Early Digital Computer Art at Bell Telephone Laboratories, Incorporated

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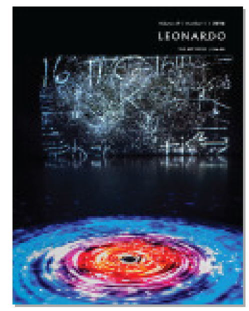

HISTORICAL PERSPECTIVE

Early Digital Computer Art at Bell Telephone Laboratories, Incorporated

A. MICHAEL NOLL

ABSTRACT

This article is a history of the digital computer art and animation developed and created at Bell Telephone Laboratories, Incorporated, 1962–1968. Still and animated images in two dimensions and in stereographic pairs were created and used in investigations of aesthetic preferences, in film titles, in choreography, and in experimental artistic movies. Interactive digital computer music software was extended to the visual domain, including a real-time interactive system. Some of the artworks generated were exhibited publicly in various art venues. This article emphasizes work in digital programming. This pioneering work at Bell Labs was a significant contribution to digital art.

Early pioneering research into digital computer art and artistic animation took place at Bell Telephone Laboratories, Incorporated (or simply Bell Labs), at its Murray Hill, NJ, facility during the 1960s. This history of that research focuses on the formative period from 1962 to around 1968. The emphasis is on the actual employees of Bell Labs who contributed to both the digital art and the technology. These employees worked in a variety of different departments; there was no single area at Bell Labs devoted to digital art and animation. A short description of computer music (and its extension to computer art) is included to present the larger context of digital media at Bell Labs.

By the late 1960s, digital computer art was fairly well established, with artists, animators and conferences around the planet. As a technology-based art medium, it continued to evolve thereafter, both in the technology it employed and in relation to the aesthetics of the era. Given today's extensive use of computer graphics, it is hard to imagine that in the 1960s the use of graphics as output from computers was novel and innovative.

This article concerns the early work related to the visual arts performed at Bell Labs. However, others also did early work in computer art and animation during the 1960s, such as Frieder Nake and Georg Nees in Germany, Leslie Mezei in Toronto [1], Charles Csuri in Ohio [2], William Fetter at Boeing, and John Whitney, Sr. Conferences were held and books written in the second half of the 1960s: One such conference was organized in 1966 by Martin Krampen at the University of Waterloo in Canada [3]; Jasia Reichardt presented the 1968 book and exhibition *Cybernetic Serendipity* in London [4]; and *Tendencies 4: Computers and Visual Research* was held in Zagreb in 1968. The Computer Arts Society also first met in London in 1968 [5].

Bell Telephone Laboratories, Incorporated, was the research and development entity for AT&T's Bell System. AT&T and the Western Electric Company (the manufacturing entity for the Bell System) jointly owned Bell Labs. The basic research done at Bell Labs was roughly about 5 percent of its work and was mostly financially supported by AT&T and the local telephone companies. Dr. William O. Baker was vice president, research, and Dr. John R. Pierce was executive director of the departments where most digital art research was performed. These two individuals are featured in two recent books about Bell Labs [6,7], and their support of digital art and animation was crucial. They both defended work in computer art and animation from criticism by AT&T [8].

The digital art at Bell Labs was both a result of research in computer graphics and a stimulus for that research. As an R&D organization, Bell Labs was keenly interested in the display of scientific data and also in computer graphics as a form of human-machine communication. Also, much of today's digital era is the result of research and innovations from Bell Labs, including information theory, negative feedback, and sampling theory, to list but a few [9].

THE BEGINNINGS OF COMPUTER ART: STILL IMAGES

Computer graphics provided a powerful means of displaying scientific and technological data calculated by a digital computer at Bell Labs in the early 1960s. The data were plotted on 35-mm film by a Stromberg Carlson SC-4020 microfilm plotter, controlled by an IBM 7090 mainframe digital com-

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puter. Early digital computer art at Bell Labs evolved from this scientific and technological foundation.

During summer 1962, I worked in the research division of Bell Labs as a member of the technical staff. My summer project involved the programming of a new method for the determination of the pitch of human speech—the short-term cepstrum. The results of the computer calculations were plotted on the Stromberg Carlson SC-4020 microfilm plotter.

The screen of the cathode ray tube in the SC-4020 plotter was photographed automatically with a 35-mm camera. The SC-4020 was intended as a high-speed printer in which the electron beam was passed through a character mask and the shaped beam positioned on the screen while the shutter of the camera remained open. Clement F. Pease, on the staff of the computer center, wrote a FORTRAN software package to interface with the SC-4020 in positioning the electron beam to draw images on the screen, mostly plots of scientific data, with a 1024-by-1024 resolution [10].

A colleague (Elwyn Berlekamp) experienced a programming error that produced a graphic mess on the plotter, which he comically called "computer art." I decided to program the computer to create art deliberately, drawing on my past training in drawing and interest in abstract painting. I described the results in an internally published technical memorandum, "Patterns by 7090," dated 28 August 1962 [11].

My early pieces were the result of combining mathematical equations with pseudo-randomness. Today this would be called *programmed computer art* or *algorithmic art*. Much art produced today by drawing and painting directly on the screen of the computer uses programs designed expressly for such purposes.

