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It Is Forbidden Not to Touch: Some Remarks on the (Forgotten Parts of the) History of Interactivity and Virtuality

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(21–49

Peter Weibel

Kinetic art and op art are being rediscovered. But the context in which these movements are regaining public awareness is new. First, they are being recognized as developments that ran parallel with the emergence of computer art, of computer graphics and animation. In the 1960s shows like "New Tendencies" (Zagreb and Milan) played a special role in this interplay among computer art, kineticism and op art. Second, this contextual shift makes it clear that works of op and kinetic art accomplished with manual and mechanical means have attributes of observer dependency, interactivity, and virtuality; indeed, terms like "virtual" were already current. Third, the presence of covert instructions to act—viewers of op and kinetic works are expected to press buttons, move components, and so on—reveals the rudiments of rule-based algorithmic art.

These procedural instructions forge a link to a further important direction of art in the 1960s: the happening and Fluxus movements, which substituted items of daily use for the work of art. These items of daily use were subsequently replaced by instructions for use which, addressed to the audience, now became instructions to act. Basic elements of algorithmic art therefore figured in happening and Fluxus, too.

Thus, the three major art movements of the 1960s—op and kinetic art, happening and Fluxus, computer graphics and animation—are being reconsidered from the algorithmic angle and placed in new relation to each other. With all three movements able to be considered as different forms of "algorithmic art," it becomes clear that the attributes of programmability, immersion, interactivity, and virtuality did not first appear in the media and computer art produced from 1970 onward, but were already present in the op and kinetic art of the 1960s.

What Is an Algorithm?

Cameras, cars, planes, ships, household devices, hospitals, banks, factories, shopping malls, traffic planning and routing technology, architecture, literature, visual arts, music—no area of social or cultural life exists that is not permeated by algorithms. In science, the algorithmic revolution began in 1930 or thereabouts; in art, some thirty years later.

An algorithm is understood to be a decision procedure—a set of instructions to act—made up by a finite number of rules, a finite sequence of explicitly defined elementary instructions that exactly and completely describe the stepwise solution to a specific problem. The most familiar implementation of algorithms is in computer programs. A program is an algorithm written in a language enabling it to be executed in steps by a computer, and therefore every computer program (as a high-level machine language) is an algorithm, too. The task of executing the steps in generating procedures or decision-making processes that sometimes require hours or days of computing has been transferred to a machine: the computer. And as these computing machines became more advanced, so the programming became more precise. Computers are controlled by algorithms in the form of computer programs and electronic circuits. The first algorithm written specifically for a computer was recorded in 1842–43 by Ada Lovelace in her notes on Charles Babbage's *Analytical Engine* (1834). Since Babbage was unable to complete his proposed machine, however, Lovelace's algorithm (whose purpose was to compute Bernoulli numbers) was never executed on it.

The lack of mathematical precision of the early twentieth-century definition of an algorithm was a source of irritation to many mathematicians and logicians of the period. In 1906, Andrey A. Markov[1] created a general theory of stochastic, or random, processes on the basis of his so-called Markov chains, which were generalized by Andrey Kolmogorov in 1936.[2] These chains represent the mathematical model of a memory-free process that describes a physical system when the probability of state transition depends solely on the state of the system at a given time and not on the previous history of the process. The transition probability of the state at time $t + 1$ is dependent solely on the state at time t. In this way, the Markov chains allow sequences of mutually

dependent variables to be studied in accordance with laws of probability. They are sequences of random variables in which the future variable is dependent on the current variables, but independent of the state of its predecessors. In the late 1950s and early 1960s this theory of stochastic processes was successfully applied to the stochastic generation of poetry and music, that is to say: random music and random text. The concept of the algorithmic coincidence was accepted as the ultimate definition of chance, and led to the foundation of an algorithmic information theory by Gregory Chaitin[3] and Andrei Solomonov.

Around 1930 the intuitive concept of computability, or of the algorithm, underwent mathematical precision. The works of Kurt Gödel, Alonzo Church, Stephen Kleene, Emil L. Post, Jacques Herbrand, and Alan Turing[4] demonstrated that all formal versions of the concept of computability are equally valid and can be viewed as a precise version of the concept of the algorithm. Algorithms are older than computers, therefore, but have been most famously deployed in computer programming over the course of the past seventy years. Any problem able to be programmed can be solved algorithmically with any current programming language (high-level machine language).

The development of programming languages began with Axel Thue,[5] whose "Probleme über Veränderungen von Zeichenreihen nach gegebenen Regeln" in 1914 delivered the first precise version of an algorithmic decision process: with the aid of a finite alphabet (i.e., six letters) and a system of rules R (i.e., two rules of transformation) it was possible to determine in individual cases whether a specified sequence of signs could be generated from the given alphabet and system of rules. Semi-Thue systems of this kind were used to develop the theory of formal languages. In the 1950s Noam Chomsky referred to semi-Thue systems in order to describe grammatical structures of natural languages. On the basis of Chomsky's semi-Thue systems, John Backus and Peter Naur around 1960 introduced a formal notation enabling the syntax of a language to be described, and from this system of notation evolved (algorithmic language) ALGOL 60, the first successful programming language.

