KINETIC ART: THEORY AND PRACTICE

SELECTIONS FROM THE JOURNAL *LEONARDO*

EDITED BY

FRANK J. MALINA

Can-Can by Jan Zach. See Article 24, "Imagery, Light and Motion in My Sculptures".

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INTRODUCTION

For many centuries different societies have incorporated real motion in artifacts designed to give aesthetic satisfaction. It was only in this century, however, that the term 'kinetic art' was coined and that kinetic art objects became recognized as visual fine art. Since the early 1950s, the number of artists who devote their talents to this kind of art has greatly increased. At the same time, under the impact of new visual experiences, of modern conceptions of aspects of nature and of man, and of novel techniques provided by science and technology, the scope of kinetic art itself has expanded. It includes:

1. Pictorial and sculptural objects incorporating motion and changes of colors with time, brought about by:
   (a) optical, mechanical, magnetic, electro-mechanical and electronic systems,
   (b) chemical reactions and the flow of liquids.
2. Objects in which changes with time are random, programmed or responsive to the intensity or the frequency of a sound input and even to the characteristics of alpha brain waves.
3. Visual experiences provided by slide projection, cinema and television techniques.

Although kinetic art is now taken seriously by the art world in many advanced technological societies, it will probably take several more decades before large numbers of art lovers turn to it for emotional satisfaction. At present, only a few museums have permanent displays of kinetic art works and a staff capable of conserving them. Furthermore, the fact that 'kinetics' has been applied in advertising, discotheques and pop concerts leads many people to conclude that kinetic art is suitable only for decorative purposes. They forget that there has long been an interplay between the fine and applied arts. The reproduction of a master's oil painting in an advertisement does not detract from the value of the original painting, any more than a kinetic beer advertisement demeans a kinetic art object using the same technique.

This collection of original articles taken from the journal *Leonardo* is intended to be of help to those interested in kinetic art, be they studio artists, teachers or lovers of art. The texts on the works of artists are unique because the artists themselves are writing about their own creations. This should be of interest to aestheticians, art historians and art critics. There are some educational institutions that offer courses on kinetic art. I believe that this book will serve as a useful source of information for such courses.

The articles are descriptive and analytical rather than literary and many of them require intense concentration on the part of the reader. The visual experience of kinetic art cannot be conveyed by still photographs but the reader should be able to grasp the significance of the artists' works by reading the artists' descriptions of their own aesthetic reactions and objectives. Artists have divulged their 'secrets' in order that other artists can participate in the advancement of kinetic art; some have obtained patent protection for novel ideas that may have commercial significance outside the realm of the fine arts. Details of special techniques and references are provided to permit the techniques to be used by anyone for his own purposes. Addresses of artists at the time of the printing of this edition are given in order that additional information can be obtained directly from them. Any other enquiries should be addressed to *Leonardo*.

Several articles containing information on subjects relevant to kinetic art are included in the last part of the book, as well as a glossary of terms used by artists, most of which have not as yet found their way into art dietionaries. The articles by Nino Calos, Masako Sato, Henri Gabriel and Joël Stein, which originally appeared in French, have been translated for this edition.

I wish to express my appreciation to Pergamon Press Ltd. (in partieular to its founder, Robert A. Maxwell) for undertaking on my behalf the publication of sueh an unusual international art journal of the contemporary artist as *Leonardo*. I have received the most friendly cooperation from Dover Publieations Inc., from its President, Hayward Cirker, and from its Managing Editor, Clarence C. Strowbridge. Although much of the work of preparing the texts for publication was carried out under my direction by the editorial staff of *Leonardo*, this book depended greatly on the efforts of my wife and colleague, Marjorie Malina.

FRANK J. MALINA
Founder-Editor of Leonardo

Boulogne sur Seine, France
November 1973

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PART I

PICTORIAL KINETIC ART WITH OPTICAL, MECHANICAL, ELECTRO-MECHANICAL AND CHEMICAL SYSTEMS

ELECTRICITY AND MOTION IN MY KINETIC ART WORKS

Nino Calos*

If one asks why use electricity and motion in visual fine art, I say because they permit the fiction contained in a work to be brought closer to perfection. Each age needs a new art to assimilate the new discoveries of matter and the new ideas of man and of the universe. An art that is based solely on the art of the past would decline into mystification.

In 1949-1950, while in Milan, I made small boxes of various shapes and covered them with glittering silver, gold or multi-colored powder or flakes. When flashing lights were projected on them, one obtained an illusion of motion on their surfaces. A dealer to whom I showed these works said that I was either crazy or that I had mistaken his gallery for the International Fair of Milan. Since then the attitude of the art world to such works has changed greatly.

Although at that time I was already convinced that kinetic art had a future, I was not satisfied with my first effort. I continued to play with electric light, as I had done since childhood, not knowing that there already were pioneers of kinetic art with light [1-11].

I made several journeys to France after 1948 but saw nothing to encourage me to work with electricity. In 1956 I settled permanently in Paris and met F. J. Malina. When I saw the few works he had made with electric light, my longing to pursue my researches in this area grew. I had been particularly struck by two of his works. The first was a geometrical construction with superposed layers of wire mesh, behind which shone lights of different color. When one moved, the moiré effect produced by the wire mesh gave an illusion of motion within the construction. The second work, called 'Jazz', consisted of a picture of 11 round and oval shapes in vivid reds, greens and yellows, which were illuminated intermittently and randomly to produce a rhythmic and attractive visual experience. There were also other works in which light patterns of different colors appeared on a translucent Plexiglas screen. These kinetic paintings used what Malina called his Lumidyne system, which he described in the first issue of *Leonardo* [12].

The Lumidyne system produces effects of light in motion on a screen of a different kind than those obtained by T. Wilfred with his reflecting system, but at the time neither Malina nor I were aware of Wilfred's work. I saw my first Wilfred Lumia in 1966.

The technique one uses to make a work is one thing; the result is something else. It is now almost 12 years that I have worked with the same technique, which is quite surprising when one sees the hurried construction of kinetic works in galleries. There is at present, it seems to me, a sort of self-styled kinetic frenzy. Every day we are offered a new parade of objects, occasionally even pleasant to look at, but obviously of little artistic significance or rather similar to works created by certain artists more than ten years ago.

Motion for motion's sake and electric light in kinetic art are worth nothing if they do not contribute to the aesthetic value of the work. Art, even when it is kinetic, is an emotional experience created by the mind of man—even man is begun by an emotional experience!

Many of the young are attracted by the apparent easiness of constructing kinetic objects. As soon as they have made a few, although they elearly resemble the works of other artists, they exhibit them and expect them to be appreciated. They believe that the important thing is to work quickly. But toward what end?

During recent years, I have replaced the transparent Plexiglas plate behind the translucent screen, called by Malina the *stator* of the Lumidyne system, by a structure made of strips of wood and aluminum, which differently affects the light transmitted from incandescent bulbs or from fluorescent tubes. I no longer use warm colors but instead light, cool ones that bring about a greater contrast with the grey or black shadows cast by the structured stator. An example of such a work is shown in Figure 1, which was shown recently at the exhibition 'Light and Movement' at the Musée d'Art Moderne in Paris. In this polyptych of six sections there are vertical lines

* Italian artist living at 55 rue Pixiérécourt, 75-Paris 20, France. (Received 11 April 1968.) (Original version in French.)

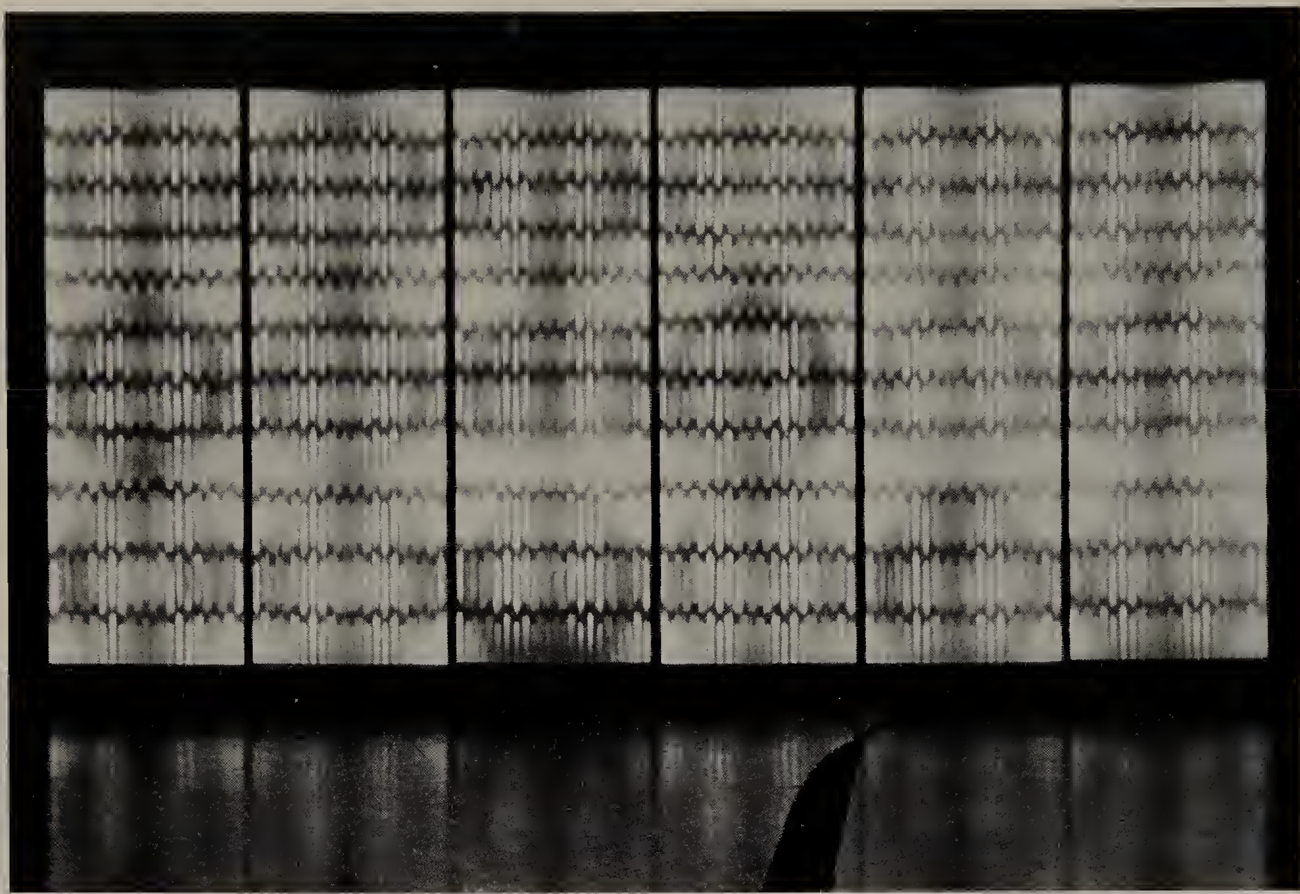

Fig. 1. *'Lumino-kinetic Panel Mural'*, *luminous mobile, Lumidyne system,* 220 × 420 × 18 cm, 1966-1967. (Photo: André Morain, Paris.)

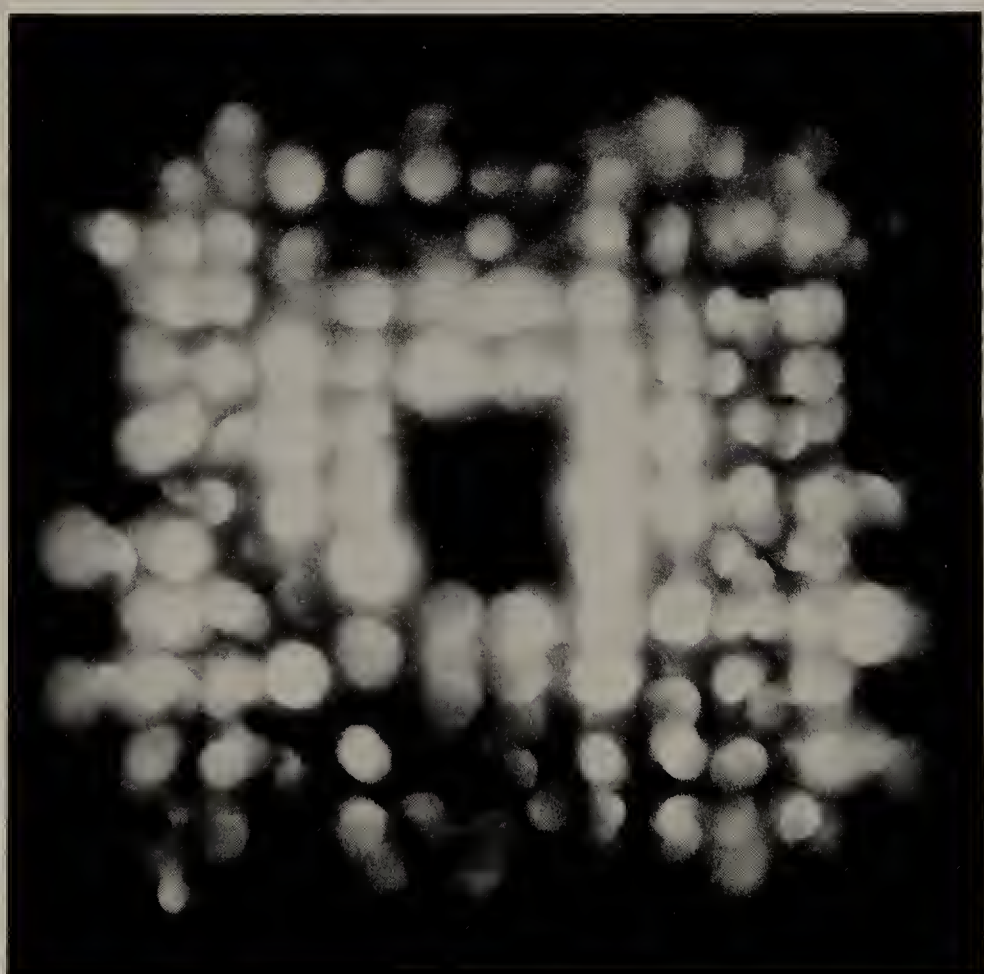

Fig. 2. *'Luminous mobile', 130/1966', luminous mobile, Lumidyne system,* 60 × 60 × 11 cm, 1966. (Collection of the Musée d'Art Moderne de la Ville de Paris.) (Photo: Alfio di Bella, Rome.)

cut by groups of horizontal ones with a slow movement of pastel color changes to soften the geometric pattern. The panel provides a wall of light with 18 halos or circular astral shapes. It could be used to provide an ambiance of light in a large room or for a high altar of a cathedral.

To obtain a larger range of motion on the translucent Plexiglas screen, I have warped the screen to vary the distance between it and the stator structure (Fig. 2). The motion in all my works is quite slow, for I wish the viewer to 'penetrate' into it and not to cause shock to the eyes (rapid motion can, of course, also be used when one feels viewer circumstances are appropriate).

My chief preoccupation has been to introduce kinetic painting into sacred art. It was for this reason, among others, that I made the rose window mobile shown in Figure 3 as a possible church window. I know that the liturgy of the Roman Catholic church forbids the use of kinetic art at present but there is a precedent—crèches with automata displayed in the eighteenth century in churches in southern Italy. I am convinced that one day the church will accept kinetic art, for in 1966, when I had an exhibition in Rome, a Catholic official who supervises art in a large diocese in the Federal Republic of Germany shared my view. I believe that churches in the twentieth century cannot limit art to the figurative kind on the grounds that only this kind can lead souls to a meeting with God. Non-figurative or abstract art can have a more efficacious force of suggestion than a representation refining iconographic images of many centuries ago.

It is interesting to note in this connection that the Jesuit Father Louis Bertrand Castel (1688–1757) in France proposed the construction of a color-organ type of kinetic art that was to have been illuminated with lights of that time, candles or oil lamps.

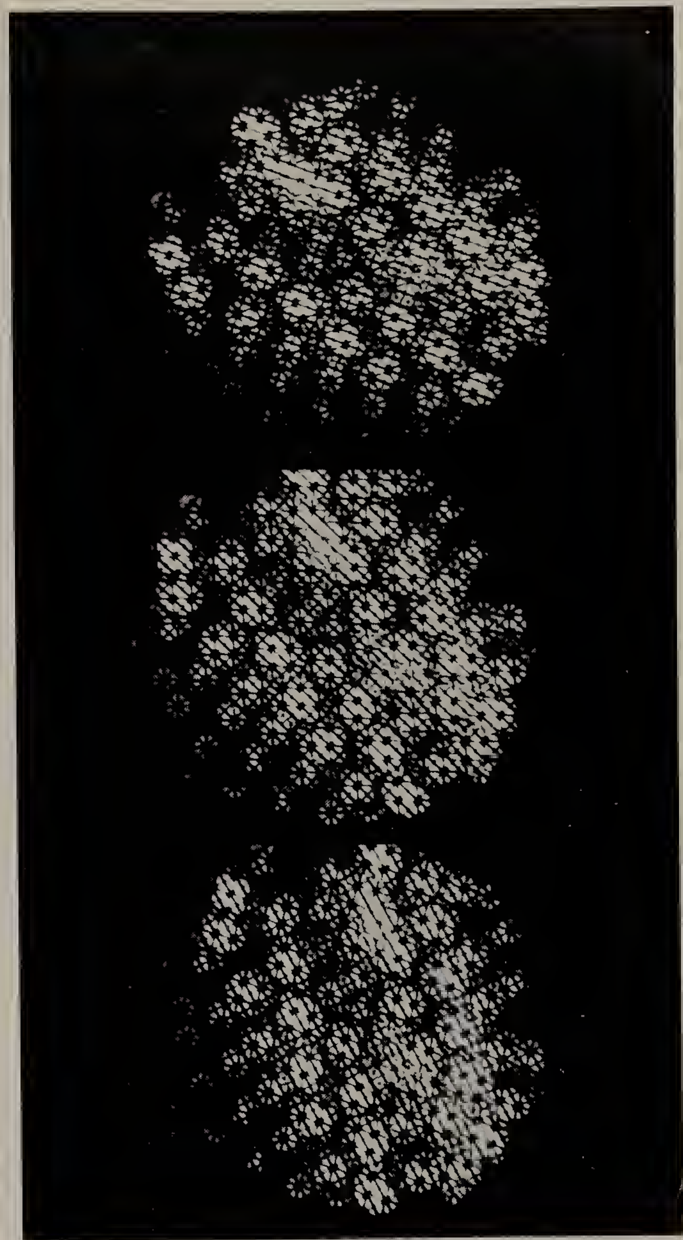

Fig. 3. 'Rose windows', luminous mobile, Lumidyne system, 210 × 70 × 12 cm, 1964. (Photo: Nino Calos, Paris.)

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*Article included in the present edition.

KINETIC ART:
THE KINOPTIC SYSTEM

Valerios Caloutsis*

When I came to Paris in 1953 as a painter in traditional media [1], I became acquainted with the works of several artists in the field of kinetic art. Those of Malina, Boto and Schöffer particularly interested me [2–4]. The first phase of my own work in this domain was devoted to making metal constructions in motion, however, the use of electric light for producing images projected from reflecting parts onto surfaces entranced me [5].

After trying various ways of using light, in 1965 I finally arrived at what I call my *Kinoptic* system (from the Greek, *kinisis*—motion and *optiki*—visual). This system permits projection of a kinetic light image from as little as 20 cm from a pictorial surface. It consists of four elements: (1) a light source (a clear incandescent bulb), (2) a fixed polished sheet-aluminum reflector, (3) a rotating polished sheet-aluminum reflector and (4) a synchronous-type electric motor to rotate element (3) (cf. Fig. 1.) These parts are contained in a box approximately 16 cm high, 24 cm wide and 10 cm deep.

The light bulb (24 W, 6V) is housed within a metal container provided with a circular opening through

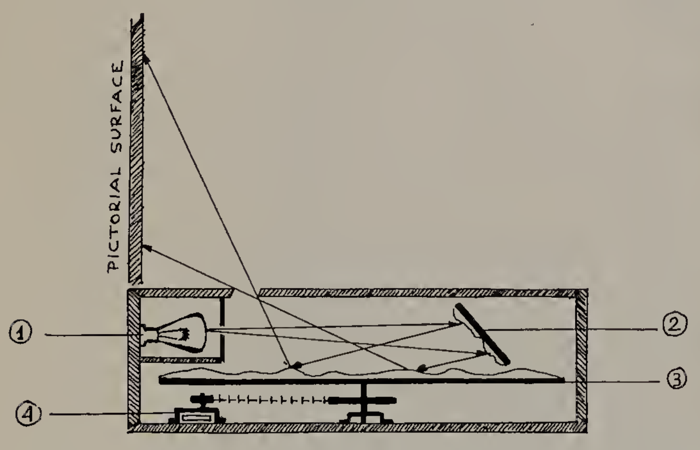

Fig. 1. Diagram of the Kinoptic system: (1) *Light source,* (2) *fixed sheet-aluminum reflector,* (3) *rotating sheet-aluminum reflector and* (4) *electric motor.*

Fig. 2 (*a and b*). *Two pictures produced by* '*Kinoptic* 7', *wall projection,* 100 × 120 cm, 1969.

* Greek artist living at 4 rue Antoine Dubois, 75-Paris 6, France. (Received 13 May 1970.)

Fig. 3. '*Kinoptic* 53', *enclosed unit with projection onto a translucid screen*, 50 × 70 cm, 1969.

which the light beam impinges upon the fixed reflector. The fixed reflector directs the light beam onto the rotating reflector, which projects it through a slit in the box onto the pictorial surface.

The forms of moving light images projected onto a surface are determined by the shapes given to the fixed and rotating reflectors. The speed of the continuously changing forms is controlled by the rotating reflector and the distance from the reflector to the pictorial surface. I find that when the reflector moves at one turn per minute the speed of changing forms is satisfactory. One can obtain a cycle of greater duration by using two or more reflectors rotating at different speeds in front of a larger fixed reflector.

It is possible for a spectator to vary the range of images produced by the *Kinoptic* system in the following way. Two or more fixed, shaped reflectors are installed that can be placed in position to intercept the light beam by turning an external knob.

Colored images can be made either by painting sections of the reflecting surfaces with transparent paints or by placing colored transparent materials between the rotating reflector and the exit slit in the box.

In my first *Kinoptic* works, a one-meter square pictorial surface was attached to the projection box to make a single unit. The surface was a sheet of aluminum painted opaque white. The images can, however, be projected directly on a wall, whose larger surface permits more of the image produced by the projector to be seen (cf. Figs. 2a and 2b). Two or more *Kinoptic* boxes placed appropriately in a room create an environment of continuously changing light forms and colors. If the projector is hung on a wall with a translucid screen in front of it, one obtains a kinetic picture that appears to be suspended in space (cf. Fig. 3).

A darkened room is necessary when the *Kinoptic* box is used for projection onto an opaque surface. When projection is made from behind a translucid screen, the kinetic picture can be viewed in a room with ordinary illumination.

I believe there are numerous applications of my *Kinoptic* system. I am particularly interested in producing large scale environments of kinetic light images and in the possibilities of using this form of art in architecture.

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KINETIC ART: ANIMATION OF COLOR FOR CINEMA FILM

Ana Sacerdote de Guthmann*

I. INTRODUCTION

The work I shall discuss is a two-minute animated 16 mm film, consisting of 2880 frames, entitled 'Ensaio de côr animada' ('A Trial with Animated Color'), which I showed at the international short-film festival held in conjunction with the 8th Biennial of Sao Paulo, Brazil in 1965 [1].

Since the beginning of this century, painters have shown much interest in the components from which a painting is made: lines, shapes, illusions of space, color effects, color relationships, etc. Artists frequently employ non-figurative geometrical compositions in order to study the visual effects produced by varying one or two components systematically. In a way, the painter might be said to assume the role of the psychologist of visual perception. Paintings of these kinds have been found to give aesthetic satisfaction to certain viewers.

Many of the works of Albers [2, 3] are primarily studies of the interaction between different colors within essentially concentric squares. Lohse [4] and Vasarely [5] are concerned with color relationships within more complex arrays of geometrical shapes. The utility of a digital computer for assigning shapes and colors within an array has been recognized for some time [6].

The use of animation for kinetic art of a non-figurative kind began about fifty years ago. Hans Richter made scroll-pictures in 1919 of two to five meters in length that were unrolled while viewing [7, 8]. He began making abstract black and white motion picture films in 1921, the first being 'Rhythmus 21', some frames of which are shown in Figure 99 of Reference 7.

Henri Valensi in the 1930s pioneered in non-figurative animated film in France and the sequence on a fugue by Bach in the Walt Disney film 'Fantasia' is known to a wide public. Many artists have continued to produce kinetic art of various kinds by means of animated film and I wish to describe the results of my work for the benefit of those interested in this form of contemporary art.

II. THE STARTING POINT IN MY COMPOSITIONS

Analogies between music and painting have long intrigued artists [7, 8, 9, 10] and my love of music has also led me to conceive paintings in musical terms. For example, I use as my starting point six or eight shades of color that I find visually harmonious. These I call a *basic chromatic unit* or a *basic chromatic syllable.* I have prepared many different chromatic units with the shades chosen in a free and sometimes arbitrary manner.

My procedure has been to select a chromatic unit for coloring a composition of geometric shapes (Fig. 1). New compositions were generated successively by varying the shapes and their positions and their color shades. I thus arrived at a sequence of compositions suitable for making an animated film, in which each arrangement of a composition would normally appear successively on two frames of the film. Thus, a static series of compositions could be made into a form of kinetic art.

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* Artist living at Vidt 2004 p. 14, Buenos Aires, Argentina.
(Received 23 September 1971.) (Original in French.)

Fig. 1. 'Monochrome', gouache on paper, 32·5 × 27 cm, 1965.

III. MY ANIMATED FILM 'A TRIAL WITH ANIMATED COLOR'

This film consists of three parts entitled 'Monochrome', 'Suggestion of Complementarity' and 'Rhythm'. Each part involves different compositional characteristics, as described below.

A. Monochrome

This was my first attempt to produce a series of compositions for a film. I restricted the colors (gouache) to one palette of red mixed with white and with black to give different shades, i.e. different tone values and saturation. Neutral greys (mixtures of black and white) acquired a blue cast in juxtaposition with warm greys, reds and maroons [2, 3]. Four strips, each with a different basic composition of square and rectangular shapes, are shown in Fig. 1. The changes in shapes, in their arrangement and in their shading from one composition to another can be seen.

B. *'Suggestion of complementarity'*

In this sequence (Fig. 2), I broke away from the restricted palette I used in 'Monochrome' by introducing the color yellow and I made the basic composition more complicated to take better advantage of animation possibilities.

The series contains a number of compositions with shades of green and small piercing red rectangular or square areas that gradually fade away, followed by a number of compositions of a red shade with small piercing green rectangular or square areas that also fade away. I am not entirely satisfied with the series because the small red and green areas fade away too quickly.

The more one subdivides the area of a composition, the richer one can make the experience of watching transitions from one shade to another. On the other hand, the labor of preparing compositions with many subdivisions obviously becomes very tedious. Since in this part of the film I did make a composition with more subdivisions, I find it an improvement over the first part. The transformation of the composition in the second part is less uniform than in the first part and the fact that one portion of the composition changes while another portion remains static adds interest to the visual experience in the film sequence. During the red portion of the sequence, one observes a suggestion of circular motion.

C. *'Rhythm'*

The two series of compositions discussed in *A* and *B* above served as points of departure for the black and white series that I call 'Rhythm' (Fig. 3). The two central strips shown are series of two different basic compositions. The shape and position of some of the areas change progressively from the basic composition to the twelfth composition. The shades of grey were constant for each series. In the two previous sequences of the film, I employed 6, 12, 18, 24, 36, 48 and (less often) 72 frames to give different time periods. But these periods are too short, even when of 72 frames, for changes to be noted by a viewer.

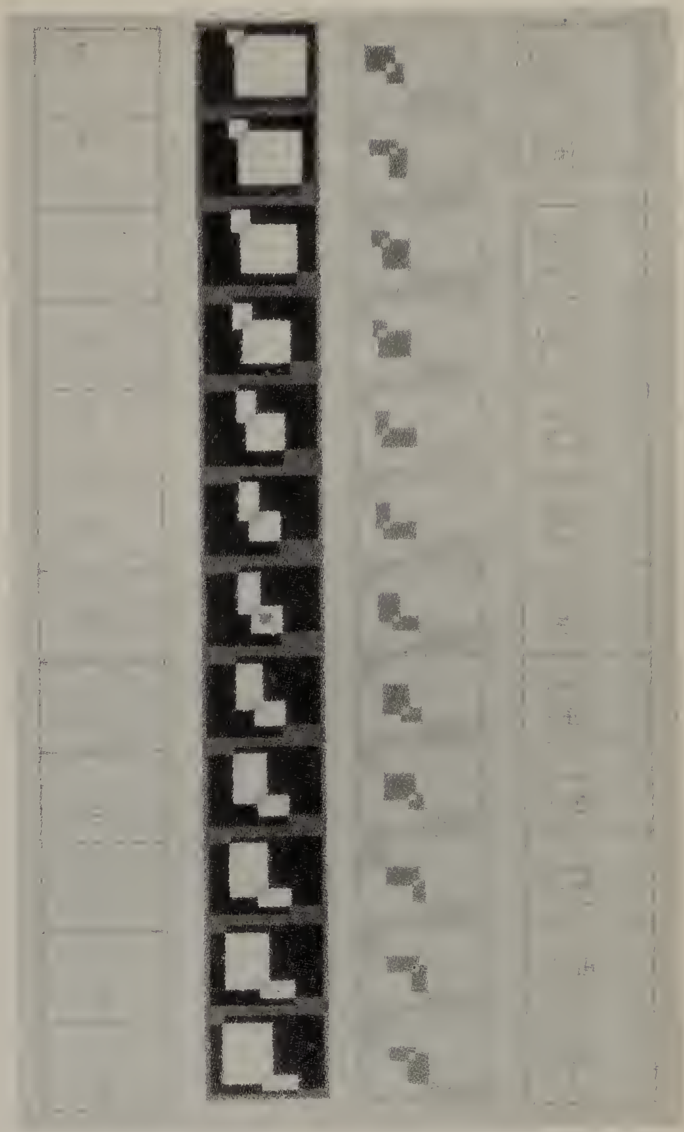

Fig. 3. *'Rhythm', gouache on paper*, 32·5 × 27 cm, 1965.

The characteristic aspect of 'Rhythm' (Fig. 3) is that there is independent motion of areas within the film sequence. The composition series in the left central strip will give in the sequence a downward motion of a small square of constant size; this is shown diagrammatically in the strip at the far left. It will also be noted that the two white areas change in shape to give motion horizontally from right to left in the sequence. A study of the right center strip and of the far right strip will show that a small white square will undergo a counterclockwise circular motion in the film sequences independently of the two dark grey areas. A shape in motion, changing both in size and shade, can produce striking effects that, however, to be observed require careful control as regards their duration of presentation.

IV. CONCLUSIONS

The results obtained with this film have led me to draw the following conclusions:

1. One would obtain a visual experience of greater interest if there were not uniform transitions of shape or of color from the beginning to the end of a series of compositions. Sequences in the film should

be adequately long but of different length and with clean breaks between them.

2. I have worked only with composition series that give straight-line and circular motions of essentially constant speed in a film. More complex kinds of motion with varying speeds should be tried.

3. The ranges and shades of colors in my compositions were limited. Transitions between harmonious and discordant colors, between monochrome and polychrome combinations and between areas of changing size in the compositions can be exploited.

4. The lengths of film sequences, the kind of composition, the amount of repetition and the rates of change of shapes and of color need to be studied to determine how they affect viewers.

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Fig. 2. 'Suggestion of Complimentarity', gouache on paper, 32 × 31 cm, 1965. *A part of the animated film 'Ensaio de côr animado'.*

HORIZONTALLY ORIENTED ROTATING KINETIC PAINTING

Robert Henry

Abstract—*An aesthetic of kinetic art is established upon the principle that all art is essentially contemplative. Art which is subject to change must also be apprehended as a total structure. The author believes that if the total structure cannot be perceived at a single moment, then it is necessary that past moments be remembered with some degree of completeness. Those elements in a work which are remembered, form a sub-structure upon which the less stable, textural elements rest. By and large, a painting is accessible as a total structure at any single moment of time. The multiple structural possibilities implicit in a non-kinetic work of art are a result of the viewer's ability to impose his own time sequence upon the work. The dynamics of the viewer's time sequence, set against the more stable structure of the picture, are the basis of contemplation.*

The illusionistic depth in a painting is heightened when stereoptic techniques and dynamic changes of focal points are employed. The focus mechanism of the eye differs in an important way from that of the camera.

If a picture is viewed obliquely, the spatial possibilities of the composition are multiplied. In a rotating, ceiling-hung painting, a number of devices which expand the possibilities of relationship are introduced into painting. As a painting rotates, forms seem to shrink and expand, and forms assume different spatial positions. The far side of the painting may appear to be near side, and the direction of rotation may seem to change. Since points on a rotating plane increase in actual speed as they approach the circumference of the circle, while at the same time, centers of the viewer's interest tend to become centers of implied rotation as well, various kinetic and spatial interpretations of a single work are possible. Because of these changes in the perception of the painting, while the painting itself does not change, the criteria for contemplation described above are met.

I. INTRODUCTION—SOME AESTHETIC CONSIDERATIONS

Kinetic art, once the concern of a few fine artists, has proliferated, so that it is being created by ever increasing numbers of fine artists, while at the same time kinetics have become one of the major attractions at discotheques and pop-music concerts.

The variety of kinetic forms, functions and materials is vast. As a consequence, it is quite difficult to establish a coherent aesthetic theory of kinetic art. Yet, a description of my work would be incomplete without a description of the aesthetic considerations involved.

The word 'aesthetic' has a range of meanings that is much broader than that limited sense in which I employ it. The 'aesthetic experience', broadly defined, can variously refer to any intuitive experience, any experience having emotional content, or any experience that generates a feeling of beauty. That feeling can be generated by a natural phenomenon, a mathematical or scientific formula, an individual, a society or no object at all.

My concern here is specifically with that experience generated by a work of art. To be sure, all of the above experiences may have attributes similar to those of a work of art and some of them may also be elements of the art experience but none of them are peculiar to the work of art alone.

It is my contention that the fine art form is most clearly definable in structural terms, current theories of art as object or pure experience notwithstanding. A work of art is structured by the artist in a conscious, subconscious, logical, illogical, accidental or random manner, or with any combination of these means and the relationships thus produced are the structure from which the spectator derives an understanding of the content of the work. Content is the product of a complex psychological confrontation of the spectator with the work.

When relationships are the principle means of structuring the content of a work, it is imperative

* Artist living at 803 Greenwich Street, New York, N.Y. 10014, U.S.A. (Received 22 November 1968.)

that those relationships can be apprehended. Now, this prescription is extraneous when we are dealing with classical painting, sculpture or literature. In these forms, the entire work is constantly available to an individual wishing to peruse the work. The simultaneous and continual existence of the work assures the possibility of the apprehension of all relationships within it.

Easel painting is the one form which can be perceived in its entire spatial extension at one time. But painting is not, therefore, 'static'. There is a time factor implicit in the perusal of a painting but this time is *psychological*, not *chronometric*. Although the physical painting does not change, our perception of it is transformed as we become familiar with it in detail. More importantly, since the possibilities of the pictorial composition of images, shapes, colors and textures are so vast, and so resistant to analysis and simple formularization; one is capable of experiencing a vast number of possible relationships. Since the viewer can see the total physical extent of the work at any time, all of the relationships created by the artist are available to him. The order in which these relationships are apprehended and arranged constitutes that phenomenon that I have called *psychological* time. The psychological ordering of experience varies from person to person.

The process by which these relationships are perceived and ordered is what I call the *contemplative* aspect of the perception of a work of art. The activity of aesthetic contemplation is the means by which the spectator comes to understand the structure of the work. I believe that aesthetic contemplation is a special activity particularly relevant to the perception of a work of art. The technique of aesthetic contemplation is useful in other fields as well and its application to science and religion is very interesting, and accounts, I believe, for the wide diversity of meanings of the word 'aesthetic'.

In the physical sciences, physical cause and effect relationships do account for the existence of phenomena and these phenomena can be understood by means of inductive analysis. In the arts, there is no meaning outside of that meaning which can only be perceived by aesthetic contemplation. The information so obtained can later be subjected to logical manipulation, as in the sciences, but its very existence lies within the contemplative sphere. It is produced by the same type of act of aesthetic contemplation. This is not thought to be true of natural phenomena, except by certain mystics.

Free-standing sculpture, architecture and literature, change within chronological time. Architecture and sculpture must be viewed from many positions in order to be fully apprehended. Although chronological time is a necessary function of the perception of these media, psychological time is also an important aspect of the work. In literature, the most chronologically oriented of the three, the reader can restructure the time sequence of the work by departing from the established sequence of the text.

It is my thesis that the apprehension of relationships is necessary in order to understand a work of art. The existence of a chronological sequence in a work of art in the sculptural, architectural, literary, terpsichorean, cinematographic or kinetic-sculptural media compels the artist to consider the problems of temporal continuity. Each artist employs the devices appropriate to his medium in order to create a structure which can be apprehended as a sensible whole. Dance, cinema and kinetic sculpture involve changes with respect to space, as well as time. They are kinetic in character. Time and motion are elements of content. In dance, theatre and cinema the problems of establishing continuity, or in other words, establishing relationships between one part of a work and another, are particularly significant, for as the performance progresses, each successive moment displaces the content of previous moments. The necessities of the chronological order of the performance prohibit the spectator from reviewing previous moments at his whim, as is the case in reading or in viewing immobile sculpture. One does not experience these performances moment by moment, however. Memory performs an active role in one's perception of a performance of this nature. Imagery, gesture, plot, rhythm and melody subserve the function of establishing relatively stable points and sequences that form a substructure of experiences available to memory and psychological ordering. One then experiences each current moment, experiencing the less stable elements such as color, texture and complex form in relationship to this substructure.

Generally, plot is the most stable literary element and image is the most stable pictorial element. Indeed, imagery, as such, can be of such a compelling nature that it often substitutes for relationship as the principal memorable element in a work of art.

There are no special restrictions in the medium of kinetic sculpture as a result of continuity considerations. The relationship of the parts of a piece undergoes transformation but the parts themselves are generally constant. They do not disappear and reappear as cinematic or light projections do. Moreover, the laws of physical mechanics supply a means of establishing continuity.

Non-figurative kinetic painting is, in the light of these considerations, a difficult medium. Without the supportive structure of representational imagery, the establishment of a continuity of relationships becomes all the more important.

What are the stable elements that form the substructural function which, I believe, is necessary to the act of aesthetic contemplation? Non-figurative kinetic painting is quite similar to musical composition on the scale that I have proposed. On one end of the scale is easel painting, the most constant of the material arts and at the other end is music, the least material and most temporal of the arts. One can compare some types of kinetic painting to musical composition but the comparison is misleading in some very important respects.

It is possible for some people to remember the complete linear or melodic development of a given piece of music. It is at least theoretically possible to also remember the polyphonal structure of a musical composition, although this is usually more difficult. Polyphonal memory is limited and tone color memory, including timbre and overtone structure would seem to be impossible. The question of memory is relevant to musical composition because music exists only within an extended temporal framework. Memory is limited by what is actually perceived. Those musical stimuli which affect sensual receptors but do not reach the level of cerebral awareness, either consciously or unconsciously, are, of course, not available to memory.

Basic perceptual constructions as well as personal idiosyncracies preclude the complete perception and consequently the memorization of any work of art. We are drawn, therefore, to listen to even familiar musical compositions many times.

In spite of these limitations, we are yet able to hold the general structure, be it melodic, polyphonal or coloristically oriented, in our minds. The retention of these basic structural patterns makes it possible to contemplate a musical composition, even without the physical presence of the music. We can, furthermore, do this on a relatively high level of awareness. The existence of a refined set of musical relationships, as well as a memory of musical flow, form a substructure upon which we can structure the less stable musical elements as we perceive them, anew, during actual performance.

It is impossible to remember color except in its most general aspects. This is, I believe, a severe limitation imposed upon certain types of kinetic painting. The diffuse quality of color memory, as well as a lack of a specific color scale, put these types of kinetic painting at a distinct disadvantage when compared to the musical medium, In so far as a kinetic painting is illusionistic, the mechanism of the motion tends to be hidden. When this happens, the laws of physical mechanics no longer subserve the function of creating continuity. The problem is exacerbated if images appear and disappear or leave the frame of the picture as in cinema.

Art films which do not rely on plot will usually substitute musical accompaniment as a device to structure the rhythmic flow of abstract images. But even here they are unsuccessful all too often. Imagery and simple or symmetrical form can perform the sub-structural function in kinetic works. The Lumia system of Wilfred is an example, in my opinion, of a basically imaginal rather than structural system. Cinematographic animation relies upon plot in addition to imagery.

Non-figurative kinetic art, on the other hand, as exemplified by discotheque light shows, is generally adventitious in structure and is certainly not contemplatively oriented. I do not mean to say that contemplation must be passive. By contemplation, I mean that a work of art must be liable to examination and internal structural elaboration. The availability of new materials and techniques, as well as the appeal of kinetic possibilities have catalyzed the growth of kinetic art [1]. Art has in times past been associated with technology and that association is important. However, the non-technological factors which contribute to the evolution of art are of primary significance. The demands of society and, more importantly, the strictures imposed upon individual awareness by society and the history of art itself are crucial to the development of art, as well as all other areas of human development. As our view of the world changes, and moral, religious and ideological strictures are removed, new ideas appear. There are many examples in the history of science which illustrate this point. Art too, like science or politics, proceeds within the limitations of the possible.

At EAT (Experiment in Art and Technology) in New York, one gets the disconcerting feeling that the technicians, having found technology unrewarding in meaningful terms are appealing to the artists to supply some of the missing meaning to their activities—a not unusual or unexpected development—and the artists—and this is disturbing—are looking to technicians to supply some meaning to theirs.

One must be aware of the simple fact that the addition of new dimensions to a work of art does not always increase the aesthetic value of the work.

Although I am doing kinetic paintings, I have stressed the difficulties of establishing an aesthetic basis for them. The appeal of the kinetic medium is strong and in the following sections I describe the particular aspects of kinetic painting with which I am working. In this section I have established the limits of kinetic painting, as I see them. I have proposed a scale of kinetic content in various media. Yet, the lure of the possibility of motion, as such, and of expanded spatial illusions and, perhaps, even of the paradoxical implications implied by the attempt to make this non-kinetic medium move are exciting. I have always wanted my paintings to 'come alive', not in order to duplicate reality, for I do not wish to destroy the barrier that separates art from reality but as an attempt to make the experience of a work of art as immediate and full as is possible within the limitations of the medium.

My kinetic paintings were designed to move. The kinetic considerations have altered both the forms used and their composition. There are broad changes of feeling as the paintings rotate. They do not, however, in themselves actually change. All that changes is their orientation and direction, and this limitation retains what I believe is the potent factor of easel painting, namely, the possibility of aesthetic contemplation as I have described it. The paradoxical relationship of motion and stability, of flat picture plane and illusionistic space heightened by the rotation of the work has developed, for me a new aesthetic.

II. DEVELOPMENT OF KINETIC PAINTINGS

I had been working for a number of years on a series of paintings in which I was using various devices to represent space in a lively and yet 'realistic' way. (By a 'lively' space, I mean a space that is the resultant of the 'activity' of the objects or events of which it is composed. Opposed to this conception is a more static spatial construction, wherein space is conceived as a *condition* of perception. Evidence of this kind of construction is supplied by the Sinopia for Uccello's 'The Nativity', from the Church of San Martino alla Scala, in Florence, recently exhibited in the Great Age of Fresco exhibition. This classical method was for the artist to first lay out the perspective grid, in order to create a unified space and later to place the objects within that space.)

In my paintings I was dealing with changes of focus and the separation of images, which are a consequence of binocular vision, in order to produce stereoptic effects within a single frame and thereby make a deeper and more convincing picture space. The idea of changes of focus is familiar in the form of aerial perspective, although classical aerial perspective includes changes of focus only in background areas, and these are in reality the result of atmospheric rather than perceptual phenomena.

The depth of field of the human eye is quite limited. It is much narrower than the depth of field of a camera lens, even if that lens is greatly stopped-down. Also, the mechanism of focus in the human eye is quite different from that of a camera lens, although it approaches that of a split-image viewfinder. This is due to the structure of the human visual apparatus, which is as yet little understood. When a camera is out of focus, the image breaks down at the edges. The edges are not resolved and the picture seems to blur. When the eye is out of focus, a different kind of lack of resolution occurs. The image does not break down but, instead, separates into many images. This has not been apparent, for it is one thing to look with focused eyes at an unresolved photograph, while it is more difficult to examine a lack of resolution in the eyes themselves. The effect can be shown rather easily by the following means.

If one draws a single straight line on a piece of paper, and stares at the paper with only one eye (so as not to confuse focal effects with stereoptic effects) so that the eye does not focus on the line, the image of the line will appear to blur (Fig. 1(a)). This can be done with a little practice by letting the eye relax so that one is staring blankly into space. If one then holds a straight edge between one's eye and the line, so that the edge is parallel to the line but does not overlap it, while continuing to stare into space, one will see that the straight edge also appears to be out of focus and its image is duplicated (Fig. 1(b)). Now, if one moves the straight edge in a plane parallel to the piece of paper on which one has drawn the line, one will see that as the edge approaches the line, the line is seen as a number of lines and there is a point at which the last image of the straight edge overlaps all but the last image of the line and the line appears to be in focus again. (Coincidentally, this kind of phenomenon is responsible for the appearance of color in black and white Op art paintings).

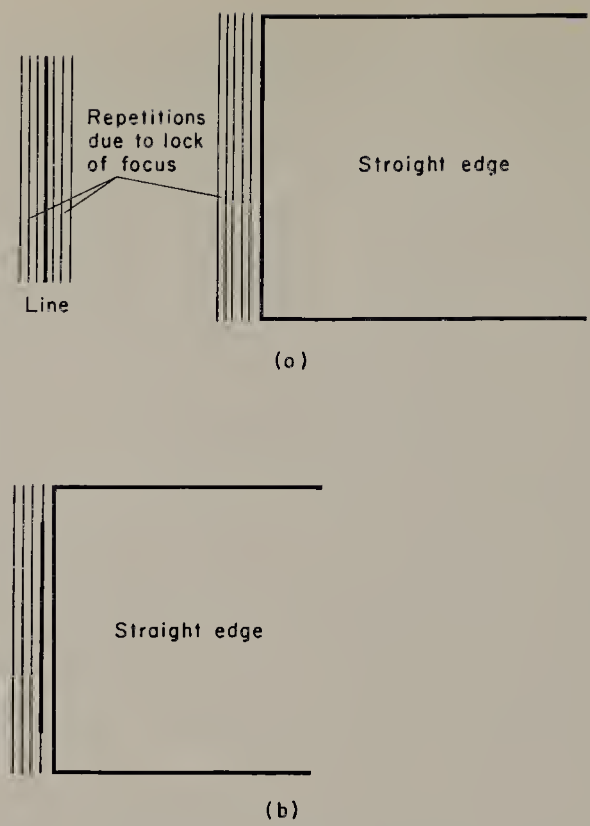

Fig. 1. *Multiplication of images when the eye is out of focus.*

With the eye out of focus, images seem to blur. This blur is really the dispersion and multiplication of many images. With the eye out of focus, a straight edge is moved toward the line. There is a point at which the straight edge overlaps all but the last image of the line and the line appears to be in focus again.

The phenomenon of linear multiplication has been used by the many artists who drew multiple outlines in their drawings in order to achieve greater plasticity in their work.

Artists long ago discovered this fact by intuition rather than by analysis. These multiple lines have often been interpreted in the past as 'spirited drawing' or the like. It is my contention that such emotional analogies are out of place in the analysis of artistic structure. All illusionistic techniques have a basis in perceptual mechanisms. Artists as diverse as Raphael, Veronese and Cézanne have used the multiple-focus line. In Cézanne, this technique is developed to the point where it is a major stylistic factor in his late work. Focal resolution breaks down in front of the point of focus, as well as behind, and this is the major difference between focally oriented painting and aerial perspective. In reality, the point of focus can be at any spatial depth and it is constantly changing as one looks through and into a scene.

The understanding of visual reality is based upon a complex dynamic process. Binocular vision is another important factor, as is well known. We are not only seeing two different pictures simultaneously but these pictures are generally at different levels. Since we usually do not hold our heads in an absolutely vertical position, the image recorded by the lower eye tends to appear lower when the images are separated. These effects account for the multiplication of outlines and the duplication of background figures as in the late Cézanne bathers (Fig. 2). Such other effects as the shifting of continuous lines to different heights is another such effect.

It has not been adequately recognized that the same phenomena were basic to *Abstract Expressionism.* Here again the ideas of changing focus and binocular vision were used intuitively. The abstract expressionists were predominately concerned with spatial expression. On a perceptual level, the use of the wide stiff brush, the palette knife slash and other devices in the action painters repertoire imitate focal effects, in addition to their expressive function. Also, it is surprising to see how many times a foreground line is doubled in action painting to produce the effect of a double image.

It is impossible to create a truly stereoptic picture on a single painted surface. A stereopticon is necessary in order to do this. On the other hand, a stereopticon does not create a genuinely realistic space. The space between forms is real enough but the objects themselves appear to be paper thin. The depth of field of the camera lens is too great and objects are in focus even though they may be at very different spatial levels.

The major technical problem in my paintings at this time was to use two images, without it looking as if there were two things there, and to vary the focus without limiting the composition by having one thing in focus and every other form progressively blurring, as it increased in distance from the focal point of the picture. Rather, it was necessary to put forms in and out of focus, simultaneously. The spatial and compositional dynamics of the painting rest, in part, on this duality (Fig. 3).

While working on this series of paintings, I realized that the sense of space was enlarged when I looked at the pictures from an angle. If the spatial illusion in a picture is strong enough to overcome and, in some cases to reverse an actual spatial differentiation, the overall illusion is strengthened. This is especially true, if the part of the picture actually furthest from the viewer has elements which illusionistically are in the extreme foreground. The background in this area then recedes into a relatively deeper position (Figs. 3 and 4).

We have become accustomed to looking at paintings from a frontal position. After experimenting with various ways of structuring the environment in order to encourage the viewer to look at the painting from an angular position and after having tried various shaped and spaced canvasses, I decided upon a presentation which would force the viewer to view the painting at an angle. I made a circular painting which was suspended from the ceiling and hung just a little above eye level. This produced the desired result. Simultaneously, I became aware of other important effects.

Paintings which are hung on a ceiling are common enough in art history. One immediately thinks of the Sistine Chapel ceiling or of Tiepolo's many ceiling paintings. These are representational paintings and the perspective illusions, as well as the imagery, are appropriate to scenes viewed from below. I am not aware of any non-decorative abstract paintings which are meant to be exhibited on a ceiling. Since an abstract painting does not have a sure indication of orientation with respect to the horizon and, indeed, since one of the basic tenets of abstract

Fig. 2. 'Bathers' by Paul Cézanne. (Private collection, Paris.)

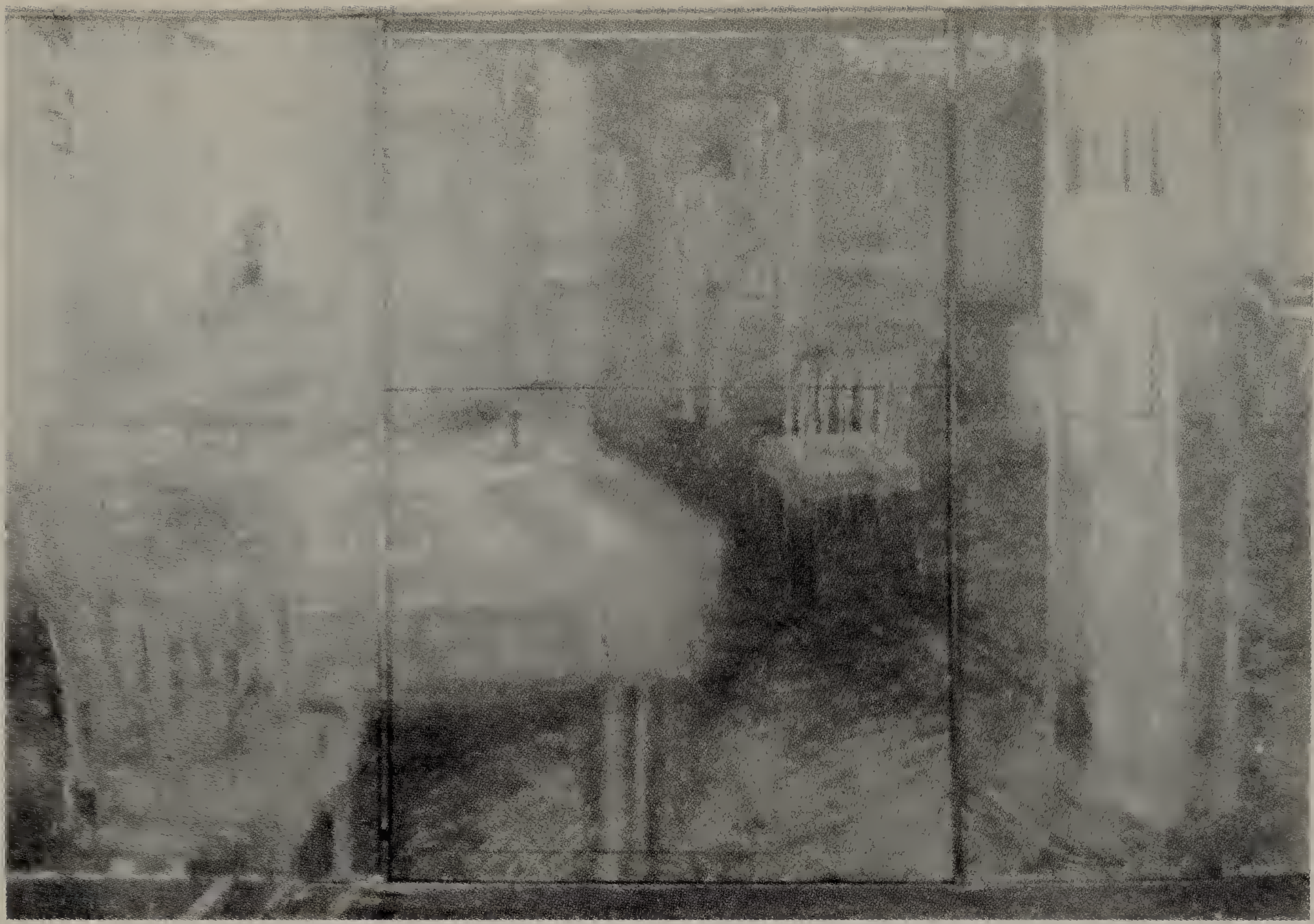

Fig. 3. '*Nude in Interior*', *oil on canvas*, 95 × 140 in., 1964. (Photo: Alan Mark.)

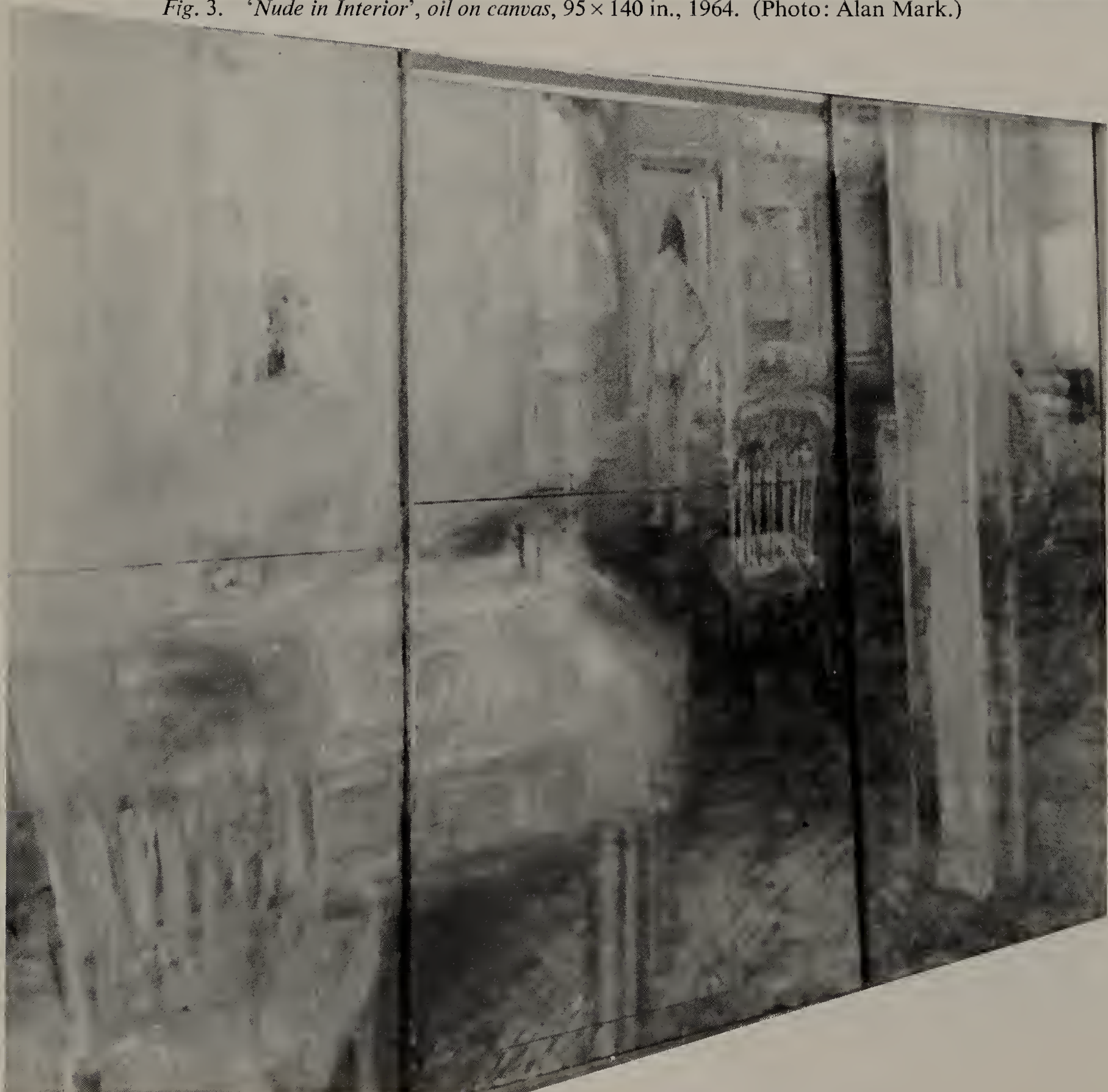

Fig. 4. *Angular view of the painting in Fig.* 3 *showing changes of spatial illusions.*

painting is the concern with multiple or ambiguous points of view, the effect of an abstraction hung from the ceiling has a potential which is not present in representational work. When you walk around a ceiling-hung abstraction, you continually reinterpret the space of the painting depending upon your relationship to it.

With this in mind, I began to rotate the painting, rather than relying on the movement of the viewer. This I did by winding the painting on the strings by which it was suspended. At this point a number of startling things occurred.

III. DESCRIPTION OF THE RELATIONSHIPS OF ROTATING PAINTINGS

In a painting which rotates in a plane which is not perpendicular to the viewer's line of vision, the forms within the painting are subjected to changing distortions due to the foreshortening of the axis parallel to the line of vision. As the painting rotates, forms seem to shrink as they approach a foreshortened axis and expand as they approach a position which is perpendicular to the line of vision (Fig. 5). The painting seems to breath and this is the first level at which the rotational illusion operates.

The second phenomenon which occurs is a shifting of spatial illusions in the work based upon the above changes. Not only do the forms expand and contract, they assume different spatial positions due to the changing perspective distortions (Figs. 6, 7 and 8). The angle between two lines seems to change, along with the length of the lines. These are both part of the actual perspective distortions involved in the situation. Equal spaces and, consequently, equal angles appear to be larger when they are on the near side of the painting (Fig. 5).

Notice that in Fig. 5(a) line AC, which is not parallel to AB and DE, appears in Fig. 5(b) to be a vertical, perpendicular to AB and DE—or that DE and AC appear to be parallel and horizontal, while AB appears to be in another plane.

In Fig. 5(c) line AC appears to descend as it approaches C and AB seems to ascend as it approaches B, while in Fig. 5(b) the reverse is true. Line AC has crossed line AB.

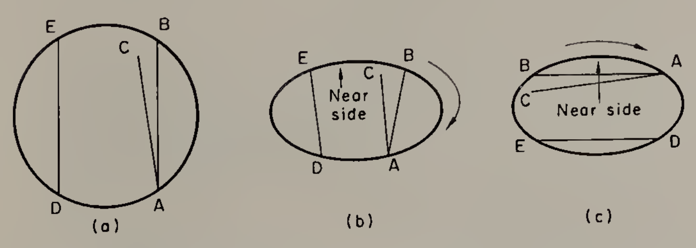

Fig. 5. Relational changes of position in obliquely viewed rotational paintings.

(a) True view of painting. AB is parallel to DE but not to AC.
(b) Perspective view of painting. AB is parallel to DE but not to AC. AC appears to be parallel to DE.
(c) Rotated perspective view of painting. AB is parallel to DE.

There are still further consequences of the revolution of the surface, even though we are still considering only a succession of discreet positions.

In Fig. 9(b) the top of the picture, which is actually the closer side, appears to be just that, while in Fig. 9(c) the bottom of the picture, which is actually the far side, appears to be the near side. When the near and far sides of the picture seem to reverse position, one can feel that one is looking down at a picture, although one knows that one is actually looking up. Also, the simple factor of looking up changes one's perception of the distance between oneself and the painting as a whole [2]. These paintings tend strongly to draw one into them.

The above are phenomena associated principally with rotation considered as a succession of discreet points of view. Other relationships appear as the painting is considered in terms of continuous motion.

1. *Relative movement of lines*

As the painting revolves, every point along a line changes its position at every moment. At one orientation all relationships along a line reverse, as in a mirror image. At other orientations one point at a time changes direction (Fig. 10).

In Fig. 10(a) points A and B are moving to the right, while C moves to the left. A is to the left of B, which is to the left of C. There is a position where B starts moving left relative to A, while A is still moving to the right.

In Fig. 10(b) points A, B and C have reversed their relative positions.

In Fig. 10(c) the entire line is moving to the left. Note that the oblique viewing angle tends to translate circular movement into rectilinear motion.

2. *Relative direction of overall movement*

There is a close relationship between the appearance of the painting as horizontal seen from below or above and the appearance of clockwise or counter-clockwise rotation. Each reversal of orientation is accompanied by a reversal of apparent direction of rotation and vice-versa.

3. *Relative speeds of movement*

The center of the rotating painting does not actually move. Any point on the circumference moves at a greater speed than any internal point. Also, there is a change of apparent speed. When a point moves into a spatially foreshortened sector, namely the sides of the painting, it appears to decelerate. Angular change is most apparent when a line passes through the axis parallel to the line of vision. A point on the interior may appear to exceed the speed of a point on the circumference for this reason.

Curvilinear forms act differently than rectilinear forms. A curve which is convex in the direction of rotation acts differently than one which is concave in that direction. The apparent expansion and contraction of rotating spirals is an illustration. Concentric circles do not appear to change position

Fig. 7. Same as Fig. 6 except showing different oblique view of painting.

at all. Eccentric circles seem to shift position as a unit.

It should be recognized that changes in relative speed as well as changes in relative position also affect the spatial character of the composition. Non-linear relationships are more complex than linear relationships, since point to point associations are ambiguous. The viewer establishes different relationships within the composition as he associates these ambiguous relationships in various ways on the basis of position, color, scale, texture, shape etc. There is always a dynamic linear relationship as well. Although each line is constantly changing its speed, direction and orientation, it is always also static, in that it never changes when considered as an integral part of the larger composition. A line which encloses a specific shape will retain its constant overall shape even though all points along that line are constantly shifting.

The specific relationships described above would change in character if the painting were rotated in an elliptical rather than in a circular manner. I plan to do this and I have designed a mechanism for elliptical rotations (which have very interesting consequences), but I have not yet been able to execute the design for lack of financial resources. Various shaped canvasses also present challenging possibilities.

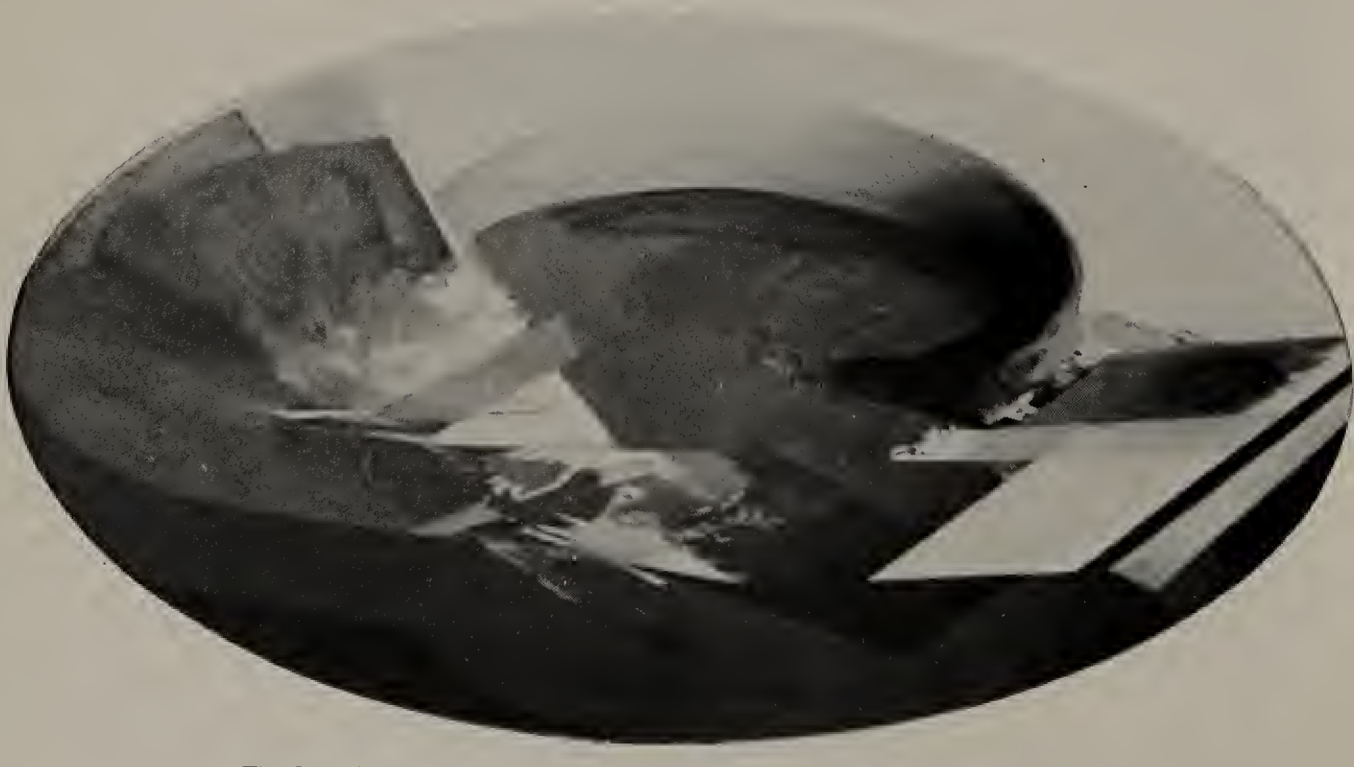

Fig. 8. Same as Fig. 6 except showing different oblique view of painting.

Fig. 6. '*Kinetic Painting No*. 9', *oil on canvas, dia*. 80 in., 1968. (Photo: Alan Mark.)

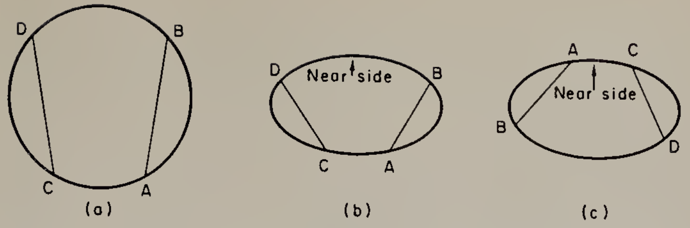

Fig. 9. *Reversal of apparent orientation in obliquely viewed rotational paintings.*

(*a*) *True view of painting.*

(*b*) *Perspective view of painting. Near side appears to be in proper orientation, if AB and CD are seen as horizontals.*

(*c*) *Rotated perspective view of painting. Near side appears to be in reverse orientation, if AB and CD are seen as parallel horizontals.*

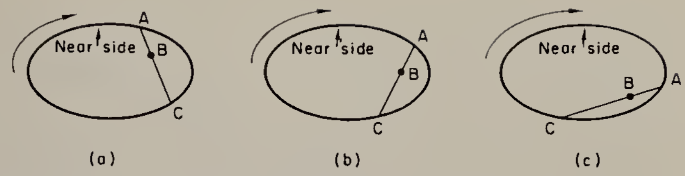

Fig. 10. *Rotational changes of direction in obliquely viewed rotational paintings.*

(*a*) *A and B appear to move to the right. C appears to move to the left.*

(*b*) *B reverses direction before A.*

(*c*) *A, B and C are all moving to the left.*

IV. RELATIONAL CHANGES EFFECTED BY THE ACTIVITY OF THE VIEWER

I have thus far described some of the changes in linear relationships that occur when a rotating painting is apprehended by a passive viewer. The changes that are based upon reversals of orientation (the picture seen alternately from above or below) and upon selection of one of the multiple possibilities of an ambiguous spatial relationship are exceptions, in that they rely upon a perceptual decision which the viewer is called upon to make. Another major perceptual decision on the part of the viewer is the decision as to the location of the actual center of the painting. In most cases the viewer cannot locate this actual center. The artist can compose his picture so that the center is pin-pointed, if he so desires. If the center cannot be located, there is no point that stands still and all movements become relative to the point of focus.

This phenomenon is similar to that of the apparent changes in direction of objects as seen from a moving vehicle (Fig. 10). As the viewer in a vehicle focuses on a particular point in space, all other points behind that focal point move in one direction, while points in the front of the focal point seem to move in the opposite direction. Because of the true spatial character of the realistic situation, those points in front of the focus will seem to move at a relatively greater speed than points at equal distances to the rear of the focus. Within the limitations of speed,the viewer may pick his focal point, at will, at any distance from himself. If the vehicle in which the viewer is riding travels along a curvilinear path,it becomes easier to focus on a foreground point, provided that the curve of the path of the vehicle is convex with respect to that point, even if the vehicle is moving at relatively high speeds. If the path of the vehicle is concave with respect to the field of vision, it becomes correspondingly more difficult to focus on any point. It is easier to focus on a point on the interior side of a circular path than it is to focus on an exterior point. The salient factor here is that the apparent motion of objects is dependent upon the will of the viewer (Fig. 11).

The implied movement of a painting changes as the viewer shifts his attention from one point to another. It is one of the compositional problems of the artist to establish focal points and to relate these points and the different implied movements and spatial constructions which appear as the viewer shifts his attention from one focal point to another. Although the painting itself never actually changes, except for its orientation, and certain color changes which result from the changes in reflective surfaces as the painted textures assume different relationships to the light source and the viewer, the composition is constantly perceived in different ways by a perceptive viewer. In this way, the painting as an objective entity performs the sub-structural function which the unstable ambiguous elements elaborate and vary.

Although many variations on the basic mechanism of the work which would add further variables have occurred to me, I have not as yet utilized them. The objectively constant nature of the painting for each successive rotation provides the means for the possibility of contemplative activity on the part of the viewer. The work can be seen in its totality at any moment and the viewer can re-establish any past interpretation of the phenomena described during any past series of rotations. In this way, the picture functions in the same manner as a classical painting.

I have in my work with these rotational paintings thus far attempted to explore a wide variety of compositional, textural and formal devices, in order to attempt to define the limits of possible meaningful variations that occur within the limits of changes in painting style and composition. For a kinetic mode to be viable as an aesthetic tool, its statement cannot be limited to one effect that is the result solely of mechanical structures.

I have been able in some of the paintings to achieve the intense spatial illusions that I had been trying for in my earlier paintings. In these spatial kinetic paintings the illusion of depth can be so convincing that once it is perceived it becomes almost impossible to re-establish perception of the flat picture plane. The more textured the painting surface is, the more likely it is that this effect will occur. It is also aided by the use of rather bright lighting. The success of the spatial illusions suggest that motion is a major factor in depth perception.

One of the illusions associated with kinetic perception is the 'waterfall' effect [3]. After looking at a rotating painting for a while, one sees an after-image consisting of an apparent rotation in the opposite direction. As R. L. Gregory states, this motion is paradoxical, in that rotation occurs while at the same time the individual units do not actually change their positions. Gregory attributes the 'waterfall' illusion to the image/retina portion of the optical system but cannot decide whether the effect is in the retina or the brain portion of the complex. My experience has been that the painting will appear to rotate while actually still, even if I had not looked at it for a period of as long as twenty-four hours. This occurred after I had spent an entire day looking at the painting before leaving it. This leads me to conclude that the 'waterfall' effect is basically, if not totally, a cerebral illusion.

The 'waterfall' effect, which results from the perception of an obliquely seen rotating painting, has other interesting aspects. When looking at a still painting while under the influence of the 'waterfall' effect induced by an oblique rotational movement, one finds that the still painting seems to move. Where the still painting has a spatial definition and the space is indicated by transparent effects rather than by hard edges, the space of that still painting is clarified by the appearance of the after-effect. The relative direction of apparent movement corresponds to the illusion of apparent depth. In other words, if areas in the foreground seem to move in a clockwise direction, areas in the background move in a counter-clockwise direction, *even if they are adjacent or overlapping areas.*

In the paintings suspended from strings, which reverse direction as the string winds and unwinds, the 'waterfall' effect produces the illusion that the painting reverses direction before this movement actually occurs. Strings are advantageous since they produce a smooth deceleration as they approach the point at which they start to unwind and they smoothly accelerate as they unwind in the reverse direction. These changes are obtained with an inexpensive and quiet method. There is a strange sliding effect that occurs at the moment of reversal and some parts of the painting seem to start reversing before others.

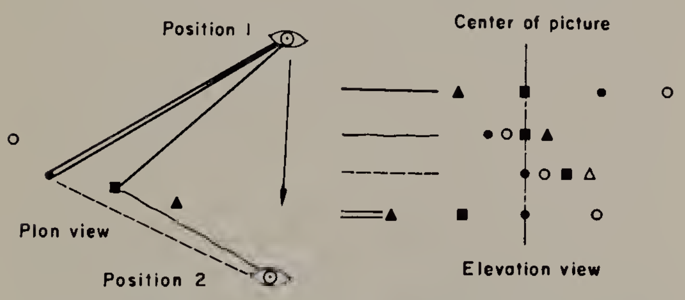

Fig. 11. *Apparent shift of object positions due to movement of viewer.*

Position of objects with eye focused on ■ position 1.
Position of objects with eye focused on ■ position 2.
Position of objects with eye focused on ● position 2.
Position of objects with eye focused on ● position 1.

With the eye focused on ■, the ○, which is the object furthest in the background, apparently moves a greater distance to the left than it does when the eye is focused on the ●.

The ■, which apparently does not move when it is the point of focus, appears to shift to the right when the point of focus is the ●. In this case, the ■ is a foreground form.

The speed of rotation is an important factor in the work. I have been rotating the paintings at relatively low speeds—from 0·5 to 8 rev/min. Speeds which are appreciably faster than this tend to blur the forms and create pinwheel-like effects, and speeds which are slower retain the effects of positional changes but not of kinetic changes.

In my most recent paintings, I have been working with transparent materials rather than on canvas with oil paint (cf. Fig. 13). I am working on sheet acrylic discs ¼ in. thick and with various transparent materials. Size is an important factor in the work. The larger the work is, the greater are the perspective distortions. The limit is reached when the painting cannot be viewed in its entirety at one glance. The size of the work must be proportional to the ceiling height and the size of the room.

I have been using a variety of transparent materials on the sheet acrylic base. These include: acetate inks, which adhere to the acrylic quite nicely, and are helpful in producing linear forms using pens; concentrated water colors, with a surface tension breaker; various gauze-like materials, which I adhere to the sheet acrylic with an acrylic medium, give a surface which accepts acrylic paints, producing effects similar to those of paintings on silk; acrylic paints; various thin overlay sheets, such as Art-Type, Burgess and Zip-a-Tone sheets; as well as Roscolene, a colored cellulose acetate sheet which is quite thick and can be cut easily, and is available at reasonable prices in a variety of colors from stage lighting suppliers.

The use of these materials permits me to easily control the lighting which is, in the transparent paintings, part of a unit which also contains the painting and the motor controls. The range of colors and textures so produced are quite exciting and the transparent effects are stylistically appropriate to the kinetic format. For smaller paintings, a central shaft can be used and, if the painting is lit indirectly, there is no shadow from the shaft. I have enclosed the painting in an opaque white plastic cylinder, with a disc of the same material placed a few inches behind the painting. On this disc, I have mounted a series of 10-watt bulbs. The front of the bulbs is painted with white ink, so that the light is reflected back onto the plastic disc and the light is dispersed so that the individual bulbs cannot be seen through the painting.

V. CONCLUSION

I believe that a rotating painting is an aesthetically potent mode of artistic expression. It is a development within the tradition of Western painting as developed since the Renaissance. A general theory of kinetic aesthetics is needed and I have tried to formulate some very basic aesthetic principles pertinent to kinetic painting. The rotating painting form is an appropriate vehicle for artistic expression that permits personal styles to appear, without restricting the expression to one artist's own style.

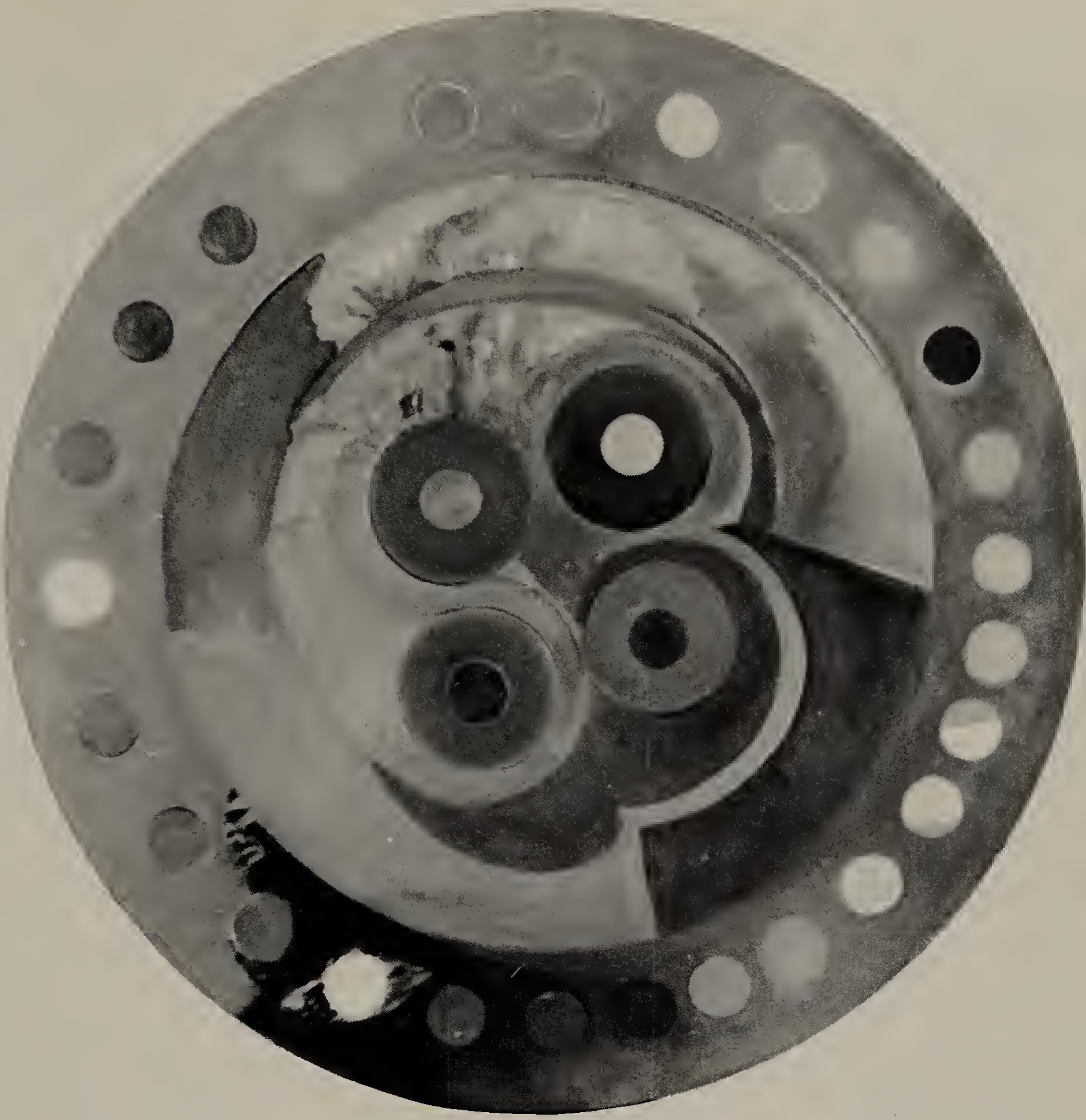

Fig. 12. '*Kinetic Painting No.* 8', *oil on canvas, dia.* 58 in., 1967. (Photo: Alan Mark.)

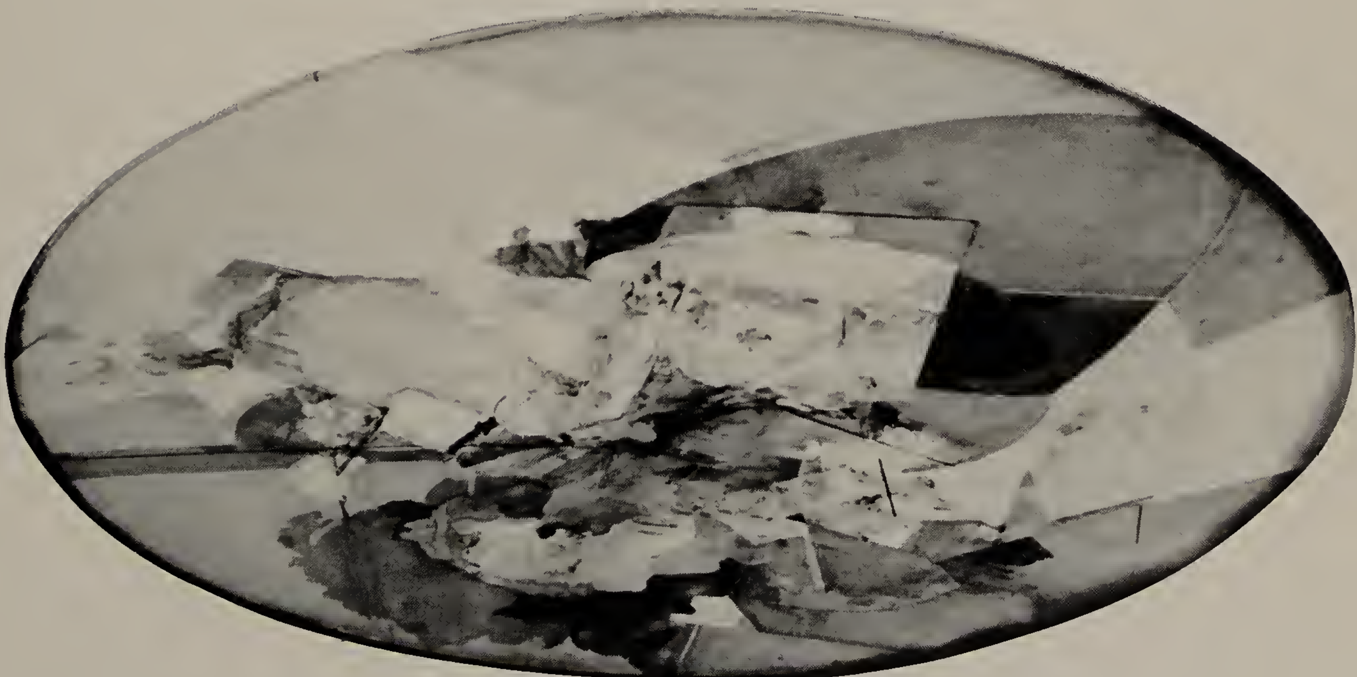

Fig. 13. '*Kinetic Painting No.* 11', *mixed media on acrylic sheet, dia.* 40 in., 1968. (Photo: Alan Mark.)

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*Article included in the present edition.

KINETIC ART WITH SUNLIGHT: REFLECTIONS ON DEVELOPMENTS IN ART NEEDED TODAY

P. K. Hoenich*

Abstract—*In the author's opinion the techniques of art should at any time equal and mirror the tendencies of development and the spiritual and scientific levels of their epoch.*

He describes his own work with the following new techniques of art:

1. *The 'Robot-Picture'—This is a moving and changing sunlight projection system which repeats itself yearly. The artist can fully control this technique and pre-determine a year's programme.*
2. *The 'Robot-Painter'—This, too, is a moving and changing sunlight projection system, but it never repeats itself. With this system the artist cannot foresee the individual pictures that will be produced, but he determines the style of the pictures by choosing the shapes and motion of the reflecting elements in the 'robot'.*

Both systems make use of Sun rays and of the rotation and revolution of the Earth; however, the 'Robot-Painter' requires an additional source of power for producing irregular movements of the reflecting elements in the 'robot'. The author has used wind energy for this task.

I. INTRODUCTION—WHAT WE NEED IN ART

'What we need in art' here means what is the kind of visual art that will have a strong impact on us—men of the space age—and what do we as artists need to do in order to create such art.

While setting down my reflections about these problems I am aware that I see them only from my own point of view, so that much of what I say will only be relatively true. All of us are bound to our Ego. But then, I do not believe that any one can proclaim absolute truths—I can only hope that my article will spur the reader to reflect on the subject and form his own opinions.

In any case, I have had ample time to reflect upon the problems of art. More than 40 years ago I frequented the art schools then in vogue, worked in their life-studios and crammed into my head anatomy for artists and history of art, the latter consisting mainly of names, dates and descriptions. It seems that even today numerous art schools still adhere to a similar programme.

After I completed my studies, I painted abstract pictures for a time. One of my opinions in 1930 was that it should be possible to paint a picture on the wings of an aeroplane without interfering with its inherent beauty. However, I soon tired of abstract painting, and started symbolic figurative painting with a will to realize the dimension of time and the realm of thought in my pictures. Now I have returned to abstract design, realizing kinetic art by means of Sun rays and of a method for automatic projection that I call 'Robot Art' [1].

Modern developments in science and technology are based on the principle that results of experiments and discoveries are published. Granting that many of these individual articles do not contain striking revelations, all of them together promote progress. The time has come for us artists, too, to drop the secrecy of the middle-ages when every master guarded his own technique and ideas. The appearance of *Leonardo* for articles by artists on their own work is certainly a step in the right direction.

II. WHAT WE HAVE IN ART TODAY

Before I claim what we need, let us take stock of what we have.

We have painting and sculpture. These two procedures do not differ essentially from the art of the stone-age. There is no real difference between mixing pigments with animal fats and buying them ready mixed with vegetable oil in an art shop.

Our figurative art with reproductions of subjects from nature or, at least, as a base for colour and

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form harmonies, will have to come to terms with photography. The latter produces not only a close replica of nature in a matter of seconds, but may and does reach in the hands of talented photographers a level of fine art. I think photography has played an important part in the development of our present abstract art.

It is usual to present a certain point of view when writing an article or a book, and to defend it in the manner of a lawyer defending his client. Perhaps some people really know what is false and what is true; but I am presenting here several problems for which I could not find a clear-cut solution, and as I do not care for subterfuges, I openly confess my indecision.

One of these unsolved questions for me is the valuation of abstract and figurative art.

It seems true that visual art in its essentials is always abstract [2]. In a still-life of apples by Cezanne it is certainly not the apples that are important, but the composition of form and colour. In this sense we are justified to see in purely abstract art a logical development and progress. On the other hand it seems essential for the full evolution of, at least, some artists to observe nature in its myriad manifestations and then to create, more or less, in its image.

I doubt that Cezanne would have reached the same aesthetic quality in purely abstract painting as he did in his works based on some model from nature. Further, I believe that visual art of all times contained an element of the erotic, which cannot, I believe, find adequate expression in abstract art.

And then there are the epic narrative contents in plastic art, which are by no means only bad literature, as the impressionists would have us believe, in reaction to captured princesses etc., of the historical school. The epos of plastic art is certainly a means of expression which can be reached only with visual means as, for example, Gruenewald's 'Crucifixion' and Picasso's 'Guernica'.

In spite of all these reservations, it seems right to use the colours and forms of visual art similarly to the manner tones are used in music. But even here I am not free from doubts. It seems that the abstract language of sounds is easier to interpret than that of colour. Everyone associates certain musical rhythms with the dance, others with marching, with joy or sorrow. In the world of colour one can express much, but it is far more difficult to make oneself understood than with sounds.

In addition, music is changeable in time-dimension, but not traditional static painting and sculpture except in a limited way through the movements of the spectator and of his eyes.

In the sphere of time-dimension we have already made some progress in the visual fine arts [2]. We have kinetic art which, like music, is dependent on the time-dimension and can also be combined with music into a new form of art. The present generation has become used to motion pictures produced by television and cinema, and kinetic art can fulfill this expectation in the fine arts.

Kinetic art in its present state seems to me only a beginning. Art is always creation—harmony, composition and an expression of spiritual content. Kinetic art can, in my eyes, only be a real art if it truly implements these principles. If one is confronted only with blinking lights, a rolling ball and similar phenomena, these can only be valued as experiments in art technology—not as art.

As to the use of blinking lights—there is a theoretical possibility of opening up a new field here. When the lights have a rhythm synchronized to that of our brain, they will exercise a hypnotic effect. This might be a way to convey the spectator into a dreamworld which, I believe, a number of kinetic artists have considered. (Experimenting with hypnotic effects is dangerous, and medical supervision of such work is indicated.) I, too, have already mentioned this possibility in my first publication on kinetic Sun projections '*Robot Art*'—*The Hopeful Monster* [1], but I do not think anyone has demonstrated this theoretical possibility.

In surveying what we have in art today, strange *avant-garde* forms have to be mentioned. In exhibitions of art one will find one-colour planes, empty frames, cars mashed by hydraulic presses, etc. I do not think these objects are without value or meaning. They are artists' reactions to the past, attempts *ad absurdum* to push out the old and the staid, and thus creating room for the new. But for me these objects are not art.

III. WHAT WE NEED IN ART TODAY—FURTHER REFLECTIONS

What we need is visual art that will make a strong impact on a large part of the public—creating joy, awakening interest in life and occupying millions passively or actively.

Art in our time, it seems to me, is more necessary than ever before. Automation of industry is creating a rapidly increasing problem of leisure time. Millions crowd passively around television sets, millions are taken care of by the hobby industry which gives them pseudo activities. These problems of our epoch are known and their analysis is not part of this article. I do not believe that visual art can solve the problems of occupying leisure time, but it could surely offer a valuable contribution towards a solution.

In another, higher sense, too, the development of art seems of supreme importance. Art embodies the noble, the creative without a material goal—the purely spiritual in man. Never was the strengthening of these qualities more sorely needed than in our time when fighting instincts, inherited from animal forbears, juggle with atomic bombs.

I admit that the art of the present has created good and outstanding works. But, to have a really strong impact on its contemporaries, art must form an integral part of the general culture of its time. This goes for its spiritual content as well as for its technical means.

It is certainly not easy to judge the spiritual content in art, and especially not in the art of the present, and I do not feel myself competent to pronounce such a judgement. But this article is mainly dedicated to the technical means of creating art, and in this field I dare say we have certainly lost a balance with the general technical developments of our time. This is why our art is ineffective; despite flourishing art dealers, art as a status symbol, art as capital investment, million-editions of art books, etc. No doubt today art gives happiness to a few, but it is incapable of reaching the masses, of bringing them joy and forming an important part of their lives.

Cinema and television have accustomed modern man to the unlimited possibilities of movement and change in pictures. Three-dimensional photography is on the threshold. Microscopes and telescopes reveal the micro- and macrocosmos. Flying, the eternal dream of mankind, is a daily routine. Press a button, and music surrounds you, another button catches nature for you in moving or still pictures. Man overcomes gravity and goes out to conquer space.

While all this has been happening, art has not changed much in the last 30,000 years. In the renaissance, art was still an important part of general culture. Art was dynamic. Artists invented mathematical perspective, studied the anatomy of man and animal, and enriched their works with their findings. Art was a necessity, the only means of visual communication, an important tool for state and church. Its necessity anchored it in life, and helped to create a numerous, understanding public which knew how to acknowledge and appreciate the rare master. Art had impact.

What kind of art do *we* need?

I will try to record my thoughts on this question without worrying if such art can be realized either today or in the future. I believe that:

1. Art should have unlimited possibilities of creation in form and colour, in movement and change.
2. It should be a three-dimensional projection, surrounding the spectator who enters it.
3. It should be united with music and speech.
4. In addition to the above it should have a simple technique.
5. A single artist should be able to use the technique without needing complicated machines or other people to help him.
6. The works should take up as little space as possible.
7. The projections should be there when desired and vanish when not needed.
8. This form of art should not serve to oust former art or art techniques, but to create new ones.

These, then, are my utopian ideas.

IV. DISCUSSION OF MY WORK

As I proceed now to a description of my work, I do not want to give the impression that I believe that I have been able to make this utopia come true. But I believe that a description of my work can only be understood and make sense if my ideas of art are known.

1. One of my systems, which I developed beginning in 1956, I call the 'Robot-Picture'. This is an ever-changing sunlight projection in constant motion for which the artist arranges a yearly programme. He foresees the exact projection of the 'Robot-Picture' upon a wall or a translucid screen for each day and hour of the year, and his design possibilities for these projections are unlimited.