Two early works I created were *Gaussian-Quadratic* (Fig. 1) and *Vertical Horizontal Number Three*. Stimulated by op art, I created *Ninety Parallel Sinusoids* (Fig. 2) as a computer version of Bridget Riley's *Currents*. I believed that in the computer, the artist had a new artistic partner [12]. I used FORTRAN and subroutine packages I had written using FORTRAN for all my art and animation.

Leon Harmon and Kenneth C. Knowlton, both researchers at Bell Labs, perfected a computer technique in the mid-1960s in which a picture would be digitized and converted into a finite series of grayscale values, with a small pixilated image then assigned to each grayscale value. Harmon suggested the technique, and Knowlton programmed and perfected it [13]. The final mosaic was drawn on the microfilm plotter. Usually small images (in an 11 × 11 or a 15 × 15 matrix) of transistors and other electronic circuit elements—or some other, richer variety of small images—were used to create the grayscale. Since the graphic output from the SC-4020 was not that large, a number of frames would be pasted together to create a bigger picture on a large panel.

The technique was used to digitize and pixilate (using an 11 × 11 matrix of small images) a picture of a reclining nude in 1966. Harmon took the photo and collaborated with Knowlton in creating *The Nude*—blown up to a 5-×-12-ft enlargement from the computer-generated microfilm—which received publicity in the *New York Times* [14,15]. *The Nude* was

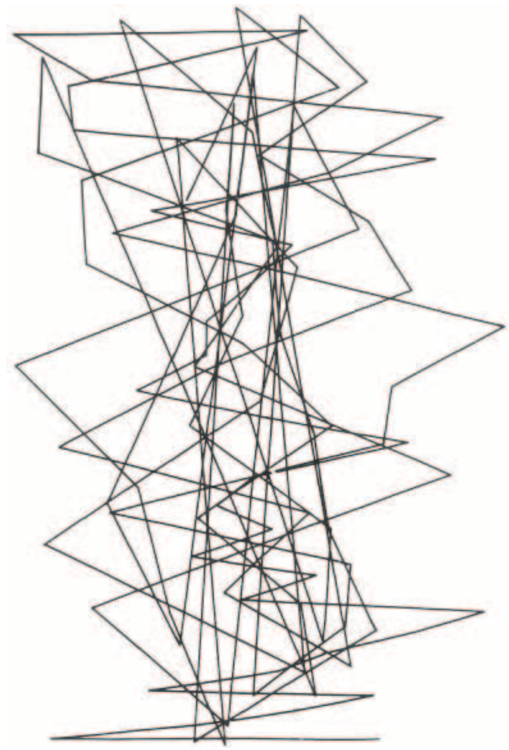

Fig. 1. *Gaussian-Quadratic* is an example of algorithmic art. Coordinates along the horizontal axis are chosen by a pseudo-random Gaussian subroutine, while coordinates along the vertical axis are chosen by a quadratic equation. When a coordinate reaches the top, it is reduced modulo 1024 to begin to climb vertically again. *Gaussian-Quadratic* was created in 1962–1963 as the culmination of a series of such images in which the parameters of the algorithms were varied. I programmed RGB color separations for a photo-enlarged color print of *Gaussian-Quadratic* and also hand-colored paper enlargements using felt-tipped color pens. (© 1965 A. Michael Noll)

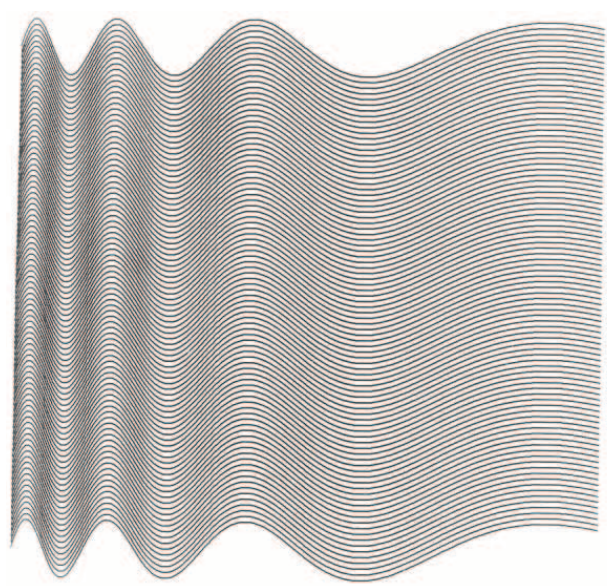

Fig. 2. *Ninety Parallel Sinusoids*, based on Bridget Riley's op-art *Currents*. This is algorithmic art, showing how easily a digital computer could be programmed to create such art. (© A. Michael Noll)

Fig. 3. Leon Harmon and Kenneth Knowlton, *Gargoyle,* 1967. Photograph of a gargoyle at Notre Dame Cathedral in Paris digitized into various gray levels, with 15-x-15 micro-images of a wide variety of objects then assigned to each gray level—in effect, a computer-generated mosaic, using small images rather than tiles to represent grayscale values. This photograph shows Knowlton looking at the large computer-generated mosaic. (Photograph courtesy of A. Michael Noll.)

