Video Synthesizers: From Analog Computing to Digital Art

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In the late 1960s, artists and engineers began building increasingly sophisticated video synthesizers, machines that produced abstract or distorted images by electronically manipulating either a video signal or the cathode ray tube on which it was displayed. This article explores how experimental videographers modeled video synthesizers on audio synthesizers, conceptualized them as analog computers, and starting in 1973, interfaced them with digital minicomputers.

In the 1960s, artists made the medium of television their own, creating the new field of video art. While many saw video as a tool for documenting and networking the world, others were more interested in the artificial electronic space inside their monitors. Some built video synthesizers, machines that electronically manipulated either a video signal or a cathode ray tube to produce abstract or distorted images. These devices represent points of convergence for the histories of computer graphics, analog and hybrid computing, synthesizer design, video art, and countercultural technology.[1] In this article, I make three closely related arguments about these video synthesizers.

First, inventors understood video synthesizers as electronic analog computers. As James Small writes in *The Analogue Alternative*, in the Cold War era, electronics and aircraft manufacturers developed analog computers in order to "bring the missile and aircraft into the laboratory, where it could be designed, modelled and simulated—or flown—hundreds of times, safely, in secrecy and relatively cheaply."[2] In the 1960s, artists adopted the electronic components produced for this industry as well as the concept of analog computing itself. They thus followed in the footsteps of John and James Whitney, who in the 1950s began using M5 antiaircraft gun directors to produce abstract films, including the opening titles of Alfred Hitchcock's 1958 *Vertigo*.[3] As the Whitneys adopted the mechanical analog computers of World War II, experimental videographers embraced Cold War electronics.

Second, designers modeled video synthesizers on audio synthesizers, just as engineers had modeled videotape on audiotape in the 1950s.[4] While some videographers spoke of audio synthesizers only as vague inspirations, others attributed specific features of their devices, such as banana plugs or interchangeable signal and control voltages, to the influence of musical instrument designers Don Buchla and Robert Moog. In their history of synthesizers, *Analog Days*, Trevor Pinch and Frank Trocco argue that while each of these men came to their craft through fascination with sound and electronic tinkering, they designed very different instruments based on their affiliations with different musical and technical cultures. While Moog thought of himself as an engineer and adapted his instruments to the requests of performing musicians, Buchla, a practitioner of tape music and collaborator of the Grateful Dead, conceived of his synthesizer as an experimental instrument. Even Moog's synthesizers became associated with the counterculture, though, as they were incorporated into psychedelic rock music.[5]

Video synthesizers were also imbued with particular aesthetic, cultural, and even political significance by both their creators and their users. Many who tinkered with them pursued the formalist project of exposing the properties of video as a medium, making it unambiguously the message. Others, inspired by a countercultural concern with altered states of consciousness, embraced video synthesis as a tool for sharing visions from dreams or psychedelic drug experiences, and for producing new ones on which to meditate—in other words, as a technology of consciousness. And some found televised beauty

 Published by the IEEE Computer Society 1058-6180/14/$31.00

a way to protest the Vietnam War's televised violence.[6]

My third argument concerns the relationship between digital and analog, which have become synecdoches for progress and tradition not only in video art but in virtually every discourse about electronic technology. "The principal goal of digitization … is manipulation," argues Nathan Ensmenger, and video artists first adopted digital minicomputers as programmable controllers in order to manipulate the behavior of analog synthesizers more precisely and intricately.[7] Once they had them, though, artists became interested in the aesthetic properties of digital graphics and incorporated digital images into their work along with analog video. The digitization of video art was not inevitable progress then, nor did it ever become absolute. Rather, it was a gradual and deliberate experiment that bore fruit in the form of new technological phenomena to explore.

This article is drawn from a broader research project on the ways in which video became a tool for artistic expression, psychological experimentation, and political revolution in the late 1960s and early 1970s. Most of this work concerns the cybernetic discourse of feedback and consciousness developed by videographers who used new portable videotape cameras and recorders. Here, I explore the parallel community of artists and engineers whose practice consisted more of manipulating video signals than shooting videotape.