Algorithms in Art

Running in parallel development with these advances in computing machines, machine languages, and the associated algorithmic procedures and beginning around 1960, intuitive algorithms in the form of instructions for use and action also began to be used in forms of analog art ranging from painting to sculpture. One might say that sequences of signs in the form of digits are instructions for machines to act. Known as programming languages, artificial languages, or digital codes, they are used in digital art. Sequences of signs in the form of letters can be instructions for human beings to act. These are termed natural languages, and are used in analog art. Accordingly, instructions to act exist for manual and mechanical tools like hands, buttons, keys, and so forth. And instructions to act likewise exist for digital and electronic tools. Accordingly, there are two forms of interactivity between work and viewer: manual and mechanical (for instance, in op and kinetic art) or digital and electronic (as in new media art).

For centuries algorithms have been used intuitively as control systems, instructions, rules of play, and as plans and scores in architecture and music. In music and the fine arts, algorithms have long been valuable instruments of creation. The artists' books of the Renaissance, such as Leon Battista Alberti's tract *De re aedificatoria* (1452), Piero della Francesca's *De prospectiva pingendi* (c. 1474), or Albrecht Dürer's illustrated book *Underweysung der Messung* (1525), already amounted to manuals for making paintings, sculptures, and buildings. Mathematical aids and even small mechanical contraptions are known to have been used by composers from Bach to Mozart, from Schönberg to Joseph Schillinger.[6] A central role is played in modern music by serial and static processes, by techniques and algorithms which are aleatoric and stochastic, permutative and combinatorial, recursive and fractal; and this function is exercised not just intuitively, but also in the sense of high-precision mathematics.[7]

There are two different uses of the algorithm in modern art: intuitive application, as in the Fluxus movement (a plausible example being Karl Gerstner's *Variables Bild* (*Rotbunte Reihen*) (Variable Image) of 1957/1965, which consists of variable wooden bars in a metal frame), and exact application, as in computer art. There have been attempts to reconcile both modes in various measures. The Fluxus artist George Brecht produced a work entitled *Universalmaschine*,[8] an explicit allusion to the computer as a *universal machine*,[9] and in 1969–1970 Karl Gerstner created a work entitled *AlgoRhythmus 1*.

Dick Higgins, another Fluxus artist, in 1970 published *Computer for the Arts* including a machine score for computer music by James Tenney (with text by Higgins). As early as 1962, a text by Umberto Eco appeared with the telling title *arte programmata*.[10] Written for the exhibition "Arte Programmata—arte

cinetica, opere moltiplicate, opera aperta" (Milan, 1962), Eco's text dealt with the interplay between accident and programming. This notion of programming was extended to architecture by the Italian architect Leonardo Mosso in 1969.[11]

In the analog art forms (op and kinetic art, Fluxus, happening) the intuitive use of the concept of the algorithm led to mechanical and manual practices of programming, procedural instructions, interactivity, and virtuality. In the "New Tendency" shows of the early 1960s in Zagreb, Milan, and elsewhere, viewer participation in the construction of a work of art played a considerable role. In works associated with Fluxus, happening, or performance, the object of painting or sculpture was entirely replaced by instructions to act. Along with stepwise instructions to bring about events, the instructions for use that implicitly accompany any item of daily use took the place of the actual item, in this way leading to the explicit integration of the audience.

Op and Kinetic Art

Kinetic art achieved major historical and popular influence in the 1960s, as evidenced by exhibitions like "Rörelse i Konsten" (Moderna Museet, Stockholm, May–September 1961), organized by K. G. Pontus Hultén and first shown under the title "Bewogen Beweging" in Amsterdam (Stedelijk Museum, March–April 1961), "Kinetic and Optic Art Today" (Albright Knox Art Gallery, Buffalo, 1965), and "Licht und Bewegung—kinetische Kunst" (Kunsthalle Düsseldorf, 1966). The titles of the shows point to the intertwining of the problem of representing movement with that of representing optical phenomena in which kineticism originated and developed. In both cases, mere representation was renounced in favor of real movement, real light. Optical illusions became recognizable as such. Real movement and real light became media of art. Perceptual phenomena and optical illusions were used not as instruments but as subjects, not as means of representation but as activated perceptual experiences in which the viewer was now a crucial factor.

As early as 1955, K. G. Pontus Hultén had curated the show "Le Mouvement" (featuring Agam, Bury, Calder, Duchamp, Jacobsen, Soto, Tinguely, Vasarely) at the Galerie Denise René in Paris, and contributed the text "Petit moments des arts cinétiques." With a title alluding to Moholy-Nagy's book *Vision in Motion* (Chicago, 1947), the exhibition "Vision in Motion—Motion in Vision" at the Hessenhuis, Antwerp that same year showed work by artists including Roth, Macky, Piene, Tinguely, Spoerri, Bury, and Klein.

Although the chronology of kinetic art can be traced back to 1900, the de facto beginning was in 1920. The sources—avant-garde film (Walther Ruttmann, Viking Eggeling), Constructivism, Bauhaus, De Stijl, futurism—are as diverse as the stations (*arte cinetica*, 1914–16; Viennese kineticism, 1920–24, with protagonists including Franz Cizek). The primary source is Russian Constructivism, which produced geometrical objects free of any mimetic function (Tatlin, Rodchenko, El Lissitzky, Gabo, Pevsner). In Moscow in 1920, Naum Gabo demonstrated to his students that a single rod of wire, if set in motion with the aid of a clock spring, can become a volume or, more accurately, a virtual volume. This *Kinetic Construction No. 1* (fig. 3.1, fig. 3.2), which in 1922 was also exhibited in Berlin, emanated from "The Realistic Manifesto" Gabo wrote in 1920. Cosigned by his brother Antoine Pevsner, it was in fact a "Constructivist manifesto" (as early as 1915, Gabo named a sculpture *Constructed Head No. 1*), and is now considered to represent the beginning of Constructivism.