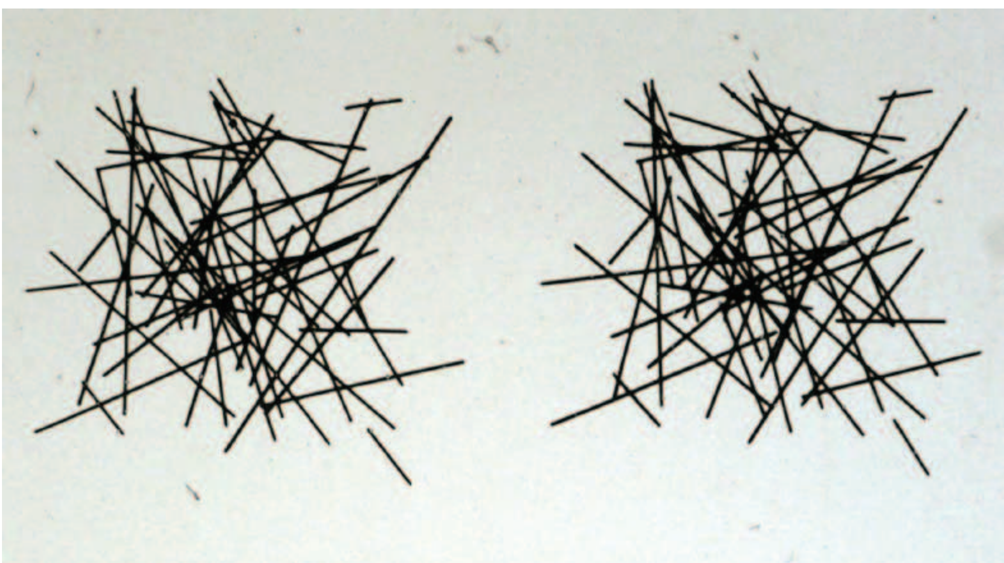

Fig. 4. A stereographic pair (programmed by A. Michael Noll) of lines placed at random in a 3D space. The 3D effect can be achieved if the left image is viewed by the left eye and the right image by the right eye. Since there are no monocular depth clues, stereoscopic viewing is the only way to obtain any 3D information. (Courtesy of A. Michael Noll.)

shown in the Museum of Modern Art's *The Machine as Seen at the End of the Mechanical Age* in 1968 [16]. Knowlton relates that they tossed a coin to determine whom the museum catalogue would list as "artist" (Harmon) and whom "engineer" (Knowlton). Another of the many computer-generated images thus created was called *Gargoyle* (Fig. 3).

Knowlton recalls that the public relations department initially advised that *The Nude* could be circulated but was not to be associated with Bell Labs. Once it appeared in the *New York Times,* however, the PR folks apparently decided that it was not pornography but "Art" and advised Harmon and Knowlton that wherever it appeared, they were to make known its provenance in Bell Telephone Laboratories, Incorporated.

Expanding upon my childhood interest in 3D stereo viewers, I programmed the computer at Bell Labs to calculate and then draw on the microfilm plotter 35-mm images of various "sculptures" for the left and right eye, combining elements of mathematical order with computed randomness (Fig. 4) [17,18]. I also used the 3D programs to plot scientific data [19]. I suggested that this 3D stereoscopic computer technique could be used by sculptors to visualize a work before rendering it in stone or metal, or by architects in designing and visualizing structures.

EARLY COMPUTER ANIMATION

A 35-mm camera was used to capture the images drawn on the faceplate of the cathode ray tube in the Stromberg Carlson microfilm plotter. A series of images could be programmed and drawn on the plotter to create a movie, thereby creating early computer animation. Similar animation was also done using a Stromberg Carlson plotter at the Lawrence Livermore Laboratory in California—although we did not know of this at the time of our work at Bell Labs. The earliest work done at Bell Labs was to display scientific data—however, artistic animation came soon after.

A researcher at Bell Labs, Edward E. Zajac, programmed the IBM computer to create a movie showing a communication satellite orbiting about the Earth as its gyros stabilized its motion [20]. This very early computer-animated film (1963) was titled *Simulation of a Two-Gyro Gravity-Gradient Attitude Control System* [21] (Fig. 5). It stimulated many others at Bell Labs to create computer-animated movies for scientific purposes. Zajac's movie was a visual demonstration to the public of what he had learned from his mathematical simulation of the gyros in stabilizing a satellite.

Frank W. Sinden, a mathematics researcher at Bell Labs, programmed the IBM computer in 1965 to create a movie showing how force and mass interact to create motion [22]. The film, *Force, Mass and Motion* [23], was a demonstration to the public of physics and an early example of the educational possibilities of computer animation.

Programmer Robert J. Tatem (working at the Whippany, NJ, military R&D facility of Bell Labs) recalls that in 1962 he used the SC-4020 to create a 5-minute computer-animated film showing the "effects of a nuclear explosion on soil at ground zero" [24]. Three filmstrips were created, one for each primary color, which were then combined optically to create a final color movie: the first color computer-animated film made at Bell Labs.

Others using computer animation for scientific and public educational purposes at Bell Labs included Joseph B. Kruskal, Jr., who in 1962 made a movie to show the results as his multidimensional scaling algorithms converged on a solution [25]. Robert M. McClure made a security-classified movie to show the results of simulations of a cloud of enemy ballistic missiles and decoys.

