in the case of Blackjack.

Objects can also be rewritten as they are repositioned vertically, so the different rows of aliens in Space Invaders look different. This capability was carried to an extreme in Activision's Freeway, with 10 lanes of traffic and different cars and trucks all over the screen. It was also used very successfully in Asteroids, in which the rocks that appear to be careening all over the screen are in two rows, half moving up and half moving down.

But an initial limitation of rewriting player objects on the fly was that the copied objects had to move together, because the VCS produces multiple images only at set spacings. A trick developed by Mr. Whitehead to allow many graphically different objects to move independently is called flicker.

Flickering displays create the illusion of extra independent player objects by showing the objects only every other frame, or every third or fourth frame. The problem with this technique is that pronounced flicker can make a game difficult or even unpleasant to play. Judiciously used, this tradeoff can make games possible that the VCS otherwise could not handle: Starship, in which the stars are made of player objects that flicker; Adventure, in which flicker occurs only when there are more than two objects on the screen; baseball and football games; and Defender, to name a few.

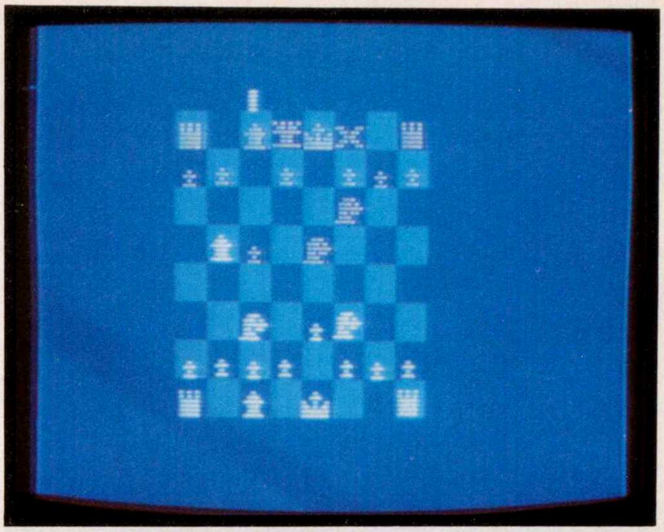
Ironically, flicker has never been used at Activision, the software company that Mr. Whitehead helped start when he left Atari in 1979. Mr. Whitehead did not say Activision will never use the technique in a game, but he noted that the company's programmers will rethink the philosophy of a game to avoid it. "It is a tradeoff that is not acceptable," he said.

Flicker can be avoided if the motion of objects is restricted to keep them vertically separated, or by use of more recent tricks. One of those tricks is "venetian blinds," and it was first used in Atari's Chess game.

Doing the 'impossible': chess

"When the VCS was first manufactured," Mr. Kaplan recalled, "the box had a chess piece on it. 'Those marketing guys! Come on,' we said. 'It'll never do chess.' Well, some guy in Florida sued because there was a chess piece on the cover and we didn't have a chess game."

A year later Atari's designers began developing Chess. "The



[2] "Venetian blinds" are used in Atari's Chess game to increase the number of objects that can be displayed on one line.

guys were playing around," Allan Alcorn, then head of engineering at Atari, recalled, "and one guy said, 'I could write an algorithm, but I couldn't get a playfield on the screen.' Another guy said, 'That's easy.' " Larry Wagner wrote the algorithm; it took him two years with the help of national chess champion Julio Kaplan. Mr. Whitehead did the display in two days, developing the trick now known as venetian blinds [Fig. 2].

To display eight chess pieces across the screen (instead of the maximum six possible with triple copies), Mr. Whitehead displayed each object on every other scan line. On the first sweep across the screen, graphics for four objects were displayed; on the next sweep, graphics for the other four were shown. The gaps were obvious, but the chess pieces were recognizable.

While primitive in comparison with today's chess machines, the Wagner-Whitehead chess game, using 4 kilobytes of ROM and 128 bytes of random-access memory, was as good as the chess machines then on the market. There was only one problem: the TV screen displayed random colors while the VCS calculated the next move; no processor time was left for the screen.

The venetian-blind technique has appeared in many games since Chess. It was used for horses in Polo, a game by Carol Shaw that was never released, and in Basic Programming to get 12 characters on a line. It was also used in Stampede, by Mr. Whitehead, to animate the animals' legs, and most recently, in Sky Jinks, also by Mr. Whitehead, where parts of the balloon baskets are displayed on alternate lines. If used subtly, Mr. Whitehead noted, the technique is hardly noticeable.