The Conception of Video Synthesis

The history of video synthesizers is one of simultaneous invention, but perhaps the most influential were those of Eric Siegel, a self-taught television technician and independent inventor in New York City. Like many videographers, in the late 1960s Siegel began experimenting with feedback, pointing a camera at its own monitor to produce kaleidoscopic effects.[8] He also built electronic devices to manipulate the video signal, including a Magic Box that "solarized" video, reversing light and dark, and also switched between two video sources using a push button, an oscillator, or an audio signal.[9]

Siegel had grand ambitions. "I see television as a psychic healing medium," he explained, "creating mass cosmic consciousness."[10] He also saw it as a way to share states of mind, to "actually take a dream you had and make it visible to other people" or induce psychedelic experiences like those he had while using marijuana and LSD.[11]

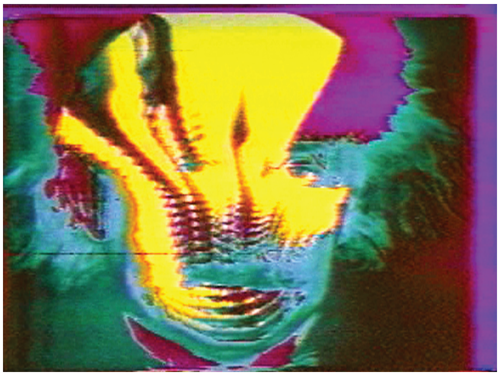

Figure 1. Eric Siegel, *Einstine,* 1968. Courtesy Electronic Arts Intermix (EAI), New York. An excerpt may be viewed at http://vdb.org/titles/einstine.

When Siegel showed art gallery owner Howard Wise his resulting "psychedelevision," Wise asked him to produce it in color, so Siegel designed an electronic colorizer that added hue to a monochrome video signal based on its brightness. The Process Chrominance Synthesizer sold about 10 units for approximately $2,400 each.[12] It also contributed, along with Siegel's Magic Box and feedback technique, to his video *Einstine* [sic], which features the scientist's face distorted by feedback and pulsating color (see Figure 1) in order to reproduce one of Siegel's dreams and "transport the mind of the viewer into Einstein's multi-dimensional world."[13] "Something extraordinary happened when we saw that flaming face of Einstein at the end of the corridor," wrote artist Woody Vasulka, "something finally free of film."[14]

Siegel's next step toward abstraction was the 1970 Electronic Video Synthesizer, "a video analog computer as far as electronic circuitry goes" that required no camera input but rather produced its own "synthetic" video signal, "like the video equivalent of a music synthesizer." The instrument featured a keyboard and an array of knobs and switches for generating, moving, and coloring geometric shapes. Electronically, it incorporated a Process Chrominance Synthesizer and additional oscillators that could cyclically change the positions and colors of the shapes.[15] It was also Siegel's last video instrument. "The motivation behind the creation of the video synthesizer," he later explained, "was to create mandalas to alter states of consciousness, and I couldn't do that quite yet."[16]

Among those inspired by Siegel's work was Korean-born artist Nam June Paik, who in the early 1960s had begun electronically modifying television sets to produce distorted images, an effect that he accomplished with the simpler technique of attaching magnets to television monitors in his 1965 installation *Magnet TV*. The electromagnets built into a monitor varied in strength continuously, causing its electron beam to scan across the monitor in a raster of hundreds of straight lines. Paik's additional magnets deflected the beam from this programmed path, manipulating the raster by curving its scan lines into surprisingly complex geometric patterns.[17] "A new decade of electronic television should follow to the past decade of electronic music," wrote Paik in 1965. "As collage technic replaced oil-paint, the cathode ray tube will replace the canvas."[18]

In 1963, Paik began collaborating with Japanese television engineer Shuya Abe. One of their projects, which eventually became Paik's 1969 *Participation TV II*, used three black-and-white video cameras to produce offset red, green, and blue images of the viewer, the brightness of which was controlled by audiotapes. Cameras could be pointed at the monitor itself to produce feedback.[19]

Paik conceived of a synthesizer in 1969, while serving as artist-in-residence at Boston public television station WGBH. He found working with engineers in a television studio frustrating and missed the autonomy of his earlier artistic endeavors. "I wanted a piano keyboard that would allow me to edit seven different sources [in] real time," Paik told art critic Douglas Davis.[20] This instrument would also provide a "'safer' and more 'authentic' art medium," he wrote, in which to experiment with the "strange 'ontology' of drug experience." [21]