A self-changing projection must be based on an automatic principle, hence the names 'Robot-Picture' and 'Robot-Art'. The technique of the 'Robot-Picture' is very simple. A cinema projector has a fixed lamp and a film strip modulating the light into a projection by means of a motor moving the filmstrip. The principle of the 'Robot-Picture' is similar, with one difference. Whereas in the cinema still pictures follow each other quickly, thus giving our eyes the illusion of movement, the 'Robot-Picture' is really in continuous motion. The dimensions of the two kinds of projectors are very different.

The 'robot' projection makes use of the Sun as a fixed lamp and of the planet Earth as a motor moving not a strip of film but rows of reflectors. The composition of the projection is dependent on the forms of the reflectors. Colour filters connected to the reflectors determine the colours of the projection. If we wish to project a picture with Sun rays we must mount the rows of reflectors in such a way that they will reflect rays from sunrise to sunset. As the course of the Sun is different during the four seasons, the rows of reflectors will be effective differently during the year (Figs. 1 and 2). A single form will not

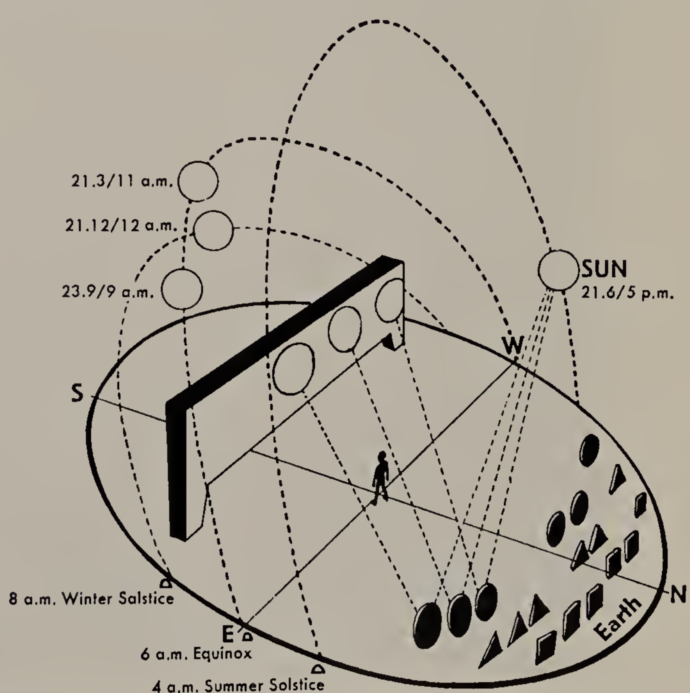

Fig. 1. The principle of 'Robot', art, as it appears to be.

necessarily be produced by a single reflector and various reflectors may unite in a single complex form.

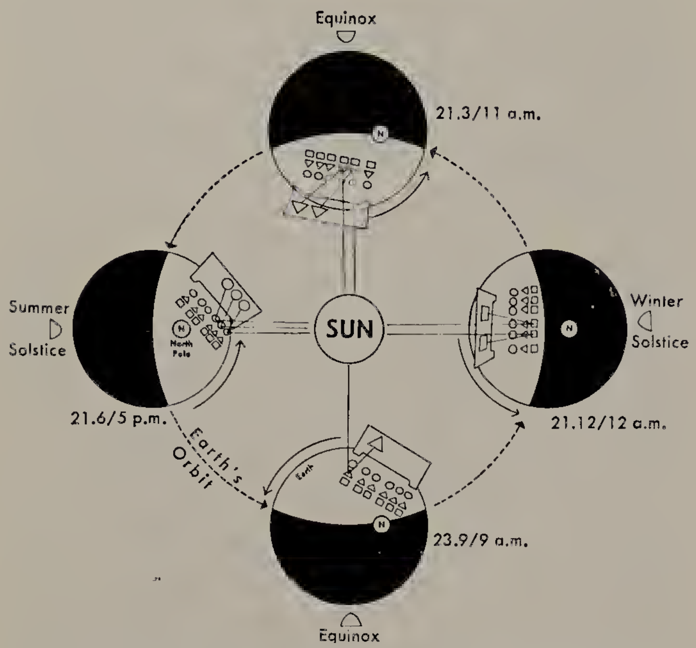

Fig. 2. The principle of 'Robot', art as it is at different seasons of the year.

The farther a reflector is from the screen, the faster its projection will move on the screen. The angle of a reflector to the Sun rays determines the course of its projection as the position of the Sun changes. Reflectors of the 'Robot-Picture' must be fixed, otherwise it is impossible to predetermine the composition of the projection.

Any opaque, bright surface can serve as a projection screen when the projection is to be seen from in front (e.g. the wall of a house). A translucent screen is needed to see the projection from the back (e.g. a window with translucent glass).

To create a yearly programme with this technique, the artist need not wait a year. He can mount a model of the screen with reflectors and filters, constructed to scale, on a drawing board, together with a sundial. When the board is moved in sunlight, the sundial will show the day and hour of each projection. The sundial must correspond to the position on the Earth at which the 'Robot-Picture' is to function.

Before continuing with the description of my work, let me insert here a few relevant remarks on the use of Sun rays for artistic purposes.

The Jesuit Abbe Castel (1688–1757) has been mentioned as the first to project pictures with Sun rays. I personally think that most probably this possibility was known already in antiquity. At present many artists work with kinetic art devices, a few of them use Sun rays.* I have no knowledge of anyone using Sun rays in the same way as I do and achieving the same results, but it is, of course, quite possible. Experience has taught us that most inventions are made simultaneously by several people in various parts of the world.

No part of my work is patented, and I place no importance on being the first in any one field. Moreover, I have published descriptions of my work several times [1, 4, 5].

*Thomas Wilfred [3] in his Lumia, which he began developing in 1905, uses an electric light bulb, instead of sunlight, and motor driven reflecting surfaces to produce projected pictures on a translucid screen with a very long time cycle. Variations of this system are used by several kinetic artists today.

Fig. 3. a, b and c. Three images obtained from the same two Sun reflectors.

Fig. 3b.

Fig. 3c.

2. The second system to be described here I call the 'Robot-Painter'. It is very similar to the 'Robot-Picture' in its individual projections, but the technique as such is much more complicated and the artistic and spiritual problems profoundly different. In my opinion it offers a far greater challenge to the artist, and a more interesting and fascinating adventure.

The 'Robot-Painter' is a sunlight projection in constant motion and change that never repeats

Fig. 4. a, b, and c. Three images obtained by sunlight projections.

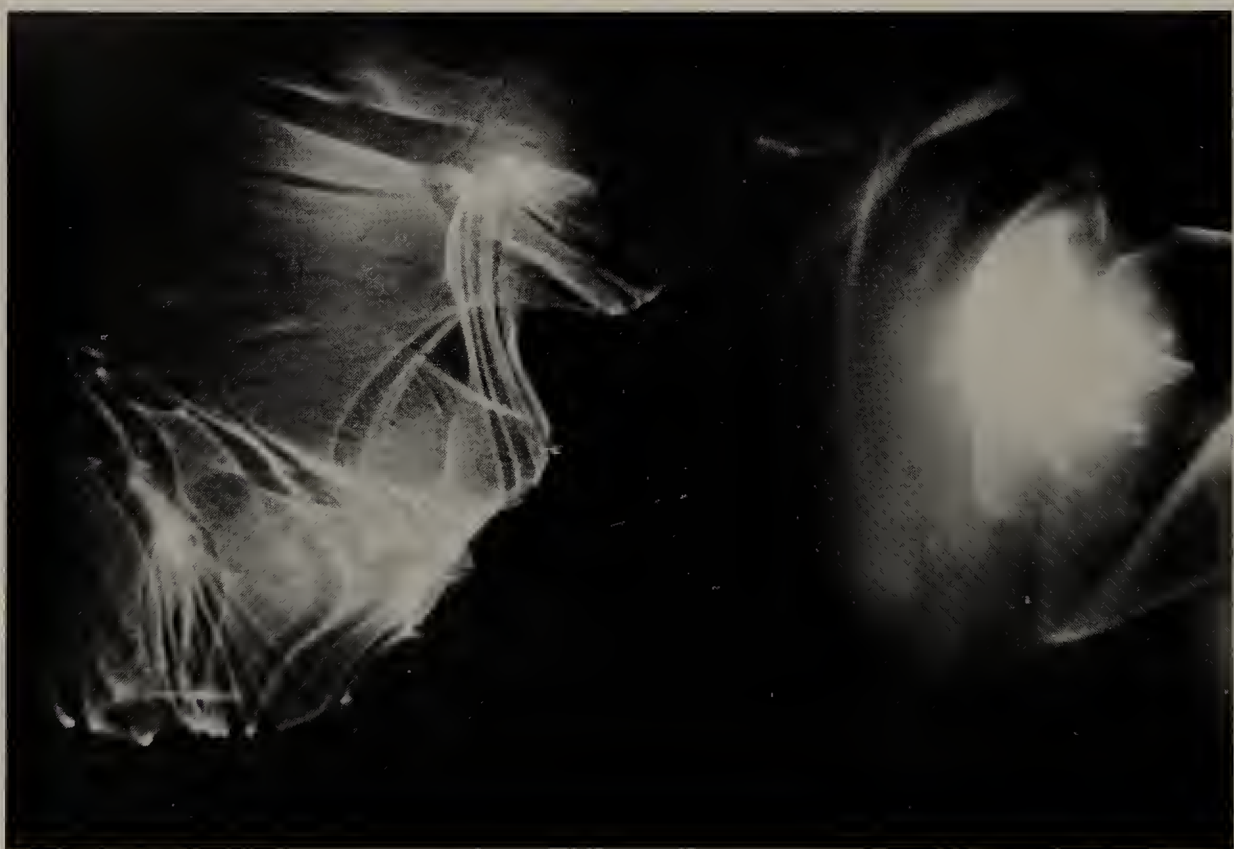

Fig. 4b.

itself. The artist cannot foresee the individual pictures, but he determines the style of the 'Robot-Painter' and is responsible for its quality. The artist will try to transplant his own art experience into the robot, and to create, in a way, his 'self-portrait'.

Here, too, the principle is simple. The 'Robot-Painter' uses Sun rays, Earth rotation and revolution around the Sun, as does the 'Robot-Picture'. But an additional source of energy is needed for producing irregular movements from movable reflectors and colour filters. Each reflector and filter has many possible motions. Certain parts may be coupled, i.e. one part may make other parts function. Undesirable movements may be stopped by brakes. If three or more parts of a system move irregularly

Fig. 5. Composition created with the 'Robot-Picture' system.

Fig. 4*c*.

and independently, they will appear in continuously changing combinations of position with respect to each other.

The pictures of the 'Robot-Painter' are produced by a multitude of reflectors and colour filters, some of them in independent motion. As a result, the 'Robot-Painter' will project new pictures which never repeat themselves. Irregular motion requires an irregular drive. In my work I have used wind energy, but Sun rays can probably be harnessed to produce motion as well.

The 'Robot-Picture' and the 'Robot-Painter' present the artist with a wide range of possibilities. Figures 3–5 give only a poor image of their richness, as Sun projections have to be seen either in the original or, at least, in the form of colour movies or colour slides (reproduction techniques which are also light projections) to do them justice.

I have made hundreds of projections, and filmed and photographed many of them. I have also tried to project them into a three-dimensional space that can be entered by spectators.

Sun projections are, of course, only visible when the Sun shines. This is quite often an advantage, as the impact is stronger with pictures for which you wait expectantly, than with those that are always visible. The hesitating, veiled appearance of a Sun projection, when the Sun is still partly hidden behind clouds, and its crescendo, coinciding with the breakthrough of the Sun, are a breathtaking event.

Where permanent decorations are required, combined techniques can be applied, such as glass-sculptures projecting moving pictures in sunshine.

It is not possible to describe here the whole variety of my work—it is only a beginning. Art techniques can only develop if they are used by many. This article was written in the hope that it may arouse interest in technological experiments and research for artistic purposes, thus helping to achieve a better balance between our time and art.

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KINETIC ART: THE CHROMARA, A LUMIA TECHNIQUE

Richard I. Land*

Abstract—*The author presents in detail the technical aspects of his* Lumia *(kinetic painting with projected light) produced by various systems under his designation,* Chromara. *There is a discussion of Thomas Wilfred's pioneering efforts in developing a form of this art for which he proposed the name* Lumia *(he called his particular instrument a* Clavilux). *Both cabinet-type instruments and large-scale wall or screen projection systems developed by the author are described and their characteristics evaluated. He comments on his experiments associating music and Lumia and, especially, the characteristics of the inherently different senses of seeing and hearing.*

Conclusions about kinetic art with light as an art form are not offered. However, he hopes others will benefit from his experience.

I. INTRODUCTION

Sunrise, sunset and auroral displays are nature's grandest manifestations of colored light or what Wilfred called *Lumia.* Fire, on all scales, perhaps led man to his first experiments in controlling light patterns. Adding chemicals to fire can change the flame color or change the amount and color of the smoke. With either a fire or a torch, shadows in motion can be produced by moving either an object whose shadow is cast or by moving sources of light. Only recently has electricity made possible simple and controlable light sources suitable for artistic purposes.

Many who have studied vision, light and optics in the past have recognized the artistic potentialities of light in motion. An adequate review of kinetic art with light is yet to be written. Thomas Wilfred was one of the first pioneers of this art form to produce generally satisfying results in a manageable way, rather than only noble experiments [1–4]. He recommended the name *Lumia* and I shall use this term as equivalent to kinetic painting by projecting light on a screen [5].

Wilfred advocated the word *Lumia* without actually defining specific devices. With reference to the many individuals working with light projections, Wilfred wrote to me [6]: 'I am urging all of them to use the word *Lumia* for the art form itself, the word thus corresponding to *Music* for the art of sound. This will clarify the issue to the public and give us all a single banner to work under, also lending dignity to our efforts. The old designations "color music" and "mobile color" are misleading. I often hear one of my compositions referred to as "your Lumia" where it should be "your Lumia composition" because no one refers to a musical composition as "a music". Another word we discourage is "machine" for a Lumia instrument. You do not refer to pianos or pipe organs as "machines". We may then name our individual instruments as we please. Your Chromara and my Clavilux are thus both Lumia instruments. An Englishman once wrote me suggesting the word "Heliomusiris", and the Germans have used "Farblichtmusik". Lumia is simpler and suggests light in many languages.'

There is a subtle distinction that leads the cinema technique to be excluded from the class of Lumia. However, the first part of Walt Disney's *Fantasia* and the final part of Kubrick's 2001 are difficult to exclude. Lumia works in the form of instruments or objects of Malina [7], Schoeffer [8], Calos [9], Healey, Reiback and others are fairly well known. Most of their work is devoted to kinetic art designed for individual contemplation. The Lumia public performances and infrequently exhibited Lumia individual instruments of Sidenius in America deserve more attention [10]. For the past six or seven years, he has been giving Lumia concerts throughout the summer in his theater at Sandy Hook, Connecticut, U.S.A., using many manually controlled projection instruments exhibiting numerous Lumia techniques. The two-hour performance is pleasing both for its variety and astute control of the medium, clearly worthy of the considerable encouragement Wilfred gave him. Future developments of kinetic art with projected light are

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not easily predicted, as new techniques may be expected to arise from modern developments in optics, solid state physics, television and computer graphics.

II. LUMIA TECHNIQUES

Techniques for producing artistic images using light appear to fall into three major divisions, although not all the results may be classified as Lumia [7]. Each division is characterized by the variety of effects that can be produced, the amount of control of pattern and of color, the brightness of images and the efficiency in using light sources. There is a distinct group of techniques in which the light source is viewed directly in the motion of the image. Another diverse group of techniques applies physical optics dependent on the optical activity of materials, such as, interference, dispersion and diffraction. Conventional techniques are light projection systems using transformations identified by the terms shadow, refraction and reflection.

Flashing lights, such as those used in advertising signs and on Christmas trees, have been incorporated in kinetic art objects. Television images using phosphors excited by the scanning beam of electrons are not Lumia but may be so classed under certain methods of control [11]. New technologies extend the possibilities with plasma displays, electroluminescent tapes and panels, laser emitting diodes and chemiluminescent fluids. In general, these techniques are limited, since elaborate transformations of images become technically difficult and expensive, however, they are characterized by great brightness, in most cases. Images in this class are most often recognized for their utilitarian function rather than for their aesthetic value.

Several of the modern technologies have not as yet achieved sufficient exposure to produce more than experiments, e.g., laser displays (Munich Opera, 1970; EXPO-70 TV projection system), use of liquid crystals and holography. The most familiar use of physical optics for pleasing effects is color, seen as the result of the direct transmission of light through plastics placed between light polarizing filters. Like the general class of such images, control is complicated and the light levels tend to be low, although the colors produced are generally well saturated.

The light source is of paramount concern in all projection systems. In my 'Chromara, 1966' (Figs. 1–4), I used 12-V automobile headlight lamps. Sources are available having small size, high intensity, adequate lifetime and good color balance [12], in particular, the tungsten–halogen incandescent lamp and the Xenon compact arcs are preferred sources, although they become very hot in operation. Incandescent projection lamps with internal reflectors are available and special designs alleviate cooling problems considerably. At low power (36 W), there is a novel design filament lamp from Japan that has a square filament only 5 mm on a side, mounted so that the lamp may be used end-on to simplify cooling. I used three of these lamps in my 'Chromara, 1968' (Figs. 5 and 6. Figure 6 at end of article). Several artists utilize ordinary household clear unfrosted lamps in Lumia devices. Malina uses fluorescent tubes in his larger Lumidynes [7], which can be viewed in normally illuminated rooms of a home.

Fig. 1. 'Chromara, 1966' (with controls on top of cabinet), Lumia instrument, shadow-type armature, 40 × 50 *cm screen,* 1966.

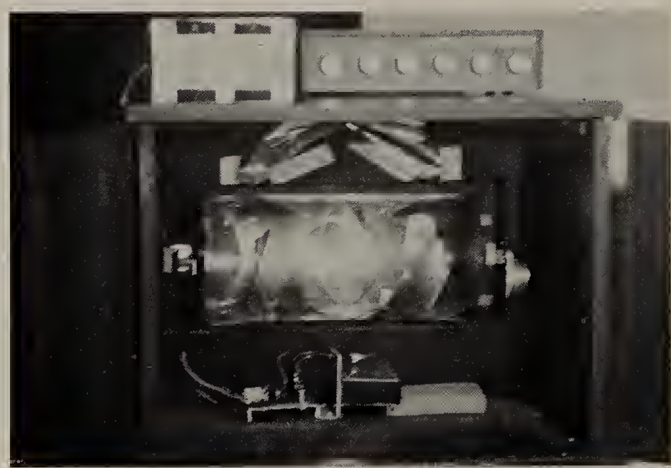

Fig. 2. 'Chromara, 1966.' Screen removed to show modulator (armature) in place. Manual brightness control is at top left and audio analyzer at top right.

Fig. 3. 'Chromara, 1966.' View of three types of armatures: (top) shadow type, (center) reflector type and (bottom) composite type.

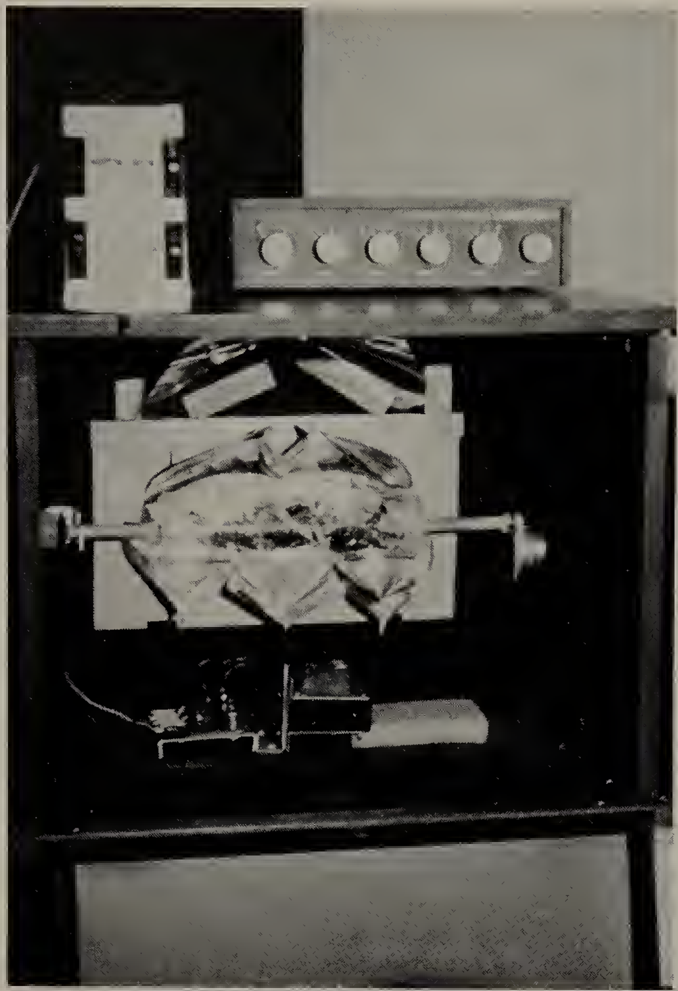

Fig. 4. 'Chromara, 1966.' Screen removed to show composite-type armature, fixed reflector behind it and light entering through slot 1 *cm wide.*

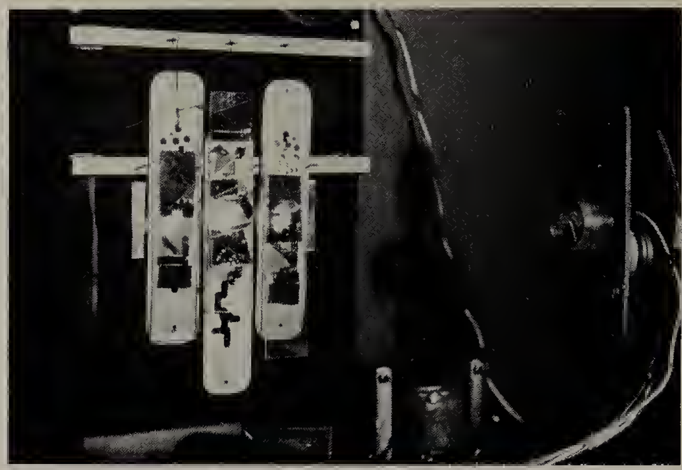

Fig. 5. *'Chromara, 1968.' Lumia instrument,* 36 × 74 *cm screen,* 1968. *Rear board and both reflectors removed. Note movable shutter and color mosaic.*

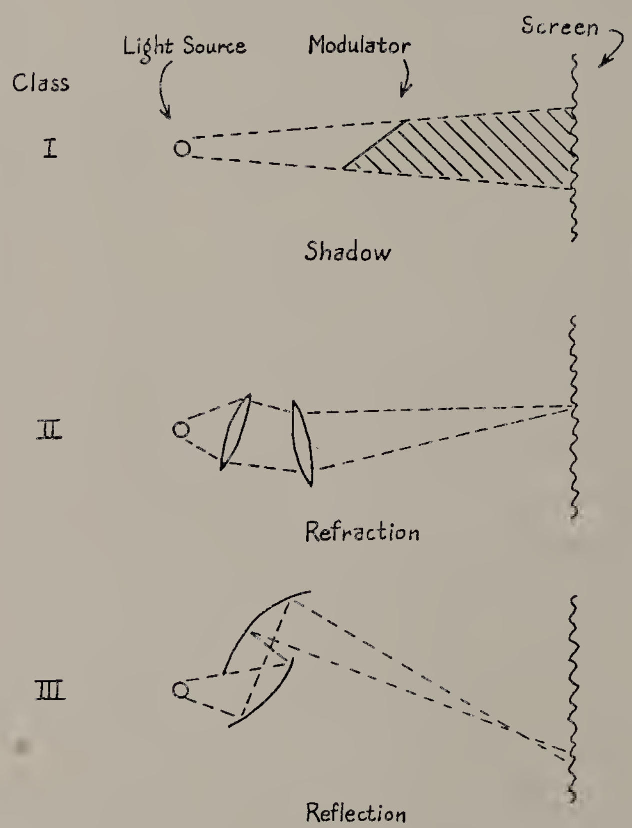

Fig. 7. *Three classes of projection systems (idealized) used in Lumia techniques.*

The surface on which images are projected is important. Most Lumia devices use rear-projected light on a translucent screen [13]. Many kinds of translucent screens have been developed in response to the needs of cinema and television and film production, as well as for industrial projection display systems. On the basis of cost and excellence of performance, I have found the flexible 'Lenscreen' [14] superior to most. For the projection of large images viewed from more than 5 m distance, there is a wide variety of cinema screens available for both front and rear projection. The startling effects achieved by Suvbuda at EXPO–67 showed that one should also consider front projection on fast moving white strips and heavily textured surfaces.

In the Lumia technique, the space between the light source and the screen is used by the artist to produce with objects specific images on the screen. I call the objects placed in this space *modulators* as they produce and modify the light images on the screen. When a modulator rotates about a fixed axis, I call it an *armature*. Simple shadow techniques are capable of producing numerous variations in the shadows (Class I, Fig. 7). When a small lamp is used, since it is not a point source of light, the sharpness of a shadow will vary with the position of the shadow-casting modulator from the screen. The closer the modulator is placed to the screen, the sharper will be its outline but at the sacrifice of size.

One of the advantages of some shadow techniques is the large image amplification obtainable, as with 'Linnebach' stage projectors, where a large surface or wall may be filled by a shadow of a slide 25 cm square placed close to the projection lamp. Cinema projectors operate in a similar manner, except that a lens is used to accurately focus the image on the screen. Plastic color filters and translucent dyes are used in shadow techniques and the color seen on the screen represents what remains as a shadow of those colors subtracted from the illumination source. Additive color mixing may be observed on a screen, e.g., when red and green shadows overlap in proper balance, a yellow color results. A very few pieces of color filter material of proper sizes in relation to their distance from the lamp to the lamp filament size can produce nearly all colors. Motion may be introduced either by moving the light source or the shadow producing elements individually or by rotating the elements as a group. In Malina's *Lumidyne* system, light is directly transmitted through a colored moving element and then through a static colored element. Kinetic paintings of two very different kinds can be made, depending on whether or not a translucent screen is placed in front of the static colored element [7].

Lenses when used in Lumia systems often produce aberrations rather than the kind of images made by optical instruments. Modulators made of deformed or defective lenses produce many interesting effects. Wilfred's early instrument for theater performances, 'Clavilux, Model G' (1937) [4], used lenses to produce large bright images at a distance. Convergent–refraction techniques (class II, Fig. 7) allow one to use light that would not normally fall on the screen. Lens-like materials are used to funnel light to selected areas of a screen. Unfortunately, many of these optical techniques cause obvious distortions of the lamp filament—monotonous patterns of spirals and 'v' shapes. An easily fabricated refraction-type modulator can be produced by applying rapid setting plastic liquids to a plane transparent surface. Transparent household plastic cement on, for example, Plexiglas works well if not applied so thickly that bubbles form. Heat treating a thick piece of clear plastic, while difficult to control, occasionally results in a useful lens-like modulator. Industrial plastic or moulded glass objects are often modulators that produce delightful images when an appropriate light source and the proper projection distance are used. Many times refraction of white light by an object produces dispersion (common with prisms) giving rainbow-ordered colors along edges. An effective refraction armature can be made of a simple *varifocal* lens consisting of horizontal sheets of clear plastic (Mylar) with water between them. If the water pressure is varied by elevating a reservoir supplying the water between the sheets, then the lens thickness will change and produce changes in the projected image. A plane mirror may be used to project the resulting images onto a vertical surface. Since imperfect images in many cases are pleasing to the eye, one need not strive for precision in making the varifocal lens.

Where the lens must have thickness to refract light passing through it, a simple surface reflector redirects the light toward the screen by turning the light beams through large angles (class III, Fig. 7). Pleasing reflection effects are generally the least bright of the images produced by the three classes of projection techniques.

The parts of a device for producing a rear-projected image will fit in the smallest cabinet when the reflection technique is used, a larger box is needed for the refraction technique and the shadow technique requires the largest installation. In both the shadow and refraction sizes, relatively large, heavy armatures must be given motion. Metal foils and, particularly, aluminum or silver coated plastic sheet permit reflecting armatures to be very light in weight, relatively small and very easy to move with either motors, air streams or more sophisticated techniques [15, 16]. In general, one uses reflecting surfaces that are concave toward the light source. A crinkled surface is inefficient in directing light over long paths and effort is usually directed to having fairly large smooth surfaces on reflecting elements. When two or more moving reflectors are used, they can produce very complicated motions of the images. For example, if two reflecting surfaces are at an angle to each other and only one moves, large image displacements result that may be perpendicular to the original reflector motion. With curved surfaces and only one moving (Figs. 6 and 9), the image may be made to rise, halt and fall in a retrograde loop.

Clearly there are many ways of combining projection techniques to achieve a wide range of effects, subtle transitions and dramatic contrasts in forms, brightness, and motion. The use of chemicals for Lumia performances has been discussed in *Leonardo* by Wier [17].

III. THE CHROMARA SYSTEM

My dream has always been to have a single high intensity light source whose brightness and color could be controlled independently. My search for ways to obtain these goals began when I was a young student in 1947 and led me to the use of theater projectors and color filter materials. My first instruments had armatures of abstract shapes rotating close to three projection lamps, each behind a color filter (red, green and blue). I call this the Class I *Chromara* technique (Fig. 8). The armatures were of sturdy theatrical color filter material, chosen such that deep shadows were cast for only one of the colors of the three projector filters, i.e., for red light a cyan object would give a black shadow but transmit blue and green light. I spent considerable time searching for screen material, suitable lamps and quiet variable-speed motors that I could afford to buy. During the next years, studies and other occupations kept me from devoting much time to my instruments. It was ten years after my first experiments when I first saw Wilfred's Clavilux 'Vertical Sequence' and realized that others were 'painting with light'.

Encouraged by several commissions I received for works in 1964, I designed 'Chromara, 1966' with interchangeable modulators (Figs. 1–4) for mass production and sale to home users. Much as the phonograph produces different pieces of music, depending on the record placed on a rotating table, we developed an optical instrument where only the armature needed to be changed in the instrument, the owner was encouraged to make his own. The 'Chromara, 1966' was produced by the Smith Laboratories, 7276 South Dixie Drive, Tipp City, Ohio. Unfortunately, inadequate sales to the public brought production to a halt.

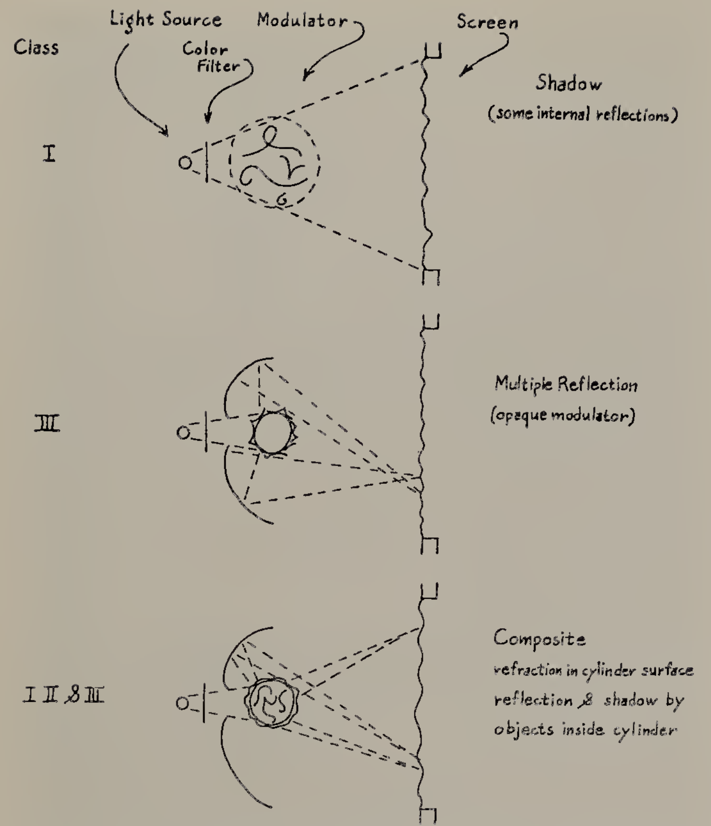

Fig. 8. Three classes of Chromara projection techniques used in 'Chromara, 1966.'

The three projection techniques shown in Fig. 8 were used. Elements within a large diameter armature produced shadows and some internal reflections between the elements when care was used in organizing the reflecting forms (Figs. 2, 3 and 8). A multiple-reflection technique consisted of a fixed large reflector having a narrow horizontal slot in front of the four lamps with a small rotating totally reflecting cylinder in the light path (Figs. 3 and 8). Projection techniques were combined by using a transparent thick-walled plastic tube having a smooth but undulating surface with reflecting forms inside. Some light was refracted through the lens-like cylinder walls and distributed in a manner affected by the shadow-producing forms within (Figs. 1, 3, 4 and 8). Four lamps were used (rather than three for the additive primaries) because the short optical path when mixing red and green light produced intensity gradients too large for much yellow to be observed. Actually, while the design permits the full use of the variety of saturated colors using amber, red, green and blue filters for the lamps, many pleasing image sequences arise from using other colors or even omitting filters for one or more lamps. Additional texturing of the image results from inserting a clear irregularly surfaced plastic sheet along with the color filters. A $\frac{1}{4}$-rpm motor gives pleasing velocities to the images and a halting switch is inserted into the electric lead to the motor. A manual control is available to adjust the lamp intensities with four thumb wheels on the small portable box (Figs. 1 and 2).

My preference is for images produced by the multiple reflection technique and I have searched

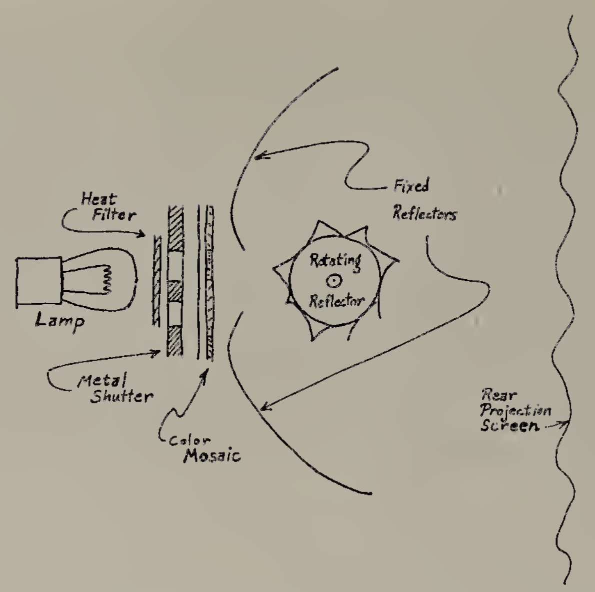

Fig. 9. Sketch of doubly reflecting Chromara technique provided with movable shutters and color mosaics for 'Chromara, 1968'.

for the simplest ways to obtain them. A moving lamp gives added interesting effects. It is impractical to move a lamp but if in front of the lamp a metal shutter with irregular holes is moved, the same effect is obtained. In 'Chromara, 1968', I used a metal shutter and color mosaic moving vertically at different speeds in a reciprocating manner in front of the lamps (Figs. 5 and 9).

For this instrument with three light sources, I provide four different motion cycles (for three shutters, three mosaics and one armature) assuring a long period (hours) before one observes repeated images. Since viewers often watch for more than ten minutes, I prevent certain spectacular, hence memorable, patterns from repeating before several hours have elapsed. When the image speeds controlled by the shutter and mosaic are made somewhat faster than those produced by the armature, the motions of the image are complex and particularly pleasing. A typical image on the screen is shown in color in Fig. 6. A static photograph cannot, of course, convey the experience of viewing Lumia.

My experiments with large Lumia systems have resulted in only limited satisfaction. One system consisted of a fully remotely controlled slide projector, a four-lamp single-armature shadow-type assembly and a second one of a two-lamp four-armature reflecting-type assembly. These instruments could simultaneously fill a screen 1·5 m square. The images were mixed by intensity control of each individual lamp and motor speeds were varied as well. Slides for such mixed Lumia systems should not have clearly defined edges but rather should be of objects within black backgrounds, so that photographic images dissolve into the less sharp images from the other assemblies. A large illusion of depth can be achieved by changing both lamp brightness and the focusing of the slides during a performance.

I designed a special shadow-type projector for incorporation into my stage design for the Loeb Drama Center production of *Much Ado About Nothing* at Harvard in May, 1969. The Lumia images were to make smooth visual transitions between scenes and an image would be held motionless as a background during each scene. The critical feature of this type of application is the need for the operator to rehearse just as much and as carefully as the actors. A large image in motion interfered with audience concentration on the actors but when it was static there was no distraction. Most of the audience never realized that a central arch within the set was as necessary for the Lumia as for the play. The instrument inside the top of the arch projected over the actors' heads onto the 'cyclorama' (a fixed back wall of the setting) an image about 6 m square, blending well into the other lighting used to give a feeling of openness. Besides controlling the speed of images, the lighting technician adjusted the brightness of a 'warm' family of forms and a 'cool' family of forms. For all the efficiency that had been designed into the system, the 4000 W used at 4·5 m distance from the white surface produced an image that was barely able to compete with other necessary stage lighting.

IV. AUDIO-VISUAL SYNTHESIS

The idea that what we see and what we hear should be related is the basis of most ballet. The belief that the two senses can be associated arises from the fact that people think that sound and light, being wave phenomena, should be related. True, a wave-like physical nature is common to both but the time scales and their fundamental processes are vastly different. No two people agree as to what aspects of the two sensations should correspond [18, 19]. One becomes ill if images change as rapidly as music follows a melodic line. I have observed that the pleasing time variation of images is about ten times slower than the simple time scale of music. Interestingly enough, this is about the same for ballet, where a body movement sequence is ten or twenty bars long before a transition to a new sequence is introduced. Without beating the issue to death, let me point out that people listening to a concert most often watch the conductor but he makes no sound. While there is no question that lightning and thunder result from the same physical event, they are never experienced at the 'same' time. Most of what we hear does not come from what we look at but the senses are associated in some complicated way that compensates for the change of time scale necessary for the appropriate sense to function.

The challenge is to discover if there are any simple associative rules for images and sounds to be related [20]. After many years of seeing the light intensities of lamps directly associated with the intensity of music, I am convinced that another way is required. An approach is to start with filters of the audio frequencies, say with three passbands near some central frequency (Fig. 10) as several experimenters

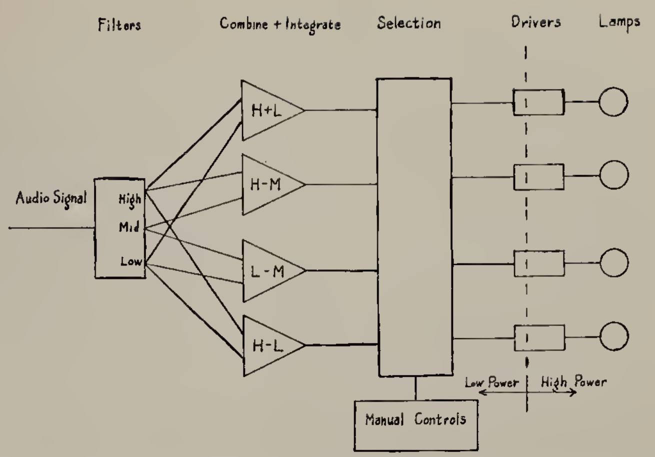

Fig. 10. *Diagram of a music analyzer for producing variations of light intensity related to components of an audio signal, similar to that used in 'Chromara, 1966'.*

have done. Then what is important is the relationship between intensities within these passbands. Also, there may be significance to the presence of high tones when low tones are absent and when high tones are present but middle range tones are absent. This may be analyzed as the difference between the three filter outputs. Furthermore, time-scale adjustment implies what is mathematically referred to as integration. That is, if within a fixed period of time the intensity of the music remains at an average value, it will produce a signal or, if only for an instant the music is very strong, a signal will also be produced, otherwise, modest but short duration and below average intensities will be ignored. A system using these rules would then consist of filters producing three carefully chosen outputs (H, M, L) that may be summed (subtraction is a negative sum) and integrated to produce four new signals having the sophisticated relationships to the original audio signal as described. These four signals may then be selected by switches and control-driving circuits for lamps (Figs. 1 and 2).

While such a system has provided considerable satisfaction to me, music often has transitions that require greater changes than a simple analyzer can produce with one switch setting. A possible modification would be to have the four signals from the sum and integrating amplifiers drive an array of small control lamps and, in the same array, provide manually operated control lamps. The driver units would then be actuated by signals from photo-detectors in the same light-tight box as the array of control lamps. Light from the array would cause the photo-detectors to respond to preprogrammed relationships between the electronically controlled lamps and the manually controlled ones. Cards with punched holes inserted into the light-tight box could represent the program and be inserted between the control lamp array and the photo-detectors. A more complicated version would incorporate rhythm-sensing circuits that could control motor speed or average illumination level. In a field where there are no apparent rules for relationships, it is clear that the imagination often runs rampant.

Malina has told me of his efforts to reverse the normal approach to audio-visual synthesis by having light images produce sounds through the use of audio oscillators actuated by photocells that intercept the images cast on a screen. This might be one way to learn whether the pleasing visual experience of a kinetic painting would also produce one for listening. He called this experience *Kusic* for kinetic music. He succeeded in getting a reflector-type Lumia to play the first few measures of 'La Marseillaise' with the help of his assistant, Didier Bouchet, who refused to continue the experiment because he began to suffer nervous prostration from trying to arrange the light reflectors to produce the images at the correct time, for the correct duration and at the correct location with respect to the screen and the photocells.

V. CONCLUDING REMARKS

My feelings about Lumia as a form of expression are still developing. I shall not speculate on this art form in this technical report on my present instruments. I have described Lumia techniques both in general and in particular. Hopefully, others will discover improved techniques, as well as fresh delight from such a flexible medium.

I wish to make special acknowledgment to Reginald Isaacs for the many years of encouragement and substantial patronage he has given me. Dale T. Smith researched the musical-analog circuits I have discussed and did development engineering for the commercial models of the 'Chromara, 1966', marketed in 1966–68. Kelly Yeaton and Warren Smith of the Drama Department at the Pennsylvania State University influenced my early approaches to Lumia by their imaginative explorations of theater lighting effects. It has been a pleasure to have had encouragement from Thomas Wilfred and Christian Sidenius in recent years. There are many others to whom I am grateful but their vast helpfulness would take a comparable number of words to acknowledge.

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*Article included in the present edition.

Fig. 6. 'Chromara, 1968', Lumia instrument, 36 × 74 cm screen, 1968. *View of an image on screen.*

KINETIC PAINTING: THE LUMIDYNE SYSTEM

Frank J. Malina*

Abstract—*The paper discusses briefly kinetic painting systems that have been devised for producing a pictorial composition on a translucent flat surface that changes with time without resorting to the projection of light through film in a darkened room. The Lumidyne system developed by the author in 1956 is described in detail. Basic principles of its design, together with variations of the system, are given as well as the method of painting used by the author. Examples of several works are shown. The picture produced by the system is considered from the point of view of real motion and of change of transparent colour with time. The need for aesthetic guide lines for the kinetic painter is stressed. The author concludes that the Lumidyne system, after ten years of experience with it, is a practical, controllable and economical artistic medium.*

I. INTRODUCTION

There are aspects of man's environment and his conceptions of it involving light from the Sun, motion and changes of colors with time that painters have long wished to express in their works of art. But it was not until the last century when the dynamo for the generation of electricity was invented that practical means became available to the painter to enter into this domain of visual experience.

The incandescent bulb and the fluorescent tube are today an inexpensive and reliable source of light, and silent electric motors of small dimension provide a ready source of rotational motion. In addition, the development of modern plastics has made available transparent and translucent plates which are lighter in weight and much less fragile than glass. There is, therefore, no longer any reason why the maker of pictures must limit himself to the use of opaque paints and opaque flat surfaces with which static images have been made since the time of the cave man. And, in fact, in recent years, we have witnessed the development of new dimensions in art involving movement and light, and now commonly called 'kinetic art'. However, the art world, from millennia long habit, and buttressed by dogmatic and restrictive aesthetic philosophies, has until recently tended to resist this new form of art.

Kinetic art includes visual artifacts of three-dimensional or constructional type with mechanical motion of solid bodies, such as animated clockwork systems (which can be found on clock-towers in many cities of Europe) and Calder mobiles driven by air currents. The second major domain of kinetic art comprises the use of cinema equipment to create pictures of changing composition and color projected on to a framed area (the screen). Norman McLaren's work directly on virgin film is a notable example of this technique. Finally, there is the whole range of the less familiar kinetic 'painting' systems, utilizing a translucid screen. In this article I shall discuss in some detail only the last mentioned systems. (I have put the word 'painting' in quotation marks, because a more suitable word has not yet entered into our language for dealing with this branch of kinetic art.)

Three principal kinetic painting systems have been devised for producing a pictorial composition on a translucent flat surface that changes with time without resorting to the projection of light through film in a darkened room.

The oldest system, developed since 1905 by the American Thomas Wilfred, makes use of rotating forms made from materials such as mirrors and polished metals [1]. These reflect changing light patterns on to a translucent pictorial surface. Colors of the patterns are determined by transparent colored materials which intercept the light source before the light strikes a reflecting surface.

In the second system, which I developed in 1956, the main composition is painted on a fixed, transparent plate (the Stator), and a design is painted on a rotating transparent disc (the Rotor). Light from incandescent bulbs or fluorescent tubes is transmitted directly through the Rotor and then the Stator on to a translucent plate (the Diffusor) to produce a picture combining light, color and movement. I have called this the Lumidyne system. (It was not until after I had exhibited my first kinetic paintings

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at the Galerie Colette Allendy in Paris in 1955 that I became aware of the work of Wilfred [2, 3].)

The third system makes use of color changes brought about by the direct transmission of light through polarizing materials, one of the sheets being rotated. The color changes are caused by the introduction of materials between the two sheets that produce birefringent colors.

The Lumia of Wilfred creates a picture the composition and colors of which change with time; my Lumidyne has movement and changing colors within a fixed composition; and the kinetic paintings utilizing polarizing materials have either a fixed or a changing composition together with changing colors.

The period of time for the repetition of the picture with these systems varies from one or two minutes to a cycle of infinite duration. The cycle for the Lumidyne system with its fixed composition is not readily discerned, even when its period is only one minute, because of the complexity of the movement that the artist can introduce.

Work in the field of kinetic painting consists of two distinct phases. The first comprises the construction of a compact system capable of producing an image with light and movement. There is no reason to believe that the three systems I have mentioned are the only possible ones, as a matter of fact, several variants of these systems are now being used by artists [4–7].

The second phase consists of creating a satisfying aesthetic visual experience on the translucent surface. recently artists in different periods worked for generations with, for example, the mosaic, fresco, water and oil color techniques to express a large variety of visual experiences. It was not expected that each artist would invent a special technique with different materials for his work. One might expect that a limited number of basic, flexible kinetic art techniques will be adopted by artists until radically new technical developments and changing times cause artists to feel that these techniques are inadequate for their purposes.

II. THE LUMIDYNE SYSTEM

1. Basic principles

The basic components of the Lumidyne system are shown in Figs. 1 and 2. There is a back board for supporting fluorescent or incandescent lights, an electric motor for driving the Rotor, and reflecting surfaces, such as mirrors. Ventilating holes in the back board and at the top and the bottom of the case are provided to reduce the temperature within the case. The Stator and Diffusor plates are shown in front of the Rotor. A wire or plastic mesh may be placed in front of the Diffusor to give texture to the picture, and may also be used as a surface for a static painting which is visible when the kinetic painting is not in operation [2, 3].

The Rotor and Stator are made of glass or transparent plastic material; the Diffusor of ground glass or translucid plastic material. Plate thickness of 2

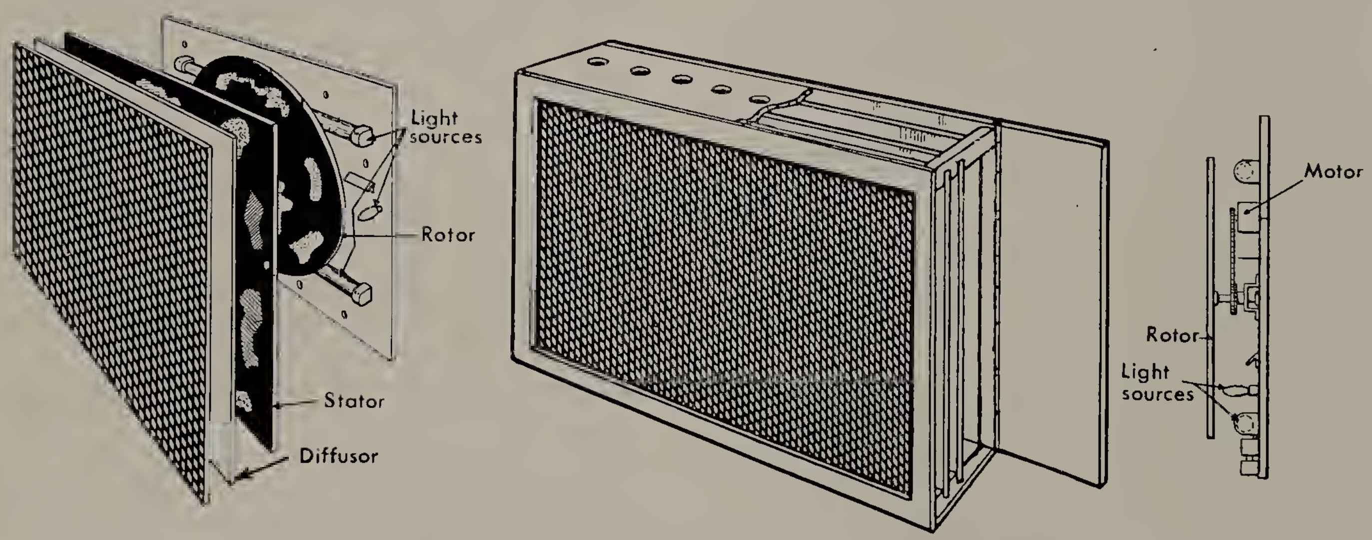

Fig. 1. Diagram of the Lumidyne system.

It is not difficult to produce interesting visual phenomena but to develop a skill for producing a controlled expression of the artist's intention is another matter.

For several years it was very difficult for me to dissociate my mind from the technical aspects of the Lumidyne while making my kinetic paintings. It was as though a composer for the piano were excessively conscious of the mechanism which causes the strings to make the sounds.

It is interesting to note a tendency in the kinetic art world to give great importance to the technical means for producing kinetic art objects. Until very

mm is used. Color contrast can be increased by adding a plate of 'black' glass or 'neutral' plastic material in front of the translucid Diffusor plate.

A practical advantage of this system is the possibility of keeping the depth of the case to around 13 cm. This permits a Lumidyne painting to be hung on walls in the same way as traditional paintings.

The case can be designed to allow easy replacement of the Stator with one of different design in order to produce a different kinetic painting with the same or a different Rotor.

The motion of points and areas of light on the Diffusor is determined: (a) by the motion of the

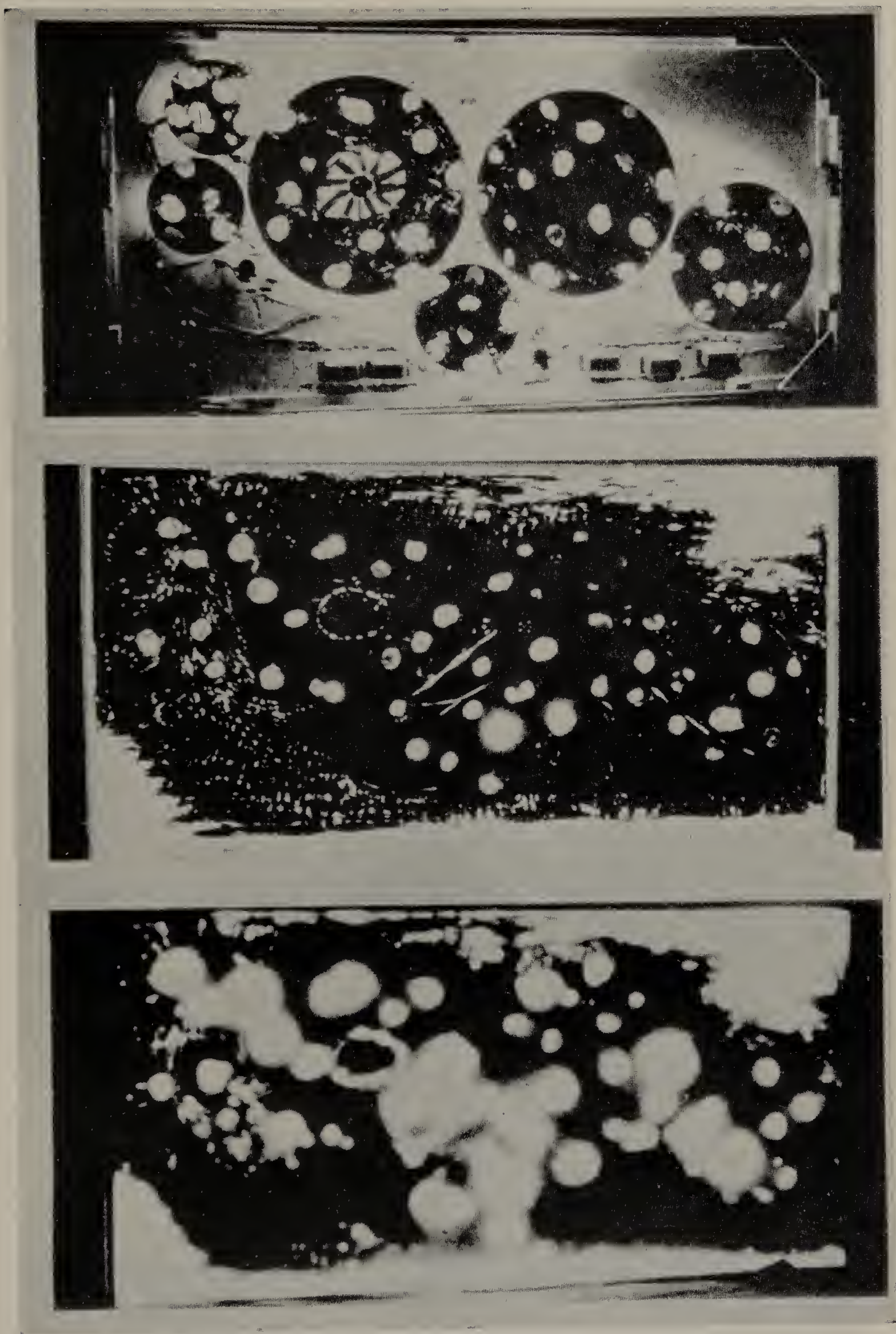

Fig. 2. Three stages in making a Lumidyne kinetic painting. (Photo: Richard Hardwick.)

Rotor, (b) by the arrangement of opaque and transparent areas on the Rotor and Stator and (c) by the distance between the Stator and the Diffusor. For example, consider the case in which the whole of the Stator is painted with opaque paint except for a fine vertical line intersecting the center of the Rotor, and the whole of the Rotor is painted opaque except for a fine curved line bent in a direction opposite to that of rotation from the centre to the edge of the Rotor. Then, when the Rotor makes one turn, on the

Diffusor a point of light will be visible which moves vertically upward from the center of the Diffusor until it disappears at the top edge to reappear again at the center and move downward until it disappears at the bottom edge. In this way rotational motion can be converted into translational motion.

If radial opaque bands are painted both on the Rotor and Stator then a rotational movement will result on the Diffusor in a direction opposite to that of the Rotor. This effect is especially pronounced when a line source of light from fluorescent tubes is used.

The distance between the Stator and Diffusor determines the amount of displacement of the light areas on the Diffusor. The more this distance is increased, the less defined will be the radial opaque lines of the Stator on the Diffusor. I have generally separated the Diffusor from the Stator by a distance of about 2 cm.

It is thus possible for an artist to produce a complex, controlled motion in various directions on the Diffusor pictorial surface even though the Rotor rotates in only one direction.

When a structure of fine transparent lines is made on the Rotor and on the Stator, with light originating from clear incandescent bulbs, a pin-hole camera effect is obtained that causes the filaments in the bulbs to appear on the Diffusor in the form of moving bright calligraphic-type characters.

Color changes are brought about on the Diffusor by painting transparent color areas on either the Rotor alone or on both the Rotor and Stator.

Fig. 3. 'Two Figures VI', kinetic painting, Lumidyne system (one Rotor), 60 × 80 cm, 1964. (Photo: Marc Vaux.)

Fig. 4. 'Paths in Space', kinetic painting, Lumidyne system, 100 × 200 cm, 1962. Reproduced in color on the back cover.

Color combinations result, for example, when a yellow area on the Rotor passes a blue area on the Stator to give a green area on the Diffusor.

By utilizing the principles described above it is possible for an artist to produce on the Diffusor a complex picture of moving light areas and changing colors within the fixed composition painted on the Stator.

2. Method of painting

I have used the following method in painting a Lumidyne. Usually I have a general idea of the composition and the types of motion to be incorporated. A Lumidyne requiring several Rotors and a number of light sources necessarily demands, before its construction, an idea of its ultimate form in order to decide the location of the lights, Rotors and motors on the back board.

It is after the lights and Rotors have been installed that the moment comes to paint designs on the Rotors for producing the desired motion and the basic composition of the Stator. At this stage I use black gouache, mixed with an indelible gouache to facilitate adherence to the plastic surfaces, and I continue to make changes in the design and composition until I am satisfied with the result viewed on the Diffusing Screen. In this sketch stage I use colored cellophane attached with cellophane tape to the Rotor and to the Stator to obtain color effects and changes on the Diffusing Screen within the composition.

The next step is to mark with a grease pencil the designs and colors on the Rotor and the Stator on the unpainted sides of these parts. The cellophane is removed and the gouache paint washed off. The final step consists of painting the opaque portion of the designs with black-board paint and the colored areas in transparent oil paint. Changes can also be made in this final stage until the painting is completed. Examples of completed Lumidynes are shown in Figs. 3 and 4.

3. Variations of the basic Lumidyne system

For large kinetic paintings a number of Rotors of different diameters and rotated at different speeds may be used as shown in Fig. 2.

Rotors may be mounted so as to overlap, and two Rotors may be mounted on the same axis to rotate in opposite directions. The problems of controlling the motion and the color changes on the Diffusor in these cases become very difficult. I have also given consideration to the possibility of replacing the Rotor by a transparent continuous belt and by a surface given a complex motion by various kinematic mechanisms.

Special effects can be caused on the Diffusor with the basic Lumidyne system by placing opaque or transparent materials between the Stator and the Diffusor. A kinetic circular column utilizing the Lumidyne system is shown in Fig. 5.

Three-component Lumidyne paintings may also be made without the use of a Diffusor by painting a traditional opaque picture on the Stator with transparent lines and areas. In this case the variety of motions that can be introduced is more limited, and the visual quality of the picture is sharper and 'colder' (Fig. 6).

III. CONSIDERATION OF THE PICTURE PRODUCED BY THE LUMIDYNE SYSTEM

1. Motion

The age-old craving of artists to express their emotional response to real movement has led to various attempts to give the viewer a sense of motion in static artifacts. An animal has been painted in a pose that could not be maintained in repose; symbols such as arrows have been used to indicate direction of movement; the Futurists made use of blurring effects and of a multiple reproduction of objects of the kind produced by the stroboscopic effect; the moiré effect has been applied which requires the viewer to move in order to see changes in the picture; and optical effects have been introduced which give an illusion of motion.

In this paper I shall use the word *motion* in the generally accepted scientific sense of the continuous change of position of a body or image, relative to a fixed reference point. Motion is characterized by displacement, velocity and acceleration. Furthermore, since the human eye is capable of perceiving only motion of a velocity very much smaller than the velocity of light, Newton's laws of motion are adequate for the discussion of kinetic artifacts, if mass of moving parts is important; in a Lumidyne, principles of kinematics rather than of dynamics apply.

I shall not attempt to list at length or to classify the kinds of motion that impinge directly upon the human eye or of which human beings have made mental constructs. Perhaps the first motion that intrigued man was the movement of animals, since the earliest known wall paintings were concerned with them. It is also likely that the movement of flames of a wood fire attracted man's attention from the time that man learned to control fire for his own purposes. The fascination of flames persists in our day from the moment a child can begin to distinguish the external world until, when grown old, one sits staring at the flames in an open fire. To the play of firelight and the reflections of sunlight has been added in recent times the continuous motion of light and intermittent light signals produced by electrical means.

The motion of water in streams, of wind blown waves on the sea, rain water running down a windowpane, the complex cantilevered flat-spring type of motion of vegetation—leaves, branches, trees, grass—caused by the wind, challenge man to express them in the form of art.

In our world, machines have been constructed which, while serving man, undergo movements of great variety—translational motion of changing speeds as in the automobile, rotational motion of the aircraft propeller, motion in space of a crane hook at a shipdock or at an excavation for a new building. Some motion of machines we not only perceive visually, but we also feel them physically, as for example acceleration in an automobile or an aircraft.

Finally, there are motions which we cannot perceive directly, such as the motion of bodies at a great distance from the earth and at the interior of the atom. The scientist and artist are able to give an appreciation of some of these motions by resorting to abstraction and illusion.

It is well known that some kinds of motion may lead to unpleasant physical and psychological effects. Sea and car sickness are not uncommon experiences. Moving bright lights can be very disturbing. The unbalanced feeling caused by the difficulty of focusing the eyes on an object in which the moiré effect is present has become well known to artists that have used this effect.

Certain movements of light have been observed to cause an effect resembling hypnosis. In France a

Fig. 5. '*Kinetic Column*', *Lumidyne system*, 158 cm *high*, 1961 *revised* 1967.

device called the *Somnidor* is manufactured which the maker promises will bring sleep to insomniacs. In this device an illuminated form appears and disappears on a small translucid screen. The subject is told to look at the screen and to breathe at a rate corresponding to the periodic movement of the illuminated form until sleep results.

Although considerable work has been carried out in the field of experimental psychology on visual perception, G. H. Groharn concludes his article on the subject in the *Handbook of Experimental Psychology* with these words: 'It still has a long way to go. Improved experimentation performed with attention to problems of specification and designed to provide a broad base for theory, will hasten the day when psychology will be provided with an inclusive system of relations to define and explain the phenomena of this important field' [8].

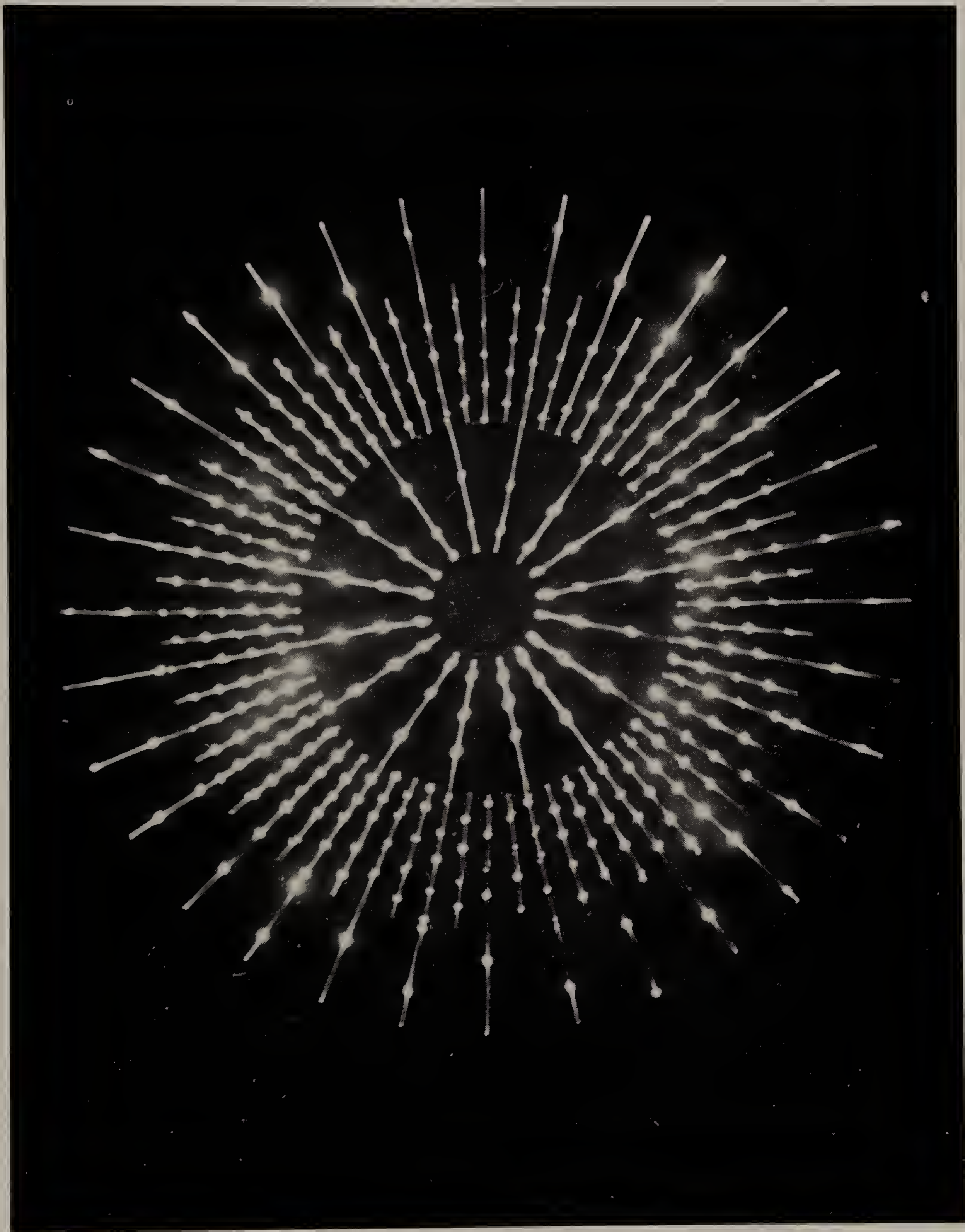

Fig. 6. 'Sink and Source', Three-component Lumidyne system (one Rotor), 60 × 80 cm, 1966.

Recently J. J. Gibson and R. L. Gregory published books dealing with the visual system and the psychology of seeing that are of the greatest interest to kinetic artists [9, 10].

2. Color

In kinetic painting an artist is primarily concerned with the visual stimulus of transparent color produced by man-made light on a translucid surface. Until this century the use of transparent color was limited in the domain of art to stained glass windows and artifacts made of glass, and the visibility of the colors has been dependent mainly on light originating from the Sun.

For this reason the degree of human appreciation of transparent color has been relatively undeveloped compared to sensibility to opaque color. A person is eapable of noting very fine differences in color hue, saturation and brightness in opaque paintings which reflect light to the eye. Color cinema, transparent color photographs and color television are now greatly increasing our familiarity with transparent color.

One should note that in the Lumidyne system, in gencral, the rules of color mixing are those for colored pigments, since the same light passes successively through the transparent pigments on the Rotor and the Stator. That is, the color seen on the Diffusor is a subtractive mixture because each pigment subtracts its quota of energy from thc original light [11, 12].

It is my impression that all color combinations adjacent to each other produced by the direct transmission of light onto a translucid surface (the Diffusor) are pleasing to the eye. In other words, certain color combinations do not appear to clash as they do when opaque pigments are used in painting.

3. Change with time in a Lumidyne painting

As I pointed out in the introduction, the Lumidyne system produces a picture with movement and changing colors within a fixed composition (cf. Fig. 3). In the simplest arrangement, where a single Rotor is used, there is a definite cycle of events which is repeated each time the Rotor makes one complete revolution. If the Rotor turns very slowly, say one revolution in five minutes, the motion of light becomes practically imperceptible to the eye, and the observer becomes conscious only of changing colors in the picture. As the speed of motion is increased by speeding up the Rotor, the various motions of light points and areas dominate the changes in color.

The problems of aesthetics of motion only become relevant when the speed of motion exceeds some lower threshold value. For example, the motion of an hour hand on a clock poses no aesthetic problems of motion. In the same way, one can expect a lower threshold for the rate of change of color with time at which problems of the aesthetics of color change arise. For example, the color changes taking place between sunrise and sunset are not perceived as a dynamic process, but rather as a series of static states. (An exception to this is experienced by the outdoor painter, who experiences frustration because colors change more rapidly than he can make a static respresentation of the scene he has selected.)

It is interesting to note the period of time persons spend looking continuously at an art object. Studies of this factor have been made by experimental psychologists. From my experience, I find that even for persons who have a highly developed consciousness of visual artifacts a period of one to two minutes is a very long time.

This compares with the capability of persons to watch the cinema, theatre or television for much longer period of time. This is probably due to the fact that such a wide variety of visual and emotional content is presented, and that a story or plot helps to sustain prolonged mental attention. On thc other hand, there are few productions that persons wish to see more than once.

It is for these reasons that I doubt that a kinetic art object, which is designed for intimate individual viewing, should follow the pattern of theatrical media. If a story or a well defined plot in time is imposed on a kinetic painting or thc painting is not rich in variety of motion and color relationships and changes, then the viewer will soon feel he knows all the answers, and interest in the art object will decline rapidly.

It is possible for the viewer of kinetic art objects to become much bettcr acquainted with motion and color changes than it is for the viewer of cinema or television, for in the latter it is rare that a re-run of a particularly intriguing portion is made.

4. Aesthetic considerations

As I pointed out in the Introduction, the visual artist has long been concerned with real motion and real light, however only in recent times have technical developments provided the means that permit an artist to work directly with these aspects of the visual world without resorting to illusions of them.

There have been objections raised to the use of motion in works of art for intimate viewing because it is felt that static painting and sculpture already give an illusion of motion. Furthermore, the arrangement of forms by the artist imposes movement of the eyes of the observer. But what is overlooked, in my opinion, is the fact that a kinetic painting, in addition to stimulating the visual reactions of a static painting, provides visual experiences of real motion and of color changes.

Aesthetic guide lines for the kinetic painter have not as yet been formulated. The artist therefore searches empirically for satisfying visual experiences. It is helpful to take into account the long experience of man with the dance and the theatre and with his recent experience with cinema and television. However, the adventurous and curious kinetic painter finds many surprises and challenges in this little explored domain.

Articles on kinetic art using a vocabulary developed for traditional painting do not appear, to me, to be adequate [4–7 and 13–18]. The problem of verbal description is further complicated by the fact that reproductions in two-dimensional form by photographs or drawings cannot transmit the experience produced by kinetic artifacts.

IV. CONCLUSIONS AND ACKNOWLEDGMENTS

The Lumidyne system, which I have described, has proved, after ten years of experience with it, a practical, controllable and economical artistic medium.

It is suitable for expressing a wide variety of subject matter involving motion and color changes. The more than 100 kinetic paintings that I have made with this system range in size from 25 cm × 25 cm to 3 × 3·5 m.

The system allows an artist to impose his own style on the visual experience finally produced. Aesthetic principles are still only vaguely understood and provide a challenge for their analysis and formulation.

I wish to express my appreciation to John Villemer for his technical assistance during the development of the Lumidyne system in 1956. Nino Calos aided me greatly between 1957 and 1966 in the mechanical construction of my Lumidynes. Since 1957 he has himself created and exhibited a large number of kinetic paintings utilizing the system. Reginald Weston, Vic Gray, Reginald Gadney and Didier Bouchet have also worked in my studio with the system.

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THE 'CHROMATIC ABSTRACTOSCOPE': AN APPLICATION OF POLARIZED LIGHT

Carlos Martinoya* and Nahum Joël**

Both of us are physicists at the University of Chile where we developed an interest in devices capable of producing results with physical phenomena comparable to the works of abstract painters. This interest led to a rather exciting experience which we would like to communicate in this note‡

An open air exhibition of the visual arts (Feria de Artes Plasticas) was held in Santiago, in a park along the river Mapocho, in December 1960. This annual exhibition is an important event in Santiago, and, as scientists with an interest in the fine arts, we decided that it would be a good occasion for showing to the public some form of expression that might constitute a bridge between science and art.

We thought that the colours obtained through the interference of polarized light by birefringent crystals would provide a good example. In polarized light the transverse vibrations are restricted to certain special directions; for instance, in plane polarized light they are all in one plane. A polarizing material, such as Polaroid sheet, has the property of transmitting only those transverse light vibrations that are vibrating in a certain plane. A birefringent material splits a wave of light into two waves that propagate through the material with different velocities, thus giving rise to interference effects which when polarized light is used produce colours.

Both of us had on many occasions demonstrated this well-known effect to our students of physics and crystallography; their reaction made us think the general public might also enjoy seeing it.

When discussing the programme and technical details of our 'show', we decided that in addition to demonstrating experiments of crystal growth by means of polarized light, we would also replace the crystals with colourless cellophane sheet (another birefringent material). When pieces of cellophane that have been folded and crushed into various shapes and textures are viewed between two sheets of polarizing material they form patterns rich in colours similar to those made by crystals. These colours undergo striking changes when either one of the polarizing sheets or the cellophane piece is rotated or tilted. Furthermore, the colours also change if a single cellophane sheet, or several layers of sheet, are inserted between the polarizing elements. A great variety of coloured abstract pictures can thus be created.

The next step was to make it possible for these abstract pictures to be seen by projecting them onto a screen, so that many spectators could see them at the same time. This we did simply by enclosing the cellophane pieces in cardboard or plastic holders used for projecting 35 mm slides. Two pieces of polarizing material, a slide projector and a screen was the only equipment required. Our show was beginning to take shape—we got a supply of holders and of cellophane with which the spectators could compose their own pictures.

At this stage of our planning we felt that an automatic device should be built which would continuously vary the composition and the colouring of a projected picture on a screen.

This was achieved with a device consisting of three colorless glass disks of different diameters that were rotated slowly by an electric motor (Figs. 1 and 2). Cellophane patterns were glued to the glass near the periphery of each disk. The three parallel axes of the disks were fixed so as to allow the disks to overlap over an area of about 5×5 cm. This area was then masked by means of a standard 35 mm slide frame. Light from a 500 W projector passed through an element of polarizing material and then through the framed area of the overlapping disks. The image of the composite pattern was focused on a screen by means of the projector lens. The second piece of polarizing material was placed in front of the projector lens, and rotated by the same motor that turned the disks. The angular velocity of each rotating part was arranged so as to make no repetition of the projected pictures during several hours of operation. In Figs. 3a and b and in Fig. 4 are shown compositions that occured during the cycle.

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‡This paper was written in 1961. Since then the authors have become aware of the work of Munari, Olson, Dantu and Malina who have also used polarized light. See, for instance, the articles by Frank Popper and by Reginald Gadney in *Kinetic Art* (London: Motion Books, 1966). (Received 4 November 1967).

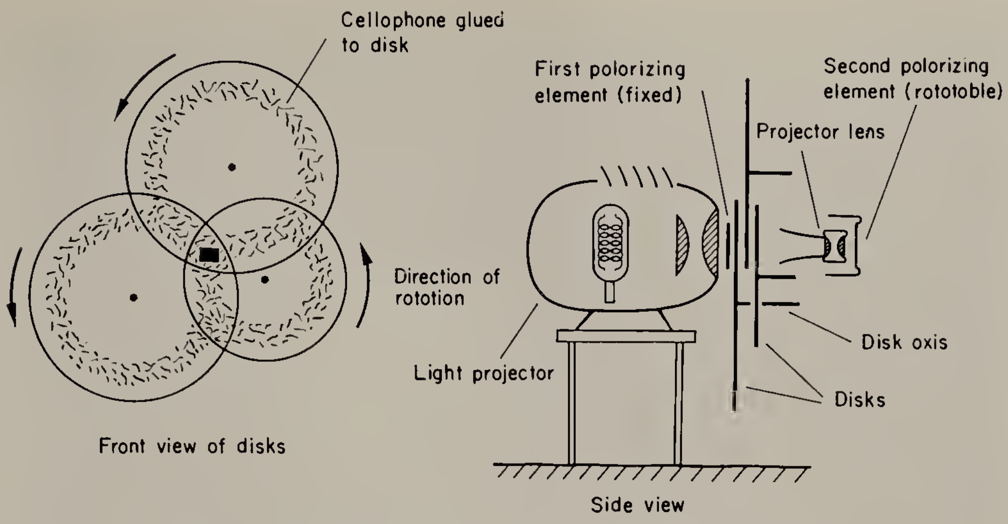

Fig. 1. *Diagram of the 'Chromatic Abstractoscope'.*

We called our machine a 'Chromatic Abstractoscope' and, for the benefit of the general public, we added the subtitle 'the Robot of Abstract Painting'. We were very curious to see the reaction of artists and the general public to our machine-produced abstract pictures.

Our show at the exhibition was presented by means of a threefold projection system. One third of a wide screen was devoted to a continuous performance of the 'Chromatic Abstractoscope'. On the second part, the spectators could project their own creations using the sheets of cellophane in the slide frames we had provided. The third part of the screen was used for demonstrating crystal-growth experiments, which were interrupted at intervals by a series of slides explaining the scientific principles of the interference of polarized light. The mechanism of the 'Chromatic Abstractoscope' was also described. The slides included a graded sequence of simple cellophane patterns for illustrating each aspect of the phenomenon described.

As our show took place in the open air, we began after sunset and continued it for 2 to 3 hours. The spectators showed a greater interest than we had anticipated in both the scientific and the aesthetic aspects of our demonstration. They read and listened attentively to the scientific explanations, asked questions and were especially excited by the crystal-growth experiments that were projected on the screen. They shared our fascination in the optical study of crystals in polarized light. They also learned how to produce these effects without using

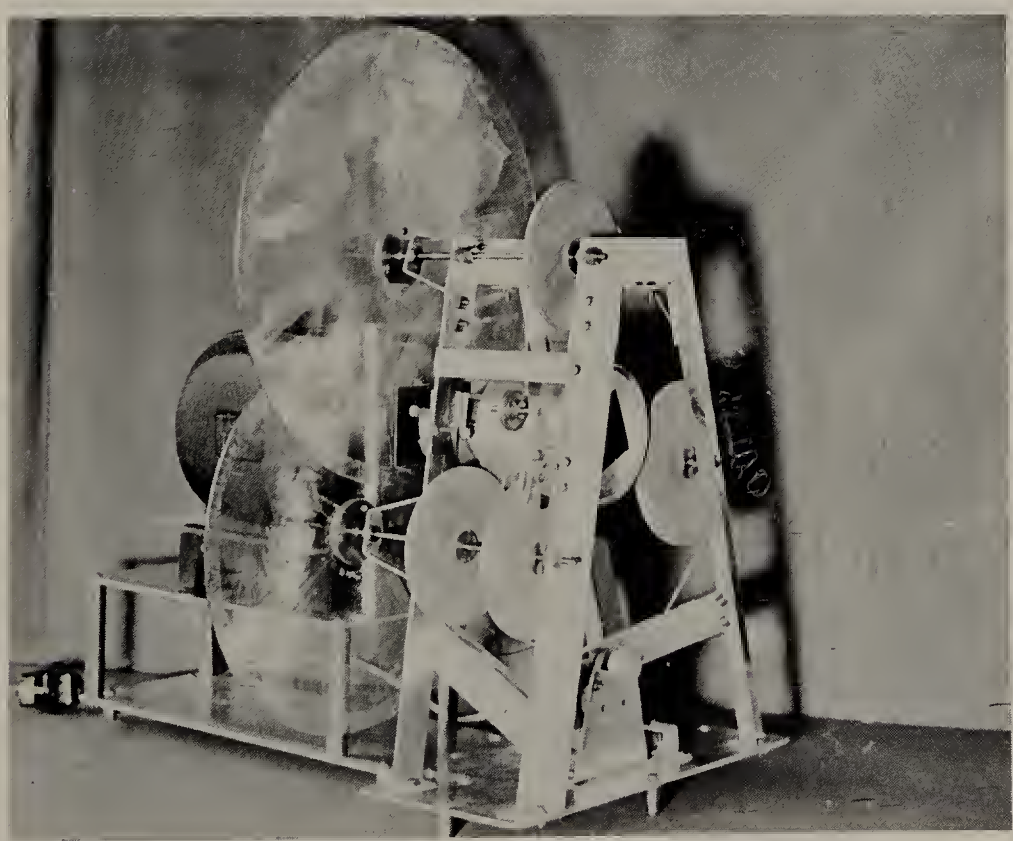

Fig. 2. *View of the 'Chromatic Abstractoscope' model.*

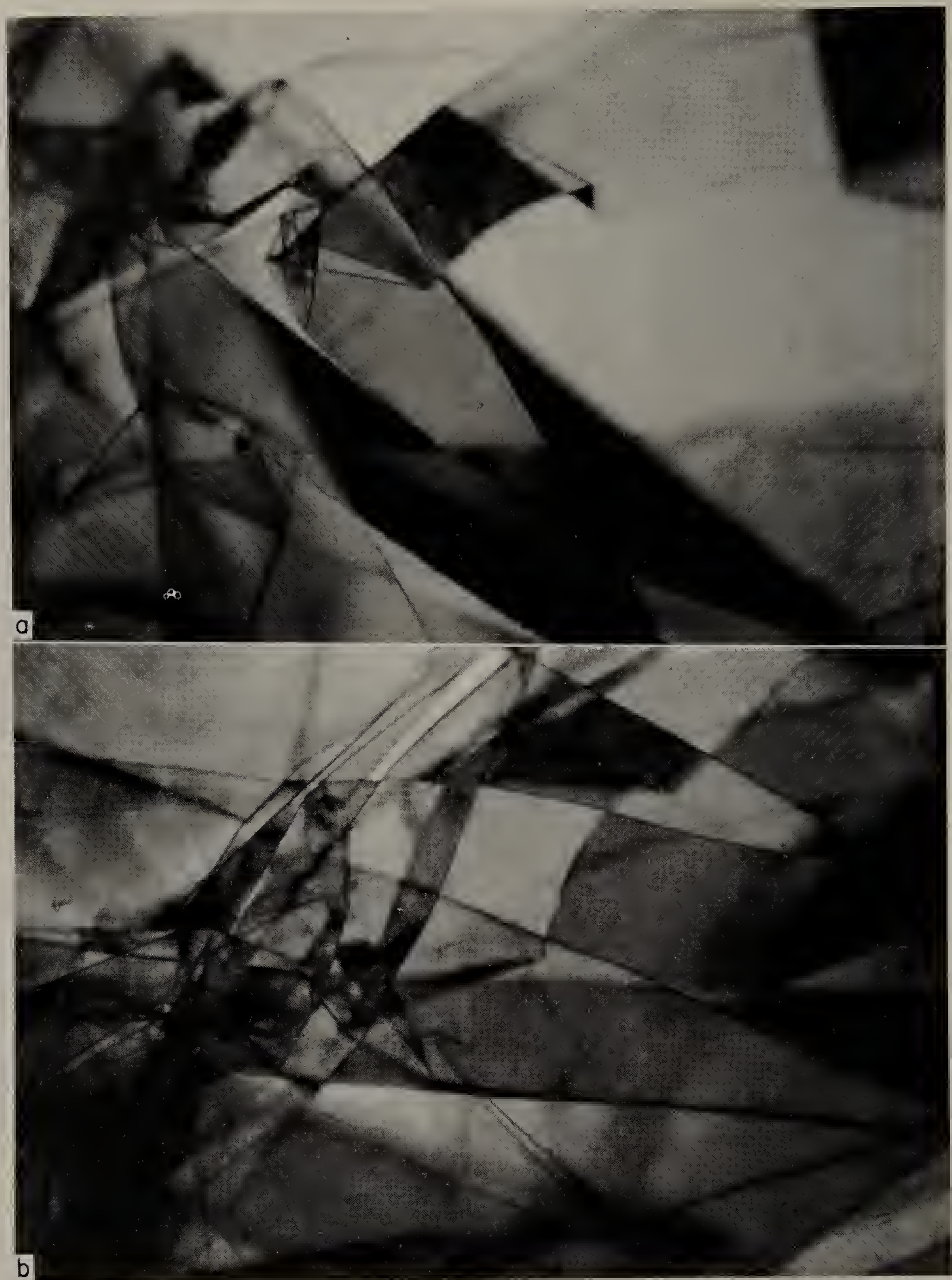

Fig. 3. *a and b. Two pictures projected by the 'Chromatic Abstractoscope.'*

man-made polarizing material, for example, with the partially polarized light of the blue sky and with light reflected by glass or a surface of water.

The spectators responded avidly to the challenge and composed a great number of cellophane shapes in the slide frames. This became a very popular form of spectator participation in creative aetivity. We found that children produced the most daring compositions. Everyone was amazed that it was so easy to compose such unfamiliar abstract pictures with such unexpected colour combinations.

We noticed that now and then a spectator began to develop a style of his own. Some tried to guess what colours an arrangement of cellophane would have on the screen. Nearly all were puzzled by the fact that such a great range of colours could be obtained without the use of coloured material (filters), and that the colours all disappeared when one of the pieces of polarizing material was removed.

Some artists felt that we were only demonstrating another undesirable intrusion of science into art. Most of them, however, were impressed and saw in the 'Chromatic Abstractoscope' a powerful source of artistic inspiration.

Fig. 4. Example of three compositions projected by the 'Chromatic Abstractoscope'. Reproduced in color on the inside back cover.

'LIFE': FROM DRAWING TO PAINTING TO KINETIC PAINTING

Masako Sato*

Fig. 1. 'Life', ink on paper, 32 × 49 cm., 1969.

It seems to me that people in Japan and other industrialized countries are submerged and perhaps lost forever in a mechanical civilization. It is no longer religion, but the sciences which tend to direct personal and social mores. People seem to be looking mechanically for happiness in what should be an earthly paradise, where they live selfishly within the limits of the law. Because of the material pleasures brought to society by technical progress, the spirtual aspect of man is neglected. This is the kind of society I live in.

But this is not all. On one hand, machines require masses of servants. On the other, man surrounds himself with machines like armour to protect him, only to find that they absorb and dominate him. Not before people become unhappy with this situation will they try to build a more harmonious society. I have tried to find harmony through art: it is my response to the life I have known. I have learned to use both the traditional tools of the artist and some of the new ones that modern technology has provided.

Recently I made a series of pen and ink drawings entitled 'Life' and wrote a poem for each of them in Japanese. One of these drawings is shown in Figure 1 and its poem is along the following lines:

As if one knew everything
as if one could see everything
as if one could conquer everything

in fact, we know nothing
the fish in the sea teach us
that we roll as do stones in a river

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strange is the hand of man
in each fingerprint are
found the wrinkles of civilization

my child which is yet to be born
is it a girl or a boy

is its outline smaller
or larger than
that of a
gorilla?

ah!
my fingernail will shed itself
the eye stays on the horizon

quiet as if there were nothing
the ball thrown by the devil
came in by the window today

whilst I dream about the unknown
about to be born in a test tube
I know nothing . . . what?
what? I know nothing.

Afterwards, I used the drawing as a point of departure for an oil painting. In transposing the drawing, I did not give much attention to details but tried to capture the feelings that brought it to life. The oil painting is shown in Figure 2.

When I saw a large group exhibition of kinetic art in Paris in 1967, I was deeply moved. The play of light and shadow, which is applied in various traditional ways almost unconsciously by the Japanese in their daily life, was systematically used by some of the artists. It was a kind of art that seemed to be adequate for our modern times. The kinetic paintings of Frank J. Malina [1] and Nino Calos [2] , in which one contemplates the motion of electric light images and their changes in color on a transparent screen, particularly intrigued me.

As no art school in Paris taught the various techniques used in kinetic art, I asked Malina to guide me. He showed me his kinetic paintings, some of which used his Lumidyne system, others a system for reflecting moving light images on a screen with a technique similar to that developed by Thomas Wilfred, still others again in which polarized light was applied. I decided to try to make some paintings with the Lumidyne system. Malina very patiently explained to me his technique in detail. A Lumidyne case was made for me in Malina's studio by Valerious Caloutsis, a

Fig. 2. 'Life', oil on canvas, 64 × 85 cm., 1969.

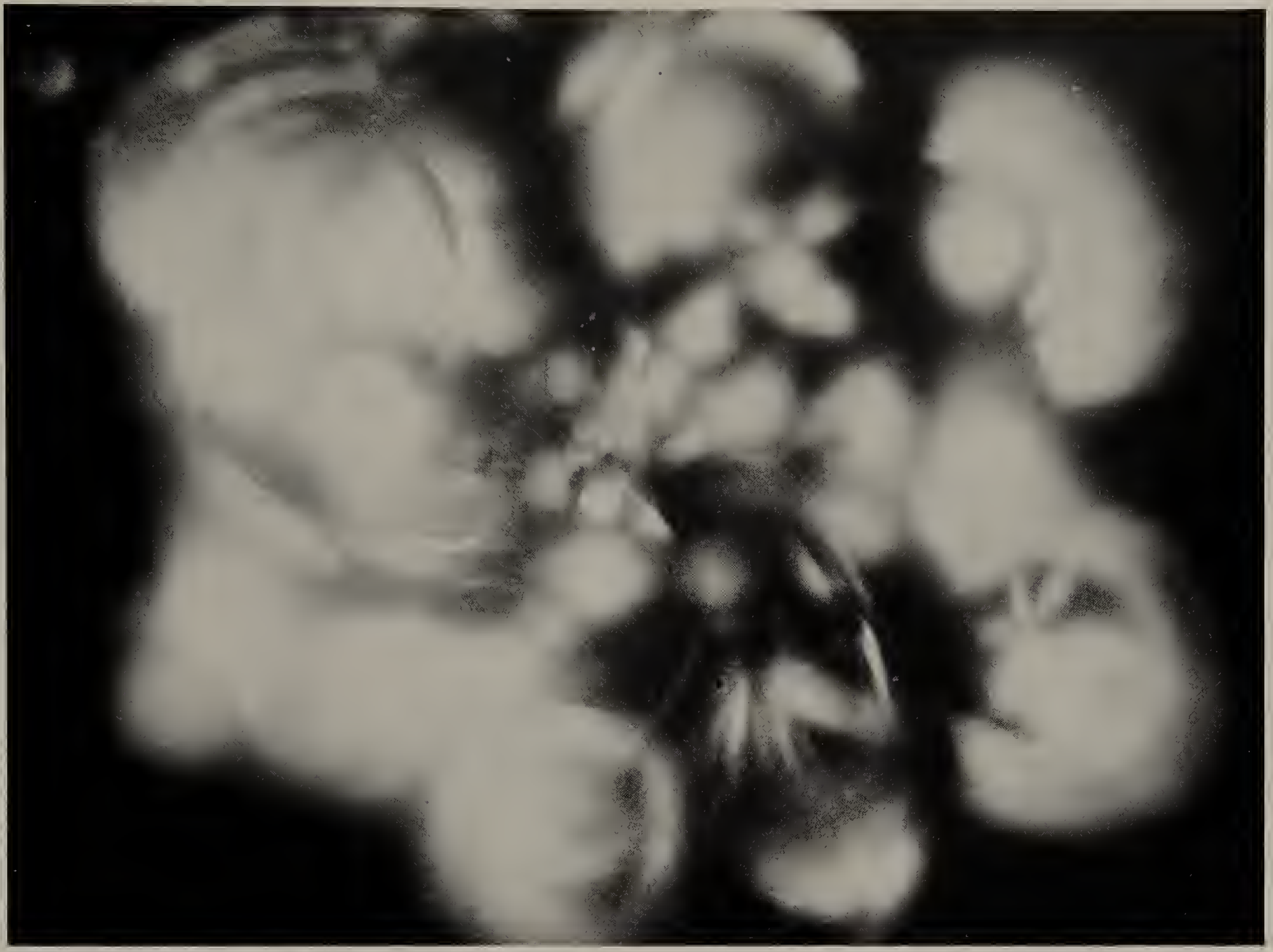

Fig. 3. 'Life', kinetic painting, Lumidyne System, 60 × 80 cm., 1969.

Greek kinetic artist living in Paris. It only remained for me to concentrate on painting the elements of the system that produce the final kinetic picture on the translucent screen. Here again, as in transposing the drawing in Figure 1 into the oil painting in Figure 2, I very freely interpreted the oil painting and Figure 3 shows a moment in the cycle of the kinetic painting.

I have now learned much about producing this type of kinetic painting. It is not as easy as one might think. A kinetic painting that satisfies me is not a matter of chance but the result of many careful changes to the two painted elements in the Lumidyne system. The continuous motion present in a kinetic painting expresses for me one's mental struggles but, at the same time, the gentle motion gives me a sense of peace. I feel that through this new form of art a kind of friendship will be developed between a work and those who contemplate it.

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IMAGES OF TRAJECTORIES OF MOBILES BY MEANS OF PHOTOGRAPHS AND CINEMA: METAFORMS

Etienne Bertrand Weill*

Abstract—*The author tells of his interest in conveying the feeling of motion by means of still photographic images. He has constructed simple sculptural mobiles for use as moving subjects for photography. These static images on photographic prints or slides he calls* metaforms. *Simple forms made of wire, paper, wood, etc. suspended by a thread and forms suspended in a manner of some of Calder's well known mobiles are preferred. A wide range of metaforms may be achieved by varying the design of the mobile, its kind of motion and speed, and the photographic technique.*

He also makes a form of kinetic art with cinematographic film and with the diaprojection of series of metaforms.

The author feels that an analogy between metaforms and music can be found. He has begun collaboration with a musician on the simultaneous composition of music and metaforms for diaprojection.

I. INTRODUCTION

My interest in motion from an aesthetic point of view was first kindled in 1948 when, working as a photographer, I wanted to make still photographs of actors, mimes and dancers in motion. It was immediately apparent to me that there were not only the technical problems of photography but also the problems of how to convey the feeling of motion that the spectator experiences and the message of the performer.

I began by taking pictures of performers with my camera in a fixed position, intentionally keeping the shutter open during moments of interesting motion. Thus, by deliberately obtaining blurred photographs of moving arms, legs, bodies etc., I succeeded in introducing the element of time in my work (Fig. 1).