Kenneth C. Knowlton constructed a new programming language called BEFLIX (a takeoff on "Bell Flicks") in 1963 [26,27]. The BEFLIX language, consisting of macros and subroutines used within a FORTRAN environment, manipulated bitmaps of imagery, moving blocks of pixels efficiently and effectively. Knowlton used BEFLIX to create a computer-animated movie in 1964 about how to make a computer-animated movie (Fig. 6) [28].

Animator Stan VanDerBeek came to Bell Labs around 1965 as a visitor to work with Knowlton using BEFLIX to create artistic movies, such as *PoemField No. 2* [29] (Fig. 7). Knowlton and VanDerBeek created the *PoemField* series of animated movies from around 1965 to the end of 1969 (numbered 1 through 10). These 10 films were made with Knowlton's TARPS language (Two-D Alphanumeric Raster Picture System, a set of macros based on BEFLIX).

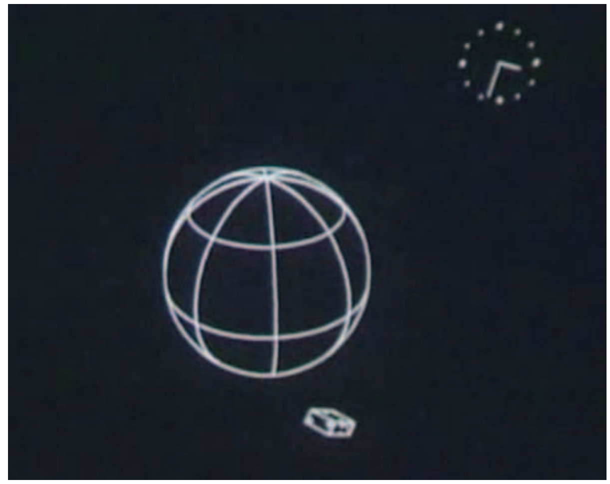

Fig. 5. Edward E. Zajac, single frame from computer-animated movie *Simulation of a Two-Gyro Gravity-Gradient Attitude Control System,* 1963. Zajac created the film using FORTRAN and the Stromberg-Carlson SC-4020 microfilm plotter. The small clock in the upper right counts the number of orbits. This film was an early computer-animated movie made at Bell Telephone Laboratories, Inc., although others would make many more at Bell Labs. (Courtesy of AT&T Archives and History Center.)

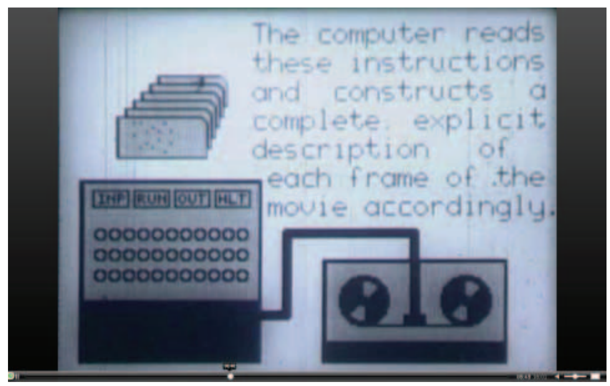

Fig. 6. Kenneth C. Knowlton, still frame from the computer-animated film *A Computer Technique for the Production of Animated Movies,* begun 1963 and finished 1964, using Knowlton's BEFLIX programming language and the SC-4020. This was Knowlton's earliest computer animated movie, leading to later collaborations with various artists. (Courtesy of AT&T Archives and History Center.)

Fig. 7. Stan VanDerBeek and Kenneth C. Knowlton, still frame from the computer-animated film *PoemField No. 2,* 1966. Made using BEFLIX and created in a collaborative manner: Knowlton was responsible for the computer programming, including the writing of macros that VanDerBeek used for some of the animations. VanDerBeek edited the sequences together and had them colorized. VanDerBeek had an interest in words and started with the idea of poems. An IBM 7094 main-frame digital computer was used, and the images were plotted on the Stromberg-Carlson SC-4020 microfilm plotter. See the AT&T Tech Channel [69]. (Courtesy of AT&T Archives and History Center.)

Knowlton made TARPS specifically for VanDerBeek to use for the *PoemField* films [30].

In 1967, VanDerBeek and Knowlton created the computer-animated movie *Man and His World* for the World's Fair in Montreal. For all these collaborative movies (co-credited to VanDerBeek and Knowlton), Knowlton was responsible for most of the programming, although they also worked together [31]. VanDerBeek added color, obtained music and did the editing to create the final movie, but according to Knowlton, "After a few months, VanDerBeek became quite proficient with TARPS; in due time he was programming almost completely on his own, while I served essentially as a debugging consultant" [32].

The movies Knowlton and VanDerBeek made all have a somewhat similar style resulting from the use of BEFLIX to move blocks of pixels. BEFLIX's grayscale and area-filling pixels were further augmented by common geometric commands (such as lines, arcs, circles), and the system was made more portable by programming in FORTRAN [33].

Knowlton also developed a programming language for linked lists called L^6 (Laboratories Low-Level Linked List Language) [34]. After developing L^6 and TARPS, Knowlton went on to develop the EXPLOR (pictures based on Explicit Patterns, Local Operations and Randomness) language [35]. After working with VanDerBeek, Knowlton collaborated with other artists, and his computer animation style continued to develop and became more sophisticated. So too did his software, culminating with MINI-EXPLOR, written entirely in FORTRAN for mini- and larger computers [36]. A Knowlton four-color image made with EXPLOR was one of the six computer-generated serigraphs of the limited-edition portfolio *Art Ex Machina,* prepared and sold by artist Gilles Gheerbrant of Montreal [37].