"Such a versatile color synthesizer," Paik predicted, "will become a standard equiptment [sic] like today's Hammond organ or Moog synthesizer."[22] As Moog sought to create a "portable electronic music studio" for aural sculpture, Paik envisioned a similarly compact "console" for electronic painting.[23] Paik did not model his synthesizer on Moog's devices, though, but on his own installations *Magnet TV* and *Participation TV II*.[24] Working with a $10,000 budget, Abe built the machine using components scavenged from video cameras and other electronic systems.[25]

The Paik-Abe Video Synthesizer did not typically produce an artificial signal like Siegel's, but rather it combined signals from black-and-white cameras into a single color image. "The seven cameras are keyed into seven different colors themselves," explained Paik. "One camera makes only red, another only blue, another so and so."[20] The synthesizer was also a raster manipulation device, featuring a black-and-white video monitor with additional electromagnets, or "deflection yokes," which could distort its image. Some of the cameras could be pointed at this "Wobbulator" to incorporate distortion into the resulting color image or at their own monitors to produce feedback. The Wobbulator and other electronic components could be controlled by audio signals or by using the synthesizer's 60 knobs.[26]

Paik described this system, designed to produce unpredictable visual phenomena, as a "sloppy machine, like me."[27] In 1970, he debuted it in the WGBH broadcast *Video Commune*, accompanying the entire catalog of the Beatles.[28] Abe left his job in Tokyo to build additional synthesizers, "depending," wrote Paik, "on the empty promises of an artist without [a] regular job and mixing with the hippy group in the California Institute of the Arts in full American cultural revolution."[29] With their student Sharon Grace, Paik and Abe produced instruments for Cal Arts, the Art Institute of Chicago, the Massachusetts Institute of Technology, the Experimental Television Center in Binghamton, and New York public television station WNET's Television Laboratory.[30]

Among the artists who used the Paik-Abe Video Synthesizer at WNET were married couple Bill and Louise Etra (now Louise Ledeen). When they met in 1970, Louise was studying painting at Hunter College, while Bill, a former resident of the Hog Farm commune and photographer for the underground newspaper *Rat*, studied filmmaking at New York University. "We began experimenting with video feedback," Bill later told Lucinda Furlong. "Then, at some point, I stopped doing everything *but* video feedback, and started buying World War II surplus equipment—oscillators, function generators—and patched them together to distort the feedback."[31]

Bill also wanted to repeat video effects, which required more precise control than he could achieve with either Siegel's Electronic Video Synthesizer or the Paik-Abe Video Synthesizer. He and Steve Rutt, who ran a small electronics factory called Rutt Electrophysics, designed an improved Wobbulator, a modular raster manipulation device precise enough to hold an image in place and complex enough to incorporate zooming as well as motion.[32] Their Rutt/Etra Video Synthesizer, "a video analogue computer," used ramp generators, oscillators, joysticks, and audio signals to control patterns of animation.[33] "Most of the modules we used were things that had been analog computer concepts," wrote Rutt, "such as multipliers, summing amplifiers, dividers, log functions."[34]

Rutt and Etra debuted their synthesizer at the 1973 International Computer Arts Festival in New York and built 17 units before Rutt discovered that using synthesizers to animate text and graphics for broadcast television production was more profitable than manufacturing them.[35] The Rutt/Etra Video Synthesizer remained in wide use among artists and—like the Scanimate, a similar but more expensive analog computer—was also used for advertisements and other television production into the 1980s.[36]

> **"A new decade of electronic television should follow to the past decade of electronic music," wrote Paik in 1965.**

The Influence of Audio Synthesizers

Although Paik referred to the Moog synthesizer in describing his ambitions, the Paik-Abe Video Synthesizer was modeled instead on his own earlier video installations. Other designers drew more deeply on the conceptual resources of audio synthesizer design. Stephen Beck, for example, was an electrical engineering student when he began using a Moog synthesizer in the University of Illinois at Champaign–Urbana's experimental music studio in 1968.[37] The synthesizer "was a very exciting concept," Beck later said. "It was patchable, it was controllable, it was real time."[38]