Marey confronted the problem of capturing motion in 1882 by devising his *chronophotograph* [1]. Some artists who wished to give an illusion of motion in static painting (Duchamp) used still photographs as a source of their visual conception in painting and some, for example Survage and Richter [2, 3], were influenced by the new visual experience of the cinema. The stroboscopic technique, in particular, proved to be effective in producing a feeling of motion in a still photograph. Since emulsion speeds were much slower in the early days of photography, motion effects were sometimes unintentionally apparent, for example, in the photograph taken in 1859 of French soldiers returning to Paris from Italy [4]. In 1947, it appears that Mac Kenny purposefully used slow emulsion film for his photographs of ballet [5].

In about 1956, I decided to go to the root of the problem by constructing my own moving objects (small sculptural mobiles or kinetic sculptures), photographing them in motion and studying the results. I then realized that I had come upon an unexplored field in visual art [6] that seemed inexhaustible. I was intrigued by the photograph of a mobile in motion, since the motion can be preserved as a blurred image *without* any distinguishable evidence of the mobile itself. The words of Klee became particularly significant to me: 'If you want a point to be in movement and become a line, time is necessarily implied, you cannot do without duration. The same applies to turning a line into a surface and surface into space' [7].

Thus, I began to work on what I call *metaforms* (static photographic images on photographs or slides of mobiles in motion, designed for the purpose) [8]. My first one was published in 1957 [9]. My first exhibition of metaforms was held in Paris at the Maison des Beaux Arts in 1962 [10, 11]. Later I made several cinema films of series of metaforms [10] and then produced a series of metaform slides for my *diaprojection* with poems [12, 13]. More recently I have been working on the diaprojection of metaforms with music [13, 14].

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Fig. 1. *'L'usine', black and white photograph of a mime by Etienne Decroux,* 1952.

II. MOBILES AND THEIR METAFORMS

I construct mobiles to produce images portraying a desired type of motion. The photographic images of motion that I obtain are dependent on the design of the mobile, the paths it describes, the speed of its motion, the film used and the camera setting. Having constructed a mobile and obtained an acceptable metaform, I continue my study of the movements of the mobile to obtain additional metaforms that are different yet related to the first one. Some mobile designs provide a very rich source of images.

I prefer to use linear elements in my mobiles because they generally lead to simplicity of form, yet they provide a great variety of images. These linear elements can conveniently produce transparent and delicate images (Fig. 2). One of my simple mobiles at rest is shown in Figure 3. The shape and surface characteristics of an element affect not only the pattern but also the texture of the metaforms. Since an element does not change in shape during motion, the images obtainable tend to have a similar character. That they may be so

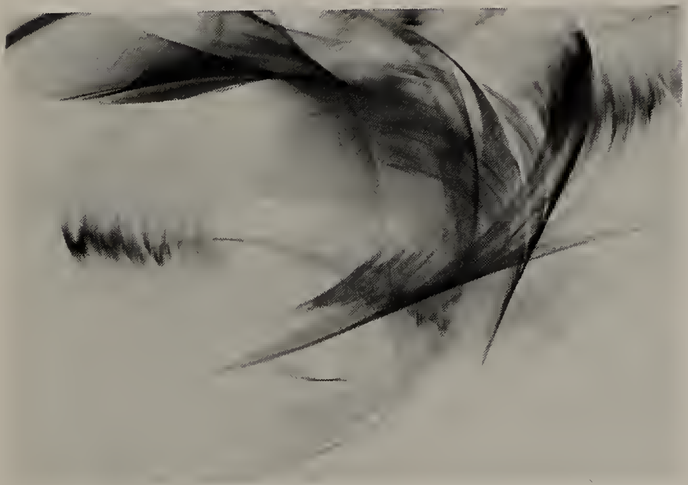

Fig. 2. *'Le vent se lève', Metaform, black and white photograph,* 1965.

Fig. 3. *View of a mobile at rest. (See Figures* 8 *and* 9 *for metaforms made from it.)*

Fig. 4. *'Magnificat', Metaform, black and white photograph,* 1963.

can be seen from the metaforms shown in Figures 4–6 each of which was made from portions of the same mobile.

In principle, the elements of a mobile can describe an infinite number of paths. The types of motion of the elements can be divided into three broad categories: (a) rotational, (b) pendular (torsional) and (c) pendular (planar). Further subdivision is possible within these categories and an analysis of them probably would be of value in revealing the choices available to an artist for obtaining desired results. I prefer a pendular (torsional) type of motion for my metaforms because I sense a relationship between this kind of motion and certain kinds of motion in nature.

My simpler sculptural mobiles are single elements suspended individually by a thread (Fig. 3). In my more complex mobiles, involving two or more elements, the elements each have interdependent suspensions such as Calder generally employs in his mobiles [15, 16]. For color photography, I employ elements of different colors or I project light of different color on them. Examples of metaforms obtained by projecting colored lights on mobiles are shown in Figure 7 and in References 14 and 17. A small uni-directional variable-speed motor drives the mobile. Long practice has taught me how to regulate the speed of the motor but better success would undoubtedly be achieved if the speed were programmed. A reversible motor would also be useful.

The design of the mobile, the choice of its kind of motion and the regulation of its speed permit the reduction of the element of chance that otherwise would leave scant hope of achieving pleasing metaforms. I do not wish to eliminate the element of chance completely, however. Chance sometimes aids discovery although, I find, discovery rarely results from chance alone.

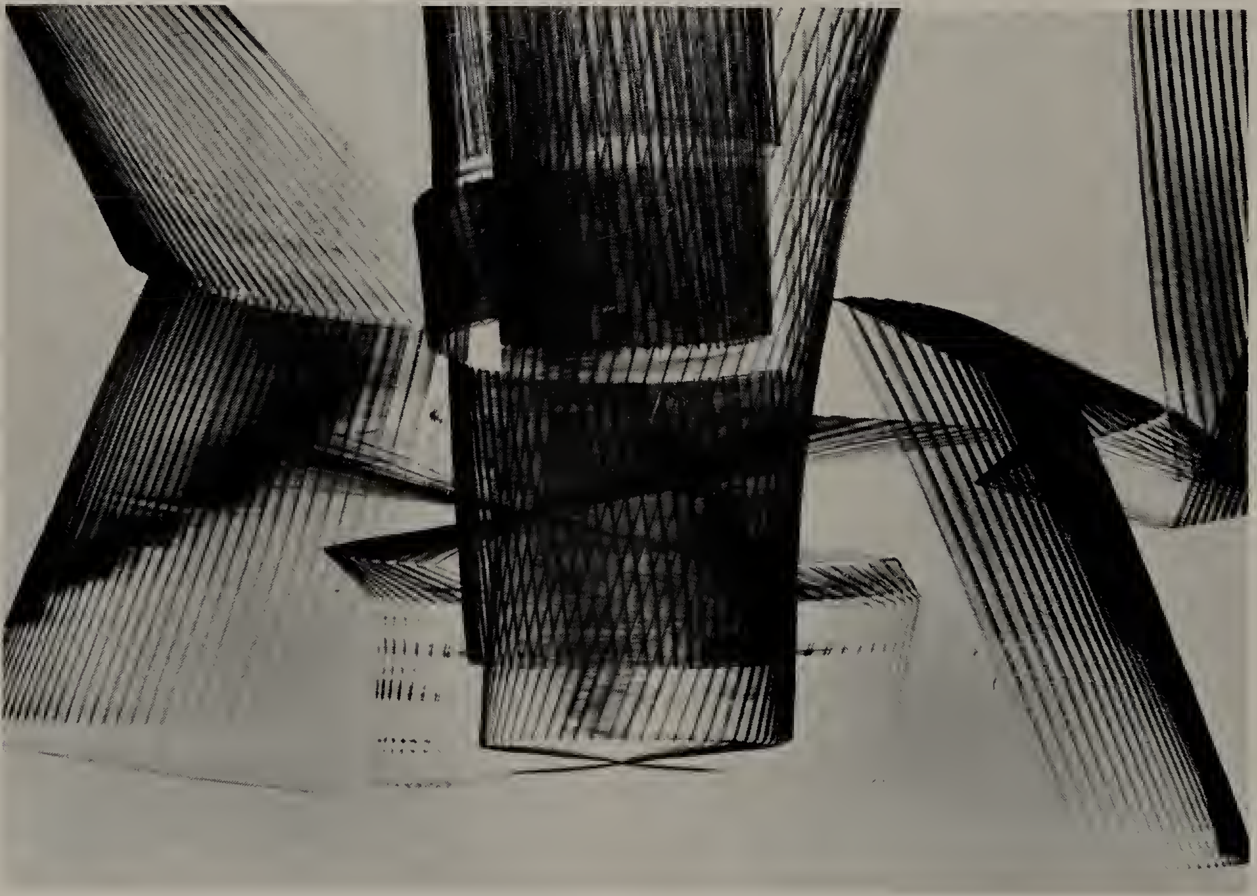

Fig. 5. *'Babel', Metaform, black and white photograph,* 1963.

Fig. 6. *'Justice', Metaform, black and white photograph,* 1963.

Fig. 9. *'Colère', Metaform, black and white photograph.* 1967.

Figures 8 and 9 illustrate two very different metaforms made from the same mobile but with a different kind of motion. The mobile had a rotational motion in Figure 8. Its motion in Figure 9 was complex and oscillatory and here a stroboscopic technique was employed in photography. Some printed metaforms and all projections of metaforms are characterized by a feeling of transparency. On the whole, metaforms also give a feeling of rhythm (Fig. 10).

I have made many metaforms as non-figurative pictures. They convey qualities that I deliberately intend. I am also interested in producing metaforms for particular applications such as in illustration and for decorative purposes in architecture. I have, for example, made a series of metaforms to illustrate Rimbaud's poem 'Le Bateau Ivre', one of which was published in a book on Rimbaud [18]. Some of my metaforms have been made for projection as background for poetry readings and for mime [19, 20], for ballet [21] and for stage productions [22]. I have used reproduction on aluminium sheet to

Fig. 8. *Untitled, Metaform, black and white photograph,* 1968.

Fig. 10. *'Figure couronnée', Metaform, black and white photograph,* 1971.

produce interesting effects. Metaforms with changing color can be projected onto walls to produce a special ambience. Sometimes panels may be made as a set of modules to be arranged in various combinations. In these cases collaboration with the architect would be desirable.

An interesting visual experience results when metaforms on cinema film or on slides are projected in sequence, with or without blending the transition from one metaform to another. This important aspect of my work is discussed in the following section.

III. CINEMA FILMS AND DIAPROJECTION OF METAFORMS

My interest with the cinematographic filming of series of metaforms began in 1960 [10]. This appealed to me because the projection of a sequence of similar metaforms obtained from a single mobile can show metaforms in motion, reminiscent of the motion of non-figurative forms in the early animated films of Richter [23] and more recently in those of Guthmann [24]. One interesting aspect of viewing metaforms in motion is that, unlike in films taken of events in ordinary life, the viewer has no preconceived idea of how metaforms should behave with the passage of time. The metaforms can be made to move at varying speeds and to have different rhythms. Rapid changes from one type of image to another, however, fatigue the eye and should be avoided. Metaforms with different patterns projected in sequence can be made to blend from one to another.

I have made several cinematographic films of metaforms but now work principally on the diaprojection of slides. Instead of a cinematographic film projector, I operate manually two or three slide projectors simultaneously. This permits me to obtain motion effects in a flexible manner and at a much lower cost. With programing and better projection equipment, swift changes and smooth transitions can be assured with, for example, ten or twenty projectors.

In my diaprojections, I employ several sequences of metaforms. The metaforms (and, indeed, the mobiles) that I employ in both cinema and diaprojection are always made expressly for the poem or the music that they are intended to accompany.

My method for making a cinema film or a series of metaforms for diaprojection is related to the methods used by some modern music composers (involving sketches and diagrams representing general outlines of a composition). I proceed as follows:

(1) Preparation of a diagram of the essential visual characteristics I intend to show as a function of time. On the diagram I usually indicate forms and colors, form discontinuities, and the rhythm and direction of motion.
(2) Construction of the necessary mobiles.
(3) Photographic study of the mobiles in motion.
(4) Final photography: preparation of the individual metaforms for slides or cinematographic films (occasionally I film the mobile directly on cinema film).
(5) Selection and programing of the metaforms in sequence and in time in accordance with the initial plan.

IV. INTEGRATION OF METAFORMS WITH MUSIC

The most recent and to me the most fascinating aspect of my work concerns the possible significant combination of visual images with sound. My long pursuit in presenting motion by diaprojection and by cinema has taken me along a path similar to one followed by a composer of music. So strongly do I feel this that when I am working I wonder whether I am composing music for the eyes or pictures for the ears.

Like many others, I find that there are striking similarities between various time characteristics of visual perception and of auditory perception [25–27]. The movement of metaforms and its rhythm can be related to sound progression and rhythm in music so that it should be possible to write a score for the visual experience of the kind I produce with metaforms.

A parallelism between sound and image seems to me to be very striking when a succession of metaforms is viewed while listening to music. I believe Schaeffer is right when he says that visual material presented while listening to music can be an undesirable distraction for the music [27]. However, I do believe that viewing metaforms can help one to appreciate music; at least a number of people have told me so.

I am now, therefore, studying sound-image relationships. I use photographs and cinematographic films to record a mobile in motion in a way analogous to that used to record and transform sound by means of magnetic tape in making concrete music [27]. Reference to a mobile used is lost. In addition, the metaform inherits from the mobile the capacity for change. The viewer is able to see the image of an object much the same way that psychologically a listener perceives what Schaeffer calls a 'sound object' [28]. Thus, the viewer of metaforms is detached from the real object in a way analogous to the listener of music, the origin of whose sounds is unknown. The aesthetic problem to be resolved is whether visual images and music can be wedded in such a way to give the viewer–listener a satisfying experience. Several artists working with kinetic art have studied the problem [27–29].

One can imagine a listener-viewer experiencing 'music' at once visual and auditory without attachment to an identifiable 'source'. Malina has called a version of this idea *kusic* [27, 29]. One would suppose that the spectator would 'listen' when seeing an image and 'look' when hearing the counterpoint of music. The effect would undoubtedly be heightened if a number of projection screens were employed, carefully placed about a room in relation to loud speakers. But, these are only speculations. Such studies would require a team of specialists from the fields of music, visual art, acoustics and psychology of perception.

I have made a modest start in this direction with very limited means to arrive at an ensemble of music and metaform slides. These have given me encouragement and I am now collaborating with a musician on a project involving the simultaneous composition of metaforms and music. My aim is to develop a kind of counterpoint between music and metaforms.

In conclusion, I wish to point out the interdisciplinary process in making metaforms. It involves techniques employed in several different arts. Photography is employed where the object photographed is not the object but the object's motion. The making of a metaform begins with design and construction. The study of the motion of mobiles and the determination of movement and rhythm in the programing of a diaprojection are akin partly to choreography, music composition and the preparation of a scenario. Thus, making metaforms involves small areas of several different artistic disciplines. This is what fascinates me.

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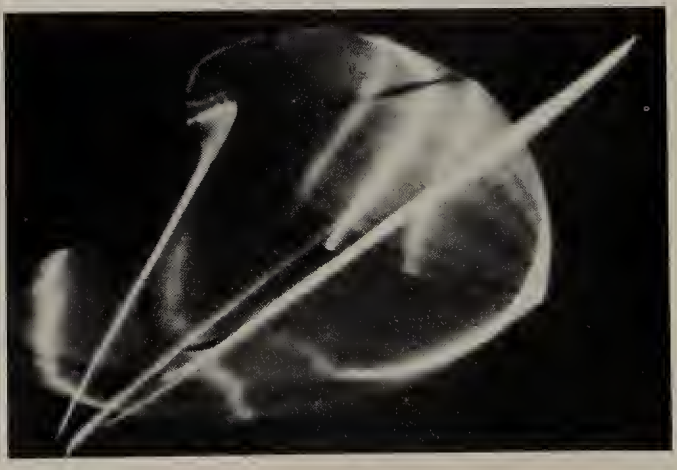

Fig. 7. 'Solo pour cuivre', Metaform, color photograph, 1961.

LIGHT SHOWS:
A KINETIC ART TECHNIQUE USING CHEMICALS*

D. R. Wier**

Abstract—*The author describes the production of a* light show *by projecting light through colored liquid materials on to a screen in the form of the wall of a room. This type of* chemical light show *is also called a* wet show. *He points out that a similar type of show was produced long ago by alchemists with simpler materials.*

The best environment for light shows, *the kinds of psychological reactions reported by spectators, the basic equipment and supplies required, and the source of visual effects are described in some detail.*

Most of the article is devoted to a useful catalog of various chemical materials to place in a clear, concave watch glass (the author used one of 15-*in. diameter, which was placed on the top of a commercial-type overhead projector) to produce interesting moving colored images. These materials include: the* starting *solution placed in the watch glass;* acids *and* bases; *pH* indicators *and* dyes *for producing various colors; and* solvents *for producing special effects. Ways of producing additional effects by mechanical means are also mentioned.*

I. INTRODUCTION

A type of kinetic art has been mentioned by Malina which 'comprises the use of cinema equipment to create pictures of changing composition and color projected on to a framed area (the screen) [1]. The term *light show*, according to Beck, is commonly used to describe *projected* kinetic art [2]. A *wet show* is a type of *light show* produced with an overhead type projector using liquid coloring materials. In this article, I will use the terms *light show* and *wet show* synonymously.

Light shows, in one form or another, have been produced since at least as early as 1732. Jung described a type of *light show* practiced by medieval alchemists [3]. The description quoted by Jung reads as follows:

Abtala Jurain son of Jacob Jurain and Coahyl; translated from the Ethiopian into Latin and from Latin into German by Johan Elias Müller, as follows:

> "Take of common Rainwater a goodly amount, at least ten Stübchens§, keep it well shut in Glass Jar at least ten days, then will the foulness and faeces settle on the bottom. Pour off the clear Water and put it into a wooden Vessel that is shaped round like a Ball; slice it through the middle and fill the Vessel one third part full thereof. Then place it in the Sun at noon in a hidden or separate Place.
>
> "This done, take a Drop of red Holy Wine and let it fall into the Water, when you will forthwith behold a Fog and a deep Darkness down on the Water, as indeed it was so at the first Creation. If you then put in a second Drop, you will see the Light coming out of the Darkness; whereupon put in again and again, each quarter hour, a Third, then a Fourth, then a Fifth, then a Sixth Drop, and then no more: when if you let your eyes light on the Water, one thing after another you will see, how God created every Thing in 6 Days, and how this took place, and suchlike Secrets that cannot be spoken of, even I myself have not the Power to reveal them. Before you undertake this Operation, fall down upon one Knee . . ." [Translated from Old German]

The *light shows* that I produced in my apartment during 1965–1966 used a process similar to the one described above, except that other chemicals were used than wine, the light source was from an overhead projector rather than from the Sun and the screen was the wall of a room. The subjective effects on viewers were substantially the same as described by Jung.

*Amateurs should be warned of the hazards involved in the use and handling of chemicals. Strong acids and bases are caustie, may cause stains and severe burns. The organic solvents used here are all considered highly inflammable and many have poisonous vapors. Light shows of this type should always be performed in well-ventilated rooms. We always prohibited smoking during light shows.

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§Stübchen: old North German chemical measure equivalent to between 3 and 4 liters each.

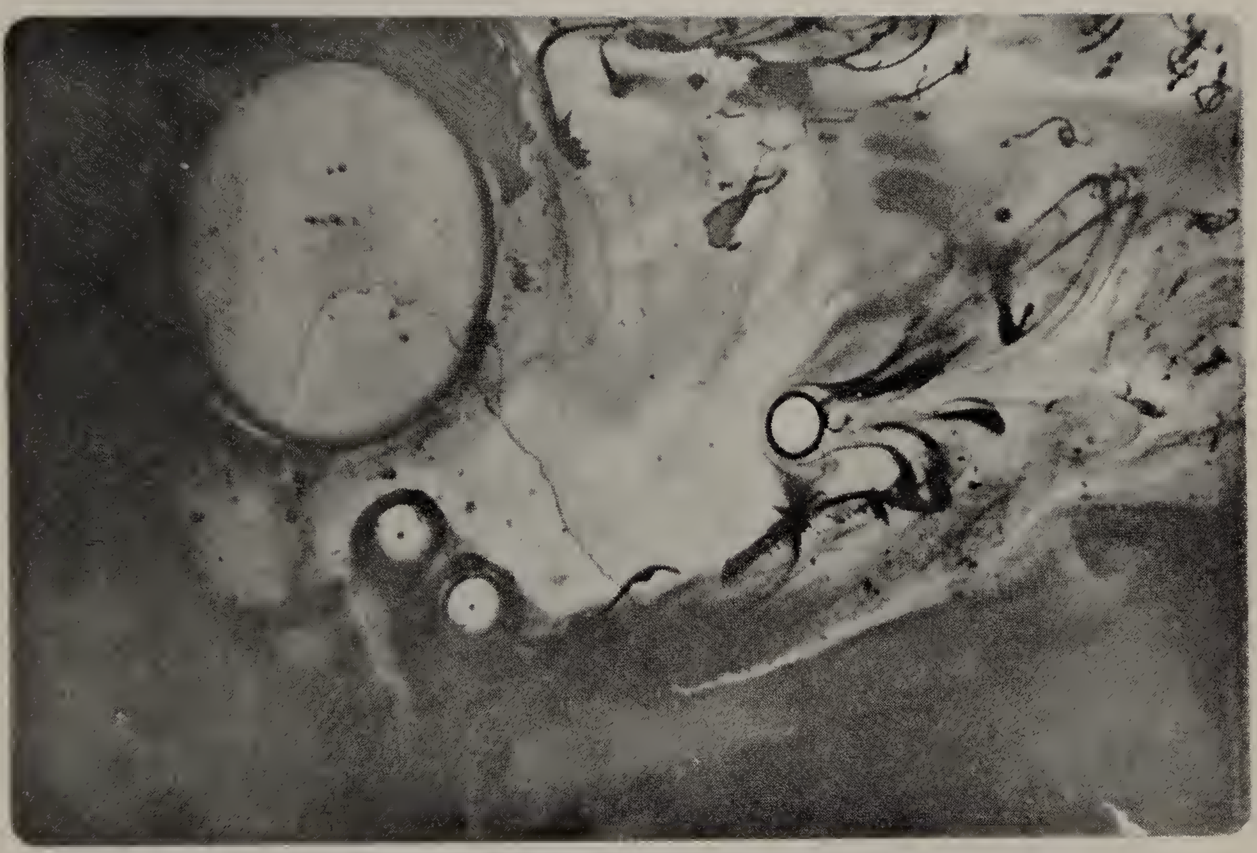

Fig. 3. Image produced during a chemical light show.

Fig. 1. Image produced during a chemical light show.

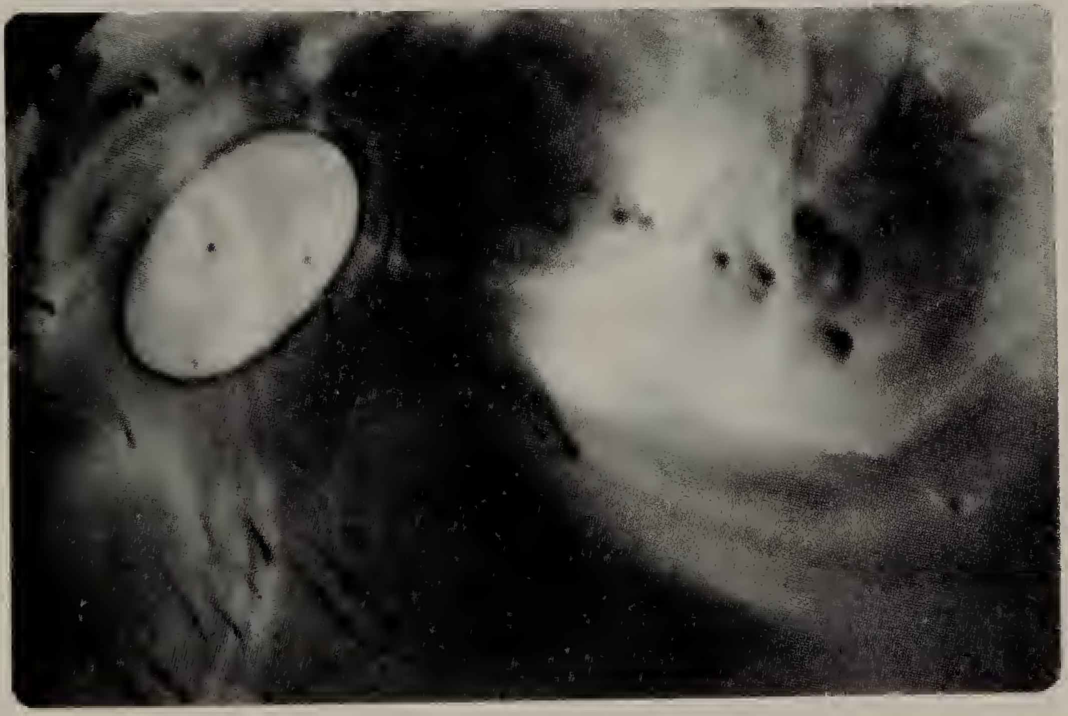

Fig. 2. Image produced during a chemical light show.

The kinds and combinations of chemicals used were derived empirically after several months of experimentation. Combinations initially used were later discarded when better ones were discovered. Initially, the only chemical reaction I used was the neutralization of vinegar with bicarbonate of soda. The visual disadvantage of this reaction was that the reaction product was insoluble in water and thus appeared black on the screen.

I then tried neutralizing 50 per cent solutions of sulfuric acid and of sodium hydroxide in the presence of *pH indicator* dyes. Subsequent additions of other chemicals and the testing of a variety of combinations resulted in the set of chemicals and techniques described below. The images they produce may be seen in Figs. 1 to 5.

II. CHEMICAL LIGHT SHOWS

1. *The physical environment for a light show*

As many of the chemical reactions take place rather slowly, the physical environment of the *light-show* room ought to be restful. We used our bedroom, with no furniture except for two lighted candles, with a white wall as the screen. The entire floor space was covered with several thicknesses of blankets, so that those who came to watch could comfortably recline. A show lasted for about 30 minutes. Since many persons came, the floor was often covered with spectators who found themselves close together—a condition which contributed to an intimate atmosphere.

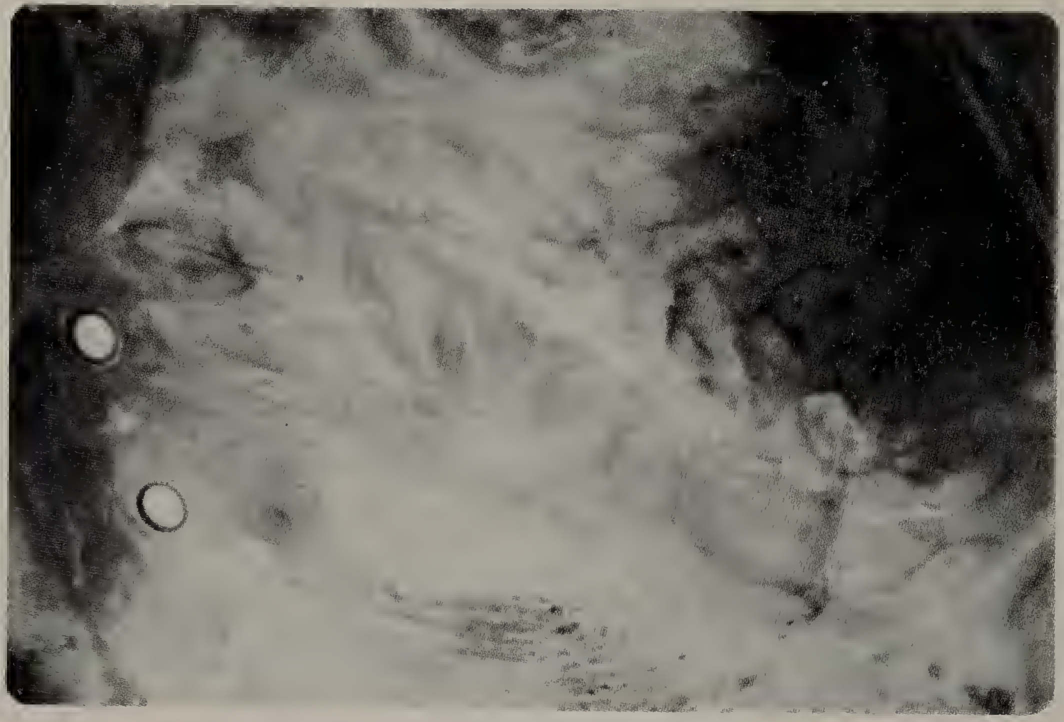

Fig. 4. Image produced during a chemical light show.

Fig. 5. Image produced during a chemical light show.

2. *Psychological effects*

Psychological effects resulting from a *light show* include those resulting from viewing the cinema. Some spectators found that the images reminded them of moving Rorschach patterns. A spectator at one stage complained of seeing 'blood' and this idea became so strong that she had to leave. On the other hand, other spectators have come to the show irritable and tense and have left calm and relaxed.

A show produced in a noisy bar caused no noticeable psychological effects on its patrons. Thus, I conclude that a relaxed and quiet atmosphere is necessary if the maximum psychological effect is to be obtained.

3. *Basic equipment and supplies*

The projector I used was an old American Optical Company overhead projector. The frame was metal and, over the year that it was used, acquired a patina and crustation consisting of dyes, stains and metallic sediments. I later purchased an American Optical Company type Apollo 6 overhead projector which, due to its plastic construction, was susceptible to attack by the solvents and dyes.

A 15-in. diameter clear, concave watch glass was used to hold the *starting* solution and additives. It was usually cleaned with methyl ethyl ketone before it was placed on the projection surface of the overhead projector. The watch glass was then filled with a starting solution to a depth of about $\frac{3}{8}$ in.

The infusion of additives and the creation of vortices was accomplished with an *infusor* made of a section of rubber hose, one end of which was fastened to a glass pipe that had a tapered end much like a pipette. The other end of the rubber tubing was attached to a rubber syringe. The pipette and rubber tube were filled either with a *reactive* or a *dye* additive, which was then introduced into the *starting* solution in the watch glass. The projected images are more effective when the additive is infused slowly, so as not to agitate the surface of the solution too much; although, occasional rapid infusion causes aesthetically satisfying effects. The *infusor* may also be used to blow a fine stream of air across the surface of the solution in order to cause selective mixing of the liquids.

I sometimes throw in solid materials, such as *indicator* crystals, held between two fingers; after some practice, I was able to throw a single crystal into a small bubble at a distance of approximately 2 feet.

4. *Source of visual effects*

The *chemical light show* derives many of its effects from the fact that the liquids in the watch glass are not homogeneously distributed in the *starting* solution. Concentrations of various liquids or of solids can be infused or thrown into different parts of the *starting* solution. An operator should also learn the nature of the chemical reactions that can occur between the *starting* solution and *reactive* additives, in order to choose the type of effects he wishes to produce. Motion of the liquids occurs either through agitation caused by infusion or through the natural dispersion of the additive by convection currents set up by the heat of the projector lamp and by exothermic chemical reactions that might occur.

Two technical considerations limit the duration of a *light show*: when the watch glass fills to overflowing or when the solution reaches a chemical and hydrodynamic equilibrium. If the operator is careful in his choice and quantity of *additives*, the duration of a *light show* will not be limited by the opacity of the solution.

III. CHOICE OF CHEMICALS

Generally, I chose materials that satisfied the following criteria:

(a) When mixed they result in no compounds that would, through secondary or tertiary products, produce an explosion, dangerous flames or poisonous fumes.

(b) They have no offensive odor. For this reason, certain solvents, such as carbon disulfide, are unsatisfactory. I found that certain chemical vapors from the watch glass combined with the hot products of the gas heater in the room to produce a very offensive odor. Methyl ethyl ketone was offensive to some viewers but because of its interesting effects I continued to use it.

(c) They are easily obtainable at a low price. Certain fluorescent dyes and exotic hydrocarbons were not chosen for this reason.

1. *Starting solutions*

The initial component I use for the *starting* solution in the watch glass is tap water. Generally, before turning on the light of the projector, I add a small quantity of a *base* chemical, for it is easier to make the solution *acid* later rather than the reverse.

A *starting* solution component of glycerine causes chemical mixing action to be slowed considerably. Glycerine also creates 'organic' patterns as it is slowly poured into the watch glass. Some *indicators* have different dissolving characteristics in glycerine than in water and *acid-base* neutralization occurs much more slowly.

A methanol rather than a tap water *starting* component is more effective with many of the *acid-base indicators* described below.

2. *Acids and bases*

The best acid solution I found to be about one part concentrated sulfuric acid to two parts water. This acid concentration causes the *indicators* to produce clear colors. If too concentrated an *acid* solution is used, then much more of a *base* must be added, if it is desired to change colors. The *base* I use is a 50 per cent saturated solution of sodium hydroxide, stored in a polyethelene bottle.

If one desires a strong reaction, i.e. with almost violent spattering in the watch glass, then one can use concentrated solutions of sulfuric acid and sodium hydroxide. But one must be very careful, as the heat from this exothermic reaction can cause a thin watch glass to crack.

3. *Indicators and dyes*

The use of pH *indicators* and *dyes* in a *wet light show* has the advantage over the more common use of inks and water color dyes in that *indicators* do not become muddy. All inks and water colors cause the solution to become irreversibly opaque if too much of one or too many are added. *Indicators*, on the other hand, often may be bleached with a 30 per cent solution of hydrogen peroxide.

There are many types of *indicators* (cf. Table 1). Many of them react only at the highest or lowest pH values and, therefore, for *light shows* are not useful. Many other *indicators* do not produce a brilliant color or interesting color change. A color change from colorless to violet, for example, was found to be uninteresting. *Indicators* that have only one color change were eliminated. The two *indicators* I mainly used were thymol blue sodium salt and bromthymol blue. For a time, I used a solution of methyl orange but the color change from red to yellow proved to be not as interesting as the more variegated thymol blue. I prefer *indicators* in crystal or powdered form, so that they can be thrown into the watch-glass solution.

TABLE 1. INDICATORS USED WITH A METHANOL STARTING SOLUTION

Acridine orange	Congo red
Alizarin	Eosin
Basic fuchsin	Fuchine (acid)
Brilliant green	Fluorescein
Bromcresol green	Malachite green
Bromcresol purple	Methylene blue
o-Cresolsulfonphthalein	Phenolphthalein
Crystal violet	

Thymol blue in a *base* solution is blue in color; between a pH of about 2·8 and 8·0 it is red, and in a strongly *acid* solution it is yellow. It costs around $1.20 per g but the effects produced are well worth the expense.

Generally, I used only thymol blue and bromthymol blue in solution form. Approximately 0·25 g quantities of *indicator* were used per liter of tap water. This concentration, far more concentrated than a chemist would use, is effective for *wet light shows.*

Congo red is a good *indicator* of brilliant red color. The powder, when judiciously thrown into the solution, makes very tiny dots as it slowly dissolves. If the surface of the solution is blown upon, the dye will create numerous red trails. Congo red turns purple or green under certain *acid-base* conditions.

Crystal violet is a particularly good *dye* and was used extensively. Not only are the crystals easy to throw into the solution but they dissolve very evenly. The trails they develop are very much like the congo red, except that crystal violet gives a thicker trail. Crystal violet has an interesting reaction with ethylene dichloride; it speeds around the inside of an ethylene dichloride bubble, spinning off a violet trail until it colors the entire bubble. If the crystal finds its way to the edge of the bubble, the crystal will spin around the edge of the bubble at high speed, ejecting lines of violet color into thc surrounding solution and often pushing the bubble through the solution.

Potassium permanganate is a crystal with fairly good dissolving properties. A reddish-purple color grows slowly around the potassium permanganate crystal in the watch-glass solution. Moreover, in the presencc of organic chemicals the color changes to red.

Gentian violet and aniline blue were also successfully used.

4. *Solvents*

Solvents with a high vapor pressure, such as methyl ethyl ketone (MEK) and methanol have the effect of agitating the surface of the watch-glass solution. Judiciously adding MEK to the *base* side of a solution consisting of sodium hydroxide, thymol blue and sulfuric acid will cause the creation of a fire-like effect on the screen, with the blue changing to yellow and red on the perimeter of the agitating and evaporating MEK. Methanol has virtually the same effect and can be used alternately with MEK in order to change some *indicator* colors or to cause opaque benzene clouds to become more rapidly translucent.

Solvents such as benzene, carbon tetrachloride, toluene and ethylene dichloride are all virtually immiscible with water but they each react differently with the *indicator dyes* and with each other. Toluene and benzene float on top of the water and spread out thinly and evenly over a large area. Crystal violet thrown on benzene will break the surface tension of the benzene and partially dissolve. Although benzene is transparent on the surface of the solution, except for distortion on the edges, adding MEK or methanol will cause benzene to turn a cloudy opaque white. The agitating surface causes the benzene cloud to create opaque moving shapes on the screen. The cloud will become translucent after a period of time. Crystal violet thrown on the opaque cloud will help it to become more translucent faster.

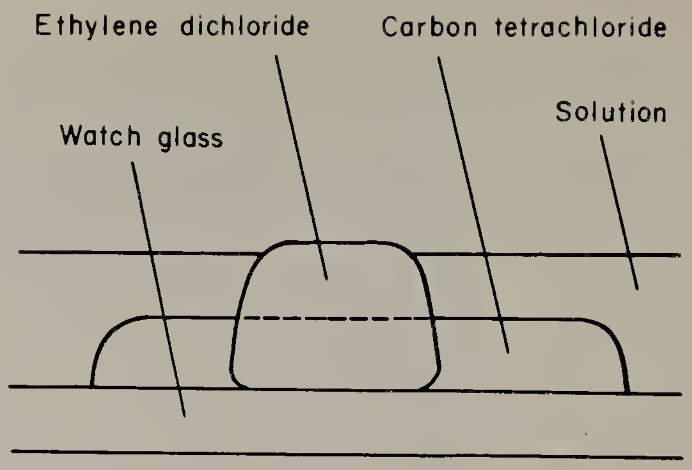

Fig. 6.

Carbon tetrachloride sinks to the bottom of the solution and, if rapidly poured or infused into the solution, will form bubbles which eventually join together at the lowest point of the watch glass. If a smaller amount of ethylene dichloride is gcntly added to the solution, ethylene dichloride will join the carbon tetrachloride but will not mix with it. The projected effect is of concentric bubbles. Enough ethylene dichloridc must be added so that the chemical breaks through the surfacc of the solution, for it is the surface tension of the chemical which prevents the mixture (cf. Fig. 6). Crystal violet thrown into the exposed surface of ethylene dichloride may break the surface tension and cause the inside bubble to vanish.

5. *Ways of producing additional effects*

A strip consisting of colored theatrical gels taped together was uscd to create special effects. When the strip was slowly drawn across the lens' aperture, the color content of the projected image was continuously changed.

Experiments with different shapes and sizes of glass crystals were performed but the effects were lessened rather than heightened by their use. Distortion seemed to be the main effect and, as clarity was the sought after effect, crystals were rarely used. Beck kindly offered the use of his moiré patterns but as these did not blend with the primarily 'organic' patterns of the light show, they were not used [2].

Other effects produced by mechanical means were found to be satisfying. Siphoning a mixture from the watch glass produced interesting patterns. At the conclusion of a show in which much *acid* and *base* had been used, siphoning most of the solution from the watch glass and letting the remainder evaporate naturally, often produced interesting image-producing crystals of sodium sulfate.

IV. CONCLUSIONS

I certainly have not tried all combinations of effects possible in a *chemical light show.* But I have tested enough effects to demonstrate the range of possibilities using a limited number of simple chemicals. Undoubtedly, the range of effects could be increased by finding materials with other properties and by resorting to other mechanical means. And, no doubt, given the right combination of chemicals, techniques and setting, an imaginative operator may truly produce visual experiences of the greatest variety for the pleasure and relaxation of spectators.

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*Article included in the present edition.

LETTER OF THOMAS WILFRED TO J. HANDEL EVANS*

Editor's note—*Thomas Wilfred, a pioneer of kinetic art using electric light, was born on 18 June 1889 at Naestved, Denmark, and died on 15 August 1968 at West Nyack, N.Y., U.S.A. He dedicated his life to the development of* Lumia, *his term for a visual fine art form using electric light as the fundamental medium of expression. He began his work with light instruments in 1905 that culminated in his* Clavilux, *a key board instrument, for the projection on a large screen of his* Lumia *compositions. As early as 1922, he gave* Clavilux *concerts in the United States, Canada and Europe. In 1930, he founded The Art Institute of Light in the United States for research on the ways of producing* Lumia *compositions. He directed it until it came to an end in 1943, through lack of funds, however, he still considered the Institute as existing thereafter at his studio. He continued to make* Lumia *kinetic art objects using reflected light on a translucid screen until his death. Beginning in about 1952 he received wide recognition for his contributions to fine art.*

West Nyack, N.Y.
November 2nd, 1966

Mr. J. Handel Evans,
Dept. of Architecture,
University of Oregon,
Eugene, Oregon.

Dear Mr. Evans

If you are studying with Professor Zach, there is not much I can add toward your thesis. You have the help of an inspired artist who has done remarkable work with light on sculptural form.

From sculpture to architecture is but a step—artistically. In actual practice it is quite another matter. While most architects submit, by necessity, to the brutal floodlighting provided by the electrical engineer, they do not welcome the lighting artist who offers to sculpture a building at night with a carefully composed sequence of changing accents in black and white or in color. For quite a while I was interested in the problem but the attitude I met with most of the time was 'if we ever want anything like that, we'll do it ourselves, thank you.'

There have been exceptions. Years ago, a large architectural firm consulted me on the plans for a large and very tall building. I did design a 'visual carillon' for the top—four curved screens meeting at the edges, each curvature showing mobile lumina compositions from a battery of clavilux projectors below their bases. From the street it would give the impression of an opalescent dome with ever-changing sequences in form, color and motion. There was much enthusiasm to begin with, but the publicity department of the firm owning the building vetoed the idea in favor of one of their own. The building is now surmounted by a huge rotating searchlight.

I should like to see daylight engineers working with architects to insure that daylight entered the rooms at angles that made work possible in them. The outward appearance of a building should never take precedence over the usefulness of its interior.

Frankly, I am no longer interested in the subject. After visiting the new Lincoln Center in New York City one can only throw up the hands and say 'what's the use'.

Our work here is now strictly limited to research in lumia in its purest form: performance of silent visual compositions played from a keyboard on to a large screen by a skilled lumianist.

Please remember me kindly to Professor Zach. It was a privilege to meet him at the time of my lecture at the University.

Sincerely yours,

THOMAS WILFRED,
Director,
Art Institute of Light

* Permission to publish letter given by J. Handel Evans.
(Received 23 January 1970.)

PART
II
KINETIC AND AUDIO-KINETIC SCULPTURE

MY OP ART OBJECTS AND OPTICO-SPATIAL MOBILES

Henri Gabriel*

Abstract—*The author states that he produces works of an Op and Kinetic art type within a framework of geometrical forms. He describes the materials and techniques he used in his first works to give an impression of relief in natural light and an illusion of motion. This is followed by a description of his string-suspended kinetic sculptures or mobiles, which are put into motion by a spectator's hand. He gives his reasons for not using electric motors to provide motion for his mobiles. To give an appreciation of a void, he has made works consisting of cubic and spherical cages with elements within them. In conclusion, he outlines his plans for constructing a mobile made of rotatable disks so that the object is transformable.*

I. INTRODUCTION

When the fabulous World Fair was held in Brussels in 1958, I was 40 years old. Amidst the vast range of ideas confronting the spectator, I was taken aback by a marvelous personal discovery, the global evolution of pictorial, sculptural and architectural art. On display were works from ancient and classical collections, and in the exhibition called '50 Years of Modern Art' one could see works ranging from very bare paintings to the most violent and aggressive compositions.

On seeing this unbelievable overflowing of intellect, taste, virtuosity, sensitivity, strength and imagination, I was tempted to make modestly my own way amongst the artists of the world. I began with drawings and water colors in which I tried to capture the impressions of movement. Since I was self-taught in the domain of technical studies, it was natural that I would be most attracted to geometrical forms and to Op art.

II. WORKS OF 1960 WITH OPTICAL EFFECTS OF WHITE PAPER OBJECTS IN NATURAL LIGHT

I decided to make my first works in the domain of Op art with very simple means. I chose sheets of white blotting paper which were at hand, and resolutely refused to use color. In the sheets I cut out squares, triangles, circles and parallelograms, and then glued together several of these on a rigid support of compressed wood. Overlapping or matching of the cut-out shapes gave a surface with relief. Figure 1 is a detail of the work 'Deux Elements' shown in Figure 2 and indicates how the shadows in the relief depend on the direction of the light source. The shadows change as either the position of the light source or of the viewer changes, giving an illusion of motion within the object itself. It can be seen in Figure 2 that the depth of the relief varies from top to bottom.

I made in this way a series of relief pictures of various sizes, the largest being 45 × 60 cm, the size of an original sheet. It takes much patience to cut out the shapes and glue the sheets together accurately but eaeh work was for me a new experience with a wide range of Op art effects. In April 1963, I exhibited 41 works from this series at the St. Laurent Gallery in Brussels under the title 'Tentative optiques' [1].

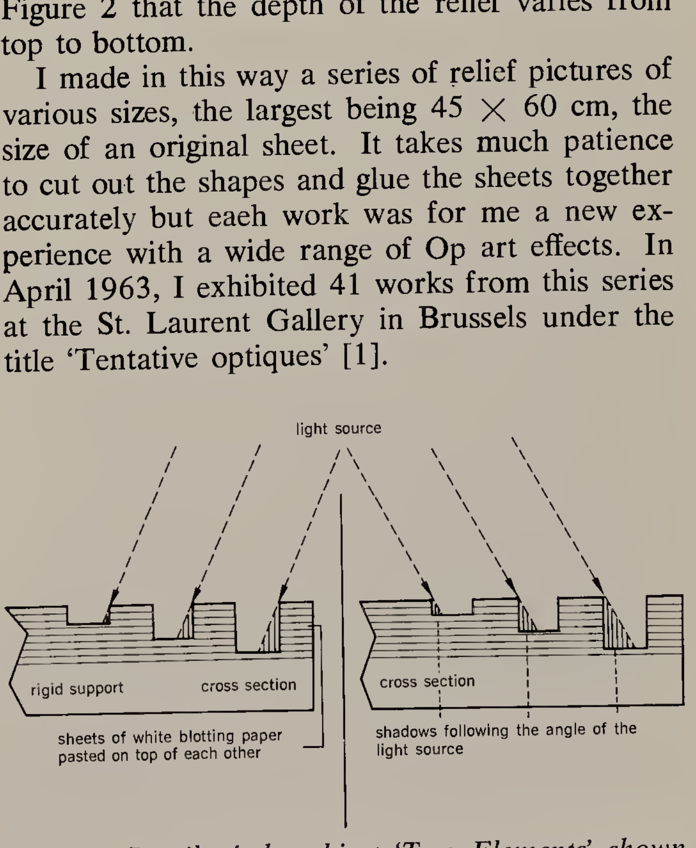

Fig. 1 Detail of the object 'Two Elements' shown in Figure 2.

* Artist living at 121 rue Masui, 1000—Brussels, Belgium. (Received 25 March 1972.) (Original version in French.)

III. CONTINUOUS PICTURES AND MOBILES OF 1964 AND 1965

I continued the cut-out technique described above with other materials, such as plastic sheet, imitation felt cloth and smooth and furry skins. In 1964, the idea came to me to make a continuous picture with this technique in the form of a circular cylinder. The support in this case was made of hard cardboard. If the cylinder was suspended by a string or wire and rotated by hand, then one would have a mobile object, which, in addition to giving visual effects due to real motion, would also have the Op-art effects I had obtained before. A kinetic object of this type, consisting of three suspended cylinders, is shown in Figure 3.

In my childhood I enjoyed ball games of various kinds and also later became a fairly skilled soccer player. This led me in 1965 to use an inflatable plastic ball as the support for a continuous relief picture made of sheets of artificial felt. The suspended sphere when rotated produced visual effects similar to those I had obtained with the cylindrical mobiles.

The last variation of a continuous picture for a mobile consisted of a transparent Plexiglas cylinder within which was placed a cylinder made up of sheets of blotting paper with cut-outs. At this time, I decided that I had exhausted the possibilities of the relief-picture technique, which I still feel to be true today. I felt like a jazz musician who had tried all the variations of 8 measures of a theme he could think of.

IV. OPTICO-SPATIAL MOBILES OF 1965 TO 1968

One day in a factory stockroom I was struck by the beauty of a bar of polished aluminum, an elegant, strong material of light weight. In my mind's eye I saw with joy a different kind of suspended mobile from the kind I had been making. It would be made of aluminum rods and Plexiglas, so that light would be reflected from it in exciting ways and, as the mobile rotated, unusual visual effects would be produced. I made my first optico-spatial or kinetic-op art mobile with the excitement of a physician assisting a birth.

To construct a mobile of this kind, I took a strip of transparent Plexiglas (3 to 5 mm thick) and drilled holes in it according to a predetermined design, with some holes at 90° and some at an angle of 45° to the surface of the strip. Through these holes aluminum rods of different lengths were forced and held in place by friction. In some mobiles, I also glued rings of aluminum rod to the Plexiglas. The number of possible arrangements of this type of construction is, obviously, very large. An example of one of these mobiles is shown in Figure 4.

Even in weak light one can observe in the mobile a subtle and exciting interplay of shadows and reflected light flashes—an alchemy of light in space. One can increase the complexity of the visual experience by introducing mobile elements that move relative to the central axis of the overall construction.

These mobiles are suspended by a nylon thread, so that they can be rotated by an air current or by a touch of the hand. I am firmly opposed to rotating a mobile by means of an electric motor, either at a continuous or at a programmed variable speed. I wish the motion to depend on a chance impulse of an air current or upon the whim of a spectator, for I believe one thus obtains a richer and more varied visual experience. I further object to the use of an electric motor because it seems to me to be a too impersonal, de-humanized element in a work of this kind.

Someone once remarked that I was a fanatic about light and I agree that this is so. This

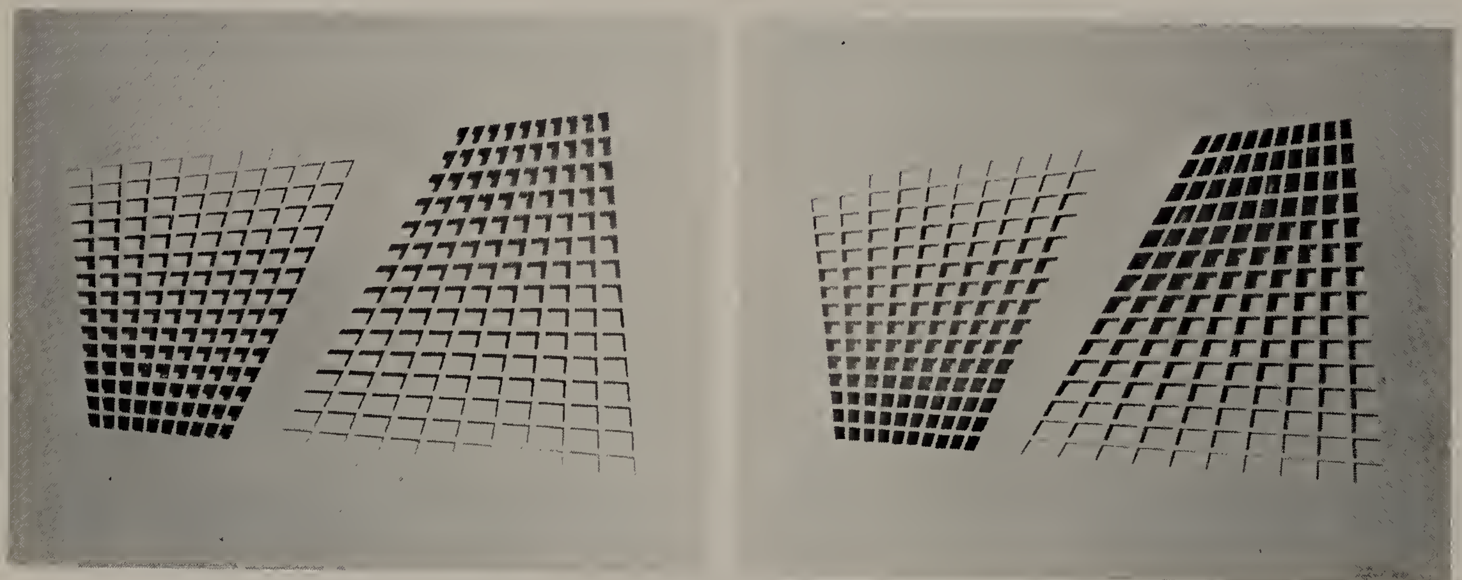

Fig. 2. Two views of 'Two Elements', white blotting paper on a base of compressed wood, 45 × 62 cm, 1962.

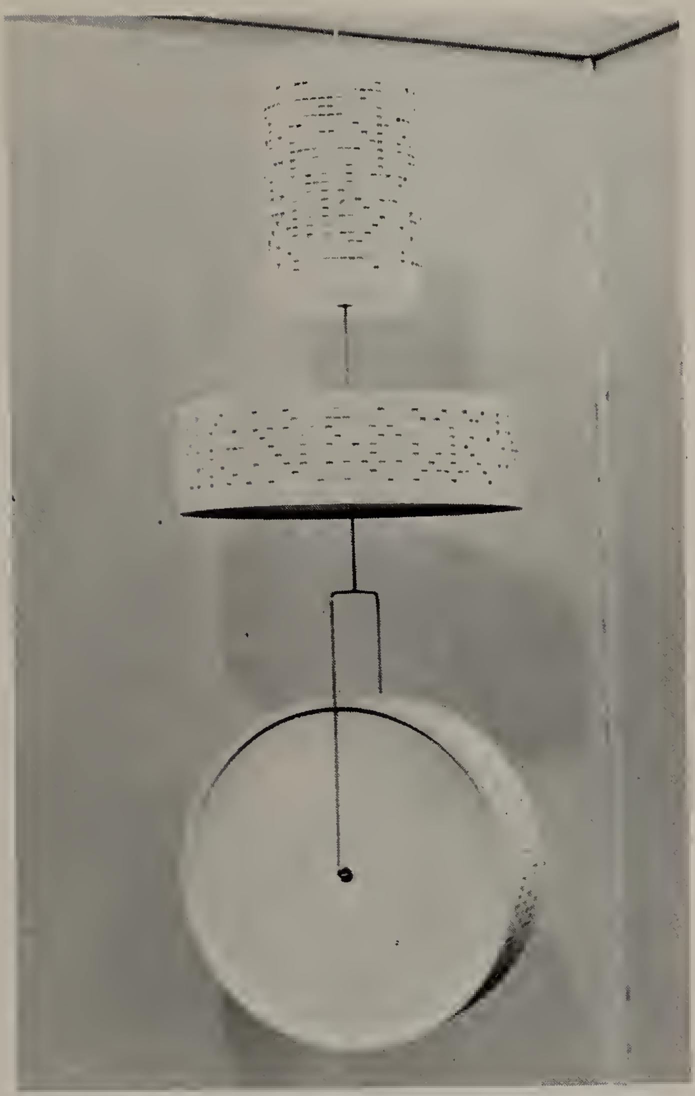

Fig. 3. 'Triptych of Continuous Pictures', mobile, white blotting paper on cardboard, 200 × 80 cm, 1964.

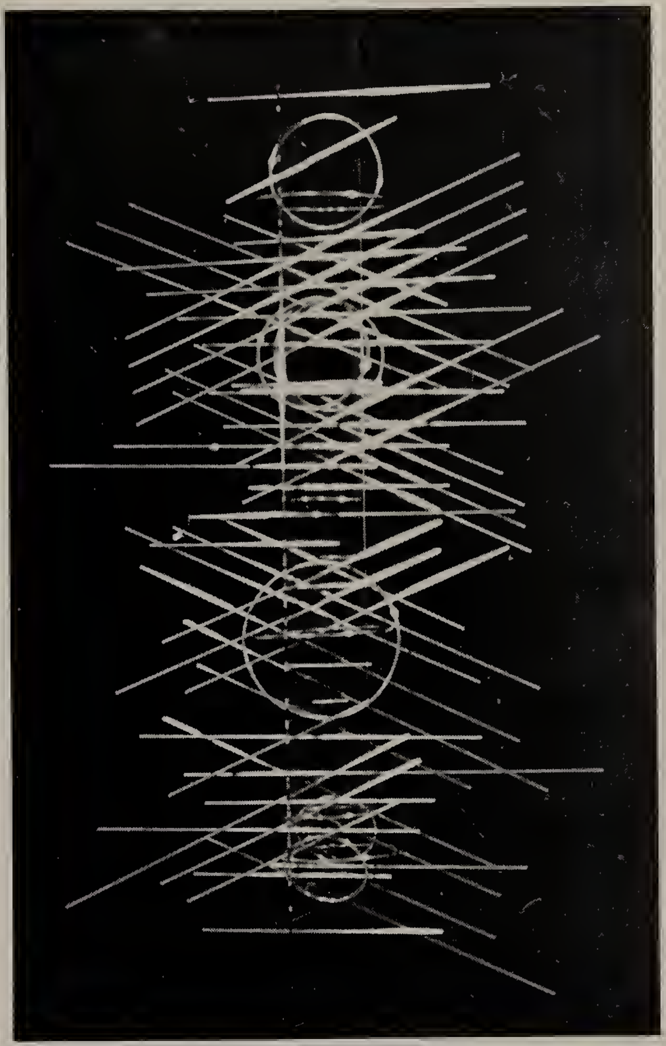

Fig. 4. 'Circles, Perpendicular Rods, Slanting Rods Put in Plexiglas', optico-spatial mobile, Plexiglas and polished aluminum rods, 75 × 25 × 50 cm, 1965.

fanaticism made me less and less satisfied with the large Plexiglas elements in these mobiles. Static electricity on their surfaces attracts dust and the shiny surfaces become dulled with time. I, therefore, decided to make a scries of mobiles in which the role of Plexiglas was kept to a minimum.

In Figure 5 a mobile is shown in which short perforated Plexiglas cylinders were used to support supple aluminum rods. It was at this point in 1966 that I first showed these mobiles and described my objective of incorporating motion in a three-dimensional work and optical effects of natural light in optico-spatial objects or kinetic sculpture. My hidden aspirations of 1958, of whose consequences I could not then be aware, had led me to these kinds of mobiles, which gave me satisfaction and encouraged me to continue their development [2–7].

The mobile in Figure 6 makes use of perforated 10 mm diameter Plexiglas rods into which polished aluminum rods were pressed to make a cube within a cube. While watching it, the thought occurred to me that one could construct an arrangement that would give the viewer the impression of an empty space in motion.

The mobile shown in Figure 7 was constructed to produce an illusion of a spherical volume of empty space in motion. Within the cubical cage of aluminum rods, I placed on its diagonal axis disks of transparent Plexiglas into which rods cut to different lengths were pressed to give an envelope of an empty sphere within the cylinder. When the mobile is set in rotary motion, the bars of the exterior cube pass by the sphere of empty space at great speed and give one the impression that the sphere itself is in motion. In Figure 8, the construction of an empty sphere is contained within a sphere of aluminum rods.

If a mobile of the above type is hung in the corner of a room (Fig. 6), the shadows thrown on the walls play a dominant part for a viewer. On the left in Figurc 8 the shadows cast on a wall by a spherical mobile can be seen.

In February 1968 at the Louisa Muller Gallery in Brussels, I showed a collection of mobiles that give the illusion of empty space in motion. It is difficult to describe this phenomenon, one must see it to bclieve it. In this exhibition I also showed a number of toys with special visual effects [8–16].

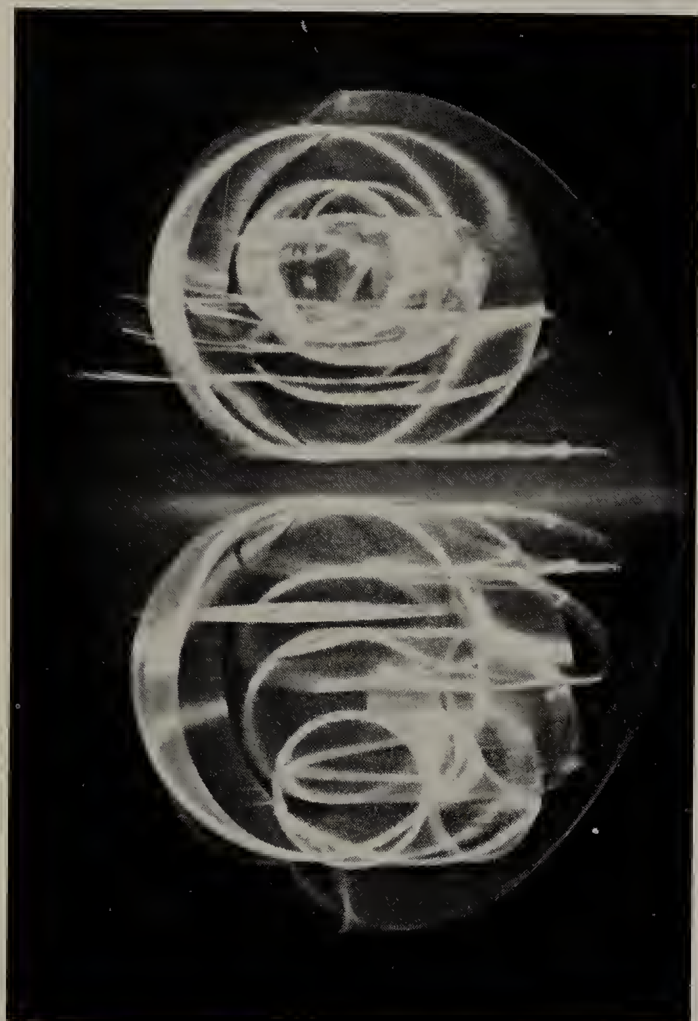

Fig. 5. 'Circle in a Plexiglas Base', optico-spatial mobile, Plexiglas and polished aluminum rods, diameter 40 cm, 1965.

V. PROJECT FOR AN OPTICO-SPATIAL MOBILE WITH A MODIFIABLE SPHERICAL STRUCTURE, 1969

At the present time, I am completing a project for a modifiable mobile with a spherical structure of polished aluminum rods, with an inner empty space. The construction, the details of which are shown in Figure 9, is made as follows:

(1) Bars of transparent Plexiglas (10 × 10 mm) are pressed onto a central metal axis so that they can be pivoted around it. The bars are cut to lengths to fit into the outline of a circle and holes are spaced at equal distances, through which aluminum rods of different lengths are pressed to fit within a spherical envelope.

(2) In the slots in the Plexiglas bars, shown on the left in Figure 9, 7 annular aluminum disks are pressed. Their diameter is varied so as to make the envelope of a central empty spherical space. Aluminum rods are soldered to the outer edge of each of the annular disks, as shown on the right in Figure 9.

The arrangement of the structure of aluminum bars can be varied by rotating the Plexiglas bars around the central axis. The mobile will be suspended with a Nylon thread attached to the central Plexiglas bar, so that it can be spun by hand. A spectator viewing this mobile may experience different visual effects produced by different arrangements of the spherical structure of rods as well as the illusion of a rotating central empty spherical space.

As the next step in my work with these kinds of mobiles, I plan to make structures in the shape of polyhedra instead of spheres.

Fig. 6. 'Cube in Cube with Vibrations', optico-spatial mobile, Plexiglas and polished aluminum rods, 50 × 50 × 50 cm, 1967.

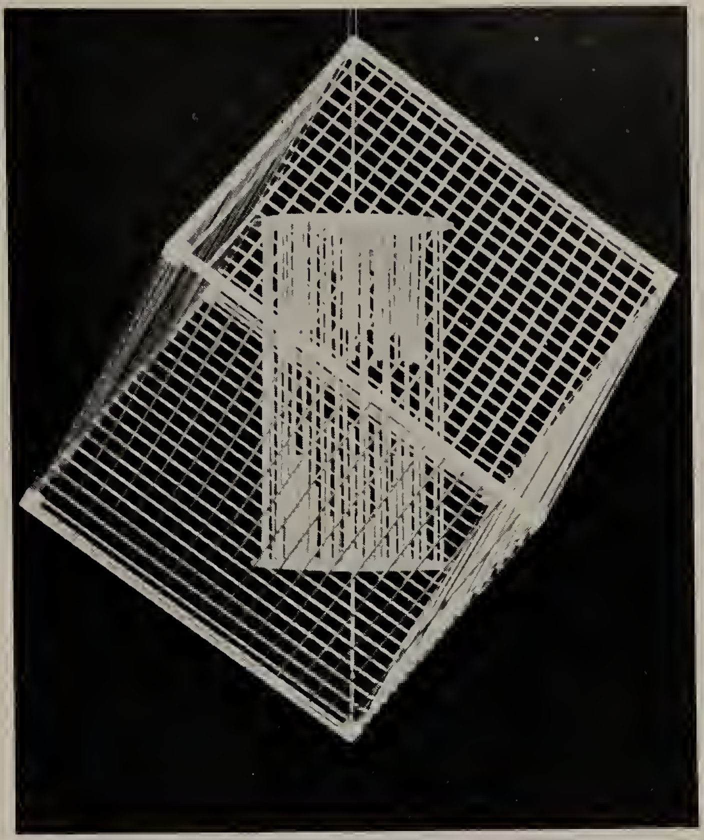

Fig. 7. 'Volume of Empty Space in Movement', optico-spatial mobile, Plexiglas and polished aluminum rods, 50 × 50 × 50 cm, 1968.

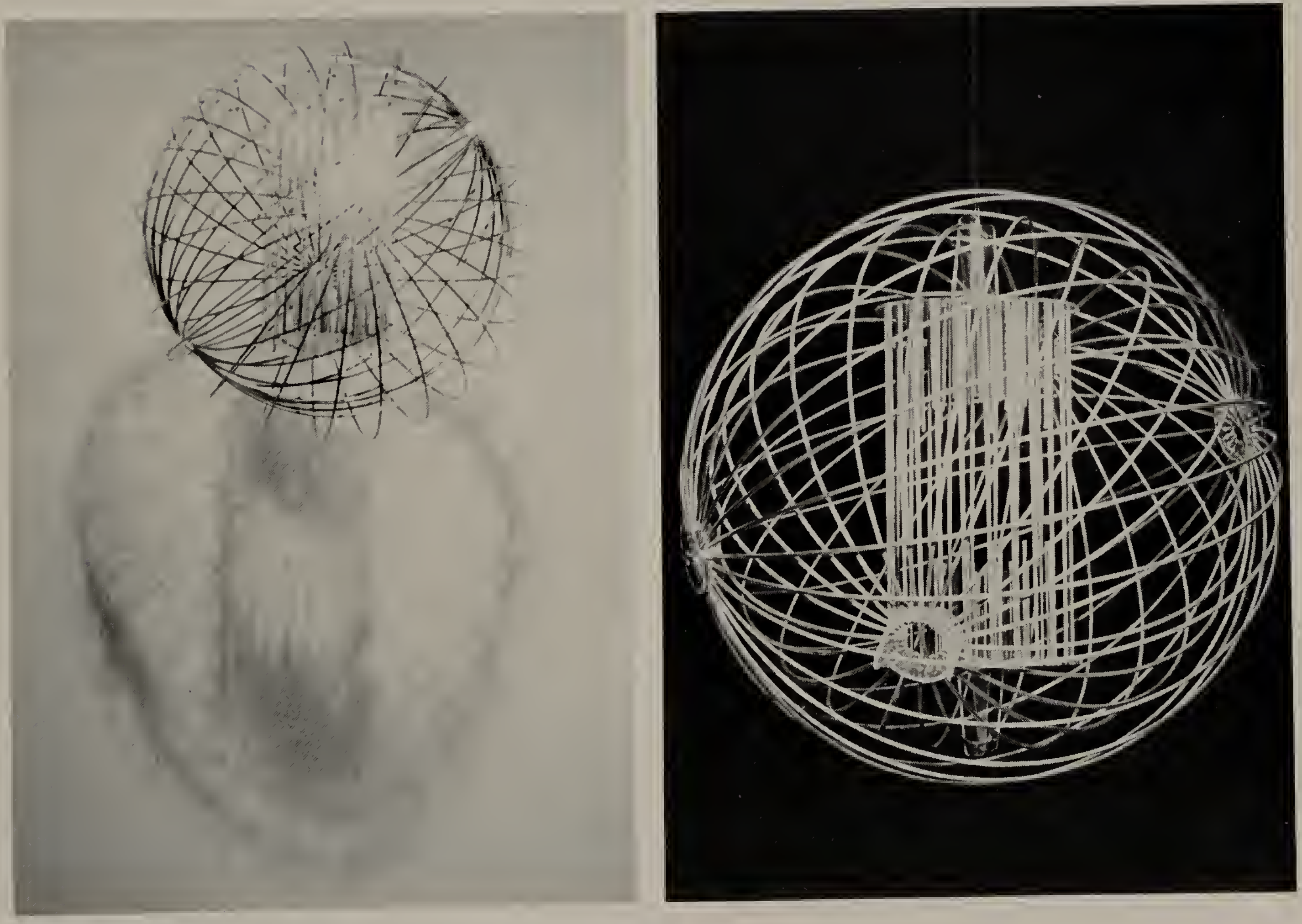

Fig. 8. 'Volume of Empty Space in Movement', optico-spatial mobile, Plexiglas and polished aluminum rods, diameter 50 cm, 1967.

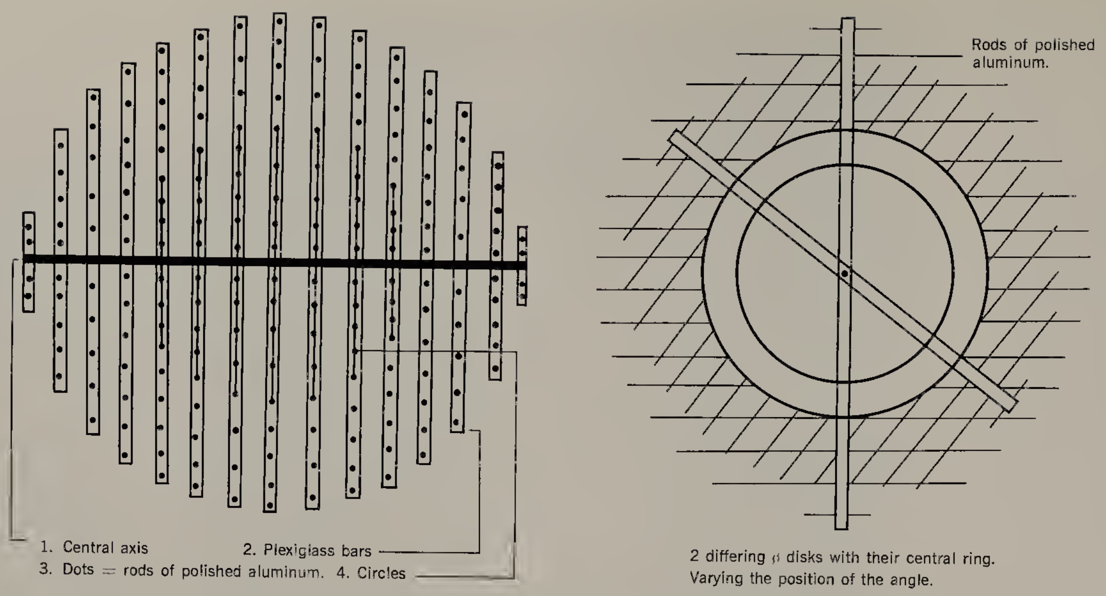

Fig. 9. Sketch of the construction details of a project for an optico-spatial mobile with a modifiable spherical structure, 1969.

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MY PLEXIGLAS AND LIGHT SCULPTURES

Jim Hill*

Abstract—*The author describes his search for a delicate balance between emotional expressiveness and intellectual content in art in order to achieve a style which is both personal and meaningful to society.*

He mentions briefly his experience in making computer drawings. He describes in detail his use of modern materials and of electrical techniques to make light sculptures that give a sense of mystery. He believes his light sculptures produce enigmatic moods and talismanic references. They are balanced by his use of mathematical proportion for the plastic shapes inside a box and by modern methods of construction. The simplicity of the shapes chosen contrasts with the effects of flashing lights on Plexiglas in the interior of the box. The random cycles of flashing lights is produced by the use of thermal interrupters.

He plans in the future to introduce greater control of light sequences to contrast with the random cycles. Eventually he intends to use lights controlled by electronic circuits instead of thermal interrupters to mystify the viewer even further.

I. INTRODUCTION

> 'How to move individuals to recognize the heartbeat of our time, how to move human sensibilities to respond in an affirmative, creative way to challenges of today are key problems of social communications, and, thus, of creative vision' [1].

This statement by Gyorgy Kepes in 1965 stresses important questions for artists in our society. It contains two objectives—perception and involvement. Both are necessary for a positive, constructive development in society as well as in the arts. The artist must learn to consciously perceive his cultural environment. He must study its structure to learn which parts have become obsolete or trivial and which offer hope for the future. In addition, the artist must be actively involved and act with reasoned commitment upon what his perceptions have shown him.

The artist serves society as a teacher of certain aspects of the present. Marshall McLuhan explains this function as follows: 'The power of the arts to anticipate future social and technological developments, by a generation and more, has long been recognized. . . . Art acts as radar acts as "an early alarm system". . . . This concept of the arts as prophetics, contrasts with the popular idea of them as mere self-expression' [2]. McLuhan describes the artist's function as one which presents current social and technological changes to society. The visual artist makes objects which are of abstractions of selected portions of the present social environment. These abstractions teach or explain to the public things which the artist thinks are important in his culture and describes directions in which they may develop.

Art, as 'an early alarm system', maintains a vital social function in contrast to the concept of art as a catatonic retreat from society or as an egocentric manner of expression. Kepes' point of view helps explain McLuhan's negativism towards those who accept 'mere self-expression'. Kepes says: 'They shrink the world to a rebellious gesture, to violent graphs of the cornered man. "The big moment came", as an articulate spokesman of this group has put it, "when it was decided to paint . . . just to paint. The gesture on the canvas was a gesture of liberation from value—political, aesthetic, moral". But in fact these artists recoil from the necessary vital dialogue with the outside environment and, thus, have broken the essential unity of the seer and the seen' [1]. 'To paint . . . just to paint' has no valid place in a progressive social environment. Gestural art constricts itself to problems of or hypotheses of art until it develops phobias to everything but itself.

Artists who deal only with the history and criticism of art may become so constrictive as to become isolated from an appreciation of the universal

* Artist living at Route 2, Box 203, Santa Fe, New Mexico, U.S.A. (Received 31 March 1969.)

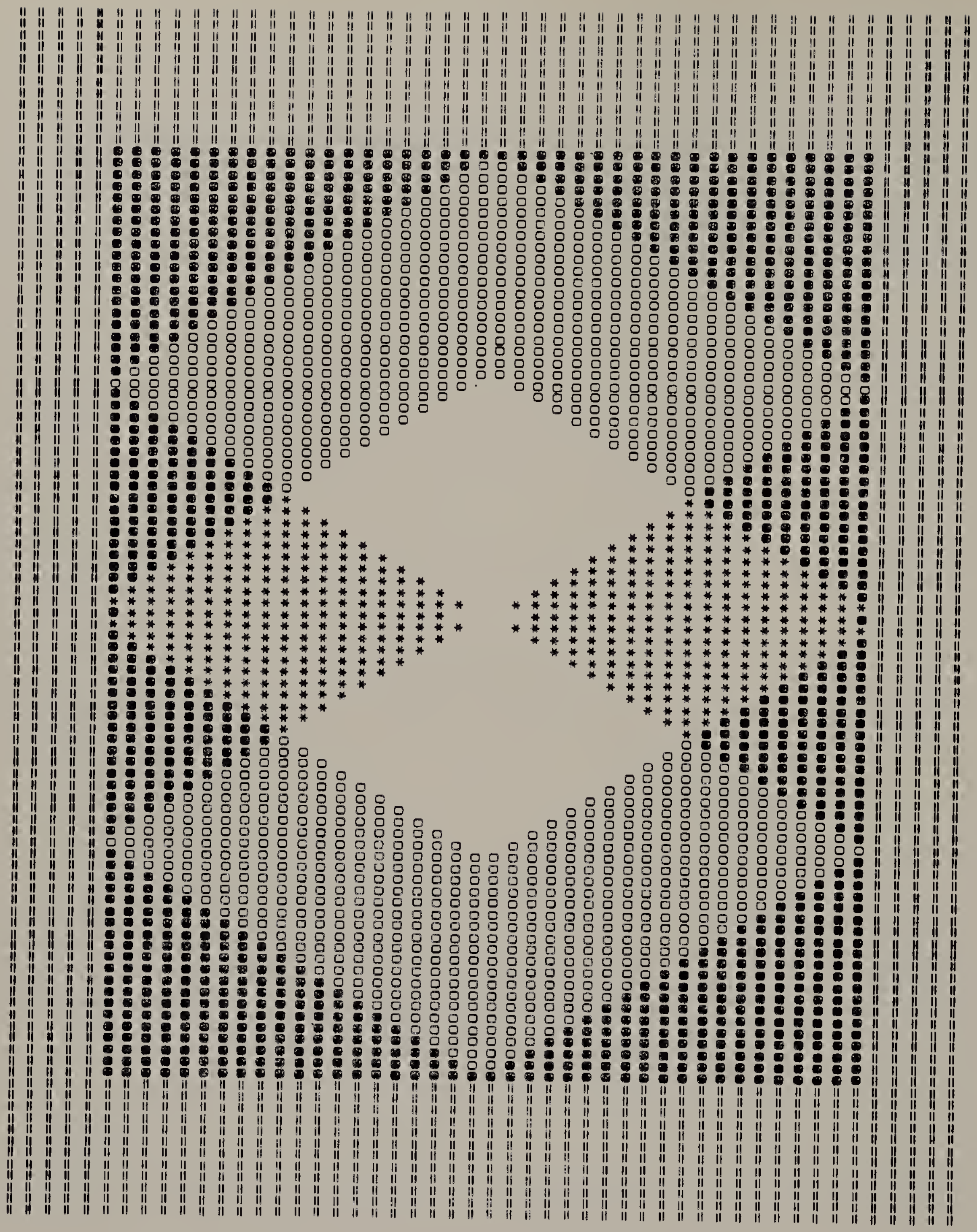

Fig. 1. 'Diamond Crusade', digital computer drawing, 12×9 in., 1969.

truths of natural phenomena. Kinetic and light sculpture, having freed itself from this isolation, can explore and assimilate not only ideas about art but about science, about society and about life. I find this freedom more rewarding than the dangerous possibility of an incestuous relationship with the secluded world of self-expression.

II. COMMENTS ON MY WORK

My encounter with the kinetic sculptor Charles Mattox led me to a different concept of art. His sculpture did not influence me as much as the philosophical questions that he raised. The question of the artist's role in today's society is an example. If the visual artist's function is to remain important, then he must absorb that which is meaningful to the present and put it into a form of visual expression. Mattox's presentation of kinetic sculpture embodied a knowledge and awareness of technology and industrial materials. Because I accepted the implications of his sculpture, I began to search for things that would be meaningful to the present and to myself. New materials and techniques sueh as plastics and electronic devices demanded more precision than traditional ones; therefore I studied their properties and characteristics as well as the industrial methods for their fabrication. These studies have been of greater importance to my present sculpture than my first experiments with light and motion. Mattox influenced me to change my interests from a private and personally-involved artistic attitude to one that involved a wider comprehension of things in our environment which have an artistic potential.

Fig. 2. '*Expo-Quadrate 3A*', *digital computer drawing*, 9 × 12 in., 1969.

> 'To get more random motion and less predictable movement in the work is important . . . I am interested in technology and science of this era and its effect on our culture . . .' [3].

This statement by Charles Mattox reflects our common interest, and his influence can be traced through the cultivation of random effects. Charles Mattox uses motion and sound with more emphasis upon mechanical devices; whereas, I have changed this interest to exploit effects of light and color sequences. We both share a common philosophy, but we express it with different media and independently of each other.

A second influence on my work resulted from my introduction to the electronic computer. Richard Williams and Charles Mattox initiated a program at the University of New Mexico in 1968 that encouraged students and artists to experiment with computer drawings. (Figs. 1 and 2 are examples of my computer drawings done in 1968 and 1969.) After I had become accustomed to the novelty of this experience, I realized that the computer was only a tool and that it had inherent capacities to express visual ideas of an artist as programmer. I decided to learn more about the way computers function. This study gave me a better appreciation of scientific and mathematical principles [4]. I also read electronic textbooks [5] and constructed electronic circuits that converted colored light into sound with a different sound for each light frequency and intensity.

Popular distrust of electronic computers remains an obstacle to their eventual greater acceptance by society. However, as long as this situation exists, computers will give rise to phobias which are typical of unexplained anxieties. A recent example is the science fiction film *2001—A Space Odyssey*. Apprehension of technology is exploited by the plot when a computer confronts man in a life and death struggle for environmental control. This episode reflects a social fear which is characteristic of man when he does not comprehend something.

The computer is a great threat to artistic sensibility because it challenges art to evoke more than physical sensations. It champions logic, thought and reason; these qualities are direct opposites to the effects produced by manual dexterity. A commercial artist or an industrial designer can learn to control his hands but it is more important to think out and to express visual conceptions of relevance to society. The computer cannot replace man for it cannot make subjective or emotional decisions that are necessary in the expression of significant visual ideas. Many artists fear the computer partly because of its challenge to traditional respect for manual dexterity; however, the main reason is the fact that artists have not investigated its technical potentialities from the point of view of art. If artists ignore the computer, the artistic spirit will be further alienated from our culture.

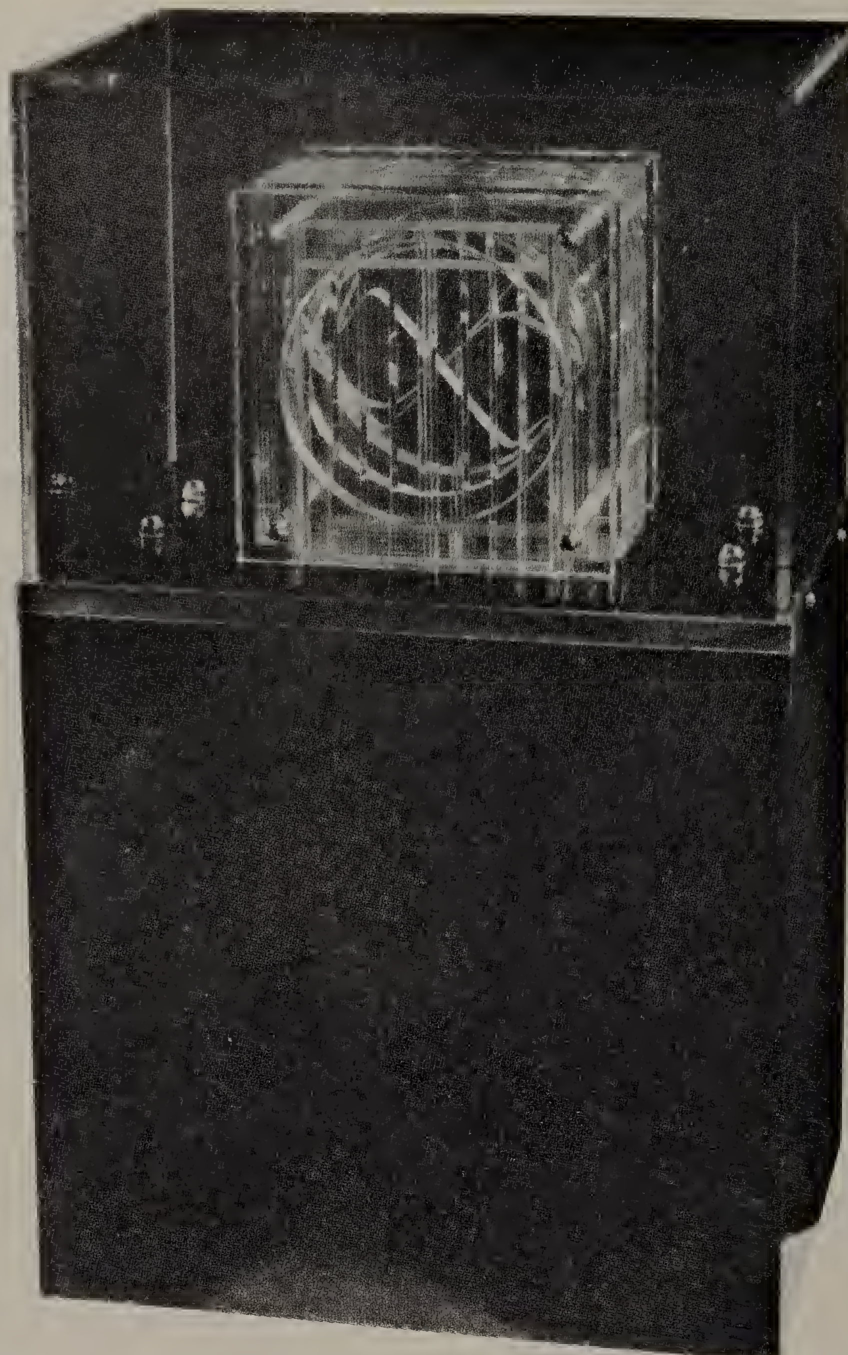

Fig. 4. 'Sine Wave Reflections', light sculpture, Plexiglas illuminated with colored lights, wood and Formica, 20 × 12 × 8 in., 1969. (Photo: R. Ayre and E. Basha, Jr.)

III. FORMAT AND CONSTRUCTION OF MY SCULPTURES

My sculptures have a format of three parts that can be distinguished within the single unit of each work (cf. Figs. 3–6). The materials are Plexiglas, light bulbs, black Formica, chrome edging and chrome cap nuts. The first part is an upper box which is made of $\frac{3}{16}$ in. Plexiglas. The function of this box is to isolate the interior object and to prevent the lower box from just becoming a base. The second part is an interior object. This object is made of $\frac{1}{2}$-in. sheets of clear Plexiglas. Each sheet has an outside perimeter of a square or rectangular shape and an inside shape of a sine wave combined with a circle or an oval (cf. Figs. 7–9). Individual pieces of the interior object are bolted together with chrome cap nuts. The third part is the glossy black box, which has a hinged door with a magnetic catch. This door allows an efficient changing of light bulbs but it is very inconspicuous. Lights are mounted in the interior; a white interior is used to reflect light. A hole, which is the same size as the interior object, has been cut in the top of the lower (black) box in order to illuminate the interior object directly above the hole. A false top is placed $\frac{3}{16}$ of an ineh above the top of the lower box in order to stabilize the interior object (cf. Fig. 9). The interior object drops through the false top and rests on a clear sheet which has been set flush to the top of the lower box.

A $\frac{3}{16}$ in. plastic strip is glued to the interior object and wedged between the false top and the lower box. The top is compressed over the strip with bolts using chrome cap nuts. A $\frac{1}{2}$-in. chrome edging is placed around the joint where upper and lower boxes meet to conceal the mechanism between the false top and the top of the black box. The edging helps to unite the two boxes.

The structure of the sculpture and the organization of parts achieve stability through the use of

Fig. 3. Illuminated part of 'Sine Wave Frequencies', light sculpture, Plexiglas illuminated with colored lights, sheet metal, 30 × 18 × 48 in., 1969. (Photo: R. Stejskal) Sculptures courtesy of Esther-Robles Gallery, Los Angeles, California, U.S.A.

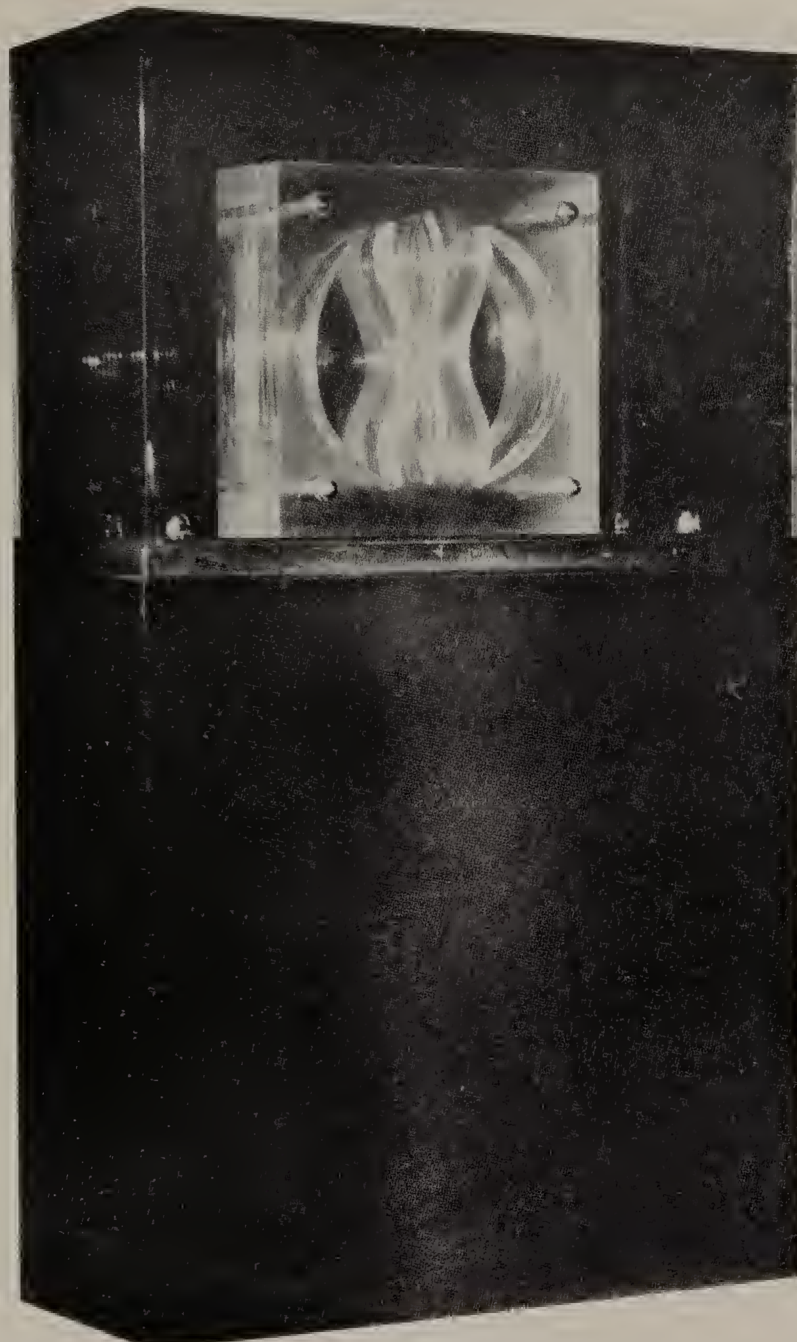

Fig. 5. 'Erros', light sculpture, Plexiglas illuminated with colored lights, wood and Formica, 20 × 12 × 6 in., 1968. (Photo: R. Ayre and E. Basha, Jr.)

perimeter shapes and mathematical proportions. The rectangular form of the box unifies the active design within the interior object. A circle was chosen as a contrast to the cubic shapes of its perimeter. Patterns in each sheet were derived from mathematical sine waves. Other interior objects which do not have sine wave shapes were extensions from the sides of the first sine wave pattern.

The structure and its materials are constants; the light and its motion are the variables. The shape of the box, derived from mathematical proportions (basically a 2:3 relationship), conservatively contains or, one might say, stabilizes the activity in the interior. Repetition of constants, such as the plastic sheets, reinforces the motionlessness of the structure. The light action on the interior object makes a contrast between this structure and itself, and the refracted, prism-like distortions of light conflict with the stable elements of the vertical box. An opposition of factors has been obtained and the product is, in a way, like the Chinese Yin–Yang symbol. The constants dominate but in the dark the variables of light change the meaning and character of the constant arrangement and proportions. Variation of light is the basic function, however, both environments are necessary to express my intent.

Interior colored lights belong to only one-half of the sculpture's two-fold purpose. I shall refer to this half as *Function One*, which is a chromatic development of light in a dark exterior environment. *Function Two* involves a constant exterior light environment that illuminates the unchanging arrangement of the object's structure in the traditional manner of art object presentation. In daylight or electric light, the interior colored lights cannot illuminate the plastic with enough intensity to clarify the chromatic purpose of *Function One*.