After they had exploited variations on player graphics, programmers turned to other areas of the Stella chip to look for tricks. One early discovery was that they could write the playfield—a low resolution background 40 bits across—on the fly. Al Miller did this in Surround, where each block in a 40 by 24 grid can be turned on or off independently. The technique was used by Mr. Whitehead in Chopper Command to create an extra player object—the chopper the player commands [Fig. 3].

Mr. Kaplan first rewrote color on the fly, changing color line by line to get a figure in his bowling game that has a flesh-colored head, a blue shirt, gray trousers, and black shoes. That technique was picked up in Superman to make the cartoon hero's costume red and blue, and it is used widely to display brightly colored alien attackers, as well as scenery that appears to recede as the colors deepen—including sunsets and oceans with rolling waves.

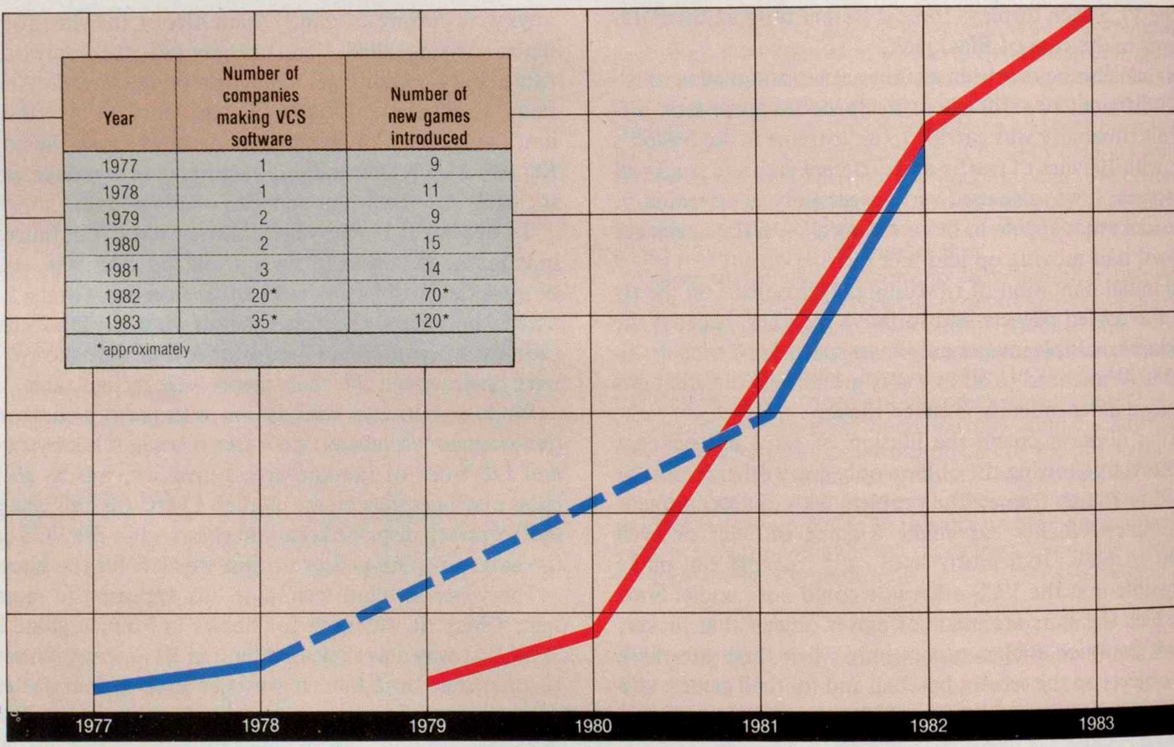
Mr. Whitehead indicated that once a game is on the market any new tricks used are apparent to experienced programmers. This thesis was confirmed by *Spectrum*'s discovery that two techniques considered trade secrets by Activision at the time of writing were widely known and, indeed, used by designers at other video-game companies.

Objects that change their size

One of the tricks designers have pointed out exploits the capability of the VCS to display an object in normal, double, or quad width depending upon the rate at which the player register is scanned. The trick comes in changing the size of the player object on the fly. In Mr. Whitehead's Boxing [Fig. 4], the game in which it is believed this technique was first used, a change in player size extends the boxer's arm into a punch. Mr. Whitehead also used the technique in Skiing, and Brad Stewart at Imagic has included the trick in his newest game, Sky Patrol.