As an opponent of the Vietnam War, "where some of the same technology was being used in very destructive ways," Beck "wanted to make something beautiful with the technology." As a participant in "shamanic rituals," he was also interested in hallucinatory imagery. "We'd get together to chant and induce visions and hallucinations," Beck explained. "This all fascinated me because for as long as I could remember I'd always seen lots of images when I closed my eyes." Synthesizers promised a way to share these images. "If Moog could synthesize music electronically," he recalled, "I figured that I could synthesize color video."[39]

Beck's first synthesizer, Direct Video Zero, used oscillators and audio signals to produce red, green, and blue video signals, which it combined on a color television.[40] "I had designed my voltage range inputs to be compatible with the Buchla synthesizer," said Beck, "thinking, I'll go look Buchla up and maybe we can team up and make something."[41] In 1970, he became an artist-in-residence at San Francisco public television station KQED's National Center for Experiments in Television and, indeed, began using a Buchla synthesizer to control his video.[42]

The next iteration of the Direct Video Synthesizer was modular, designed to separately manipulate the form, motion, texture, and color of an image. It was premised on an understanding of the video raster as "a series of vertically stacked horizontal lines which represent the locus of the electron beam as it scans the cathode ray tube." By turning electron beams on and off as they traced this pattern, Beck could produce areas of light and dark, and thus form. The core of his synthesizer was a set of eight "voltage to position converters," each of which compared a reference voltage representing the current position of the electron beams with a (possibly oscillating) control voltage representing the desired form, producing a pulse when they were identical. The instrument used digital logic chips to compare pulses from the eight converters, and the resulting digital signal in turn activated and deactivated an electron beam—although analog modules determined whether it activated a beam associated with red, green, or blue and at what intensity. Thus began the gradual digitization of video synthesis.[43]

Like Paik, Beck used his synthesizer as a performance instrument, playing with musicians and for a live KQED broadcast in 1972.[44] He saw his technique as sculpture rather than distortion, though (see Figure 2). "Paik was always trying to tear things apart," Beck explained, "while I was trying to put things together."[45]

Figure 2. Stephen Beck, *Illuminated Music*, 1972–1973. (Courtesy Stephen Beck, used by permission, all rights reserved.) More information may be found on Beck's website at http://stevebeck.tv/ and Electronic Arts Intermix's website at http://eai.org/. Two performances of *Illuminated Music* may be viewed at http://ubu.com/film/beck_illuminated.html.

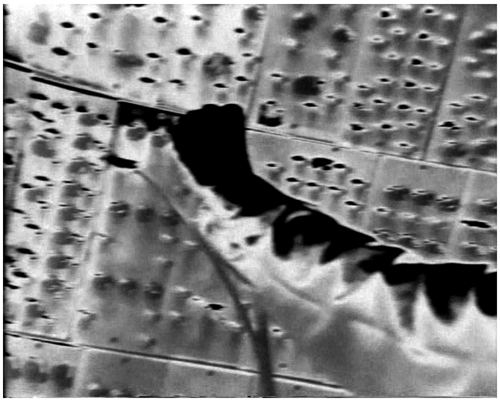

Figure 3. Dan Sandin. *Five-Minute Romp through the IP*, 1973. (Courtesy Dan Sandin.) A version may be viewed at www.evl.uic.edu/core.php?mod=8&indi=7.

While Beck borrowed the principles of voltage control and artificial signal production from audio synthesizers, physicist and photographer Dan Sandin was more influenced by the idiosyncrasies of Moog's specific synthesizer architecture. Sandin was teaching kinetic sculpture at the University of Illinois at Chicago Circle in 1969 when he started using video to help organize student demonstrations against the Vietnam War. He began designing "the visual equivalent of a Moog synthesizer," adapting the architecture to support a video signal. "I just went through all the Moog modules," explained Sandin, "and said if you center their bandwidth to handle video and you do the right things with sync, what would they do?"[46] He also modeled the resulting effects on photographic techniques including, as Christine Tamblyn noted, "colorization, solarization, superimposition, burning and dodging."[47]