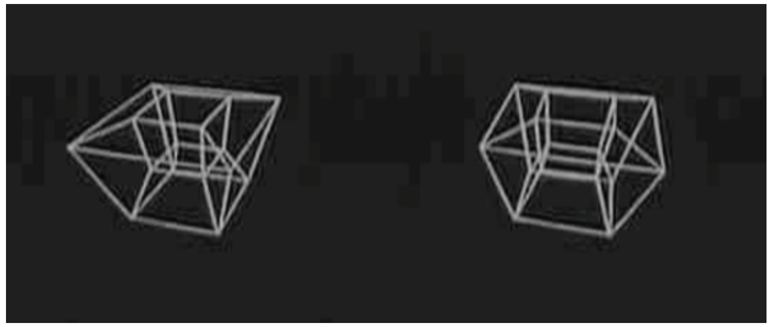

Fig. 8. Stereoscopic pair from A. Michael Noll's computer-animated film of the three-dimensional projection of a rotating four-dimensional hypercube. I later placed words in four-dimensional space and created computer-animated films of their rotation projected ultimately to two dimensions [70]. (Courtesy of A. Michael Noll.)

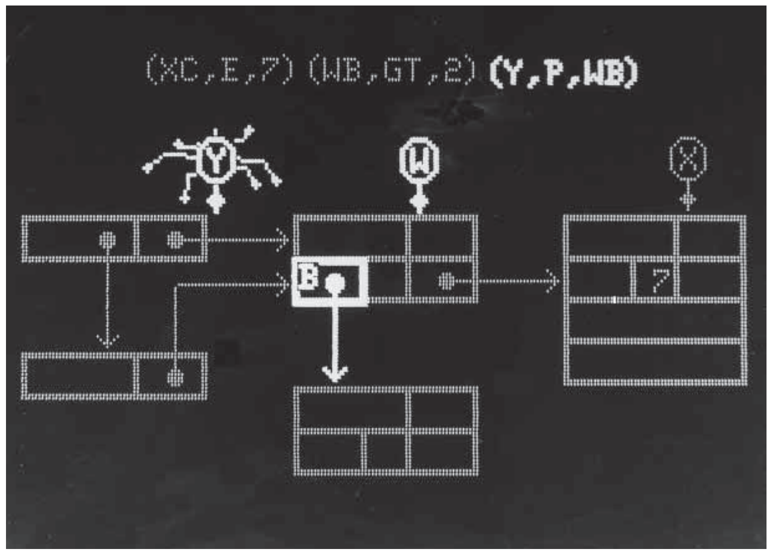

Fig. 9. A frame from Kenneth C. Knowlton's computer-animated movie about how to use his L^6 programming language. A beetle-like shape moves about the screen. An arbitrarily complex web of pointers and data is built and managed by beetle-like pointers that navigate the network. (Courtesy of AT&T Archives and History Center.)

I programmed 3D stereoscopic computer animation in 1965 [38]. Some of the films I created included a pseudo-random object that changed its shape, a computer-generated ballet of stick figures [39] and the 3D projection of a rotating four-dimensional hypercube [40] (Fig. 8). I later extended this four-dimensional technique to words placed in a four-dimensional space that were then rotated and projected prospectively to a two-dimensional movie. This technique was used to create the animated title sequence for the 1968 documentary film *Incredible Machine,* made for AT&T [41]. About a year later, I used the technique to create the animated title sequence for the NBC color special *The Unexplained,* written by Arthur. C. Clarke.

This stereoscopic computer animation was also used to simulate 3D movement of the basilar membrane in the human ear [42]. Robert C. Lummis, Man Mohan Sondhi and I made this 1966 movie, which was a scientific application of the technique to create 3D computer art. The 3D software was also used to generate the perspective images required to make a computer-generated hologram, using one of my 3D random artworks as the subject [43].

The optical attachment that facilitated stereoscopic viewing of the computer-animated stereo movies was the Prism-Stereo device, manufactured by Tri-Delta Engineering of Fair Lawn, NJ. The left and right binocular images were plotted head to head on each frame by the computer and SC-4020 and then separately projected by a prism through polarized filters in the Prism-Stereo adapter, which was attached to the lens of the movie projector for viewing with polarized glasses.

In 1966, Knowlton used his BEFLIX language to make a computer-animated movie showing the basic principles of L^6 and how to use it [44]. The crawling beetle is an artistic touch in this early demonstration of six-legged articulated animation (Fig. 9).

In 1966, a symposium entitled "The Human Use of

Computing Machines" was held at Bell Labs in Murray Hill, by invitation only to academics. The computer-animated films by Zajac, Sinden, Knowlton and myself were shown. The logo for the conference was a computer-generated work of mine.

The documentary film *Incredible Machine* (mentioned above) was made for AT&T by Owen Murphy Productions and released in 1968. Produced and written by Paul Cohen, it was shot entirely at the Bell Labs research facility in Murray Hill. It opens mentioning a "new wave of research" and features much on the use of computer graphics for both research and animation. The AT&T Tech Channel reports that the film won a CINE Golden Eagle [45]. The documentary shows among others Knowlton and VanDerBeek discussing programming aspects of their collaboration, and Peter Denes and Ruth Oster discussing speech research. Examples are shown from such computer-animated films as the computer-generated ballet *Man and His World*, the orbiting communication satellite and the basilar membrane of the inner ear.