Illusory Movement—Illusory Volume

Kinetic Construction No. 1, whose very title expresses the historical connection between Constructivism and kinetic art (incidentally, in 1941 Zdenék Pešanék's book *Kineticism* appeared in Prague; it represents the missing link in the evolution of avant-garde film and kinetic sculpture) refers not only to motor-driven movement, the agent for all future kinetic sculptures of artists from George Rickey to Jean Tinguely, but also to a lesser-known motor driving the development to kineticism. That motor is apparent movement, virtuality: for Gabo's line—a rod of wire—produced an apparent volume. Virtuality connects kinetics with op art. Kinetic art evidently lies between Constructivism and op art, is connected with them both, and the connecting element is evidently perceptual phenomena. This realization allows us to advance beyond the purely mechanical categories of kinetics and chart the evolution from analog mechanical to digital electronic kinetics. Mobile parts are more than mere machine components; they are virtual components, too.

This finding also points to a further important source of kineticism, namely to the science of perception, of special optical phenomena encompassing everything from stereoscopy to stereokinesis. The new schools of gestalt and per-

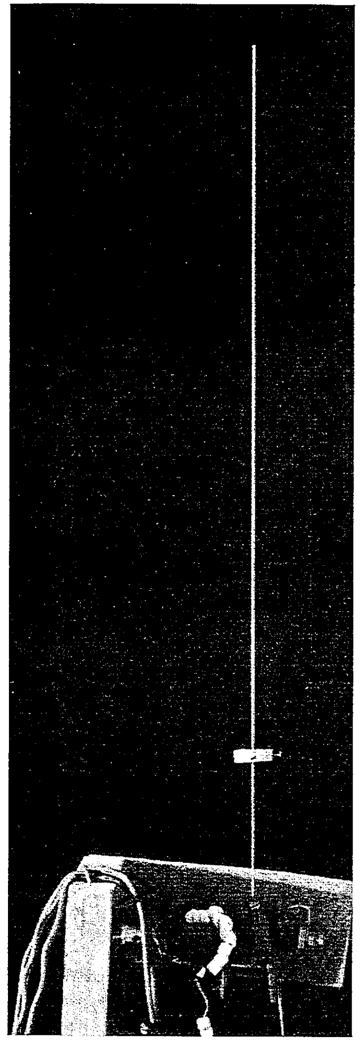

Figure 3.1 Naum Gabo, *Kinetic Construction No. 1*, 1920 (stationary). By kind permission of the Neue Galerie Graz.

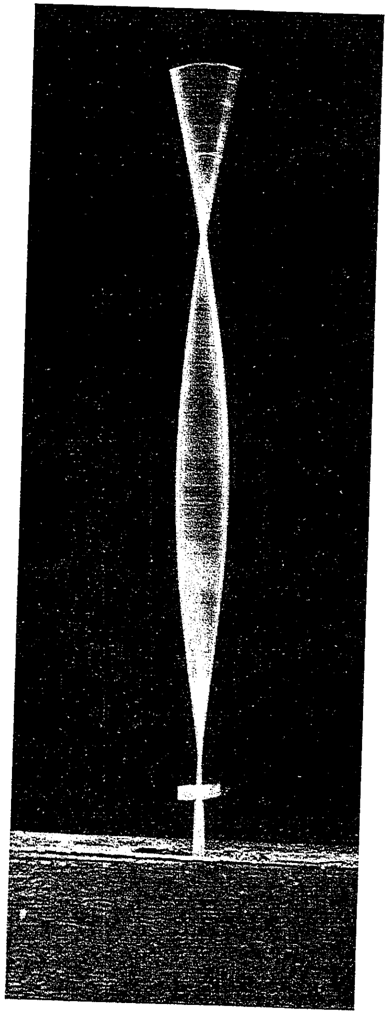

Figure 3.2 Naum Gabo, *Kinetic Construction No. 1,* 1920 (in movement). By kind permission of the Neue Galerie Graz.

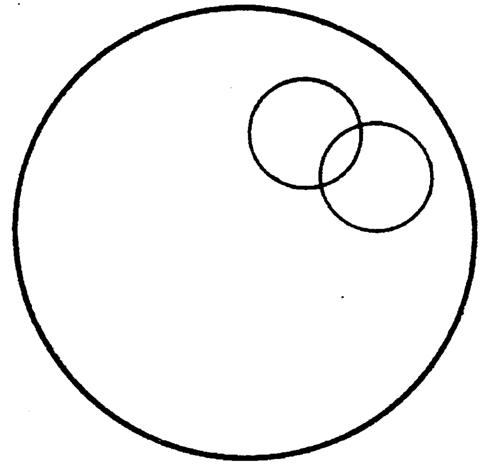

Figure 3.3 Vittorio Benussi, 1912. Apparent transparency with the stereokinetic phenomenon. If the circle pieces are glued or drawn onto a piece of card which is then slowly rotated, monochrome circles can then be seen—like the sheared edges of a roller—stretching backward. By kind permission of the Neue Galerie Graz.

ceptual psychology that arose around 1900 (Vienna, Prague, Graz, Berlin, Frankfurt) and are connected with names such as Ernst Mach, Christian von Ehrenfels, Alexius Meinong, Alois Höfler, Vittorio Benussi, Wolfgang Köhler, Max Wertheimer, Kurt Koffka, experimentally investigated the laws of visual perception, in particular gestalt and movement experiences, illusory movements, optical illusions, and so forth.