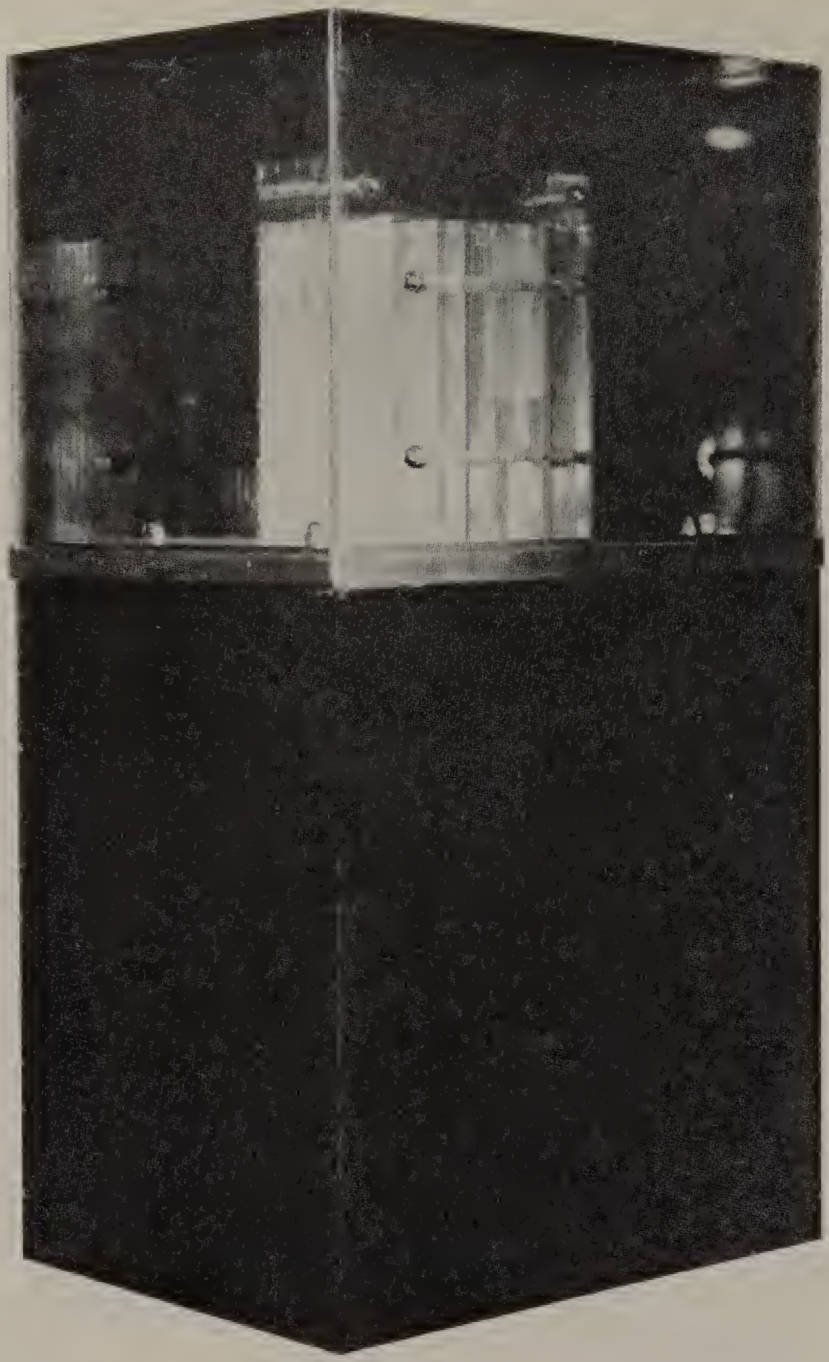

Fig. 6. '*Cross Currents*', *light sculpture, Plexiglas illuminated with colored lights, wood and Formica*, 20 × 12 × 8 in., 1968. (Photo: R. Ayre and E. Basha, Jr.)

Therefore, my work has a dual function and both must be self-sufficient.

Function Two deals with what I call the 'Box Mystic'. Something encased in a glass box becomes more special or sacred as, for example, artifacts in a museum or a church. Because the object is isolated from human control, it achieves an energetic force or life of its own. The object is beyond human desires or aspirations. I believe that man tends to develop myths or subjective philosophies to explain phenomena beyond man's comprehension. Human psyche may not change but the stimuli which affect man's ability to understand the inexplicable does change from one age to another. Even though my work is deeply concerned with technology, I believe it contains a talismanic reference because stimuli have evolved enough to allow technology to mystify or affect our emotional comprehension.

In *Function One*, the illumination of the interior plastic object intensifies this feeling of supernatural power because the light sequences occur at random and usually never in the expected pattern or speed. One would like to impose his will upon the speed and probabilities of color combinations; however, the sculpture cannot be controlled. Instead, it forces the viewer into watching its behaviour. This inability of the viewer to anticipate the sculpture's next state creates the magical qualities which I associate with talismen. To the person observing the sculpture, it becomes baffling, perplexing or enigmatic. The apparently self-generating oscillations of the plastic parts approach the inexplicable because the cause of the variations of light is hidden.

There are no complicated circuits or programed timers to regulate the lights. Instead, I use, as other artists have done, small incandescent lamps which are commonly used as Christmas tree lights. Resistance to electrical current through a tiny metal bar acts as a switch. The electrically produced heat expands the bar until it breaks contact with one

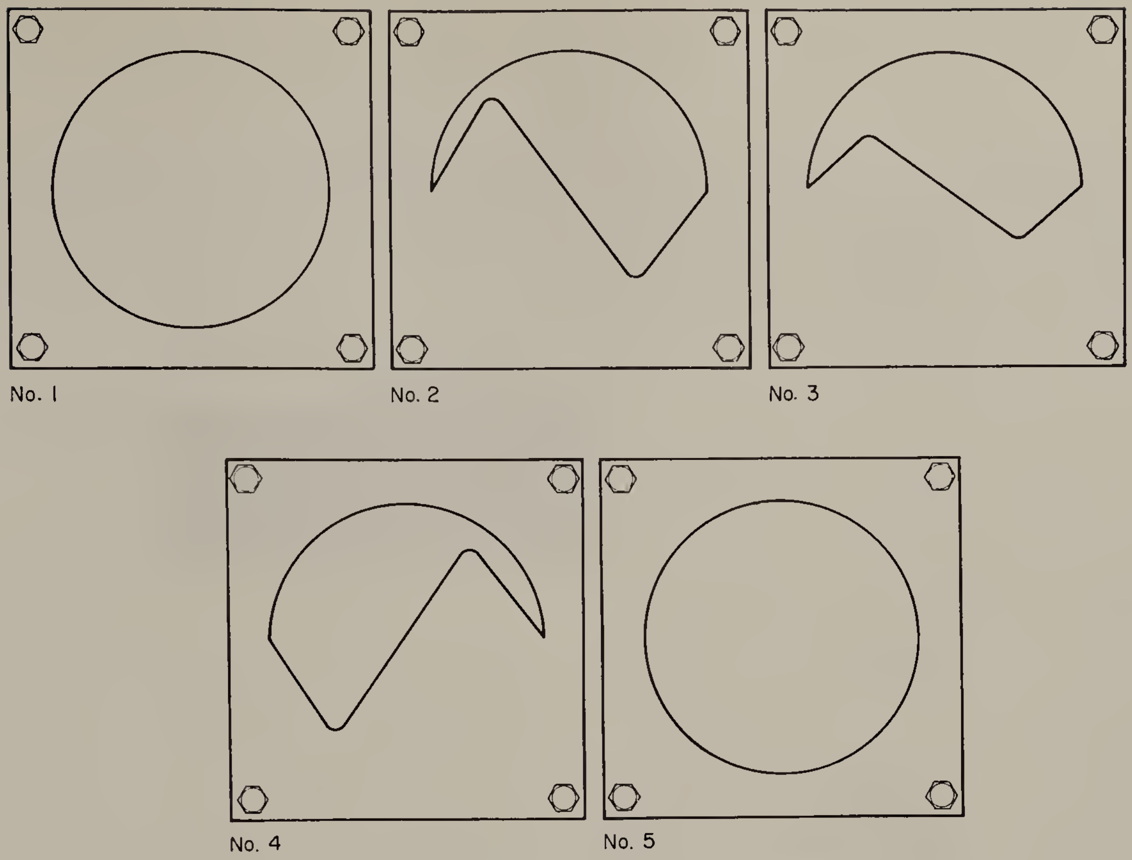

Fig. 7. *Shape of individual pieces of interior Plexiglas object.*

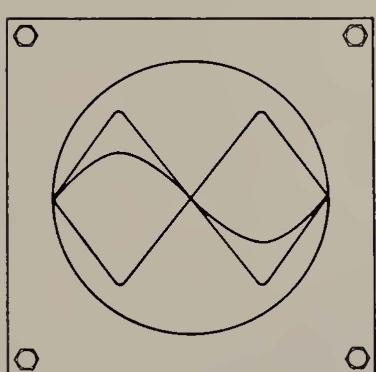

Fig. 8. *Combined pieces of interior Plexiglas object.*

end of the filament in the bulb. As the gas cools, the bar contracts until it again makes contact with the filament to turn on the light. Random cycles produced by the thermal interrupters occur with a probability of over 60 per cent. The color of each lamp can be changed by painting it with transparent paint. I use a lacquer base paint. The timing of each lamp cannot be altered. Since these lights blink in a random fashion, sophisticated color combinations can be produced with little expense and effort.

Enclosure of the interior light bulbs eliminates the stigma of 'the mechanical' and allows illumination alone to become a major stimulant. In fact, my sculptures are not glorification of the machine. An admiration or hate of the machine, as such, is, I believe, a relic of the last century. In our society simple mechanical devices are being replaced by more complex systems. Burnham describes the change as a shift to a 'systems-oriented culture' [6]. My sculpture reflects this break by utilizing kinetic systems of light, sound and motion without visual evidence of the mechanical means of producing one or a combination of these effects.

I have eliminated physical motion in the sense of change of position with time in order to allow the changes of light with time to become more stimulating and meaningful. Motion combined with light sequences presents too much for the eye to perceive if my intent for *Function One* is to be met, that is, to provide a subjective feeling of light. In this way, the interior object maintains its delicate balance of constants, derived from reason, and variables, which produce the sensations of my original intention. Mobility has been expressed by on-off light. The random light patterns appear to move the object in space whenever a rapid or unexpected change happens, such as a quick pulsating sequence from high-intensity red to low-intensity blue. The placement of light bulbs also gives an illusion of motion. When a red lamp flashes on one side of the interior and the same color flashes on the other side as the first stops, the effect produced on the viewer is that of a color moving through each sheet of Plexiglas from one side to the other.

Since light passes directly through a plate of Plexiglas, colors can only be seen on the edges of this material. Some designs for interior objects are seen from the plate side. This type utilizes the linear qualities of the patterns. I also make another design with or without cut patterns but the view is from the sides of many sheets of Plexiglas instead of from the plate side. This type produces more refractions and allows more light transmission (cf. Fig. 6).

The randomly variable light flashes, which produce effects that appear to the spectator to have no technical basis, together with the constant structure

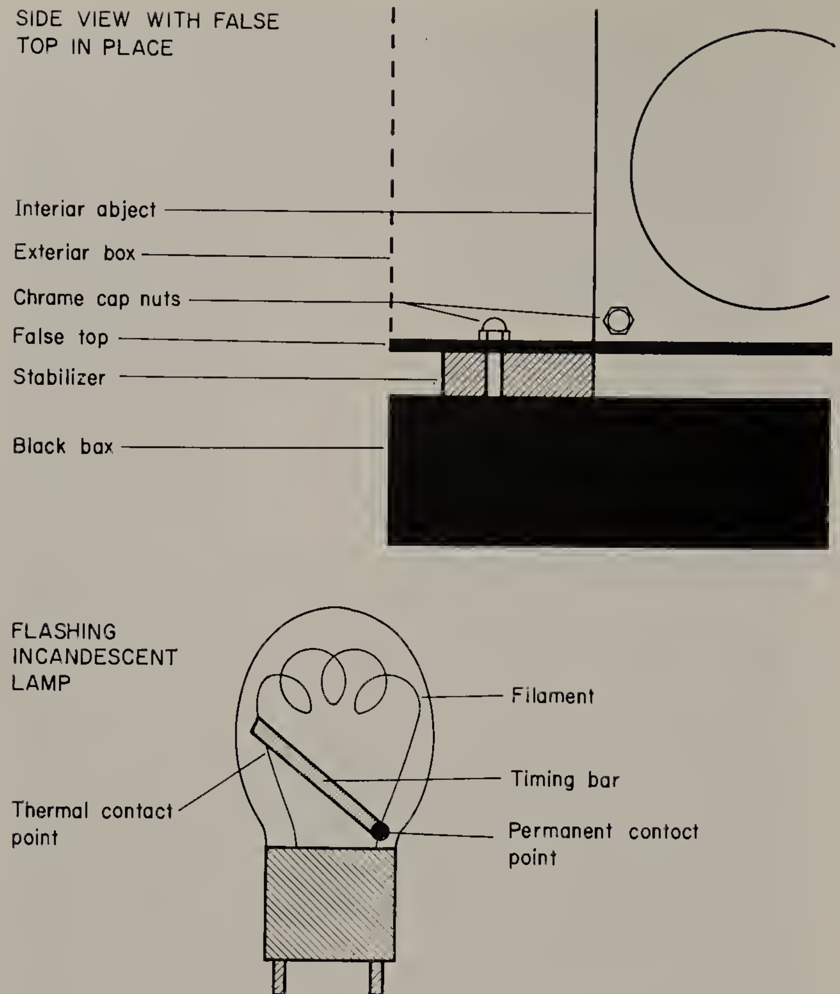

Fig. 9. Details of construction and of flashing incandescent lamps.

demonstrate my concerns with technology and fabrication techniques. This combination produces a unique object with a jewel-like quality. The sizes of my sculptures also reinforce their jewel-like qualities. The choice of black gloss Formica, transparent Plexiglas and a slim strip of chrome enriches the enigmatic qualities. The jewel-like preciousness, the subjective effects created by the illuminations, the talismanic imagery of *Function Two* and the contrast of constants and variables express my positive attitudes about myself as an individual in our technologically oriented culture.

The material, aesthetic and intellectual development of my sculpture is not concluded, for I have only begun this work. I plan a greater control of the light sequences to make a contrast with the periods of random change. I may expand the interior object to the dimensions of the exterior box so that the encasing plastic box will not be necessary. I will combine the sine wave and the edge pattern designs; this will maintain abundant illumination and develop my original interest in the sine wave refraction of light seen only from the edges of Plexiglas. Eventually I plan to use electronic circuits to operate the lights as well as the thermal interrupters. The basic concepts of my light sculptures are flexible enough to allow me to develop them as my artistic ideas grow.

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MY THERMOFORMED PLASTIC AUDIO-KINETIC LIGHT SCULPTURE SINCE 1966

Milton B. Howard*

The *time* experience in which we find ourselves today forces us into a heightened awareness of the present and our continuation and our interaction with this world of things and processes. My work gains meaning through the positive relation it has to this type of reality and gains interest not by ingenious change but rather by repetition, invention and extention within conspicuous unity.

Events considered to be simultaneous from the point of view of one observer will from the point of view of another be separated by a certain time interval because of the four-dimensional geometry in which space distances and time intervals are involved. Albert Einstein's graphic solutions to such events are the source of my subject matter and imagery. Einstein's graphs were made-up of points, lines, arrows, letters and numbers which became drawings of exceptional tension and beauty [1].

I worked for a while with all of these visual images and then the point within the graph (or event) began to have the most meaning for me. This circular shape now greatly enlarged, transformed into a separated sphere and taken out of context has a new character and meaning. My forms, however, still have a similarity with the original graph ideas, since they connect various simultaneous happenings in time and indicate forces and directions in space (cf. Fig. 1).

The serial system (repetition of the same or similar images) is for me a vital means of development. Variations are found within one form. Ideas become

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Fig. 2. *'Spherical Form—Red No.* 1', (*rear view*), *acrylic plastic illuminated with flashing incandescent light*, 36 in. dia., 1967.

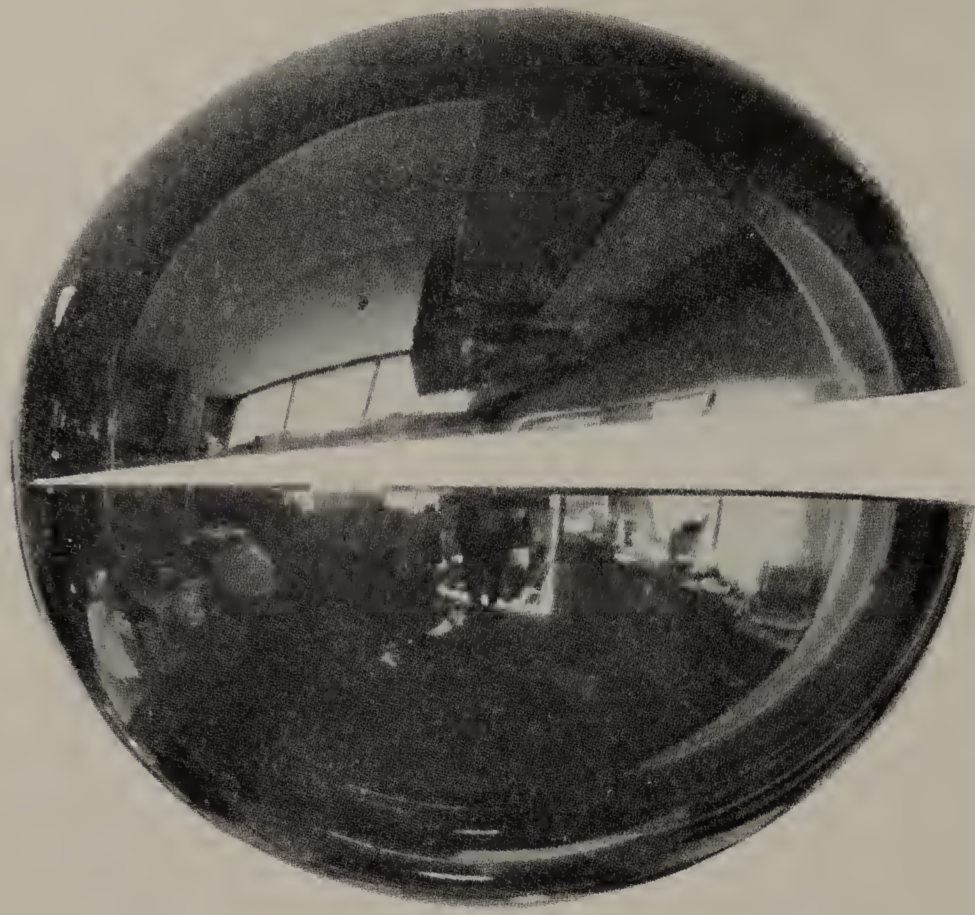

Fig. 3. *'Spherical Form—Red No.* 1', (*side view*), *acrylic plastic* 36 in. dia., 1967.

extended by starting each work further along in the process of knowing and understanding that form. New inventions and extentions are completed through the environmental interaction of color, shape, light and sound [2].

The use of colored transparent or translucent acrylic plastic, combined with thermoforming machines, became a breakthrough in solving the seemingly impossible problem of making near-perfect spherical shapes. Acrylic plastic has many advantageous innate eharacteristics: malleability, color, transparency, light transference, reflections, strength and light weight (cf. Figs. 2 and 3).

I use color to arrive at specific visual and physical sensations, i.e. coolness, warmness, deliciousness and sensuousness. Certain colors and lights create after-images so that a viewer seems to see front and rear views simultaneously, while the additive color effect causes colored shapes to change and to disappear as one looks through the various hanging spheres. The reliance on the after-image (the effect one has after looking at a bright color or light and then looking away) and the additive color sensations provoked by looking through the transparent colored spheres are also important factors in my ideas of simultaneity.

Light is important because of its instantaneous, direct energy and its capability of increasing or decreasing color brightness, color interaction, motion and direction, and to significantly heighten attention and participation by the observer. Variable light intensity also allows me some control over the environment. I use incandescent, fluorescent and neon lights for different light requirements in my various works.

I also use sound to increase my control of the environment. Various sounds and sound levels can change one's sense of physical space and motion through a personal sensation of either disturbance or pleasure. The source of the sound is not as important to me as the kind of sound and when and how it is used. Most of the sounds have been recorded from varied sources and programmed along with the lights to arrive at some desired environmental effect.

I have now become interested in the use of a computer as a result of the spiralling number of problems resulting from making combinations of these visual and sound factors. In future works, I hope to use a computer to program the light, sound and kinetic effects. Eventually a computer might produce on tape a whole work, including the visual forms themselves, thus eliminating or minimizing structural, production and transportation problems.

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Fig. 1. *View of one-man show of spherical forms. University of Minnesota Gallery, Minneapolis, Minnesota, U.S.A., May*, 1968.

SCULPTURE:
FANTASY MACHINES

Timothy Hunkin*

I started making machines under the name of Mrs. Gronkwonk when I was about twelve. Mrs. Gronkwonk is a large, fat, imaginary lady, who runs a country called Indoslimia by making machines to keep the inhabitants happy. My earliest surviving example is a machine for putting man-appeal into Oxo cubes. It was based on a toy radar station, with the aerial converted to pick up any bits of man-appeal in the atmosphere and the screen converted to a meter, indicating the amount of man-appeal in the cube. When the cube was full the machine turned itself off and the cube shot out of the side.

Since then my machines have changed greatly. My early works were built mainly of hardboard and were powered by miniature electric motors with Nylon gears. This technique worked adequately for a burglar-catching machine, a fortune-telling machine which read feet, a lift and a factory for bed-birds (birds who live on beds in Indoslimia), a Blobbling machine (for punishing bed-birds) and various others but my ideas continually grew more elaborate. I finally abandoned this form of construction after making an automatic doctor who was supposed to test blood pressure, heart beat and temperature, and then to deliver a diagnosis such as foot rot or baldness, a giant pill and the doctor's ever fatalistic thoughts behind an alluring door marked private. The doctor was so unreliable that he hardly ever ran a full cycle without some part breaking.

I had also begun to feel that Mrs. Gronkwonk was slightly childish and to be interested in the aesthetic appearance of the finished objects. A machine called an 'Ego Pump' (cf. Fig. 1) is my favourite from this period. It is made out of mahogany (from an enormous Victorian wardrobe) and is designed to boost a patient's morale by a pair of vigorously clapping hands and a flashing sign saying, 'gosh you're gorgeous'. It also relieves any aggressive feelings in the patient by a lead weight which sploshes satisfyingly into some water and a festive atmosphere is produced by a pair of clashing cymbals. It sits on top of a harmonium that the patient plays to enhance the effects and, if all else fails, there is a device that projects packets of Yeast Vite ('the lightning pick-me-up') around the room at high frequency. It is powered by electricity, is quite reliable and is still used by my father when he feels in need of encouragement, which I find most satisfying.

Since then, the element of fantasy in my machines has grown smaller and their appeal is now primarily aesthetic. After leaving school, I had nine months in which to work continuously. This may sound a short period but I found it remarkably valuable, completing seven machines and greatly extending my range of ideas. Before this time, I had always feared that I might run out of inventions and felt intensely possessive about my works. I now feel confident that I will continue to have new ideas and I am now prepared to part with them.

One of the machines I made then is the 'Rolling Drum' (cf. Fig. 2). It is mounted on gimbals and has a silent motor that tilts the drum-skin from side to side, giving it a rolling motion. When balls of different materials and sizes are placed on the drum-skin, they produce different sounds and patterns. There is a strip of rubber around the edge of the skin

Fig. 1. 'Ego Pump', fantasy machine, 30 × 24 × 12 in., 1967.

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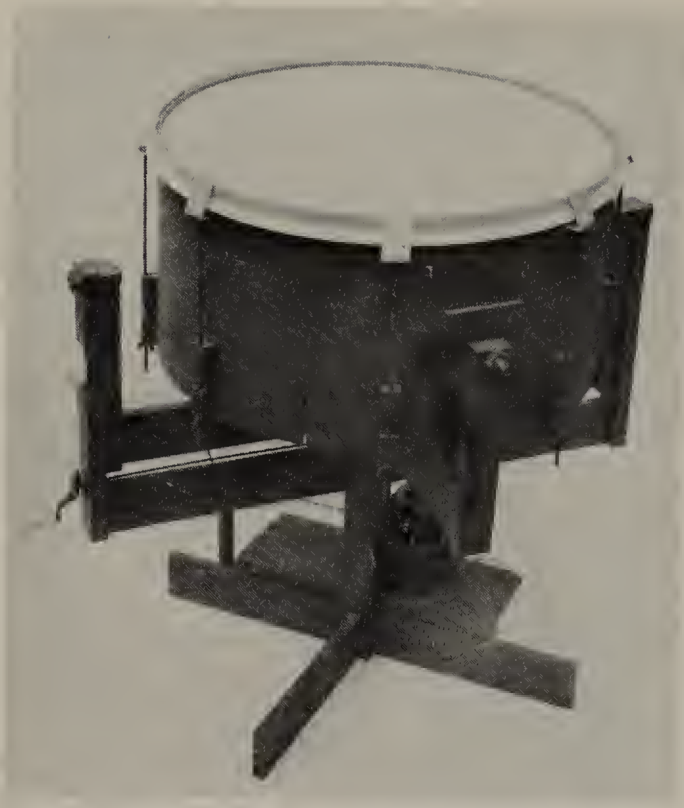

Fig. 2. '*Rolling Drum*', *fantasy machine*, 32 × 32 × 30 in., 1969.

against which the balls rebound. The handle under the switch adjusts the speed of rotation. Small billiard balls tend to coalesce in a hexagonal shape that breaks up when they hit the rubber but reforms

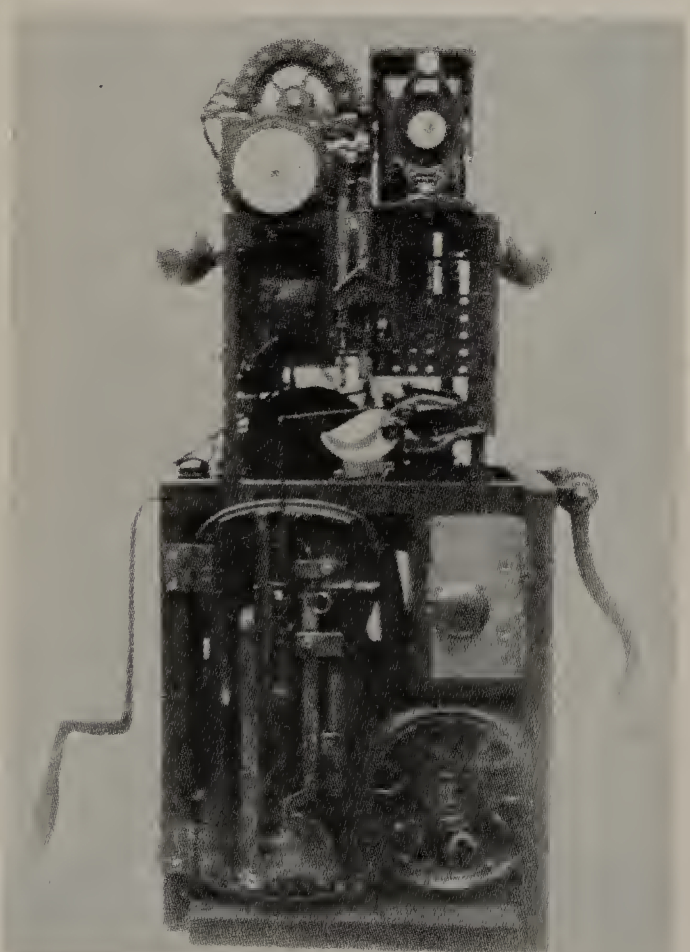

Fig. 3. '*Mechanical Man*', *fantasy machine*, 28 × 18 × 12 in., 1969.

if the rotation is above a critical speed. Marbles can be made to play a game in which they start moving across the surface of the drum but eventually strike the rubber at some critical angle and speed and from then on roll around the rim. This can take as long as five minutes. My favourite effect is obtained with a large number of $\frac{1}{8}$ in. diameter steel balls. They form patterns like sand being moved by breaking waves and make a noise similar to the hiss of the sea. The result is most hypnotic.

The 'Rolling Drum' was originally intended to work in conjunction with a device that would drop balls on to the surface at a preset frequency but I am sure now that it would only further confuse the infinitely variable patterns. One variation of the machine I am hoping to try is a bigger version with a circular billiard-table surface instead of a drum-skin. If this is made sufficiently accurately, the patterns formed by the balls should be predictable and should repeat themselves regularly.

Another machine built during this time was the torso of a 'Mechanical Man' (cf. Fig. 3). He is made from an old sewing machine and other bits I had collected from a scrap-yard. He does not do anything useful so I do not feel justified in calling him a robot. I made various other mechanical persons out of scrap metal and government surplus mechanisms but he is my favourite. He is activated by a large switch on his back and, therefore, is under complete control of the spectator. I am not sure if this is appropriate because I feel he is hostile and should turn himself on and off (either at random or activated by sound). His eyes are glass eyes and roll continuously in their sockets. His mouth gives a most alarming movement with a pair of secateurs that chatter fiercely and noisily. He has numerous other moving parts, including: high speed rotating door-knobs for ears, a kilowatt meter, a uniselector and a fan in his brain, and an oscillating 'hot' bath tap in his heart.

Since October 1969 I have been at Cambridge University reading engineering and have had less time to make things. I felt I wanted to do something with my machines before they rusted up irrevocably and, therefore, I mounted an exhibition of the best of them at Cambridge. The machines operated on a four minute cycle so there was always something happening. This produced an exciting and jolly atmosphere, which I greatly preferred to the restrained, silent feel of most art exhibitions. The exhibition attracted a wide cross-section of the public and large numbers of children, who added greatly to the festive atmosphere.

It could be thought that my machines are too whimsical to be classed as art although I have always thought of them as such as I believe art should above all things be enjoyed. Some artists who work with machines similar to mine wish to educate the spectator along special lines. The often morbid works of Bruce Lacey [1], who makes robots out of scrap parts, blatantly imply social comment. (He is especially fond of incorporating artificial limbs and has one called 'Population Explosion'.)

Charles Mattox [2], who has made machines something like my 'Rolling Drum', states that his motive is 'to make people aware of our technological society'.

I do not share their objectives but have views closer to those of Juan Downey [3], who says he likes his machines to be useless and irrelevant and he gets satisfaction from seeing children play with them. I am sure Tinguely [4] and I have a common outlook, for he said: 'My machines are innocent'.

My recent machines still differ very much one from the other and it sometimes worries me that they do not seem to have much evolutionary continuity. For the future, I feel I could be happy working in a large number of spheres but my chief ambition is to be self-employed so that I can develop my inventions as inspiration takes me.

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MY 'MOBILE HYDROMURAL'

Gyula Kosice*

Fig. 1. View of the 'Mobile Hydromural' from above, Plexiglas and aluminum, electric lights and water, 16 × 6 m, 1966.

Since 1958 I have been using in my kinetic sculptures flowing water and water droplets on surfaces, and the motion of air bubbles in water. Parts of the objects are made of transparent Plexiglas supported by plastic or aluminum components. Some of the objects have parts in various colors and some have interior electric light sources.

One of my largest projects was the 'Mobile Hydromural', which was installed in 1966 at the Embassy Center, Galeria del Este, Buenos Aires, Argentina. An over all view of the mural, from above, is shown in Fig. 1 and details of it in Figs. 2 and 3. It is 16 m high and 6 m wide, with a water pool at its base to catch water flowing down the mural. At the bottom of the pool are two transparent blue, Plexiglas hemispheres of 1.30 m dia. that are illuminated from within. There are also vibrators in the pool to produce ripples on the water surface.

The panel of the mural is constructed of anodized aluminum of 4 mm thickness. This panel has 500 holes (15 and 20 mm dia.) drilled through it to contain short transparent Plexiglas rods. One-third of the rods are cut at an angle and are distributed

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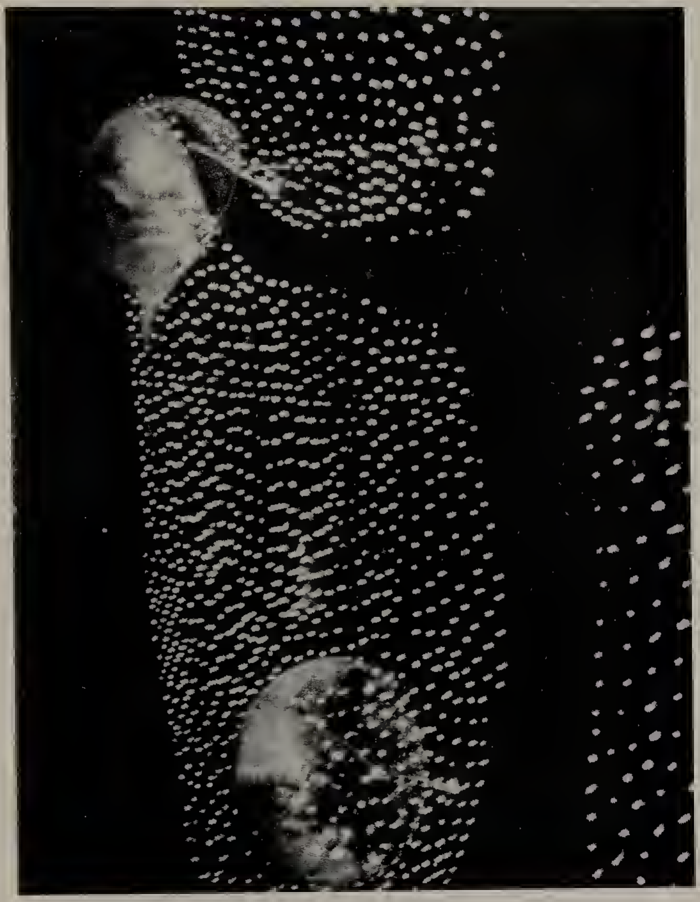

Fig. 2. Detail of the 'Mobile Hydromural'.

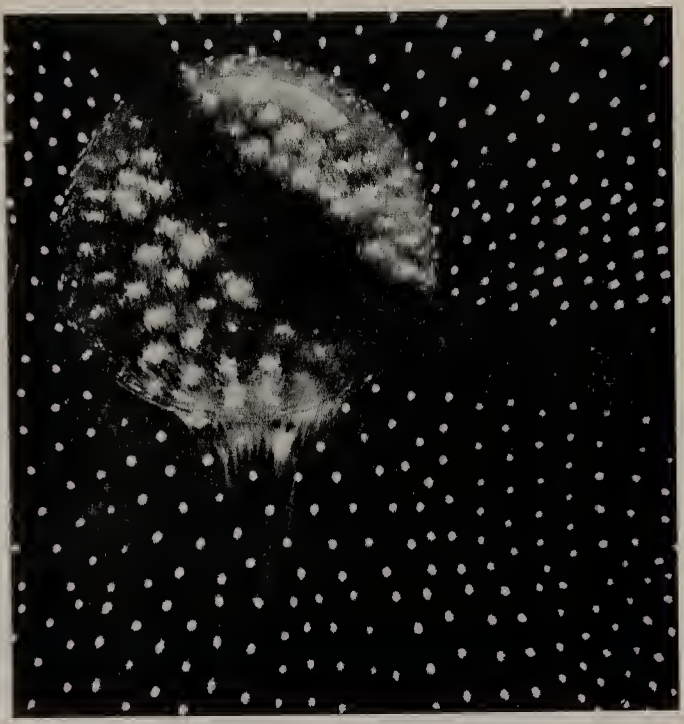

Fig. 3. Detail of the 'Mobile Hydromural'.

at random in seven groups. Revolving disks are mounted in front of lights at the rear of the panel to throw beams of blue, orange, and green light onto the rods for producing a scintillating effect.

Three 130 cm dia. hemispheres are attached to the panel. The two upper ones are tipped at an angle of 35° from the vertical to allow water jetting into them to fall in a cascade into the pool below (cf. Figs. 2 and 3). The lower hemisphere contains water that is agitated by an air jet.

The mural panel is supported by a steel structure, 60 cm in depth. Behind the panel are installed 220 fluorescent light tubes, the revolving colored disks, ramps and ladders. A 5000 liter water reservoir and an electric pump capable of circulating 3000 l/hr are provided. The water is changed when it has accumulated too much foreign matter.

A musical composition especially composed by Jorge Slullitel is played from tape during the operation of the mural. Thus my 'Mobile Hydromural' integrates the motion of water and of colored light with music.

KINETIC ART: CONSTRUCTIONS WITH STRETCHED FABRIC STRIPS

Thorbjørn Lausten*

The kinetic constructions I make consist of three-dimensional structures made of steel tubing with strips of sail cloth stretched between the tubes (Fig. 1). The constructions, suspended by a rope or wire at a single point, are to be rotated manually.

The frame in the construction shown in Fig. 1 is white and the strips are painted with red and white acrylic paint. When the construction is rotated, the strips seem to pulsate incessantly and cause one to lose a sense of the passage of time.

A more complex construction of this type is shown in Fig. 2. The core is a cubical framework and frameworks of different shape may be attached to each of the six sides of the core. The steel tubes are white and the stretched 10 cm-wide strips are painted orange, pink, and light and dark green. Interesting color and visual illusion effects are obtained when the construction is rotated.

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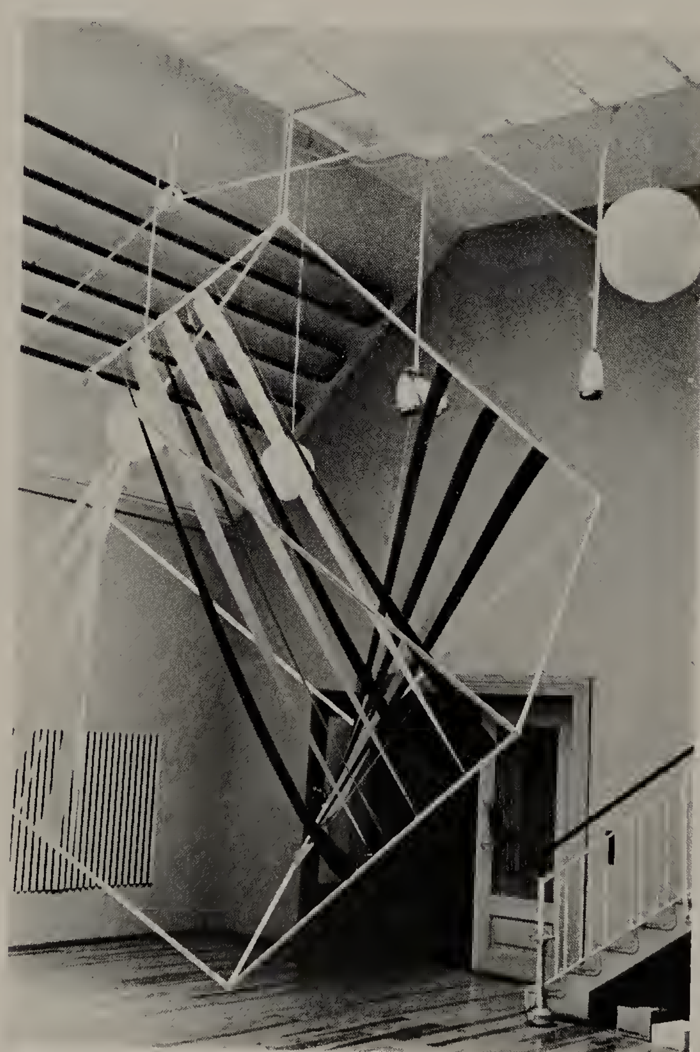

Fig. 1. 'Kinetic Construction', steel tubing, sail-cloth strips, acrylic paint, 200 × 200 × 200 cm, 1970.

Fig. 2. *'Kinetic Construction'*, *steel tubing, sail-cloth strips, acrylic paint*, 300 × 300 × 300 cm, 1970.

THE EVOLUTION OF MY AUDIO-KINETIC SCULPTURES

Charles Mattox*

Abstract—*The author describes the evolution of his work with kinetic sculptures and its relation to modern technology. The forces in our society that offer feed-backs to this approach are discussed. He describes in detail a series of his works that, over a period of twenty years, have been concerned with science, mathematics and art. His latest sculptures, in addition to being kinetic, produce sounds. The author believes that art (at least, some art) should be concerned with our environment in order to make people more aware of the structure of our technological society.*

I. INTRODUCTION

Since automation and industrial processes are an integral part of American life, as well as part of the rest of the rapidly developing world and have a profound effect on the quality of life and art, I have in my sculpture tried to emphasize something of this interlocking of art and technology. Lewis Mumford in *Art and Technics* says, 'man is both a symbol maker and a tool maker from the very outset because he has a need to control his inner life and to control his outer life' [1]. My sculptures are,

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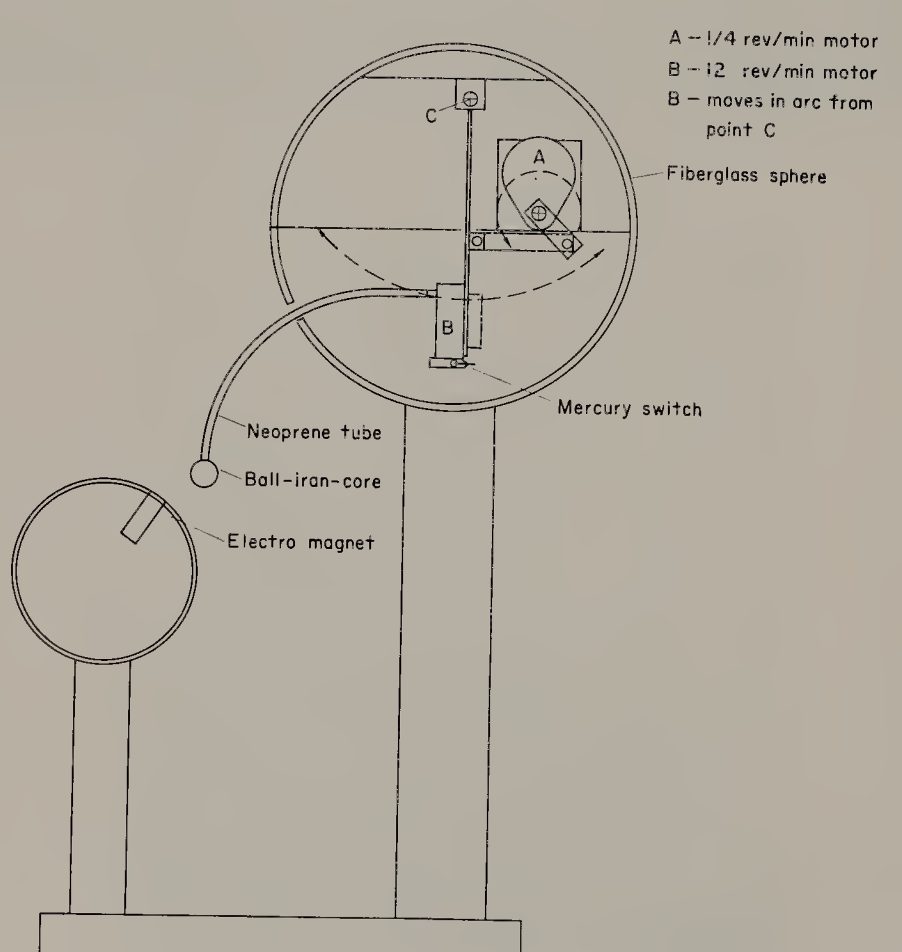

Fig. 1. Drawing for 'Act of Love', kinetic sculpture, motor driven and with magnets, wood and metal, 1964.

Fig. 2. '*Conversation Piece*', *kinetic sculpture, motor driven, wood and metal*, 25 × 30 × 12 in., 1963. (Photo: F. J. Thomas, Los Angeles.)

in a sense, analogues of machines. The emphasis is on aesthetic principles, but I use mechanical-electronic and harmonic devices to widen the experience of the viewer. In all my pieces I try to involve the spectator. This may be done directly by means of a foot switch or by applying some necessary force to activate the piece. Some pieces may be activated more indirectly by sound or by light sensors and some must be played by the viewer, who must become aware of the resonating characteristics of the particular machine in order to make it work.

The Southern California environment, with its freeways and animated signs, and its motion-oriented culture is a direct stimulus to my work. The *hot-rod* and *drag racer* have a mystique by which I have been influenced. The aesthetic of the racer with its chrome-finished and colored surfaces directly relates to much of modern sculpture. The drag racers speak of the 'show' and 'go' of their machines. The 'show' (finishes, design and chrome) is very much a consideration in the effect produced at a drag race. The spectators are turned on by the sights, sounds, smell and finally by the speed. Sculpture, I feel, should function in much the same way; that is, be a combination of sight, sound, etc.

II. DISCUSSION OF MY SCULPTURES

Building sculpture with those considerations in mind, we are faced with some of the same problems that are a part of a machine culture. Sculpture designed to move or be moved with motors and electronic parts has a short life span as compared to traditional sculpture. I feel this is as it should be, and I am willing to accept the fact that my works will have to be serviced, refinished and finally be expended [2–4].

This does not mean that the pieces are not well-built and finished with great care. All the large forms are fiberglass covered and finished with eight to twelve coats of automotive lacquer. The metal parts, wherever possible, are machine-finished or chrome-plated. I usually use primary colors and have found many standard automotive colors that suit my needs. For exterior pieces, I have been using either epoxy, which is very difficult to handle, or vinyl floor finish, which stands up well but does not have a wide range of colors.

I have been working for some time now on two large projects. One is a 'fountain' for lack of a better name. It is a large kinetic form floating in water and is activated by solar energy. It has rest periods when it stores up energy until a predetermined level of energy is reached, then it performs. The basic form is an ovoid, 15 feet high floating on its large end which contains the pumps, batteries and system for operation. This weight holds the piece upright. At the top, there is an 18 foot stainless steel mast free to rotate 360 degrees, and counterbalanced so that it remains upright when the piece oscillates under

Fig. 3. '*Affection*', *kinetic sculpture, motor driven, wood and metal,* 6 × 10 × 5 in., 1969.

Fig. 4. '*Twist No.* 1', (*shown on right*), *kinetic sculpture, motor driven, wood, metal and nylon line*, 96 × 12 × 12, 1963. (Photo: E. Mays, San Francisco.)

Fig. 5. *'Geneva Wheel', kinetic sculpture, motor driven, metal,* 32 × 26 × 8 in., 1964.

the force of jets that spray water from alternate sides. The structure will be fiberglass over a hardwood frame with airtight seal at the center line where the piece is joined. The whole piece will carry four or five pounds air pressure internally. It is now in the model stage and is being considered for a large marina project in Florida.

The other project, also in the model stage, is a childrens playground of musical sculpture. The playground would have a pentagonal shape, 30 feet across, with five levels. The low steps from ground level into the lower levels would be step switches arranged like a hop-scotch layout. These step plates would activate electronic tones in five notes. All the pieces would be in a five-tone scale arrangement with five large gongs at the lowest level and groups of pieces in sets of five at the different levels. The next set in pitch will be large marimba-type boxes, then, next brass tube-type marimbas and, finally, heavy stringed boxes to be struck with mallets. All the pieces would be in color with a system of five colors to identify each related tone. For example, the lowest-toned gong would be red, the second in pitch, blue, etc. through yellow for the highest tone. The groups of five would each be an octave and the combination of pieces would cover several octaves. Some of the pieces, other than the hop-scotch steps, would be electronically amplified and at the ground level there would be a control box for the electronic equipment with controls and speakers. The sculpture could be played either randomly or with some instruction. A group would be able to produce musical compositions.

Several years ago I made a series of pieces that were non-machinelike in their effect, in spite of the use of motors and magnets, highly finished surfaces

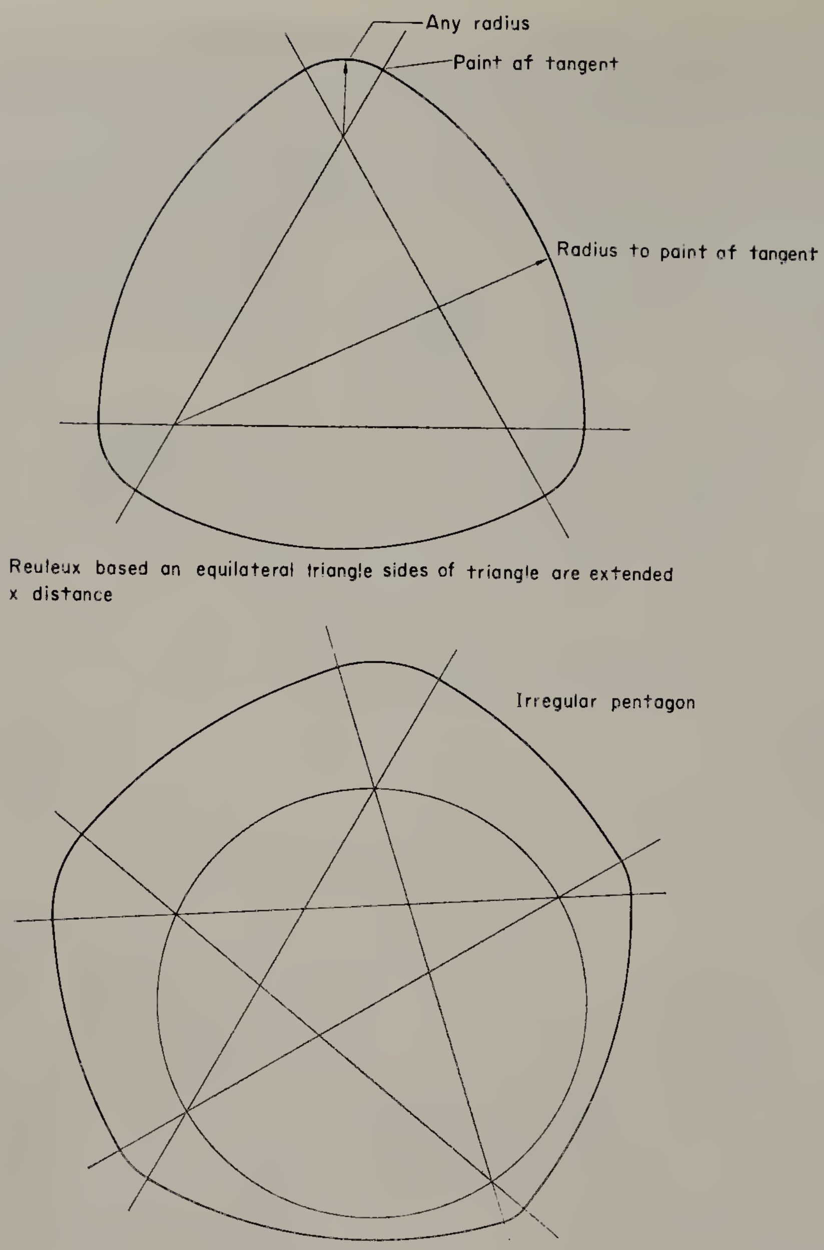

Fig. 6. Reuleux constant diameter shapes.

and geometric shapes. 'Act of Love' was one of the first of these. Figure 1 shows one of the drawings from which the sculpture was constructed. A small red ball detaches itself from the parent ball and moves toward an 'erogenous zone' on the neighboring ball. It crawls around the zone for a while and then returns. The metal parts are stainless steel, polished and machine-finished. Activated by the top motor in the large sphere through a cam and spring arrangement, the lower motor is made to move through an arc. This action causes the flexible plastic tube on the lower motor to extend and retract through a hole. This tube has a small red ball at its extremity. The tube is activated by closing the mercury switch on the lower motor. This switch also activates an electric magnet in the smaller sphere which attracts the turning ball issuing from the large sphere. The motor is slow (4 minutes for a complete cycle). The effect is very erotic and has a great deal of randomness in it. The piece is built of plastic and stainless steel. The two spheres are black automotive lacquer and all the metal surfaces are machine finished. The small red ball is the only spot of color.

A similar machine is the 'Blue Seven', 32 × 18 × 15 in. in size. It consists of an upright figure that looks like the numeral seven. It sits at one end of a red platform and very slowly begins to tilt toward a large black sphere sitting on the other end of the platform. When the seven almost touches the ball, the ball jumps and buzzes, whereupon the seven shape retreats to its former position and stops.

Another of this group is a piece called 'The Fuzz is Your Friend', built in 1967. A large ball covered with black monkey fur is suspended in space on a hexagonal table by three springs. The table is 39 in. high and the ball 24 in. in diameter. The ball has a motor and eccentric inside and gets current through two of the springs. When a foot switch is stepped on, the ball begins to jump up and down rather sluggishly. The moving fur has erotic overtones. People usually react strongly to the piece; some are frightened whereas some seem to enjoy touching it.

Still another of this series is called 'Conversation Piece' (cf. Fig. 2). The smaller box has two counter-rotating discs and the large seven-sided figure has a center motor with an eccentric that is suspended by

Fig. 7. '*Yellow Rotating Form*', *audio-kinetic sculpture, motor driven, birch plywood covered with fiberglass and metal*, 60 × 48 × 12 in., 1964. (Photo: F. J. Thomas, Los Angeles.)

seven springs. With this many degreees of freedom, it has a very erratic motion. The two elements are on a random timing device and a flip-flop switch, so that after the first one runs a few seconds and then the other one picks up, when the first one stops. It has the effect of the two elements speaking to each other. The timing between the pieces is random.

At the time I built the above-mentioned three sculptures, I built several others that were dissimilar in configuration but similar in concept. I mention this because it often happens that I return to older concepts. I have just done so in a new piece, called 'Affection'. This piece consists of a similar 6 × 10 × 5 in. box with five springs. The box has five tubes projecting from it. All of these tubes twist and move at different speeds. The main interest is focused on the two upright springs which come together and seem to caress each other and then move away. The speeds are quite slow and have a random effect (cf. Fig. 3).

In 1963 I made a series of pieces that were based on the mathematical figure of the helix. There were several large ones and a multiple edition of ten small ones. Just recently I made three more on commission. The piece consists of two drums connected by a series of nylon lines arranged in a circle on the outer limits of the upper and lower drums. The lower drum is suspended by the nylon lines and is thus free to twist. The lines stay taut but become diagonals. It works as a circular pendulum. Power is supplied by the starting torque of a motor in the upper drum which flips on and off by a mercury switch. The system has a phase of oscilla-

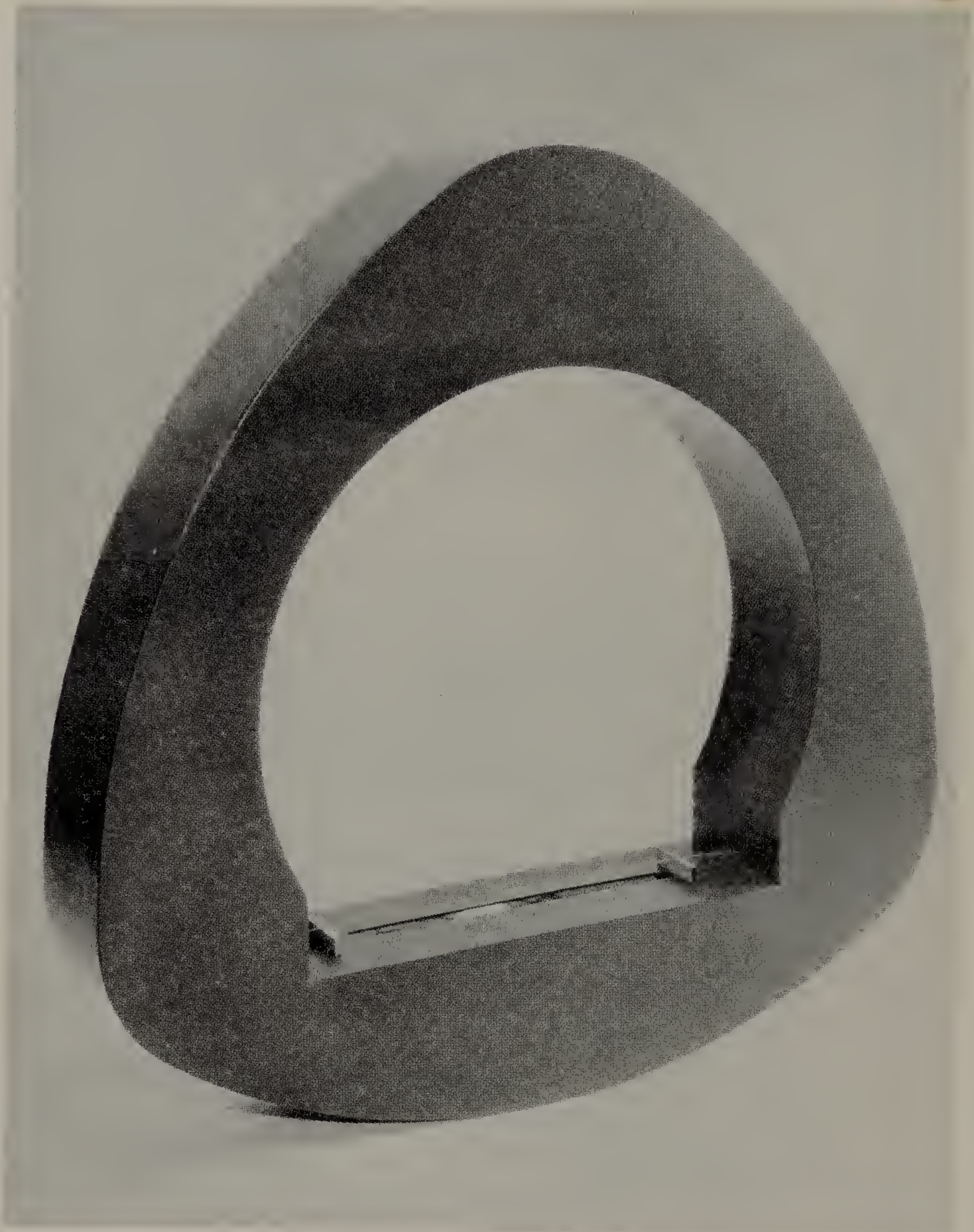

Fig. 8. 'Musical String Series, No. 1', *audio-kinetic sculpture, motor driven, birch plywood covered with fiberglass and metal,* 48 × 48 × 10 in., 1966.

tion that is determined by the weight of the lower drum and the length of the lines (cf. Fig. 4).

The Geneva Wheel series was the result of some explorations in pure mechanical systems. Figure 5 is an example of this group. The smaller disc with a pin topped by the triangle rotates and the pin engages the slots and rotates the large white disc by one-eighth of a turn. The ratio of movement is thus 8 to 1. This movement is very beautiful to watch either in a machine (and it has been widely used in machinery) or in a piece of sculpture.

Mathematical configurations have been the stimulus for the shape and movement of many of my recent pieces particularly the pieces that incorporate sound. Franz Reuleux, a nineteenth-century mathematician wrote on the subject of man and machines in three-dimensional space, and discovered the particular set of geometric figures that are constant diameter shapes [5] (cf. Fig. 6). They can be drawn from any regular or irregular odd-sided polygon and they move in a non-circular curve of constant diameter enabling them to rotate, oscillate or turn over on themselves while maintaining their balance.

'Yellow Rotating Form' is based on a Reuleux form derived from an irregular pentagon (cf. Fig. 7). In this piece, the form, which is 48 in. in diameter, rotates on the three rollers in the base and shifts from one set of rollers to the other. The center roller is the drive and the two outside rollers are idlers. It rotates at 0·25 rev/min. There are inner sound chambers that create sounds, as well as the sounds of chimes produced by the center stainless steel rods that are activated when the piece shifts. The rotating form is yellow and the base is black.

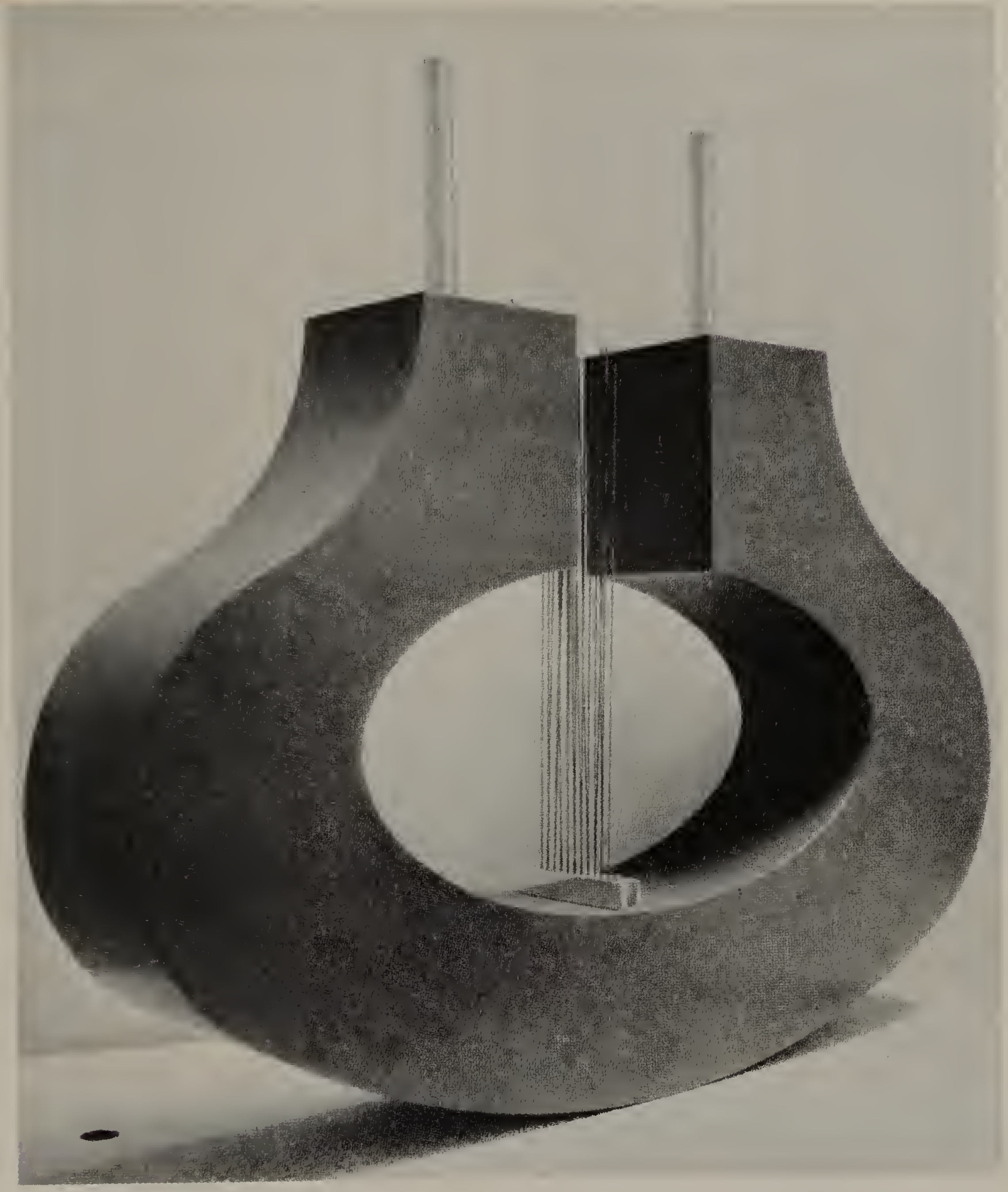

Fig. 10. *Untitled, audio kinetic sculpture, electronic sound, birch plywood covered with fiberglass,* 36 × 40 × 8 ins., 1969. (Photo: F. Eversley, Los Angeles.)

Related to this piece is one I call 'Rotating Drums'. A base containing motor and drive mechanisms is located in a rectangular base 48 in. high. Riding in rollers at the top is a 12 in. diameter tube, 60 in. long that is bent at a 30° angle in its outer third, in opposite directions. The piece that rotates is in balance and at either end are drum heads. Inside the tube, balls rotate freely and drop down against the drum heads as the tube turns. The roller is bright yellow and the base is yellow and white.

Figure 8 shows another Reuleux form based on a regular isosceles triangle. This piece is 48 in. in diameter. The two strings at the base over a sound board with frets are cello strings and can be tuned. A piano wire suspended through a diaphragm at the top of the piece extends between the two cello strings and has a weight at its lower end. The length of this pendulum is shorter than the radius of the lower arc and, as a consequence, the rocking of the piece is out of phase with the swinging of the pendulum. The sounds produced by the vibration of the three strings is like a primitive string instrument.

Both of the sculptures shown in Figures 7 and 8 are built of birch plywood covered with fiberglass. The birch plywood, $\frac{1}{8}$ in. thick, stressed over the curved form produces an ideal resonating chamber for the musical vibrations. I might mention here, that it was in 1965 that I began to use musical sound to replace the unintentional machine-induced noises that my pieces made. It was the composer, Harry Partch, who advised me to make use of the noises by making them musical rather than to try to disguise them.

The 'Double Pendulum Reuleux Form', shown in Fig. 9, built in 1968, was a direct result of the piece shown in Fig. 8 and is built in much the same way. I was interested in the out-of-phase pendulum effect produced. So, I increased the size and weight of the inner pendulum to make it effect the rocking of the piece more directly. The outer shells contain balls that give drum-like percussion effects when the piece is rocked. The effect is strange when the yellow-painted inner form rocks to a distance of 2 ft outside the black outer form, and then retreats inside again, to come out the other side, etc.

I have built many other similar sculptures some using electronic amplifiers in the sound systems. The smallest of this series is about 30 in. high and I have made some up to 12 ft high. One of the latter is finished to withstand the weathering of the elements since it is an outdoor piece.

The latest in this series, completed in April, 1969, has a theremin built into it (cf. Fig. 10). The theremin is an electronic instrument that changes tone and volume by body capacitance. If you move your hand near the right-hand chrome tube on top of the piece, the tone (or pitch) becomes higher and moving the other hand near the left-hand tube changes the volume. Thus, the viewer produces electronic music. The center rods play sounds when the piece is rocked and can be used alone or in conjunction with the theremin.

At the present time I am working on sculptures that incorporate more sophisticated electronic devices. I feel that my work now should be directed towards constructing pieces also involving the viewer through sensors of various kinds in order to make controlled environments. This will include forms with light and sound.

For the past year I have been experimenting with the use of a computer. This is a new tool that offers a new kind of approach to art and will, in the near future, open up new vistas for art. Environments can be created that will have sound, light and color in motion and can be programmed for long periods of time. The environment will be controlled by the computer program but, through sensors, will respond to the persons in the environment as well as to other factors, such as temperature, humidity and light levels.

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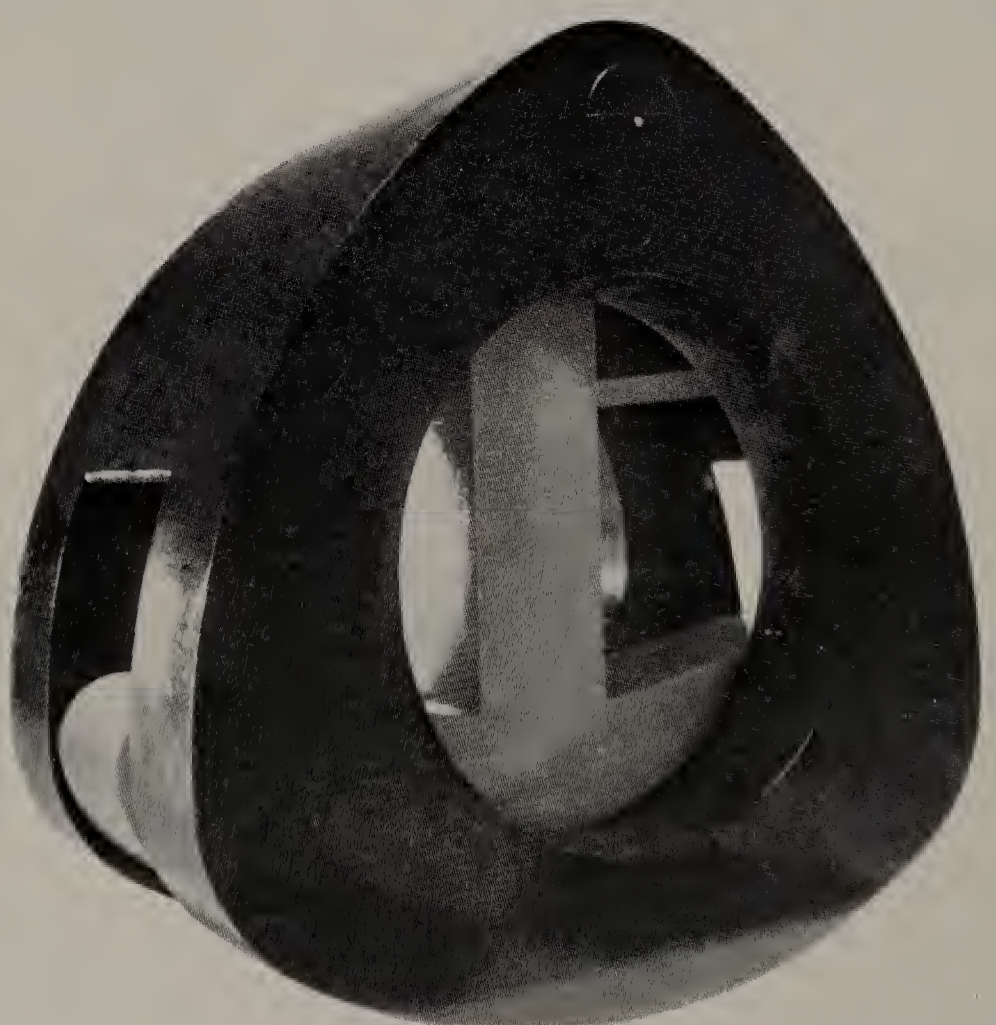

Fig. 9. 'Double Pendulum Reuleux Form', audio kinetic sculpture, motor driven, birch plywood covered with fiberglass and metal, 1968.

AN INTERVIEW WITH STEPHAN VON HUENE ON HIS AUDIO-KINETIC SCULPTURES

Dorothy Newmark*

Interviewer's note—*Stephan Von Huene was born in Los Angeles, California in September* 1932 *and is currently residing there at* 1336 *Sutherland Ave. He studied art at Chouinard Art Institute in Los Angeles and at the University of California at Los Angeles* [1–4]. *He teaches at present at the California Institute of the Arts in Valencia, California.*

Newmark—'Tap Dancer' (1969) (cf. Fig. 1) is your latest audio-kinetic sculpture. Do you feel it is the culmination of a period in your work?

Von Huene—All of the sculptures that were in my 1969 exhibit at the Los Angeles County Museum of Art were the culmination of a certain direction; that is, the use of biomorphic forms activated by a player-piano mechanism and accompanied by music. 'Kaleidophonic Dog' (1967) (cf. Fig. 2) was my first machine to operate successfully. A dog is lying on its back with parts of it moving, accompanied by sounds of a wooden drum, 8 organ pipes and a xylophone. Used in the machine are five loops of 2 in. tape with perforated programs that move along a tracker-bar arrangement. The pneumatic system causes parts to move and the drum, organ pipes and xylophone to produce sounds.

N. Would you describe the mechanism you use?

V. H. The basic part of it is a valve that acts like a switch and a tracker bar over which rides a perforated tape. When the perforations in the paper tape line up with holes in the tracker bar,it turns on the valve switch and allows air to be pumped out of

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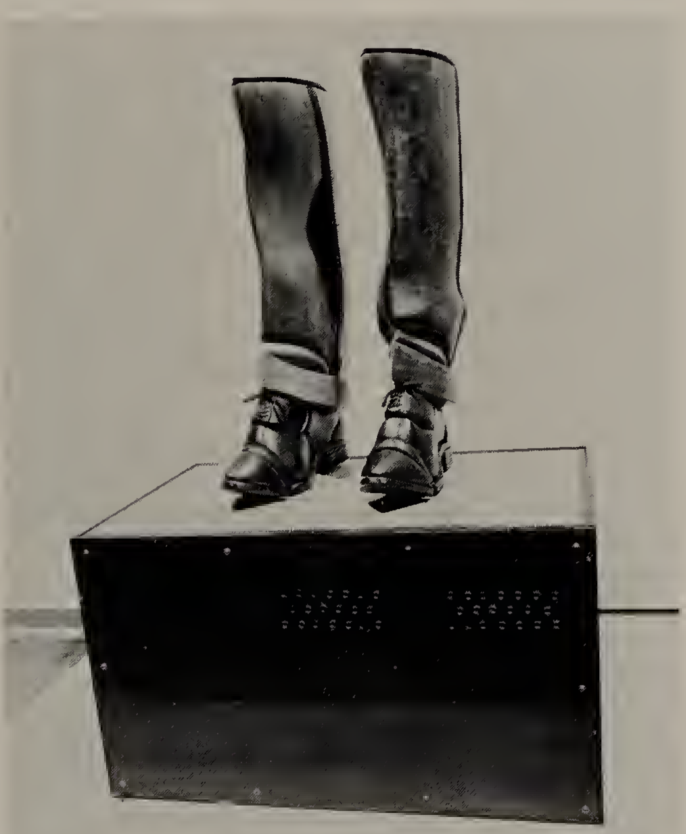

Fig. 1. *'Tap Dancer' by Stephan Von Huene, audio-kinetic sculpture, wood, foam covered with leather and pneumatic system,* height 4 ft, width 4 ft, depth 3 ft, 1969.

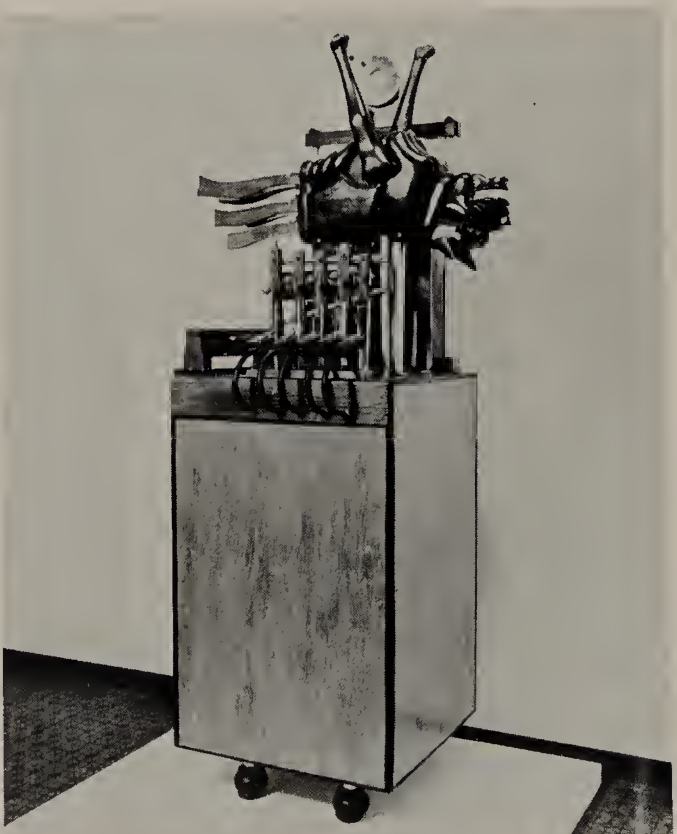

Fig. 2. *'Kaleidophonic Dog, by Stephan Von Huene, audio-kinetic sculpture, wood, wood covered with leather and pneumatic system,* height 7 ft, width 3 ft depth 3ft, 1967.

a small bellows that has a hammer attached to it. The hammer may hit a drum or it may operate another small bellows that opens a palate valve connected to one or more organ pipes. The organ pipes are operated by an air blower. The perforated tape, or several of them, can be rewound automatically; the system can also be operated during the rewinding phase. If anyone is interested in the details of the system I use, I would be glad to provide them.

N. What led you to use the player-piano mechanism?

V. H. I was at first simply interested in finding out how it worked. I found that the 11·5 inch player-piano paper strip was too wide for my purposes and now use a 2 in. paper tape. I punch holes in the tape at random or with a specific program of sounds in mind. I would like to make it possible for anyone to prepare the tapes, so they would produce sound combinations to suit themselves—either ordered sound sequences, which are, I suppose, what we call *music* or haphazard sound arrangements.

N. Would you describe your most recent piece, 'Rosebud Annunciator' (1969) (cf. Fig. 3).

V. H. It has an overall appearance of early California architecture, heavy and oak-furniture-like, an influence that stems from a very romantic part of my early life in Pasadena, California. On top of the machine is a leather rose, made up of sixteen sections that can be inflated and deflated. Then, on each side there is a post with an inflatable, deflatable leather sphere in a box on top of it, connected by tubing to the pneumatic system. The center part is made of a large xylophone with twenty-four notes, two cymbals, a drum and an octave of reeds.

Fig. 3. 'Rosebud Annunciator' by Stephan Von Huene, audio-kinetic sculpture, wood, formed leather pneumatic parts and pneumatic system, height 7 ft, width 8 ft, depth 4 ft, 1969.

N. I note that 'Rosebud' is 7 ft high and 8 ft wide. What led to the center part being so large, was it the xylophone?

V. H. The xylophone determined the width but it was the pneumatic system underneath it that brought about the rather large height.

N. Tell me how you incorporated inflatable parts with sound producing elements in this audio-kinetic sculpture.

V. H. First, I made the rose as a relief in wood. Then I formed over it separate pieces of leather. Later, I mounted these pieces so that the assembled form could be activated by air pressure. The motion of the rose and the sounds are controlled by the player-piano mechanism and the roll, both when it unwinds and rewinds. The roll rewinds faster than it unwinds in this machine. While the roll unwinds the animation of the rose and the spheres is slow, monotonous, ceremonial, then on the rewind there is a fast jumble that gives the feeling that the machine is falling apart amidst a din of sounds.

N. Has anyone commented on the sounds emitted by 'Rosebud'?

V. H. In the fall of 1968, I was asked to exhibit 'Rosebud' in the Electromagica Exhibition in Tokyo. That was an international exhibition of art objects using electricity. It was organized by the Japan Electric Arts Association. At the show I met a Chinese scholar who said that he noted with interest that my machine was playing Japanese music. I explained to him that I had based the music, more or less, on Bach's 'Two-Part Invention' and the beat was related to some of the music composed by Stravinsky. Perhaps this combination sounds Oriental to some. To me the beginning part sounds a little like the music I heard in Vera Cruz, Mexico. The end, as I said before, is a jumble of sounds, nevertheless, the complete program has, I believe, a certain kind of consistency which I enjoy.

N. Did it take you a long time to complete 'Rosebud'?

V. H. Approximately two years—'Kaleidophonic Dog' took three years. 'Washboard Band' (cf. Fig. 4) and 'Tap Dancer' each took me only six months to complete.

N. Would you give some details on 'Tap Dancer' and 'Washboard Band'?

V. H. 'Tap Dancer', as you can see in the photograph (cf. Fig. 1), consists of the legs of a man below the knees. The shoes are a bit odd looking. The legs oscillate in clockwise and counter-clockwise directions, while the toes of the shoes go up and down. The toes are connected pneumatically to wood blocks inside the supporting box to make tapping sounds against the top of the box. The sculpture is programmed by a tape loop that lasts about 4 minutes and it automatically plays over and over.

'Washboard Band' (cf. Fig. 4) consists of two major elements. The taller column supports an ordinary laundry washboard upon which beat four sticks. There is also a sliding piece that moves

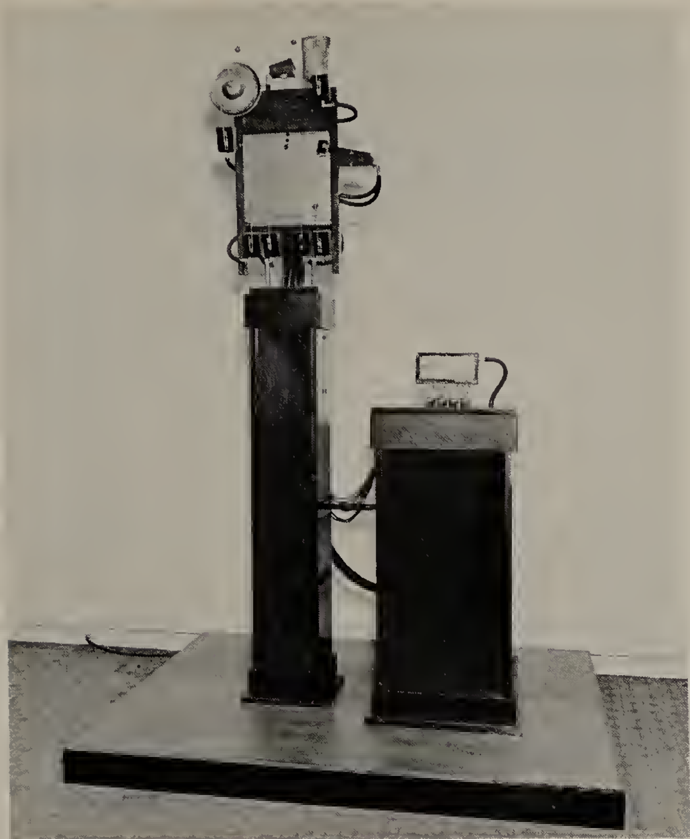

Fig. 4. '*Washboard Band*' *by Stephan Von Huene, audio-kinetic sculpture, wood, leather trim, reeds and pneumatic system*, height 7·5 ft, width 4·5 ft, depth 2ft, 1969.

horizontally, back and forth, to produce a rasping sound. Above the washboard is a cymbal and a cow bell, which are struck periodically. On the top of the shorter column, there is a plastic box containing reeds that vibrate when air is blown past them. (The air also moves leather strips above the reeds.) The sculpture is programmed by two tape loops of different length. With each revolution of the loops the program on each tape phases into a new relationship.

N. Do you have some new ideas you want to apply to your audio-kinetic sculptures?

V. H. Yes. I want to handle the whole sculptural lay-out in a different, simpler way. Also I want to use different sound-producing objects that produce less well-known sounds. I'll still use wood and leather for some moving parts, as I find them satisfactory materials—I used wood and leather even before I started to make audio-kinetic sculptures. When I became interested in player piano mechanisms and organ pipes, I found they also had wood and leather parts. I believe I have improved the old systems for sucking and pumping air both to activate pneumatic parts and to produce various kinds of sound. When I made figurative sculpures in the past, I used wood covered with leather rather than with paint. You may find it surprising that I also used bread instead of wood because I like its tactile, sensual qualities.

N. But is bread sufficiently durable?

Fig. 5. *Untitled drawing by Stephan Von Huene ink on paper*, 12 × 14 in., 1964.

Fig. 6. *Untitled drawing by Stephan Von Huene, ink on paper*, 12 × 14 in., 1964.

V. H. I made it durable. After the bread formed, I dried it and covered it with resin. Sometimes, I used fresh dough and allowed the rising of the dough, caused by the action of yeast, to fill a desired shape. I enjoyed working with a material that has life-like properties. I became quite obsessed with bread for a while. I wrote stories on paintings I had seen that seemed to me to be all bread. People seemed to be all bread. It was as if they became what they ate. No doubt, a very primitive attitude on my part. Why make images of people out of stone, of metal? Why not make them out of bread or leather? Certainly, these materials are most appropriate for making images mimicking people.

N. The two drawings before me (cf. Figs. 5 and 6) made in 1964, are they related to your recent audio-kinetic sculptures?

V. H. Yes. There is something in them that I find affected my conception for 'Tap Dancer' and 'Kaleidophonic Dog'. Some of the drawn figures have trumpets attached to them as though they are parts of their bodies. After all a human being can make sounds not only through his mouth. The idea of God giving life to a clay figure by breathing into it fascinates me. Like the primitive idea of making a clay image, then breathing on it and feeding it. In a way, when a sculptor makes an image out of clay he is doing the same thing. But one can make this idea more explicit by using pneumatic objects activated by bellows.

N. Would you say something about the colors of your machines?

V. H. Dark mahogany stain, with black leather trim, is very satisfying to me at present. 'Kaleidophonic Dog' has a reddish finish on the leather because at the time I had some reddish trim and orange shellac finish on hand. Oak crotch veneer is glued to the external wood surfaces of the drum.

N. As you know, Charles Mattox does not expect his audio-kinetic sculptures to last indefinitely [cf. *Leonardo* **2**, 355 (1969).] What is your attitude on maintaining your machines?

V. H. I feel that they should require as little attention as possible and that they should be easily kept going. When someone buys one of my machines, I assure him that replacement parts can be obtained easily from sources I indicate. Most parts are standard ones and, for example, the player-piano parts are obtainable from the manufacturer.

N. What are you interested in now as regards your work?

V. H. First, I am interested in making use of the simple organ pipe. Sculpturally, I think it is a beautiful shape and it is such a simple device for producing sound. Second, I have recently become more interested in the possibilities of using electrically operated audio-kinetic sculptures. I am developing a sensuous feeling for electricity so I can make, at least, the most elementary applications of it.

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CYBERTHEATER

Lev Nusberg*

I conceived the idea of creating a 'Cybertheater' in early 1966 but it was not until the summer and autumn of 1967 that I began to work out the details. Together with my kinetic artist colleagues, we constructed part of a large mockup in Leningrad. The whole complex of the mockup occupies about 20 m^2 and within it are 15–18 models of cybernetic devices or 'cyber-creatures' or 'cybers' most of them measuring about 130 × 80 cm, though some are smaller. For the moment, the models operate with the simplest automatic mechanisms and programs (owing to the temporary lack of technical means). The models of the 'cybers' are capable of producing (cf. Figs. 1, 2 and 3):

(a) fairly complex movement, with five to six degrees of freedom;

(b) interior lighting of a fixed, pulsating and scintillating type plus illumination from light sources external to the models;

(c) lighting whose color and intensity can be varied;

(d) sounds in the form of semi-phonetic language, music, 'concrete' sounds, etc. correlated to the movement of the models; and

(e) puffs of vari-colored non-toxic smoke or gas and smells of various kinds (some not pleasant).

It is estimated that the 'Cybertheater' will occupy an area of approximately 3·5 to 4 km^2. The largest of the 'cybers' will be 35 to 40 m high, the smallest about 10 m. Not only will each 'cyber' be programmed but so will the whole complex. The site of the theater would be provided also with a number of pools (at different levels), some with mirror-smooth surfaces, others with swirling water and

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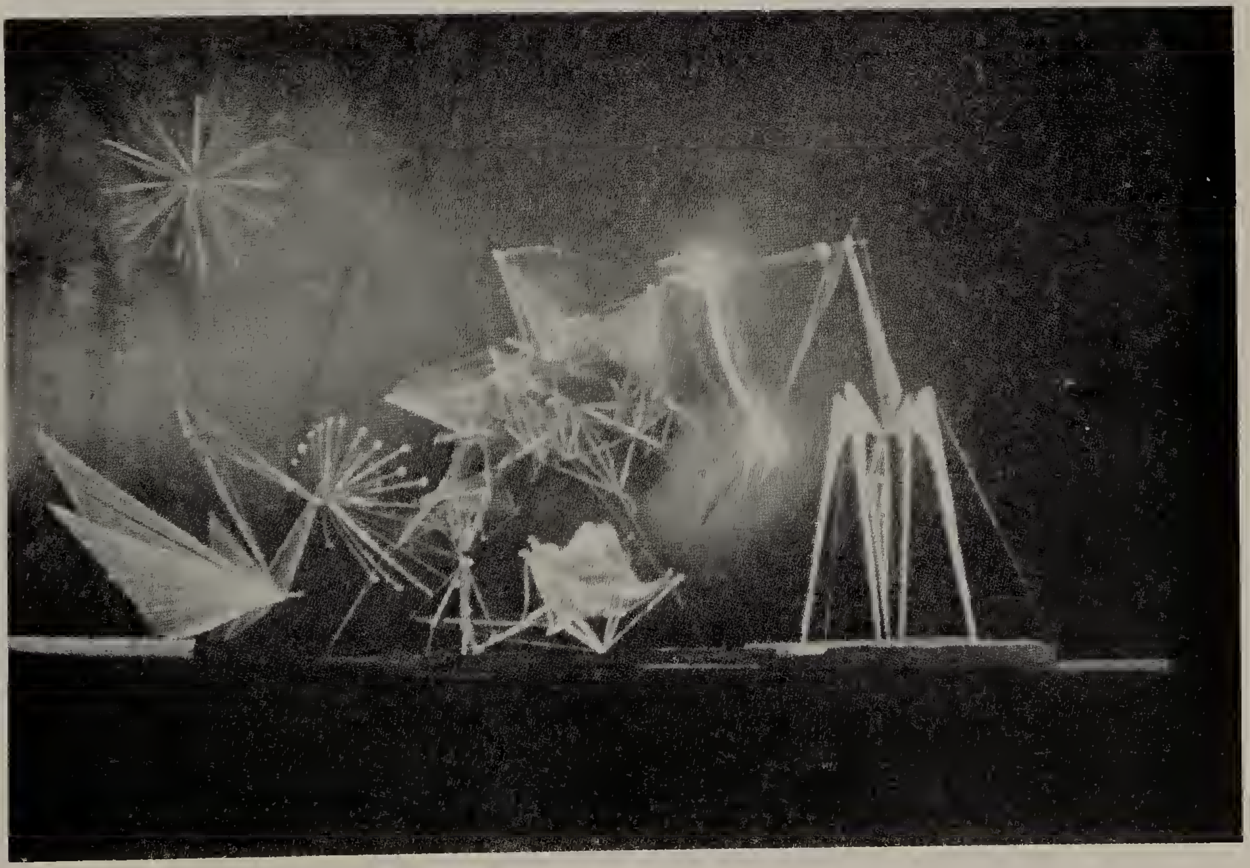

Fig. 1. *View of models of 'cybers' for the 'Cybertheater' of the Russian Movement Group.*

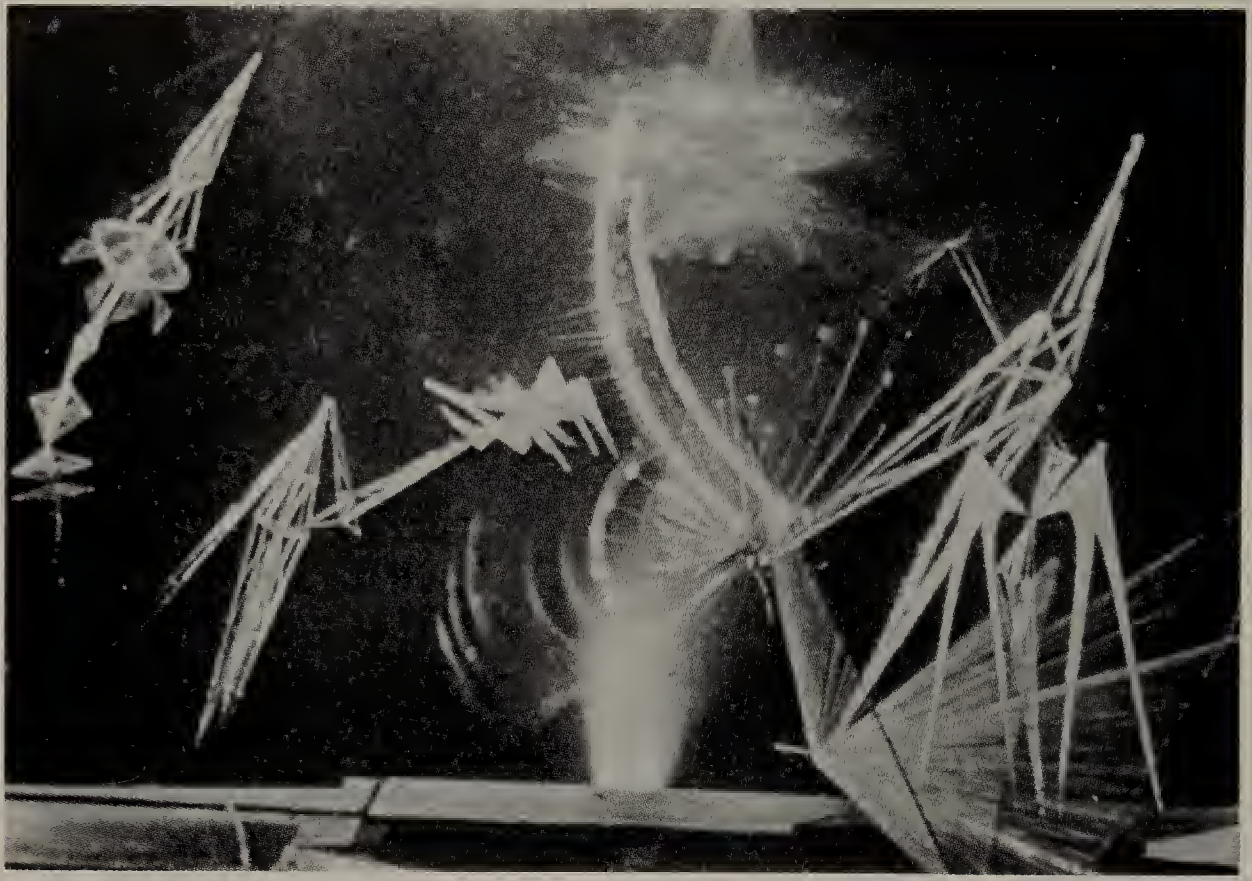

Fig. 2. Close-up view of models of 'cybers'.

with specially designed cascades tinted in different colors.

Paths will be marked out for spectators to follow. Some paths, it is true, will lead through water but the pools will be only 8–15 cm deep (visitors will be issued with special boots and protective clothing). There will be automatic signs and safety devices in places where flames or gases emerge from beneath the water or from the 'cybers'.

Paths leading through the inside of certain 'cybers' will enable spectators to take part in their programmed action and experience both fear and pain and also the joy and satisfaetion of surviving the experience. But even when outwardly sharing the experience of the machine and being involved, psychically, in the struggle with machines—Man remains Man.

The 'Cybertheater' is intended to be yet another reminder to Man of the fantastic possibilities of technology and of the need for developing it further; but, at the same time, it is intended to serve as a warning of the dangers inherent in highly developed machines.

The 'Cybertheater' serves in a way as one model of our man-made world and of the relationship between the Machine and Man. It is of course an aesthetic fantasy, perhaps with prophetic overtones. Is not Man himself creating more and more of his environment on the planet Earth (using matter in the same way as a sculptor uses clay for his sculptures)?

Herein lies the significance of the 'Cybertheater'. Here Man clashes with Machine in the most non-utilitarian and aesthetic sense, with the Machine expressed in elegant form. But even in this form, the Machine remains only a machine. I do not believe that the Machine will ever (no matter how developed it becomes) be capable of becoming a Creator, even if Man, the maker of machines, gradually evolves biologically or otherwise into a higher type of rational being.

Nearly all the members of our 'Movement' group took part in elaborating the project and constructing the models of the 'Cybertheater': Francisco Infante, Nikolai Kuznetsov, Tatiana Bystrova, Aleksandr Grigoriev, Galina Bitt, Vyacheslav Borodin, Natalya Prokuratova and others [1]. We are at present preparing to make a color film, 'Cybertheater', by our own efforts and with our own resources.

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Fig. 3. View of models of 'cybers' for the 'Cybertheater' of the Russian Movement Group.

MY SCULPTURES OF COMBINED OPAQUE AND ILLUMINATED FORMS

Ted Vincent*

Real motion was incorporated within my sculptures of 1968 to join up separate grey static solid forms. Motion was achieved in the following ways: by projected light images moving over the surfaces of the static forms; by mobile appendages protruding from the static forms and by balls travelling along transparent tubes from one static form to another. This combination set up a conflict between the motion of light or of solid forms and the static forms. I felt that the mobile aspects of the arrangement detracted from my intended static aspects of the overall structure.

The use of neon tubes (provided by Radiant Sign Ltd., London) offered a solution to my problem of finding a way of forming a static linear illuminated structure to join the static forms. Motion could be implied rather than real and thus would not conflict with the monumentality of the sculpture as a whole (cf. Figs. 1 and 2). Although the light structure was of a different visual character than the solid opaque forms which it joined, it was nonetheless a static structural element forming a physical connection in space, in contrast to moving projected light or to moving solid elements in my previous works.