EXPERIMENTAL AESTHETICS

In 1965, I programmed the computer to create an image consisting of horizontal and vertical parallel black bars within a circle. The bars were placed at random, with a density chosen to mimic a painting by Piet Mondrian [46]. In what became a classic experiment, I showed reproductions of both the computer image and the painting to people at Bell Labs. The majority preferred the computer image and believed it to have been created by Mondrian [47]. *Computer Composition with Lines* (Fig. 10) was awarded first prize in the annual computer art contest conducted by Edmund C. Berkeley's magazine *Computers and Automation* [48].

I later created a series of variations on the computer version of the Mondrian, with varying amounts of pseudo-randomness, to use as stimuli in an experiment to determine whether people had a preferred similar choice [49]. Each subject had unique preferences, and the artistic training of the subjects had no effect on their artistic preferences.

In yet another experiment performed ca. 1965–1966, I showed 2D and 3D images that combined order with randomness to determine aesthetic preferences [50]. The 3D stereoscopic version was preferred over the flat 2D version, and the more ordered images were the least preferred.

THE HOWARD WISE SHOW

Bela Julesz was a research scientist working at Bell Labs in the area of visual perception. He used the microfilm plotter to create stereograms in which each separate image for each eye was totally random, yet an image of an object would appear when viewed stereographically [51]. Julesz called these patterns *random-dot stereograms*. His research received much publicity and came to the attention of Howard Wise, who operated a renowned art gallery on West 57th Street in New York City. Wise contacted Julesz and asked to showcase the random-dot stereograms. Julesz and Wise then added my computer art to the March 1965 show *Computer Generated Pictures* [52] (Fig. 11).

Later in 1965, many of my works from the Howard Wise show were exhibited at the Fall Joint Computer Conference (FJCC) of the American Federation of Information Processing Societies (AFIPS) in Las Vegas, 30 November–1 December 1965. Analog computer art by Maughan Mason was exhibited along with my digital computer art.

Very early computer art used analog computers configured using cables and settings on knobs. Computer art created with digital computers came later, in the early 1960s. For

Fig. 10. *Computer Composition with Lines,* 1965. *Computer Composition with Lines* was created algorithmically with pseudo-random processes to mimic Piet Mondrian's *Composition with Lines*. Copies of both works were shown to people, a majority of whom expressed a preference for the computer work and thought it was by Mondrian—which became a classic experiment in aesthetics. The work won first prize in August 1965 in a contest held by *Computers and Automation* magazine. (© 1965 A. Michael Noll.)

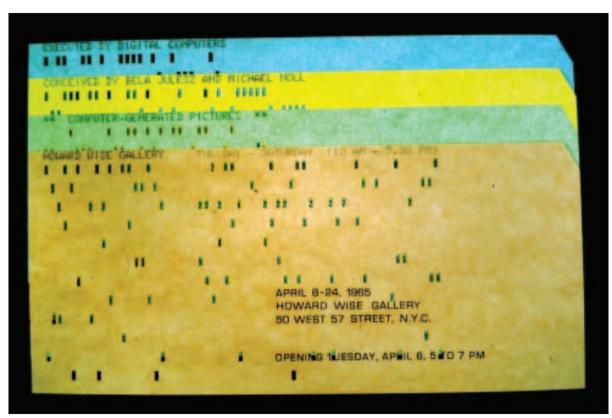

Fig. 11. An early exhibit of A. Michael Noll's digital art was held at the Howard Wise Gallery in 1965, along with patterns created by Bela Julesz as stimuli in his investigations of stereoscopy. This announcement for the show appeared on a small deck of IBM punch cards. (Courtesy of A. Michael Noll.)

this reason, the prefix "digital" was frequently placed before "computer art." Analog and digital computer art were exhibited together at the 1965 Las Vegas conference.

OTHER VISITORS AND EMPLOYEES

Bell Labs engineer Billy Klüver collaborated with artist Jean Tinguely in producing a one-time exhibit of a self-destructing machine at the Museum of Modern Art. Subsequently, Klüver and Robert Rauschenberg organized Experiments in Art and Technology (E.A.T.) in 1966 to put artists in contact with engineers and scientists at Bell Labs and other institutions for collaborative artistic ventures.

Bell Labs scientist Jerry Spivack created an interactive art piece titled *Computer Descending a Staircase,* which was selected by E.A.T. for exhibition at the Brooklyn Museum toward the end of 1968. The interactive piece was composed of three slides created by the microfilm plotter, with each slide consisting of squares with random grayscales. Each square was filtered into RGB colors, with the intensity of each color controlled with knobs by the person viewing the overlapping three slides, resulting in the transformation of the observer into the artist.

Researcher Carol Bosche worked with Bela Julesz on experiments in stereopsis. She modified Knowlton's BEFLIX language to generate "patterns, using randomness in conjunction with symmetries and periodicities" [53].

Bell Labs physicist Manfred R. Schroeder, working with programmer Sue Hanauer, programmed the microfilm plotter to draw images based on number theory. The complex images showed the patterns created by the equations and were exhibited at the Brooklyn show *Some New Beginnings* in 1968 [54]. Stimulated by Harmon and Knowlton's mosaics, Schroeder also created mosaic images from text characters [55].