The Graz-based experimental psychologist Vittorio Benussi, an Italian national, in 1912 published "Stroboscopic Illusory Movements and Geometric-Optic Gestalt Illusions." The year 1921 saw the publication in Leipzig of Johannes Wittmann's "Über das Sehen von Scheinbewegungen und Scheinkörpern." Pentti Renvall's "Zur Theorie des stereokinetischen Phänomens" appeared in 1929.

These apparent movements and illusory bodies take us into the realm of the virtual. In 1912 Benussi had conducted a simple experiment that connected movement (kinetics) with depth perception (op art). Patterns of circles on

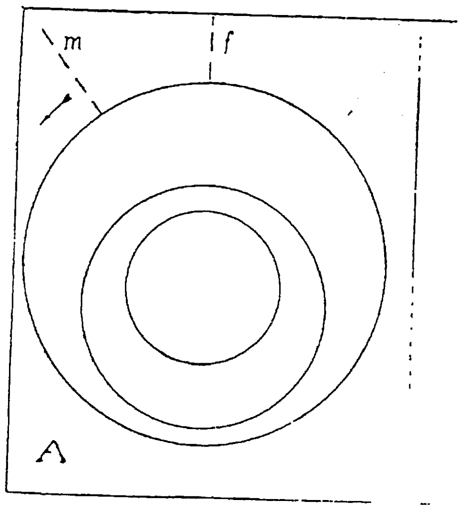

Figure 3.4 Cesare L. Musatti, 1924. Circles which produce stereokinetic effects when rotated. By kind permission of the Neue Galerie Graz.

rotating disks generated the optical illusion of moving cones, and as a result produced the illusion of a three-dimensional structure in movement (fig. 3.3). Movement in combination with depth perception (stereo manifestations) leads to a kinetic spatial effect (or the "stereokinetic effect," to borrow the term which Cesare L. Musatti, a pupil of Benussi in Padua, coined for stereokinetic spatial images and illusory bodies) (fig. 3.4). The optical disks of the film *Anémic cinema* (1925–26) and Marcel Duchamp's *Roto-Reliefs* (1923–35) are based on the same stereokinetic phenomenon (fig. 3.5).

Research into illusory bodies and illusory movements was carried forward in the 1950s and 1960s, partly with the assistance of apparatuses. Gaetano Kanizsa, a pupil of Musatti, followed up the investigations of Friedrich Schuhmann, who in 1900 had published the first "illusory contour," that is to say, the perception of a nonexistent, illusionary, virtual line. From 1955 onward, Kanizsa popularized as "subjective contours" those in reality nonexistent illusory contours, illusory boundaries, and illusory edges (*Scientific American* 234, April 1976, pp. 44–52) (fig. 3.6). Working in Innsbruck in the 1950s,

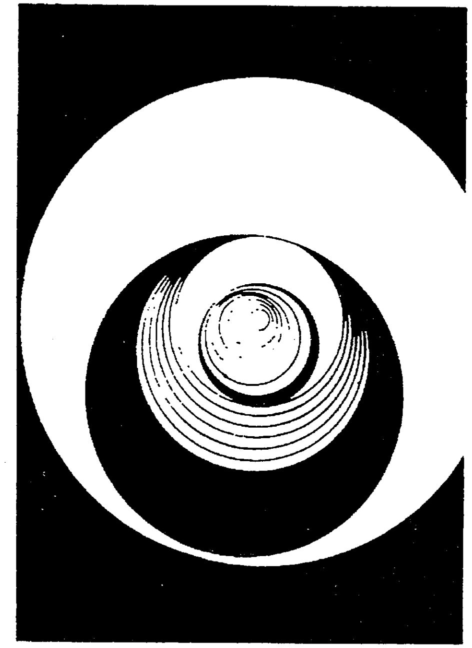

Figure 3.5 Marcel Duchamp, optical disk from the film *Anémic cinéma,* 1925–1926. By kind permission of the Neue Galerie Graz.

Theodor Erismann and his assistant Ivo Kohler deliberately generated optical malfunctions by means of inverting spectacles, thus adding to the foundations for understanding illusory worlds (fig. 3.7).

From Virtual Volumes to Virtual Environments

As can be seen, Naum Gabo's *Kinetic Construction No. 1* generated apparent—virtual, we would say today—movement. Art history shows us that the realm of virtual movement and virtual bodies stretches from the painting to the sculpture, from plane surface to three-dimensional space, and that already in the 1920s the term "virtual" had begun to be used instead of "illusory."