"There were two crucial ideas embedded in what Moog was doing," write Pinch and Trocco. "First, that voltage control could be applied to an electrical musical instrument, and, second, that the instrument could consist of discrete modules… that could be wired together in a variety of ways and controlled by the output voltages of the devices themselves."[48] As Sandin built his Image Processor over the next four years, he retained these features, producing what he described as "a patch programmable general purpose analog computer, optimized for the real time processing of video images" (see Figure 3).[49] In particular, Sandin followed Moog's example in using the same connectors for signal and control voltages. "Since most of the processing modules are voltage controllable and control voltages and images are interchangeable," wrote Sandin, "fantastic combinatorial power is possible."[50] Personal computing visionary Ted Nelson, who was also working at Circle Campus, described this in his 1974 *Dream Machines* as "a very profound decision, whose far-flung results have not yet been fully explored even among Sandin's rather fanatical students."[51]

Sandin gave away plans for the Image Processor with a "distribution religion," stating that "the Image Processor may be copied by individuals and not-for-profit institutions without charge." A blank space was included on the document within which licensees could "put in your own method of returning energy to me," but Sandin's generosity was motivated by his conviction that "culture has to learn to use high-tek [sic] machines for personal aesthetic, religious, intuitive, comprehensive, exploratory growth."[52] Although the Image Processor could generate artificial images using oscillators, Sandin generally used it to process video he taped in "a sacred place," most often of water.[53] The roughly 25 artists who built their own Image Processors, many of them in Chicago, shared a sense of video synthesis as "a kind of practical philosophy or personal discipline, a way of life."[54]

Moog's synthesizers were not the only model for such technologies of consciousness though. Bill Hearn was influenced instead by Don Buchla. Like Moog, Buchla was a physicist who designed modular, patch programmable, voltage-controlled musical instruments. He was "immersed in the world of the avant-garde," particularly at the San Francisco Tape Music Center, where founders Morton Subotnick and Ramon Sender "were trying," in Subotnick's words, "to move away from cutting and splicing to get something that was more like an analog computer." Buchla designed synthesizers more for composers than performing musicians, omitting keyboards to push users, in his words, "into the knobs and the wires and the interconnections and the timbres."[55]

Hearn had a conventional engineering career at Signetics, an integrated circuit manufacturer in Silicon Valley founded by alumni of Fairchild Semiconductor, but he also participated in Experiments in Art and Technology, an organization for collaboration between artists and engineers. "Through E.A.T.," he explained, "I met a number of budding electronic music composers," including Buchla.[56] "I think about the person who made organs for Bach," Hearn told Vasulka. "What I really lust after is to make machines that are so clear to a creative person."[57]

Hearn moonlighted as a curator at the Exploratorium, an innovative San Francisco science museum and in 1969 began building an exhibit there called the Vidium, "a really large console that made complex color Lissajous patterns: multiple locked oscillators and pseudo-three-dimensional shapes." In its final 1970 "Mk II" form, Hearn's Vidium—like Paik's Wobbulator—used a television with customized deflection yokes.[58] Like the Buchla Box, the Vidium incorporated a sequencer, making it possible to program a six-step series of control voltages that would modify the behavior of pattern and envelope generators.[59] Although Hearn hoped to find a commercial market for the Vidium, he built only two prototypes.[60]

In 1972, an art collective called Video Free America asked Hearn to build a colorizer, and he developed techniques for adding distinct hues to four regions of a monochrome video based on their brightness. Hearn and business partner Holly Childhouse formed the Electronic Co-op and produced at least 10 Model 100 Colorizers, which featured knobs for adjusting the hue, saturation, and value of each color region and sold for $1,300. They soon changed their name to Electronic Associates of Berkeley and released the Model 200 Colorizer, which could be voltage-controlled by another machine.[61]

At the suggestion of Rutt and Etra, in 1975 Hearn incorporated this colorizer into a full-featured synthesizer, the Videolab, which also produced effects like switching, fades, dissolves, wipes, and chromakey.[62] Although the Videolab used analog video signals, it accommodated either analog or digital control voltages, facilitating its operations by a digital computer.[63] In doing so, it depended on a firm differentiation between signal and control, following the model of Buchla who—unlike Moog and Sandin—enforced this conceptual distinction materially by using different wires and plugs for each.[64] "Buchla was the strongest influence I ever had in terms of the way he did things," wrote Hearn. "If you look at this you'll see that it's very similar to his synthesizer in the philosophy of what it does: control voltages, logic voltages, signal voltages and unshielded banana jacks, so that you can stack them which makes the flow much simpler. I think technically you can say that this machine could have been designed by Don Buchla."[65]