In 1969 I invented and designed a raster scan display using a television monitor (assisted by engineer D. Jack Maclean) for the DDP-224 (by Computer Control Company, later Honeywell)–dedicated laboratory computer installation [56]. Initially monochrome, it later incorporated a color monitor, allowing direct color graphics from the computer. Schroeder headed the research area in which I worked and in which the interactive DDP-224 computer was installed and managed by Peter B. Denes (assisted by Ozzie Jensen and Barbara Caspers), primarily for speech research.

Aaron Marcus, then a graduate student in the Graphic Design Department at Yale's School of Art and Architecture, having studied FORTRAN programming there, worked as a research intern at Bell Labs in summer 1967. His research project at the Labs concerned how to perform overall page layout and design using the interactive DDP-224 computer system. This project continued for a few years after Marcus took a position at Princeton University. Beginning in 1967, Marcus programmed the mainframe GE and IBM computers and microfilm plotter to create artistic images with geometric patterns based on mathematical algorithms (Figs 12–14) [57,58].

The video artist Nam June Paik initially visited Bell Labs in late 1966 to explore the possibilities of digital computers in the visual arts, after Max V. Mathews and I visited Paik's studio on Canal Street in New York City. Paik was already aware of the 1965 Howard Wise Gallery show. Paik learned to program in FORTRAN from Jim Tenney and me and used the mainframe computer at Bell Labs to program a number of experimental works, including computer animation, in 1967 and 1968 [59]. However, the algorithmic aspects of programming were quite different from the analog, hands-on approach of his video art, and he did not continue at Bell

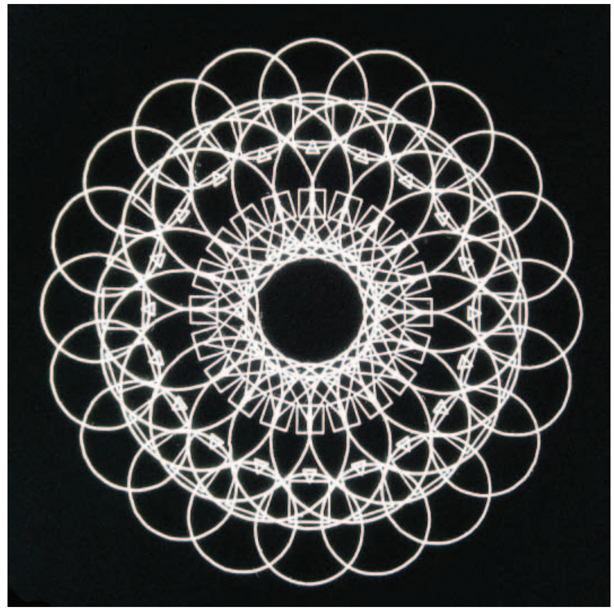

Fig. 12. Aaron Marcus, computer art created in 1967 using the GE 635 mainframe computer and Stromberg Carlson SC-4020 microfilm plotter. The program was written in FORTRAN and allowed for easy variation of angles of rotation, sizes of shapes and choices of combination of shapes. This series of computer-art images explored the visual effects of symmetry and the use of repeated simple shapes to create visual complexity. (© Aaron Marcus. Courtesy of A. Michael Noll.)

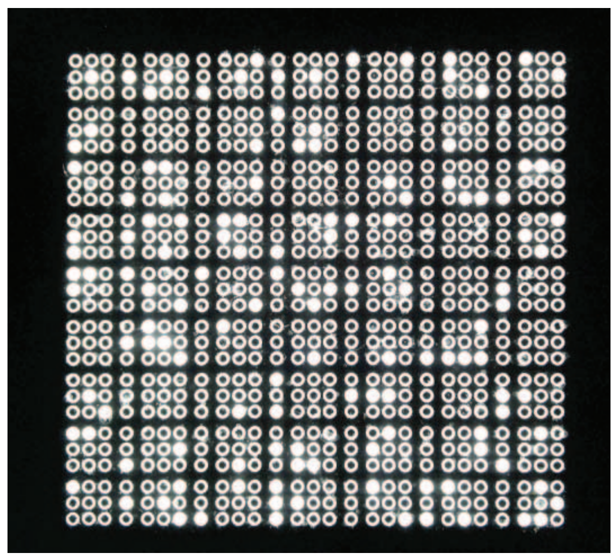

Fig. 13. The lights representing commands and/or data in the computer's central processing unit, which were actively displayed on the "dashboards" of computers in the 1960s and 1970s, inspired this 1967 computer-art image by Aaron Marcus. The program allowed for variation of which buttons would be lighted and which would be dark according to random-number generators. (© Aaron Marcus. Courtesy of A. Michael Noll.)