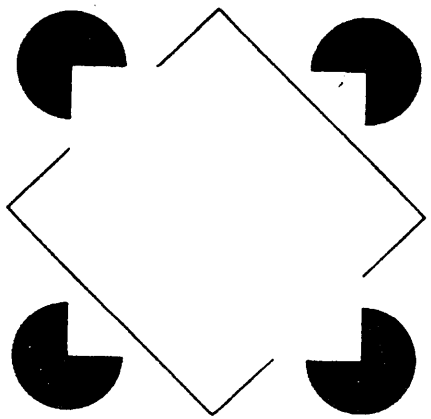

Figure 3.6 Resistance to superimposition is a measure of the intensity of perceiving subjective surfaces. Separating lines appear to be superimposing themselves over a subjective surface, but the subjective contours are destroyed by the line. Source: Gaetano Kanizsa. By kind permission of the Neue Galerie Graz.

Figure 3.7 The peaked cap with the mirror that turns everything on its head. Source: Ivo Kohler. By kind permission of the Neue Galerie Graz.

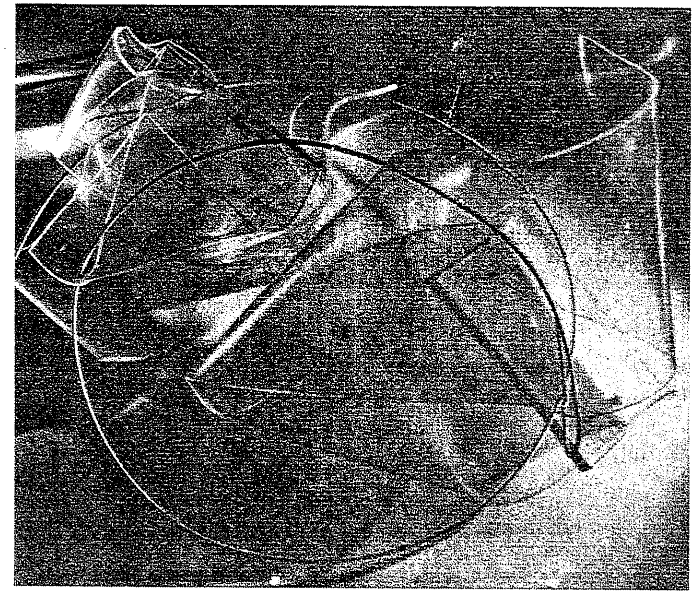

Figure 3.8 Moholy-Nagy, *Space Modulator,* 1940. By kind permission of the Neue Galerie Graz.

In his book *From Material to Architecture* (1929) Moholy-Nagy describes as the fifth stage in the development of sculpture the addition of the fourth dimension of time to the three dimensions of volume. Mass tends toward immaterialization as a result of movement. Through movement sculpture becomes the manifestation of virtual volumetric relationships. Moholy-Nagy therefore explicitly refers to the development of material and static volumes into ones that are kinetic and "virtual" (fig. 3.8).

Jesús Rafael Soto produced kinetic art not by fusing light and movement but by the classical device of producing with two-dimensional means the illusion of movement (fig. 3.9). In the process he quickly recognized the laws governing apparent movement, whereby precisely the relations among the elements, as opposed to the elements themselves, are crucial to the generation of illusory motion. He therefore spoke of "virtual relations" and extended these

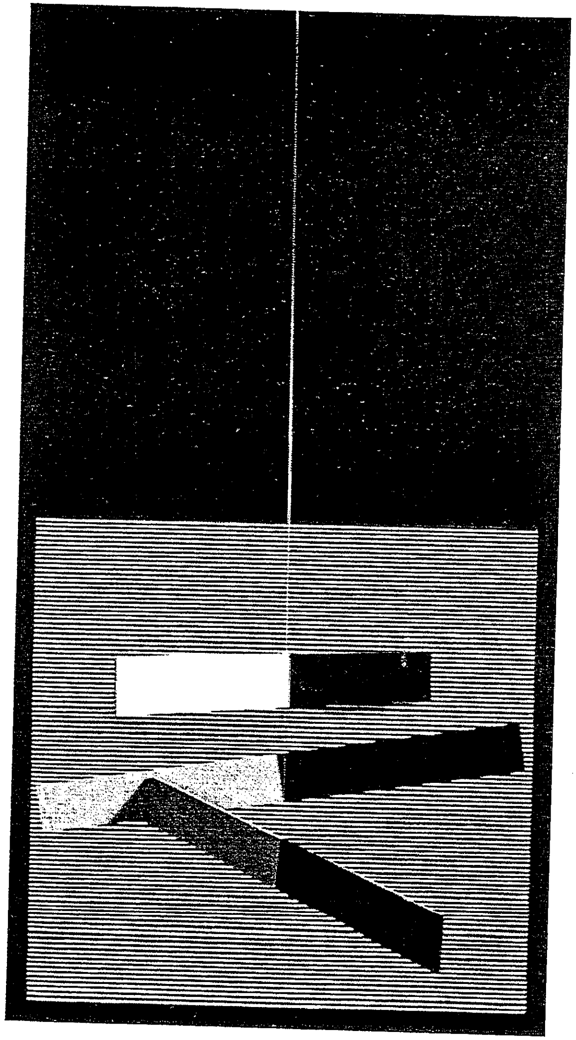

Figure 3.9 J. R. Soto, *Deux relations virtuelles*, 1967. By kind permission of the Neue Galerie Graz.