In my third sculpture of this series, shown in Fig. 3, the neon tubes were programmed to flash at set intervals. This conception proved to be visually unsatisfactory to me. It was a return to my previous type of sculpture in which two visual experiences of a very different character were incorporated in the same structure.

Two alternatives appear open to me. Firstly, the construction of linear forms from neon tubes, as other artists have done, for example, Don Flavin and Billy Apple (cf. Ref. 1); although this approach has good formal possibilities, one must accept the linear character and the limited colour range of neon light. Secondly, to continue to use the same static opaque forms but in a way which stresses their architectural and monumental character.

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Fig. 1. '*Neon Structure No.* 1', *green neon light, grey painted wood,* floor area 84 × 84 in., height 48 in., 1969.

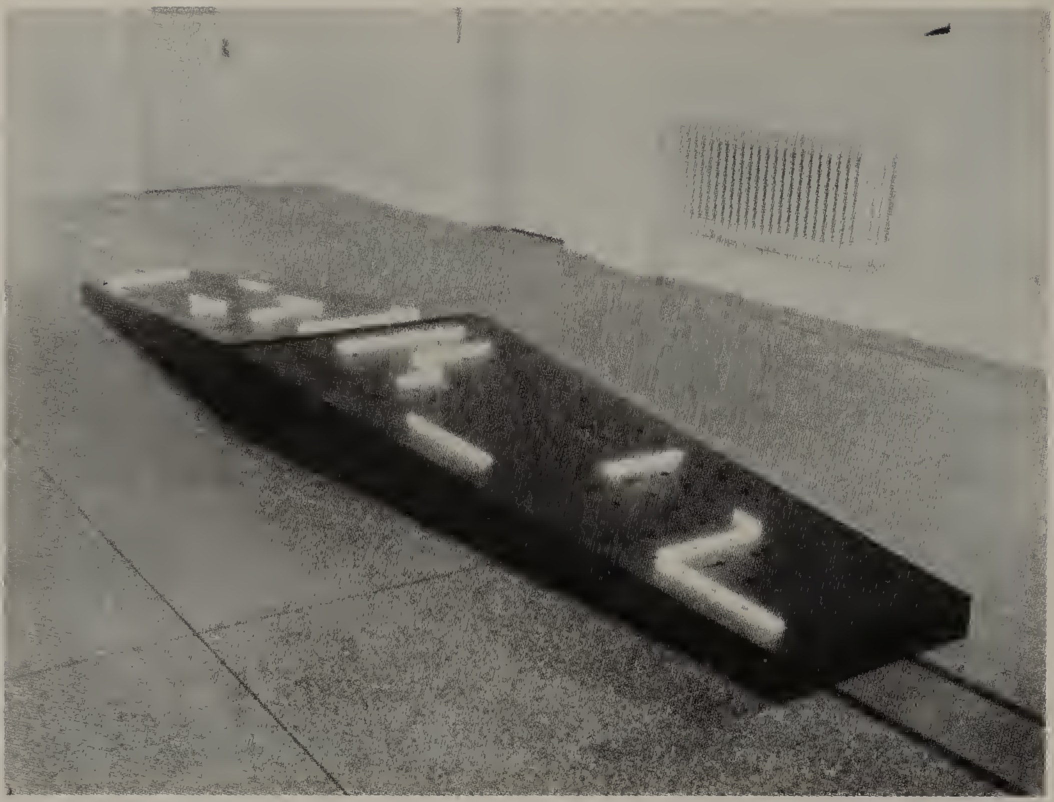

Fig. 2. '*Neon Structure No.* 2', *blue neon light, grey painted wood*, floor area 192 × 48 in., height 12 in., 1969.

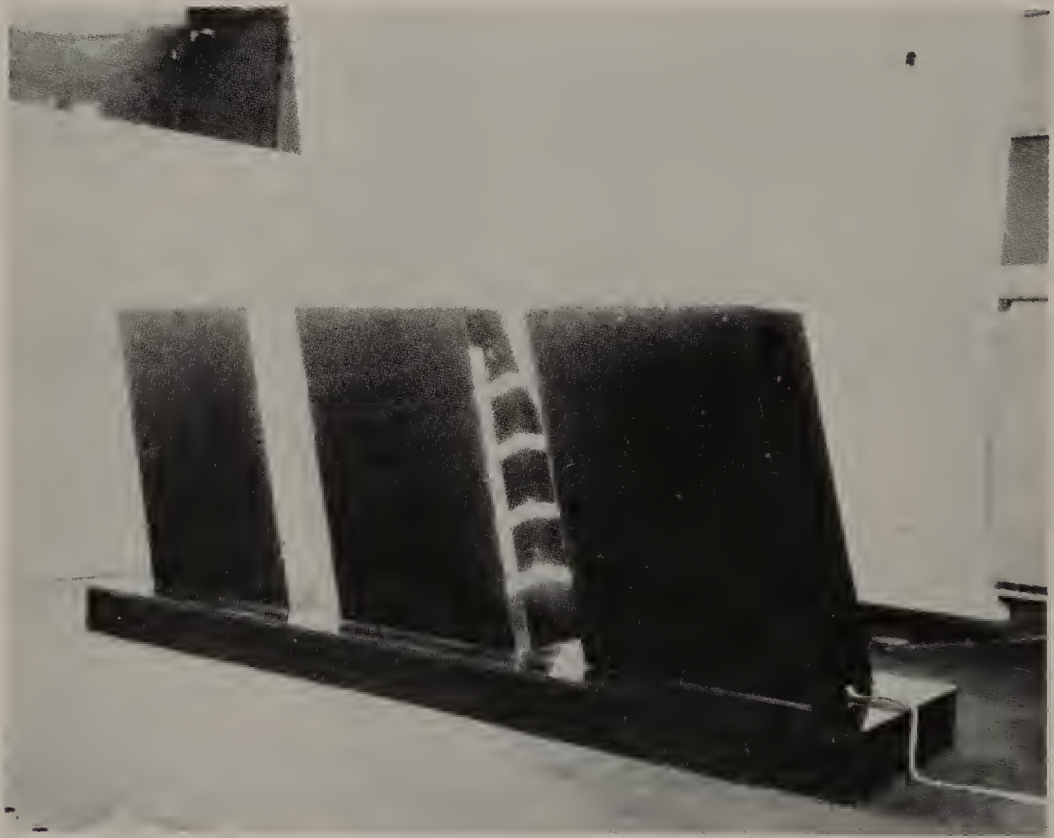

Fig. 3. '*Neon Structure No.* 3', *red, yellow, blue and green neon flashing lights, mirror surfaces, Perspex tubes and grey painted wood*, floor area 108 × 24 in., height 48 in., 1969.

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KINETIC ART:

ROTATING BARS AND DISKS ON A ROTATING PLATFORM

Rhonda and David Whitehead*

We have been working in the field of kinetic art since 1968. This note concerns two works we completed in 1971. Our objective was to show the aesthetic aspects of coloured or mirrored parts in motion in relation to a background surface or platform also in motion. Other artists have made objects of this kind, however, the parts moved in front of a fixed background surface. Tinguely showed such works at the Galerie Arnaud in Paris in 1954.

'Rotating Disk with Bars' (cf. Fig. 1) consists of a $33 \times 33 \times 5$-in. matt black box for housing the main synchronous electric motor for turning counter-clockwise a 27-in. diameter metal platform at $\frac{1}{2}$ rev/min. At the rear of the platform are mounted three synchronous motors of 1, 2 and 3 rev/min to drive two wooden bars in a clockwise and one in a counter-clockwise direction. Brush contacts for the three motors are installed on the inside periphery of the circular platform. Bars of different dimensions and different colors may be mounted.

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Fig. 1.

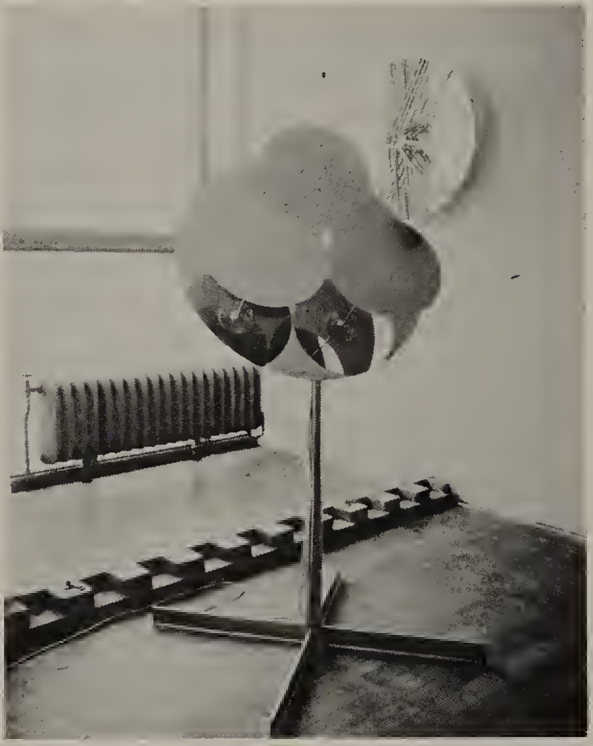

Fig. 2.

We have found the complex motions of the assembly very interesting. Sometimes there is produced an illusion that the bars are floating in front of the platform. This illusion is especially noticeable when the platform and bars are coloured with fluorescent paint for viewing under black (ultra-violet) light.

A free-standing version of this object with mirrored 10 in. diameter disks instead of the bars is shown in Fig. 2. The disks are mounted off-centre to the axes of the motors. As the disks turn, they reflect whatever is in front of them.

We plan to make a photographic record for the study of these objects when they are in motion and at rest in different positions.

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IMAGERY, LIGHT AND MOTION IN MY SCULPTURES

Jan Zach*

Abstract—*The author states that solid and hollow volumes of sculpture and the shadows and reflections caused by solar or artificial light are his chief concern. He discusses the various phases of his work in Brazil, Canada and the United States.*

For giving motion to kinetic sculpture he prefers the use of natural air currents.

Most of his recent work involves the use of stainless steel sheet in curved forms. Among the works he describes are his large work 'Sculpture in Suspension'; his series of modular objects, called 'Flower of Freedom', which are transformable; and his 50 ft-high kinetic sculpture 'Can-Can'. He feels that 'Can-Can' brings together all his studies and efforts of the past thirty years.

I. INTRODUCTION

My concern in sculpture is the illumination of form in space, with the utilization of the resultant shadows and reflections (whether created by solar or artificial light) and with considerations of solid and hollow volumes as a means of expressing space.

Light was, from the beginning, my basic interest. In Czechoslovakia, my country of birth, the work of the sculptor-architect Zdeněk Pešánek impressed me deeply. Pešánek's electric piano, exhibited in the Czechoslovak pavilion for the Universal Exhibition in Paris in 1937, considerably influenced my way of thinking.

Pešánek was a pioneer of lumio-kinetic sculptures. His first lumio-kinetic fountain was dated 1920. In his electric piano, he employed 1000 light bulbs with 238 tones of colour. The light patterns or 'score' corresponded to the perforated rolls of the player-piano and were replaceable. Some of his lumio-kinetic sculptures were 35 ft and more in length or height.

In his other works he made use of the following methods:

(a) Light, moving in a syncopated beat, reflected on two intercepting forms emerging (one vertically, one diagonally) from a group of horizontal discs.
(b) Light employed as a component of a sculpture, enhancing the strong sculptural concept and spatial design, not only as projected on a two-dimensional screen.

His concepts were published in 1941 in Prague in a book entitled *Kinetismus* [1]. Pešánek died on the 21st of November 1965 at the age of 69, near Rumburk in Czechoslovakia, having realized few of his dreams and until recently he was all but forgotten. Unfortunately, almost all of his works were destroyed during the occupation by Nazi Germany in the Second World War.

During the past fifteen years or so, many artists have used artificial light and real motion in paintings and in sculptures. Several artists have described their works in these domains in *Leonardo* during the past two years [2–6].

II. PHASE ONE

For eleven years, beginning in 1940, I lived in Brazil, where I was drawn into close contact with verdant, tropical nature. I became very conscious of the tremendous impact of sunlight and of shadows. I observed that the shadows projected by a group of trees created a four-dimensional visual experience. This experience came to dominate my outlook as a sculptor.

While in Brazil, I was also doing stage design, especially for ballet. I designed the sets and costumes of Sibelius's 'Valse Triste' which was premiered by the Original Ballet Russe of Colonel de Basil at the Teatro Municipal in São Paulo. The world of the ballet has remained of interest to me since that time.

III. PHASE TWO

I left Brazil in 1951 and went to Canada where I came in contact with the powerful, organic world of the Pacific Northwest. Victoria's magnificent beaches exerted a strong influence on my sculptural forms. The endless variety of shapes cast up by the sea, roots of trees, branch fragments and seaweed impressed me with the immense vitality inherent

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Fig. 1. '*Dancer*', *carved cedar, wire suspended,* height 6 ft, 1948–1952. (*Shadow cast on* 15 ft *high canvas.*) (Photo: K. McAllister, Vancouver.)

in the organic world. They clarified for me certain sculptural concepts of growth and movement through time, as expressed in the twisting and thrusting trunks and roots of trees. This feeling of movement in time prompted me to explore means to use a fourth dimension in sculpture, to go beyond its hitherto static nature to something more closely in harmony with Einstein's vision of nature—that of the space-time continuum.

'The Dancer', shown in Figure 1, conceived in Brazil and completed in Canada, reflects my interest in ballet. The sculpture is suspended by a wire from a 4 rev/min motor attached to the ceiling. Because the suspension is eccentric, the shadow cast on the screen by the sculpture moves up and down, expanding and diminishing, giving the impression of a dance. Although the figure is abstract, the shadow is realistic. Light and shadow, sculpture

Fig. 2. '*Totem*', *painted plywood*, height 8 ft, 1952–1954. (*Shadows cast on parts are considered part of color pattern.*) (*Rotatable by air.*)

and movement, create a unified image. I favor natural currents of air but, if not available, I use a motor—with caution, however, in order not to be led away from sculpture into a mechanical labyrinth.

I was struck by the tremendous vitality of the totems and masks of the Indians of the Pacific Coast with their particular rhythm of color patterns and their plastic understanding of carving. 'Totem', of painted plywood, shown in Figure 2, derived from studies of that art.

The beaches along the Dallas Road of Victoria were my out-of-doors studio where I spent long hours observing the unfolding drama of life. At that time, my design in sculpture was the continuing parabola. I was pursuing the 'endless' concept of

Fig. 3. *'Three Rivers'* (*The Willamette, McKenzie and Columbia*), *cast aluminum*, height 9 ft, 1961–1963. At new Eugene City Hall, Eugene, Oregon.

natural design. Frederick Kiesler's theories of *correalism* took on meaning for me. He explained *correalism* thus:

'. . . My sculptures I also see as consisting of divergent chunks of matter, held together yet apart, appearing like galactic structures, each part leading a life of coexistence, of correality with the others. Yet this correlation, whether close or far apart, does not necessarily depend on physical links. As in wireless electricity, there is correlation without connection. These "endless" paintings and sculptures lead a life of inner cohesion. Between these corporeal units there lie the various empty fields of tension that hold the parts together like planets in a void' [7].

IV. PHASE THREE

In 1957 I closed my studio and art school in Victoria and left to teach sculpture at the University of Oregon in the city of Eugene. The surrounding country, of volcanic origin, was very different from the beaches I had become used to. The luxuriant landscape here reminded me of parts of my native Czechoslovakia.

Here I began a series of cast metal sculptures based upon my preoccupation with organic nature. An example of these works is shown in Figure 3 [8]. The process of casting of iron, bronze or aluminum made use of the low melting point of polyethylene, which I had, by chance, discovered in Victoria.

During 1958–1959 a series of explosions occurred in the foundry with this process. The shape of the polyethylene moulds permitted gas to accumulate in pockets until explosive pressures were reached. I then began designing the form as if it were folded paper, so that the gases would be released vertically through the sand. The result of this development was that I became only interested in the designs formed by the folding, which started me using metal sheeting in my sculpture.

Fig. 4. '*Cloud Shape*', *zinc sheet*, length 3 ft, 1964–1965. (Photo: R. Brooks, San Miguel de Allende, Mexico.)

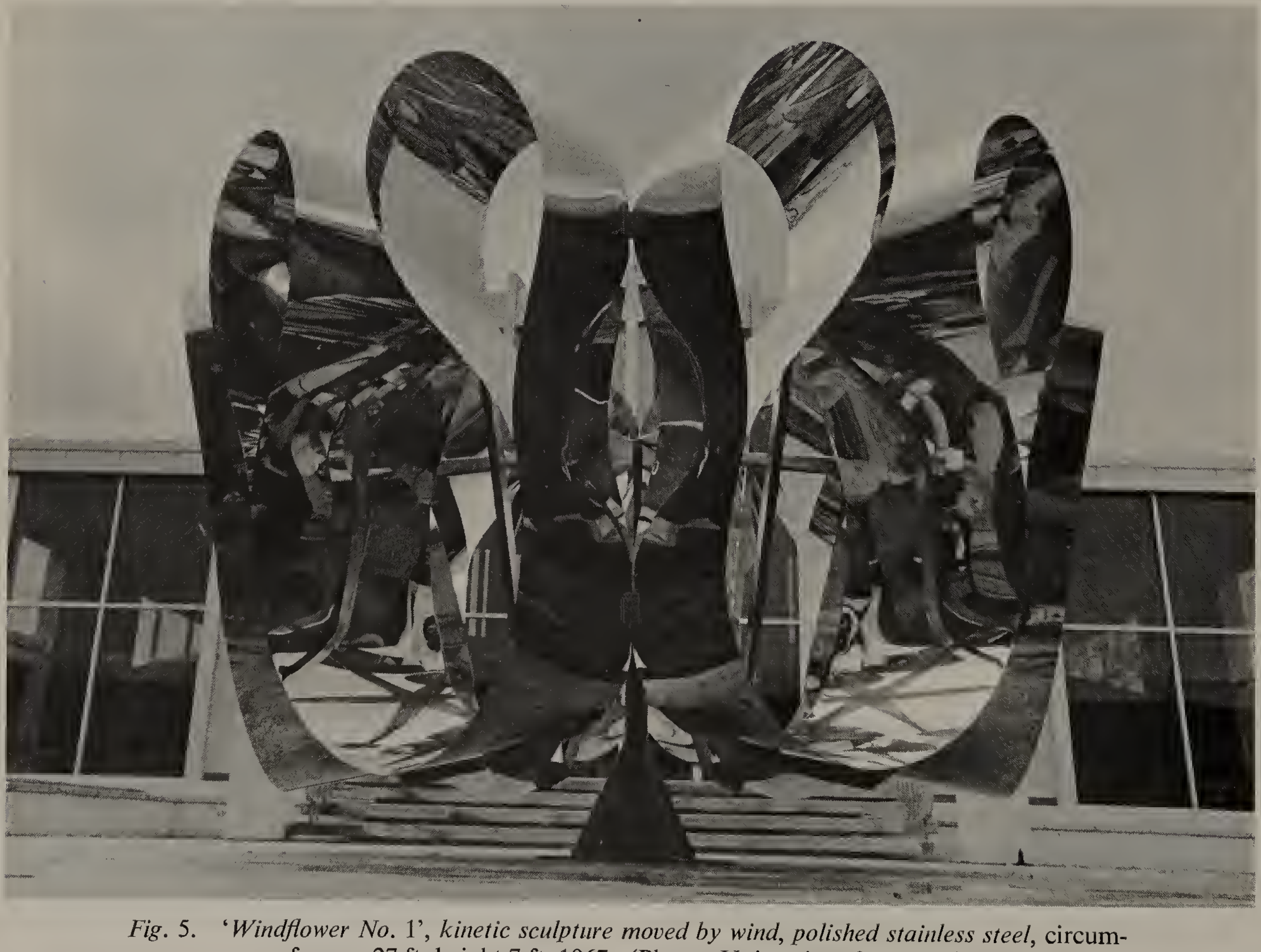

Fig. 5. '*Windflower No.* 1', *kinetic sculpture moved by wind, polished stainless steel*, circumference 27 ft, height 7 ft, 1967. (Photo: University of Oregon.)

Fig. 6. *'Sculpture in Suspension', Rockwell stainless steel, three bell-like shapes each* 25 ft *wide and* 16 ft *high, suspended between four telephone poles of* 40 ft height, 1968. *Installed on land adjoining the artist's studio.* (Photo: K. McAllister, Vancouver.)

V. PHASE FOUR

In 1964, my wife and I went to Mexico for my sabbatical year from the University. I visited many archaeological sites and made some preparatory drawings for future sculptures. I had hoped to obtain experience with the casting of solid glass; however, this hope was frustrated as I did not have at my disposal a satisfactory annealing oven.

One day, I found a source of inexpensive zinc sheeting that lent itself very well to making sculptures of folded forms. The sheeting was 25-gauge and came in 2 × 3 ft pieces that could be readily worked by hand. 'Cloud Shape' (cf. Fig. 4) is one of the series of objects I made with this material.

Upon my return to Oregon, I searched for metal sheeting that would not corrode, oxidize or erode and would maintain a mirror-like surface. I found that only stainless steel would meet these requirements. I first used this material, with a high polish, in 'Windflower No. 1' (cf. Fig. 5). The kinetic sculpture turns by wind pressure around a central axis.

In the summer of 1968, I undertook with four of my graduate students, R. Cross, T. Rieste, M. Hondo and J. Burton, the construction of a suspended sculpture on the land adjoining my studio. The 'Sculpture in Suspension' was made of Rockwell stainless steel with a silvery-frosted surface (cf. Fig. 6). The three bell-like shapes were each about 25 ft wide and 16 ft high, and were made from parts cut and folded from 9 × 20 ft sheets riveted together. The folding of the sheet was carried out with one end clamped between two 2 in. × 6 in. × 20 ft boards. The sculpture is suspended between four 40 ft wooden poles in an area of 100 ft × 60 ft and is stabilized by means of steel cables and nylon ropes.

I noticed during the construction of the forms in the 'Sculpture in Suspension' that they possessed

Fig. 7. '*Flower of Freedom, No.* 1', *polished stainless steel,* 3 × 3 × 3 ft, 1968. (Photo: Nolph, Eugene, Oregon.)

interesting acoustic properties. I plan to install loud speakers inside the bell-like forms and also to project coloured light patterns upon it at night, electronically synchronized with music.

VI. PHASE FIVE

Following the completion of the 'Sculpture in Suspension', I began a series of modular sculptures which, by articulation and reassembly, can be made to create an infinite variety of shapes. The series of seven objects is all called 'Flower of Freedom' (cf. Fig. 7), in homage to those who died for freedom and who are living for it.

The construction of a large modern market was begun in Eugene in November 1968. The architect, James Ruess of the Meier and Frank Co. of Portland, Oregon, invited me to make a sculpture for the rotunda in the main entrance of the market, which is 60 ft in diameter and 82 ft high. This building was designed by Raymond Loewy and William Snaith of New York.

I had been, at this time, making sketches of an object incorporating several of my flower-like modular objects mounted on a eentral pole, little suspecting that I would find a place for it. The commission came at the right moment, for I was ready.

The completed kinetic sculpture, which is called 'Can-Can', is shown in Figures 8 and 9. The central pole is an 8-in. steel pipe, 34 ft in height, welded to a $\frac{1}{2}$-in., 4 ft diameter carbon steel base plate attached by 12 bolts to the cement floor. The pole supports two spindles, each made of two 4 ft diameter discs on ball bearings. To each spindle are bolted seven boomerang-shaped ribs, each 8 × 15 ft, made of $\frac{1}{8}$-in. Rockwell stainless steel. Between the ribs are bolted shapes of polished stainless steel sheet, which might be recognized as flowers, miniskirts or tutus

Fig. 8. *'Can-Can', kinetic sculpture, polished stainless steel,* height 50 ft, diameter 20 ft, 1969. Installed in rotunda of the Meier and Frank Valley River Center, Eugene, Oregon. (Photo: University of Oregon.)

of ballerinas. The 'flowers', up to 24 × 16 ft, are made of three, four or five pie-shaped or triangular elements, riveted together. The complete sculpture is 50 ft in height and 20 ft in diameter.

The flower-like shapes of the sculptures were made to turn by the pressure of air currents around the central pole. As it turned out, the air currents were insufficient, so motors were installed. The flower-like shapes are electronically programmed on a random pattern, moving in opposite directions.

I feel that this kinetic sculpture brings together my studies and efforts of the past thirty years and also poses new possibilities for my work in the future. The following students aided me greatly in constructing 'Can-Can': J. Brookings, whose help was especially important, and R. Cross, B. Baker, H. Wunker and W. Green, who helped me on a part-time basis.

ACKNOWLEDGEMENTS

I wish to express my great appreciation to the University of Oregon Development Fund, The Republic Steel Corporation, Cleveland, Ohio, the Weyerhaeuser Company, Eugene, Oregon, and the Eugene Water and Electric Board for making possible the construction of 'Sculpture in Suspension' and Steel Structures, Inc., Eugene, Oregon, for the excellent production of parts for 'Can-Can'. Important encouragement was given me by an award from the

Chapelbrook Foundation, Boston, without whose help it would not have been possible to realize my work in stainless steel.

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Fig. 9. 'Can-Can', kinetic sculpture, polished stainless steel, height 50 ft, 1969 (cf. *Fig.* 8). (Photo: W. Rolfe, Eugene, Oregon.) *Reproduced in color on the inside front cover.*

PART III

KINETIC ART WITH ELECTRONIC SYSTEMS AND COMPUTERS

KINETIC ART: ON PRODUCING ILLUSIONS BY PHOTIC-STIMULATION OF ALPHA BRAIN WAVES WITH FLASHING LIGHTS

Robert Baldwin*

INTRODUCTION

An artist who wishes to make works of relevance to the present-day world has the opportunity to apply new media developed by technology and new results obtained by psychologists of perception [1, 2]. One way to try to do this is to add to the traditional art object designed for passive contemplation the direct involvement of the viewer in controlling the object to obtain an aesthetic experience prepared by an artist. Viewer participation might involve several senses and psychological aspects of a human being.

Electricity and electronic systems offer possibilities of attaining artistic experiences through viewer participation [2, 3]. In *Leonardo*, during the past four years, many artists have published discussions of the results they have obtained through the use of electric light in kinetic art. The work described by artists in References 4–8 are particularly related to my interests.

APPLICATION OF PHOTIC-STIMULATION OF ALPHA BRAIN WAVES BY FLASHING LIGHTS

The kinetic picture I shall describe was made in 1970 and consists of a box 22 × 22 × 6 in, the front of which is covered with a Plexiglas plate that is divided into nine squares of 7 × 7 in, as shown in Fig. 1. The Plexiglas in five squares is of transparent blue and the other four are green. Behind each square is a xenon gas lamp and each is connected to a potentiometer that can vary the flash rate of a lamp from 1 to 25 flashes per second. Either each lamp can be individually controlled by a viewer or the flashes can be made to occur randomly or in a predetermined order. I call the picture

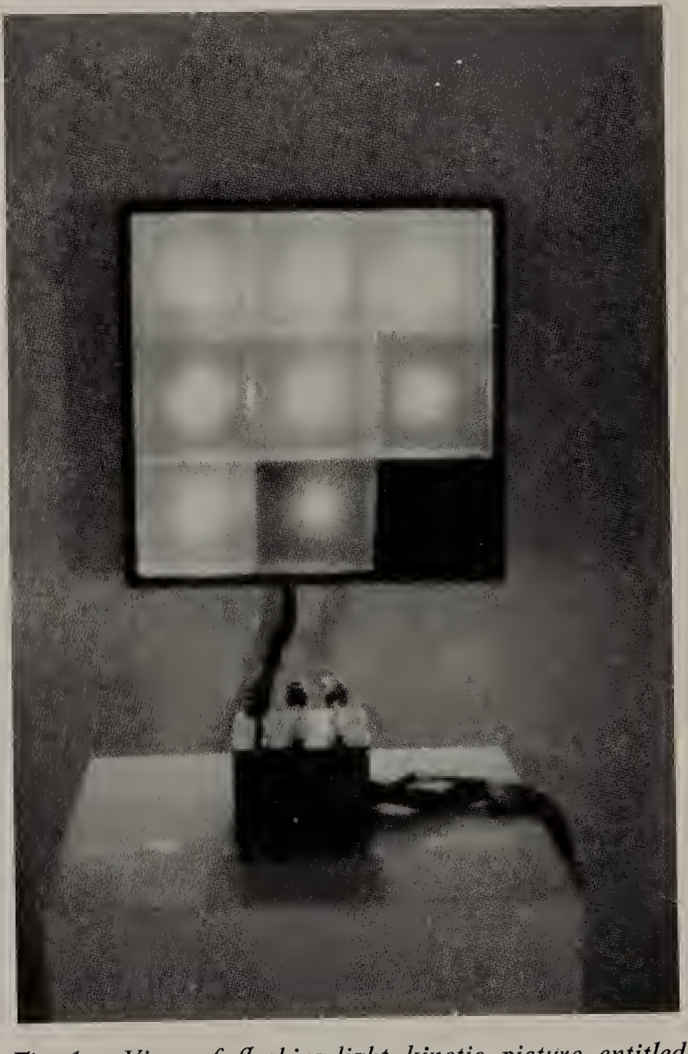

Fig. 1. *View of flashing-light kinetic picture entitled 'Kinetic Light, No.* 1', *flashing lights*, 22 × 22 × 6 in., 1970. (Photo: M. Boschker, Albuquerque, N.M., U.S.A.)

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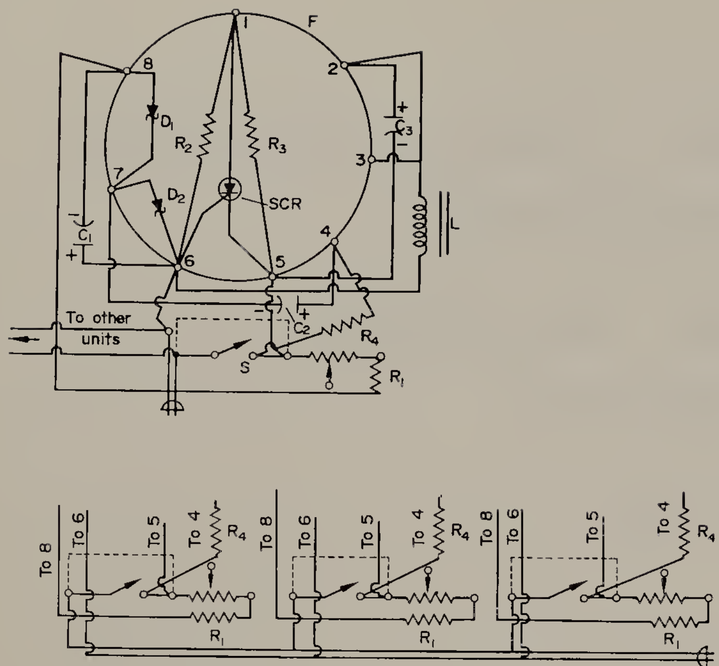

R_1 150,000-Ω, $\frac{1}{2}$-W
R_2 220,000-Ω, $\frac{1}{2}$-W
R_3 240,000-Ω, $\frac{1}{2}$-W
R_4 50-Ω, 10-W
C_1 40-mF, 450-V, electro
C_2 10-mF, 450-V, electro
C_3 0.22-mF, 200-V, electro
D_1 1000-V, 1-A, zener
D_2 1000-V, 1-A, zener
SCR silicon-controlled rectifier G.E. No. C106A2
L kicker-choke coil (Castle Inc. No. 91846)
S potentiometer-switch, 500K
F 8-pin, xenon gas lamp
Miscellaneous: 8-pin lamp sockets, wire, Vectorboard.

Fig. 2. Circuit used in the flashing-light kinetic picture 'Kinetic Light, No. 1' incorporating viewer photic-stimulation brain wave reactions to the flashes.

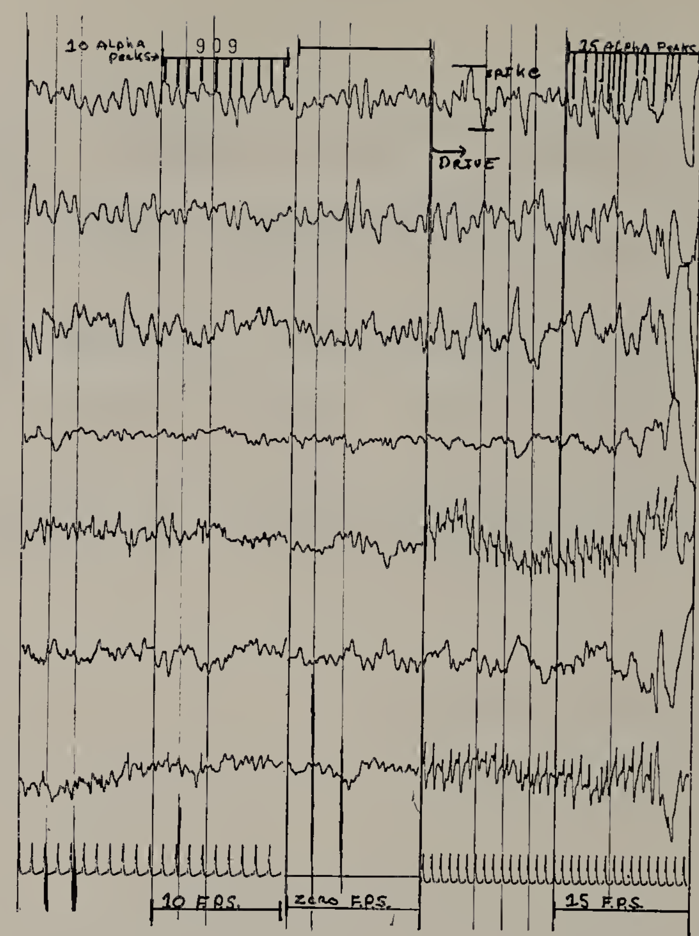

Fig. 3. Sample of Alpha brain wave EEG traces made in June 1970 under conditions of photic stimulation in a subject. Note correlation of Alpha wave peaks with the rate of light flashes per second (F.P.S.).

'Kinetic Light' and it is the first of a series of such pictures that I have designed utilizing the photic-stimulation effect.

The circuit for controlling the flashes, shown in Figure 2, works as follows: it is a fairly simple circuit to construct, consisting of a xenon gas lamp designed specifically for use in strobing or modulated light circuits. On the base of the lamp, there are eight contact pins that I placed in a standard eight-pin lamp socket, so that the various components were easily connected. The 115 a.c. voltage is converted to d.c. by two high-voltage zener diodes and two medium voltage capacitors are used to store up the charge. To trigger the lamp, I used a silicon-controlled rectifier in conjunction with a kicker choke-coil, which was especially designed for strobe circuits by Castle Lighting Inc. of Los Angeles, Calif. To control the flash rate, I chose a combined potentiometer and switch. It enables the viewer to vary the flash rate or turn it on or off, with a single control. The individual flash-control units were connected for convenience sake in groups of three, using a common line plug. The amount of power needed to run all nine units at once is low and excessive amounts of current from a single 115 V line will not be drawn. A note of caution: after approximately 15 to 20 min of steady use, the units should be switched off to cool for a few minutes. Due to high resistances in the units, some components (50-Ω, 10-W resistor and 40-mF, 450-V capacitor) get quite hot and, if left on for several hours, probably would damage the units or some of the components. Although there are many different circuits that have been designed for flashing light type units, I have found this particular circuit to be the lowest priced (about $15.00) and the simplest to construct.

The reaction of the brain to stimulation from light flashes is called *photic-stimulation.* It has been found that when measurements are made by means of an *electroencephalograph* (EEG) recorder of the Alpha waves emitted by the brain (Fig. 3), there is a frequency of the waves that will correspond to the flash rate of a flashing light and the rate at which the correlation occurs varies from person to person in the range from 1 to 25 flashes per second [9, 10]. Individuals suffering from epilepsy are greatly affected by a *flicker-flash test*, as made evident by the character of the Alpha waves they emit.

It has also been found that the character of the Alpha waves can be affected by the psychological state of the subject, such as a form of relaxation throughout the body resembling what athletes call a state of 'muscle tone'. This phenomenon has been applied by D. Rosenbloom [2] by means of what he calls a *biofeedback performance system*, with which a subject can cause a sound to be maintained by a tone generator or a light to stay on when he controls and sustains a particular pattern of the Alpha waves.

I do not provide a monitoring EEG recorder that would permit the viewer to see when his Alpha waves are correlated to the rate of one or more of the flashing lights. However, as the viewer varies the rate of each of the nine flashing lights, there occurs a rate of at least one of the lights at which the viewer experiences color changes in the flashing-lights of the picture or in nearby objects and he may have the illusion that objects are vibrating.

Those who have obtained a pleasurable experience from controlling the picture until they notice the production of the illusionary effects find that they wish to repeat the experience. I have tried only blue and green colors and, therefore, I cannot report if the choice of colors has any special significance. I have watched my 'Kinetic Light' picture for many hours without distressing emotional effects.

Anyone planning to carry out experiments with the photic-stimulation effect should note that one of the tests used by means of EEG recordings to find potential epileptics is called *flicker-flash test*, [9]. The flash rates used in this test are within the range of the rates used in the picture. Since the average flash rate at which a person's Alpha-wave rhythm is affected is eight to twelve flashes per second, at the first feeling of any discomfort, the flash rate should immediately be changed or the circuit shut off. Some 2000 people have viewed my kinetic picture and about ten have reported what I call 'strobe sickness'. At certain flash rates, they reported that they felt very dizzy and nauseous but as soon as the lights were turned off they recovered. Furthermore, staring into high intensity lamps for any length of time can cause damage to the delicate cells in the eye or to the optic nerve itself. I suggest great caution be used by those experimenting or utilizing this effect in art. Epileptics or potential epileptics could be driven to the point of having a seizure by the flashing lights.

Since an artist is not content to only repeat experiments carried out by psychologists of perception or to simply demonstrate a flashing-light system, I hope to find a way to make another picture of this type that will contain aesthetic qualities of my choice. Perhaps I may be able to introduce content or messages of different kind that I feel should be communicated to the viewer when he is in the special state of seeing illusions produced by photic-stimulation of Alpha brain waves.

I wish to thank the psychiatrist, Carlo P. DeAntonio, of Los Angeles, California, for my useful discussions with him on photic-stimulation and the EEG Laboratory of Van Nuys, California, for supplying me with much practical information and material on Alpha waves and photic-stimulation.

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*Article included in the present edition.

ELECTRONICALLY OPERATED AUDIO-KINETIC SCULPTURES, 1968

Juan Downey*

If the choice were given to me, I would pick complete inaction for my entire life. Nevertheless, I persist in the activity of building electronic sculptures because:

> Their existence or destruction is irrelevant to the life in them.
> They cause people to play.
> They make people aware of the vast number of different kinds of energy in the universe.
> They are ephemeral. This is part of a new development in the history of art: to create works of art that are not supposed to last for a long time.
> They pose a problem for the collectors of art objects.
> They create the illusion that the public can participate in the work of art. Actually, we are still spectators mystified by the order that makes the world grow and move, although, we pretend that we are determining what happens to us.
> It is fun to talk with friends about them.

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Fig. 1. View of 1969 *exhibition at the Corcoran Gallery of Art, Washington, D.C., U.S.A. Foreground piece: 'Radioactivated Chair', kinetic sculpture activated by radiation from radioactive material or cosmic rays; plywood, Formica and electronic parts,* 1968. *Centerpiece: 'Invisible Energy', audio-kinetic sculpture activated by radio waves; plywood, Formica and electronic parts,* 1968. *Background piece: 'A Machine with Three Conditions', audio-kinetic sculpture; plywood, Formica and electronic parts,* 1968. *All made in collaboration with Fred Pitts.* (Photo: Shunk-Kender, New York.)

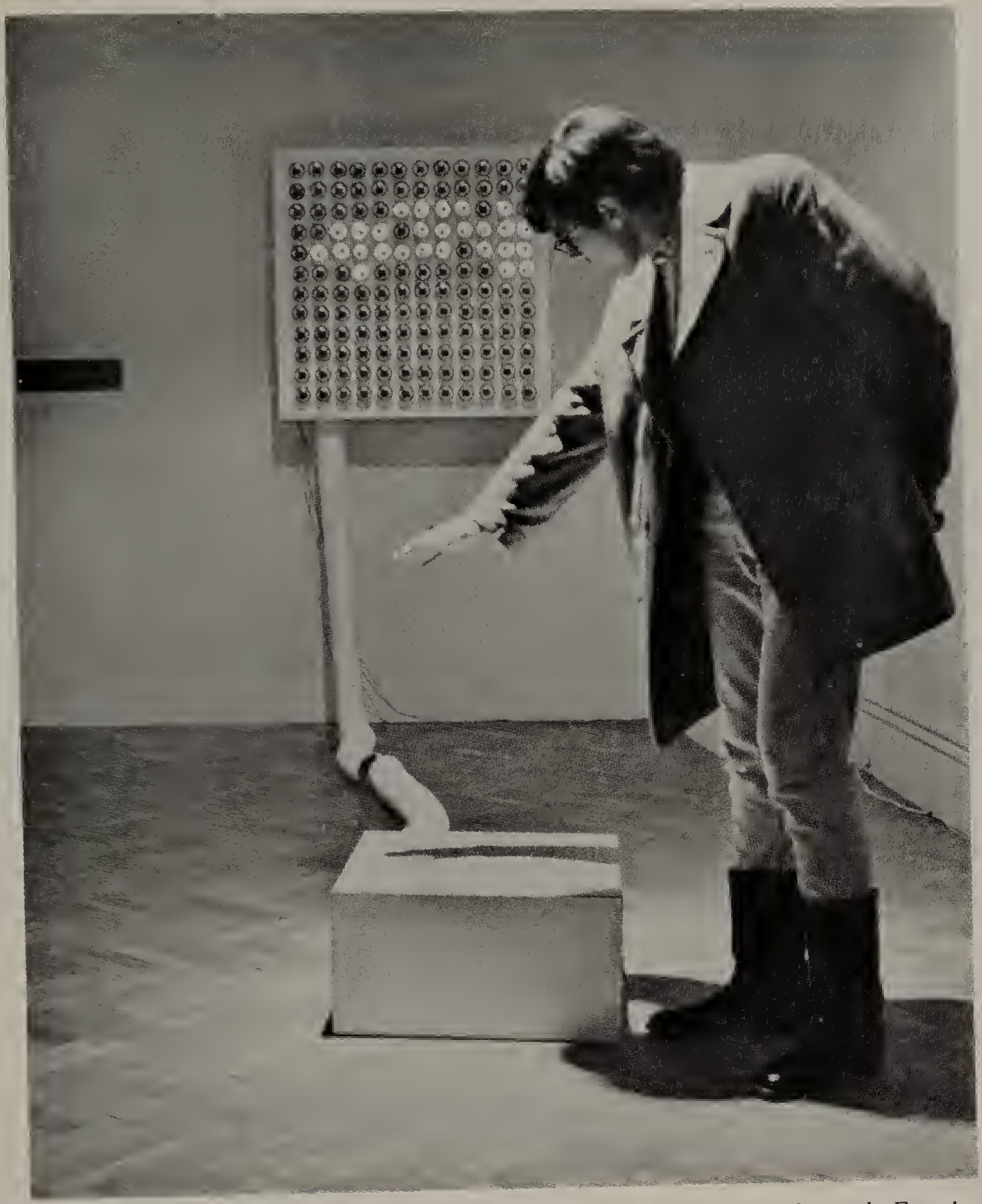

Fig. 2. 'Against Shadows', kinetic sculpture activated by shadows; plywood, Formica and electronic parts, 1968. *Made in collaboration with Fred Pitts.* (Photo: Shunk-Kender, New York.)

They imitate aspects of movement in life.
Art is more concerned with thinking about what people experience than with producing objects.
They make people aware of the lively relations between different kinds of things.
Children like them.
Sometimes they produce a reversal of natural phenomena, for example, as demonstrated by the sculpture 'Against Shadows', described below.

I made the following electronically operated sculptures during 1968 in collaboration with the engineer, Fred Pitts, except for 'The White Box', which I designed alone. He not only contributed his technical knowledge but also worked with me for long hours during which we conversed and drank together. He was, therefore, a partner in the creation of the sculptures.

1. '*Radioactivated Chair*'

   Contains a Geiger counter. When it receives radiation from radioactive materials or cosmic rays, the stool, on which one may sit, vibrates (cf. Fig. 1, foreground piece).

2. '*Invisible Energy*'

   Is sensitive to two different frequencies of radio waves. When either of the two receivers is activated, they operate two separate sets of electro-magnets that cause the side forms to rock back and forth. Since the tops of these forms carry mirrors, they reflect moving squares of light on the ceiling (cf. Fig. 1, center piece).

3. '*A Machine with Three Conditions*'

   A sculpture that demands certain conditions from the surroundings before it is activated. The machine, somewhat like the brain, selects and receives an input, adds it up and then produces an output.

   Condition 1—If touched, the machine repeats over and over: 'somebody is touching me'.

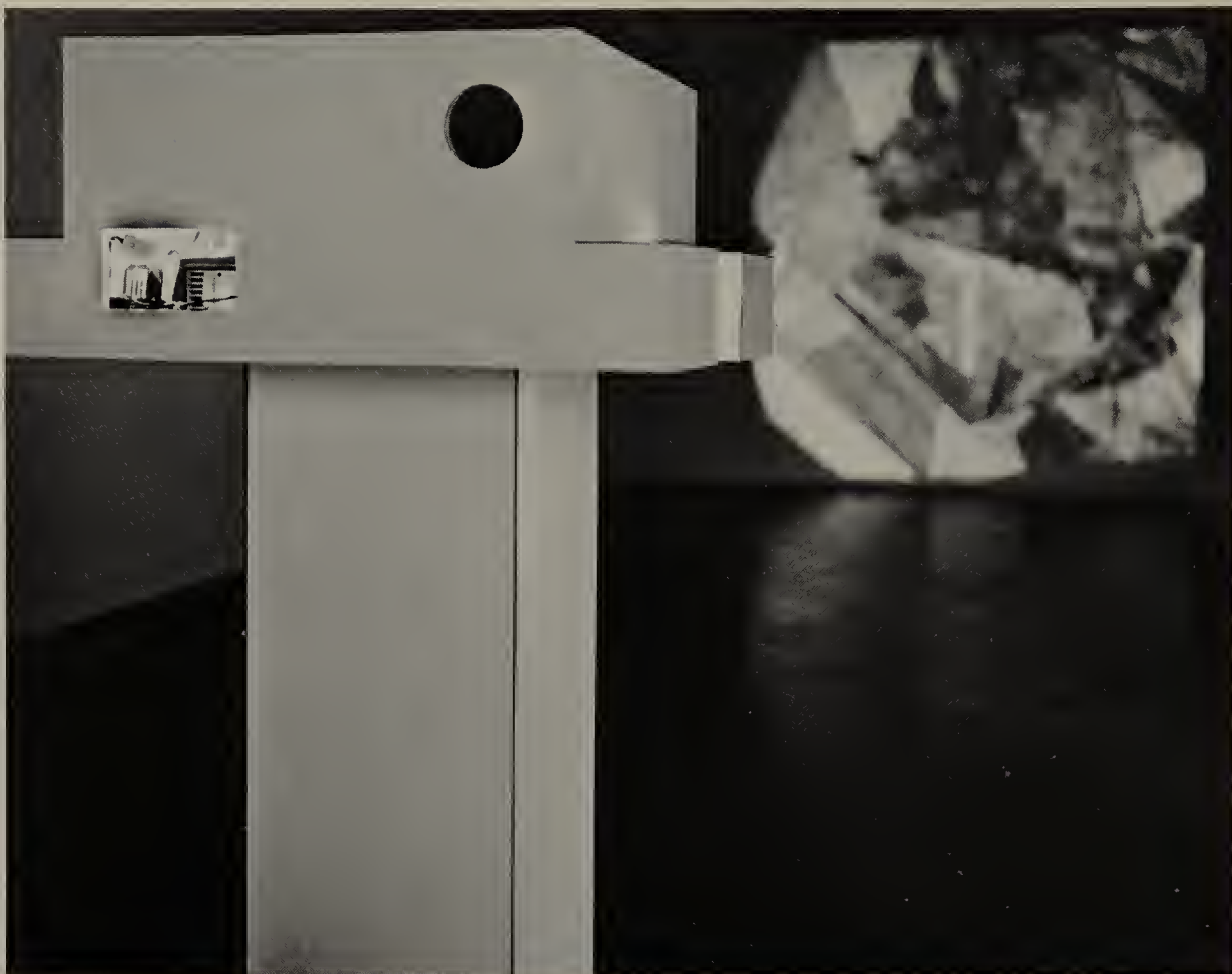

Fig. 3. 'The White Box', audio-kinetic sculpture containing polarizing projector and electronic musical instrument, both activated by photocells and sound-operated switch; plywood, Formica and electronic parts, 1968. (Photo: Shunk-Kender, New York.)

Condition 2—If the room becomes dark enough, the machine repeats over and over: 'the room is dark enough'.

Condition 3—If the machine receives radio waves of a certain frequency, they will be heard. When all three conditions are met simultaneously, the sculpture produces light and sound (cf. Fig. 1, background piece).

4. *'Against Shadows'*

Photocells are located in the small screen box on the floor. When a person casts a shadow on this screen, the photocells activate corresponding lamps on the larger wall screen, thus lighting up an amplified version of the shadow. The sculpture thus produces a reversal of the natural shadow phenomenon (cf. Fig. 2).

5. *'Do Your Own Concert'*

By pressing button-switches or by touching two plates at the same time, a person can record electronic music that will be played back later. Music will also be created when a group of persons hold hands and the person on each end of the chain touches one of the two plates.

6. *'The White Box'*

(Made without the collaboration of Fred Pitts.)
Clapping hands twice near the pedestal activates the sculpture, which then projects a polarized image on a wall and produces sound. It has photocells on both sides. One of them activates the polarizing filter and changes the pitch of sound emitted. The other one changes the appearance of the image.
This sculpture was made by a carpenter in Paris who followed my written instructions, which I mailed to him from New York where I was printing a portfolio of etchings called *Do it Yourself.* The etchings explain the operation of my early machines. The prints and sculpture were exhibited at the Galerie Jacqueline Ranson, Paris in April 1968 (cf. Fig. 3).

7. *'The Human Voice'*

If sounds are produced near the top of any of the three boxes, the sculpture answers back. One can speak into any of the boxes and hear one's voice from the other two. The piece has options in terms of its response: either one may turn on a radio, one may hear an explanation of the sculpture or one may hear a recording of one's own voice or of the sounds that have occurred thus far in the room.

The reaction of the general public, in particular children; scientists; men who helped to build the sculptures and salesmen in stores of electronic devices have been highly positive. They appear to understand the 'game' attitude required. On the other hand painters and sculptors have responded negatively, with rare exceptions, for they say that what I do is not art [1–4]!

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COMPUTER AND KINETIC ART: INVESTIGATIONS OF MATRIX CONFIGURATION*

J. Kenneth Edmiston**

Abstract—*The author describes the development of his investigations of matrix configuration. The investigations follow two directions, the first dealing with a linear system of relationships, the second with square or quadratic system. The systems exhibit complete sets of combinational relations between four or a multiple of four elements. The original visual elements have been coded, worked with numerically and then retranscribed back into visual form.*

Computer machinery has been utilized to produce both numerical and visual output. In addition, a variety of other materials and processes have been employed for system manifestation in art works. In each investigation, a geometrical transformation of the initial manifestation generated a second work, which is identical in combinational relations to the first but which isx increased in dimension by a factor of one.

The author concludes with an observation regarding his working relationship with both the numerical–conceptual and visual–physical systems of the investigations.

I. INTRODUCTION

My initial idea of *matrix configuration* derived from an early painting, a diptych that consisted of two square canvases, each displaying a different image, and either of which could be placed on any one of its four sides and combined with any of the possible four sides of the other. At first, working intuitively, I made drawings of possible combinations of the two canvases; soon I was led into a more analytical approach as I began to search for every possible combination. Ultimately I came to see the manifestation of complete sets of possible combinations as an end in itself. This became the principal impulse behind my investigations.

In my investigations of matrix configurations I have followed two different but related directions, the first dealing with a linear system of relationships, the second with a square or quadratic system of relationships. Each investigation—linear and quadratic—has in turn taken two forms, an initial manifestation and a transformation of that manifestation. Although the transformation preserves the combinational relations developed initially, its manifestation has been dimensionally increased by a factor of one.

The works produced during the investigations were not subjected to any material or dimensional limitations and I have utilized a variety of materials and processes. However, the sets of possible combinations have, throughout the investigations, remained subject to two conditions. The first condition is that in each set there are four elements or a multiple based on four elements, which originally represented the four possible orientations of the square canvas but which evolved to represent a variety of visual elements. The second condition is that these elements combine in some way to produce a complete set or closed system of relationships, although the definition of closure for each set may vary. The specific image of the element plays a secondary role to its position as carrier for the overall structure of the system.

II. LINEAR INVESTIGATIONS

My linear investigations began with the diptych mentioned above. I coded the orientation of the canvas as follows: 1, 2, 3, 4 for the four sides on which the first square could be placed and 1′, 2′, 3′, 4′ for the four sides of the second. As a result, I could easily determine that the diptych produced the complete set or closed system of sixteen binary combinations: 1–1′, 1–2′, 1-3′, 1-4′, 2-1′, 2-2′, 2-3′, 2-4′, 3-1′, 3-2′, 3-3′, 3-4′, 4-1′, 4-2′, 4-3′, 4-4′. At the same time it also became evident that an identical set of combinations could be produced by utilizing a single image—from one of the canvases—as follows: 1-1, 1-2, 1-3, 1-4, 2-1, 2-2, 2-3, 2-4, 3-1, 3-2, 3-3, etc.

I thought I might further simplify things by stringing the combinations together in a line, rather

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than thinking about them as discreet sets of two elements. One element would then relate to the element on either side of it. For example, the '1' in the middle of the string 1-1-2 is shared by the two sets 1-1 and 1-2. By stringing together the combinations so that all sixteen possible relationships were present, I produced one of many possible data lines: 1-1-2-2-3-3-4-4-2-1-3-2-4-3-1-4-1. I then repeated the line sixteen times, one under the other, to form a 'square'. In this way I produced the first matrix.

Any of several data lines could be used to develop a matrix. For instance, the data line 1-2-1-4-4-2-3-2-2-4-1-3-3-4-3-1 also fulfills the condition that all sixteen possible combinations be present. New conditions could be defined. Thus the condition that an element must relate to every other *excluding* itself would produce a data line exhibiting the twelve possible relationships: 1-2-3-4-2-1-3-2-4-3-1-4-1. In addition, simple rotational operations could be performed on the completed matrix to change its internal organization and therefore its configuration.

These cyclical permutation operations proceed as follows: for any line, all elements of that line move in unison one or more places in some direction. Elements pushed outside the large square move around the 'back' as if they were on a continuous band and come in to fill the place left open on the opposite side. For example, one might start relative to the bottom horizontal line of a 17 by 17 matrix and then make the following vertical axis permutation progression on the matrix: no moves (0), no moves (0), one place to the right (1R), two to the right (2R) . . . fifteen to the right (15R). The change in the total configuration of the matrix (in this case to a diagonal) produced by this permutation (listed to the right of the matrix below) is visually evident even in the numerical array:

2	2	3	3	4	4	2	1	3	2	4	3	1	4	1	1	1	15R
2	3	3	4	4	2	1	3	2	4	3	1	4	1	1	1	2	14R
3	3	4	4	2	1	3	2	4	3	1	4	1	1	1	2	2	13R
3	4	4	2	1	3	2	4	3	1	4	1	1	1	2	2	3	12R
4	4	2	1	3	2	4	3	1	4	1	1	1	2	2	3	3	11R
4	2	1	3	2	4	3	1	4	1	1	1	2	2	3	3	4	10R
2	1	3	2	4	3	1	4	1	1	1	2	2	3	3	4	4	9R
1	3	2	4	3	1	4	1	1	1	2	2	3	3	4	4	2	8R
3	2	4	3	1	4	1	1	1	2	2	3	3	4	4	2	1	7R
2	4	3	1	4	1	1	1	2	2	3	3	4	4	2	1	3	6R
4	3	1	4	1	1	1	2	2	3	3	4	4	2	1	3	2	5R
3	1	4	1	1	1	2	2	3	3	4	4	2	1	3	2	4	4R
1	4	1	1	1	2	2	3	3	4	4	2	1	3	2	4	3	3R
4	1	1	1	2	2	3	3	4	4	2	1	3	2	4	3	1	2R
1	1	1	2	2	3	3	4	4	2	1	3	2	4	3	1	4	1R
1	1	2	2	3	3	4	4	2	1	3	2	4	3	1	4	1	0
1	1	2	2	3	3	4	4	2	1	3	2	4	3	1	4	1	0

The possibilities seemed overwhelmingly numerous and quite impossible to research by hand. I decided to investigate the feasibility of using a computer to work out the matrices and, more importantly, to attempt to use computer graphics

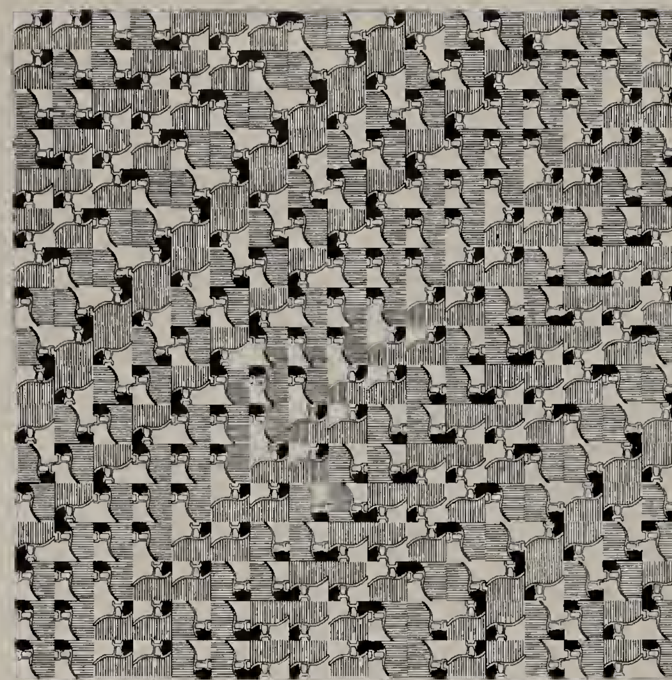

Fig. 1. 'Computer Plot, II', IBM 360–65/Calcomp 750, 17 × 17 in, 1967–70.

procedures to retranscribe the coded data back into its original visual form. This led me into some collaborative research with professionals in the computer programming field at the Louisiana State University Computer Center. Test programs to generate and permute the numerical matrices presented no problems on the IBM 1401 system but the first attempt toward a visual retranscription proved unsatisfactory. In the initial experiment, the different tonal densities of alphabetical and numerical characters (from a distance, a group of 'M's' appear darker than a group of 'I's') provided a very crude picture on the IBM 1403 line printer. I found this picture unusable, however, because the printer distorted the squares into rectangles and it was impossible to change its set of single-spacing within the line and double-spacing between the lines.

In the second and successful retranscription, I employed a piece of computer hardware specifically designed for visual output, the Calcomp 750 incremental plotter. This machine operates offline (i.e. not directly connected to the computer system), using programmed instructions and data via magnetic tape supplied by the main IBM 360-65 system. The plot program requires data for the images in numerical terms, in the form of x and y graph coordinates. For curves, a continuous line of coordinates must be hand or machine plotted; but for straight lines, such as may be used for shading, beginning and end coordinate points are sufficient. To control the orientation at which cach image is reconstructed, a numerical matrix furnishes the second set of data required by the plot program.

The result of the linear investigations described above was a group of works plotted on the Calcomp 750 and utilizing 17 by 17 matrices. Figure 1 shows one of the works of the series, 'Computer Plot, II.' The 289 images which together form this plot have been reconstructed using the permuted numerical matrix listed above.

III. TRANSFORMATION: "TORUS"

The 17 by 17 matrix of the computer plot series developed as a result of using a seventeen-element line that was necessary to produce the sixteen combinational relations required by the 'all sixteen possible' condition. In the 17 by 17 matrix, one of the four elements had to be repeated five times within each line, whereas the other three elements were repeated only four times within each line. In an effort to eliminate this 'inequity', I produced a work, the 'Torus' (Fig. 2), which manifests the identical combinational relations (i.e. 'all sixteen possible') exhibited in the 'Computer Plot, II' but which uses only sixteen elements, each element being repeated four times. The operation by which this was accomplished was suggested by the cyclical permutations performed on the matrices of the computer plot series. As I observed in describing the operation of the cyclical permutations above, one might view the elements of the matrix 'as if they were on a continuous band'. For the 'Torus' I 'bent' the original data line so as to make a closed circular form. This creates a connection and a relationship between the first and last elements of the line. The creation of this additional relationship made it possible to subtract one element from the data line—resulting in a 'line' of sixteen elements producing sixteen relationships.

If the bending operation is applied to the two-dimensional matrix, it may be performed on both axes. When the matrix is bent around the y-axis, the result is a cylinder; the bending operation performed on the x-axis joins the top and bottom of the cylinder. The result is a geometrical and dimensional transformation of the square matrix into a doughnut shape or torus.

Fig. 2. 'Torus', wood, cadmium-plated steel, Plexiglas, height 29 × diameter 36 in, 1969. (Collection of Don Nugent, Baton Rouge, La.)

The 'Torus' has been fabricated out of wood; each of the elements or facets had to be miter-cut on four sides in order that they might be assembled into the torus form. Instead of images on the surface of the facets, I utilized cadmium-plated square-cut flooring nails placed at right angles through the center of each facet, coding each one according to four different depths of penetration. A clear Plexiglas stand 'floats' the 'Torus' about 18 in. above floor level.

IV. QUADRATIC INVESTIGATIONS

Just as the diptych served as a point of departure for the linear investigations, another early work, 'Construct with 90° Elbow', provided the impetus for an investigation based on a square or quadratic system of relationships. The original visual element, a 90° elbow constructed within a square, was repeated four times to form a large square, with the four elbows oriented in such a way that together they formed a circular shape or movement within the large square. As with my early linear investigations, I was at first working intuitively and, although I knew that the four elements of the 2 by 2 matrix could be arranged in a variety of ways, I was not yet aware of the possibility of coding the material and systematically determining every combination. Thus, in the beginning, although there were numerous possibilities inherent in even so simple a matrix, I simply chose the combination with an obvious gestalt—the circle.

Upon further investigation, I realized that I could apply the orientation coding utilized in the linear investigations to the 90° elbow element. However, this should not obscure the essential difference between the linear investigations and this series of investigations, the quadratic, in which I concentrate on the matrix. While the linear investigations included matrices, they were line-generated and operations were always performed on them in terms of lines. By contrast, the quadratic investigations have dealt with the complete set of possible combinations of 1, 2, 3, 4 (i.e. elbow orientations) and all the relations between the four elements within the 2 by 2 *matrix as a whole*. The complete set of possible combinations resulting from these investigations numbers twenty-four:

```
1 2   1 3   1 4   1 3   1 2   1 4
4 3   2 4   3 2   4 2   3 4   2 3

2 3   3 4   4 2   4 1   3 1   2 1
1 4   1 2   1 3   2 3   4 2   3 4

4 1   2 1   3 1   3 2   2 4   4 3
3 2   4 3   2 4   1 4   1 3   1 2

3 4   4 2   2 3   2 4   4 3   3 2
2 1   3 1   4 1   3 1   2 1   4 1
```

A simulation of the corresponding set of elbow images is shown in Figure 3.

Since twenty-four items cannot be arranged in a square array, the twenty-four 2 by 2 numerical

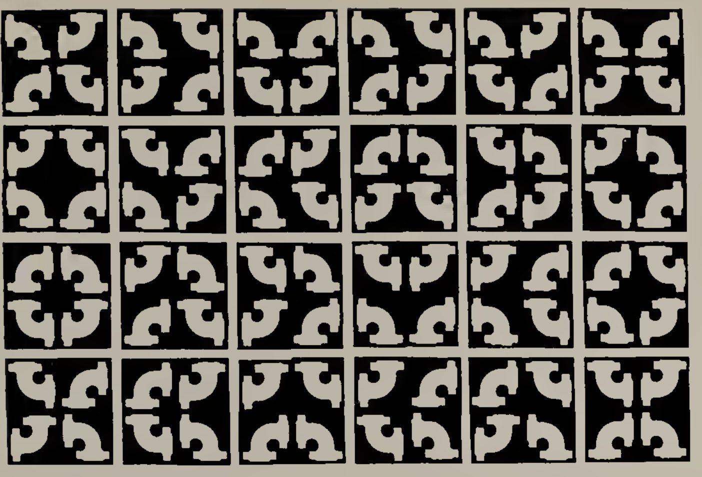

Fig. 3. Simulation of the twenty-four possibilities of 90° elbow images.

matrices listed above and the corresponding elbow images simulated in Figure 3 have been necessarily arranged in an arbitrary rectangular array. A significant manifestation seemed impossible to achieve using a rectangular form, since conceptually I was working with a quadratic theme and a square form. But as in the case of the 'Torus' in the linear investigations, the surface of a three-dimensional form provided a solution to the problem. The faces of four cubes, each having six sides, provided the necessary twenty-four squares upon which to display the elbow images; in addition, each face retained its integrity as the image of a unique matrix and the four cubes themselves comprised a set which remained conceptually within the quadratic system. The resulting manifestation, entitled 'Four-element Matrix Configuration with 90° Elbows' is shown in Figure 4.

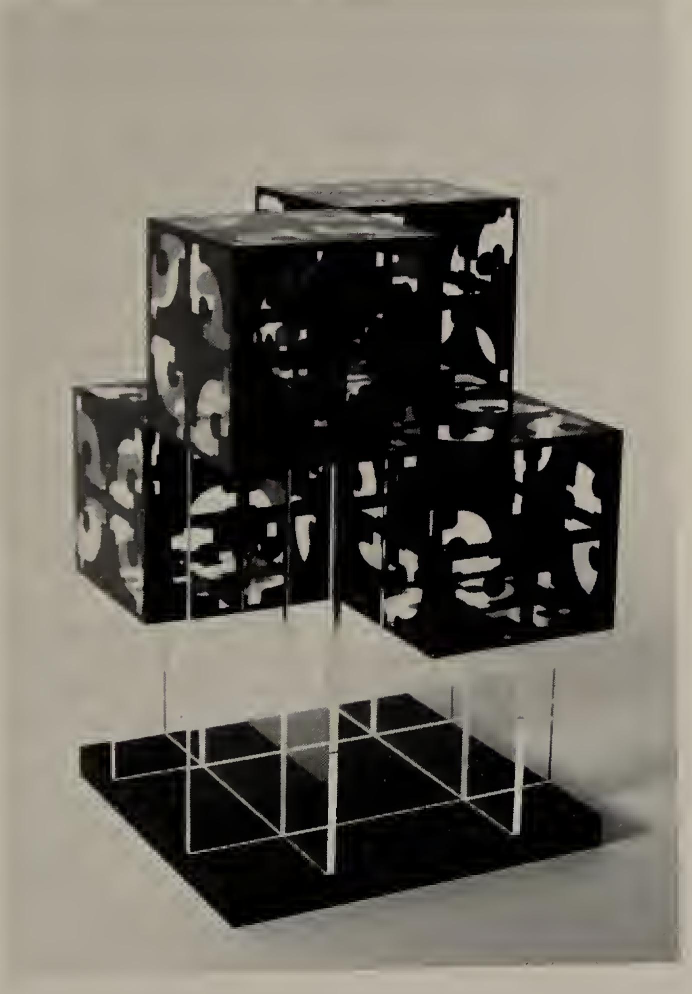

Fig. 4. 'Four-element Matrix Configuration with 90° Elbows', screened Plexiglas, height 19 × 12 × 12 in, 1969–70. (Collection of Louisiana State University Union, Baton Rouge, La.)

The cubes for the 'Four-element Matrix Configuration with 90° Elbows' were fabricated of clear Plexiglas; a photographic silk screen process was used to stencil the images onto the six faces of each cube. The printed area bears a negative image of four elbows and the inside of each elbow has been left clear. By virtue of the resulting transparency, the total image received from the 'Four-element Configuration with 90° Elbows' includes not only the image on the surface of one face of each cube but also images from other faces seen through the transparent elbows.

The four smaller screened cubes are arranged to form a large cube in such a way that all six faces of each cube may be viewed without interference. Applying the quadratic concept to this arrangement, it can be described as a three-dimensional matrix (2 by 2 by 2), where any non-diagonal binary relation within the matrix can be expressed as 0–1 or 1–0, where 1 represents one of the four cubes and 0 represents a negative space the size of one cube.

The large cube is 'suspended' over a solid base on a transparent stand. The interlocking planes of the stand describe a cube-form that is identical in size to the large cube and that has two negative areas into which are fitted two positive cubes of the large cube. This effects an interpenetration between the large cube and the stand, and provides the physical means by which the individual cubes are presented as described in the preceding paragraph.

V. TRANSFORMATION: "LIGHT CLOCK"

A kinetic art work that resulted from the quadratic investigations, the 'Light Clock' (Fig. 5), manifests the same quadratic combinations as 'Four-element Matrix Configuration with 90° Elbows' but the dimension of time has been introduced. The visual element represented by 1, 2, 3, 4 is a different color of light projected through a square translucent surface. The complete set of twenty-four possible quadratic combinations build one from the other by means of axial transitions occurring within a visual 2 by 2 matrix. The complete set of possible combinations develops and recycles; the recycling operation may be compared to the bending operation performed in the development of the 'Torus'.

Figure 6 shows the complete program chart for the 'Light Clock': the twenty-four matrices are on the far left; on the far right is the complete numerical program listing of seventy-two displays, beginning with the same full combination as shown in the matrix on the left and followed by two interstitial displays; the middle portion of the program chart shows between which two small squares the axial transition is taking place and the direction of the apparent

Fig. 5. 'Light Clock', Plexiglas, wood, aluminum, incandescent bulbs, electrical components and 2 RPM motor, height 27 × 17 × 9¼ in, 1969–70.

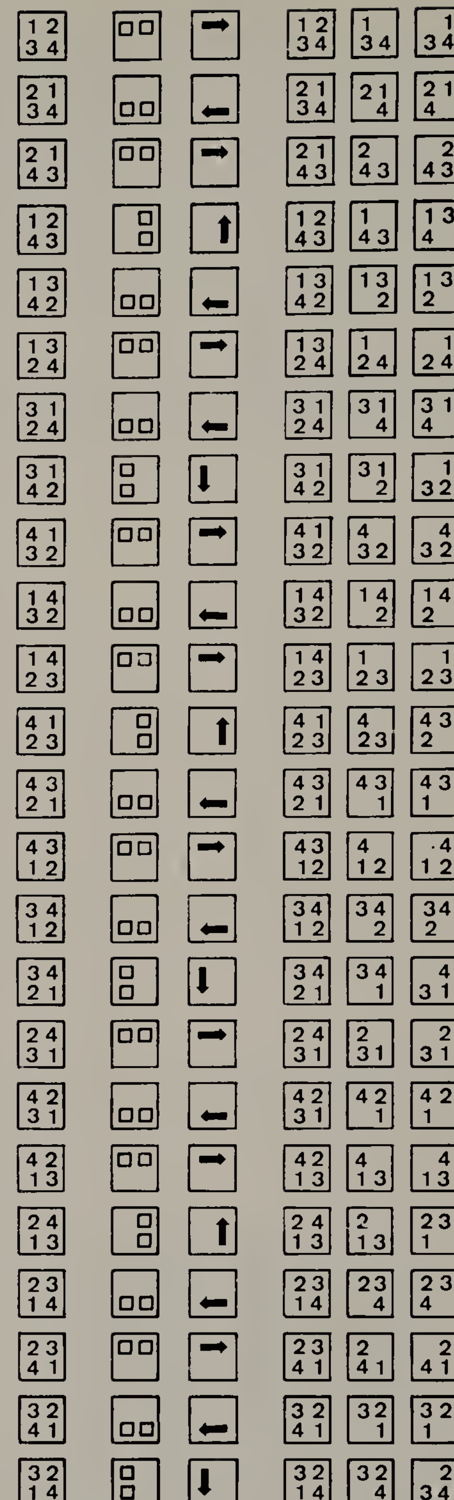

Fig. 6. Program chart for 'Light Clock'.

motion. The operation of the 'Light Clock' is as follows: Between each of the twenty-four full combinational displays, the two interstitial displays appear; the interstitial displays have been programmed to read as cyclical permutations on the axes of the 2 by 2 matrix. From a full combination (completely colored 2 × 2 matrix), the color goes off in one of the four small squares (first interstitial display); the color from an adjoining square, on either the vertical or horizontal axis, moves into the darkened square—the illusion of movement is produced by turning the colored light on in the darkened square, while at the same time turning the same colored light off in the adjoining square (second interstitial display); the color that originally went off in the first square now reappears in the second square, completing the transition and displaying another full combination.

Mechanically, the 'Light Clock' is controlled by micro-switches which ride on circular cams notched to correspond to the program described above and shown in Figure 6. The cams were attached to a shaft which is rotated by a synchronous motor. As the cams turn, the switch arms fall into the depressions in the cams, each turning a corresponding colored light bulb on; then the switch arms ride up on the cams, turning the light bulbs off. Sixteen light bulbs, each controlled by a micro-switch, were needed so as to be able to illuminate, according to the program requirements, none or any one of the bulbs in each of four sections of a compartmentalized box. Each section of the box houses four different colored bulbs; the bulbs are of different wattages to ensure that all four colors of light illuminating the translucent surface are equally brilliant (i.e. the yellow and red bulbs needed only 15 W of illumination to equal the intensity of the 25 W green and 40 W blue bulbs). The compartmentalized wood box which houses the bulbs also has a section for the control system; this box fits into an exterior plastic casing. Five openings have been machined in the casing, four for the large square (the 2 by 2 matrix) which are backed with translucent Plexiglas and which the bulbs illuminate with colored light, and one at the bottom, backed with clear Plexiglas, through which the machinery may be seen.

In operation, the full displays of the 'Light Clock' are 'on' three times as long as the interstitial displays. This internal timing rhythm, 3-1-1-3-1-1-3-1-1- etc., has been cut into the cams. The timing of the full program, however, is set by the RPM's of the cam shaft. This full-program timing must be fast enough to create a sense of movement and slow enough to allow the separate motions to be perceived. A variety of gears allows the machinery to operate at speeds ranging from 1 RPM (one minute for the full program cycle of seventy-two displays) to 4 RPM (1/4 minute for the full program cycle). Its present speed has been set empirically at 1.33 RPM.

VI. AN OBSERVATION

Reflecting on my preceding discussion of matrix configuration, I would like to point out that as linearity is a necessary consequence of verbal or written discourse as well as certain logical operations, there emerges an organization to the description of my investigations that is not quite correct. In each case I described the numerical–conceptual system first and the visual–physical system second. Also, although I tried to soft-pedal my words in these areas, many times it was necessary to describe the physical system as works 'manifesting', 'exhibiting' or 'resulting from' systems, as if fully developed conceptual systems existed prior to their 'physical' manifestations. I do not believe that this was actually the case. At least the relationship seemed one much more of reciprocity between alternate modes, the conceptual system being developed along with, interacting with but standing alongside, the physical system of the works.

I am expressing these ideas not for their own sake, as they involve various arguable aesthetic questions but rather in order to state that I personally find it necessary to work with both systems, since an exclusive concern for conceptual systems seems to me unrealistically abstract and an exclusive concern with a physical system seems simply unintelligible. In fact, it is not so much a matter of having worked with either system or with an interaction between the two but rather the act of having constantly tried to place myself at a point of intersection between the two 'alternate' modes which has been, for me, the real value of the whole investigation.

* * * * *

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COMPUTER ART:
COLOR-STEREO DISPLAYS

Richard I. Land*

Abstract—*The fundamentals of producing graphic designs by a computer are reviewed. Examples of display techniques are discussed, in particular, printers, plotters and display scopes. A novel system of producing color-stereo displays, with which the operator may interact in real time, is considered in detail and examples of the displays are shown. The machine used was the PDP-*1 *Computer of Harvard University. The basic program for producing the displays was developed by Dan Cohen as part of his graduate research work.*

I. INTRODUCTION

Computers draw, paint, make music, sculpt and do almost anything man can do! Rubbish. Computers do what men tell them to do and nothing more. The instructions may be sophisticated and the results rather distantly related to the initial data but there is nothing inside the 'black-box' of the computer which has taste. That is the prerogative of man. *Computer art* is produced by a sophisticated pantagraph, where the instruction set used is considerably larger than 'magnify by χ' where χ is the value determined by the programer setting the holes on the arms of the drafting machine. If such a machine is carefully operated and the input data is a sketch by Rembrandt, the resulting enlargement may well be deemed art, indeed, computer art of sorts. The fact that we have in this century devised a machine of almost unimaginable complexity and versatility merely taxes man's mentality in finding ways to put it to use and evaluate its results.

The initial intent of many early computers, apart from the abacus and similar mathematical engines, was recreational—to play tic-tac-toe, chess and similar games. It is only recently that the computer has graduated from the accountant's desk-top to the grand-scale instrument capable of advancing whole new industries and making possible man's reach into space. Yet almost every advance of the computer, from Babbage's first conceptions of 1833 to the present, has engaged man's fancy in fiction and games. Today it is usual for the first testing techniques of a new machine to take the form of games or the production of something with creative appeal, such as visual art.

As techniques developed for computer output in visible form, operators seized upon the recreational opportunity thus engendered and began producing images of various forms and qualities. This is another step in the continuum of history, where a new technique readily finds employment in artistic expression. Leonardo da Vinci is justly famed for both his anatomical drawings and detailed observations of fluid phenomena. Both have artistic distinction in addition to their scientific worth.

Since the earliest machines were developed by man, wheels and levers have come to the aid of artists in a variety of designing engines, culminating perhaps in the sophisticated machines used for engraving portions of forgery-proof security documents. The current mixture of chemical and optical techniques being applied defies any simple survey by its diversity. Using popular jargon, one might say that the computer is just another entrant in the media explosion available to the artist. The profusion of work that currently falls under the title *computer art* or *computer graphics* almost precludes any one person surveying the field successfully [1-4]. Any discussion will have to rely on personal experience and limited published material.

Although machine-produced art is in some elements indistinguishable from *computer art*, present-day opinion would likely restrict the term to works produced by the large computers primarily designed for general logical operations and only available in the last 25 years (commercially available in the last 15 years). The trend of modern thought on the subject is inclined also to eliminate from the category of *computer art* those instruments which seem to have artistic expression as their sole purpose, even though the control system they use is in fact a computer of sophisticated elaboration utilizing combinations of mechanical and electronic elements.

In his *Lumia*, Wilfred used mechanical linkages to program his optical effects, Malina [5] and Schöffer [6] among others, have employed electronic and mechanical control elements in kinetic art, and like so many of the currently popular art objects, my *Chromara* [7] can be driven by a small electronic analogue computer using audio signals as a control input. The designation *computer art* seems destined to remain attached to those art forms produced by a machine originally designed

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for other purposes—the machine becomes an instrument of extra-logical expression only as the result of the operator's intention.

As the computer becomes an obiquitous servant of our culture, at once important to industrial progress and also an indispensible tool of the scientist, many of its features escape the general understanding of the public. Even the largest of today's machines are simple and direct actors of logical commands. Essentially, the process is 'do this', 'do that', where this and that refer to taking data from somewhere, performing elementary operations and putting data somewhere. The operations appear complex by virtue of the conditional logic that may be used and the speed with which long logical sequences may be followed.

One of the drawbacks of the computer revolution is the growth of a new language; this makes many people feel themselves outsiders, intimidated by the new words. It is amazing how fast one assimilates the new terms after working with these machines and then forgets to explain them in ordinary discussion. I will make an effort to introduce special computer language gradually and explain each term clearly. There are numerous projects considering 'artificial intelligence' and whether computers can be considered to 'think' but this falls outside these considerations [8].

II. BASIC PROCESSES

Most people think of computers as adding machines. They are really instruction performing machines where addition is just one of the fundamental techniques for executing an instruction. The operation of detecting a fit or match, for instance, is merely the negative adding of one thing with another and then observing a null result or 'not different'. When we match two lines, we place them together to see if they have the same length. The computer in its own perceptive way takes a description of the lines, their numerical length, and places them together, adding one, subtracting the other and notes the difference. When there is no difference, it declares a match. The modern computer can do this millions of times while man does it once. In this way it was not hard for a computer to scan a print of the Mona Lisa, read the output of a photo-sensitive device and transform these intensity measurements into a printed output using normal alphanumeric characters (letters, numbers and signs of printing) which rendered a remarkable likeness to the original. Artistically, this was primitive but it was an early step in what now seems to be a boundless excursion of computer activity in the arts. In science, the most elaborate use of such scanning techniques has been the enhancement of space probe photographs of the Moon and of Mars.

Perhaps it is easier to explain the artistic use of computers by reversing the usual discussions of computer basics where one first considers the logic used, then the details of *input* information and finally *output* techniques. Once the simple level of operation is clear, elaboration of techniques will be more meaningful.

To start with the third step—the simplest output appears on a plotter. This instrument uses a pen to draw a line on paper and the computer must provide three commands for each point. Horizontal and vertical position relate the pen to some reference point (lower left corner, or center) previously determined and then the command to draw makes a mark on the paper. From this alone it is clear we can draw figures either by points, each with specific coordinates independent of the previous point, or by writing lines where one command to draw is followed by a series of vertical and horizontal instructions, each small enough to provide a smooth contour. Generally, the computer provides discrete incremental instructions which are smoothed out electronically as the pen moves.

To draw a square using the plotter, the only input needed is where to start, say the lower left corner at a certain location in relation to the fixed corner of the plotter page. Then we give instructions for the points one by one along each of the four lines, changing the direction at each of the corners of the square. We might say our picture consisted of a file of locations, the first location being the starting corner, with its associated instruction to draw, and specific points, one after the other, until completion with the final instruction to draw the last point adjacent to the first point. The detail of the drawing will depend on how many points we put in the file, unless the plotter is of a special sort where it makes straight lines and needs only commands for the end points. In this case only the corner points need be specified for a square to be drawn.

With the addition of a computer between the input and output, drawing a square becomes somewhat more complicated but in general much more powerful. First, we must instruct the computer what to read as *input* and what to say as *output*. This matches its internal handling of data with the operator and plotter. Then we must detail the instructions of how to take each input instruction and generate the points which are the only instructions understood by the plotter. Once we have given the computer this *program*, we may, depending on its sophistication, give very simple commands as input and let the computer do all the drudgery of generating the file of points for the drawing. All that is really required for a square is the length of a side, its orientation and the starting point; thus with a computer one can designate a position for the corner, what direction to start drawing in and the size, and let the program do the rest.

For a first composition we might give instructions that ask the computer also to remember the starting position, rotation and size of the design, and systematically change these according to simple rules. Thus we might fill a page with squares which grow and shrink in size, rotate and seem to follow a pattern. We would then have a computer composition of possible artistic merit.

We have essentially two choices at this juncture of programing our computer. As presented, it is clear that the program waits until it has all the information from the input and then it proceeds until it comes to the command which says it has finished. Thus one is required to specify the entire drawing from the onset and merely wait for the completed output, called *batch processing*. The other alternative is to instruct the program to halt from time to time to read a specific input, perhaps a dial set by hand. Using that information in a specified way, the program can proceed with its instructions. Here the operator and computer co-operate in processing the initial input. The progress of drawing the squares is continually controlled by the operator. The only limitation on his freedom of action is imposed by the input *hardware* (knobs, switches, etc.) and the original program given at the start. This direct interaction with an operator is called *real-time computer processing*.

There are many distinctions, advantages and disadvantages with these two major processing concepts but clearly the *batch process* technique requires much careful planning, since no revision is available during the active production. *Real-time production*, on the other hand, usually finds the computer wasting its considerable capacity just waiting for the operator to 'do his thing'.

From a large collection of instruction sets, a machine would be able to produce hundreds of patterns using the square generator as described. We could then throw away those without value and learn from the more successful ones how to make better ones. This might be more fruitful than manipulating the instructions in real-time overcarefully, producing only one or two labored drawings, each very dependent on the momentary whim of the operator. There are many fascinating subtleties in both of these methods and considerable thought should be given to their advantages and faults before becoming too committed to either one or the other. One should also note that there is often an economic question to be considered in making the choice between *real-time* and *batch processing* that complicates the alternatives.

The term *off-line* needs a word of consideration in this respect. Very often a computer does batch processing in its own fast-time and places outputs into storage, for example on to a magnetic tape. Later this tape is used to drive the plotter to produce the drawings. The transfer of the computed output to another station for the hard-copy is termed *off-line*. When the plotter is driven while the processing takes place, it is called *on-line*, and generally delays the computer operations (costs more money!).

III. COMPUTER FUNCTION

Although the output device must eventually have point by point instructions for any image produced, the computer can deal with an image in a more abstract manner. Certainly any file of points may be logically processed through any conceivable system of instructions but this usually requires excessive machine time and storage, and is cumbersome to control in the program. The first simplification would be to group the points into lines and then specify the file of lines and the operations with the lines. This may be still further simplified by logically describing a family of lines or figures and doing transformations on these compound elements.

As each higher abstraction from the detail of the image is achieved, the program generally becomes more elegant, saving time, storage and labor of the programer. The loss in this progression is intimate control of all details or of some specific detail that may come to appear important after the processing is underway. In every case, one expects to learn from an initial program what modifications must be developed to achieve specific effects in the ultimate result and be ready to change the program accordingly by modifying the initial one or devising an entire new scheme.

The basic instructions of a computer are not relevant here but the notion of *conditional statements* should be clarified. Often the system of instructions will ask for one transformation until some size is reached, then a change to another transformation. Doing one thing and then changing, *if* something happens, is one of the great powers of computers. But it also provides an interesting demand on the initial program, for one must anticipate *all* such conditional alternatives with appropriate instructions.

The major problem in programs is that one gives a system of instructions assuming that the available information coming into processing has a certain form but neglects the special case when the form is different. In such a case the computer may not recognize the input or may try the usual transformation that leads to an unusable result. Having no instruction what to do then, it may halt, or worse, it may blithely continue making something unrecognizable by anyone—'garbage'.

A simple example of this problem is what happens when the plotter of the previous example comes to an edge of the plotting surface. It is useless to have all the points piled up on the edge, so this situation must be tested for in advance and the decision to ignore all points 'off the paper' must be programed. Note that the actual computational transformations generally have to include all these unwritten points, so that later, when the transformations change, these unwritten points will reappear. There are often special built-in program aids that simplify operations of this type which the operator must know.

One of the most challenging problems in computer graphics is the solution of the 'hidden line' problem. This is the case of a figure being represented as eclipsing another and we observe lines apparently disappearing behind an overlying image. The conditional instructions must here seek out the intersections of all lines, test for the line that is supposed to be in the foreground and continue with the transformations, while remembering which lines are to be 'visible' or 'invisible'. Clearly the details and complications that can be encountered here require sophisticated conditional logic.

It would seem relevant to consider how much effort of the artist should go into the program and how much into the input data. The more structure is included in the latter, the simpler the program may be for elaborate results. The opposite seems more satisfactory. The output reflects the ingenuity of the artist when the input specification is minimal and of high generality, and the program incorporates the adaptive instruction sequences.

Up to now the methods for communicating with the computer have not been simplified for the artist and only the mathematician and logician finds simple languages (sets of instructions which may comprise the program) available for most systems. Work is currently in progress on specific drawing languages of sufficient power for general graphic displays. All of this progresses as the hardware for illustrating becomes more satisfactory. The following recent advertisements indicate some of the possibilities:

(a) '*The Adage Graphics Terminal* is a general purpose, user-oriented product line (of input–output equipment) which will meet the needs of a wide variety of disciplines, initially centered in engineering and scientific research but potentially extending to architectural design and business management. These systems are designed to extend man–machine communication techniques by allowing the user to generate, observe and interact with complex images while they are dynamically displayed on a cathode ray tube.'

(b) '*The Sanders Advanced Data Display System 900* features a larger variety of display sizes and speeds than any other comparable system available today. High-speed vector, position and character function generators permit unrivaled density of displayed graphics and alphanumerics. ADDS/900 offers rotation and translation of data, and exclusive graphic overlay on TV or radar video data. Data entry devices having a common interface for standard I/O (input–output) data transfer include hot-pen, trackball, joystick, keyboard, data tablet and cursor control' [9].

IV. INPUTS

Since the high-speed operations of the computer are electrical, the artist has to translate his intentions into the same terms. Electric typewriters are the most common starting point for input, requiring an alphanumeric code for all information being offered. There are several 'drawing' techniques for input called, *Light-pens*, *Rand Tablet* or *Wands*.

Drawing with a light-pen leaves a line on a TV-tube-type face. Input proceeds much like usual drawing but there are many special advantages in the computer-aided drawing, for one may move lines and change the mode of the pen from writing only to participating in the instruction processing. The *Rand Tablet* is a limited surface (25 cm square) where each point located under the tip of a special pen may be accurately sensed by the computer. On such a surface, any drawing operation may be completely transferred into the computer's electrical terms. *Wands* are now becoming more numerous as devices whose position in space is read into the computer for three dimensional input [10, 11].

Special optical scanning techniques are becoming available and the variety of pictures or images that may be 'understood' by computers is limited only by the expense of the devices. The familiar punched cards and paper tape are merely a translation from the electric keyboard to a more easily stored form of input and generally this storage is further translated to magnetic tape for online processing.

V. OUTPUTS

Computers are designed to produce their results (*outputs*) as fast as possible in an attempt to keep up with the processing speed. Currently this means using some kind of magnetic storage device, such as magnetic tape. Later, what is on the tape may be converted into printed pages, drawings or the control of any imaginable instrument for the production of a result determined by the original program. In the real-time case, speed remains important. The operator must receive the output and comprehend it at a maximum rate for the processing to continue efficiently. This generally means some form of visual output: printed words, pictures or images produced by electrical and optical techniques.

Printers are presently capable of delivering hundreds of lines a minute with hundreds of characters per line. The characters available are generally letters, numbers or symbols used in printing. There is limited flexibility in arranging irregular spacing, overstrikes and the like. The paper must be of a specified quality and size to be handled with such speed. Plotters today are becoming both fast and flexible. In some cases, the pen moves in two directions over a fixed sheet of paper, up to a meter square and of almost any quality, color or surface.

In other cases, the pen moves in one direction only, while the paper moves in the perpendicular direction. In this case, the size of the paper may not be limited in length, only in width, but it must be of a certain kind to fit the moving surface mechanism. Both methods can produce accuracies better than 0·1 mm in locating points and are capable of remarkable renderings. Obviously, the pens may have ink of any color. The major problem is the consumption of time, for the average 20 cm drawing might take several minutes.

The *cathode ray tube* (*CRT*), in which electrons striking the phosphor screen produce a visible trace as in television, is currently being exploited in many ways. The only limit we need consider to writing speed for CRT output is the comprehension of the viewer or the speed of photographic techniques being used. The photographs accompanying this article generally covered about 20 cm square.

The computer could produce the complete color image in less than $\frac{1}{20}$ second but, since the photographs were exposures of 4 to 8 seconds, the computer had to continue repeating the same pattern over and over.

Most of the CRT outputs are single units having active areas about 25 cm square for producing images in black and white. Flicker has been a problem, so generally the phosphor is selected with a long decay time to permit low refreshing rates for the display commands. The image only exists when the electron beam strikes the phosphor, that is, it disappears during the decay time of the phosphor. For the picture to remain visible, the computer must be instructed to repeat regularly the same motions of the electron beam to refresh the image. This differs from television, where the fast changes of images demand fast decay-times in the phosphor and rapid refreshing rates (decay times are generally less than 100 microseconds and the repeat rate of pictures is about 30 times a second).

Color TV tubes are a simple choice for making color computer outputs. These tubes have until very recently all been of the shadow-mask type, where three electron beams are used, each focused on either red, green or blue dots of phosphor comprising the display screen. The information must be properly filtered, so that the three beams at every instant have the correct intensity instruction to produce the required color. Though this is relatively easy in the color TV case, where the information is received in the filtered (colored) state, it is time consuming to make the necessary transformations for generating a full color image from programed computer instructions.

Recently, penetration phosphors for color-display CRTs have been developed that are in layers, so that the energy of a single electron beam determines both the brightness of the color and the hue itself. While requiring the same color-filtering transformations, the operation of a single beam is easier and the detail rendered still has high resolution.

The development of the *storage tube* has helped visual output techniques in the black and white category. Here the CRT screen can be considered to have a memory that may be switched on and off. At the beginning of writing a picture one turns on the memory and writes the picture as fast as one can—it will then persist until the erase instruction is given.

A family of optical techniques are adaptable to computer output. Small-mass mirrors may be moved electromagnetically at high speeds, giving both a displacement or a change of focus. Small changes in pressure, produced in an electrical transducer, may also be used to change the focal length of lenses comprised of liquids within elastic membranes. The fastest technique of all is the control of light sources either directly or by using fast shutters electronically activated. This field of display is limited in development by the specific images produced.

Before leaving output devices I should point out that, obviously, visual stimuli are not the only ones used for communication with man. Computers can play music directly through Hi-Fi systems and may speak a limited number of words. Fortunately, in my opinion, not very much has been tried in the taste and smell category and when one smells something, it means there is electrical trouble in the machine room! The use of the tactile sense is receiving limited attention at present.

VI. COLOR OUTPUTS

Colored inks for the plotters and printers and the color TV techniques have been mentioned above. These might be considered intrinsic color systems. There are other color techniques not so closely incorporated in systems.

With black and white CRT displays, photographic techniques offer several approaches. Conceptually, the simplest color system is to have the computer produce a red display, photograph it on color film through a red filter, then proceed similarly with green and blue filters making a triple exposure. Processing of the film will then yield the full color photograph. In the same manner, using negative color media, one could separately make the three negatives and combine them in the darkroom, retaining the flexibility of adjusting the color balance at the same time. This process yields the best color reproductions at present.