Finally, one video synthesizer, the EMS Spectron, was actually manufactured by the English audio synthesizer company Electronic Music Studios. In 1973, engineer Richard Monkhouse was designing a visual spectrum display for the owner's music studio when he became fascinated by the images themselves. Apparently ignorant of American video synthesizers, Monkhouse designed a hybrid analog/digital instrument that incorporated a small pin-based patch panel, the most distinctive feature of the EMS VCS3 audio synthesizer.[66]

The Quest for Digital Control

As the first video synthesizer designed for digital control, the Videolab was a culmination of attempts over the previous few years to use digital minicomputers to more precisely control unruly analog synthesizers. These efforts recapitulated the development in the 1950s and 1960s of hybrid analog/digital systems in aeronautical engineering, which were similarly intended to combine the real-time capabilities of analog computers with the precision of digital ones.[67]

As Bill and Louise Etra wrote, "while the video switcher, special effects generator, colorizer, synthesizer, film chain, slide chain, cameras and video tape recorders represent literally billions of possible combinations of distortion, mixes and generation of images, they also represent hundreds of button, levers and dials with an equal number of permutations." An artist, then, was limited by "how many dials, button, etc. he or she, and possibly those working with the artist, can touch in harmony at any given moment," and because choreographing such interaction of humans and instruments was difficult, effects were usually irreproducible. In contrast, "a computer with a simple language controlling a complex video system gives the artist total access through a standard typewriter keyboard.… [An effect] now exists as an exact set of computer commands and is easily repeatable."[68]

The Television Laboratory at WNET made the first attempt to realize this vision in 1973 when it bought a used Digital Equipment Corporation PDP-8/L under a $10,000 grant from the New York State Council on the Arts.[69] Paik, who had used digital computers to produce art at Bell Labs, and engineer Bob Diamond, who had worked at Control Data Corporation, began interfacing it with the Paik-Abe Video Synthesizer—"the first case," wrote Paik, "in the application of a full-fledged digital computer into [a] video-synthesizer or beauty in video at large."[70] The computer, explained WNET's grant application, "will give the video artist 100 times more control over image making… and can allow the synthesizer to be used for creation of hitherto unknown heights of creative grandeur."[71]

Although WNET reported to the Council in 1974 that "production of the interface of a digital computer with the Nam June Paik videosynthesizer is completed," it never actually worked.[72] "A variety of factors inhibited the project," recalled artist Tom DeWitt (now Tom Ditto), the son of a senior IBM engineer. "Diamond's interface box never worked properly, partially due to delays and errors made at Rutt's Greenwich Village factory. Paik was not able to get a handle on the arcane PDP-8 programming code. Finally, the computer itself broke down."[73]

When WNET gave up on digitizing its synthesizer in 1976, DeWitt, along with Phil Edelstein and George Kindler, founders of the multimedia dance troop Electronic Body Arts, took the PDP-8 to the State University of New York at Albany's electronic music studio and repaired it.[74] The computer became a component of Pantomation, "a specialized video system designed to follow movement, read graphs, and connect live action with synthesized spaces" that also incorporated a Hearn Videolab. Pantomation tracked colored objects through the video frame and superimposed effects upon them, enabling dancers to trigger image processing in real time.[75] The system outlived WNET's PDP-8; DeWitt ported it in 1983 to run on an Apple II microcomputer with a custom video interface card.[76]

Bill Etra also began pursuing digital control of video synthesizers in 1973, when he visited an electronic music studio at the University of South Florida that had a PDP-11/10 minicomputer programmed to control Moog and Buchla synthesizers. After connecting this computer to his Rutt/Etra Video Synthesizer as well, Etra produced *PDP 11-10-Abstractions on a Bedsheet*, a video in which both sounds and wavelike visual representations of them were generated by a system consisting of the computer, video synthesizer, and audio synthesizers.[77]

The Etras became increasingly involved in computing, codirecting the 1974 and 1975 International Computer Art Festivals in New York.[78] They connected a leased Tektronix 4013 graphics terminal to timesharing computers, which they ultimately used to generate images as well as control synthesizers, and began collaborating with Lou Katz, a molecular biophysicist who directed a computer graphics facility at Columbia University's medical school.[79] In 1976, Katz and Bill Etra published an article in the ACM's journal *Computer Graphics* that described the process of producing a computer-generated line animation and mixing it with a Rutt/Etra-processed image so that a tiny Louise Etra appeared to construct a spiderweb.[80]