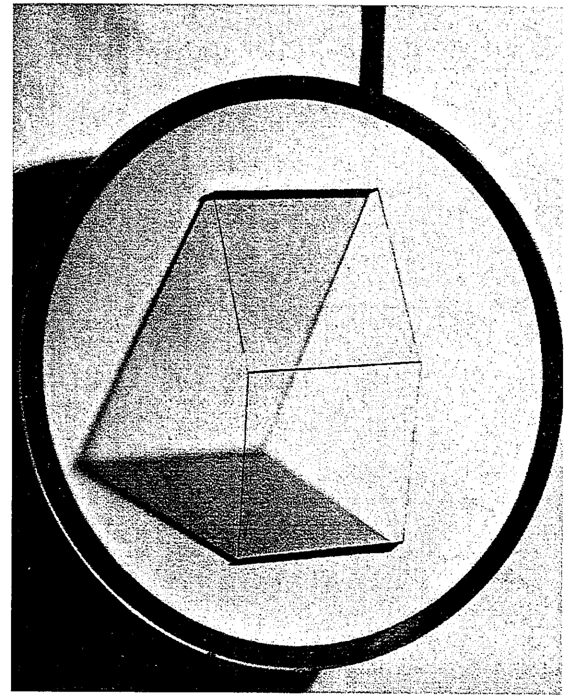

Figure 3.10 Gabriele de Vecchi, *Strutturazione virtuale A*, 1964. By kind permission of the VAF Foundation.

relations from the surface within a room into the "environment," at the same time drawing the viewer, too, into the work of art. In 1964 Gabriele de Vecchi spoke of "*Strutturazione virtuale*" (fig. 3.10), and in 1963 Giovanni Anceschi created a kinetic object with the title *Strutturazione, cilindrica virtuale* (fig. 3.11). In awareness of this tradition, Jean Tinguely in 1955 likewise made an electro-motorized sculpture entitled *Volume virtuel no. 1*, as well as an entire series of "virtual volumes" (1955–59), which were motor-driven sculptures with moving parts, wires, and wheels that, when moving at relatively high speed, produced the retinal impression of transparent three-dimensional bodies—virtual volumes, in other words.

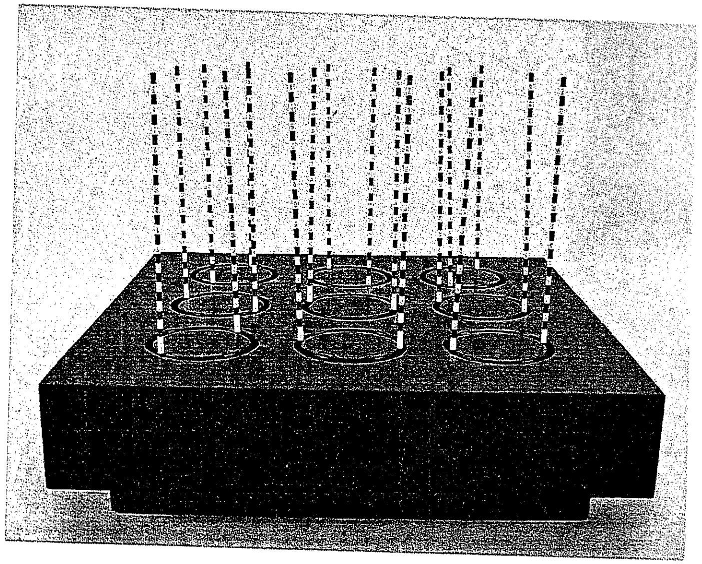

Figure 3.11 Giovanni Anceschi, *Strutturazione, cilindrica virtuale*, 1963, VAF Stiftung. By kind permission of the VAF Foundation.

Using analog means, Soto delivered a notion of a virtual environment that changes along with the viewer. Polysensual environments with optical and kinetic effects were likewise constructed by Getulio Alviani (*Cubo-Environment*, 1964–69), Gianni Colombo (*Spazio elastico*, 1967) (fig. 3.12), Mario Balocco (*Effetti di assimilazione cromatica con figure virtuali*, 1968–72) (fig. 3.13), Yaacov Agam (*Kinetisches Environment*, 1970), Domingo Alvarez (*Raumgrammatik Environment*, 1971), and Stanislav Filko (*Universum Environment*, 1966–67; *Kosmos Environment*, 1968). Under the title "Cinétisme, Spectacle, Environment," a show featuring de Vecchi, Colombo, Mavellet, Mari, Le Parc, and other artists was mounted in Grenoble in 1968.

Spectator participation soon extended from the adjustable painting (Yaacov Agam, *Transformables*, 1956, whose various pictorial elements could be slid around) to sculptures (by artists from Colombo to Tinguely), and from the sculpture into the space, the "environment" (Colombo, *Spazio elastico*, 1967). GRAV (Groupe de Recherche d'Art Visuel), founded in 1961 and made up