These techniques require darkroom delay and are, therefore, *off-line* not *real-time* systems. However, it was clear to early TV experimentalists that all one need do is mount the color filters in a wheel and rotate it synchronously with the display. In this way, there are produced superimposed three color images within the eye response time, giving to the eye the appearance of full color. This was the system proposed by the Columbia Broadcasting System (CBS) just after World War II for color television. Note that if the display area is a 25 cm square, one needs a filter wheel nearly a meter in diameter, whirling at about 1000 rev/min.

After trying subjective colors using display techniques, I wanted to avoid the cumbersome large wheel. Ivan Sutherland suggested that the rotating wheel be hand-held close to the eyes like a lorgnette and then several viewers, each with a properly synchronized unit, might see full color. We quickly realized that this permitted stereo separation of the images as well. The necessary device was designed, the computer programs developed and full color stereo images were easily obtained from any file of display data [12].

Diagrams of chemical molecules, curves of mathematical relationships and vision experiments have been enhanced or made possible by these techniques. Freehand drawings can be made in three dimensions. The draftsman can see the line in space (by stereo illusion) as he is drawing it.

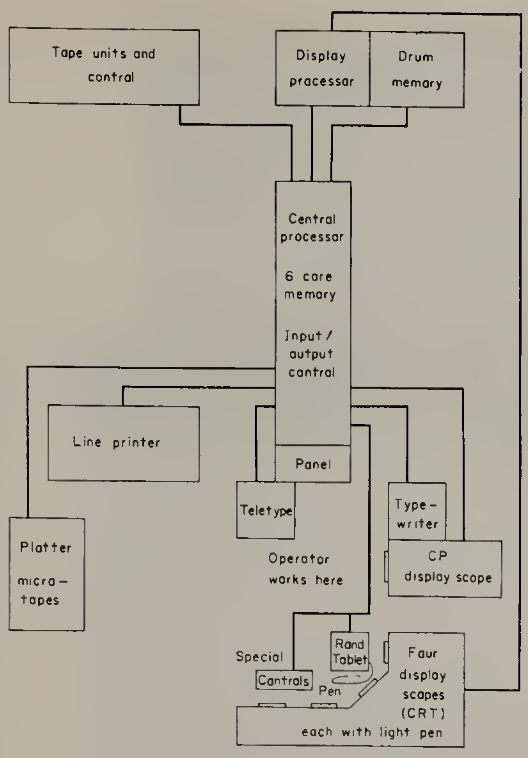

Fig. 1. *PDP*-1 *installation at Harvard's Cruft Laboratory.*

The diagram shows the layout of principal units of the computer. All peripherals are connected to the central processor (CP) except the four display scopes that are driven by a separate processor. The scopes receive instructions from the CP and can share the core memory.

VII. EXAMPLES OF COMPUTER ART

1. *The Harvard PDP*-1 *Installation*

The pictures accompanying this article were produced from displays on the PDP-1 installation at Harvard University. These are a byproduct of research being carried out to enhance man–machine relationships with rapid, unambiguous, high-information content output systems. Since vision appears to be man's widest bandpass sensory channel, the general emphasis is upon display techniques.

The installation shown diagrammatically in Fig. 1 consists of the central processor (CP) unit, its control panel and the peripheral equipment. The input devices include a teletype, paper tape reader, typewriter, Rand Tablet, light pens, switch boxes, rotating knobs and joystick (handle which inputs two directions of motion). In addition, there are magnetic tape units and telephone links capable of very high rates of information transfer.

Information storage can be achieved in several ways, most often in the six cores (arrays of magnetic storage units), or the drum (disks on a common shaft with magnetic surfaces) or the magnetic tapes. The output devices include a high-speed line printer, a plotter, four cathode ray tube (CRT) display consoles (the fifth is generally used only for editing programs), a Hi-Fi amplifier and speaker, and a number of other special devices.

For the uninitated, I will attempt to explain the purpose of the above items. The central processor (CP) is the 'brain' of a computer where the basic instructions are executed, from which all the rest of the equipment gets its instructions or to which the equipment gives information. The CP works directly from the core memory, various special input channels and with several instruction performing registers, called the *arithmetic unit*.

While remote units may continue without specific instructions from the CP, they only start on command and usually tell the CP when they have completed a job and are ready for another one. The instructions to the CP are executed in serial order, with the possibility of skips and jumps called for by the program. The CP is like a master chef who sees to it that all the other kitchen helpers do their job, while he supervises the procurement of food, makes all the important decisions and keeps the whole operation on schedule.

Often a special typewriter or a data-logging device prepares a punched paper tape for use during run time. This off-line prepared input information, including instructions and data may then be run through the paper-tape reader or easily stored for future use. A teletype and typewriter are alternative devices for putting instructions and alphanumeric data directly into the program under way or for manipulating the major processing operation of the entire system.

A Rand Tablet is a handy surface; its million points may be read as a pair of co-ordinates (x, y) by the computer, upon which one may by hand draw or trace a drawing for the computer to 'read'. Depending on the program that one devises to be 'read' from the tablet, the computer can acquire symbols, data or solely graphic elements. The tablet can, in addition, act as an instruction input device.

Light pens give similar results when used in conjunction with the CRTs and a proper pen 'reading' program. They offer the operator the chance of interacting directly with a drawing that the computer is in the process of displaying or to change, elaborate or give additional information. The switches, knobs and joystick may be used to provide continuous control of variables in the program while processing continues.

The magnetic tapes permit a large amount of data to be transferred and very great storage areas to be used. Generally, drum storage area is used as a back up for core storage. Though it is of large capacity it acts as an intermediate storage with slower retrieval speeds than the cores but faster than other larger storage devices.

Although I have already mentioned the plotters and printers, the CRT consoles demand further explanation. The main computer would be greatly delayed in its operations if all it could do was give point by point instructions to the CRTs themselves. In the PDP-1 system being described, the displays are actually controlled by a second or auxiliary computer driven by *Central Processor* (CP). This auxiliary computer receives special instructions and then proceeds to do the rest of the drawing without consuming valuable CP time. Thus, one may

Fig. 2 *Color-stereo display in use.*
The operator looks through a hand-held rotating filter wheel held close to the eyes. Switches automatically change the colours of the display. The knobs on the left control the stereo depth illusicn. Note the stereo filter wheel (uncolored) resting on a piece of paper.

designate a starting place in the memory at which the display is to begin and it will find the place and thereafter follow previously deposited instructions. There are many special instructions that permit communication between the two computers. For example, the light pens may interact with an image so that the program may be changed by virtue of what it has just accomplished (the point 'seen' by the pen). The advantage of having the auxiliary computer figure out character symbols, lines of a previously described nature etc. is that the operating program in the CP is greatly simplified and speeded up.

The hand-held, rotating filter device incorporates a small motor that is synchronized with the computer in such a way that the orientation of the disk mounted on the motor is known at all times. Thus, if the disk is half opaque, the computer knows when the left eye can see and only displays the view for the left eye. When the disk exposes the right eye, the display changes to right eye information and thus provides almost simultaneous stereo views giving the illusion of depth.

By writing on the Rand Tablet and moving the joystick back and forth for the third dimension, the unique experience has been developed where one may draw in space and see the result 'spacially' at the very time it is drawn. One needs considerable time to get used to the experience and, as we do not seem to be naturally adapted to space sketching, one particularly needs practice with the technique in which the pen and the sketch are in different spaces.

Color is easily added to the display by using color filters on the rotating disk. When the eye is looking through the red filter, the computer draws in white what is seen as red and, similarly, for blue and green. The colors may then be additively mixed so that a line drawn in both green and red will appear yellow, a line drawn twice in red and one in green will appeared orange, etc. Indeed, the sequence used for stereo color views is to have a six sectored filter disk with red, green and blue filters interposed by opaque sectors. Thus, when the right eye is eclipsed, the left looks through a filter, etc. The computer essentially displays six renderings in continuous sequence (red-right, blue-left, green-right, red-left, blue-right, green-left), synchronously as the color filters change so fast the eyes only see the sum of all the displays. Typically, one complete cycle of the six sectors takes 50 milliseconds, that is, it repeats twenty times a second.

The photograph in Fig. 2 shows a demonstration. of a hexagon (each of whose sides is a different color) with two rhomboids and a rectangle inside. The switches permit selection of the color of the central objects. The knobs at the left adjust the depth desired (hence the stereo separation which is calculated by the CP). Important to this system is the type of display screen chosen for the CRT. It must both provide enough intensity for each color filter in the system and be fast in the time it takes to darken after stoppage of excitation by the electron beam which writes the display. The P-4 phosphor surface used in the display screen is not an ideal white but has a large fast blue response and a slower and weaker yellow-green response, all rated at less than 100 microseconds decay time. (The decay is exponential, yet one may still see the

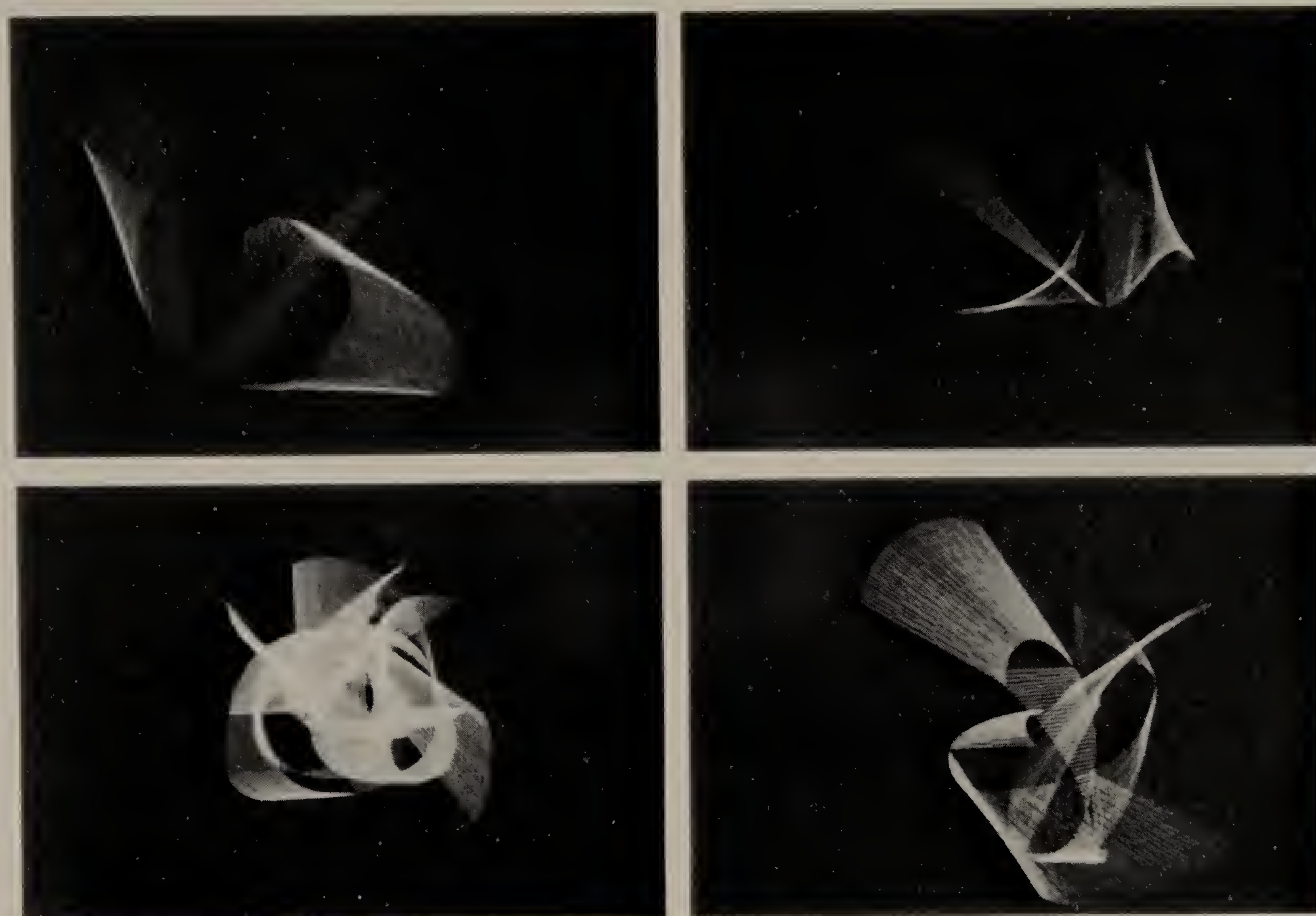

Fig. 3. Color images produced by the Harvard PDP-1 computer under control of the author. The lower right-hand illustration is reproduced in color on the front cover.

Fig. 4.

red component of this phosphor persisting at an observable level for what must be more than 20 milliseconds, 200 times the rated decay time.)

One should be aware that the spectral character (detail of color absorption) of the filters, photographic materials and printing techniques all served to degrade the color effect seen in Fig. 3. To the observer watching the computer display the colors are highly saturated and cover a wide range of hues. With little effort, more than 30 colors in a single image may clearly be distinguished.

2. *Color 'Flowers' and 'Birds'*

As part of his graduate research program, while working on a variety of display interactive programs, where the operator consciously interacts with the display, Dan Cohen developed the basic program for the computer art shown here. I merely adapted the program to the color system, adjusted the constants to suit my taste and made the photographs. (Kodak Ektachrome, EHB-135 film, about 4 sec exposure at f/2·8 through one eye hole of the filter wheel.)

The 'Flowers' and 'Birds', as I call the images produced on the display, are sensitive to initial values set for the program, as well as to the many controls operated while the program is in progress (cf. Figs. 3 to 6). Essentially, the program generates a line. This line or vector has two controls which move the starting point (one end of the line) in two circles of different diameter and a third control which rotates the line itself in a circle. The number of lines in any given display may be selected up to some fixed maximum (in most of the illustrations about 500). Switches permit adjustment of the color synchronism, the stacking of displays one over the other, erasure of the image for a new start and the freezing of a pattern so it will stop evolving while a photograph is being taken.

The observer views the 'Flowers' and 'Birds' through the hand-held rotating filter wheel synchronized with the display on the CRT. The pattern normally is changing continuously, evolving into successive patterns under the operator's control. The computer also continuously generates new instructions for the positioning of the line and stacks these one after the other in a memory file accessible to the display processor.

Perhaps the most fascinating aspect of the 'Flowers' and 'Birds' is the simple circle generating sub-routine (a small program used repeatedly by the main program) which positions and rotates a line. The discontinuities present in the circles are the result of not keeping the circle generation continuous but allowing a mathematical error to go uncorrected. Also there is a routine in the program which carefully prevents the lines from intersecting the margins of the display area (about 25 cm square).

3. *Other examples of computer art*

Life Magazine [13] recently featured several pictures of computer art. One picture demonstrated the use of the alphanumeric high-speed printer to produce what looks from a distance like a half-tone print of birds against a cloudy sky. There were also examples of off-line color techniques.

In the course of study of image processing and pattern recognition, John Mott-Smith [14] has developed several techniques of computer art. Currently his work is being exhibited internationally and he has been commissioned to prepare material for *Life Magazine*. He has developed displays both

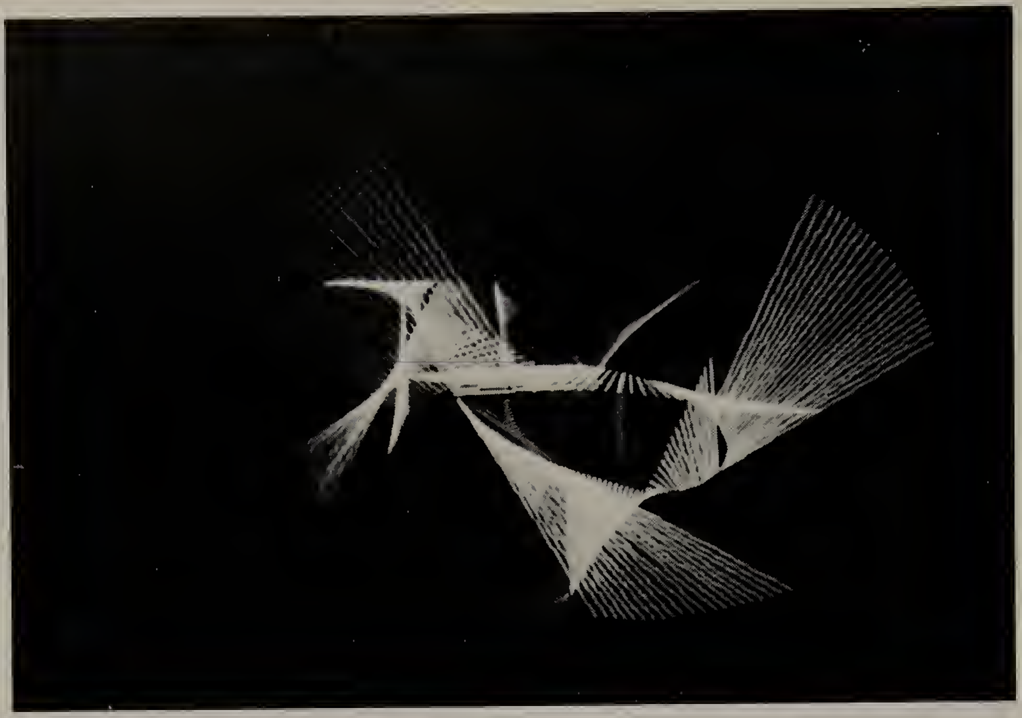

Fig. 5.

Fig. 6.

Figs. 4 *to* 6. *Image produced by the Harvard PDP-*1 *computer from a program by Dan Cohen and the author.*

in real-time and delayed-time for still and moving photographic techniques. He has apparently developed considerable flexibility in the handling of color, including the use of shadow-mask display tubes, synchronous filter techniques and individual preparation of color-separated negatives.

Working with the Cognitive Information Processing Group at the Massachusetts Institute of Technology (MIT), Charles Seitz has produced a fascinating series of dynamic programs which include sound. One may observe dancing circles and delicate 'splashes' with trills of notes that actually sound as though they belong to the pictures. Seitz's visual programs are run on a PDP-9 computer and the sound comes from a loudspeaker driven by an amplifier using the x-deflection signal for the display as an audio signal.

Bell Telephone Laboratories have been involved in numerous display developments. Perhaps most attractive to artists are the programs that provide animation routines. Used in technology, they may design electrical circuits by gathering the electronic symbols into appropriate connected arrangements and then allow the computer also to display the characteristics of the electrical behaviour of the circuit so designed. Much of this type of animated display interaction stems from Ivan Sutherland's *sketchpad* innovations [15].

Other large industries have developed special graphic systems. In reference 16 it is stated that: 'The Electronics Laboratory of the General Electric Co., Syracuse, N.Y., has developed a computer generated simulation technique that involves: (1) storing the data describing the environment in computer memory; and (2) solving in real time the perspective equations that define the environment image on the display or image plane. All hardware for modelling and photographing in connection with the simulated display is eliminated and replaced by a computer with numerical data stored in its memory. A color TV monitor or set of monitors shows the actual display using a purely mathematical-scanning and perspective-image-computation process.'

General Motors Research Laboratories had the IBM Corporation design special computers for them. One of these, the DAC-1, permits the usual interactive drawing and data handling, and can also produce large photographic prints from precision negatives and use data from scanned drawings as computer input. Another computer can form a full-scale model of an automobile in clay from numerical specifications, taking about thirty minutes for the job.

VIII. CONCLUSION

Perhaps the computer is more than a new medium. It is a challenge to artists in all media to learn the characteristics of this powerful tool and the ways in which it may give wider scope to their talent. Talent, taste and intuition must be brought to the computer by man, it has technique to spare. There is one major problem at present—computer time is very, very expensive.

A Computer Arts Society has been organized in London and interested persons may obtain information on it from Alan Sutcliffe, ICL, Brandon House, Bracknell, Berks., England [17].

ACKNOWLEDGEMENTS

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OSCILLONS:

ELECTRONIC ABSTRACTIONS

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Abstract—Oscillons *or electronic abstractions, as electronic oscillograms composed for art, are defined. The instrument used to display the* Oscillons, *the cathode ray oscilloscope, is described and its various functions discussed. Basic waveforms which may be displayed are illustrated and explained. Some of the means by which oscilloscope traces may be combined and controlled to form* Oscillons *are briefly outlined and several examples are shown. The kinetic nature of many* Oscillons *is brought out. The author briefly describes methods of composing them as art forms and the photography of the electronic abstractions is explained, including some problems involved. Exhibitions and publications of the* Oscillons *are noted.*

A review is made of the author's interest in designs derived from mathematical, physical and technical sources which led up to his Oscillon *project. The first suggested use of them for design is mentioned, along with work of others in this field. They are compared to other kinds of non-figurative and mathematical art, and some relationships considered. A comparison is made to electronic music. The author concludes that the* Oscillons *are a good example of the use of technology for art and as manifestations of natural phenomena.*

I. INTRODUCTION

Since the technology of electronics has become such an important part of modern life, it is inevitable that it be employed in the creation of art. The subject of this article is the composition of electronic oscillograms as art forms. To distinguish these art forms from oscillograms as they are used in research, testing, radar displays and in other ways, I have chosen to call my own creations *Oscillons* or *electronic abstractions* and the technique of their creation, *Oscillonics*.

Oscillons are unique images in light composed of waveforms as they appear on the screen of a cathode ray oscilloscope. They may be monochrome or multi-colored, in motion or static on the cathode ray screen and they may be so displayed as art, either on an oscilloscope or on a television screen. They may be recorded as photographs in black and white or in color, or as motion pictures. They may also be shown as drawings or paintings. In the case of computer-derived oscillograms, they might be traced by electronic plotters.

II. THE OSCILLOSCOPE

The basic device for displaying the *Oscillons*, the oscilloscope (cf. Fig. 1), is an instrument widely used in research and engineering, as well as electronics service work. The screen is the face of a cathode ray tube, most familiar in its larger sizes as the television picture tube. On the oscilloscope screen may be displayed traces in light which are formed by electrical waves. To the technician, these waves may give various kinds of information, such as voltages, currents, frequencies, phases, pulse durations and other factors.

The electron beam within the cathode ray tube is actually the pencil or brush by which these traces are formed. It is focussed and deflected either by electrostatic fields within the tube, by electromagnetic fields outside the tube or both. It may be varied in intensity by signals applied to the grid of the cathode ray tube—in the way that the dark and light portions of the television image is formed. In the case of the shadow-mask television tube, the color image is formed by three electron beams impinging on the fine phosphor dot array on the inside face of the tube. Since the spot at the end of the beam moves very fast and retraces itself many times a second, the persistence factor of the phosphor of the cathode ray tube produces a continuous line or form on the screen, which can be seen by the eye or a camera.

The waveforms which may be displayed may be of various kinds. The basic types that I have used for the *Oscillons* are the sine wave, sawtooth, square wave (cf. Fig. 2), triangular wave and pulses. The sine wave is the familiar curve formed by the projection of a moving circle and is also the waveform made by an alternating current generator. As a pure wave, it is not of so much interest as an

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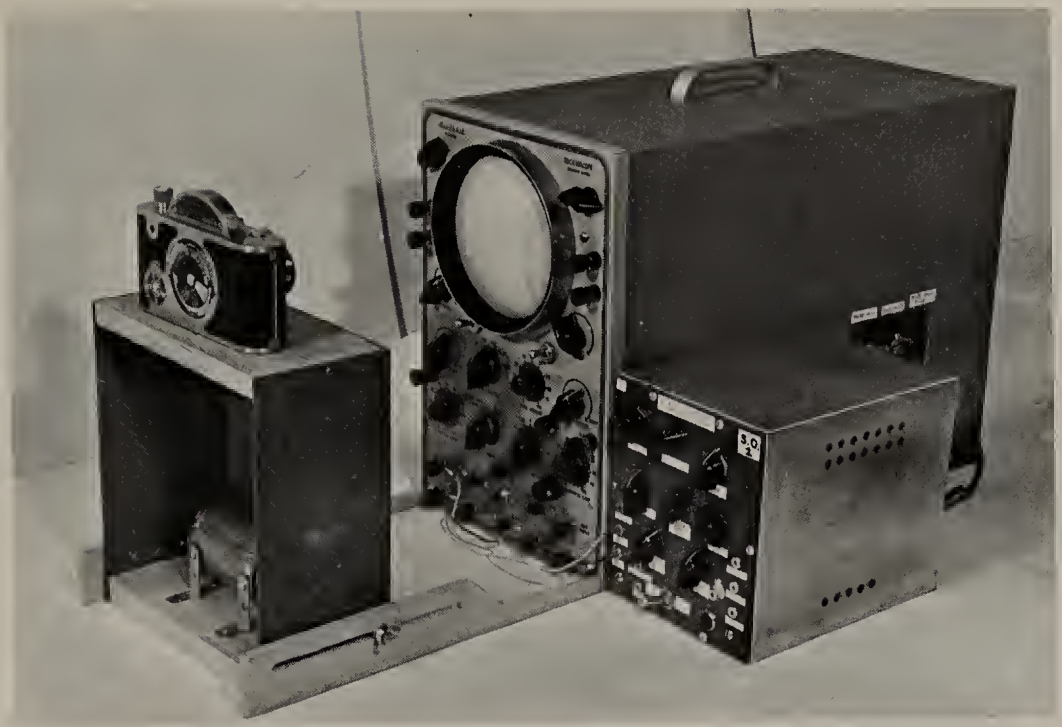

Fig. 1. Modified oscilloscope with sine wave generator and photographic setup.

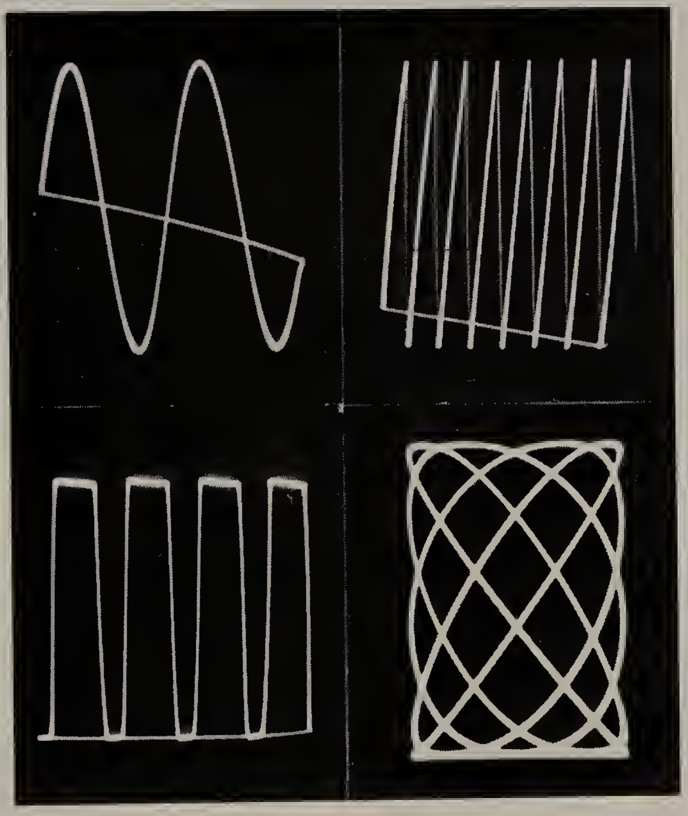

Fig. 2. Basic waveforms and Lissajous figures.

element of design, just as the pure sine wave in sound as a tone in music is likewise not so interesting to hear. This wave, as well as the others, may vary in its amplitude (size) and frequency or number of cycles per second. For *Oscillon* work, I have used sine waves from about 30 through 100,000 cycles per second. The high frequencies produce more solid appearing sheets and forms.

The sawtooth wave (second trace in Fig. 2) is not as simple in form as it appears. Mathematically and electronically it is the resultant of all the harmonics of the basic sine wave. That is, if successively higher multiples of the sine wave are plotted, then added and smoothed on a graph, the resulting form is a sawtooth wave. Another form similar to this is the triangular wave, which is the resultant of all the even harmonics of the basic sine wave.

The square wave has also been used to compose *Oscillons* (third trace in Fig. 2). This wave is considered to be electronically composed of all the odd harmonics of the sine wave.

Before going on to consider how these fundamental wave shapes are used to make more complex

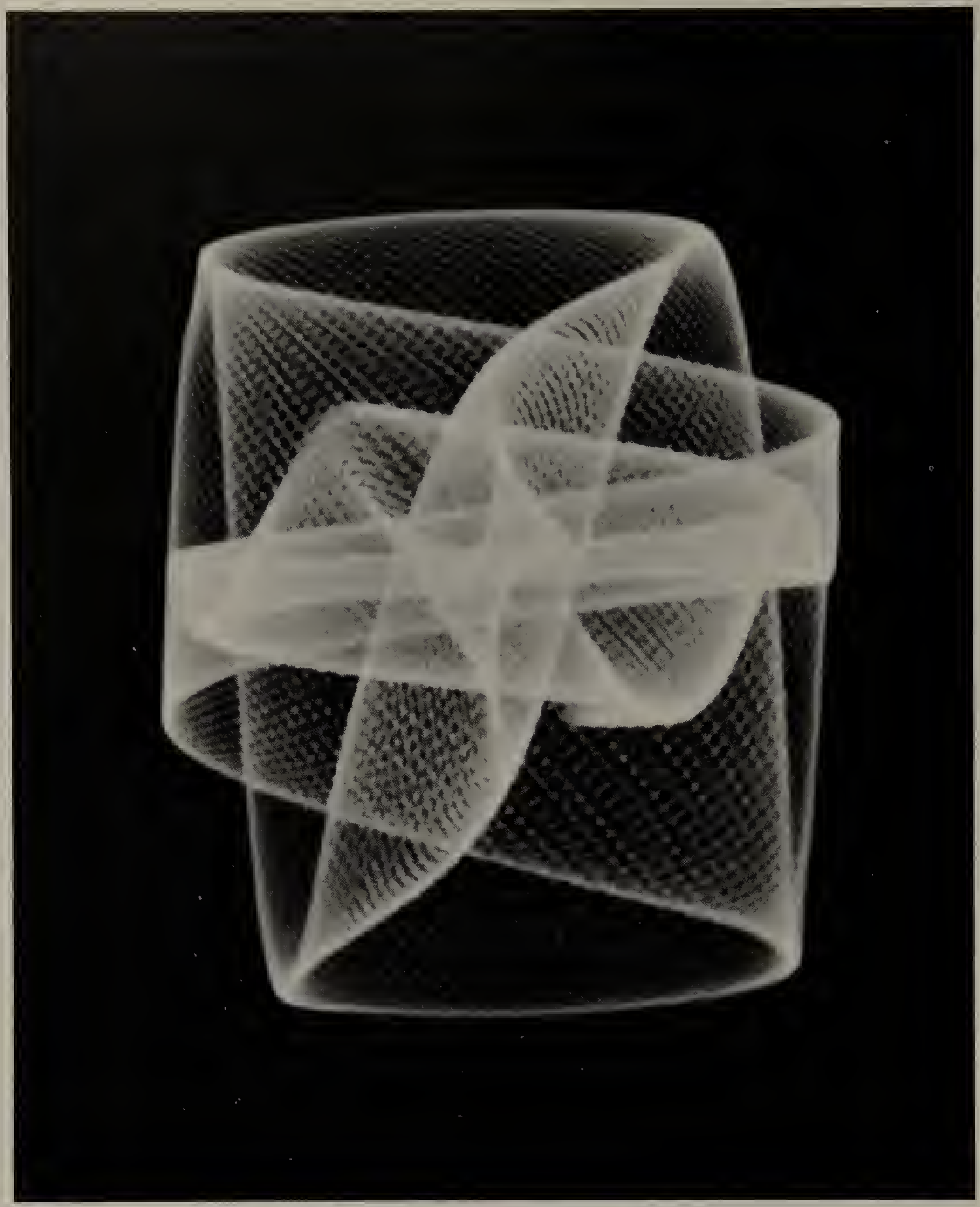

Fig. 3. *Oscillon* 19, 1952.

figures, more should be said about the oscilloscope itself. The basic oscilloscope consists of input amplifiers, controlling the deflection system; the electron beam circuits; a sweep circuit, which is usually a sawtooth waveform, and the necessary power supplies. The various controls make it possible to alter the shape and size of the figures on the screen by means of the horizontal and vertical amplifiers. The figure or trace may also be moved about on the screen by means of the horizontal and vertical positioning controls. Intensity and focus controls affect the brightness and sharpness of the spot or trace line of the electron beam.

III. OSCILLONS

The oscilloscope alone will not produce anything more than elementary figures, for it normally contains only the sweep circuit and a provision for using a 60 cycle trace (on American types.) These will display sine wave figures of varying frequencies, from simple lines to solid rectangles or rasters. So, to obtain more complex figures other waveforms, pulses and signals must be fed into the vertical and horizontal connections of the respective oscilloscope amplifiers or into the magnetic deflection circuits.

If a sine wave is fed into the horizontal input amplifier and another sine wave into the vertical one, it is possible to get a variety of figures. The simplest will be a circle or ellipse, if the input frequencies are equal. If they are other multiples, then Lissajous figures will result, one of which is shown (fourth trace in Fig. 2).

From this point on, many other electronic procedures may be employed to obtain other shapes and textures. Various waveform generators are connected to the oscilloscope inputs in parallel, in series or otherwise modulated. Electronic switches, which can display two separate figures on the screen (or other even multiples), may be used. Other modifications of the input circuits may produce spirals, roulette figures, rosettes and so on.

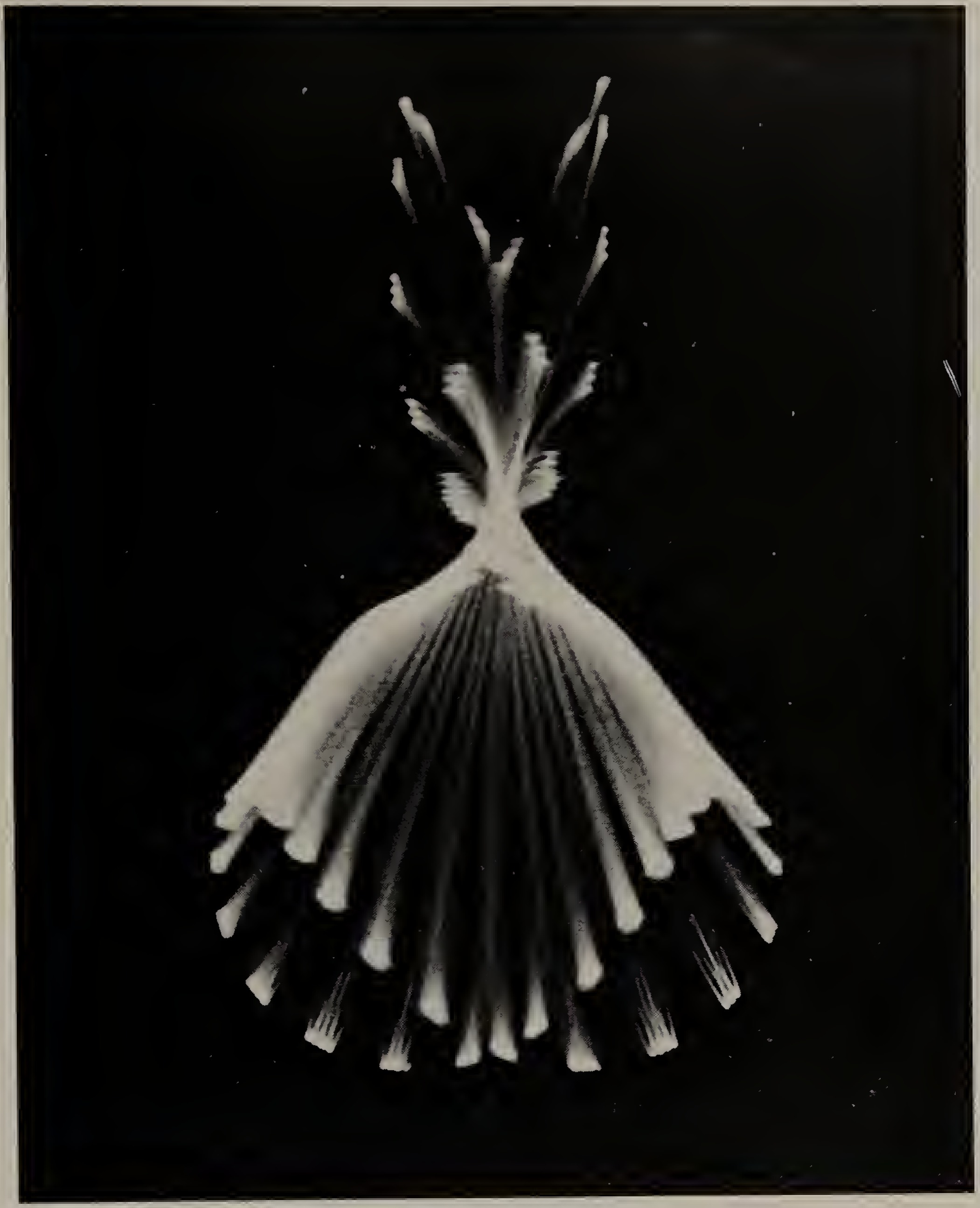

Fig. 4. *Oscillon* 3, 1952.

To obtain the wide variety of compositions I have created as *Oscillons*, additional special circuits were added to the four different basic oscilloscopes I used. Many of these were uniquely designed magnetic deflection circuits, to which were fed waveforms—especially low-frequency sine waves. These inputs were in addition to the normal horizontal and vertical inputs of the oscilloscope. Also waveforms were fed into the beam circuit, modifying the intensity of the electron beam itself, and also creating new figures or textures.

The resulting forms are often very complex as regards all their basic factors (cf. Figs. 3–8). Some *Oscillons* involve as many as 70 different settings of controls on the oscilloscope and of other combinations of input waveform generators, amplifiers, modulating circuits and so on. I have constructed and used over 60 different electronic instruments for this work, many of standard types, others of specialized design.

A very condensed description of the circuitry involved in *Oscillon* 19, shown in Fig. 3, is as follows: a sine wave generator output to a circular amplifier (as used in some radar-type circular sweeps) modulated by a sine wave generator output; with amplifier distortion, amplifier to oscilloscope and low frequency range of sine waves.

The screen of the usual type of oscilloscope has a glowing trace (P1 phosphor) but a number of other phosphor colors are available. For black and white photographic work I also used a blue trace phosphor tube (P11). For color work a white trace tube (P4) was employed—this is the same as the type in television black and white tubes.

IV. COLORED OSCILLONS

Color in the *Oscillons* may be achieved in three different ways. If they are set up on television screens, tri-color shadow-mask tubes may be used. However, there are problems of control, distortion, high voltages and so on, with this method; the figures will also have a half-tone effect. A second way is to use three different color cathode ray tubes

Fig. 5. *Oscillon* 7, 1952.

with red, blue and green phosphors. Then the images from these may be projected through dichroic mirrors and combined on a screen to produce multi-colored figures. This system, however, requires very precise registry and optics and was not used for the *Oscillons.*

The third and simplest method I used employed a white trace tube and color filters before the face of the tube to obtain an image in color. These filters were either stationary or rotating. By using a circular wheel with red, blue and green segments, and rotating this at variable speeds, multi-color images are obtained. (This method is similar to the first color television system which also used a color wheel in front of a white trace cathode ray tube. Practical considerations, such as the size of the wheel required for a picture of 10 inches or more in size, rules out this system in favor of the tri-color television tube, although it does produce excellent color images.)

The color in the image as seen at the plane of the rotating filter wheel will depend on the frequencies being used to form the *Oscillon* and the speed of the wheel. For instance, if the part of the moving trace whieh is on the screen at the same time that the green segment of the wheel is over it, then a green line will be seen. As the wheel revolves,this line would change to red, or a part of it would be red, then blue, as the wheel revolves. All this happens in very small fractions of a second.

Besides the basic red–blue–green color wheels, I have used other combinations as well, sueh as various sized segments and different sequences of the colors arranged on the wheel. The speed of the wheel and resulting chromatic effects are controlled by a rheostat. (In the television setup, it was synchronized with the television image in order to get the correct color placing in the picture). In this way, varying color effects could be obtained (cf. Fig. 9).

I have experimented with polarizing filters with birefringent plates to produce color results in place of the segmented color wheels. However, low light transmission of the polarizing filters raised problems

Fig. 6. Oscillon 263, 1960.

with color photography, so it was not further employed. The possible refinement or development of other types of filters, such as Kerr cells, electromagnetic color filters and the new liquid crystal filters, which can be electrically modulated, may be of use in this technique at some future time.

Since the *Oscillons* in color are formed by transmitted light, additive color effects are obtained. For example, a red trace superimposed over a green trace produces yellow and all three basic colors will result in a white area.

V. DESCRIPTION AND DISCUSSION OF OSCILLONS

The forms seen on the oscilloscope screen (or in the plane of the color filters) are kinematic entities. They are traced by a constantly moving spot (the end of the electron beam as it impinges on the inside of the face of the cathode ray tube) which causes the phosphor to fluoresce wherever the spot is located. Besides that, the figures themselves may be kinetic—they may pulsate in their parts, expanding and contracting, or change back and forth between two shapes. Fine wave lines may undulate across the pattern. The shapes change as the forces and magnitudes of the electrostatic and electromagnetic fields within the cathode ray tube interact. All this, of course, may be altered either by the controls on the oscilloscope, by the input waveform or by other instruments.

What the final form of the *Oscillon* will be is determined, first, by the kind and number of input circuits connected to the oscilloscope and, second, by how these circuits are controlled in combination. The *Oscillons* are normally not accidental or naturally occurring forms—they must be composed by the conscious decision and control of the artist using the apparatus. Of course, aesthetically interesting traces sometimes accidentally show up during the normal use of the oscilloscope for technical purposes. In some cases, it is possible to get such traces either by the chance selection of input circuits or the chance setting of various controls but this is not the usual way. Of the great number of possible traces, only a small portion will

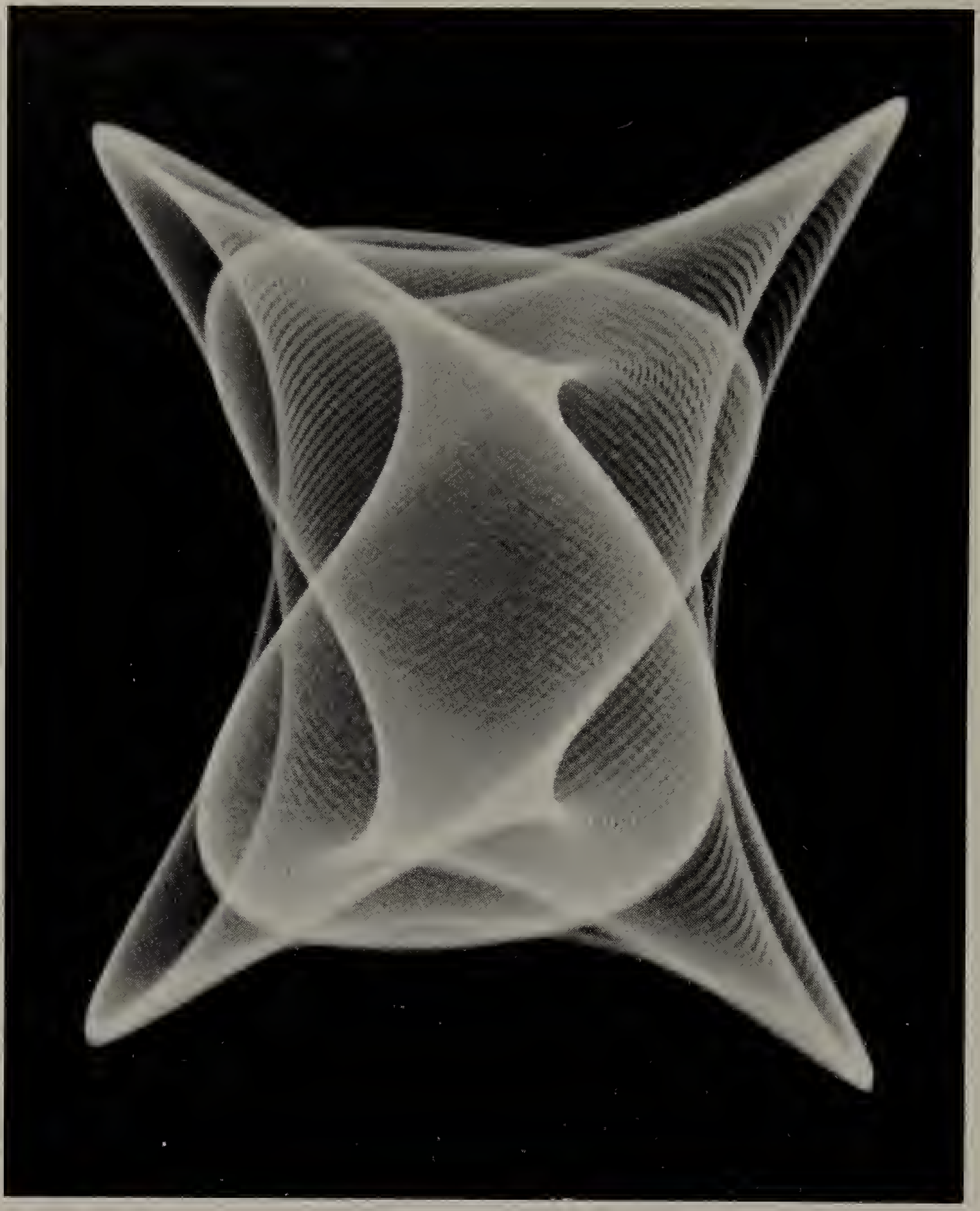

Fig. 7. Oscillon 281, 1960.

be of value as abstract art or as designs. What can be done must be learned by observing the results of combining various basic waveforms and shaping these figures with other deflection and modulating fields. An entire system or theory of composition could be worked out for the oscillonic medium but I believe that this might lessen the often spontaneous creativity which is possible by the method I have used so far.

It may be asked whether a particular figure or kinetic cycle can be exactly repeated on the screen after a period of time. This will depend on the accuracy of the circuitry used. Precision components, such as close tolerance resistors and capacitors, and very fine controls would have to be employed—all of which would affect the cost of the equipment. Accurate voltage regulation, crystal controlled oscillators, fine vernier tuning and so on would also be required. A complete record of all control settings would be needed—this can run to many factors. I did not find that the economics of the situation justified all of the additional refinements. Once I had composed and photographed a particular *Oscillon* composition, I did not feel the need to repeat it exactly, although records were kept of much of what was done, in particular, instruments used, approximate waveform frequencies and other factors.

Since it would be costly to arrange a separate oscilloscope or television screen with all of the necessary accompanying equipment for each composition for public exhibitions, except in special situations, I chose to record the *Oscillons* by photography. Because of some factors, such as working at close-up distances, motion in many of the *Oscillons*, low light intensity of the oscilloscope traces and low film speeds, some special procedures had to be used in the initial stages of my work. High speed lenses (such as an f 1·2) and Linagraph 35 mm recording film were used for the black and white photographs of the first group of electronic abstractions. Later 4 × 5 inch films were used, especially some of the newer very fast black and white types.

In the case of color work (started in 1956), I first used an aerial color film, as this was the fastest

Fig. 8. *Oscillon* 1049, 1960.

then available and it also had a high contrast and could be forced in development. Since then, higher speed color films of other types which became available have been used. The use of a 4 × 5 inch camera with an f 2 aerial lens necessitated time exposures of up to one-half a second. This required that motion of the *Oscillons* be stopped on the oscilloscope screen. The movement of the figures can usually be stopped by employing 'sync' circuits, which will stop the formative motion of the trace. However, in some cases this did alter the shape of the *Oscillon*. Since in the color compositions the various colors would also shift, close control of the rotating filter wheel was necessary in order to hold color to the desired areas. The traces could not be held static on the screen for too long a time, as this would result in destructive burn spots on the phosphor of the cathode ray tube, requiring replacement of the expensive tube.

Out of over 10,000 black and white traces photographed and several thousand in color, the best were selected and printed for use in exhibits, for publication or for artwork in commercial applications. The black and white [1] and color *Oscillons* have been widely shown in the United States and abroad, in all over 188 times, in 37 states and 16 countries. The *Oscillation* exhibit shown in 1953 at Sanford Museum, Cherokee, Iowa, is considered to be the first exhibit anywhere of computer-type art [43, 44]. A variety of publications have carried articles or illustrations of *Oscillations*—some of the publications are listed in References 2 to 18.

I have produced *Oscillons* of a wide variety of shapes, textures, multi-color harmonies and contrasts, undulating lines and interpenetrating planes. While non-figurative in intent, many suggest, for example, fantastic flowers, birds and fish. Some have mathematical precision, others are free-flowing in their curvatures and symmetries.

The emotional appeal of the *Oscillons* is perhaps similar to the abstract aspects of music—as is the appeal of other art using light. While giving impressions of sweeping rhythms, the pulsating trace of the oscillating electron beam reveals their formation. Like other types of kinetic art, they involve the factor of time, in addition to giving an illusion of three dimensions on a two-dimensional surfaee. Some of the oscillons have an almost sculptural quality. Because of the highly-eontrasted, non-illuminated background of a oscilloscope screen or the black area of a photographic print, they may seem to be images of luminescent moving masses or suspended in space.

Other phases of the oscillon project which may be undertaken in the future inelude lighted transparency displays, motion picture sequences and direct displays, as on a large television screen controlled possibly by video-tape and other multi-channel tape sources.

It was while investigating possible sources of non-figurative art in 'magic line' patterns from mathematical magic number squares and projections of geometric solids [19] some 30 years ago that I began to work out abstract compositions that eventually resulted in the *Oscillon* projeet. This earlier work included consideration of serial rhythms as expounded by Joseph Schillinger [20] and of Jay Hambidge's dynamic symmetry [21, 22].

The possibility of using eleetronic oscillograms for design was first suggested by the electronic engineer, C. Burnett, in 1937 [23]. However, it seems that little was done by artists in developing or exploiting the idea. I began work in 1950 on the electronic abstractions while experimenting with other related design sources from mathematics and physics, such as harmonograph tracing machines and pendulum pattern makers. This latter technique uses pendulum bobs to whieh are attached pens which trace intricate figures [24, 25], (cf. also *Leonardo* **2**, 267, 1969). Pendulums with a pinpoint light at the bottom have been suspended over photographic paper or a camera with an open shutter in a darkened room; many examples of these tracings have been published by others [26]. While these two methods gave a number of interesting designs, I felt that the electronic method had greater possibilities, especially in regard to control of the results and variety of possible forms.

Among others who have worked with electronic oseillograms have been Norman McLaren, who made a stereographic movie short for the Festival of Britain and Mary Ellen Bute of New York, who also made a hand-colored 16 mm motion picture, modulated by music, 'Abstronics' [27, 28]. Herbert Franke of Germany has also done some work with electronic oscillograms [29]. Examples by others are shown in Gyorgy Kepes' 'Vision and Value' series of books [30]. Recently John Whitney of California and other computer graphic engineers or technicians have also displayed oscillograms programmed by computer methods [31, 32]. Nam June Paik has displayed television images distorted by magnetic fields [33].

Oscillons are related to other types of light art, kinetic art, design derived from mathematical sources and Op art. The filmy or nebulous effects produced by various light devices, such as, for example, A. B. Klein's Colour Projector, Thomas Wilfred's *Lumia*, Frank Malina's *Lumidyne*, Jim Davis' abstract films, the *Luminola* of C. E. Singletary and Carl Rieback's *Lumia* [34–39] may be simulated in some ways by the oscilloscope, especially when high frequency traces are used. However, I believe that many of the above methods of using electric light may be much less costly than would be an electronic oscillogram apparatus assembled to produce similar results.

The roulettes and other spiral figures traced by harmonograph machines [40] can also be duplicated on the oscilloscope with appropriate input circuits; also the intricate traceries made by the pendulum and the geometric engraving lathe,which make the patterns for currency, may be simulated. Op art illusion effects may also be obtained, including some kinds of moiré patterns [41]. By the use of special circular sweep cathode ray tubes, it may be possible to produce kaleidoseope figures.

The three-dimensional appearance of some *Oscillons* are due to phase differences in the waveforms that compose them. *Oscillons* are basically visual illusions, especially those in which the color effect lies only in the plane of the color filters in front of the face of the cathode ray tube.

There is an analogy between electronic music and *Oscillons*. Both are created by means of waveforms or vibrations—one affecting the aural, the other the visual sense; many of the same types of oscillators may be used for both. An input of musical waveforms into the oscilloseope can also create some interesting patterns in rhythmic motion. I have used several means to do this,including filter systems and stereo reeordings. However, these figures are usually not as aesthetically pleasing as those composed in other ways. They are also diffieult to photograph exaetly because of the very fast motion of the musical traces.

VI. CONCLUSIONS

Oscillons are, I believe, an excellent example of the possibility of employing modern technology in art and of demonstrating a relationship between science and art. They are also visual manifestations of some of the basic invisible aspects of nature, such as the movement of electrons and energy fields. The non-figurative art forms of *Oscillons* represent the reality of various intricate combinations of electricity and magnetism, such as fields, frequencies, phases, voltages and currents. Their composition from electrical vibrations is in accord with the waveform character of light, atomic interactions, sound and other phenomena of nature [42].

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Fig. 9. Oscillon 1206, 1960. *Reproduced in color on the back cover.*

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*Article included in the present edition.

METHOD FOR PRODUCING SOUNDS OR LIGHT FLASHES WITH ALPHA BRAIN WAVES FOR ARTISTIC PURPOSES*

David Rosenboom**

Abstract—*The author discusses his attitudes to music and the possible impact on it of technological developments. He describes the work he has done to apply the EEG Alpha brain-wave monitoring technique to a group encounter performance system for producing sounds by the conscious control of the character of the Alpha brain waves. This system can also be used at present for producing the flashing of lights.*

Questions posed by an audience after an informal talk on the subject by the author and his replies are included at the end of the text.

1. INTRODUCTION

I believe that through the use of computers as appendages of man's brain and methods of learning with bio-feedback, rates of information processing will be achieved that approach the speed of light. Thus, conception will be less necessarily bound with action, ellicited or observed, and life will eventually be embodied by information–'energy' networks creating non-physical art; communal art will be revived as established networks connect us firmly.

Further, future man may be possessor of greater personal freedom as energies turn from violence, a counterpart of our world of spatial boundaries, and are directed toward a cultural restructuring.

The representation of art as object or singular event will have less meaning, rather, cybernetics and the theory of systems will manifest themselves in information–'energy' exchange rituals. They will stimulate non-centralized expression and more profound interactions so needed in our mechanistically functional world.

I am also very concerned with a schism I see today between artists who still use technology as a way of expressing themselves and those departing from it . . . I am constantly running into composer friends who are dropping their Moog synthesizers and their computers, throwing their hands up in anguish and running off to some commune to make music with flutes and sticks. I was recently talking with the *Musica Electronica Viva* people in Rome who used to make up one of the great electronic music innovative groups. They have stopped most electronic activity and are now involved in making music by getting large groups of people in an appropriate space and helping them all to play music with traditional instruments—similar to group encounter activities and experiments that are going on up and down the west coast of North America [1].

I am not very interested in art-world conceptual game playing. I am interested in realizations. So I am concerned with the time–'energy' versus output ratio, which I have learned to deal with in computer work, practically the same way I used to deal with the signal to noise ratio in the construction of analog systems.

2. FIVE PROBLEMS

The first problem is posed by music being most importantly a performing medium. Unfortunately, most of the computer hardware that has been designed and can be tapped by artists is orientated toward creating a finished material product. Western music, of course, has been so involved—making a finished product—because we have been concerned with the Bauhaus-type of thinking about art; that is, thinking of objects as end products or as industrial prototypes rather than maintaining a systems-oriented thinking that is necessary when working in the performing or the kinetic art media

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[2]. I am upset by many of the ways in which the Western musical mind works. It spends as much time as possible creating composition by precognition rather than through experience or listening. We have studied at length Indian music, which I believe is one of the most sophisticated musical systems ever developed; certainly, I think, during its purest periods—not what it is today—it was more complex and better developed than our Western system.

In Indian music, everything was generated by doing, by contribution to a set of knowledge that the whole culture developed and to which no individual's name was attached. The ego obsession of Western art has held it back a great deal because we speak too much of the individual makers and not enough of the actual experience they produce. The heart of the matter for us, then, is how to design computer hardware for live performance—this is the second problem. Recently, digital systems have become sophisticated enough to be used in this context. Computer 'languages' present more problems than the hardware. They too, however, are beginning to be understood sufficiently for us to begin to deal with their subtleties.

The problem of getting a computer to be a performer and not only a producer of finished material products is related to the problem arising from the difference in the age span of music and of computers. Music goes back several thousand years and has become a highly refined human activity. In traditional Western music, we have fairly commonly accepted criteria for an idea being useful (we do not say the idea is 'good' or 'bad'). When a new machine is developed that has the possibility of doing almost anything, that becomes its problem: it can do almost everything. Computer programs that can deal with aesthetic qualities have to be developed. The tendency is to require that they allow all possibilities to be scanned, whereas the artistic sensibilities of our minds, if we are honest with them, permit us to make selections and eliminations at lightning speed. We need to develop computer programs that select such qualities with equivalent speed without the programmer having to wade through all the computer hardware characteristics [3].

The third problem is that of useful musical 'languages'. Many answers lie in the approach to them that the composer-mathematician, David Rothenberg, describes in his adaptive pattern recognition models for pitch and visual materials [4]. The method of analysis is the same as that for synthesis. We are often faced in musical and other art systems with theorists who have such preconceived notions of what they want to find that, when they begin to analyze them, they merely create those that will confirm their preconceptions. This is not the way to obtain synthesis.

The fourth problem is the 'new-sound' syndrome. During the past fifteen years, Cage and other composers have concentrated on new sounds. New sounds were of most interest in much of the music of the nineteen-sixties—the flute playing double stops, the oboe playing five note chords etc. There seemed to be more concern with their impact on society than on their organization or on what they communicated and after all, communication of messages is, one of the basic aspects of the arts.

There are two aspects of my interest in music that I presently find somewhat irreconcilable, however, I am little worried about bringing them together. The first is my concern with very high standards of musical composition. The second is my desire to release creative talents of groups of individuals who have no knowledge of music as a discipline or, in fact, very little experience with complex music. The idea is to develop a creative intra-group musical communication rather than sounds, as such. Jazz bands and improvisation groups, for example, are able to develop this kind of communication through music.

Finally, I believe it is important to consider the problem of the ways in which those with artistic talents can make contributions to the development of future technology; ways for our economic mode of life to take into account the economic value of artistic creativity. More and more, the idea is spreading that before a new technology is launched in society it must be evaluated comprehensively from many points of view, especially, its possible impact in the future on man and his environment, including the ecological balance of nature.

3. SOME POSSIBLE SOLUTIONS

A solution to the problem of designing computer hardware for the live performance of music lies in the direction of making a more direct connection or 'interface' between man and machine. This may be achieved by directly transmitting information from the brain [5] or from the muscles or from a combination of the two.

I have studied with two other physiological psychologists, Edgar E. Coons and Lester Fehmi, at New York University and at the State University of New York, new ways of conditioning the conscious control of brain wave patterns. The studies follow the lines Neal Miller and his associates at Rockefeller University in New York have been using to condition people to control their heart-beat rates, blood pressures etc. [6] and their possible application to activities involving aesthetic principles.

We began to realize that one of the most likely developments in the performance of music will involve the direct use of brain electrical outputs by means of electronic pick-up systems and we have obtained quite dramatic results in this way.

There are those who say: 'Who wants to have a plug at the back of the head to produce music?' But would this be so different from teaching the fingers to play a piano? The problem is how to make a *bio-feedback* system that would permit a person to control the brainwave output for musical purposes.

The system we have developed consists of electrodes taped to the frontal, temporal, parietal and occipital parts of the head (Fig. 1). These lead to an

Fig. 1. Participant in 'Ecology of the Skin' group encounter brain bio-feedback performance. (Photo: P. Moore, New York).

electroencephalograph (EEG) machine that transforms the electrical fluctuations received from different parts of the brain into a graphical form on paper and, at the same time, feeds the electrical-wave information to a digital computer. The computer carries out a programed selection of one type of wave pattern and discriminates against all others. This selected pattern is fed to a *tone generator*, which produces a musical tone only if the selected wave pattern persists for a specified minimum duration.

The selection of wave patterns is based on the possibility of identifying specific ones associated with specific psychological states of a person. Of the different kinds of brain waves, the *Alpha waves* are used because they are the easiest to detect and control. The waves have a high amplitude and normally lie in the region of 8 to 13 cycles per second.

A performer with this system first tries to keep the tone generator producing sound and to identify his psychological state that maintains the sound. With practice, one can develop considerable control of the Alpha waves one's brain emits as regards frequency, amplitude and phase relations between waves emitted by different parts of the brain. I have been able, after some 50 hours of practice, to increase considerably my continuous Alpha-wave voltage amplitude, which normally is between 25 to 40 microvolts. When one has identified 20 to 30 wave patterns, then one has a basis for trying to communicate by means of sound combinations—to compose by emotion. If a *music synthesizer* were used, then it would be possible to control parameters of tonal quality. If a digital computer were used, then it would be possible to control more parameters of musical language. I have discussed in a more rigorous way the above studies and their implications in Reference 7.

An *EEG Alpha-monitoring technique* for what I call 'Ecology of the Skin', a group encounter brain bio-feedback performance system for 10 participants, is described below. A view of a rehearsal in which various components of the monitoring system can be seen is reproduced in Fig. 2. A diagram of the hook-up of the components is shown in Fig. 3.

Fig. 2. View of a rehearsal in which the various components of the EEG Alpha monitoring technique can be seen. (Photo: P. Moore, New York)

Alpha waves picked up by the electrodes on the head are detected by a high gain *differential amplifier* (marked DIF AMP in Fig. 3), then pass to the *low pass filter* (LFP) and the *band pass filter* (BPF). A *wave envelope follower* (ENV FOL) produces a DC voltage corresponding to the peak amplitude of the

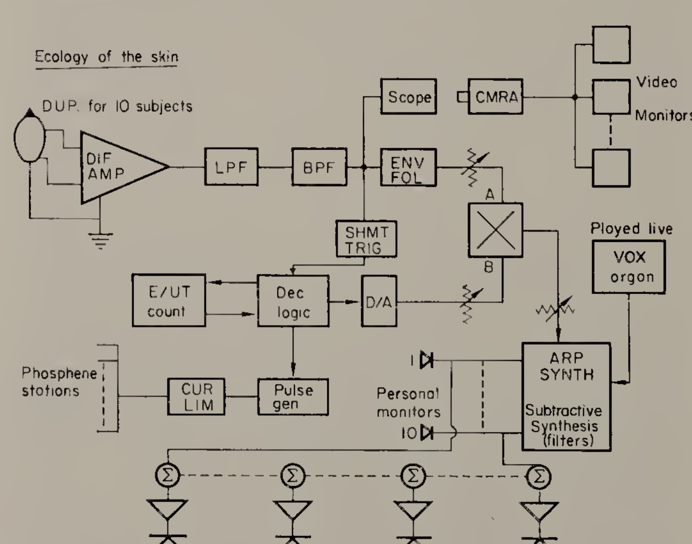

Fig. 3. Diagram of the hook-up of components of the EEG Alpha monitoring technique for the 'Ecology of the Skin' group encounter bio-feedback performance system.

Alpha waves. This voltage is then sent to an *analog multiplier* (X). The other side of the multiplier receives voltage from a *digital to analog converter* (D/A) corresponding to a count of the subject's average time spent emiting Alpha waves per minute. This count is accomplished by a Digital Equipment Corporation *logic system* (DEC LOGIC) and an *events per unit time counter* (E/UT COUNT). The Alpha waves are sent through a *Schmitt trigger* (SHMT TRIG) to prepare them for entry into the logic system.

The product of the Alpha wave envelope and the percent count-voltage is used as a control in a network of voltage-controlled amplifiers and filters in an *ARP electronic music synthesizer.* Ten lines of counterpoint, played live on VOX electric organs, are also fed into the synthesizer. Each line is gated and filtered by the Alpha wave monitored from a particular subject who hears 'his line' on a small speaker on his lap.

An oscilloscope trace of each subjects Alpha wave output is displayed by a closed circuit television system (VIDEO MONITORS) and the combination of sounds produced is amplified over four channels for the audience. Stations for electronic stimulation of visual phosphenes (PHOSPHENE STATIONS), driven by the logic system according to Alpha wave frequency, are also provided for the audience. The phosphenes, flashes of light or colored patterns occurring when the eyes are closed, are produced by pulses of extremely low current received by two electrodes placed over the temples of a subject.

4. QUESTIONS FROM THE AUDIENCE AT AN INFORMAL TALK ON THE SUBJECT

Question: What would happen if you just used one brain-wave output?

Answer: I've never used less than four. The basic reason being when you're first trying to make these discriminations you need that much information in order to get something meaningful. One of the most important things, for example, that we've discovered is that when the subject achieves the highest state of ability to control, there will be a high degree of phase synchronization among the different channel outputs.

Q: Can you explain how you obtain this kind of mental control?

A: I can only relate to you subjectively my experiences. I'm just beginning quantitative studies. My interest in this work began when a friend called me and said: 'Listen, I've just been to this laboratory and I was hooked up and I was able to tap out rhythms with my head.' I went to the laboratory and the first thing I was told to do was to try to sustain a tone. The tone was then monitoring Alpha waves. The ability to produce sustained Alpha seems to be somewhat related to a relaxed, very calm, controlled state of mind, so my first mistake was to try to concentrate very hard. Nothing happened, the tone generator just went on beeping indiscriminately. The next mistake was to try to relax completely. I tried to use what I knew about Yoga and anything else on how to relax—still nothing. I finally found, very quickly, that one must try to maintain a kind of balance throughout one's entire body. Athletes call it 'muscle tone'. The muscles are not active but they're on the verge of being able to be active. This kind of balance must be maintained *throughout* the entire body. Unless it was maintained, I was limited to some degree in my ability to control the waves. This also has something to do with one's psychological state. If one is worried about a lot of things, the controlling ability will also be limited. This observation may be of therapeutic value in that one learns to better control one's mental processes. Perhaps this is what Zen philosophy tries to achieve.

Q: While it seems to be quite a reasonable way to train oneself to attain certain mental states, suppose a girl in a miniskirt sits in the front row during a performance, what happens to the control?

A: I wasn't thinking of this in an audience context. I like neither the separation that we have between perceivers and performers in Western music nor the architectural trouble we go to in theaters to try to maintain that separation. I think in terms of group participation within a small space. Group after group would use the space.

Q: Have you studied the effect of mild drugs on control?

A: Yes. And not only mild ones. So far, we find they seem to inhibit control.

Q: Can you reproduce these states or feelings without the help of the equipment?

A: Certainly, but it depends on how well one has learned the technique of control. It is also necessary to practise a lot to maintain it.

Q: What's the number of different states that you've achieved or been able to discriminate?

A: About 25 identifiable 'energy' states, in terms of the EEG output. The reason I balked at using the word 'affective' states is that the experience so far was always a relaxed and happy state. That's why I use the term 'energy', for there seems to be some subjective feeling that I get for the locus of particular concentrations of 'energy' or level of it in my body. It's hard to describe.

Q: Those wave patterns that were being reinforced were they randomly selected?

A: No.

Q: Have you given any thought to working it the other way round where, instead of composing by being plugged in, you're a listener?

A: Everyone asks me that. So far there are only a few experiments that have been done to transmit information directly into the head. One can produce phosphenes, those visual patterns one sometimes see when one's eyes are closed, by pressing on the eyelids. There has been some experimentation done on auditory stimulation by sending pulses into the auditory nerve and, thus, creating heard sounds in the brain.

Q: Have you done multiple channel experiments where more than one person was hooked up?

A: So far, the largest number of people has been three and each of them had a great deal of experience on the machine prior to working with others. We've only tried it once but it seems we were able to freely synchronize and coordinate our outputs.

Q: Is there any time delay between an 'energy' state and the production of music?

A: No.

Q: What is the longest sound you've been able to make?

A: The longest, which was associated with Alpha waves, was two and a half minutes.

Q: How much of a break occurs before one can re-establish the sound?

A: A break of a second or so but then one can't always produce another long sound. Only once have I been able to hold a tone for two and a half minutes.

Q: Do you believe there would be any advantage in having a richer sound feedback?

A: Well, not initially, because it's a very hard thing to learn to do right away and that's why we just use one tone. We've tried with visually oriented people to have them turn on a light and that works just as well for them. Of all the people we've tested, those who are involved in stringent disciplines of some kind are able to achieve quite a high degree of control very quickly. We've tried musicians, visual artists, a Zen master, a karate expert and a mathematician. These subjects were able to develop control much more quickly than subjects who do things that do not require high concentration.

Q: What about using music controlled by brain waves during the performance of music by a conventional composer?

A: That would probably be very interesting. This is what I had in mind when I spoke of Indian music, where I described it as a kind of cultural mass knowledge into which a musician plugs his influence only for the duration of his life as a musician.

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Editor's note: See also in this issue the text by R. Baldwin entitled "Kinetic Art: On Producing Illusion by Photic-stimulation of Alpha Brain Waves with Flashing Lights", *Leonardo*, **5**, 147 (1972). *

*Article included in the present edition.

KINETIC ART:

THE SHIFT REGISTER, A CIRCUIT FOR SEQUENTIAL SWITCHING OF LIGHTS

David Smith*

During 1970, while a student at Sydney University in Australia and a member of the Optronic Kinetics Group there, I constructed my 'Kinetic Kaleidoscope' (cf. Fig. 1) [1]. The on-off or flashing lights in the array making up the picture are operated by an electronic circuit called a *shift register*. I will describe this circuit before giving details of the construction of the picture and my reflections on the application of modern technology to art.

The shift register circuit can be made easily by one who has some experience with digital switching electronics [2]. Basically, it consists of a circuit made up of any number of identical devices, called '*JK*' *flip-flops*, connected in series as shown in the diagram in Fig. 2. A view of the circuit as it appears from the rear of the picture is shown in Fig. 3. The variable voltage output of each flip-flop controls a *transistor switch* that allows or disallows the current to flow through a 12 V, 2 W light bulb. The transistor conducts when the voltage output at its base is a predetermined value.

The properties of an individual flip-flop are the following: It has two voltage outputs, indicated by Q and $\bar{Q}$ in Fig. 2, each of which can have either a high or a low voltage level. The two outputs are always complementary, that is, when Q is low then $\bar{Q}$ is high and vice versa. For a change in output to occur, a *trigger* or *initiating pulse*, generated by a *clock circuit*, must be applied. The type of change in output is also determined by the input voltage levels on terminals J and K of each flip-flop. Each of the terminals Q and $\bar{Q}$ are connected to the input terminals J and K of the adjacent flip-flop, as indicated in Fig. 2.

If the input levels at J and K are changed and a trigger pulse is applied after each change, the following corresponding changes in output occur: When J is high and K is low, Q becomes or remains high; when J is low and K is high, Q becomes or remains low; when both J and K are high, Q remains unchanged after triggering and, finally, when both J and K are low, Q becomes the opposite of what it was before triggering.

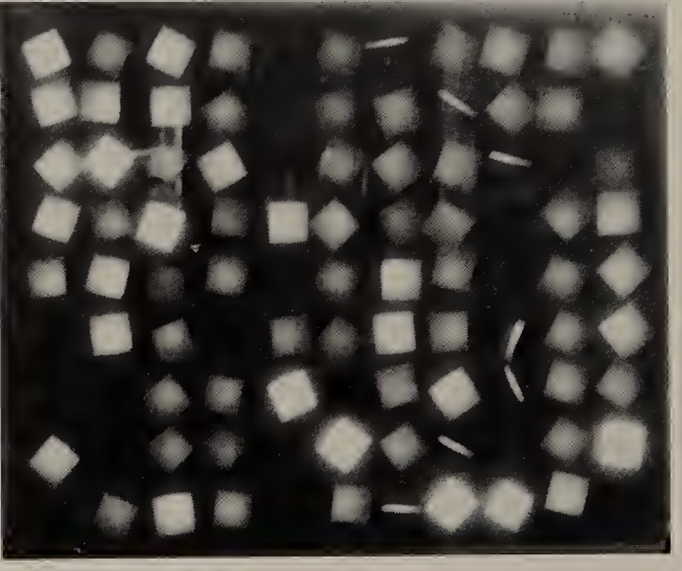

Fig. 1. 'Kinetic Kaleidoscope', kinetic picture with sequentially switched lights, 250 Watts, max., 90 × 105 × 22 cm, 1970.

The output Q of any flip-flop may also be changed by applying an external voltage to it. For example, if Q is low and an external high voltage is applied to it by closing switch B, then Q will change to its high value and remain there even after the switch is opened.

When the shift-register circuit consisting of a chain of flip-flops is first turned on, the output Q of each flip-flop is low and none of the bulbs will light up. If one momentarily introduces a positive external voltage at switch B to the Q output of the first flip-flop, it will change to this value and cause the first bulb to light up. Upon this occurrence, the inputs J and K of the second flip-flop receive the new voltage and, according to the properties of the circuit described above, the first trigger pulse will cause bulb No. 1 to extinguish and bulb No. 2 to light up. The second trigger pulse causes No. 2 to extinguish and No. 3 to light up and so on.

Thus, information in the form of voltage level is passed along the chain, its presence made evident by the illumination of a bulb. The eyes see a light that *appears* to move continuously from bulb to bulb. When the voltage information reaches the last bulb,

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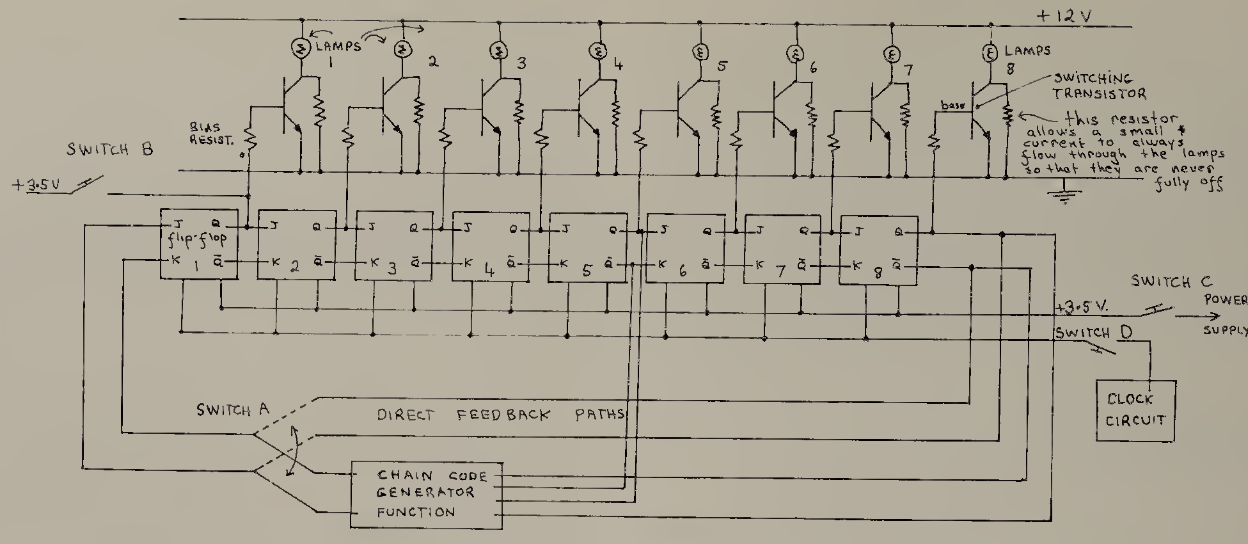

Fig. 2. Diagram of shift register sequential switching circuit for 'Kinetic Kaleidoscope'.

it is directed back to the first bulb by a feed-back line and the cycle repeats itself. By introducing the change in voltage level at the first flip-flop output between trigger pulses, one can pass as many illuminating voltages as one likes. When the power supply is disconnected, the shift register forgets the information it has been transferring and one can start another sequence.

The repetitive character of a sequence can be changed by automatically introducing voltage levels in an apparently random manner at the *J–K* inputs of the first flip-flop. This is achieved by inserting a *chain code generator circuit* in the feed-back loop at switch *A* (cf. Ref. 2, p. 143). This makes it difficult for a viewer of the picture to anticipate the behaviour of the apparent light motion.

All of the modes of operation described above can be accomplished easily by the inclusion of manually operated switches in the circuitry. For example, the switch *A* (cf. Fig. 2) is inserted in the feed-back path to determine whether the circuit is to operate in an automatic pseudo-random fashion or in the normal shift-register mode. The switch *B* may be introduced to connect a high voltage supply to the outputs of the first flip-flop to allow a viewer to control the illumination of the bulbs. The switch *C*, controlling the main power supply input, allows cancellation of information in the circuit. The switch *D* connecting the trigger pulse generator to the circuit allows removal of the trigger pulse and, hence, the freezing or holding of any group of illuminated bulbs.

The speed of the operation of the trigger circuit may be controlled by switching in different values of timing capacitors across the clock circuit (a *capacitively cross-coupled dual buffer.*)

My 'Kinetic Kaleidoscope' has twelve shift registers, each independently controlling a group of eight light bulbs. The 96 bulbs are supplied with a 12 V, 20 amp direct current. The bulbs were arranged in an array as shown in Fig. 4. Clipped onto the bulbs, like lampshades, are small square boxes provided with removable colour filters made of a British plastic material called 'Cinemoid'. The arrangement of the array of bulbs and of the colour combinations I chose were influenced by my exposure to the paintings of Vasarely [3].

The front of the picture is a translucent or opalescent Perspex plate of 3 mm thickness. Thus, the viewer sees essentially square illuminated areas of colour appearing on the screen (cf. Fig. 1).

A shift register can be connected to any 8 light bulb sockets by means of a 96-element plug-and-socket arrangement mounted in the centre of the circuit as shown in Fig. 3. There are two control panels, one remote and one attached to the side of the picture (cf. Fig. 3).

The main control panel incorporates the switches necessary to carry out the various possible combinations I have described. Each of the twelve shift registers can be controlled independently. The remote control panel has an initiating and a cancelling switch for each shift register. Also on the remote control panel is a switch that operates a motor to drive the translucent screen to any position within a range of 8 cm in front of the bulbs. The screen is moved forward and backward by a kind of hinged concertina frame on the four sides of the picture (cf. Figs. 3 and 4). Only one driving point is needed, since the frame is sufficiently rigid to move as a whole when pushed at one point.

The shift register using sequential flip-flops for switching in the form of printed circuits, once thoroughly tested, would be trouble-free and should serve for years. It could be made in the form of a standard unit, leaving to artists the arrangements of the light bulbs and the control of their sequences of illumination by adding a few mechanical switches at desired points in the circuit.

My experience with building 'Kinetic Kaleidoscope', involving the assembly of the shift register, has reinforced certain feelings I had about the application of complex devices provided by modern technology to art. If one wishes to design the parts of complex devices and put them together oneself, several years of learning are required to acquire adequate theoretical and practical knowledge. Furthermore, one must keep abreast of new developments. To play the role of artist in addition to that of engineer, demands of the individual an almost

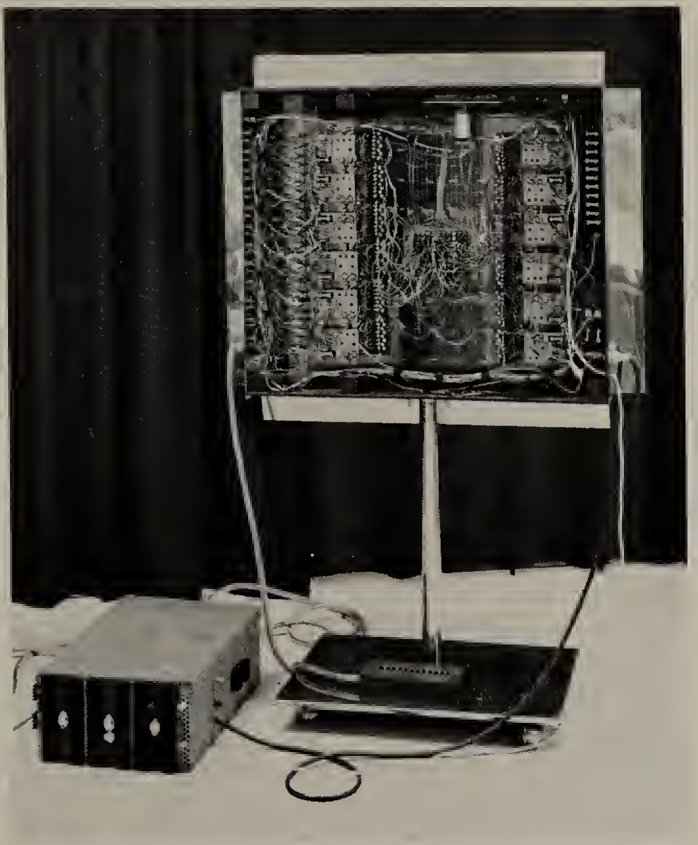

Fig. 3. View of shift register sequential switching circuit for 'Kinetic Kaleidoscope'.

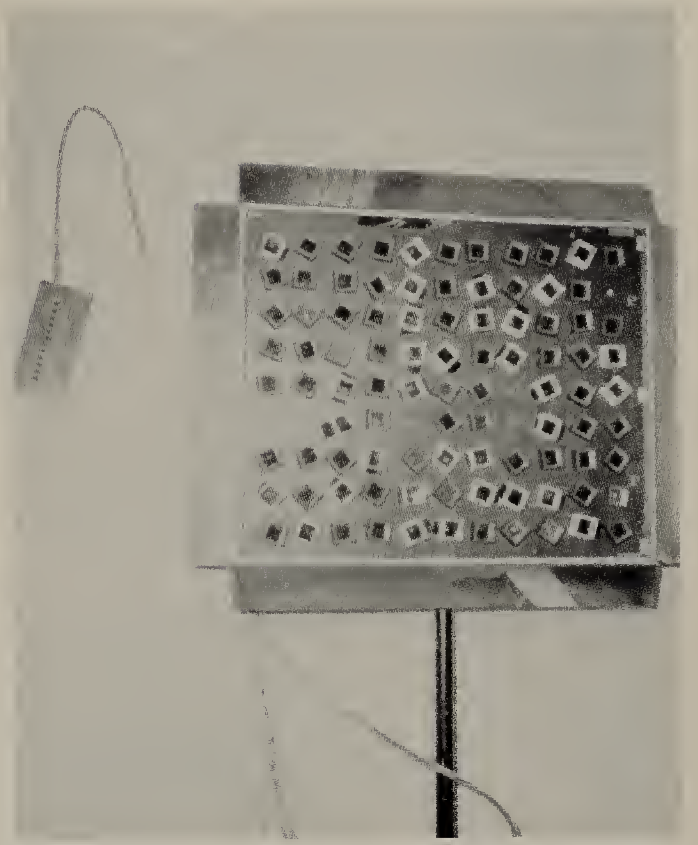

Fig. 4. Front view of light bulb installation in 'Kinetic Kaleidoscope' with the translucent Perspex screen removed.

impossible amount of time. I was able to carry out the work of an electronic engineer and of an artist because I worked with a group of artists who had a taste for technology. Even then, I found myself so involved in the technical aspects of my picture that I sometimes became impatient to get on with its aesthetic aspects. Malina has written that he had a similar experience during the first several years of developing and applying his simpler Lumidyne system for making kinetic paintings with continuous motion of light forms [4].

Some applications of modern technology can be very expensive when compared to traditional technology used by artists, such as oil painting and stone or metal sculpting. In addition to the fixed cost of tools and components, one can consume a lot of money experimenting with devices to make them perform as desired.

Although many decry narrow specialization, I do not believe that we can expect that many who specialize in art will also become specialists in one or more fields of engineering. At best, one can hope that artists who wish to apply, for example, electrical or electronic principles and devices will obtain at least a sufficient knowledge of them to apply them imaginatively in their works and to not harm themselves or innocent viewers.

Fortunately, for those wanting to use electronic devices and circuits, technology is making available components or units designed for different purposes that can be put into operation by making a few simple connections.

For artists with only a limited knowledge of any form of technology, there is the alternative of trying to make art by means of instruments produced for sale, such as the tape recorder, camera, television, video tape, the Moog synthesizer and, of course, the computer. These may require the effort of learning to operate or communicate with the instruments but, at least, the task is simpler and demands much less time than building special devices.

I would be glad to supply to anyone interested additional information on the technical details of the shift register circuit.

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THREE KINETIC ART PROJECTS WITH LASER LIGHT

Joël Stein*

The *laser* (an acronym for Light Amplification by Stimulated Emission of Radiation) produces light beams whose coherence, monochricity and intensity are far greater than light from any other light radiation source. The beam appears tangible, like an incandescent rod of metal.

It is possible to produce structures of light beams by reflecting a laser beam from mirrors, highly polished metal surfaces or plastic sheets coated with a layer of reflecting material. In the projeets I shall describe, I have used a laser beam not only for the illumination of an object but also for producing a visible three-dimensional arrangement or structure of beams of light. The beams may be at rest or in motion, depending on the system used for producing the structure of light beams. Motion can readily be introduced by moving the reflecting surfaces.

I find that space in which this kind of structure of light beams is seen, is perceived differently from space around an object made of solid parts. Therefore, the visual experience provided by my projects may be useful to those interested in the psychology of perception of space.

I began working in 1968 with a *Spectra-Physic helium-neon 132 laser*. A laser beam can be seen when it impinges on solid surfaces, especially brightly in a darkened room. One way to make a laser beam visible in air is to fill the air through which it passes with smoke by a technique developed in wind tunnels for aerodynamic research. It is worthwhile noting that the beam can be seen in a liquid sueh as water.

It is now well known that a powerful laser beam is dangerous [1]. However, over a period of two years I have experienced no injury, even to my eyes, from exposures of short duration to a laser beam of up to 5 milliwatts. Nevertheless, every precaution must be taken by an artist using laser beams to protect spectators from direct exposure to the beam. I first showed one of my projects in 1969 at the 'Sigma' exhibition at Bordeaux, France.

The three projects I shall describe were constructed in my studio.

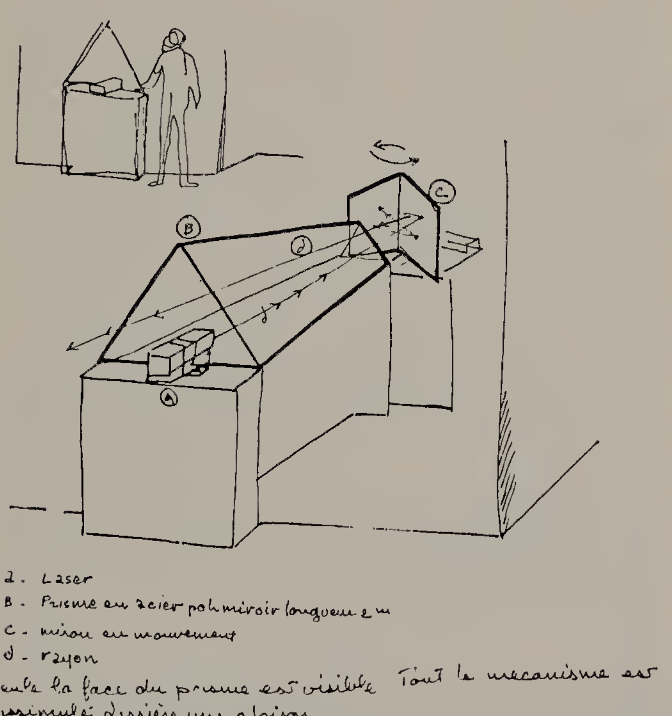

Fig. 1. Sketch of the setup of the first project. (A) *Laser apparatus,* (B) *hollow prism,* (C) *movable mirror,* (D) *reflected beam.*

Fig. 2. An example of an image produced by the setup of the first project. (Photo: P. Hinous, *Connaissance des Arts,* Paris.)

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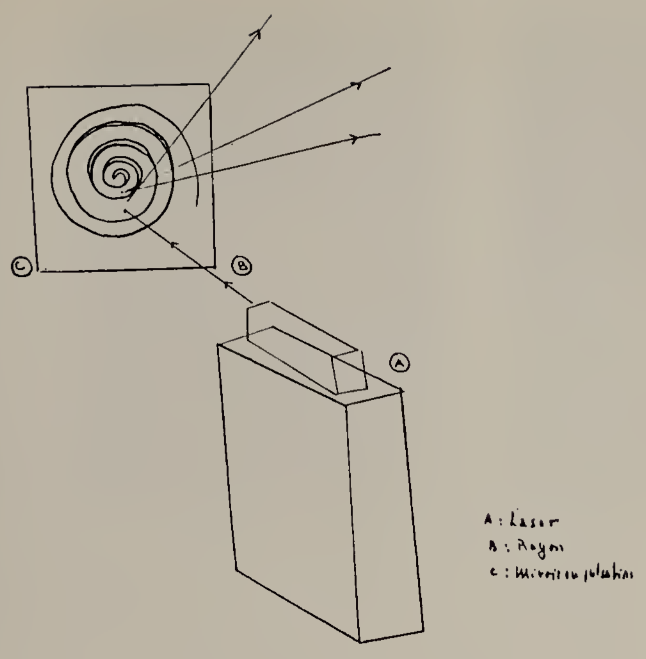

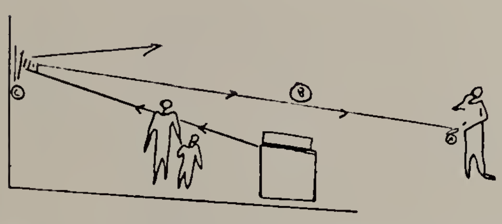

Fig. 3. Sketch of the setup of the second project. (A) *laser apparatus,* (B) *laser beam,* (C) *pulsating spiral mirror.*

First Project. A sketch of this project is shown in Figure 1. A beam from a helium-neon laser (A) passes through a 2 m. long hollow prism (B) made of polished steel and strikes a corner mirror (C), which is mounted on ball bearings to permit it to be given an oscillatory motion. (The mirror mechanism was built by the company ARC at Creusot, France.) The laser beam is reflected by the mirror back through the smoke-filled hollow prism as points and intersecting lines of light. All but the laser apparatus and the forward end of the hollow prism is behind a screen, so that the spectator sees the resultant points and light beam structure in the smoke at the forward end. The laser apparatus can be moved by the spectator to vary the angle at which the beam strikes the mirror. An example of the kind of image seen is reproduced in Figure 2.

Second Project. In this project (Fig. 3) a helium-neon laser (A) projects a beam (B) to a surface (C) on which is affixed a spiral made of pieces of mirror. The surface is mounted to permit a rotary oscillation or pulsation to be imparted to it. On striking the pulsating spiral, the laser beam is reflected onto the walls, ceiling and floor of a room. A spectator is given a mirror so that he can direct one or more of the reflected beams reaching his position to the surrounding surfaces of the room.

Third Project. A sketch of the setup of this project is shown in Figure 4. A beam from a helium-neon laser (A) is projected vertically downward through a suspended helical mobile of transparent polished material (B) which breaks it up into beams (C) some of which strike two polished aluminum surfaces (D) placed at right angles to each other, which then reflect them onto the walls, ceiling and floor of a room.

I have also designed installations for projecting laser images on a stage for a ballet produced by Michel Descombey at the Opera Comique in Paris and also for special effects for a science fiction television production called 'L'Oreille Absolue', directed by Philippe Condroyer.

At the present time, I am working on special projects of laser games destined for young children and on the integration of laser effects in urban architecture.

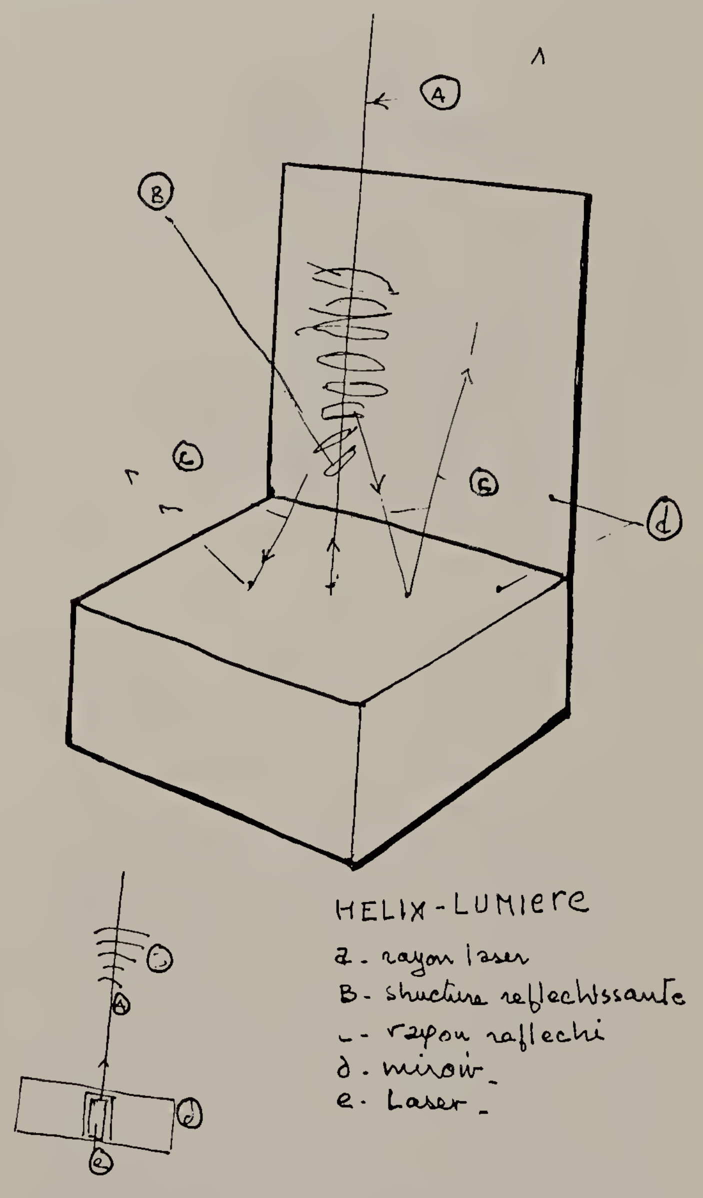

Fig. 4. Sketch of the setup of the third project. (A) *laser beam,* (B) *helical mobile,* (C) *reflected laser beams,* (D) *polished aluminum surfaces,* (E) *laser apparatus.*

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SONOVISION:
A VISUAL DISPLAY OF SOUND

S. R. Wagler*

People were intrigued by the possible relationship between patterns and colors to sounds already at the time of the ancient Greeks. Aristotle, in his 'De Sensu', expressed his desire for a harmonious relation between colors and musical chords. Isaac Newton attempted to find a correspondence between the frequencies of colors and the notes of the musical scale. Bertrand Castel, a philosopher and mathematician, in 1734, developed his '*clavessin oculaire*', a color organ that related seven colors to the seven whole notes of the occidental musical scale. The American physicist, Albert Michelson, predicted in 1899 that there would develop a color art analogous to that of music, 'color music', in which the performer would play the colors of the spectrum in any succession or combination. In 1922, Thomas Wilfred, an American of Danish origin, built an instrument such as imagined by Michelson and gave public demonstrations of it. Wilfred died in 1968. A large example of his 'Lumia', a light picture in motion on a translucent screen, can be seen at the Museum of Modern Art in New York. The 'Lumia' does not respond to sound. A more detailed historical account of work on color music can be found in the essay by Philip Steadman in Reference 1.