As hobbyist microcomputers became available in the mid 1970s, Katz and Bill Etra also began using a MITS Altair 8800 with a Cromemco Dazzler color graphics card, implementing a version of Bell Labs computer graphics researcher Ken Knowlton's EXPLOR language.[81] This computer became part of their system, as did Hearn's Videolab, which Katz and the Etras used in their video *Flypaper* to selectively replace elements of computer graphics from the Altair with video from tapes and cameras, literally placing digital images and analog video side by side on a single screen (see Figure 4). "The input video images are dynamically assigned to 'layers,'" they explained in a second *Computer Graphics* article, "which are displayed in screen regions which are defined by their color and brightness."[82] Both Bill Etra and Louise Ledeen—who divorced in 1984—continued to work in computing: Ledeen for Silicon Graphics and

NetApp, and Etra for employers including Atari and Sun Microsystems.[83]

Dan Sandin also began using a digital computer in 1973 when the University of Illinois at Chicago Circle hired computer scientist Tom DeFanti, whose dissertation project at the Ohio State University was the real-time Graphics Symbiosis System, or GRASS.[84] At Circle Campus, GRASS ran on a PDP-11/45 and a Vector General graphics display, both owned by the chemistry department. DeFanti and Sandin integrated it and the Image Processor into the Circle Graphics Habitat, a hybrid facility for real-time computer animation. "The two systems are complementary," they wrote, "because video analog electronics can process and reproduce vast amounts of information in color that digital line drawing displays cannot attempt in real-time, and because vector displays can generate animation in ways that video cannot."[85]

Among the Habitat's functions was the generation of animations for "a color videocassette course in freshman pre-laboratory chemistry," and creating such educational animation became part of the curriculum of the university's doctoral program in educational technology.[86] Both GRASS and the Image Processor were designed as artistic instruments though, and in 1975 Sandin, DeFanti, and their students began performing live "Electronic Visualization Events."[87] The Habitat eventually became the Electronic Visualization Laboratory, a site for continuing collaboration between artists and engineers.[88]

In the late 1970s Sandin began designing a Digital Image Processor that would be programmable from a conventional digital computer using either GRASS or a GUI. "The biggest gain," he said, "will be in the control structure."[89] With DeFanti, he "designed equipment for artists that were based on the video game technology of the time," but both began to focus their efforts on virtual reality in the late 1980s.[90] In 1991, this research resulted in the construction of the Cave Automatic Virtual Environment (CAVE), "a room whose walls, ceiling and floor surround a viewer with projected images." The National Center for Supercomputing Applications, Argonne National Laboratory, and the Defense Advanced Research Projects Agency soon had their own CAVEs, and such systems later became commercially available.[91]

Although Stephen Beck wrote in 1971 that "eventually a small computer, perhaps a PDP-8 or whatever 'they' have then, would drive"

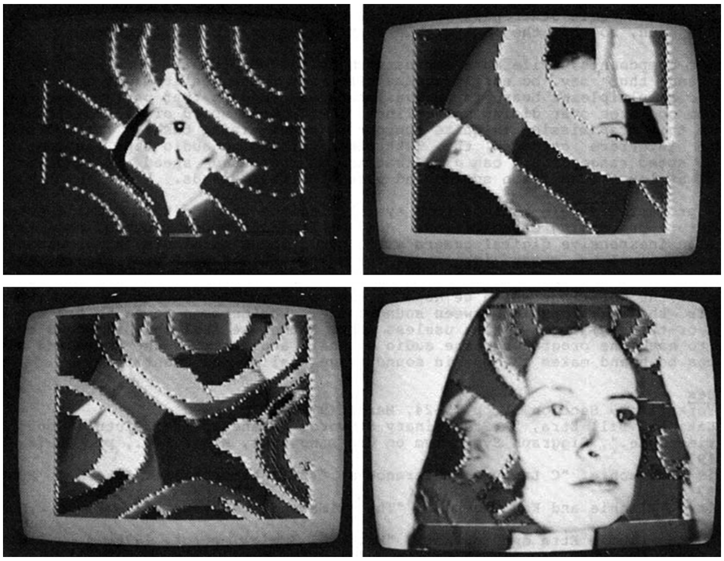

Figure 4. Lou Katz, Louise Etra, and Bill Etra. *Flypaper*, 1976. (Courtesy Louise Ledeen.)[82]