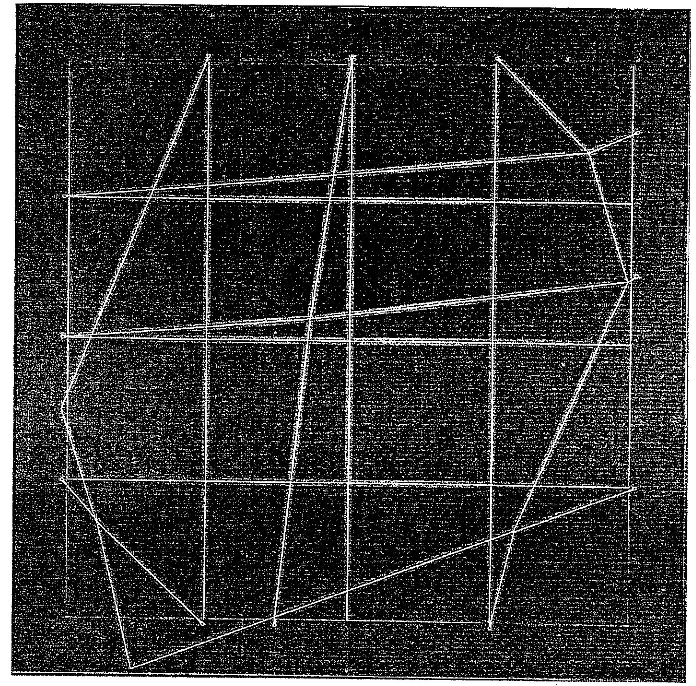

Figure 3.12 Gianni Colombo, *Spazio elastico*, 1967. By kind permission of the VAF Foundation.

by the artists Horacio-Garcia Rossi, Julio Le Parc, François Morellet, Francisco Sobrino, Joel Stein, and Jean-Pierre Yvara, in 1963 presented its first collective work: a labyrinth still on display at the Museum Cohue de Vannes. Twenty-two meters long, 3.65 meters wide, and made up of twenty single parts, the labyrinth is a homogenous space in which it is only too easy to lose one's bearings. Visitors can walk freely about the structure—in line with the museum's exhibition motto, which reads "Défence de ne pas participer, Défence de ne pas toucher."

As well as the movement implied by its name, therefore, kineticism produced elements which played an important role in the further development

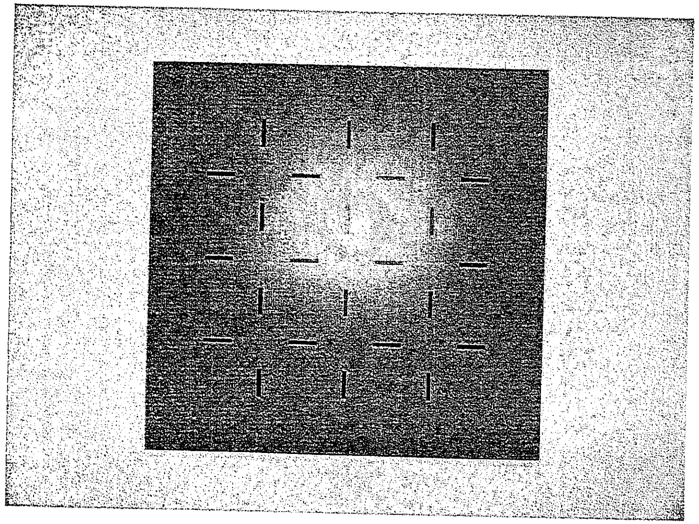

Figure 3.13 Mario Balocco, *Effetti di assimilazione cromatica con figure virtuali*, 1968–1972. By kind permission of the VAF Foundation.

of art: virtuality, the environment, the active spectator and/or user. Everything that would later characterize computer art and the interactive virtual environment was there already, albeit in purely analog or mechanical form.

Arte Programmata

The future of digital art can be found in approaches explored by kinetic practitioners. Bruno Munari in 1952 published *Macchinismo*, a manifesto aimed at reconciling art with the machine: "The machine must become a work of art! We will discover the art of the machines." This idea was carried forward in the 1962 exhibition "Arte Programmata: Arte cinetica, opera muliplicata, opera aperta," which was curated by Bruno Munari and Giorgio Soavi. Umberto Eco contributed a text from which the movement took its name. Arte progammata is a form of kinetic art in which on the one hand the movement is predictable because it more or less follows the rules of mathematical programs, but on the other hand, it at the same time permits random processes. That is

to say, the course of movement fluctuates between random and programmed, between precise predisposition and spontaneity, and therefore occurs within a system we would today term dynamically chaotic. Programmability—at least as a concept—had now taken its place alongside the notions of virtuality, the environment, the internal observer and/or interactivity (the user sets in motion the mobile work of art, the kinetic sculptures, co-constructs the "kinetic construction").

Working with colored light elements and movable machines in the period 1966–1968, Lev Nusberg and other members of the "Moscow kineticists" already produced so-called cyber-creatures. Viewers of this "cyber theater" were invited to participate in the programmed actions. Jeffrey Shaw, a leading pioneer of virtual environments and interactive art, similarly progressed from kinetic to cyber art. The virtual space, or environment, of his *Virtual Museum* (1991) likewise contains virtual sculptures caught up in virtual movements, apparent bodies in apparent movement in an apparent space—the transition from kinetic to cyber art is complete.

The optical changes induced by movement of the viewer in op art, the mobile elements of kinetic paintings and sculptures, the incorporation of viewers expected to manually interfere, to press buttons or keys: All this amounts to early—precomputer—forms of mechanical and manual interactivity. The works of art were exposed to random influences, or were rendered manually or mechanically controllable and programmable—algorithmic, in other words—by their viewers. Images were produced by programs before the computer came along, just as interactive and virtual relationships existed between works of kinetic and op art and their viewers. It is there—and not with the availability of the computer as technical interface—that the history of interactive and virtual art begins.