Many artists and engineers have, in recent years, attempted to realize the aspirations of the early pioneers. However, in my view, most attempts have failed to produce an aesthetically satisfactory visual display of music. A major reason for failure in the early phases of this development was the lack of an optical and electronic technology. The first types of audio-visual devices were very complicated and expensive. Also, most early investigators were confused by the attempted mathematical analogy between sound and light wave frequencies, where frequency = wave velocity/wave length.

The term 'color organ' of the pioneers arises from the idea of correlating light frequency (or color) with sound frequency (or tone). To the best of my knowledge, neither a physiological mechanism that relates color with sound nor a universal psychological relationship between them has been found [2].

More recent attempts in this field have placed emphasis on relating sound intensity or loudness to light intensity, leaving color changes of the resulting display to projection of light through a color wheel that is not correlated to the music. Although many of these devices have initial fascination, the lack of intricate audio–visual coordination soon leaves the viewer bored. F. J. Malina, who has also worked with such devices, in personal correspondence has told me that he agrees with my opinion.

A new device has been invented by Lloyd G. Cross that makes a visual display in color correlated to sound by projecting a krypton or helium–neon laser light beam on to a translucid screen or opaque surface [3]. A diagram of the major components is shown in Fig. 1.

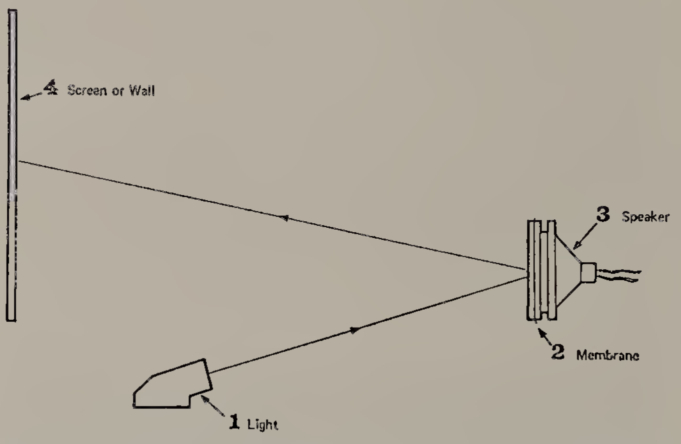

Fig. 1. *Diagram of the major components of a* Sonovision *system for a visual display of sound.*

When there is no sound input to the device, the beam gives only a pinpoint of light, When one simple sound or musical note is introduced into the device, the dot moves in an ellipse at the frequency of the sound supplied. The size of the ellipse is related directly to the loudness of the note and can be adjusted by turning a knob on the control panel. When the note is changed to another one, a different ellipse with a new orientation is formed. When two notes are introduced simultaneously, the laser beams produce a combination of the two ellipses, similar to the Lissajous patterns obtained from cathode-ray tubes. Thus a symphony of notes will result in a symphony of ellipse interference patterns on the display screen (cf. Figs. 2(a), (b) and (c)).

Music, which is usually a complex of many frequencies at any given instant, is represented as a mixture of pure tone patterns. The pattern generated

* Sonovision, Inc., P.O. Box 1746, 290 South Wagner Road, Ann Arbor, Michigan 48106, U.S.A. (Received 5 January 1970.)

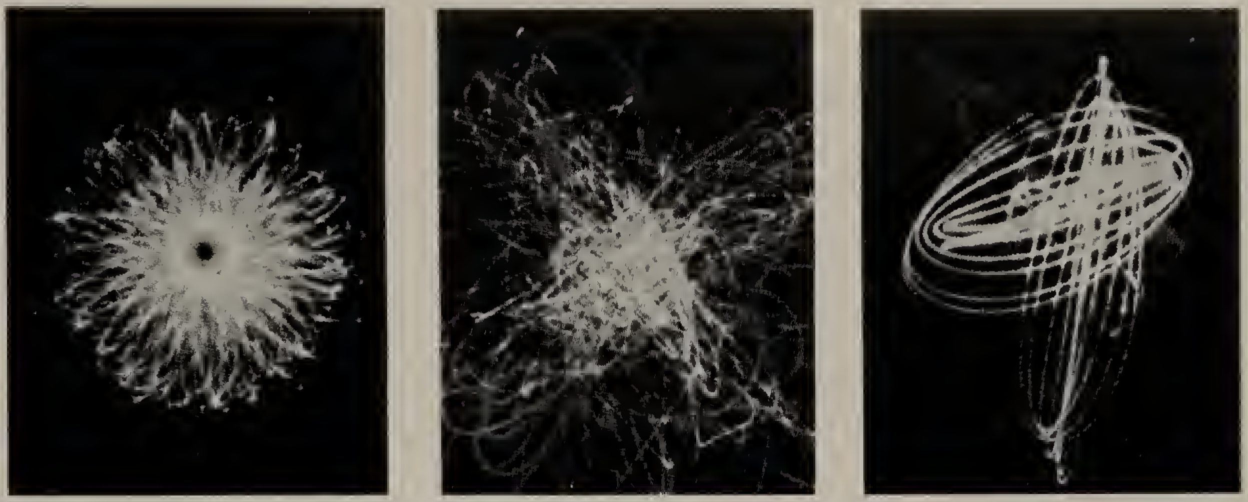

Fig. 2. Examples of laser light patterns produced by Sonovision, *multi-color laser projector.*

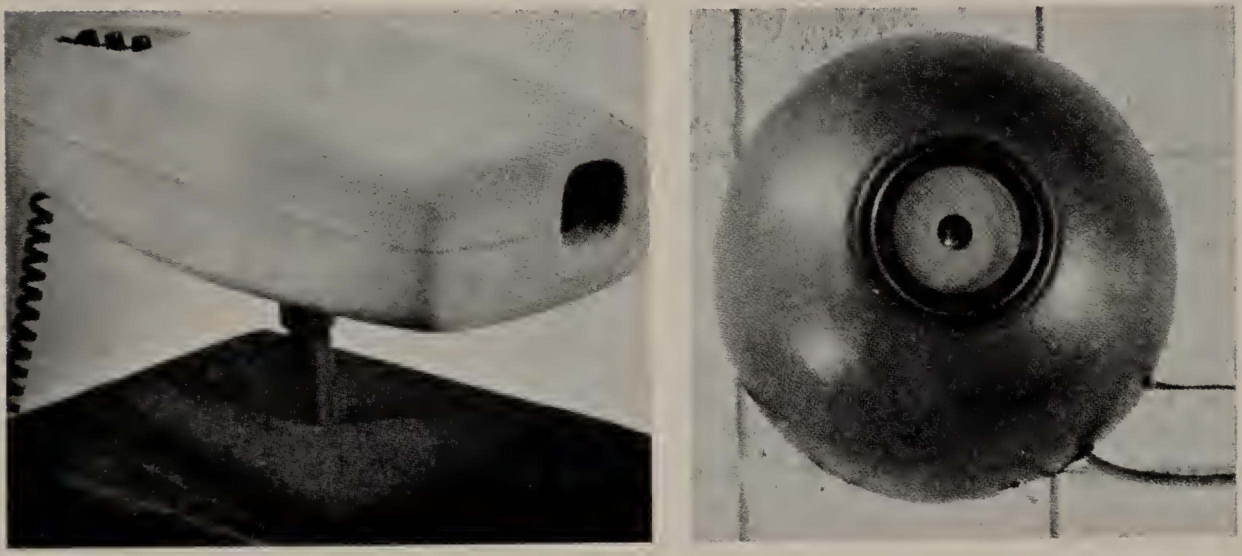

Fig. 3. (a) Self-contained 2·0 mW *helium–neon laser* Sonovision *projector. Produces a single frequency red light image. Price* $1,095.00 *F.O.B., Ann Arbor, Michigan, U.S.A.*

(b) Self-contained helium–neon laser Sonovision *wall model projector. Produces a single frequency red light image. Price* $150.00 *F.O.B., Ann Arbor, Michigan U.S.A.*

by a particular passage of music is not only in correspondence to the music but is also repeatable, so that a phonograph record may be seen each time in the same way each time it is played.

Repeatability means that a way is now available for the deaf to 'see' music and to obtain a new experience, and the device may also be useful in speech therapy.

A second mode of operation is available in the same set. A spinning prism produces a circle in place of the dot when the beam is at rest. When one or more notes are fed into the device, petal-type deviations from the circle result.

Separate channels are provided for the control of color (specifically red, blue, green and yellow), permitting any one to be switched on or off at will. These four colors result from the passage of the white laser beam through a prism. Patterns corresponding to separate sound sources can be colored individually. For example, a voice microphone can be put on the red, the microphone for the violins on the green, that for the brass on the yellow, etc. No provision is made, however, to assign the four colors to various notes or bands of frequencies from sound issuing from a single source. Furthermore, in this set, other hues (e.g. violet, turquoise, etc.) cannot be obtained. Color interchanges are produced where lines of different colors intersect. In some areas white is produced. This occurs when all four colors are recombined to yield the original white beam.

The invention of Cross has been incorporated in several kinds of commercial units under the trade name, *Sonovision*, and can be obtained from Sonovision, Inc., P.O. Box 1746, Ann Arbor, Michigan 48106, U.S.A. Two kinds of projector are shown in Figs. 3(a) and 3(b). A cabinet installation is also produced.

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Editor's note: Attempts to contact Sonovision, Inc., and S. R. Wagler in 1972 were unsuccessful.

PART IV

INFORMATION ON SUBJECTS RELEVANT TO KINETIC ART

HEALTH AND SAFETY HAZARDS OF ART MATERIALS

George A. Agoston*

Abstract—*Many contemporary artists are working in new and diverse media. Some are reporting health problems and injuries resulting from their use of materials on which they have had insufficient information. The purpose of this article is to point out some of the important health and safety hazards arising from the application of plastics and synthetic resins. The hazards both to the artist and the viewer of electricity, magnetism and ultraviolet radiation are also discussed. Readily available literature is cited to enable the artist to find detailed information on preventative measures to be followed when venturing into the domains of new materials and techniques provided by modern science and technology.*

I. INTRODUCTION

For hundreds of years artists have been using virtually the same media in their work. Only occasionally have they attempted to produce different effects using nontraditional materials. In a world witnessing very rapid advances in science and technology, artists in multiplying numbers are now prompted to express themselves in new and widely diverse media and techniques they provide. For example, many painters and sculptors are now turning to the chemistry of plastics or synthetic resins [1–5]. While others are employing mechanical, optical, electrical and magnetic devices to produce special effects [6, 7].

The contemporary artist, usually untrained in either science or technology, confronts not only unfamiliar properties and terminology of new materials but also unexpected hazards to health and safety. Fortunately, many of the hazards can be dealt with by using everyday knowledge and experience combined with common sense. Yet more precise technical knowledge of the character of the hazards is often a distinct aid and sometimes a necessity.

In the following paragraphs chemical health hazards are discussed in general. Several important instances concerning plastics and synthetic resins are then presented in more detail. Succeeding sections treat fire and explosion hazards and the dangers of electricity, magnetism and ultraviolet radiation.

II. CHEMICAL HEALTH HAZARDS

1. *Skin ailments—Allergies* [8–10]

After exposure to certain chemicals, individuals sometimes suffer from skin ailments, allergic effects and other toxic effects. For example, many artists working with plastics are experiencing troublesome skin reactions. Generally two types of reaction are observed. One called *dermatitis* or *chemical burn* (or more accurately, *toxic dermatitis* or *primary irritation dermatitis*) is a superficial inflammation of the skin. This occurs when an *irritant* touches the skin. The area affected is usually limited to the area of contact and complete healing usually occurs within a period of several days to two or three weeks. Nearly all persons react to irritants, provided that either the concentration is high or the exposure is sufficiently long for low concentrations.

The second type of skin reaction is called *contact eczema*. This is more serious because of *allergic* manifestations. What can occur is the following: After one or more exposures to an offending substance (in this instance, the *sensitizer*) an individual acquires hypersensitivity to it. There may be no immediate outward effects. But, after an incubation period of perhaps weeks during which the body has become sensitized, the skin reacts, sometimes severely, on new exposure to that substance. The individual is now said to be allergic to the sensitizer. It is sometimes possible to lose an allergy if there is no further exposure during a period of months or years. But renewed contact may start the individual on a new incubation period.

The skin outbreaks in contact eczema are not limited to the areas touched by the sensitizer. The extent and location of an outbreak cannot always be predicted because essentially the whole body is sensitized. Unfortunately, there are some substances which act both as irritants and sensitizers, bringing on both toxic dermatitis and contact eczema. Allergic manifestations after repeated exposure may develop into an *asthmatic* condition, according to some authorities.

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One need not look only to bottles of unfamiliar chemicals to find potential irritants and sensitizers. They are present about us in our everyday life. Naphthalene and linseed oil, for example, are sensitizers; either can cause contact eczema or allergic asthma in some individuals [11]. Fortunately, the percentage of persons who will acquire a hypersensitivity to a particular sensitizer is usually small. (However this may not be true in instances where sensitizers are especially potent.) It is fortunate, also, that the individual allergic to naphthalene will not necessarily acquire an allergy to linseed oil, or to strawberries, detergent powder, rose pollen, or the countless other sensitizers to which he may be exposed [11]. While eaution is clearly always advisible, artists suffering from certain everyday allergies should not feel that the domains of chemicals and of plastics are necessarily forbidden to them.

2. *Toxic effects* [8, 12]

Toxic substances enter the body generally by the proeesses of *absorption* through the skin, *inhalation* and *swallowing*. The first process, skin absorption, has been discussed above in relation to dermatitis and contact eczema. In addition, it should be mentioned that there are liquids which are absorbed readily through the skin in amounts suffieient to produce illness and even death. Amines, such as those used in curing epoxy resins, and phenol, which is used in the manufacture of certain plastics (phenoplasts), are examples of such chemicals.

The entry of eertain gases, vapors, dusts or smokes into the respiratory tract can have serious consequences too. This hazard may be present more frequently than realized. For example, plastics being *overheated* or *burned* often release noxious decomposition products [13]. The artist who applies a torch to plastics should be aware of this. For the same reason, dusts produced by sawing plastics can be dangerous. If the sawblade is dull, there may be local overheating with each grain of saw dust becoming a carrier of toxic deeomposition products.

Some *dry pigments* are poisonous and should be handled with great care [1, 14, 15]. Perhaps the most toxic are those containing *arsenic*, e.g. emerald green and light cobalt violet, and pigments containing *lead*, e.g. white lead (or flake white, Chemnitz white), red lead (or Saturnine red), litharge, Naples yellow and chrome yellow, orange, red and green. Chemical dusts are generally dangerous to inhale even when the substance is not considered a poison, e.g. mica powder and fine talc [16, 17].

The inhalation of vapors of certain liquids, particularly of *solvents*, is a frequent cause of toxic effects [18, 19]. Many solvents evaporate rapidly, producing dangerous vapor–air concentrations. It is true that some having disagreeable or strong odors may be unbearable before dangerous concentrations are reaehed. But odor is not a generally reliable guide, because in other instances dangerous concentrations are reaehed before the odor is perceptible. Carbon tetrachloride, a very toxic substance, is an example of the latter [12]. The odor of benzene, another insidious solvent, is not unpleasant and can easily be tolerated up to the region of dangerous concentrations. Even disagreeable and irritating odors (like that of styrene) can cease to become a good warning signal because the individual frequently becomes aeeustomed to them.

This is an appropriate point to call attention to the fascinating, but toxic, metal mercury [12]. Caution should be taken in its use to prevent inhalation of its vapors. Mercury exposed in an open vessel or dispersed in tiny droplets on the floor can be hazardous, imperceptibly evaporating into the air. Mercury should not be permitted to become heated (e.g. near a radiator or stove) because the risk of reaching dangerous vapor–air concentrations increases rapidly with increase in temperature. When metallic lead is melted it may also produce dangerous vapor–air concentrations. Care should be taken to avoid inhaling the toxic lead oxide dust which forms on the hot liquid surface [20].

The third process, entry via the digestive tract, is so obvious that it hardly requires explanation. Yet, it remains an important factor in occupational hygiene: hazardous substanees are readily transferred from fingers to food, cigarettes and chewing gum, and then into the mouth.

Toxie effects vary with the nature of the substance; the severity depends upon the amount introduced into the body and other faetors such as health, age, sex, etc. The effects range from those of relatively minor consequence sueh as headaches, dizziness, nausea and drowsiness to the very serious ones such as blood disease or injury to an organ or to the central nervous system.

3. *Preventative measures*

Artists may work with hazardous materials as chemists and laboratory technicians do. The protective measures necessary vary, of course, with the nature of the material, the size of the work and the operations involved. Several general statements can be made. First of all, the recommendations in trade literature and the warnings on bottle lables ('Avoid skin contact', 'Do not inhale vapors', 'Keep open flames away', etc.) should be followed. Admittedly, this may be difficult to do in large-scale work. But even then, dangers can frequently be reduced or eliminated simply by common sense hygiene. In some instances, for example, a thorough washing of the hands in soap and water may be all that is required to assure no harm from a certain sensitizer. When offensive dusts are produced a shower after work may be advisable. In such cases, the need of frequent changes to fresh work clothing should not be overlooked and perhaps a respirator should be worn. Attention should always be given to adequate ventilation. In situations requiring the handling of hazardous liquids, the use of protective clothing, such as neoprene rubber aprons or gloves, may be advisable. In all cases, the tools and general work area should be kept clean and the waste disposal problem should be solved.

III. PLASTICS AND HEALTH HAZARDS

1. *General comments* [8, 16, 21–25]

Most finished plastic articles on the market today present little or no health hazard. Plastics are used safely in many ways: in chewing gum, food packaging, contact lenses, dentures, toys etc. Although the final commercial product may be safe, there may be a considerable hazard in making the plastic or in working it. It is in these last two operations that an artist is sometimes involved. In the *preparation* of the plastic, he may have to measure and mix hazardous materials. These may be any of the following: monomers, solvents, catalysts, accelerators, plasticizers, hardeners, stabilizers, anti-oxidants, lubricants, anti-mold agents, fillers and pigments. And in *working* the plastic, excessive heat may be employed or generated releasing a hazardous monomer and other chemical products.

Some insight into the relative toxic hazard of plastics can be gained from a simple concept based on the sizes of molecules [26]. Molecules of many substances are very small, containing, say, less than 50 atoms. A molecule of water, for example, has only 3 atoms; cane sugar, 45; ethyl alcohol, 9; phenol, 10; styrene, 16; methyl methacrylate, 15.

Many small molecules, whether toxic or not, can pass easily through body membranes into the blood stream. Phenol easily traverses unbroken skin; one-third of a teaspoon of absorbed phenol is a fatal dose [8]. Solid plastics, on the other hand, are composed of very large molecules, each composed of thousands of atoms. Such long complicated molecules forming a piece of plastic are so tangled with their neighbors that they can barely move. Even if they were freed, they are still too large to migrate into human tissue.

In processes for making one important type of plastic, small molecules of one kind (*monomer*) are linked together (i.e. they *polymerize*) to form very long *polymer* molecules. For example, a piece of the plastic *poly methyl methacrylate* (Plexiglas, Perspex and Lucite are common trade names for this plastic) is literally a mass of polymer molecules mixed together like spaghetti. In this case the *poly*mer (*poly* methyl methacrylate) is formed chainwise by linking perhaps 1000 molecules of the *mono*mer (methyl methacrylate). A dentist preparing an acrylic denture mixes powdered polymer and pigment with liquid monomer to form a moldable paste [26]. A bit of catalyst is added to start the polymerization. The liquid monomer cures (i.e. polymerizes; the small monomeric molecules link up) producing a solid polymer mass and fusing together the grains of the powdered polymer initially present. Being a small mobile molecule, the monomer methyl methacrylate is potentially hazardous; indeed it is a sensitizer. Frequently dentists who prepare dentures suffer from contact eczema, whereas their patients wearing the polymer dentures do not.

The artist should regard all ingredients for making plastics and all prepared polymer products in solution as being potentially hazardous. Not many years ago when commercial polymers were still in a state of development, plastic products often caused skin problems because they contained occluded unreacted monomers or partially reacted material (i.e. molecules of small and intermediate size). While this seldom occurs today, the artist who permits a plastic to become overheated may recreate this hazard *in his final work*.

2. *Several synthetic polymers of interest to artists*

The word *plastics* is more commonly applied to solid polymer consumer items which have been molded or extruded. The term *synthetic resin* applies to synthetic polymer products which have applications similar to those of natural resins and gums, i.e. in paints, varnishes, glues. Like the natural materials, the synthetic resins are supplied in granular or powdered form, in solution and in water emulsion. Often a given polymer can be regarded both as a plastic or a synthetic resin. Clearly these terms, as well as their brothers *synthetic fibres* and *synthetic rubbers*, are inadequate. While they continue to be used generally in commerce and technology, in chemical science the term *synthetic polymer* is employed.

Acrylic polymers are familiar to artists in the form of emulsions or pastes (e.g. acrylic medium, acrylic paints), powders, and *poly methyl methacrylate* (Plexiglas, Lucite and Perspex) plates and sheets. These are fully polymerized products; normally no health hazard in the commercial item is expected. In the case of powders, however, allergy properties have been reported [27].

The sensitizing hazard of the monomer methyl methaerylate has been mentioned above. In addition, its vapors produce systemic effects on the brain cortex, such as irritability, headache, loss of appetite and drop in blood pressure [8]. When Plexiglas is drilled or planed with insufficient cooling the monomer and other vapors are released [28]. Sawing with a dull blade can produce not only vapors but also a dust having skin sensitizing properties. The inhalation of this dust and fume can lead to serious respiratory problems [27].

The *vinyl* polymers appear very commonly in consumer items. Most vinyls are produced in granular or powder form for heat molding into rigid objects. Some are available in emulsion form for paint manufacture. Among the vinyls are *polyvinyl chloride* (*PVC*) and *polystyrene*. While PVC is generally considered nontoxic [28], PVC glues and lacquers sometimes contain highly toxic solvents such as dichloroethane, trichloroethylene or dioxane [8]. PVC may be welded at 390°F—but with caution, because decomposition to toxic fumes occurs at this temperature. Inhalation of the fumes can produce chronic gastritis, liver disturbances, anemia and hypertension [8].

Polystyrene is also nontoxic [28]. A rigid foam of Polystyrene, called *Styrofoam*, is currently being used by sculptors. The chemical agents employed in generating the foam may present hazard [29]. In one instance, in 1959, the sawing of Styrofoam released occluded methyl chloride gas killing a worker and making two others seriously ill [8]. It is expected that now, ten years later, such products are not on the market. Nevertheless, it is advisable to consult the manufacturer's literature to be certain that an innocuous foaming agent (e.g. carbon dioxide) has been used. Overheating polystyrene produces fumes probably containing the monomer styrene and ethylbenzene. Inhalation of styrene vapors may bring on nausea, vomiting, loss of appetite and/or general depression. Prolonged exposure is said to lead to disturbances of the nervous system and to blood problems (leucopenia: reduction in white cells) [8].

The *epoxy* resins are used in laminating and in making castings, glues and lacquers. Their application involves combining uncured epoxy resin with a hardener (curing agent). Both the uncured resin (polymer molecules of small and intermediate size) and the amine hardener are dangerous [8, 28, 30, 31]. The amine hardeners appear to be particularly potent sensitizers. Skin outbreaks on the arms and face have occurred as soon as several days after initial contact and, in other cases, up to as long as two years later [31].

Great care must be exercised during the curing process, because the heat released can be sufficient to produce dangerous fuming of the hardener. Overheating of the resin during sawing or machining should be avoided to prevent fuming and contamination of the saw dust and turnings [30]. In 1961, epoxy resins and amine hardeners were considered to be the greatest single source of contact eczema in industry [8]. While efforts are being made to discover less offensive hardeners, it is still necessary to take preventative measures to reduce the hazard [31].

The *polyester resins* (*unsaturated polyesters*) are used in the manufacture of reinforced plastic boats, translucent panels, automobile bodies, etc. In industry, the molding processes are mechanized so that manual operations are reduced to a minimum. However, the artist making a sculpture from polyester reinforced with *glass fibre* is usually restricted to the 'hand lay-up' method. In this method, the glass fibre is placed in a mold, the polyester syrup is added and the work is permitted to cure [8].

The syrup is a solution of polyester in styrene. Chemical additives (i.e. catalyst and accelerator) are mixed into the syrup immediately before application; these additives start and control the curing process. Health hazards arise from manual contact in distributing the syrup and in shaping the work and from inhalation of styrene evaporating from large wet surfaces. Styrene is an irritant and there is evidence that the polyester is a sensitizer [8]. The toxic properties of styrene vapor and its influences on the nervous system and on the blood have been mentioned above in a paragraph on Polystyrene (Styrofoam).

The handling of *glass fibre* yarns, mats and cloths sometimes leads to skin reactions: erythema (reddening), swelling, papules and scaling [8]. Often the troubles can be traced to the coatings that have been applied to the fibre to provide bonding and 'finishing'. Although glass fibre is not a sensitizer, the skin irritation which it produces evidently can render the individual more vulnerable to sensitizers. The cutting of glass fibres and the machining of reinforced plastics can produce a 'glass dust'. Care should be taken because 'glass dust' exposure evidently can cause eye and nose irritation and even gastric disorders.

The *polyurethane* resins find application in the preparation of lacquers and glues and in the formation of plastic foams (*urethane foams*). The finished (i.e. cured) products present no toxic hazard [28]. The principle hazard is in the making of the foam [8, 26, 32]. Artists form foam sculpture by means of a special spray gun having two nozzles. The sprays of two different liquids intersect and immediately react chemically with the generation of a foaming plastic mass. Flexible and rigid urethane foams are two types in current commercial use. The flexible type is made from the very dangerous chemical *TDI* (2,6-toluene diisocyanate). Its effects on the respiratory tract can be very serious, leading to acute asthma [8]. In the case of the rigid foams a less dangerous chemical, *MDI* (4,4-diisocyanate diphenyl methane) is used. In both cases, there is the additional problem of the development of excessive heat in the chemical reaction introducing the risks of fire and of the release of monomer vapor [8].

IV. FIRE AND EXPLOSION HAZARDS

1. *Solvents and monomers* [12, 33]

The artist working with polymers may become introduced to a host of different liquid chemicals, principally solvents. Generally these are flammable; many can present serious explosion hazard. Water and several other liquids like carbon tetrachloride and chloroform are, of course, the notable exceptions.

As in the case of health hazards, common sense rules often suffice in minimizing fire and explosion hazards. For example, it is evident that very flammable liquids like cigarette lighter fluid and nail polish remover present little hazard when they are used *in small quantities*. When the amounts are increased to quarts, to gallons and finally to drums, the destruction potential rapidly becomes very serious [34, 35]. A common accident is spillage and ignition. The result can be an uncontrollable fire or even an explosion.

Some idea of the nature of fire and explosion hazard can be gained by considering ordinary gasoline. When a quart container of gasoline is opened, vapors are released which can easily be ignited by a spark or by a cigarette or by an open flame. If there is air mixed with the vapors within the container, one not fitted with a flame arrester, flame can spread into the mixture and cause an explosion. If gasoline is spilled on to the floor, the liquid spreads quickly

TABLE 1. FLASH POINTS AND DATA SOURCES FOR HAZARDOUS MATERIALS

	Flash point °F (°C)	Data sources		
		AIHA	MCA	NSC
Acetone	0 (−18)	×	87	398
Amyl acetate	77 (25)	×	—	208
Benzene (benzol)	12 (−11)	×	2	308
Benzoyl peroxide	—	—	81	—
n-Butyl acetate	72 (22)	×	—	—
Butyl alcohol (butanol)	84 (29)	×	—	—
Butyl cellosolve	141 (60)	×	—	—
Carbon disulfide	−22 (−30)	×	12	341
Carbon tetrachloride	—	×	3	331
Cellosolve	104 (40)	×	—	—
Chloroform	—	×	89	—
Cresol (cresylic acid)	178 (81)	×	48	—
Cyclohexane	−4 (−20)	× ×	68	—
Diisobutyl ketone	140 (60)	×	—	—
MDI	—	—	—	489
Dioxane	54 (12)	×	—	—
Epoxy resin systems	—	×	—	533
Ethyl acetate	24 (−4)	×	51	—
Ethyl alcohol (ethanol)	55 (13)	×	—	391
Ethyl ether	−49 (−45)	×	29	396
Formaldehyde	—	×	1	342
Gasoline	−40 (−40)	—	—	—
Heptane	Below 0 (−18)	×	—	—
Hexane	Below −20 (−29)	×	—	—
Lead	—	×	—	443
Lime	—	—	—	241
Mercury	—	×	—	203
Methyl acrylate	27 (−3)	×	79	—
Methyl alcohol (methanol)	52 (11)	×	22	407
Methylene chloride	—	×	86	474
Methyl ethyl ketone	21 (−6)	×	83	—
Naphtha VM & P	20 (−7)	×	—	—
Naphthalene	174 (79)	—	58	370
Petroleum naphtha	Below 0 (−18)	×	—	—
Phenol (carbolic acid)	175 (80)	×	4	405
Propyl alcohol (propanol)	59 (15)	×	—	—
Styrene	90 (32)	×	37	—
Tetrachloroethane	—	—	34	—
Tetrachloroethylene	—	×	—	—
Tetrahydrofuran	6 (−14)	×	—	—
Trichloroethane (methyl chloroform)	—	×	90	—
Toluene (toluol)	40 (4)	×	63	204
TDI	275 (135)	×	73	489
Trichloroethylene	86 (30)	×	14	389
Triorthocresyl phosphate	—	× ×	—	—
Turpentine	95 (35)	×	—	367
Xylene (xylol)	63 (17)	×	—	204

in all directions. Evaporation commences, ignition is easy and flame sweeps over the wet surface immediately. Gasoline vaporizes readily at room temperature; a quart of spilled gasoline can produce a dangerously explosive vapor–air mixture in a closed space having a volume of 360 cubic feet, e.g. a room 5 × 9 × 8 ft.

An idea of the relative fire hazard presented by a solvent may be gained from its *flash point* [12, 23, 33] [cf. Table 1]. The flash point of a liquid is the lowest temperature at which a sufficient quantity of vapor is given off to form an ignitable vapor–air mixture immediately above its surface. Thus a spilled liquid at a temperature exceeding the flash point may become ignited by a lighted cigarette nearby. Gasoline has a very low flash point (−40°F). This means that liquid gasoline must be chilled to below −40°F in order for there to be no danger of its accidental ignition! Clearly gasoline is a very hazardous liquid. Some liquids like brandy or turpentine must be warmed sufficiently above normal room temperature before their vapors will ignite. On a hot summer day the temperature may exceed the flash point (about 95°F) of the turpentine on an artist's bench. This means that on such a day the liquid can be ignited by a burning cigarette and that a sufficient quantity spilled in a closed room can form an explosive vapor–air mixture. At temperatures below the flash point a liquid like turpentine represents a potential fuel, which, in the event of a general fire, will become heated to the flash point and contribute to the conflagration.

The importance of working with the minimum amount of solvent and with good ventilation cannot be over-emphasized. Explosive vapor–air mixtures can be formed easily and there are numerous possible ignition sources. In addition to open flames, *electric sparks* are a frequent source of ignition. These are produced commonly in light and appliance switches, in electric motors and in thermostats. *Frictional sparks* produced by iron tools and even the scraping of iron shoe nails on a stone floor are sufficient. Then, too, there is the sparking of *static electricity* produced by walking across a carpet, by combing one's hair, or by pouring a liquid from one container to another. In industry explosion proof motors and electrical fixtures are in common use and elaborate measures are often taken to prevent static electricity [34, 36].

2. *Plastics* [23]

The question which naturally arises is: Do plastics present a fire hazard? One polymer product, *cellulose nitrate* (*pyroxylin*), definitely does. It is very easily ignited. In fact, in thin sheets it often decomposes spontaneously finally bursting out in flame [12]. Most other plastics employed by artists burn relatively slowly. It should be noted that, although a standard test piece of specific dimensions may burn slowly, e.g. 1 inch per minute, the same material extruded into a thin strip or formed into a foam may be much more flammable [29]. Occasionally, plastic products are available which are 'self-extinguishing'. In some cases this has been made possible by the inclusion of fire-retardant chemicals.

3. *Drying oils*

Linseed oil, poppy-seed oil and other drying oils present the hazard of *spontaneous combustion.* The 'drying' of an oil painting is actually a chemical transformation in which linseed oil and oxygen absorbed from the air combine to form a durable solid film. The heat released by this chemical reaction on the surface of an oil painting is harmless because it is not confined. But heaped oily rags and scrap can confine the heat. The temperature increases to the ignition point and then fire breaks out spontaneously.

4. *Powdered metals* [37]

Metal powders can present a serious fire hazard. Many ignite easily and burn with a fierce hot flame. Airborne aluminum or magnesium dust can form explosive clouds. In fact, when a fire is being fought, there is the danger of stirring up powder into such a cloud. Metal powders should be stored in moisture-proof containers. Aluminum and magnesium powders can react with moisture to release hydrogen, a very flammable gas. Hydrogen is also produced when aluminum powder is mixed into a caustic solution and when aluminum and magnesium react with certain acids. Furthermore, aluminum powder must not come into contact with the solvents methyl chloride and carbon tetrachloride; each can produce an explosive reaction with the metal. (Obviously, a carbon tetrachloride fire extinguisher may not be used to fight an aluminum powder fire!)

5. *Peroxides and ethers* [12]

An artist working with plastics may have in his studio two very dangerous types of chemicals: *peroxides* and *ethers.*

Benzoyl peroxide is a catalyst additive in some polymerization reactions. It is one of a number of common peroxides which behave essentially as explosives. A one-pound quantity of benzoyl peroxide powder can constitute a serious storage problem. Explosive decomposition of benzoyl peroxide can be initiated by heat from such modest sources as steam radiators, light bulbs and sunshine. Friction, for example, in the screw closure of a jar can be the source of ignition. The explosion of a pound quantity can be initiated simply by the addition of several drops of certain chemicals, e.g. the monomer methyl methacrylate. Everyone using or storing benzoyl peroxide or other organic peroxides should be thoroughly familiar with recommended safety practices [12] (cf. Table 1).

The exceptionally high flammability of the solvent *ethyl ether* (often simply called *ether*) is evident from its very low flash point (−49°F). There is another serious problem common to certain ethers: ethyl ether, isopropyl ether, dioxane and tetrahydrofuran. These substances absorb oxygen from the air, forming explosive peroxides in small amounts. Thus ethyl ether evaporating from its container may leave behind a very dangerous residue. Also dangerous deposits of the peroxide can form around the closure. Ethers should never enter the artist's studio.

Undoubtedly there are other fire and explosion hazards which confront, and will confront, the artist in the domain of chemistry. It is impossible to predict precisely what the difficulties will be in the future. It seems reasonable, nevertheless, to recommend that artists seek sound technical and safety advice before embarking on any work involving hazardous chemicals.

V. ELECTRICITY, MAGNETISM AND RADIATION HAZARDS

1. *Electricity*

Many artistic constructions having electrical drives and illumination and even electronic components are now being shown in galleries. Actually, the care given in their technical design should be the same as that given in the design of consumer appliances. That is, the shock, burn and fire hazards should be maintained at an acceptable minimum level for the protection both of artist and eventual viewer. Naturally, such work should not be undertaken without adequate technical know-how or assistance.

Fire hazard often is present because of defective or improper wiring. Old wire with sharp bends and nicks, wire of insufficient diameter, insecure connections and live parts coming in contact with grounded objects may lead to overheating or sparking and eventual ignition [38]. Another possible source of fire is the overheating due to insufficient ventilation of enclosed motors and light bulbs.

The possibility of *electric shock* should always be given very careful consideration in any design. Wires should be insulated adequately and connections should be well covered or shielded. If more than one electrical component, say a motor and an incandescent light lamp or a fluorescent tube, are used in the circuit, care should be taken to wire the components so that a shock will not result when a person simultaneously touches the contacts of two components.

If there are elements which cannot be shielded sufficiently, then certain safe limiting voltages must not be exceeded [39]. The value of a limiting voltage depends upon the current frequency and ambient moisture conditions. For example, when a person out-of-doors in the rain and 'drenched to the skin' grasps a live wire, he receives much more electric current, perhaps three times as much, than he would under completely dry conditions. Undoubtedly the reasons for this are that the electrical contact at wet surfaces is better and wet skin is a better conductor of electricity than when dry. Generally, for indoor use where conditions can be considered *dry*, a potential of 25 volts at 60 cycles for an exposed part is not considered dangerous, although a very startling shock can be received [39]. This corresponds to a current of 16 milliamps through the human body. In applications where dry conditions cannot be assured (e.g. out-of-doors), certainly 8 volts should not be exceeded.

While these voltages may be taken as reasonable upper limits for design against injury from accidental exposure, no one would allow that these voltages be employed in gadgets designed deliberately to give people shocks. For the protection of radio repairmen, who repeatedly receive shocks in their work, a permissible leakage current of 5 milliamps has been established [39], which suggests an upper voltage of 7·5 volts at 60 cycles under *dry* conditions.

Although it should be obvious from the above, it must be emphasized that the standard line voltages of 110 and 220 are *very dangerous under all conditions*. If the path of the electric current is through the heart, the shock from either of these voltages may be fatal.

2. *Magnetism*

Strong permanent magnets are now being used in some art objects or, at least, in devices in which physical phenomena produced by a magnetic field are being shown and sold by art galleries. The magnets are not a danger to man; however, watches and clocks can be ruined by them and magnetic tape upon which music or voice has been recorded can be spoiled if exposed to them.

3. *Ultraviolet radiation*

Some artists are producing brilliant colors by playing *ultraviolet light* upon fluorescent paint. The use of ultraviolet lamps may introduce the possibility of eye and skin injury to both artist and viewer. But, before describing these hazards and preventative measures, it is helpful to mention a few facts about radiation, that from the sun, for example.

Only a small portion of the sun's radiation is visible, i.e. capable of exciting the retina of the human eye. This portion is represented virtually completely by the color spectrum evident in the rainbow. Invisible radiation is represented by the regions off to both sides of the rainbow: the invisible region off the red side is called *infrared* and that off the violet side, *ultraviolet*.

Having wave properties, radiation is characterized by wavelength, which is commonly given in units of length called angstroms, Å. Visible radiation is limited to wavelengths within the region 3800–7600 Å. The visible violets start at 3800 Å and merge into the blues at 4400 Å. With increasing wavelength the blues are followed by the greens, yellows, oranges and, finally, the reds that complete the visible spectrum at 7600 Å. The invisible ultraviolet region includes all radiation from 100 to 3800 Å; at shorter wavelengths X-rays are encountered.

All radiation of wavelength shorter than 3200 Å is dangerous. Exposure to radiation between 2000 and 3100 Å can result in the skin ailment *erythema* and eye injuries [40]. Erythema is a red skin condition produced by congestion of the capillaries; it remains for a period of 2 days to a week after exposure. The nature of the eye injury (*conjunctivitis*, *keratitis*, *permanent eyesight impairment—cataracts and blindness*) depends on the time of exposure and on the intensity of the radiation received. Conjunctivitis is an inflammation of the membrane lining the eyelids and covering the eyeball, a condition which normally disappears in one or two days. Keratitis is an inflammation of the cornea. Radiation of wavelength shorter than 2000 Å is particularly dangerous; however it is not produced from lamps normally employed.

Ultraviolet radiation of wavelength between 3200 and 3800 Å, where visible violet begins, does not generally cause injury to eyes and skin [41]. There are exceptional cases, however, where persons under the influence of drugs (e.g. sulfamides), plant extracts and bacterial infections become photosensitive [42].

Artists generally employ fluorescent-type 'black light' lamps with emission *principally* between 3200 and 4000 Å. Such lamps conceivably *can* present hazard because there is *some* radiation of wavelength shorter than 3200 Å. In a particular 40-watt lamp, for example, the principal emission (3·8 watts) is in the wavelength range 3200–3800 Å [43]. There is about 0·4 watts of radiation of wavelength *shorter* than 3200 Å. With a similar 100-watt lamp, the objectionable radiation may well be about 1 watt in strength. It is difficult to estimate the danger of exposure to such a lamp; obviously time of exposure and distance are important factors.

Shielding an ultraviolet lamp from direct view does not guarantee protection. Ultraviolet, like visible light, *can be reflected.* (Aluminum and wall plaster are rather good reflectors [40, 42].)

Ordinary window glass is an effective filter against harmful ultraviolet radiation. A plate of only 0·04 in. thickness, which certainly is transparent to visible radiation, transmits less than 1 per cent of impinging radiation of wavelength 3200 Å [43]. At the harmful shorter wavelengths the percent transmission is still smaller. A plate of $\frac{1}{8}$ in. thickness reduces essentially to zero all radiation at wavelengths shorter than 3200 Å.

The dangers of infrared radiation are present at very high temperatures (e.g. of molten iron); it is unlikely that this is of much concern to artists. However, the possible adoption of new techniques such as holography will present the hazards of laser radiation to eyes and skin [12, 44].

VI. SOURCES OF INFORMATION

The above discussion is necessarily limited to the health and safety hazards of certain media of current interest. Clearly an artist contemplating work with any of these media will desire information about such matters as personal protective equipment, chemical storage, waste disposal, ventilation, fire control, and first aid. For many situations, these matters are discussed fully in inexpensive pamphlets and data sheets. A list of these publications is presented in Table 1 (more complete lists are available elsewhere) [12, 45]. The addresses of three publishing organizations and instructions for placing orders follow:

(1.) The American Industrial Hygiene Association (AIHA),
14125 *Prevost Street,*
Detroit, Michigan, 48227 U.S.A.

AIHA Hygiene Guides are available for subjects indicated in the table by × (25 cents each) or by × × (30 cents each).

(2.) The National Safety Council (NSC),
425 *North Michigan Avenue,*
Chicago, Illinois 60611, *U.S.A.*

NSC Data Sheets (45 cents each) are indicated in the table by number. Orders should include the stock number 123.04, the title, and the Data Sheet number. For example:

123.04—Acetone—398

In addition to the items indicated in the table, NSC Data Sheets are available on special topics indicated by Data Sheet number and year:

Industrial Skin Diseases (510) (1961)
Chemical Burns (523) (1962)
Dusts, Fumes, and Mists in Industry (531) (1963)
Flammable Liquids in Small Containers (532) (1963)
Chemical Safety References, Revision A (486) (1968)
Static Electricity (547) (1964)
Electric Handsaws (344) (1953)
Electric Extension Cords (385) (1955)
Hand Soldering and Brazing (445) (1957)
Respiratory Protective Equipment (444) (1957)

(3.) The Manufacturing Chemists' Association, Inc. (MCA),
1825 *Connecticut Avenue,*
Washington, D.C. 20009, *U.S.A.*

MCA Chemical Safety Data Sheets are available for subjects indicated by number in the Table (30 cents each). In addition the MCA has published a short series of *Safety Guides* (20 cents each). Those which are pertinent are:

Health Factors in Safe Handling of Chemicals (SG-1) (1960)
Flammable Liquids; Storage and Handling of Drum Lots (SG-3) (1960)
Plastic Foams; Storage, Handling, and Fabrication (SG-5) (1960)
Disposal of Hazardous Waste (SG-9) (1961)

Among the useful publications concerning plastics are the pamphlet *Safety Code for Using Synthetic Resins* (1964) by L. B. Bourne, which can be obtained (1*s*.) from

British Safety Council
Mason House,
163/173 *Praed Street,*
London W2, England.

and the *Plastics Safety Handbook* (1958) which is available ($5.00) from

The Society of the Plastics Industry, Inc.,
250 *Park Avenue,*
New York, N.Y., U.S.A.

The above publications have been written for use in industry. They are, nevertheless, helpful to the artist in appraising the hazards in his situation and in taking the necessary protective measures.

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CYBERNETICS AND ART

Michael J. Apter*

Abstract—*This article is a non-technical introduction to cybernetics, the study of 'control and communication in the animal and the machine'. A number of fundamental cybernetic concepts are described including some of those involved in information theory (like the notion of a message and amounts of information), in control theory (like homeostasis, negative feedback and servomechanisms) and in automata theory (like algorithms, Turing machines and networks). The structure of cybernetics is outlined showing the relationship between work on the further development of the theory, on understanding organismic processes in cybernetic terms (especially through model building) and on constructing more purposeful hardware systems. Bionics, cybernation and artificial intelligence (which especially involves heuristic programming) are all fields concerned with the development of such hardware systems.*

It is argued that cybernetics is related to art in three ways: it may be used by the scientist in studying art, it may be used by the artist in creating works of art—and may have been one of the influences behind the development of the idea of machines as works of art and machines for creating art, as well as the increasingly process-oriented nature of contemporary art—and finally cybernetics may itself be regarded in certain respects as an art form in its own right.

I. INTRODUCTION

In recent years increasing attention has been paid by artists to a new scientific discipline called 'cybernetics'. Perhaps at least part of the reason for this attention is that cybernetics represents a development in science whieh holds out the promise of taking art seriously—in contrast to previous movements in psychology like psychoanalysis and behaviourism which have, in their different ways, tended to denigrate art.

Unfortunately, a great deal of confusion exists as to exactly what cybernetics is, not only among artists but among scientists themselves. The reason for this is not hard to find: the term 'cybernetics' is one which refers to a number of related tendencies in science and mathematics, to a number of developing areas and techniques which overlap each other in different ways. The situation is further confused by the emergence of a host of new names to refer to many of these overlapping areas: information theory, communication theory, servo-mechanics, control theory, automata theory, computer science, artificial intelligence, bionics, automation, cybernation and so on.

The aim of this article is firstly to provide a simple introduction to cybernetics by reviewing in a non-technieal way some of its fundamental unifying concepts and by attempting to show how the different parts of the subject relate to each other. (In doing this I am sure to be accused of over-simplification. My defence is that it is impossible to do otherwise in treating such a complex subject in so short a space.) Secondly, the aim is to suggest briefly how cyberneties relates espeeially to art.

The word 'cybernetics', as defined by Norbert Wiener, the American mathematician, when he coined the word in its modern context in 1948 [1], means the seience of 'control and communication in the animal and the machine'. The word is derived from the ancient Greek 'kybernetike' meaning, roughly, 'steersmanship'.

Underlying eybernetics is the idea that all control and communication systems, be they animal or maehine, biologieal or technological, can be described and understood using the same language and concepts. Thus where the word 'machine' is used in cybernetics it tends to be used to refer to anything which is 'essentially constructible' and this includes cats and dogs and human beings, as well as aeroplanes and computers. To avoid confusion with the everyday use of the word 'machine', the word 'system' is used increasingly in cybernetics. Indeed the newer term *systems theory*, which covers much of the same area as cybernetics, may eventually replaee it as the name of the field. Much of the content of cybernetics is not new or specific to cybernetics: but it is this general synthesizing attitude which characterizes it above all.

II. CYBERNETIC THEORY

Let us look at some of the basic concepts of cybernetics. They can be grouped reasonably meaningfully in terms of three theories.

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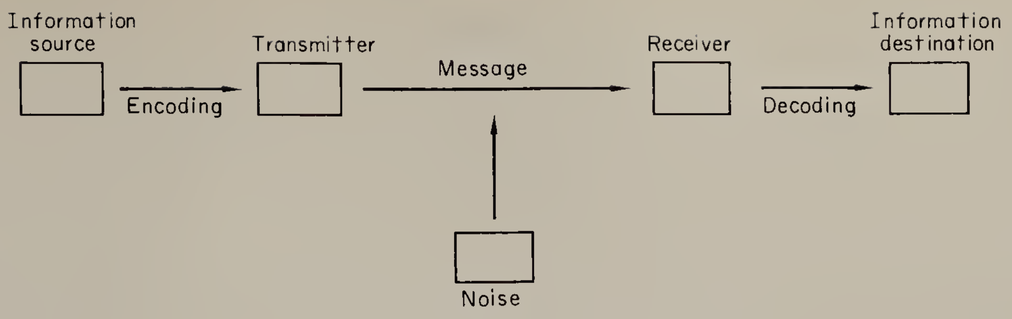

Fig. 1. *Information transmission situation.*

Information theory

A number of formulations of information theory, or communication theory as it is sometimes called, have been put forward; but it is probably true to say that that of Shannon and Weaver [2] is the most widely accepted and used today.

Although deriving from the field of communication engineering, Weaver himself has said of the theory: "This is a theory so general that one does not need to say what kinds of symbols are being considered—whether written letters or words, or musical notes, or spoken words, or symphonic music, or pictures. . . . it is dealing with the real inner core of the communication problem—with those basic relationships which hold in general, no matter what special form the actual case may take" [2].

Indeed, the notion of a *message* is one of such generality that it refers in effect to any sequence of measurable events distributed in time. These events can be the symbols of a deliberately communicative message, and information theory has naturally been most interested in messages of this kind. But the theory can also be applied to other sequences of events and it is in these terms that, for example, biologists have tried to use information theory to measure the amount of information in an organism at different stages of its development [3, 4].

However, in order to be able to measure the amount of information contained in a message, the message must have a certain property. The events, or symbols, in the message must be ones to which it is possible to assign consistent probability values which express, for each such event, the probability of its occurrence. When this can be done, the amount of information in a given event occurring at a given time can be measured and the total information in a sequence of such events given an overall quantitative value. Information theory is therefore, in effect, part of the mathematical theory of probability.

In general, there is an inverse relationship between probability and the amount of information: the less probable an event, the more the information when it occurs. This may seem an odd way to think of information but if we examine it we find that it is not entirely inconsistent with our intuitive understanding of the meaning of 'information'. Thus if someone tells me in July that it is snowing in St. Tropez, there is more information in the message than if someone tells me in March that it is raining in London: the former event occurs less often and is therefore less probable than the latter. Similarly, a cliché contains less information than an original remark. In general, the more random and therefore unpredictable a sequence of symbols constituting a longer message is, the more the information in the message. (The contemporary artist's obsession with randomness may be seen as an attempt to increase the information he is conveying.) The average (rather than total) amount of information per symbol/event in the message is known as its *entropy*.

Communication engineers use information theory in the context of the information transmission situation depicted in Fig. 1. In the first instance this diagram most obviously represents situations like the transmission of information over the telephone, radio or television. The information is encoded, i.e. altered into some form suitable for transmission, then transmitted, when it may be interfered with by the intrusion of uncontrollable 'noise', and then decoded again into some form usable by the receiver. But the conceptualization is a general one and can represent a wide variety of communication situations including people talking to each other, artistic communication, operators controlling complex pieces of equipment, etc. Much of information theory is concerned with the question of how information can be encoded and subsequently decoded, so as to combat the effect of noise and to ensure that all the information reaches its destination. (Methods have been developed, too, which allow information theory to be applied to continuous as well as discrete forms of information.)

Control theory

When we take into account the effects that messages have in a system, we enter the realm of control theory. Control theory, however, as its name implies, is especially interested in systems which control themselves towards goals and which may therefore be considered as purposeful. What is of concern in this area is the way in which information is used within a system and between a system and its environment which allows it to achieve its goals (using the term 'information' in its widest possible sense).

The central explanatory concept of control theory is that of *negative feedback*. By negative feedback is meant that some part of the output of the system is fed back into the system again in a negative direction in order to control that system (cf. Fig. 2). This process is most easily exemplified in terms of what are called *homeostatic* systems: these are systems which maintain certain of their variables within

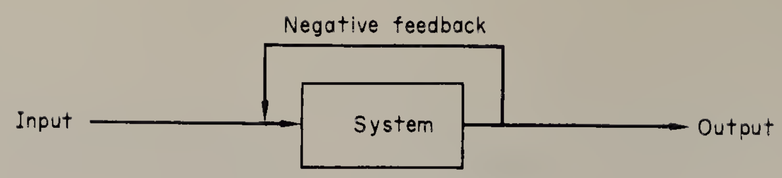

Fig. 2. Negative feedback.

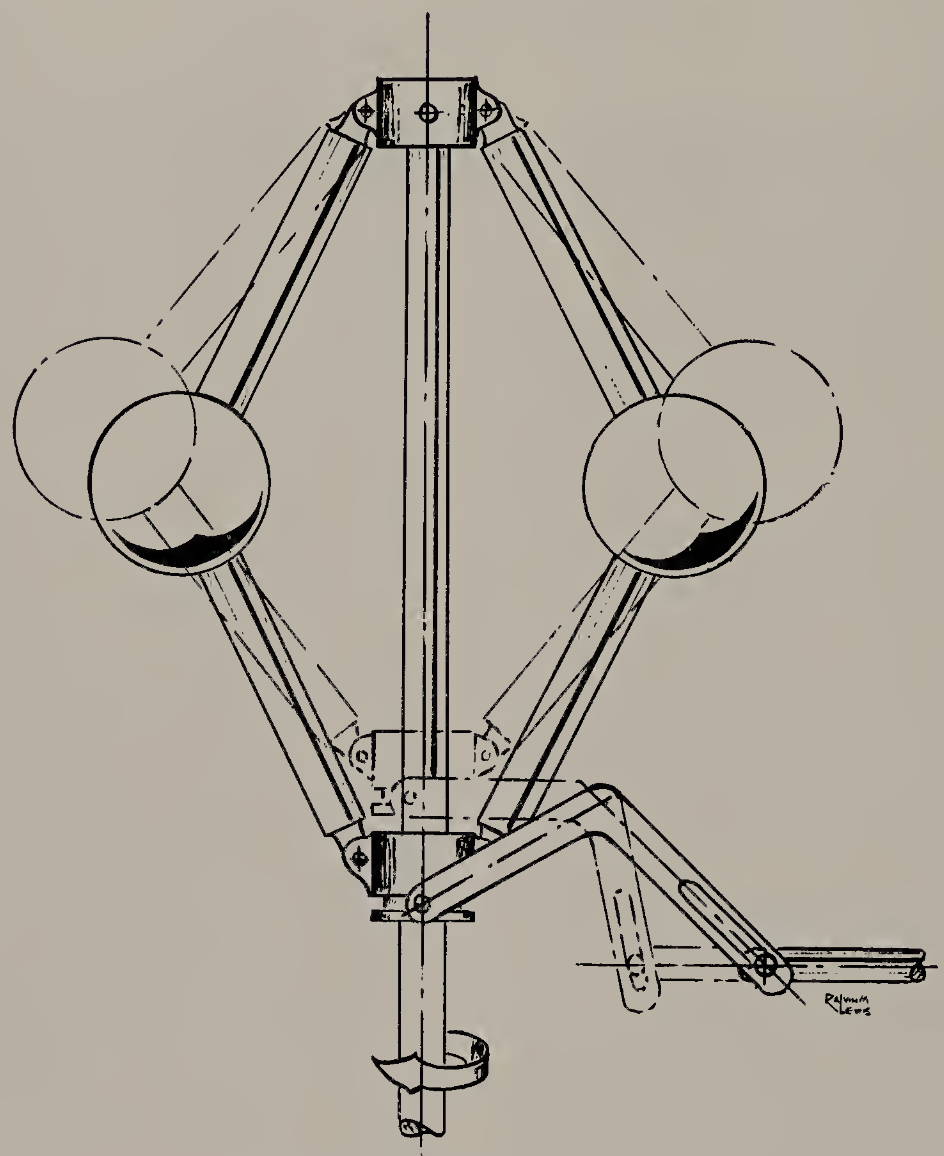

Fig. 3. The Watt governor.

certain limits. For example, pressure cookers maintain pressure within certain limits, the human body maintains a large set of physiological variables (like temperature) within limits, viable business organizations maintain certain economic variables within certain limits and so on. Homeostasis may be achieved by means of negative feedback.

Let us look at this in terms of one of the first, and certainly one of the most famous, homeostatic systems in the history of engineering: the Watt governor (cf. Fig. 3). An engine using the Watt governor is homeostatic in that it is able to maintain its speed of operation within limits. Part of the output of the engine is to turn a set of weighted arms which are mounted on pivots so that they rise by centrifugal force as they revolve. This small part of the output is used to control the engine speed automatically because the arms operate a valve which admits steam or fuel to the engine. What happens is that as the speed of the engine increases, so the weighted arms move at an increasing speed and therefore rise. As they do so they operate the valve, closing it in proportion as the speed of the engine mounts. The result of this arrangement is that the more the engine exceeds a given speed, the less it is supplied with steam, so that it slows down again. But as it slows down, so the valves are opened again to admit more steam, and so it can speed up again. This negative feedback counteracts the speed of the engine as it goes above or below the homeostatic point and the engine soon settles down to a stable speed. It is important to note that it is the speed of the engine itself which in effect controls the speed. This situation is represented diagrammatically in Fig. 4.

A thermostat controlling the temperature of a room represents a slightly more complex system in

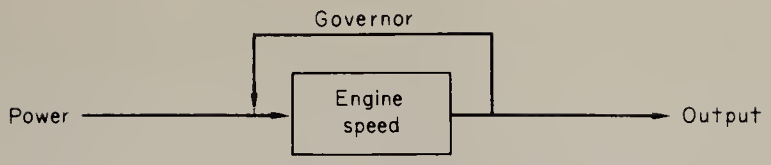

Fig. 4. *Diagrammatic representation of the Watt governor.*

that not only does it control a heating system (through negative feedback) but it maintains the heat of the room in relation to variations in the environment. Not only is it homeostatic, but also *adaptive*—the room is kept at the same heat whether it is snowing outside or the sun is shining. It does this by continually monitoring the temperature of the room and automatically turning on the heat when the temperature drops below a specified level and turning it off when it goes above a higher specified level. This is an example of what is known in engineering as a *servomechanism* [5].

Let us look at a biological example of a similar process. A man walking along a pavement normally tries to stay on the pavement: as long as he does so we can say that he is maintaining homeostasis in this respect. Any change of direction which causes him to move away from the pavement causes him to note that his direction of movement is no longer correct and to move in an opposite direction from the direction of error. So movement by him away from the desired direction of movement results in action being taken which corrects this error. This allows him not only to stay on a straight pavement but to adapt to changes in direction of the pavement itself. Here the negative feedback is in part (seeing himself move away from the desired position) more obviously informational (in the everyday sense of the term) than the negative feedback in the Watt governor example. And the error correction is less inexorable. But the principle is the same.

Many systems incorporate the converse of negative feedback—positive feedback. With positive feedback, part of the output of the system is fed back into the system in a positive direction. This has the effect of increasing rather than reducing deviation in the system. Typically this is unadaptive: for example, the more anxious one becomes the less able one may become at performing a certain skill which in turn leads to increased anxiety and further decreased performance. On the other hand, positive feedback can be related to negative feedback so as to increase the effectiveness of the latter. For example, power brakes amplify pressure on a brake, braking being a form of negative feedback controlling the speed of the vehicle.

A system may control its behaviour, using negative feedback, not only to maintain a state it is normally in but also to achieve some future state that it has not yet been in. For example, the man walking along the pavement may be going to the shops: the whole activity may be regarded as error-correction in terms of the desired end-state of being at the shops. A ground-to-air missile homing on its target would be another example of a future-directed, error-controlled system. The point may seem trivial and yet it is of great philosophical importance. For centuries people have been able to argue that there is a fundamental difference between living and non-living entities in that animals, including man, are able to be purposeful, to act towards the future in some mysterious way. Non-living entities, on the other hand, were supposed to be always subject to cause-and effect principles, to be explicable in terms of previous rather than future events. In terms of the examples we have just seen, this particular argument is clearly not valid. Purposeful behaviour by animal or machine can be explained in identical 'cause-and-effect' terms.

Automata theory

Although in terms of the definition of cybernetics, automata theory may seem to be less central than information and control theory, in practice it has been closely bound up with the development of cybernetics.

Its nature can perhaps be most easily understood by contrasting it with information theory. If information theory is essentially a part of probability theory and is concerned with quantities, automata theory is part of metamathematics and is concerned with proof. We could perhaps call automata theory 'the logic of systems'. The term *automaton* means in this modern sense essentially a system or machine which is deterministic and to which probability notions do not have to be applied. In automata theory an automaton is an ideal, an archetype, rather like a diagram in Euclidean geometry in which we do not have to take into account the thickness of the lines.

Automata theory is concerned with what kinds of behaviour can and cannot, in principle, be achieved by different kinds of systems. For example, what are the minimum properties which a system would need in order to carry out a computation of a particular kind? An especially striking question of this sort is: Is there any logical contradiction in the idea of a system being able to reproduce itself and, if not, what are the requirements? This particular question in automata theory has received much attention, the classic work being done by von Neumann [6].

Metamathematics, the field which automata theory derives from, is concerned with studying the notion of proof in mathematics. That is, it is concerned with questions like: In what sense are mathematical statements true? How can we justify the methods of deduction used in mathematics?

In order to carry out investigations in this area, Alan Turing [7], a British mathematician, proposed that for certain purposes (those relating to a general problem described by Hilbert and Ackermann [8]) it might be useful to think in terms of a theoretical

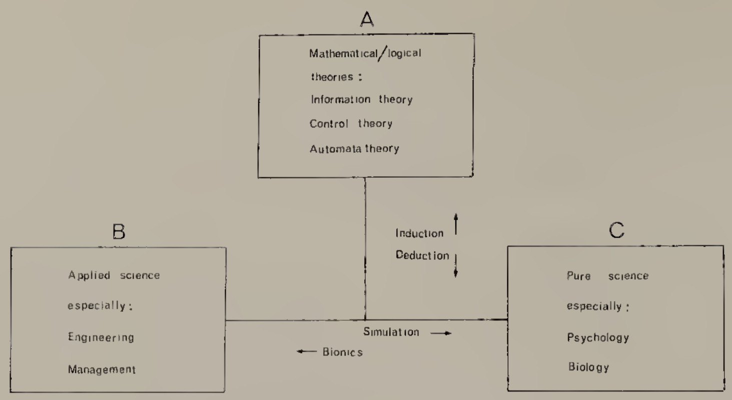

Fig. 5. Relations between the three different poles of interest of cybernetics.

$A \to B$	Using theory for practical purposes, e.g. control theory to construct missile systems.
$A \to C$	Using theory to increase understanding, e.g. automata theory to understand biological development.
$B \to A$	Development of theory due to practical problems, e.g. information theory developed for needs of communication engineers.
$B \to C$	Hardware systems used to increase understanding of organismic systems, e.g. computers programmed to help to understand human thinking. (Often A and $B \to C$.)
$C \to A$	Development of theory due to pure research problems, e.g. concept of homeostasis from study of physiological processes.
$C \to B$	Biological systems studied to help construct better hardware systems, e.g. study of human thinking to improve computer programming. (Often A and $C \to B$.)

machine, since called a *Universal Turing machine*, for carrying out mathematical computations by means of well defined programmes (sequences of instructions which specify how the machine will act). When automata theory developed, the use of Turing's archetype computer became a widely used way of carrying out investigations in the area. It also, incidentally, stimulated the realization in hardware form of the modern general purpose digital computer.

A successful programme for a Turing machine—that is, a programme which inevitably leads to a given end-product being achieved—is an example of what are called 'effective computational procedures' or *algorithms*. Much of automata theory, therefore, is concerned with discovering whether there are algorithms for achieving different mathematical and logical ends.

Another type of theoretical machine used in automata theory is the *network*. This type of automaton was first introduced into the theory by McCulloch and Pitts [9]. A network consists of a set of interconnected elements, information being able to flow under appropriate conditions between elements so connected. The network as a whole acts to transform information inputs of various spatial and temporal configurations into various outputs. The algorithm of a network is not represented by a programme as it is with a Turing machine but is implicit in its structure.

III. THE STRUCTURE OF CYBERNETICS

So far the impression may have been given that all of cybernetic research is devoted to developing various mathematical and logical ideas for their own sake. If this was the case, cybernetics would not have the pervasive influence which it is coming to have across a wide variety of subject-matters including engineering, biology, physiology, medicine, psychology, psychiatry, anthropology, sociology, economics, education and business management. In fact, there is something of a two-way process involving abstract ideas from cybernetics becoming applied in various concrete situations, the latter sometimes giving rise to further developments of theory.

There is also something of a two-way process at the level of concrete systems in that cybernetics is in part, as implied by its definition, a comparative study of animals and machines. On the one hand, biological processes are studied in order to discover ways of designing more sophisticated (purposeful, intelligent, adaptive, flexible) machines for various purposes. On the other hand, study of the way in which engineering systems (like computers) achieve various ends (and also the building of special-purpose hardware models) may give insight into the way in which organisms achieve similar ends. In this way, continual interaction between the study of engineering and biological systems is mutually beneficial to both. Typically, however, this interaction will be mediated by ideas at the more abstract level of cybernetic theory. In doing this cybernetics is not so much reducing man to the level of 'machines' (in the conventional sense) as elevating machines to the level of man.

The whole situation, representing the relations between the three different poles of interest of cybernetics, is represented in Fig. 5. The six relationships that are involved are listed in the table below this figure.

Let us look at some examples of cybernetic research directed towards the ends of pure and applied science.

A widely used technique in pure science is that of *simulation*, of making a model of the process being studied in order to understand it better. A cybernetic model of a biological or psychological process is a dynamic, or behaving, system, which is in some way directed by, or described in terms of, cybernetic concepts of the type described earlier. Two types of model are especially prevalent in cybernetics: hardware models and models in the form of computer programmes. A well known example of a hardware model is that of Grey Walter's mechanical tortoises [10]. These ingenious devices demonstrate that life-like purposeful behaviour can be produced by a comparatively simple hardware system. A mechanical tortoise is in fact not much bigger than a living tortoise and moves around on wheels searching for sources of light and finding its way around barriers placed between itself and the light source. An example of a computer model would be the General Problem Solver programme of Newell, Simon and Shaw, which can prove theorems in symbolic logic and in parts of mathematics, and which appears to do so in a similar way to human beings faced with the same problems [11].

When we turn to the practical problems of applied science, we are faced with a number of terms which refer to different aspects of the contribution of cybernetics to this area. The term *bionics*, for example, is used to refer to the technique of designing and constructing hardware systems using principles derived from the study of biological systems. And the term *cybernation* is used to refer to the application of cybernetics to industry. The aim of cybernation is to go further than automation by increasing still further the autonomy of an industrial system. Looking to the future, this might involve the construction of equipment which not only controls itself but also repairs itself when it goes wrong and also perhaps equipment which can learn for itself how best to carry out various tasks. The idea of automating the board room to some extent as well as the factory floor is also part of the brief of cybernation.

But the best established area of 'applied cybernetics' must be that referred to by the term *artificial intelligence*. Most of the work here has been on the question of how to programme computers to think more intelligently: to learn in various ways, to play games like chess, to prove theorems, to make decisions, to take intelligence tests, to recognize patterns, to control experiments, to translate, to understand and use ordinary language, to teach ('computer-assisted instruction') and so on.

The most important development in the attempt to programme computers to achieve the ends listed has been the idea of *heuristic* programming. A heuristic programme is one which uses a general strategy (rather like human beings appear to do) which gives good odds for the achievement of a solution even though it cannot guarantee, as an algorithm does, that the problem will be solved. This technique has two advantages over algorithmic programming: firstly, it can increase the speed with which a solution is found, algorithmic methods tending to be lengthy and inefficient. Secondly, it can be used in situations where there are no known algorithms, so giving the computer a chance of coming up with a solution which would otherwise be unobtainable. An example of this is Samuel's programme [12] to learn to play checkers and to improve its performance continually. Now checkers is a game which is complex enough to prohibit the use of algorithms for all practical purposes and this learning programme can be regarded as heuristic. A token of its success is that it has been able to beat Samuel himself and this brings out an important point: the ability or intelligence of a programme is not limited by the intelligence of the designer of that programmer. The old idea that 'you only get out of a computer what you put into it' is therefore, in an important sense, incorrect.

It would be possible to argue that the contribution of cybernetics to applied science is much greater than would be implied by the last few paragraphs alone. It could be pointed out for example that the attempt by the United States to put a man on the Moon involves the practical use of control theory, information theory and artificial intelligence. Such work as the Apollo project derives in a very real way from the work of Wiener and others during the Second World War on designing computational devices for use in anti-aircraft warfare—the work which led Wiener originally to the concept of cybernetics. However, the point at which cybernetics proper merges into other areas is difficult to determine.

Finally, in the light of the broad description of cybernetics given here it can be seen that there are many misinterpretations of cybernetics and that many of these are widespread. Cybernetics is not just another name for automation, or for information theory, or for computer technology. It involves more than the concept of feedback. It consists of more than a simple analogy between men and machines. What it does represent, above all, is a certain attitude to complex purposeful systems and a host of precise conceptual techniques for dealing with them.

IV. THE RELEVANCE OF CYBERNETICS TO ART

Let us now turn to the question of the relationship between cybernetics and art, using the term 'art' in its widest sense to include for example musicians and poets, as well as practitioners of visual fine art.

Understanding artistic behaviour

The first relationship that one can specify is this: cybernetics, in its quest to understand complex human behaviour may be able to throw light in due course on that highly complex type of behaviour called 'artistic'—a type of behaviour clearly involving control and communication.

By 'artistic behaviour' I am referring to the whole process of artistic communication which starts with various interacting emotional and intellectual processes in the nervous system of the artist himself, becomes transformed into a 'work of art' through a channel which may be noisy (e.g. incompetent technique, bad materials, random disturbance), the work of art in turn communicating to an audience through another noisy channel (e.g. incorrect interpretation in music and drama, poor translation in literature, damage to a piece of sculpture, poor lighting of a picture and the various shortcomings of the audience itself, including the noise caused by preconceptions, physical incapacities, span of attention, etc.); finally it becomes involved in the interacting emotional and intellectual processes in the nervous systems of the spectators themselves. And this whole situation is one which involves many feedback processes, including those between the artist and the work of art he is in the act of creating, between the work of art and its audience, and between the audience and the artist through criticism in the short-term and, in the long term, through the giving or withholding of financial support. A more precise and detailed understanding of this whole control and communication situation might help the artist himself in due course to improve his technique.

As can be seen, then, some of the concepts of cybernetics are directly applicable to art. Meanwhile much cybernetic-oriented research is helping to unravel the mysteries of human thinking and communication through, for example, computer models of problem-solving, pattern-recognition and so on. This may in due course help to provide a more substantial insight into art. A few workers like Pierce [13], Goldacre [14], Mueller [15] and, especially, Moles with his book on *Information Theory and Esthetic Perception* [16] have already started to investigate art directly using cybernetic ideas and techniques. In such cases the temptation to try to reduce art to something simpler has been avoided: it is accepted as complex in its essence. The Gestalt view is one which is entirely consistent with cybernetics, except that cybernetics now provides techniques unavailable to the Gestaltists for a precise and objective treatment of what one might term 'non-decomposable' systems. Indeed, I have argued elsewhere [17] that the work of art itself may be conceptualized from a cybernetic point of view as a complex dynamic system which in certain of its aspects may be similar to the functioning of a developing organism.

Creating works of art

We now come to the relationship of immediate interest to practising artists: the use of cybernetics in the creation of works of art. Although cybernetics has been used in a technical sense in, to give the major example, programming computers using information theory to compose music, its main influence has been rather different. That is, it appears to have captured the imagination of many artists, in a general way, and so stimulated new works of art or even new types of art. (It may also have changed the attitude of the spectator to some degree.) The reasons for all this are none too clear. But one can list the following speculative reasons: the promise that cybernetics holds out of taking art seriously (as mentioned at the beginning of this article), the feeling that cybernetics is in some way bound up with exciting intellectual developments in other fields and that in some obscure way it points to the world of the future, and also possibly a feeling that a rapprochement between science and art would be beneficial to both and that cybernetics represents an ideal vehicle for such a rapprochement. None of this explains why artists have become attracted to some cybernetic ideas, like the idea of feedback, rather than other ideas. One cannot help but feel that if the idea of algorithms had been adopted by artists instead, then a quite different, more ordered, more deliberate, kind of cybernetic art would have emerged.

In this section I shall, then, be simply reporting on the ways in which cybernetics happens to have excited and influenced artists up to the present, rather than on what one might consider rigorous inferences to be made from cybernetics to art. It is possible to list these developments under three closely related headings.

1. *The idea of machines as works of art.* One way in which cybernetics may have influenced art is through helping to break down the widespread feeling that there is some necessary antagonism between art and machinery. If it had not been for the demonstration by cyberneticians of how intelligent and purposeful machine behaviour can be and how arbitrary the living/non-living distinction is for many purposes, it is conceivable that the negative connotations towards machinery might have been so great that, for example, kinetic art would have taken longer to develop.

2. *Machines to create works of art.* Some artists have thought in terms of not only creating works of art in the form of machines but creating machines to create works of art. Many examples of this were included in the exhibition of 'Cybernetic Serendipity' which took place in London in 1968 and represents a high point in the early development of a self-consciously cybernetic art [18]. Examples include pendulum drawing machines and Tinguely's painting machines. With Tinguely's machines both the machine in action and the results of this action may be regarded as art. Another notable example of a machine-artist is the robot painter of Hoenich [19].

In this category we must include computer programmes written to simulate (and even improve upon) the work of the artist. Examples of this include computer-generated visual patterns, e.g. Noll [20] and Mitchell [21], programmes to write poetry, e.g. McKinnon Wood and Masterman [22] and programmes to compose music. As far as the latter is concerned, the work of Hiller, Isaacson and Baker [23–25] represents probably the most detailed and serious work yet on computer-generated art of any kind and is related to their analysis in statistical and information theory terms of different types of music. Many other examples of computer art will be found in the catalogue of the 'Cybernetic Serendipity' exhibition [18].

3. *Art as a process.* The emphasis of cybernetics on process and change may have been one of the

factors generating an increasing feeling among artists that art should be regarded as a process rather than as the production of static objects. This feeling has manifested itself in a number of ways, including the production of works of art which are impermanent, the advent of the 'happening' as an art form and the deliberate and creative utilization in some works of kinetic art of the participation of the spectator, i.e. of feedback between the spectator and the work of art. Ascott has argued forcefully [26] that the aim of art should be the process-oriented one of producing further artistic activity in the observer, and that this can be achieved by both the stimulation of art objects and also by certain kinds of social interaction, especially a type of social interaction which constitutes what he calls a 'cybernetic art matrix'.

One of the consequences of the developments under these three headings is the blurring of some of the traditional distinctions between the work of art and the system which creates the work of art, and between the work of art and the system which observes the work of art. How far cybernetics has really been instrumental in bringing this about and how far other major factors have been involved is impossible to estimate.

Cybernetics as art

As well as the two kinds of relationships outlined above between cybernetics and art, there is possibly a third and even more intimate kind of relationship: it may be the case that cybernetics is, in part, an art form as well as being a science. In a sense most applied branches of science (e.g. civil engineering) involve elements of art. But cybernetics appears to generate art even in its pure science aspects. It produces, especially through the process of model building, entities which often seem to possess aesthetic as well as scientific value.

Of course it could be argued that pure science and art are in any case not as incompatible as they are often assumed to be and that the same processes are involved in both. Koestler's idea of 'bisociation' for example demonstrates that creative activity in all fields may be essentially the same [27]. Nevertheless there could be a particularly close relationship between cybernetic model-building and artistic creation in that the cybernetician as modeller (at least in hardware) is creating as well as discovering, is expressing his ideas in concrete terms and, in doing so, has a flexible choice of methods and materials which to some extent allows him to express his own preferences and individuality. It is my own impression that a successful model often involves a combination of elegance and satisfying complexity which together are irresistibly pleasing. It could be said that models like Ashby's Homeostat [28] and Grey Walter's mechanical tortoises [10] were among the first, and are still among the most satisfying, pieces of kinetic art. It is perhaps not without significance that in introducing the exhibition of cybernetic serendipity, Jasia Reichardt was able to point out how difficult it was, without checking the notes relating to the works, to know whether one was looking at something made by an artist, engineer, mathematician or architect and she could easily have added biologist and psychologist to the list.

ACKNOWLEDGEMENT

I should like to thank Mr. Alvin Lewis for his drawing of a Watt governor shown in Fig. 3.

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*Article included in the present edition.

HOLOGRAPHY AS AN ART MEDIUM

Margaret Benyon*

Abstract—*Art ramifications of holography are discussed, begining with an account of the author's change from painting to holography in 1968. The perceptual directness of holography was one of the factors that led to this change. The possible place of this new medium for art is discussed, bringing in such factors as our awareness of three dimensions and the reaction of the public to holograms in exhibitions. Possible future directions are indicated. She points out that the use of advanced technology by artists raises ethical questions and other issues.*

A number of holograms made by the author are described, demonstrating aspects of the medium, such as pseudoscopic images, the making of 'non-holograms' and multi-exposures. She covers briefly some of the technical limitations and potentialities of holography.

I. INTRODUCTION: THE HOLOGRAM

The reaction of most people on their first look at a *hologram* (Fig. 1) is one of astonishment and occasionally disbelief. They look through what appears to be an almost clear piece of glass, as if through a window, to see on the other side a three-dimensional image which looks like an actual scene but exists only in the form of light. They have a strong desire to reach round the glass and touch objects that they can see round and behind, and,

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Fig. 1. View of a hologram. A photograph cannot properly show the three-dimensionality of holograms.

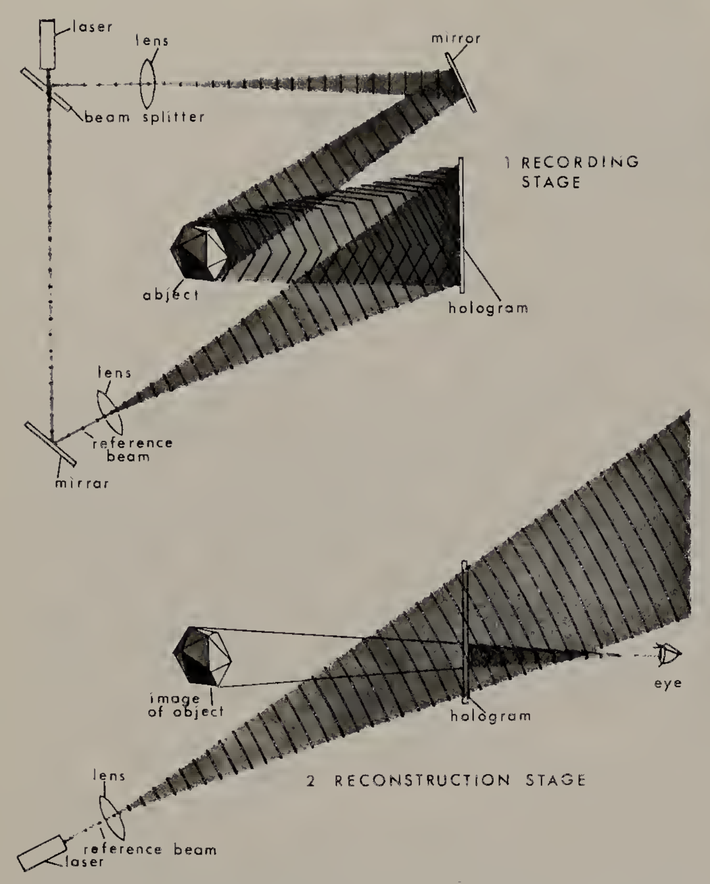

Fig. 2. Diagrams showing the recording and reconstruction stages used in holography.

if they attempt to do this, their fingers pass right through the image. The three-dimensional (3D) image is seen as if a real object were present, unlike other methods of recording 3D images, which show only one angle of view.

An article in *Leonardo* by H. Wilhelmsson [1] gives a full technical explanation of holography but I believe a brief account of the holographic process is desirable here. To make a hologram of an object (Fig. 2), a *laser beam* is split into two and both beams are spread out by a lens. One beam, the *reference beam*, falls straight onto the holographic plate; the other, the *object beam*, falls onto the object and the light is reflected onto the plate. The holographic plate is *photosensitive* and records the *interference pattern* from the two beams falling onto it. The plate is then processed like an ordinary photographic film. The point about the interference pattern is that it allows a record to be made of the detailed properties of the light reflected from the object, that is, the phase relations to which the plate is not sensitive as well as the intensity to which it is. The laser light used is *coherent*, that is, the light waves are 'in step' or *in phase*, so that the crests or troughs in the waves all travel along together. The *random* wavefront from the object meets the coherent wavefront from the reference beam at the plate and they interfere to produce a pattern of light and dark according to whether the waves are in or out of phase. To view a hologram (Fig. 2), the plate is illuminated with a spread laser beam or reconstruction beam directed at the plate at the same angle and distance from it as the original reference beam. The reference beam acts

Fig. 3. Vibration-damped table (8 × 6 ft) *built in the Department of Architecture, University of Strathclyde.*

as a sort of coder and the image is decoded by the reconstruction beam. The light is diffracted to produce a 3D image of the same size as the original object. The interference pattern in the emulsion directs some of the reconstruction beam to travel on, as did the light from the object in the first instance. To the eye there is no noticeable difference between the image and the object.

II. NOTES ON THE HOLOGRAPHIC TECHNIQUE

Holographic work requires a laser, optical components such as lenses and mirrors, and a vibration-free working surface (unless one is fortunate enough to have a pulsed laser). Pethick has devised a system of sand-based holography that replaces the need for a vibration-free table [2]. Figure 3 shows my own table, which consists of a concrete slab supported on inflated motor scooter inner tubes.

Factors that can present problems in the practice of holography involve size of objects and plates, coherence of light used and rigidity of objects and of equipment. The size and coherence are linked in that the distance over which the coherence of the laser can be relied on is short. For instance, the helium-neon laser has a coherence length of approximately 30 cm. and the lengths of the reference beam and the object beam must not differ by more than this by the time they reach the plate. This means that objects are restricted to sizes not over 30 cm. Recently, however, coherence extenders have been added to lasers to increase their coherence to lengths of several metres. If the object being recorded moves more than a fraction of a light wavelength (about 1/10,000 mm) a hologram will not be obtained. This problem can be overcome by 'flash' holography, involving the use of pulsed lasers. Conductron Corporation of Ann Arbor, Michigan has produced holograms of scenes fitting into a space 8 ft high, 10 ft wide and 10 ft deep by using a pulsed laser they developed.

Fig. 4. *Hologram Exhibition, Nottingham University*, 1971.

The cost of equipment at present is high, especially that of lasers, but laser prices are expected to drop considerably in the next few years. Mass-produced small lasers (1–3 mW) suitable for taking small holograms are now available at approximately £100–£200. The power required to take 8 × 10 in. holograms would be from 8 mW upwards. An 8 mW laser at present costs about £700 and, with the additional cost of optical equipment, it would cost approximately £1000 to establish a basic studio/workshop with this laser.

The special light sources for viewing are monochromatic in the case of *transmission* holograms. Optimum viewing conditions for this type of hologram are by means of a laser in a darkened environment but a mercury arc lamp with a narrow band filter can provide an image comparable to that of a laser and is less expensive. In fact, any compact white-light source is suitable, provided that a filter with a narrow enough bandwidth is available. Reconstruction only requires coherence over the area subtended by the eye at the hologram plane. A brighter hologram can be obtained by bleaching the plate. An inexpensive light source providing reasonable image reconstruction is the sodium lamp, the yellow light used in street lighting. Figure 4 shows the layout of my exhibition at Nottingham University in 1971. (Under normal exhibition conditions overhead illumination is not used. All that is seen are the individual light sources of different colours and the illuminated glass plates of the holograms.)

It is possible to make a hologram which can be reconstructed in ordinary white light by putting the reference beam and the object beam on opposite sides of the plate in the recording stage [3]. This has the effect of recording the interference fringes in the thickness of the emulsion, hence the designation *volume* hologram. The hologram can be viewed in sunlight or with a torch, the emulsion selecting only the wavelengths it needs from the colours in the white light to reconstruct the image. These are also called *white-light* or *reflection* holograms and have been produced on film on a large scale in the United States.

Full colour holography involves a similar process to white-light holography, in that each wavelength of colour is recorded in the depth of the emulsion, so, like white-light holography, it also suffers from a lack of suitable recording material. There is interference between the colours and the colours change due to emulsion shrinkage [4].

Some of the possible future developments in holography are, for example, computer-generated holograms of hypothetical objects and recording of a hologram with sound to be read out with light. Microwave holography, holographic memories for data storage, holographic movies and T.V. are also under investigation. The development of holographic T.V. and large scale movies [5] are probably beyond the next decade but holography is at the end of the 'settling-in' stage necessary for new inventions and is at the point where it can begin to be used by artists.

III. AN HOLOGRAPHER'S VIEW

Put simply, a hologram is a 3D photograph. It can also be a powerful way of affecting human sensory response. My use of holography as a medium began in 1968 as a logical development from my interests as a painter and was associated with the making of a number of large *stereoscopic anaglyph* paintings. As early as 1963–1964 I had been using the interference pattern on which holography is based, in order to question the abstract expressionists' assumption that the criterion of excellence in a painting was that it should be treated as a flat surface. The graphic interference pattern was a means of altering the picture plane spatially without reverting to Renaissance space, perspective and traditional illusionism. My first holograms were of constructions incorporating interference patterns. The holographic principle was carried over into the subject matter, to make an image in which a change in the pattern occurs as the spectator moves.

An important factor in my change from painting to holography was that the latter is perceptually a more direct medium. By this I mean that to experience a hologram one needs no special art education. The illusion is self-evident.

The nature of the image, as opposed to its interpretation, cannot be misunderstood. Unlike the painted illusion, it is not dependent on suggestion and variable subjective responses. This is not to say that there are no difficulties in viewing the hologram—in our culture a sophisticated awareness of three dimensions is undeveloped. The situation could be compared with that of early movie-goers who were disturbed by parts of bodies cut off by the edge of the screen.

I should not like to give the impression that the illusionistic connections behind my change from painting to holography are important now. My motivations have changed. There are, as yet, no hypotheses in aesthetics for the domain of holography. There are none of those esoteric criteria one has to take for granted as a painter, which tend to make a mystique of art. It would be undesirable to perpetuate old art hypotheses in a new form like holography. This means that the public's general knowledge about art can be a disadvantage, so occasionally I have deliberately referred back to earlier art forms to bridge the gap between public expectations and my use of the medium. This is possible with holography because it is close enough to the traditional forms of painting and sculpture. An example of what I mean is a hologram I made of a 3D model interpreting Picasso's 'Demoiselles d'Avignon', a Cubist masterpiece that is now part of a common area of knowledge. The hologram was intended as a comment on the way holography automatically achieves the aim of Cubism to show three dimensions on a two-dimensional surface.

Another example of what I mean is a series of holographic still lifes (Figs. 1 and 5) I made from 1969–1970 as a result of feedback from viewers of holograms. These comprised a cross-section of

Fig. 5. Detail of a holographic still life, 8 × 10 in, 1969.

viewers who largely did not understand what was being seen and who were further confused by abstruse subject matter. My intention in the still lifes was to provide the viewer with images of familiar objects, in order to present the 3D properties of holograms in a commonly known art genre, without the encumbrance of new ideas.

Response to holograms depends on the way they are presented and the intention behind their presentation. A recent experiment carried out by an environmental psychologist, D. Canter, and myself compared a hologram and photograph of the same model room. It is interesting to note that viewers showed no major difference in attitudes towards the two. However, in exhibition conditions, where it is obvious that there is nothing behind the plate and there is no experimental task to perform, response varies widely. Some people, for instance, saw colour in holograms where the subject matter was familiar to them, occasionally to the extent that it was difficult to convince them that the image was monochromatic. One five-year-old reacted more violently than one would wish, bursting into tears of frustration because she could not grasp an illusory apple. (I have in fact on occasions included real apples amongst the illusory ones presenting the two together so that they are seen as equivalent.)

I am aware that, in the still lifes, I am operating with a restricted code but this does not preclude an elaborated one on a different level in the same work, which the viewer has more chance of ascertaining once there is an understood basis of communication. Art-for-art's sake activities attempt to make art as 'serious' as science or philosophy and forget that these subjects, especially the former, have an interface with the general public even if these fields are not understood by them. I see the still lifes as one way of inviting people to become involved; there are others, ranging through the possibility of viewers handling the holograms physically and searching for the images themselves, to actually making holograms.

The fact that I have my own laser equipment and have begun teaching holography to students I see as a breakthrough in my own development. One idea connected with people handling holograms would be to make a hologram which would be cut into regular pieces. Each piece will still contain the whole picture because the necessary visual information is contained in each fragment of the plate. The cues for fitting together this holographic jigsaw puzzle would come from the different angles of view of the image and not from the edges of the pieces, as with the usual 2D game.

Increasing the availability and flexibility of the medium is of more interest to me than virtuoso work, such as full-colour holography. White-light holography greatly increases the availability of the medium because the image can be reconstructed by sunlight or the light of a torch. I have done some (so far unsatisfactory) work with this technique. Art possibilities with a new medium depend on the state of development of the medium. For instance, development of suitable hologram copying techniques could lead to multiples for large-scale distribution. This has in fact already begun. Over a million holograms on a film base have reached the hands of the public, most of them reproduced in journals. This aspect of the technique I view with ambivalence, as the desirability of severing the connection between art and the art market made in working with holography as research is an attractive proposition. Nevertheless, the research stage will be passed through, technical difficulties will be overcome and, hopefully, more and more artists will be using holography to produce different work from that now possible.

In this sense, I am not circumscribed by the medium, because the technique of the medium is developing all the time. In using holography, specialization is necessary to provide the knowledge and expertise required in any exploration of the means of expanding perception. Clearly, if one is going to use a new medium in a way that is new, one needs to work with it to understand its potential. Holography is difficult, requiring effort and patience, even for a highly experienced technician, so credible assessment is not possible in determining whether or not holography will develop as an effective art medium but I believe it is essential that it becomes more accessible to other artists.

Progress has been made in this direction by physicist Lloyd Cross and sculptor Gerald Pethick [6]. In 1969, they formed Editions Inc., the world's first non-industrial holographic studio, open to artists interested in pursuing holography as an art form, as well as to commercial media groups. They give holography courses at their School of Holography in San Francisco and planned to open a branch in London in 1972. In 1970, they were instrumental in bringing about an exhibition called 'N Dimensional Space', which started at the Finch College Museum, New York, and toured the U.S.A. It comprised work by a small number of artists such as Robert Indiana and George Ortman and I was able to take part in this simply by mailing a hologram. Another artist using holography is Carl Frederick Reutersward who has been making holograms for several years. A large hologram (46 × 61 cm), constructed by J. H. Jaffe of the Weizmann Institute of Science, Rehovot, Israel was shown at the Art and Science Exhibition held on the occasion of the opening of the new Tel Aviv Museum in Israel in 1971 [7]. Bruce Naumann, a Los Angeles, California, artist, has had holograms made of himself by Conductron Corporation mentioned above (one of the very few firms to my knowledge to have made custom holograms). Unfortunately, this firm has reduced its work in holography but has done some notable work. There may be no reason beyond the experiential why Naumann's body should be shown in the form of holograms rather than photographs but the holograms are interesting and a good example of the gap in the approach between an artist and those whose ideas of pictorial holography do not go beyond the 'pin-up'.

Most displays of holography are limited to images of, for example, toys and chess sets. An holographer, Ralph Wuerker, has recently been making holograms of art treasures in Florence, Italy. This application differs from mine in that I use it as a medium in the way a film-maker uses film or a painter paint. Rather than producing holograms of art works, there seems more point in using holography as an art medium itself and developing its unique properties. It could be very disappointing as a medium if new visual ideas are not realized through it.

Many authors in *Leonardo* have stressed the desirability of artists being aware of developments of the mid-20th century, both from technical and philosophical points of view. They have also stressed the danger of subcultures of artists proliferating without a broad sense of social responsibility. Only thoughtful use of holography will prevent it from being left to the 'fun' specialists. I see my own use of holography in art as complementary to the objectives of engineers or of physicists [8]. An artist is not subject to the same restrictions. This may be the reason for the cooperation I have met with on the part of most engineers and physieists with whom I have worked. In the words of the scientist J. Gates [9]: 'It seems likely that since so much of our conception of the outside world comes to us in visual terms, and holography is likely to extend and expand the scope of visual presentation, that some effect, and possibly a very great effect, will eventually be felt by the man in the street. In a way, one may perhaps draw a parallel with the understanding of electricity and the development of that new technology at the time of Faraday. The uses made of those ideas have so permeated physics and life in general today that we probably never spare a thought for the kind of doubt and uncertainty for the true worth of the ideas that must have existed at the time. Although it is rather a farfetched speculation that holography might have a comparable significance, we must not underestimate the very great impact that visual presentations can have.'

An artist working with aspects of new technology should share the concern for the social misuse of it, instead of sitting back and 'doom-watching'. I see holography as being part of a future world in which grass would also grow. One can take an optimistic view of new technology that it can lead to conservation of effort and resources —the miniaturization of computers is an example—achieving the same results with less and less consumption of materials and energy. Many persons think of the assembly line and dirty machines as symbols of technology but many new technologies require clean surroundings and quietness (for holography these are essential). I agree with Toffler's statement [10]: 'Those who prate anti-technological nonsense in the name of some vague "human values" need to be asked "which humans"? To deliberately turn baek the cloek would be to condemn billions to enforced and permanent misery at precisely the moment in history when their liberation is becoming possible. We clearly need not less but more technology . . . Reckless attempts to halt technology will produce results quite as destructive as reekless attempts to advance it.'