Figure 5. Stephen Beck. *Video Weavings*, 1976. (Courtesy Stephen Beck. Used by permission, all rights reserved.) An excerpt may be viewed at http://vdb.org/titles/video-weavings-excerpt.

his Direct Video Synthesizer, he too found digital technology a source of alternative aesthetics rather than additional control.[92] In 1974, Beck built the Video Weaver, a machine that demonstrated the analogy that "the warps of a loom correspond to pixel segments of a video scan line, while the wefts of a loom correspond to the individual scan lines forming the raster" (see Figure 5). The resulting device used three four-bit counters—a "pixel or warp counter," a "line or weft counter," and a "frame counter"—to produce a repeating 16-frame pattern of 16 $\times$ 16 pixels that was electronically tiled and reflected to produce higher-resolution images. Each

Rather than a tale of digital triumph, it is a story of a community of technologists adopting two waves of electronic technologies for image manipulation.

combination of warp and weft values indexed not only a specific pixel in the pattern but a specific three-bit color stored in a kilobit of random access memory. Beck avoided a limited color palette, though, by using his Direct Video Synthesizer to translate these digital signals into more varied analog color.[93]

In the late 1970s, Beck began designing electronic toys, and in 1982 he released an Atari Video Computer System game, *Save the Whales*.[94] Like Beck's own Direct Video Synthesizer, the VCS was designed around the form of the television raster to which it displayed. Rather than holding an entire frame in memory like competing consoles, it required programmers to write software that produced individual scan lines in real time, "racing the beam."[95] The distinct structure of analog television thus persisted in the videogame console, which was itself designed as a component of a hybrid analog/digital system. "The video game," Beck told Furlong in 1983, "is the synthesizer of the '80s."[96]

Digital computers did ultimately become sources of additional control for analog synthesizers. In 1976, Buffalo artists Steina and Woody Vasulka and engineer Jeff Schier interfaced an LSI-11, a compact model of the PDP-11, with analog equipment including a Siegel Process Chrominance Synthesizer and a Rutt/Etra Video Synthesizer.[97] In an allied effort, videographers at the Experimental Television Center in Binghamton, initially including Paik, began efforts to use an LSI-11 to control a colorizer and other image-processing equipment.[98] Over the next 20 years, that LSI-11 was replaced by Cromemco Z-2, Amiga, and Microsoft Windows computers, which were used both to control analog machines and to produce digital images.[99] "To this day," wrote administrators in 2009, "there are such devices as an analog Sandin Image Processor (using voltage controls for regulators) interconnected with a G5 Macintosh computer systems [*sic*] housing Max/MSP and Jitter programs, a synthesis of older and newer technologies, the digital and the analog."[100]

Conclusion

Pinch and Trocco conclude their book by observing that "analog days are here again," with musicians returning to analog synthesizers out of not only nostalgia but also "the sentiment that somehow the synthesizer did not evolve as they wanted or expected it to," that digital technology was too precise, too predictable, and ultimately too controllable.[101] If this revival is also occurring in video, it stems as much from continuity in the use of hybrid systems as from a return to analog aesthetics. When videographer Liz Larsen and engineer Ed Leckie began producing a new modular analog video synthesizer called the LZX Visionary in 2010, they attributed their optimism about their market not only to a renaissance in the use of analog audio synthesizers but also to "the effectiveness of integrated analogue and digital workflows."[102]

This is not, then, a tale of total digital triumph. Rather, it is a story of a community of technologists adopting two waves of electronic technologies for image manipulation. In the 1960s, video artists became interested in synthesizers as tools for expressing their inner states or exploring the form of a new medium, finding rich resources of components and techniques in both audio synthesis and analog computing. When they adopted digital computers, another Cold War electronic technology, artists initially valued them for their promise of control over analog synthesizers but ultimately became more interested in their unique aesthetic properties. The electronic analog modes of work and works of art that experimental videographers created facilitated the development of digital art.

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