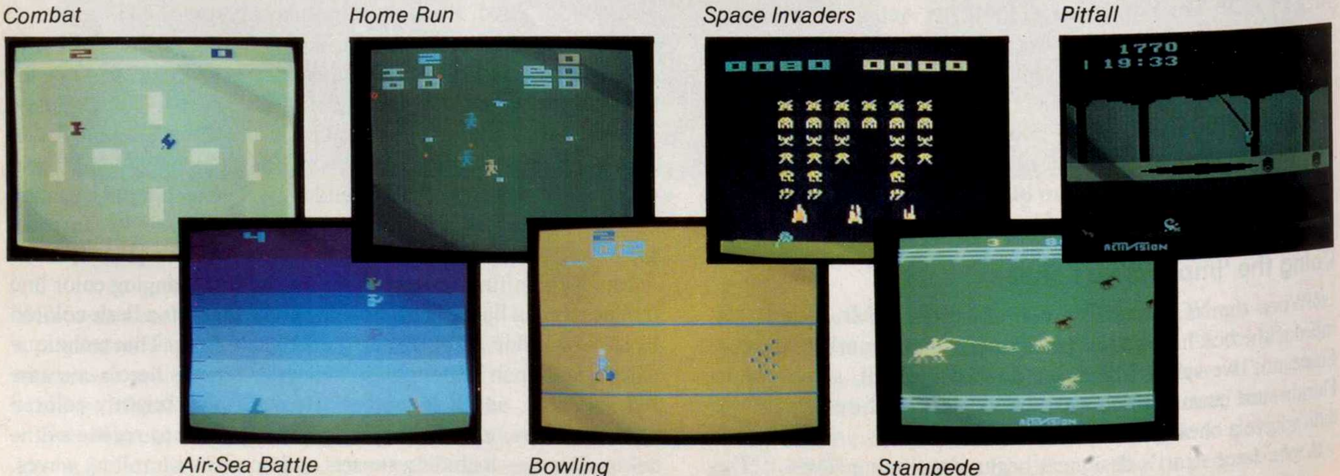
Another trick first appeared in the game Dragster. Designer David Crane, known in the industry as "a coding machine," wrote an entire kernel on the fly. The code, of course, does not move physically, but rather moves in time, so that the program is no longer in synch with the television set, and what would otherwise be a static display scrolls horizontally. When Dragster first appeared, the trick was considered impossible to repeat, but it is now understood throughout the industry. One designer using it is Imagic's Bob Smith in the game Dragonfire.

Perhaps the ultimate trick is being marketed by a company called Starpath, in Santa Clara, Calif.: a 6-kilobyte RAM module that fits into the VCS in place of a cartridge and accepts software from cassette tapes. (This option had been considered for the original VCS but was discarded.) The extended RAM allows programmers to use graphics tricks that would not fit in the VCS's 128 bytes—consistently finer resolution and sophisticated rewrite-on-the-fly techniques. Adding RAM to the VCS is not easy, nor is making cartridges with more than 4 kilobytes of memory. In order to save money, Atari limited the cartridge connector to 24 pins, omitting read-write and clock lines for RAM, as well as lines for addresses greater than 4096. Mr. Miner and Mr. Decuir agreed in retrospect that this decision was a mistake, since a 30-pin connector would have cost only 50 cents for each



Year	Number of companies making VCS software	Number of new games introduced
1977	1	9
1978	1	11
1979	2	9
1980	2	15
1981	3	14
1982	20*	70*
1983	35*	120*

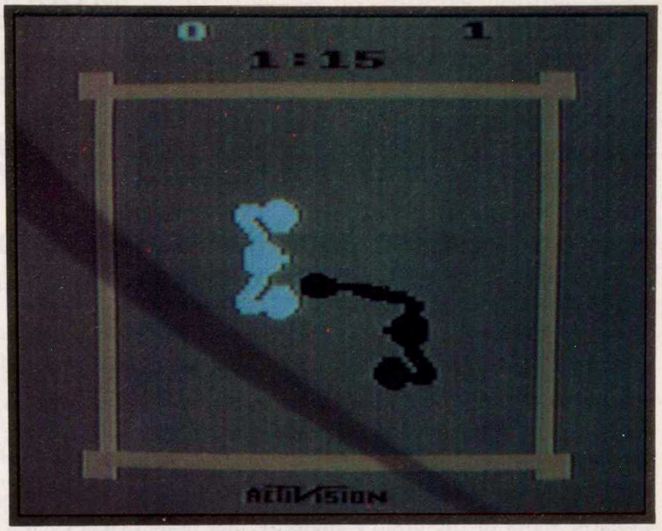
*approximately



Combat — Home Run — Space Invaders — Pitfall — Air-Sea Battle — Bowling — Stampede

Games were supplied by manufacturers and photographed by *Spectrum*.