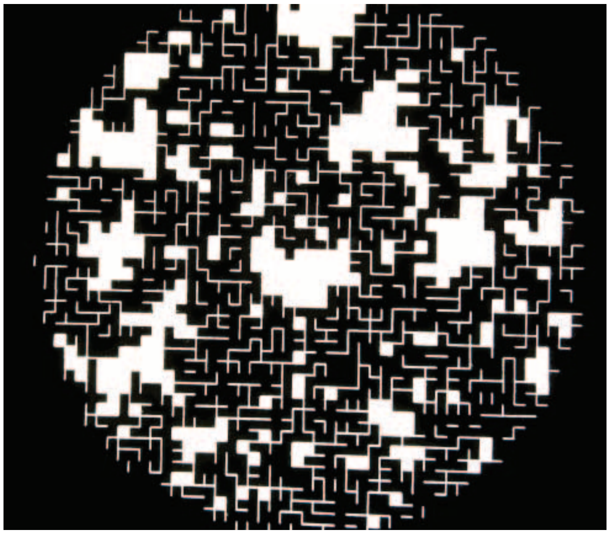

Fig. 14. Aaron Marcus, computer-art image, 1967. The image explored the visual effects of random filling in of a grid of lines and solid areas within that grid according to the results of a random-number generator. The objective was to create visual complexity and images with a somewhat handcrafted artifact quality as well as a high-tech style, typical of both modern art and ancient artifacts from thousands of years ago. (© Aaron Marcus. Courtesy of A. Michael Noll.)

Labs. Charlotte Moorman, who directed the yearly summer Avant Garde Festival in New York City, also visited Bell Labs to learn about the computer art and animation research.

Expanding upon the educational application of computer animation initiated by Zajac and Sinden, William H. Huggins of Johns Hopkins University and Don Weiner of Syracuse University visited Bell Labs for a few months around 1967 to make an educational film. Their film, using the SC-4020, illustrated harmonic phasors and waveforms for electrical-engineering education.

COMPUTER MUSIC

The history of computer music at Bell Labs has been well documented and is not the focus of this history. A short mention seems warranted, however. Digital computer music was pioneered and championed at Bell Labs by researchers Max V. Mathews and John R. Pierce [60]. A number of visiting composers were allowed to use the facilities at Murray Hill during the hours when the computers were not being used for research and other official work. These visiting composers included Jean Claude Risset, Emmanuel Ghent and Laurie Spiegel. Composer James Tenney was also an employee. Other researchers at Bell Labs who used the

Fig. 15. Laurie Spiegel, still image (photographed from a scanned color video display), 1975, drawn using FORTRAN IV software Spiegel wrote for creating still images, real-time interactive video and algorithmic image generation using a DDP-224 computer at Bell Labs. Input devices (a Rand tablet, knobs, switches and push buttons) were used for drawing still images and also for real-time interactive improvisation of animated visual materials. These input devices controlled various visual parameters of the program, including color, location, path, texture, size, logical operations and contrapuntal relationships (such as inversion and imitation) derived from music. Time-based video output generated by this same software system (VAMPIRE) was recorded directly to analog videotape. (© Laurie Spiegel.)

computers there to compose music were Joseph P. Olive, F. Richard Moore and Joan E. Miller.

During the mid-1960s, musicians such as Leopold Stokowski and the conductor Hermann Scherchen visited Bell Labs regarding the computer music research that was being done there. Scherchen observed that he could create music just as well using audio oscillators at his electronic music studio in Switzerland. However, he was impressed by the computer animation, which he believed could be done in no other way. Interestingly, Roy Disney visited Bell Labs and was shown the computer animations but saw no application of the technology to the Disney studio.

Composer Laurie Spiegel also created computer art at Bell Labs, writing her own computer programs to create it. Spiegel used a Rand tablet, knobs, 3D joystick and color cathode ray tube to create computer art interactively, writing one of the earliest color digital "painting" or "drawing" programs for use on the DDP-224 computer system. She created a "visual musical instrument" (VAMPIRE—Video And Music Program for Interactive Real-time Experimentation/Exploration) that allowed real-time performance through the manipulation of various visual parameters, as well as digital recording and playback of improvised or other kinds of animations [61] (Fig. 15). The final output could be recorded in real time on standard videotape or non-real time on film. Although a random-number generator was used for some variables, Spiegel's musical and visual software were primarily deterministic. Spiegel indeed was one of the "new breed" of artist-programmer advocated by Knowlton and Noll.

DISCUSSION AND CONCLUSION: ARTIST-TECHNICIAN

The distinction between art and technology was quite blurred during these early years of computer art and animation. The artistic application was sometimes used to motivate the development and application of the software and technology.

The artistic works of such individuals as Marcus, Paik, Spiegel and I were done individually. We all knew how to program and made all artistic judgments ourselves. I believed that the artist should learn the computer technology and how to program and use it—I was not a fan of collaboration, such as promoted by Klüver's E.A.T. [62].

Most of the later films created by Knowlton were done collaboratively with various artists. However, Knowlton created his earliest computer animations alone, and a clear style emerged that permeated most of the latter works that were done collaboratively (although Knowlton stated, "On computer art I've usually lacked the courage to work entirely alone . . . and trusted [the artists'] judgment for the final form of the films") [63]. In my opinion, Knowlton's computer languages, and his programming in them, were crucial to these computer-animated films. His artistry was also later demonstrated by his mosaics [64].

Both Knowlton and I went on to invent and develop novel computer hardware and software for the interactive DDP-224 computer facility at Bell Labs: Knowlton, a virtual keyboard [65] and I, a tactile, haptic "virtual reality" system [66]. Knowlton conceived a musical "beat that seemed to endlessly speed up (or slow down)," which was implemented by Spiegel [67,68].

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