Notes

1. 1856–1922; Russian mathematician who helped to develop the theory of stochastic processes, especially those called Markov chains. Based on the study of the probability of mutually dependent events, his work has been developed and widely applied in the biological and social sciences. A. A. Markov, "Extension of the limit theorems of probability theory to a sum of variables connected in a chain," reprinted in Appendix B of R. Howard, *Dynamic Probabilistic Systems*, volume 1: *Markov Chains* (New York: John Wiley and Sons, 1971).

2. 1903–1987; A. Kolmogoroff, "Zur Theorie der Markoffschen Ketten," *Mathematische Annalen* 112: 155 (1936).

3. 1947–; Gregory Chaitin, *Algorithmic Information Theory* (Cambridge: Cambridge University Press, 1987).

4. 1912–1954; Alan Turing, "On Computable Numbers with an Application to the Entscheidungsproblem" (1936) in *Proceedings of the London Mathematical Society*, series 2, volume 42 (1936–37) pp. 230–265.

5. 1863–1922; Axel Thue, "Über unendliche Zeichenreihen," *Kra. Vidensk. Selsk. Skrifter*. 1 *Mat.Nat.Kl* 1906, Nr. 7, Kra 1906; "Über die gegenseitige Lage gleicher Teile gewisser Zeichenreihen," *Kra. Vidensk. Selsk. Skrifter*. 1 *Mat.Nat.Kl* 1912, Nr. 1, Kra 1912; "Probleme über Veränderungen von Zeichenreihen nach gegebenen Regeln," *Kra. Vidensk. Selsk. Skrifter*. 1 *Mat.Nat.Kl* 1914, Nr. 10, Kra 1914.

6. Joseph Schillinger, *The Schillinger System of Musical Composition*, volume I: books I–VII, volume II: books VIII–XII (New York: C. Fischer, 1946). First published as a correspondence course under the title *The Schillinger Course of Musical Composition* (ed. Lyle Dowling and Arnold Shaw, New York: C. Fischer 1941).

7. See Pierre Barbaud, *Musique Algorithmique (A Collection of Compositions Spanning Twelve Years of His Work)*. Compositions include "Mu-Joken" (for six instruments, 1968), "Saturnia Tellus" (tape, 1980), "Apfelsextett" (for string sextet, 1977), and "Hortulus coelicus" (instrumental ensemble, 1975). Beginning in 1958, Barbaud championed a rigorously determined algorithmic composition process, made possible with the assistance of computers. His goal was to create human-made music with machines, reflecting only the human thought process, without emotion. Performances were by Ensemble GERM (Pierre Marietan, conductor), Élèves de l'École d'Archet Tibor Varga (Pierre Marietan, conductor), and Ensemble Instrumental de Musique Contemporaine de Paris (Konstantin Simonovitch, conductor). "Saturnia Tellus" was realized at l'INRIA; constructed by Pierre Marietan.

In 1979 Pierre Barbaud and his collaborator Frank Brown employed their computing program *Ludus Margaritis Vitreis* to produce music in the style of Bruckner. The task of the program is to work out musical sequences with harmonic part writing, using a simulated orchestra of ten instruments. One of the primary compositional tasks is carried out by a stochastic matrix responsible for linking together the chords. To define this matrix in specific cases, a work of the particular composer must first be analyzed—in this case Anton Bruckner's String Quartet in C Minor. The music so recomposed is then converted into audible form by a conversion program called

AUDITV, with every tone being assembled from units of 1/20,000-second duration, producing a remarkably precise adjustment to the required tonal effects. After being recorded on magnetic tape, the piece can then be performed. The *Ludus Margariti Vitreis* program was evaluated at the Research Institute for Information and Automation Science (IRIA) in Rocquencourt; the magnetic recording with the assistance of AUDITV took place in the Research Institute for Acoustic-Musical Coordination (IRCAM).

8. In 1965.

9. Responding to Hilbert's question about "decidability" in mathematics, until then unanswered, Turing came up with the idea now called a Turing machine. It was his exact formalization of what had informally been described by expressions such as "effective method."

Turing argued that his formalism was sufficiently general to encompass anything that a human being could do when carrying out a definite method. The Turing machine concept involves specifying a very restricted set of logical operations, but Turing showed how other more complex mathematical procedures could be built out of these atomic components. He had the further idea of the universal Turing machine, capable of simulating the operation of any Turing machine.

A universal Turing machine is a Turing machine with the property of being able to read the description of any other Turing machine, and to carry out what that other Turing machine would have done. It is not at all obvious that such a machine, a machine capable of performing any definite method, could exist. While one might intuitively think that tasks of ever-increasing complexity would need machines of ever-increasing complexity, this is not the case: It is sufficient to have a specific, limited, degree of complexity, and then greater amounts of storage capacity for more laborious tasks.

10. Originally published 1962 in the catalogue, ed. by Bruno Munari, accompanying the exhibition "Arte programmata" at the exhibition space of the Olivetti company. Reprinted in Volker W. Feierabend and Marco Meneguzzo, eds., *Luce, movimento & programmazione-, Kinetische Kunst aus Italien 1958/1968* (Cinisello Balsamo: Silvana 2001, 242–248).

11. Leonardo Mosso, *Architectura programmata* ed. Studio di Informazione Estetica and Vanni Scheiwiller (Turin: 1969).