[3] *The helicopter and laser that it fires in Activision's Chopper Command are created by writing playfield on the fly.*



[4] *A change in player size on the fly extends the boxer's arm into a punch in Activision's Boxing.*

VCS and 10 cents a cartridge and would have allowed both RAM and a 64-kilobyte address space.

Many companies now use 8-kilobyte cartridges by means of a technique called bank switching, where a read from a certain address triggers a flip-flop, directing all subsequent addresses to a different section of memory. The first bank-switched cartridge was a 6-kilobyte chess game by Larry Wagner; the game was "scrunched" to 4 kilobytes by Bob Whitehead, eliminating the need for bank switching, before it was marketed.

RAM in cartridges is made possible by resynthesizing clock signals for RAM from those timing lines that do find their way to the cartridge port. The increased speed of instructions dealing with the first 256 bytes of memory by the 6502 is all that makes the VCS possible, and so the VCS uses similar techniques internally to conserve address space. A read and a write call to the same address may deal with two completely separate registers, Mr. Miner noted: the read-write line is actually being used as another address line, in addition to its intended purpose.

Making the hardware work

The VCS design, it sometimes seems, affords nearly limitless possibilities for programmers. But the basic design of the machine did not come easy. The MOS layout was done directly on the screen of an automated IC drafting system, and circuit analysis was performed without sophisticated tools. Mr. Miner recalled simply counting the maximum number of gate delays in any line, adding the line delays, and multiplying by two for a safety factor. The first pass of silicon failed, he noted, because "there was one line that didn't go into the flip-flop I thought it did; it went around it through 12 more gates. That was twice as many gates as any other line."

The VCS was also a near nightmare to produce, according to the people involved. For example, the mechanical design specified two sizes of self-tapping screw, and few workers on the production line could distinguish between the two. If the wrong screw was used, it shaved out myriad metal filings that raised havoc with the interior circuitry. Further, when unassembled cases were stored for a time, the plastic would warp, and the two halves would no longer fit together. Production workers learned the "VCS karate chop" to pop the cases together.

But if production problems were not enough, the VCS also had testing problems because so few of its internal states were accessible: instructions came in from the cartridge, and composite video came out through the television jack. Digital testers could not deal with the video signals, and analog testers were not sufficiently programmable, recalled Mr. Mayer, noting that Atari had not faced such problems before, because "we'd never built anything with more than one custom IC in it."

The inability to test sufficiently cost Atari millions of dollars in the first year of production when one of its suppliers had process problems but the chips still passed incoming inspection. The chips were fast enough to make Atari's test software rate them as acceptable, but not fast enough to function properly when placed in an assembled VCS.

While the process problems were being resolved, Atari instituted a test program based on visual inspection of the final product: a test cartridge was developed, and inspectors would plug it in, plug in simulated controllers, and watch 20 seconds or so of "game" on a TV set to determine if each VCS were working.

Market acceptance

Even though Atari was late delivering the VCS to retailers for the 1977 Christmas season, its sales volume went from $60 million to $120 million that year. Still, the company lost money. In 1978 Atari decided to build 800 000 VCS machines, more than twice as many as the year before. A total of 500 000 orders came in by late summer, and after fall shipments went out, they disappeared from retailers' shelves in a few weeks. But few additional orders came, and Atari was left with 300 000 unsold machines; the company had doubled its sales volume for the second year in a row, Mr. Decuir recalls, and still it lost money.

Warner Communications Inc., New York, had bought Atari for $28 million in 1976, largely on the strength of expectations for the VCS. But "for two years," Mr. Mayer recalled, "Atari managed to single-handedly drag down the return on equity of Warner stock by a significant amount." Today, thanks largely to the success of the VCS, Atari is responsible for over half of Warner's total profit.

Messrs. Mayer, Milner, Miner, and Decuir set out to make a simple consumer product that would sell for two or three years—slightly longer than a dedicated game. By creating a machine with an elegant architecture that left all its inner workings accessible to the programmer, they ended up—as did early manufacturers of phonographs—creating an industry, one that today has over 70 companies competing for a share of the video-game software market, estimated this year at $2.4 billion. ◆