I raise this issue because I have been condemned for using technology in art—and a potential instrument for war, at that. I do think that many artists can be blamed for the ecological crisis in our part of the world because they try to avoid the reality of society's productive processes in a reactionary and dangerous way. The separation of art from the changing patterns of life could lead to the end of art. Art activities taking place outside art galleries are brought back into them instead of widening the art location. In working with a medium from the beginning of its development, it should be possible, in a small way, to influence the direction of its use and perhaps even of the direction of further technical researeh. Working 'underground' in engineering and scientific laboratories, having little contact with other artists and the art world, I see as signifieant in itself.

Some claim that artists might be considered a part of an early warning system of dangers to society. This is a functional view that as an artist one is responsible not to art history but to the society in which one lives. I am not so naïve as to think that art can effect changes except through the infiltration of artists into areas not traditionally theirs and the slow progress of education.

With holography virtually unused as an art form, I feel that to use it in any one particular way would be to achieve an artificial and limiting sophistication. Instead, I prefer to look on the holograms I make as prototypes, some capable of generating others at a later date and some not.

One could use holography to obtain visual disorientation similar to that experienced during hallucinatory states. An example of this would be to look into a hologram of a mirror and not see one's reflection. With holography it is possible to record things invisible to the naked eye or turn space 'inside-out'. I have been working with holograms in which the conjugate of the virtual image is used to show pseudoscopic space, that is, the image is turned back to front spatially. I have found that this phenomenon is most readily seen with a non-figurative configuration in whieh hollows become mounds and vice versa. I have made a 'pseudoseopic' hologram containing a hypercube. (Just as a square is a 2D section of a cube, so a hypercube is a 3D section of a 4D 'cube'. The latter exists only as a mathematical concept, although its three-dimensional sections can be constructed.) In the hologram, the back of the hypercube appears to come forward and the front to recede. We are, like Alice, on the other side of the mirror. The hologram serves to remind us that notions such as left and right are one-dimensional and are determined by an arbitrary act of choice.

My most recent hologram was of a continuous surface. The viewer sees the front and back of the object as continuous. The idea came from G. L. Rogers, a pioneer holographer, and the technique involved the making of a mould of the back of the object, then making a double exposure hologram of both front and back. I do not think there is a need to deform objects to make them look mysterious or surreal—holography does this anyway. If the intention is to make a metaphoric statement with objects, I do not believe the hologram is useful except possibly as a photographic record.

An example of a hologram showing something invisible to the naked eye is shown in Figure 6. Anything that moves more than a fraction of a wavelength of light during the exposure will not record. Normally invisible currents of hot air show as blaek traces when seen against a lit lackground. The hand in the hologram appears as a solid

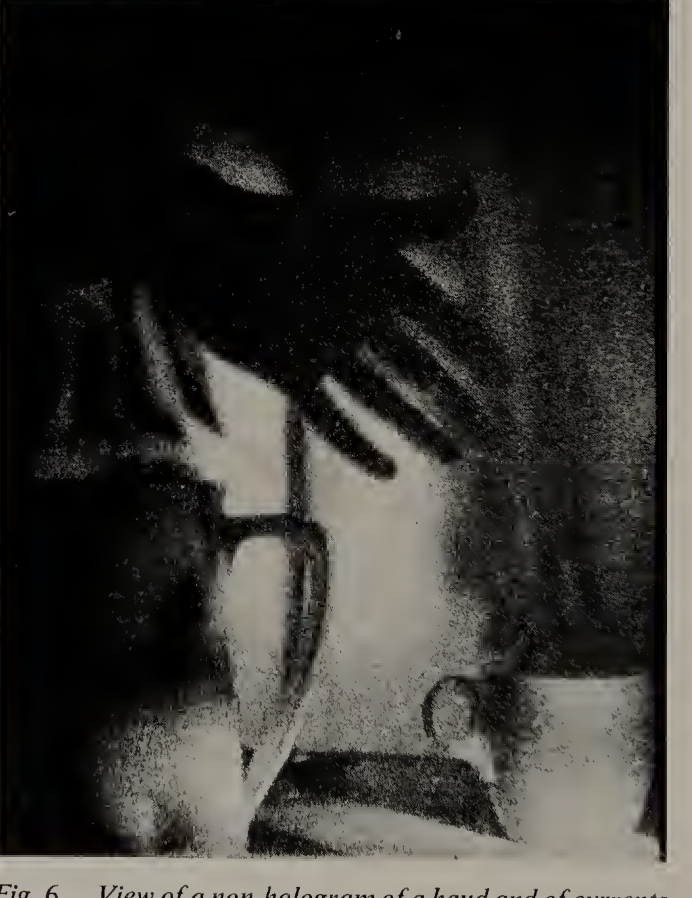

Fig. 6. View of a non-hologram of a hand and of currents of hot air above a cup of hot liquid, 10 × 8 in., 1970.

Fig. 7. Views of holographic exposures of a loaf of bread 15 days apart, 9 × 12 in plates, 1971.

hole that one can look around, a three-dimensional silhouette.

Another paradox can be seen in Figure 7. A series of exposures of a loaf of bread, taken over a number of days, shows a reversal of our normal experience of freshness. The last image looks the freshest because the bread was stale and hard enough to record well. The first image looks black because the bread was moist and soft. This series shows one of the differences between holography and photography.

Figure 8 shows a double exposure hologram. By exposing the plate to two different set-ups, it is possible to achieve, for example, the appearance of weightlessness. The glass in the hologram appears to float in space above the fruit and the orange through the bottle of milk. In one of my earlier holograms, pieces of folded metal appeared to float in space because their supports were covered with black velvet. Because this moved slightly during recording it eliminated the image of the supports.

A hologram of a more straightforward nature is one I made of nine long metal rods. These were arranged in a three by three square and came right up against the holographic plate, casting shadows across its surface. Viewed from the ends, the rods emphasize parallax. 'The strange black shadows they cast remind us that this is not a sculptural object, but a pattern of interacting events in space and time'

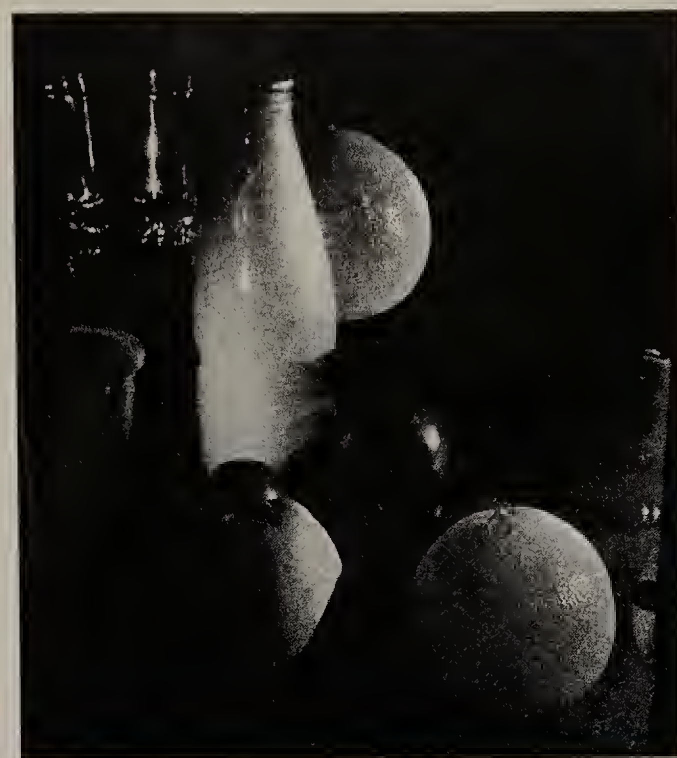

Fig. 8. View of a double exposure hologram, 10 × 8 in, 1970.

[11]. The shadows leave their mark in the emulsion and can be seen in ordinary light, without reconstruction of the hologram. In another hologram the direct laser beam is reflected by a set of parallel glass plates to multiply into many points of light. Holography could be an extension of existing uses of light in art, which rely mainly on the fixture in which light is contained or on the 'painting' of surfaces with light.

The small format and restricted field of view of a holographic plate is an excellent means (similar to psychology of perception test objects) of presenting an object for concentrated study. Figure 9 shows a triple exposure hologram that resembles a perception demonstration. Three separate images can be seen as the holographic plate is turned through 60°. Each image gives a cue as to whether the other exposures are of the same arrangement of regular solids taken from different positions or of different ones. The hologram gives more information about this than is possible with a two-dimensional photograph, since one is able to look round the sides of the image. I see the use of holography and its remarkable properties as favourable conditions for art to take place. It provides a visual analogy of relativity and quantum theory as methods of enquiry which suggests undivided wholeness rather than the relationship of parts to the whole [12]. In this way, holography has also provided a possible explanation of the way the brain works [13].

Present limitations on the size of holograms disturb some critics of the medium, as does the fact that the record formed on the plate cannot be manipulated because one is dealing with a light phenomenon involving lines too small to be etched or drawn by hand. I feel that hologram size is only

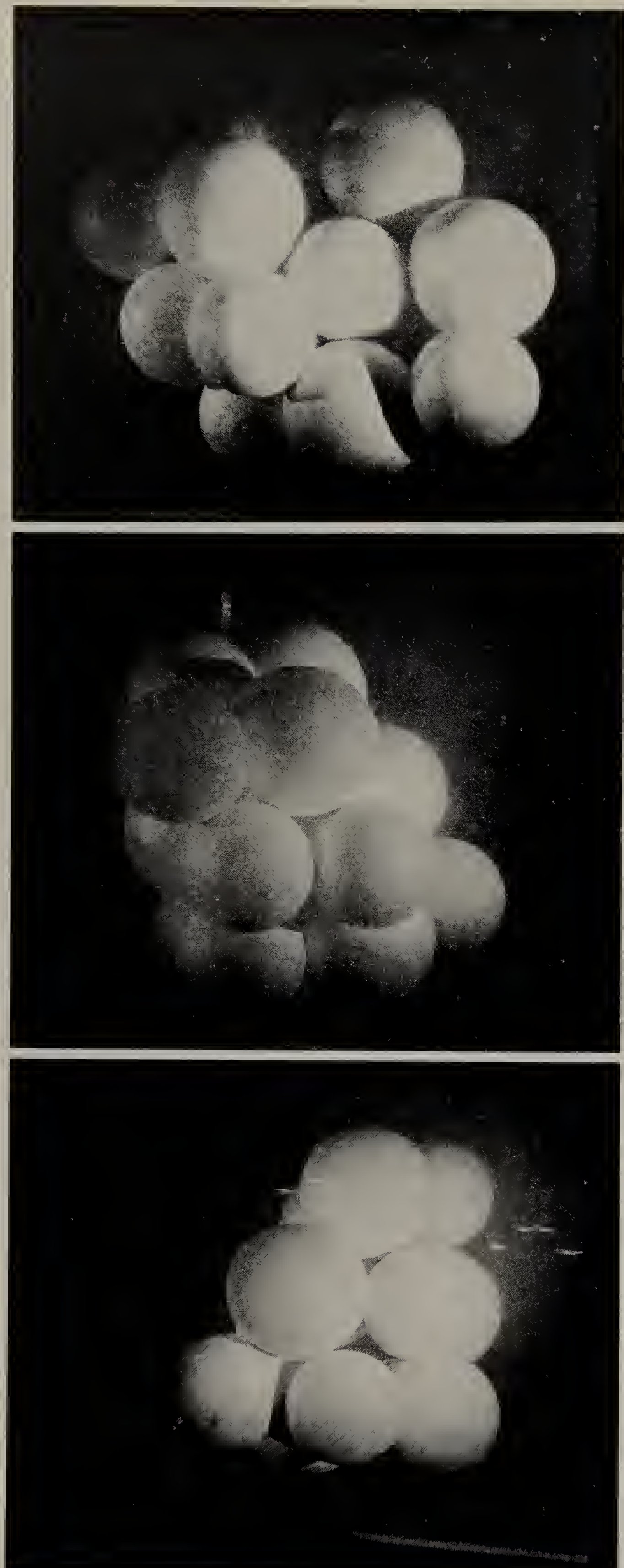

Fig. 9. View of a triple exposure hologram (three separate images are seen on the same plate as it is turned through 60°), 8 × 10 in, 1970.

a problem from the point of view of art tradition. The requirement of direct intervention of the artist's hand would rule out a large amount of established work of this century. Matter in all its states has been used by a number of artists in recent years. In any case, it is becoming widely acknowledged that art does not reside in material entities. The choice of medium is not in itself significant. The credit for exhibitions arranged by artists of laser beams as purely physical phenomena, for instance, should go to the inventor and manufacturers of the laser, rather than to the 'artist'. To quote, for example, D. Gabor, the inventor of holography: 'Too much of the true creativity of our times has gone into science and technology' [14]. It is up to the artist to change this state of affairs.

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ON SPACE AND TIME IN MUSIC AND THE VISUAL ARTS*

Elena de Bértola**

Abstract—*The author notes that the concept of the interdependence of space and time is one of the most exciting ones in contemporary physics and philosophy. In works of art, there is also an interlocking of space and time, however, she points out that it does not involve problems of relativistic physics.*

She outlines the temporal and spatial aspects of music and of different kinds of visual art, such as static painting and sculpture, Op art and kinetic art. The differences between objective *space and time, and* psychological *space and time are discussed as they pertain to these arts.*

She concludes that it is not correct to classify music as simply a 'temporal' art and the visual arts as 'spatial' arts, for in both of these art forms there is an interrelationship between time and space.

I. INTRODUCTION

The concept of the interdependence of space and time is one of the most exciting ideas in contemporary physics and philosophy. Let us recall Kant's thoughts on space and time: he believed they function together, in that they are both necessary before anything is perceived, for their synthesis to be carried out in the imagination and that they make human knowledge possible. Actually, space and time can only be determined one from the other. Although events and objects exist in time, time cannot be perceived without resorting to space. A line traced by hand is made as a succession of points, which is a manifestation of the passage of time. Thus, one can speak of the 'spatialization' of time and of the 'temporalization' of space [1].

The concept of the space–time continuum in physics was introduced by Minkowsky and then applied by Einstein in his special theory of relativity. Contrary to the concepts of space and time in Newtonian physics, in relativistic physics there is no absolute time that is independent of space. This viewpoint has brought about a new awareness of the relation between time and space in the universe.

In works of art, there is also an interlocking of time and space, however, it must be made clear that it does not involve problems of relativistic physics. Nevertheless, to speak of 'arts of space' and 'arts of time', as if time were not required to look at a picture or as if space were not implied when listening to music, is not satisfactory.

I shall take as an illustration the art of music, which is considered essentially 'temporal', to bring out, in detail, how space is also involved. Then I shall choose that which is considered an essentially 'spatial' art, static painting, in order to bring out how time is involved. I shall devote the last section to an analysis of kinetic and Op art, which more clearly demonstrate the space–time relationship in the visual arts.

II. ON EXPERIENCING SPACE IN MUSIC

Sound involves matter and its principal characteristic is that it takes place in objective or chronometric time. This does not mean that since human perception of sound is essentially temporal, sound has no relation to space. There is only one physical space that, however, is perceived differently by the different human senses, so that one speaks, for example, of 'visual space' and 'sound' space.

The space of sound, Winckel says, is 'psychological' [2]. But 'psychological' does not mean 'a space belonging to the human subject exclusively'. The space of sound is actually 'objective' in the sense that it involves the spatial locations of the vibrating object and of the receiver of the sound. 'Psychological' time also is involved in music, that is, a 'personal' time of the listener.

What does Winckel mean by 'psychological space'? In music, it is not meant to be in opposition to objective space but rather to visual space. The individual character of the space of sound comes

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from the fact that it is not perceived visually but instead felt aurally.

When one speaks about 'sound' space, it is as an appropriate analogy of visual space. In effect, whenever one speaks of 'space', one generally means visual space and, in a parallel sense, whenever one speaks of spatial perception, one thinks of visual perception [3].

An object in a room, for example a chair, is perceived visually and it can be located in space with precision. In the case of sounds, however, even though matter is involved, they cannot be directly perceived visually and it is for this reason that a listener does not perceive objective space but rather has a 'feeling' of space. Hearing locates sound only 'very vaguely in space' but, on the other hand, 'it locates its occurrence extremely well in time' [4].

This lack in precision of locating sounds in space is the reason why different listeners give different interpretations and analogies for 'sound' space and visual space. And artists, no less than listeners, have felt the temptation to make analogies between music and painting, between sounds and colors. All these analogies are based on purely subjective reactions. Kupka often gives names to his non-figurative compositions borrowed from music ('Fugue in Red and Blue', for example). Kandinski said that the world is sound ('Die Welt klingt'). In his *Regards sur le passé* [5], he tells how he was struck in his youth by a production of Wagner's 'Lohengrin' at the Court Theater in Moscow—'I believed that I saw all my familiar colors. They were all before my eyes. Wild, almost extravagant, lines were drawn before me.'

In what ways is a musical piece 'spatialized'? Musicians have long known that different instrumental timbres produce particular effects: the sounds of trumpets 'appear' in relief and can give the impression of sounds approaching or receding in space. It is very common to find in all sorts of compositions 'protruding' themes and 'sound volumes' that depend on the character and combination of sounds produced.

Highly pitched sounds and deep sounds appear to the ear to penetrate space differently. The former are 'directional', whereas the latter 'radiate', giving the impression of filling a room uniformly. Winckel distinguishes several types of 'spatial' sensations [6]: sensation of a fictive source; sensation of sound displacement; sensation of contraction and of expansion; and sensation of sounds that travel in space, leap off to one side, etc.

Two loud-speakers separated by several meters give the sensation of a 'fictive' source situated in between them. If one increases the sound level from one of the loud-speakers, one notes a sensation of 'displacement' of the fictive source from one speaker to the other. Thus, just as one speaks of visual illusions, one can speak as well of 'sound illusions' where the same differentiation between physical facts and psychological effects applies.

'Spatial' music, produced by several sound sources (loud-speakers) placed in different regions of space, multiplies or diversifies the spatial effects of sounds In Fig. 1 is a diagram showing the directions in which the audience faces and the positions of four orchestras for the performance of K. Stockhausen's composition 'Carré', written in 1958–59.

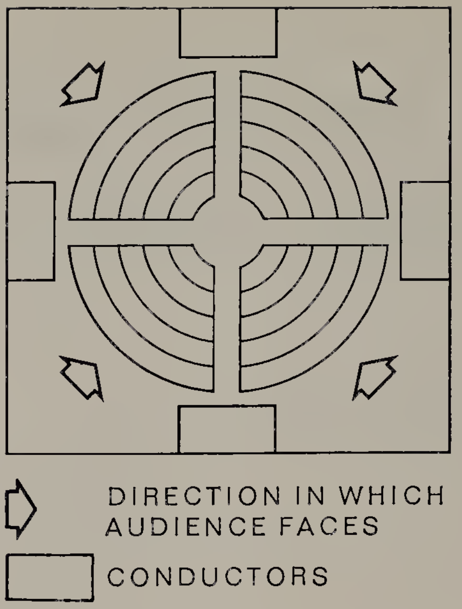

Fig. 1. *Directions in which the audience faces and the positions of four orchestras (indicated as conductors) for the performance of K. Stockhausen's composition 'Carré', written in* 1958–59.

By increasing and decreasing the volume of individual loud-speakers placed in opposite corners of a room, one can produce sounds that appear to travel around the room, that appear to jump to one side, to echo, etc. In the sound environment that was designed by F. Winckel and the composer Boris Blacher for the German pavillion at the International Exposition at Osaka, the effects of expansion and contraction were systematically exploited. The capability of the ears to notice 'spatial' effects of sounds has also been exploited by other composers [7].

III. ON EXPERIENCING TIME IN STATIC PAINTINGS

I have pointed out above how music, an art considered to be essentially temporal, also produces in listeners a consciousness of space. Apparently, in music it is not possible for a listener to separate time from space. I shall now consider whether in static plastic or visual fine arts both space and time involve the consciousness of a viewer. As I said, a line in space can only be drawn by hand as a continuous succession of points and has the dimension of time. In the same way, the work of an artist is first conceived in time.

Obviously, the conception and accomplishment of any kind of art work involves the passage of time. But, what is of particular interest in this study is the question of how time enters into the *perception* of a static object in space, for example, a painting. A painting is by definition a static arrangement of graphic elements and colors on a two-dimensional surface, however, an illusion of three-dimensions can be produced through the use of perspective geometry and of special color combinations.

When one looks at a static picture, one has the complete composition before one's eyes whereas in music one must allow time to pass before the complete composition is heard. Nevertheless, the perception of a static picture is far from being instantaneous. If one wishes to become well acquainted with a painting, one must spend a considerable amount of time scanning its elements [8]. In a painting, as in all kinds of plastic art, one can continuously see aspects that one did not notice before. 'In order to drain the riches of my perception would require infinite time' said Sartre [9].

An object that does not change with time can be perceived immediately as a whole (except, of course, large objects, such as murals, that require the viewer to change his position). Experiences that require the passage of time to be perceived, such as music, kinetic art, the cinema etc. are clearly of another category of experience. Still, time is involved when static objects are perceived, as one says 'to see something is to let one's eyes wander over it' and this requires the passage of time.

Dufrenne asserts that in visual perception, simultaneity is made evident through a continuous scanning over an object by the eyes; they do not ever rest completely [10]. The motion of the eyes can be more or less guided, for example, by the shape of lines, such as diagonals, arabesques, etc. Perspective representation, for example, is composed of a special type of order to guide viewing. It leads the eyes toward a vanishing point, pausing at various illusory distances along the way [11]. Leonardo da Vinci thus spoke about the double function of perspective as a kind of round trip for the eyes from the foreground to the vanishing point and back again [12].

Cubism broke apart images as seen normally into images made up of views including those normally hidden from sight from one viewing station. In this 'art of discontinuity', according to Jean Cassou [13], it is the brain that then mentally reconstructs the object. The motion of the eyes when viewing a cubistic painting will have a character different than in the case of perspective representation.

In addition to the influence on eye motion of the mode of presentation in a picture, there are subjective causes that affect it, such as special sensitivity toward certain forms and colors, memories of the subject, etc. It is difficult to make a separation between perception and subjective factors, since eye motion is the result of them both. Thus the temporal factor implicit in viewing a painting is subjective or *psychological*, not chronometric or objective. It varies from person to person, depending on accumulated individual experience. In the temporal arts, such as music, it is the experiencing of sound that extends over time—in this case an *objective* or chronometric time. In the static plastic arts, such as painting and sculpture, since the objects do not incorporate motion, the temporal aspect enters only through the process of perception [14].

'If I contemplate the portrait of Descartes by Franz Hals', wrote Sartre, 'I can look at the lips of the philosopher starting with the commissures or, on the other hand, start from the middle of the mouth and move to the corners and the resemblance that they have with the real lips will not be changed. In these contrasting cases, we distinguish clearly the form of the perceived object and the movement of our eyes'. Then he added: 'Facing the object that is presented as an inalterable whole, the ocular movements are presented as an infinity of possible and equivalent paths' [15].

IV. EXPERIENCING KINETIC AND OP ART

Kinetic art is defined as a visual fine art form that incorporates real motion and/or changes of color with time in a completed work [16]. Thus, a viewer in addition to 'psychological' time experiences objective chronological time [17]. Such a complex experience of time is also provided by, for example, ballet and cinema.

With respect to objective time, kinetic art is closely related to music, however, 'sound' space is psychological whereas the space of kinetic sculpture is objective and the 'space' of a kinetic painting is a visual illusion.

One should note that the term 'psychological' with respect to time in a static painting and to space in music has different meanings. In painting, 'psychological' signifies that a sense of time arises from the visual process, whereas in music it signifies a feeling of space that is not visually perceived.

There remains another type of contemporary plastic art to consider and that is Op art. Op art is defined as a visual fine art in which a painting or sculpture (usually consisting of clearly defined geometric figures) is designed so as to produce a strong optical or rather a strong effect of visual illusion. The means for producing the effect may be simultaneous contrast, optical illusionary designs (including the moiré effect), metallic reflections, etc. [18]. There is also a type of Op art in which a

TABLE 1

	Music	Static Painting	Static Sculpture	Op Art Painting	Op Art Sculpture	Kinetic Painting	Kinetic Sculpture
Space	Psychological	Psychological	Objective	Psychological	Objective	Psychological	Objective
Time	Objective Psychological	Psychological	Psychological	Psychological	Psychological	Objective Psychological	Objective Psychological

corrugated or undulating surface is painted so that as the viewer walks past the surface the painted forms undergo change in shape.

In the case of an object utilizing the moiré effect [19], the viewer obtains an illusion of motion in the object when he changes his position relative to the object. Thus, the object gives an experience of 'psychological' time, since the experience is the result of motion of the viewer rather than of motion within the object itself. Both psychological and objective time can be experienced in Op art, if it is made kinetic.

The above discussion is summarized in Table 1, from which it can be seen that it is not correct to classify music as simply a 'temporal' art and the visual arts as 'spatial' arts, for in both of them there are interrelations between time and space of either an objective or psychological kind.

REFERENCES AND NOTES

1. M. J. Nabert in his study entitled The Internal Experience According to Kant, *Revue de Métaphysique et de Morale*, Paris (1924) states that 'succession itself, which concerns the intuitive character of time, resides, if one can express it thus, above consciousness, as long as it is not determined by a sort of reciprocity of the category of causality and of the irreversibility of motion in space' (p. 255). The causal series of events in space serve thus to determine succession. This signifies that internal experience of time is not independent of external experience of space. 'The order of time is concerned only with the irreversibility of motion in space. We must for all mental conceptions extract the determination of the length or periods of time from what exterior events mean to us as change' (p. 256).
2. F. Winckel, Architecture et musique spatiale, *Bull. groupe d'accoustique musicale*, No. 51 p. 7 (1970).
3. In the same manner, when one speaks of 'space' arts, as Jean Miquel does, one means the the same arts that Nédoncelle calls 'visual' arts (painting, sculpture).
4. P. Fraise, *Psychologie du temps* (Paris: Presses Universitaires de France, 1967) p. 89.
5. W. Kandinsky, *Regards sur le passé* (Paris: Drouin, 1946) p. 15.
6. F. Winckel, *ibid.*
7. Sounds can also be given a spatial character when not heard, for example, through analyses and interpretations of spatial codes, such as music notation and sonogrammes.
8. J. P. Sartre, *L'imaginaire* (Paris: Gallimard, 1940) p. 21. He contrasts an imagined object with a perceived object. The first is nothing more than an awareness that one has of it because imagination is a synthetic act. An imagined cube is presented with all that I know about it, with its six sides, while the perceived object demands a successive assimilation, 'it appears to me only in a series of profiles or projections'.
9. J. P. Sartre, *ibid.*, p. 24.
10. M. Dufrenne, *Phénoménologie de l'expérience esthétique* (Paris: Presses Universitaires de France, 1967) p. 349.
11. M. Soucault, *Les mots et les choses* (Paris: Gallimard, 1966) Chap. 1. He distinguishes two sequences in Velasquez's painting 'Ménines': one develops in the surface plane, the other in the dimension of depth, that is to say, in perspective.
12. Carnets de Léonardo de Vinci, *Optique* (Paris: Gallimard, 1951) Vol. 1, p. 221.
13. J. Cassou, *Panorama des arts plastiques contemporaines* (Paris: Gallimard, 1960) p. 176.
14. P. Francastel, *Etudes de sociologie de l'art* (Paris: Denoël-Gonthier, 1970) p. 56. He stresses the phenomenon of 'reading' a picture: 'the figurative image is fixed but its perception is mobile' p. 56. J. J. Gibson in The Information Available in Pictures, *Leonardo* **4**, 27 (1971) takes exception to the idea of 'reading' a picture and proposes a new theory.
15. J. P. Sartre, *ibid.*, p. 69.
16. Terminology, *Leonardo* **1**, 197 (1968).
17. F. J. Malina, Kinetic Painting: The Lumidyne System, *Leonardo* **1**, 25 (1968). *
18. Terminology, *Leonardo* **1**, 197 (1968).
19. G. Oster, *The Science of Moiré Patterns* (Barrington, N.J.: Edmund Scientific, 1969).

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THE AESTHETIC POTENTIAL OF THE SENSORY MODES

Donald Brook* and John Ritchie**

Abstract—*A tentative bibliography of experimental psychology is sketched. The selected texts deal with the investigation of the human sensory processes. Their collection together is intended to provide reference information and creative suggestions for artists—especially those working in intermedia arts.*

The system of the bibliography is to fill 81 logical boxes that are given by two co-ordinates: nine sensory modes and nine important forms of stimulus or of experienced phenomena. Most, if not all, the logical possibilities for a sensory-based art form will lie somewhere within this schema.

The bibliography is certainly incomplete but, if the reasons that are given for constructing it in the proposed way are by and large accepted, then revision and extension, in due course, will be justified.

I. INTRODUCTORY

The material of this essay may be seen either as the sketch design for a number of related programmes of research or as a practical guide to some portions of the literature of the experimental psychology of perception. It is presented so as to be immediately useful to practising artists and, especially, to those artists who are working in *intermedia* arts.

The basic schema is very simple but, taken with the reservations that will shortly be made, it should not be misleadingly so. In brief, it is proposed that the several human sensory modalities and the more distinctive varieties of stimulus might usefully be seen as forming the axes of a two-dimensional logical schema (cf. Table 1). Within the schema it will be possible to map all the forms of art that make their appeal characteristically through the activation of one or more of the modalities of sense perception.

The literary arts most distinctively, and others in different degrees, have no obvious place in such a schema, since it is arguable that a paradigm poem, for example (excluding such special cases as concrete poetry or lieder), does not depend for its aesthetic effect on the activity of specific senses. A poem has a certain autonomy irrespective of whether it is heard or read and of whether it is read in manuscript, print or braille. This reservation probably extends in some degree to all the arts (a musician may appreciate a work, without significant loss, on sight of the score) but there are nevertheless aesthetic effects that require the active engagement of specific senses: Op art, for example, to take a paradigm at the far pole from literature.

It may even be the case that a classification of the arts into sensory-dependent and sensory-independent types would turn out to have useful advantages as compared with the confused—and collapsing—distinction between the *fine* arts and the other arts.

Some of the traditional art forms occupy only relatively small and concentrated regions of the proposed schema: painting, for example, falls mainly into a column under the single sensory mode of sight. In spite of that, it is not suggested here that the sensory modes are utterly independent and autonomous (that a person might feasibly have no sense but that of sight or that he might be qualified to appreciate painting fully if he had no other sense). Other arts, such as opera, invoke at least the two primary modes of vision and of hearing and other senses, either potentially or by implication.

There seems to be no reason in principle why an art should not be devised that operates at any number of different modes and through any distribution of regions of the basic schema. For example, we might develop an art form that relies upon patterns of pressure or temperature variation, or upon the effects of rivalry in the vestibular senses (the jargon terms will be explained in a moment). It is arguable, perhaps, that we already have such arts, languishing for the moment in greater or less cultural dis-esteem, such as the arts of love-making or of participatory dancing. Nevertheless, it is clear that, even if all that is possible in human experience is already actual in some form and degree, not all the possibilities are equally developed to the pitch of a deliberate art. Artists are predisposed to those forms that are traditional for them, and tend to

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TABLE 1. THE SCHEMA

THE SENSORY MODES

FORM OF STIMULUS OR EXPERIENCED PHENOMENON	Vision	Hearing	Taste	Smell	Vestibular sense	Kinesthetic sense	Pressure	Temperature	Pain
Mixture of basic stimulating energy	1	10	19	28	37	46	55	64	73
Spatial localization	2	11	20	29	38	47	56	65	74
Pattern or order (inc. figural after-effects)	3	12	21	30	39	48	57	66	75
Simultaneous contrast	4	13	22	31	40	49	58	67	76
Masking	5	14	23	32	41	50	59	68	77
Adaptation	6	15	24	33	42	51	60	69	78
After-sensations or successive contrast	7	16	25	34	43	52	61	70	79
Rivalry	8	17	26	35	44	53	62	71	80
Flicker	9	18	27	36	45	54	63	72	81

The jargon terms used are explained in parts III and IV.

devise novel forms at random and piecemeal. There is much to be said for setting out the whole range of aesthetic possibilities so that investigation might go forward systematically, as well as by occasional creative insight.

II. A TENTATIVE SCHEMA AND A BIBLIOGRAPHY

Our study amounts to little more than a tentative schema and a bibliography, with some notes and explanations. Nine sensory modes have been adopted as fairly representing the human range (cf. Table 1). The traditional five senses are certainly too few and it is not difficult to conceive of additional ones. Partly under the influence of a feeling for symmetry and partly because they seem adequate to the purpose, nine characteristic varieties of stimulus (or, from the perceiver's point of view, apparent phenomena) have been distinguished.

Thus, there are eighty-one boxes in the schema. An attempt has been made to supply a bibliography for each box that will take the artist directly to the accounts of scientific research that may be most suggestive to him, should he wish to feed his intuitions on information. Some of the boxes are empty, either because the possibility of filling them seems logically or practically remote or because we have not been diligent enough. Under *pain* for example, there are numerous blanks. It is to be hoped that the majority of artists will not resent either the lack of extensive scientific guidance to the sadistic arts or be excessively eager to remedy it.

III. THE HORIZONTAL AXIS: THE SENSORY MODES

There are two kinds of obstacle to any simple and succinct account of the nature and range of the human sensory modes. One of them is philosophical or, at least, semantic, and the other is scientific.

Philosophically speaking, the words *feel* and *feeling*, which are so intimately related to the ideas of experience, sensation and the sensory modes, are remarkably multivalent. One feels the texture of the stone with a finger and the missing tooth with one's tongue but the pangs of remorse are felt without exploring. Feeling sick or dizzy is usually disagreeable; feeling fit, 'on top of the world', or ten feet tall, is not. One may not feel the cold, the blows of the rain, or even one's chronic rheumatism, if one is feeling sufficiently angry or frightened.

The feeling that one is being observed or discussed does not really require a sixth (or sixth and seventh) sense. Yet, it is sometimes claimed that feeling sure about tomorrow's weather, a winner, or the next card may be a function of that most debatable mode—extra-sensory perception. And, if there are subconscious thoughts, ambitions, fears and purposes, then presumably there is a range of subconscious feelings, as well as of subliminal perceptions [1].

To simplify for convenience: there appear to be at least three fairly distinguishable notions active within the concept of perception. There is the idea of getting information about the external environment through the senses; and there is the idea of monitoring the internal environment, that is one's own body, or mind and body as dualists might prefer to have it. The first of these is usually illustrated by the operation of the paradigm *distance* senses of sight and hearing; and the second divides into what have been called *bodily sensations* and *bodily feelings*. Bodily sensations are contingently private to each individual. They concern such matters as our awareness of the positions of our own limbs and our feelings of (inner) warmth and cold, independently or whether we are, in fact, warm or cold. They do not seem to be attributable to any specific sense organ (although there may, in fact, be specific receptors involved, as in the case of the vestibular sense). On the other hand, they may be highly localized, as when one feels that one's cheeks are hot, that one's foot throbs or that one's tooth aches.

Bodily feelings are similarly private but they are even less readily attributable by the perceiver either to any specific organ of the body or to any particular sensory mode. Unlike bodily sensations, they are not localized: for example, feeling tired, feeling thirsty or feeling faint. They shade off imperceptibly into metaphorical and dispositional senses of feeling, such as feeling gay and feeling broken-hearted.

These distinctions have not been marked in the schema, but they should be borne in mind. At least some of the difficulties encountered by experimental psychologists may be conceptual rather than empirical. In general, the scientists and the philosophers of perception are too often ignorant of each others' literature [2].

The problems of perception and sensation as an empirical science have been investigated traditionally in the light of two hypotheses that attempt in different ways to isolate the sensory modalities for purposes of study. The first of them seeks its distinguishing principle in the kind and quality of the stimulating energy—electromagnetic, mechanical or chemical. The second assumes a doctrine of *specific nerve energies*. This doctrine holds that each of the senses operates through a distinctive type of nerve ending or receptor-neuron, which is responsible for the characteristic experience or sense-impression of the mode, irrespective of the kind and quality of the energy impinging on it.

The first approach is vulnerable to objections arising out of such cases as the so-called *pressure phosphenes* (faint purple rings experienced much as light is experienced, but as a result of mechanical pressure on the closed eyes instead of electromagnetic stimulation of the retina). The doctrine of specific nerve endings handles the case better, however, it has the disadvantage that there is little or no evidence that the receptor neurons of the different modalities are functionally different. In such significant respects as rate of firing and fatigue characteristics the neurons appear to be much alike.

A third and more recent hypothesis is that of specific *projection areas* in the cortex, to which the nervous impulses are severally conveyed [3]. It is cited in evidence that if the projection areas of the cortex are much damaged, then the relevant sensations are not experienced, even though the stimulating energy is active and the receptor neurons are intact and functioning. Moreover, direct electrical or mechanical stimulation of the projection areas may produce sensations of the relevant modality.

The position is now somewhat complicated. Although there are good scientific reasons for abandoning the definition of sensory modes in terms of stimulating energies, the fact remains that the public nature of the energetic stimulus gives us an excellent reason for retaining the practice. We may compare notes and measurements as well as impressions of purple rings of light, however faint, but we cannot, at the moment, examine either the same pressure phosphene or any other private sensory phenomenon. And secondly, connected with the problem of privacy and publicity, we owe our common language to certain contingent regularities, as, for example, the fact that electromagnetic energy *normally* stimulates vision; a certain form of rhythmically applied mechanical energy activates hearing and so on.

In terms, then, of the kind and quality of energy that *under normal conditions* will stimulate the receptors, the nine sensory modes may be seen in the following way:

(1) *responsive to electromagnetic energy* in the range from 400 to 700 millimicrons: vision.

(2, 3) *responsive to chemical energy:* taste and smell.

(4, 5, 6, 7) *responsive to mechanical energy* in various forms: hearing, vestibular sense, kinesthesis and pressure.

(8) *responsive to thermal energy:* temperature. (Temperature sensitivity might be more correctly considered as warmth and cold sensitivity [4].)

(9) *responsive to all forms of energy* in excess or misapplied: pain.

The sensory modes that have been distinguished may be further elucidated in the following ways:

Vision

The mechanism of vision is generally quite well enough understood for present purposes. The receptors are the well-known *rods* and *cones* at the back of the eye, which are sensitive to radiation in the range we refer to as visible light, from red to violet. The receptors are connected to neurons, or nerve fibres (which are specialized body cells), leading to the *visual projection area* of the cortex. The visual neurons are among the twelve billion or so nerve fibres in the human body.

Hearing

The receptors for hearing are hair cells in the inner ear that are sensitive to fluctuations of the material (usually air) impinging on the eardrum. They are connected by neurons to the *auditory projection area* of the cortex.

Taste

The sensitive receptors of the tongue are clustered in *buds*. They are responsive to chemicals in solution.

Smell

The receptors for smell are located in the top of the nasal passage. They are responsive to stimulation by gaseous chemicals.

Vestibular sense

The vestibular mechanism is much less familiar. It is a structure of the inner ear that provides information about the state of motion and about the gravitational equilibrium of the body—or, more precisely, of the head.

The vestibular mechanism is responsive to acceleration rather than to states of regular linear motion. People adapt quickly to even the most rapid motion after acceleration has ceased and no longer experience motion through the vestibular sense. Most experimental work has been concerned with the accelerations and decelerations of rotary motion. The fairground is the traditional site of those kinetic experiences in which the vestibular sense is activated. Quite complex devices have been constructed to superimpose varieties of angular, rotatory and oscillating movement on the willing—and indeed paying—subject.

The mechanism consists principally of three fluid-filled *semicircular canals* set mutually at right angles and extending from a pair of central globular structures. Little is known about the central *sacculus* but the central *utricle* is responsive to gravitational force. It is a fluid-filled sac containing numerous calcified particles called *otoliths* that lie on top of hair-like endings. The orientation of the head in relation to the prevailing gravitational force is matched by shifts in the position of the otoliths and the degree of tilt of the head determines the rate of nervous discharge in the neurons [5].

Each of the semicircular canals is maximally sensitive to acceleration in its own plane and it is speculated that movement in any particular plane determines a characteristic *pattern* of nervous discharge. There is evidence that the *rate* of discharge in the neurons of the semicircular canals increases when the head is rotated in one direction and diminishes on rotation in the opposite direction [6].

It is interesting that there appear to be distinct eye movements associated with the vestibular mechanism. When motion begins, the eyes tend to drift in the direction of the motion. This drift is interspersed with rapid, automatic eye movements in the opposite direction. This state of affairs continues throughout the vestibular activity (that is to say, while acceleration is maintained) with the magnitude and frequency of the eye movements depending on the magnitude of the acceleration. When acceleration ceases, the eyes drift in the opposite direction.

The common symptom of excessive vestibular stimulation, nausea, can be achieved without any movement of the subject, merely by rotating his visual field. Presumably the eye movements of true rotation are simulated.

Kinesthesis

Kinesthesis is the sense of articulation and movement of the various limbs of the body, arising out of the stimulation of receptors in the muscles, tendons and, especially, in the joints. It has proved difficult to study experimentally because of the normal interplay of the other senses, particularly, that of pressure or touch. Moreover, studies have tended to concentrate on visual-kinesthetic tasks such as target-tracking, rather than on kinesthesis in isolation.

Kinesthetic information relates both to voluntary and to involuntary bodily movements. The involuntary system arises mainly out of reflex muscular activity culminating in nervous discharge from receptors in the tendons [7]. Mediation of the process is not cerebral but takes place in the spinal cord.

Information about voluntary movements is obtained through nerve fibres in the joints. Unlike muscular kinesthesis, these fibres have connections at a higher level of the central nervous system and are not merely spinal. Particular nerve cells in the joints have been shown to respond only within a restricted range of movement of the joint [8].

Pressure

Pressure sensitivity is attributable to receptors located in the skin. The sense of touch varies considerably in different parts of the body and there are already well-developed arts of touch-stimulation, especially in love-play (in which, of course, most or all of the other sensory modes are also invoked). There is some evidence that women are more sensitive to touch than men.

The various sensitivities of the skin and, especially, pressure sensitivity, have long been neglected both by fine art and by technology but a new impetus of research now seems to be gathering around such questions as the possibility of using the skin as a communications channel. There are obvious applications for the blind and deaf, and for the normally sensed as well. Israeli pilots, for example, are reported to make use of vibratory code messages applied to the lips through a small device in the oxygen mask.

Temperature

The sensations of warmth and cold are not absolute but relative to an *adaptation temperature* at which, for any given observer and occasion, neither warmth nor cold is reported.

Strictly speaking, there are two senses involved, neither of them having yet been identified conclusively with any particular physiological formations, although there are precisely determinable *cold spots* and *warm spots* all over the body. They belong to distinct systems, although there are peculiar phenomena of *paradoxical warmth* and *cold* (the wrong information being conveyed) and the sensation of *hot* is not, as one might expect, produced by excessive warmth alone but by the stimulation of both warm and cold spots.

A count indicates between five and eight cold spots to one warm spot per square centimetre of the forehead. Comparative figures for the nose are between eight and thirteen cold spots to each square centimetre and no warm spot at all.

Pain

The specificity of pain receptors is not clearly established. One researcher writes of pain-sensitive spots in the skin in terms of 'what appear to be in some respects sensory units, but which are capable of inducing, under different patterns of stimulation, sensations of light contact, prick, itch or pain, all from the same minute locus' [10]. He is sure that itches do not *merge* into pricks, or pricks into pains, with increased stimulus intensity. 'It is as if increased frequency of fiber response registered not only as increased intensity of sensation, but as certain levels, switched in a different central recording system' [11].

The philosophy of pain has been more thoroughly investigated than the neurophysiology but it is still a contentious and difficult topic. For some years, interest has been concentrated on the analysis of the concept of pain, especially in relation to the alleged immediacy and incorrigibility of our knowledge of bodily sensations, of which pain is often taken to be a paradigm [12].

IV. THE VERTICAL AXIS: THE FORM OF STIMULUS OR EXPERIENCED PHENOMENON

The awkwardness of this section heading, which seems to collect entities from different categories, reflects very clearly the problem of bringing public and private realms together under a single designation. It is often supposed that, aesthetically speaking, it makes no difference whether a viewer is aware of (say) a patch of green on a wall or a similarly shaped green afterimage. Yet the former would be a public entity falling naturally under the designation *form of stimulus*, while the latter would be a private one, an *experienced phenomenon*.

The doctrines of *phenomenalism*, of course, represent a systematic attempt to assimilate the former to the latter. In European continental philosophy, and recently in some American art-critical writings, it has been assumed that experienced phenomena are all that are knowable and relevant. Ordinary public objects that seem to common sense to be seen, heard and touched are alleged to be some sort of construction or fabrication wrought out of the experienced phenomena that are claimed to be the ultimate and fundamental data of human knowledge.

The entire philosophical issue of realism vs. phenomenalism is outside the range of our present argument but it has to be remarked that from the aesthetic point of view the difference between the way things *are* and the way they *look* (which is the microcosm of the issue) is often of the most pressing importance to the formation of critical judgments and no glib assimilation of the one to the other handles the problem convincingly [13].

We ought, perhaps, to show our position at this point by declaring for realism and against phenomenalism, although the form of the present paper does not require agreement on the point. We take it that whatever *ulterior* unity there may be, the patent commonsense distinction between, for example, public images on a wall and private afterimages in one's mind deserves to be noticed.

The items listed here under the mixed designation are not grouped or individually marked as *public stimuli* or *private phenomena.* Some of them involve the sensory perception of public objects, others the experience of private bodily sensations or bodily feelings. Occasionally, as with images and afterimages (although not with pressure phosphenes), there is a systematic relation between some aspects of the forms of the public and of the ensuing private entities. Also, there is a wide range of level of inter-subjective agreement about experienced phenomena—most people will admit to very similarly shaped green afterimages following red images but there are very considerable variations in reaction to vestibular stimulation or to tolerance of tickling.

It should also be mentioned, before sharpening up the account of the vertical-axis items, that there is at least one obvious way of extending the two-dimensional schema into three or more dimensions. The temptation to do this has been resisted because it is not felt that the basic issues are yet clear enough to warrant extension; that the bibliographical material would thin out rapidly and that there is virtue in simplicity. But it is obvious that, for example, *experienced phenomena* are mutable for any given stimulus in relation to the initial state of the subject. People may be conditioned to different responses in a great many ways, both accidentally, that is *naturally*, and deliberately. Historical and cultural conditioning operates on entire societies, and the plasticity of individuals under brainwashing (not to consider chemical or other energetic constraints) is considerable. Particular groups and classes may vary in their perceptual judgments in ways intermediate between the unique conditioning of an individual and the historical and cultural conditioning of whole societies. Poor children, for example, are found to overestimate the sizes of coins more frequently than rich children [14] and the blind may develop special acuity in the other senses.

One of the artist's resources in the development of intermedia and intersensory arts is the preparation or conditioning of his audience, so that the work, or some aspect of it, is apprehended in an optimum physical state or frame of mind. This need not be a sinister suggestion. Indeed, we already have many primitive examples of the sort that are easily overlooked because of their familiarity—dressing up for the opera and entering an exaggeratedly artificial environment or the directive conditioning of the background noise (commonly music) at the movies.

The initially prepared state of the observer is a variable and to some extent artistically manipulable element in the construction of a work of art. *Directive State Theory* (as it is called), however, is not included explicitly in the bibliography in Section V.

The vertical-axis items may be further elucidated as follows:

Mixture of basic stimulating energy

Clarification here is either unnecessary or else it reveals, bathetically, that one has been, so to speak, 'composing prose all one's life'. Colours have always been used by painters and harmonies and mixtures of sound by musicians. These commonplace artistic resources are, for those two sensory modes, mixtures of the basic stimulating energy. Indeed, basic stimulating energy in a very pure form —say, an unmodulated sound—seems to have an almost negligible artistic potential unless it forms part of a pattern of stimuli, whether spatial (see under *pattern* below) or temporal (see under *flicker*).

Spatial localisation

This term is also very readily explained. By sight, by hearing and by touch, and sometimes by smell, we are able to locate objects or sources of stimulus. The artistic exploitations of this capacity are already legion, from illusionistic painting to stereophonic sound. This is not to say that there is no room left for fresh manoeuvres. A revived interest in the ambiguities and paradoxes of spatial location has been an important component in recent Op art and in the *sub-optical* colour-field art that activates regions at different apparent depths.

Pattern or order (*including figural after-effects*)

To attempt any radical clarification of the notion of *order* in one paragraph would be too ambitious. The connections with the aesthetic concept (or concepts) of *form* are both complex and obscure. It will have to be sufficient for our immediate purposes merely to repudiate any honorific content to the idea of order or pattern. The ways in which bad music or bad painting may be as elaborately ordered and patterned as good music or good painting, give us the required common-sense account of order. Order may be distinguished from chaos as easily as the hirsute from the bald.

Simultaneous contrast

Simultaneous contrast is commonly presented in terms of brightness, colour, size or intensity. The artistic effect of contrast is very often to heighten, distort or exaggerate the impression made by one of the contrast-partners, rather than to reveal more precisely (as by comparison) the true qualities of both.

Josef Albers' experiments with colour [15], for example, illustrate some paradoxes of contrast to perfection: colours that are unalike are made by contrast with an intermediary to seem exactly alike and colours that are alike are made to seem different. It is perhaps not often enough pointed out, however, that the aesthetic effect depends heavily on the viewer's access to the fact of paradox. To appreciate Albers' effort properly, he must be able to see at once or in quick succession both the truth and the untruth of the matter.

The classical example of contrast in experimental psychology is that of visual brightness. If a dull light and a bright one are presented together, the bright one seems more brilliant than when it is presented alone.

Masking

Masking is the partial or complete obscuring of one sensation by another in the same mode. For example, an audible tone that is just above an individual's threshold of perception may be masked by another, so that the first persists unheard until the masking tone is extinguished. (Pains also are subject to masking.)

Adaptation

Night-vision adaptation is familiar to everyone, yet experimental psychologists tend to emphasize the negative aspects of adaptation—the way in which a sensory mode ceases after some time to respond to a particular stimulus.

There is some ambiguity in the term. We may be said to have adapted to an unpleasant odour when we no longer smell it at all. On the other hand, we may not wish to claim that we are adapted to reduced or increased illumination until we can see again tolerably well. In any case, the aesthetic potential of adaptation, in the temporal arts, does not seem to have been investigated much.

After-sensations or successive contrast

After-sensations tend to be negative in contrast to the stimulus generating them. For example, the vestibular after-sensation of movement is in the opposite direction to the movement that was actually imposed, and visual afterimages are in the complementary colours to those of the presented images.

After-sensations are to be distinguished from figural after-effects (see above under *Pattern* or *Order*). Figural after-effects amount to judgments of relationships of pattern that are distorted (while scrutiny of the public object continues) by directing attention to different aspects of stimulus in turn. If one attends, for example, to a circle, ignoring as far as possible a smaller square drawn within it and then one attends to that square, the square will appear smaller than an identical square that is drawn for comparison outside the circle [16]. The difference between after sensation and figural after-effect is given by the status of the object described—or mis-described. The after-sensation is spoken of in terms of private objects, while the figural after-effect gives rise to faulty descriptions of public objects. *Optical illusions*, so-called, rely on both effects [17].

After-sensations are well-established in other sensory modes than the visual.

Rivalry

Rivalry relates to masking, although the competition of stimuli is rather through a pair of sensory channels than through a single channel and it is not a matter of relative intensity. For example, if two colours are presented binocularly, the viewer's perception of one of them may be much inhibited or even entirely suppressed.

Flicker

Rapid intermittent stimulation has its distinctive effects that may even be undesirably dramatic, as in the case of epileptic seizures induced by light flickering at a rate in sympathy with certain oscillations of electrical potential in the cortex [18]. In spite of this, strobe lights have found extensive artistic applications in the last few years and the possibility of extension to other sensory modes is open.

There is, for any stimulus, a certain *critical flicker frequency* at which the effect of continuous stimulation is felt. One need look no further than the cinema screen for an example in the arts.

V. BIBLIOGRAPHY

Material listed here is tentative. The modest Sydney University Research Grant under which the programme was undertaken yielded an exploratory rather than a definitive effort. In any case, the literature is constantly expanding and it would be a valuable service if readers would make good any serious omissions and submit additional titles—especially in the empty boxes—toward a revised publication, in due course.

Box numbers follow the schema drawn up in Table 1.

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NEW MATERIALS AND METHODS FOR THE MUSICAL INSTRUMENT DESIGNER, THE AUDIO-KINETIC SCULPTOR, MUSICIAN AND COMPOSER

John Grayson*

Abstract—*The author points out that recently developed materials offer many possibilities for the development of new types of musical instruments with different musical vocabularies. There is as yet not enough work being done to determine the sound properties of these materials. A list of tested and untested materials is provided.*

Once a material is chosen, the designer is faced with the problems of selecting the shape of sound-producing forms and the method of making them vibrate. The author discusses these problems at some length.

He describes the construction and sound-producing characteristics of five instruments he has built, one built by Erv Wilson and an audio-kinetic sculpture by Charles Mattox. He states that greater control and acoustic range in the areas of pitch, intensity and timbre will result if contemporary materials are applied to the development of new musical instruments.

I. INTRODUCTION

Modern technology provides the musical instrument designer and the kinetic sound-sculptor with a different and, as yet, mostly untapped sound spectrum. New and greatly improved materials are primarily responsible for this. When I say materials for musical instruments, I mean percussion types making use of sounding shaped forms and of strings. Wind instruments, which rely only on a particular type of vibrating air column, rather than their material to produce sound, are not considered. That materials are less important for wind instruments was demonstrated by researchers [1] who constructed a wooden trumpet, comparing its sound to a standard brass trumpet. None of the musically trained listeners could tell which trumpet was being played. Among these new materials are '. . . glasses with the strength of steel; alloys and ceramics that remain tough and rigid whilst white-hot; plastics on which one can play a blowlamp; materials with the most curious facility for manipulating electricity or light waves; crystals that can change their color; incredibly strong fibres and filaments of the most unlikely substances . . .' [2].

During the last five years I have been experimenting with these new materials and have been developing musical instruments based on them. In the beginning, the approach I took was largely based on my studies of the musical instruments evolved by the American composer Harry Partch [3], along with his 'corporeal' concept [4]. I am also aware, to some extent, of the work of the Baschet brothers in France [5].

Since the scientific contributions made by H. V. Helmholtz (1821–1894) [6], little acoustic research has been done that is applicable to problems inherent in evolving new musical instruments whose sound is physically produced *directly* from the originating material in real time. Areas such as investigation into optimum infrasonic or sub-bass amplitude reinforcement and studies of the molecular or crystalline structures of sounding bodies in relation to their 'response', 'musical value' and 'temperature-pitch variance' are unknown territory.

My research into the nature of the materials to be described was carried as far as possible. However, the extent of my research cannot be compared to the scope of deductive conclusions that would result in a fully equipped laboratory. Only a portion of the instruments that I have developed are described in this article and the materials in the following list probably represent only a fifth of existing, viable new music materials.

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TABLE I. SOUND SOURCES

Tested and utilized	Relevant, untested
Metals:	
Stainless, carbon and high speed steels	Titanium
Silicone bronze	Berillium copper
Brass	Precipitation-hardened monel
Copper alloy (type L)	Tempered magnesium alloys
Iron–nickel–lead alloy	Silicon–manganese steel
Tempered aluminum	Chromium–vanadium steel
	the Nimonics
Glass and ceramics:	
Standard glass	Pyro-ceram (Pyrosil in England) [7]
Borosilicate (Pyrex in U.S.)	Aluminosilicate
	96% Silica glass
	Pure silica glass (in bar form)
	Chemically toughened glass (giving flexibility)
	Reaction sintered silicon nitride [8]
Fibrous and other materials:	
Types of Bakelite tubing	Rigid vinyl (vinylidene chloride) Monofilament extrusion
Hard rubber/plastic tubing	Polyamide (Nylon) extrusion
Most hardwoods and hardwood ply	Aluminum-coated fibre silica extrusion, coated with Kanigen [8]
Resin impregnated canvas	Novawood [9]

Most of the materials listed under 'tested' will be discussed in the section sub-titled 'Applications'. The implications of the materials listed as 'untested' are largely not discussed. The choice of a material for the latter category was based mainly on one or a combination of the following factors: (a) promising but incomplete experiments; (b) hardness; (c) uniformity or parallel structure; (d) stability. Stability in a metal is particularly necessary when utilized in the production of microtonal pitches. In fact, a metal with a strong pitch variability resistance to temperature variance becomes the most important consideration when dealing with small sounding bodies.

II. DISCUSSION OF APPROACHES

The choice of a material is but the beginning of the process involved in making a material function optimally in an instrument. The experiments that give rise to the choice of shape, thickness, method of mounting and the means of vibrating are the most important processes relative to the development of a new musical instrument.

In choosing a shape to be made from a sheet of material, the only criterion that can presently be suggested is that, if the shape is either aesthetically satisfying or composed of whole numbered proportions, it will, assuming that the proper mounting and vibrating procedure is used, produce good musical results. The thickness of a material, especially a metal, is always an important consideration. There are times when the difference of a thousandth of an inch results in a high contrast in tone quality.

Since most of the materials in Table I will be used in instruments of a percussive type (for a philosophic justification see Ranta [10]), the choice of the method of vibration (manual or mechanical) and the type of surface that will act upon the element to be vibrated must be clearly resolved.

Vibrating manually usually implies the use of mallets. In working with unexplored materials, it is essential to have on hand a complete range of hard and soft mallets. (Ultra soft mallets can be made by using the recently developed 98 per cent resilient, hard rubber as a core, covered with layers of latex and then covered with a soft, long-haired skin or alpaca cloth.) Also various sized cork mallets reduce or remove the possibility of breakage when striking glass or ceramic objects.

An example of a mechanically induced vibration could be the use of tuned electromagnetic transducers, coupled to a large membrane to produce a controllable sub-base or bass drone. A transducer is a device that transforms energy from one form into another. For example, a phonograph pick-up transforms the physical motion of the needle into electrical oscillations.

An inadvertent and amusing example of this principle of mechanically producing sub-bass frequencies occurred in a San Francisco night club where the sound of the loudspeaker was emitted by an entire, acoustically-designed hardwood wall. The wall was a substitute for the paper cone of standard loud-speakers. The sub-bass range of the speaker was so strong that during low frequencies in the music the top molecular layer of the waxed dance floor was transmuted and became slick. As a result, many dancers slipped and fell. This trouble was stopped by adding filters to the speaker input, in order to reduce the intensity of the sub-bass range.

A description of a very bizarre and rare ethnic musical instrument, which reflected a profound understanding of the physical power and mechanics of sub-bass tones, was described by the anthropologist Christian as follows:

'I then wondered what was the purpose of the large polished wooden disks, about 3 inches thick and 3 to 4 feet in diameter (one or two were even larger). Evidently each section was cut with adzes from some large hardwood tree after it had been felled: an enormous labour, when the extreme hardness of the wood and the very primitive tools employed are taken into consideration.

It appears that they were used during the dances, which seemed to coincide with the full Moon and to last from 10 to 16 days. During this time the men, who occupy the upper floor of the two-storey houses, eat little, but drink vast quantities of water, conveyed to them through long sections of bamboo (from 10–15 feet) which line the walls of the house like hot-water pipes in one of our own houses. Five or six of the men sit around in a circle and balance the disks either on their toes or on their knees. Each man lifts his diaphragm, and the edge of the disk is thrust deeply into the pit of the stomach; all then depress their diaphragms on to the upper surface of the circumference of the disk and open their mouths. An old man then takes a stone-headed hammer and gently hits the centre of the disk. The sound appears to reverberate from the distended lungs, and issues forth from the mouths of the seated men; the effect is a deep booming sound . . .' [11].

The fundamental or lowest frequency of complex shapes, such as partly involuted and tapered cones, usually is not heard [12]. What is heard, however, is a particular, complex harmonic-inharmonic combination of partials of the lowest frequency that is usually distinctive and very satisfying to the ear. Recent refinements in the precise forming of complex shapes by explosive and electromagnetic means would seem to promise the possibility of building an instrument tuned to a particular sequence of predominant partials rather than the fundamental frequency of the shape. The musical advantage of such a tuning is consistent and increased harmonic—inharmonic interplay between tones. Furthermore, the production of large gongs should be feasible that do not have to age for decades before their sound pattern (perceived pitch) is stabilized. Large-scale production of specifically pitched gongs and cymbals by explosive forming seems economically feasible and preferable when compared to present-day methods of forming by pressure or by hammering.

The sound characteristics of a material are drastically changed, perhaps significantly enhanced, by subjugating them to various heat, stress and fatigue treatments. An instrument using materials subjugated to stress tests under a high temperature is described later on under 'Applications'. If the effect of these treatments is to be fully explored, it will be necessary to use an industrial furnace and various heavy-duty tools. One can expect that such an exploration will lead to materials that are unique for their sound quality.

There are many descriptions of the application of sound-producing principles and of instrument design in the reports of ethnomusicologists—particularly in Dutch and German publications of the early twentieth century, which concentrate on the music of the South Pacific, Africa and South America. One frequently described principle is the resonated flange or tongue which is firmly fastened at one end to a resonator whose air column is tuned to the fundamental frequency of the flange. Hybrids of the African slit-log drum are common examples of the ethnic use of the principle. Recently, Harry Partch used the principle of the flange in his 'Bamboo Marimba' and he plans to build a giant flange marimba similar in range to his 'Quadrangularis' [3], using a refinement of the principle. A further extension of this principle uses steel flanges welded to steel resonators of the same thickness to obtain even greater coupling power (sound intensity) than that obtainable with wood and also a completely different tonal quality.

Scientific developments imply the eventual design of more efficient types of resonating cavities and planes for stringed and sustained tone instruments. Some of these are:

(1) The development of a mathematical formula as a guide for the design of a cavity that is placed within the existing resonator of an instrument to increase the amplitude of that instrument's weaker frequencies is now possible. Such a formula would be complex enough to require the aid of a computer and would require beforehand the analysis of the timbre-transmitting power of all materials involved. This formula would especially be useful for researchers like the Baschet brothers [5] and other innovators.

(2) Transforming the inner space of existing instrument *bases* into tuned cavities that will increase the amplitude of a predetermined frequency. This would be useful to composers and sculptors interested in creating a type of drone sound effect.

(3) Certain non-commercially made African thumb pianos are constructed of a balsa-like wood that has minimal strength but extraordinary resonance. If the irradiation techniques of Novawood [9] (exposure to gamma rays gives wood, previously impregnated with a monomer, a strength such that a nail cannot be driven into it), were applied to close, straight-grained balsa-like wood, it would be possible to construct an instrument that would not need a resonating cavity but only a resonating plane, which would function in much the same fashion as the cone of a standard loudspeaker.

Materials that have been the most useful for mounting sounding bodies to resonators of various types are: silicone, Neoprene and latex *rubbers* (both liquid and sheet); vinyl, RTV and latex *foam rubbers*. Latex foam is usually used for mounting small and delicate sounding bodies because of its fine resiliency which, unfortunately, disappears within one to two years due to oxidation and has to be replaced. Other less orthodox mounting materials are soft and silent mono-filament Nylon springs, flexible polyester honeycombs and sealed air bubbles.

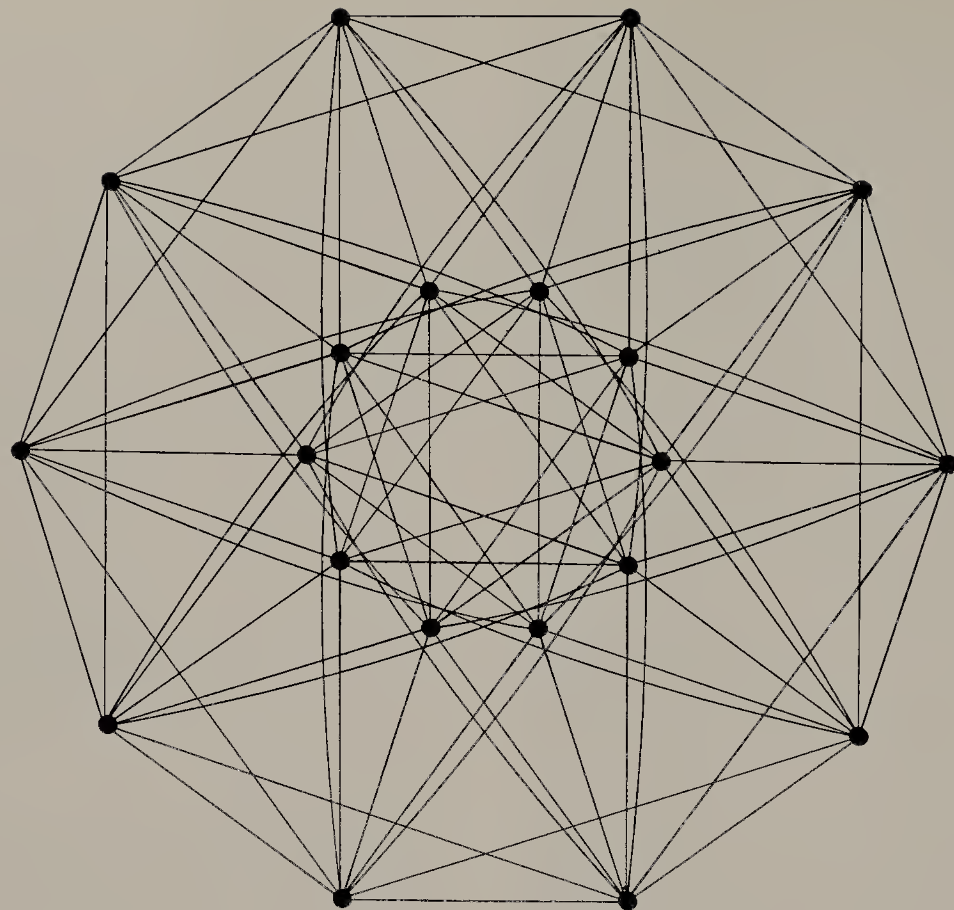

Fig. 1. *'The Eikosany' by Erv Wilson. Graphic reduction of* 20-*tone construction in hexadic tone space.* (Reproduced with permission.)

III. APPLICATIONS

No specific tunings are given with the descriptions of instruments in this section because of the complexity of the subject, as will become evident from the following discussion.

My colleagues and I have long sinee left the mutant cocoon of the *western tempered system*, the piano scale. The reasons for this departure would take a volume in itself to list. It has been shown that a man has a biologically instinctive desire to hear his music 'in tune' [13] and that a man's normal hearing capacity, most markedly in the areas of pitch and intensity perception, has been greatly underestimated [14]. The piano scale is totally incapable of expressing either of these qualities. With the aim of developing a music medium that does not ignore the characteristics of man's biological mechanism [15, 16] or environmental influences [17, 18], computer-aided explorations into all aspects of the *Just*, *Equal*, *Cyclic* and *Tempered* scale systems, along with analyses and delineations of scores of scales ranging from the remnants of man's so called primitive music to the most highly evolved ancient Chinese, Arabian and Indian systems are being made.

During the next decade, I plan to combine these studies with a computer program of pattern recognition that is in the final stages of its ten-year development by the New York mathematician David Rothenberg [19]. This analysis will have many results, all of which will help lead to the establishment of a more efficient music medium. An especially interesting facet will be the development of a series of multi-dimensional tonal references or 'universal' scales, each based on particular combinations of sound relationships, each a mathematically precise aeoustical format ready for further statistical and problematical manipulation [20].

A graphic reduction of a multi-dimensional tone structure is illustrated by the 'Eikosany' (cf. Fig. 1), a 20-tone construction in *hexadic* tone space, developed by the Californian music theorist and practitioner, Erv Wilson. The 'Hebdomekontany', the next logieal progression beyond the 'Eikosany', is a 70-tone construction in *ogdoadic* tone space (cf. Fig. 2). To faeilitate such research, Arthur Lim of Lim Electronics Co. in Santa Monica, California, has designed and built a tone generator capable of producing 1024 specific pitches in each 'octave' (numerically expressed as the ratio 2 : 1) with stability to within one-twelfth of the presently aecepted threshold of pitch relationship discernment.

When this work has been completed, I plan to publish a discussion of the visual results of these sound explorations, along with descriptions and appraisals of the work of others—especially the work of Alain Daniélou (France) [13], Adriaan D. Fokker (Holland), Martin Vogel (Ger. Fed. Rep.) and John Chalmers (U.S.A.).

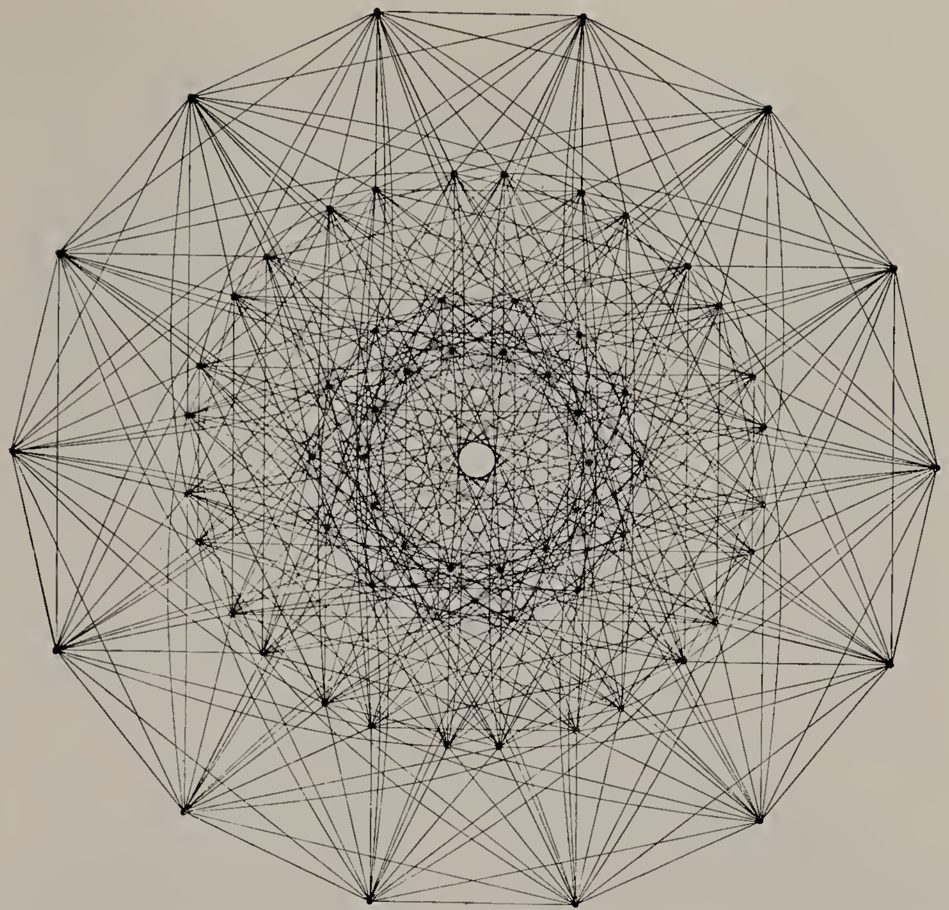

Fig. 2. *'The Hebdomekontany' by Erv Wilson. Graphic reduction of a 70-tone construction in ogdoadic tone space.* (Reproduced with permission.)

Fig. 3. *'Heat Stress Gongs', metal, fiberglass on cardboard tubing, wood, epoxy and lacquer,* 72 × 60 × 36 in., 1968

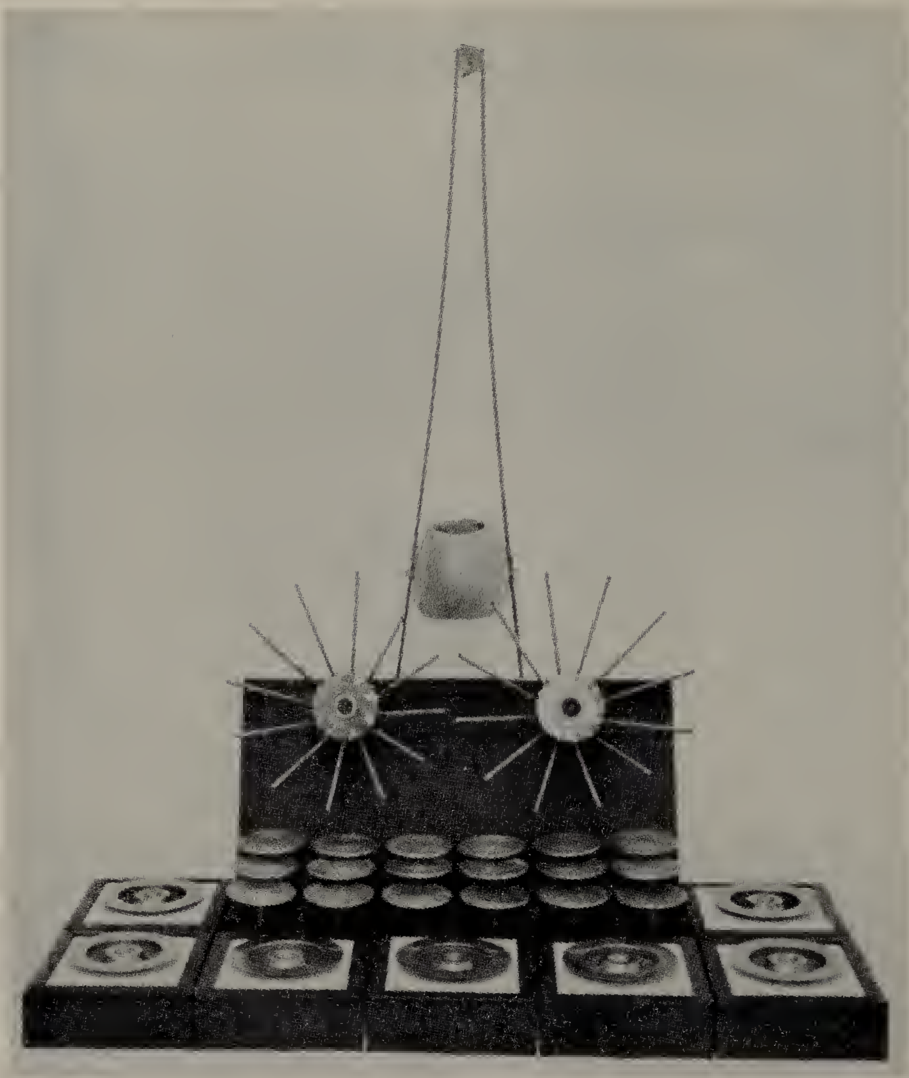

Fig. 4. Top: '*Electric Ektara*', *wood, gourd, canvas, resin and music wire*, 60 × 12 × 12 in., 1966.
Center: '*Brass and Steel Marimba*', *metal, wood and plastic*, 36 × 21 × 29 in., 1968.
Bottom: '*Nipple Gongs*', *metal, wood and latex*, each unit 12 × 13 × 4 in., 1968.

A. '*Heat Stress Gongs*' (cf. Fig. 3)

In this instrument, the seven large discs (top-rear) are made of 5059-heat treated-7 stainless steel. These discs are $11\frac{1}{4}$ in. in diameter with a $\frac{3}{4}$-in. center hole. The center hole increases the amplitude of the fundamental pitch and eliminates most of the inharmonic overtones.

The twelve discs below the seven suspended large discs had been subjected to non-destructive stress tests under high temperatures by the aerospace industry in Los Angeles. This gave the 8-in. austenitic stainless steel discs a greatly enhanced tonal pattern and extended ring time. All of the discs are mounted to their respective resonators at their nodes by four $\frac{1}{2}$-in. squares of $\frac{1}{4}$-in. thick pure latex foam rubber.

The complexity and sometimes impossibility of discerning stable nodal points in materials of high harmonic-inharmonic content is illustrated by Bergmann [22] with a beautiful series of photographs that show the nodal harmonic progressions of circles, squares, rectangles, triangles, hexagons and ovals.

B. '*Electric Ektara*' (cf. Fig. 4, top)

Music wire, $1\frac{1}{2}$-m or longer, when mounted on a highly resonant surface (such as canvas impregnated with laminating resin) and electronically amplified by direct coupling, produces a sound that can be clearly heard for twice the length of time of an unamplified setup. A greatly extended range of complex and subtly interrelating harmonics and overtones also results. The 'Electric Ektara', based on an African monochord [23], was designed to illustrate these phenomenon. A contact microphone was placed between the base of the playing wire or string and the resonator skin, which in turn was connected to an internally mounted F.M. wireless transmitter. The pitch is lowered by squeezing the two mahogany struts together and is raised by pulling the second string. Although the instrument is usually struck or plucked, hypersonic effects, not produced by any other known instrument, result when a specially designed bow of less than 40 hairs is used.

C. '*Brass and Steel Marimba*' (cf. Fig. 4, center)

This instrument consists of two main sections: (1) the two 'spoked wheels'; (2) the 18 steel discs arranged below the 'spoked wheels'.

Each member of the two 'spoked wheels' consists of 0·3750-inch o.d. and 0·28125 (9/32)-in. i.d. brass tubing, 12 to 15 in. in length, each embedded in a base of silica bronze. Each of the two 'spoked

Fig. 5. *'Pyrex Marimba', glass, wood, fiberglass, springs, Nylon and epoxy*, 60 × 25 × 54 in., 1967.

Fig. 6. *'Transcelest', by Erv Wilson. Brass, redwood, rubber and Nylon*, 64 × 48 × 6 in., 1967. (Reproduced with permission.)

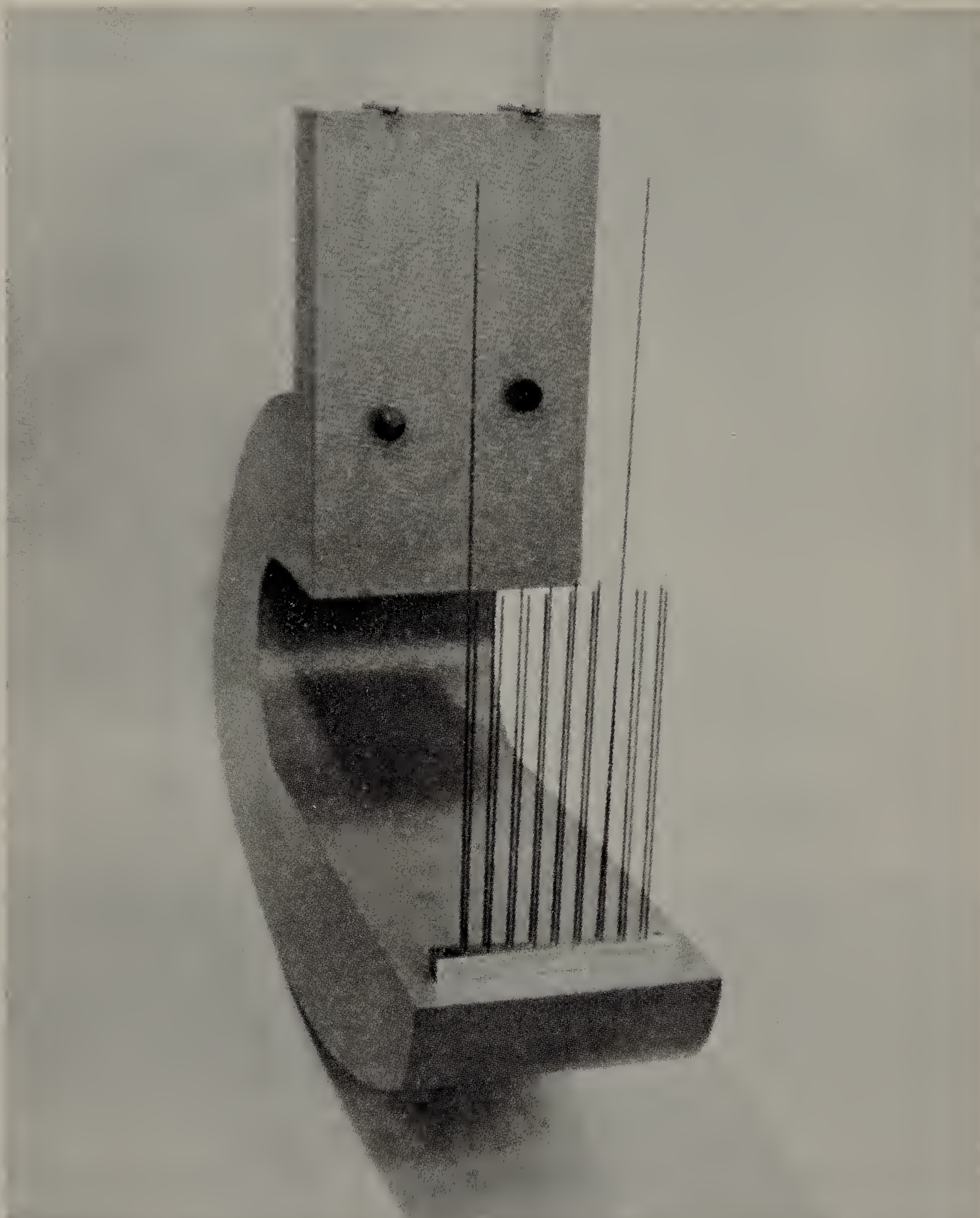

Fig. 7. Instrument by Charles Mattox. Birch plywood, fiberglass, metal, and black and orange epoxy, 36 × 36 × 12 in., 1967. (Reproduced with permission.)

wheels' were originally fixed-frequency radio landing beacons for aircraft. Their sound quality is not particularly harmonic but emanate, when struck in rapid succession, a harsh distinctive sound, similar to that of Javanese bronze scrappers [24] used in their ritual-dramatic theatre music. The 'spoked wheels' span a 2:1 together and each has its own tuning. At the center of each of these 'wheels', a high-speed steel industrial milling wheel supplies interchangeable supplementary tones.

The lower section consists of 18 steel discs, in three rows of six, all 5·3750 in. in diameter and $\frac{1}{4}$-in. thick. Steel rods have been inserted in $\frac{1}{2}$-in. center holes and welded on the bottom side. The amount of weld determines the pitch. In its present tuning, the steel discs cover an approximate range of one-third of a 2:1. Because of this closeness of pitch and the nature of the material, when the instrument is played there is created a unique aural illusion of ascending of pitch when actually descending (as observed on an oscilloscope) (and vice versa) [25].

D. 'Nipple Gongs' (cf. Fig. 4, bottom)

The seven circular gong units, each mounted on latex foam sheeting on black rectangular bases, are made of 400 series (martenistic) alloy stainless steel. Each circular gong has two distinct, harmonically related pitches: (1) a clear strong edge tone; (2) a short, sharp center tone. The 14 tones of the 7 gongs cover a 2:1.

E. 'Pyrex Marimba' (cf. Fig. 5)

The twenty-four Borosilicate (Pyrex) shapes that comprise the tones of my 'Pyrex Marimba' were carefully chosen from a great number of commercially available variations on this basic form. The range is about one and one-half 2:1's and the individual shapes range in diameter from 3 to 4 in. at the front apertures and from $4\frac{1}{2}$ to 6 in. maximum outside diameter. They are held in place by a spring system that allows the tones to 'flex' as they are played. Breakage has been no problem.

F. *'Transcelest' by Erv Wilson* (cf. Fig. 6)

Erv Wilson developed this instrument in 1967. The 47 tones (bar lengths range from 11 to 24 in.) are all 1 in. square seamless tubing, of hard drawn No. 218 brass alloy with 0·035-in. wall thickness. The tubes are suspended conventionally by nylon cord drawn through rubber grommets inserted at the nodes. The instrument covers a range greater than two 2:1's and is tuned to a scale of twenty-two tones per 2:1. An ethereal harmonic interplay and a long ring time are the special characteristics of this instrument.

G. *Instrument by Charles Mattox* (cf. Fig. 7)

The use of stainless steel and aluminum vibrating rods as a sound material has been studied by the audio-kinetic sculptor Charles Mattox. The instrument shown in Fig. 7 has stainless steel rods 0·109375 ($\frac{7}{64}$)-in. in dia. Their length ranges from 11 to 22 in. To mount them, the tip of each rod was first precisely tapered, then coated with Loctite (an industrial compound that catalyzes under the semi-vacuum of a force fit and gives a holding strength greater than that obtainable by a weld or screw attachment) and forced into a piece of $1 \times \frac{3}{4}$-in. aluminum bar stock. The sound unit was then fastened to the sculpture, which has been constructed from resonant materials (birch ply and fiberglass) and carefully designed internal resonating cavities. When the sculpture is rocked by means of a push by a viewer, the rods begin to wave and strike one another, creating microtonal melodies and harmonies that cover a 2:1. At the same time, a progressional off-beat rhythm pattern is heard, merging and countering the sounds of the vibrating rods. This thumping, similar to the sound of a muted tenor drum, is caused by two hard rubber balls (98 per cent resilient rubber that is moulded at 80,000 p.s.i.) suspended from the top of the sculpture by Nylon strings. The 'style' of the sounds produced by the sculpture is determined by the force of the push. An average performance lasts about 5 minutes.

IV. CONCLUSION

One of my basic aims during the past 8 years of investigation was to work toward the elimination of the music listener's present ability to easily distinguish between synthetic and immediate, real-time sound.

The electromagnetic loudspeaker is the major cause for synthetic sound to be aurally identified as such. For instance, an electromagnetic speaker cannot reproduce with complete realism a magnetic tape signal. An experimental flame speaker (being studied by an American corporation), which has complete response and 360 degree equal sound radiation, is a good indication that a commercial replacement for the electro-magnetic speaker may soon be developed. Electronic music would then have the acoustic realism it presently lacks.

The problem with immediate, real-time sound (i.e. musical instruments) is the lack of any significant developments during the last 200 years. To date, I have been concentrating most of my efforts in this area. I conclude that modern materials make possible the construction of unique new musical instruments that, as a body, will equal the gamut of electronic music in acoustic range, fidelity and flexibility. This is not a competition between the two methods of sound production. They will soon be synonymous. 'Electronic music is really only a sub-division of instrumental music' [20]. In order to develop these musical instruments, much more information is needed on the sound-producing properties of natural and industrial materials.

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PATHS BY COUPLER FOR KINETIC ART

Richard S. Hartenberg*

Abstract—*The Lumidyne system developed by Malina for kinetic art employs the circular motion of a Rotor or disk to provide real motion of points or areas. This article discusses a simple mechanical assembly for producing with a Coupler plane non-circular paths of an infinite variety that are traversed at varying rates, although the drive is by constant-speed motor. The assembly controlling the motion of the* Coupler *is called in kinematics a* crank-rocker four-bar linkage.

INTRODUCTION

One form of kinetic art makes use of the *Lumidyne* system that Malina developed especially for kinetic paintings [1]. The basic system has a moving element, a motor-driven *Rotor* (a circular disk) carrying an opaque-transparent design. Any point on the Rotor moves along a circular path at a constant speed prescribed by the position of the point and the speed of the motor. A set of arbitrarily chosen points will describe concentric circles.

In this article, I will examine what kinematicians call a *crank-rocker four-bar linkage*, a mechanism less formidable than its name suggests. It has three moving parts, one of which, the *Coupler*, is somewhat analogous to the Lumidyne Rotor: a set of arbitrarily chosen points on the Coupler move along odd-shaped curves at a varying pace, despite a constant-speed drive, instead of developing concentric circles. Typical Coupler curves are shown in Fig. 1; the perimeter of a Rotor to the same scale is indicated by the dashed line. For both mechanisms —Lumidyne or four-bar linkage—the axis of continuous rotary motion input is the point O_A.

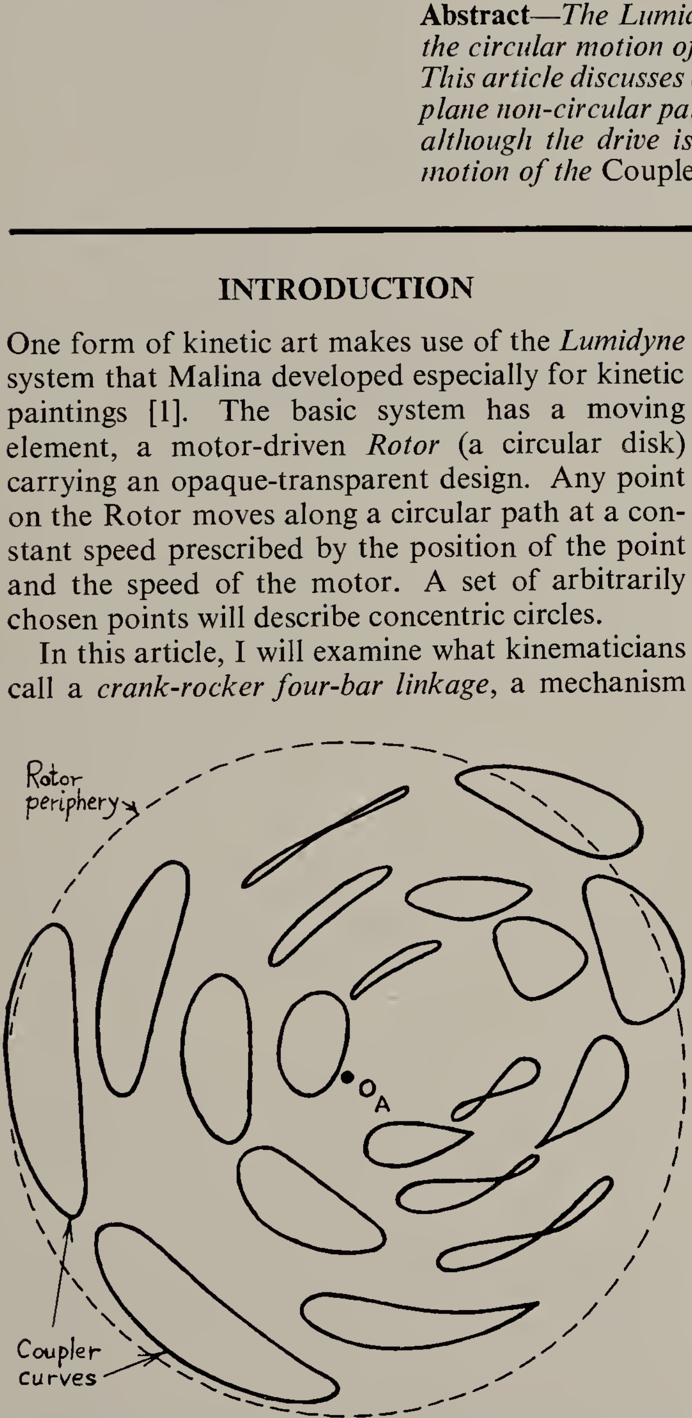

Fig. 1. *Curves generated by* 19 *arbitrary points of the Coupler of a crank-rocker four-bar linkage.*

The circle (dashed line) represents the periphery of a Lumidyne Rotor; other Rotor points would describe circles concentric with this. Point O_A is the axis of rotation for both Coupler and Rotor (cf. Fig. 4).

GENESIS OF A FOUR-BAR LINKAGE

I will approach the construction of the four-bar mechanism by starting with the Lumidyne Rotor and adding to it to produce a four-bar linkage. Fundamentally, Malina's Lumidyne involves two planes (cf. Fig. 2(a)), one moving, the other stationary. The moving circular plane (labeled 2) is the Rotor and it turns about the point O_A of the stationary rectangular plane (labeled 1). This fixed plane 1 (the plane of the paper) is called the frame (of reference) of the mechanism and is indicated by the cross-hatching. Clearly, any point A of the Rotor will trace a circle upon the paper.

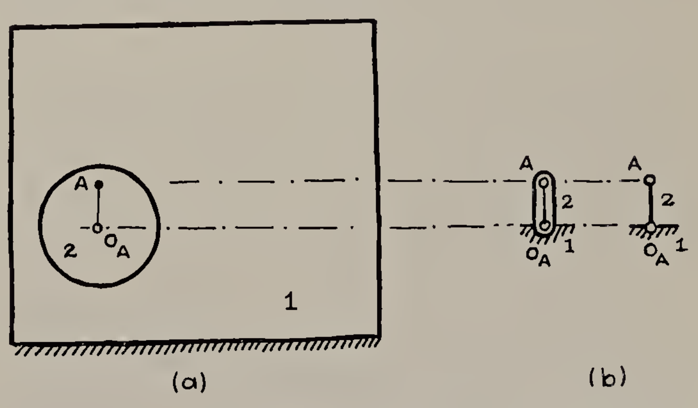

Fig. 2(a). *Lumidyne system, in which Rotor* (*plane* 2) *turns about the axis* O_A *of fixed plane of paper* (*plane* 1).

Point A is a point on the Rotor, that is, in plane 2.

Fig. 2(b). *Schematic representations.*

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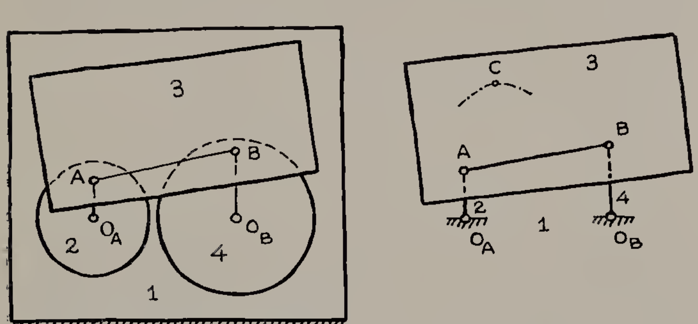
It will be convenient now to introduce the schematics shown in Fig. 2(b); the simplest form is at the far right. The fact that O_A is a fixed axis of rotation is denoted by the crosshatching; plane 2 has been reduced to a 'bar' or 'link' of length O_AA and it follows that point A sweeps a circle of radius O_AA on the paper, plane 1.

Suppose another plane, again in the form of a disk, is added to the configuration, as shown in Fig. 3(a); this plane 4 is simply pivoted to plane 1 at O_B. Any of its points, such as B, could describe circular arcs on plane 1. Finally, let another plane 3 be connected to planes 2 and 4 by means of pins at points A and B; plane 3 is called the *Coupler plane*, for it couples or connects the circular motions of planes 2 and 4. Familiarly, plane 3 is known as the *Coupler of relevance.* The situation is redrawn in schematic form in Fig. 3(b), with planes 2 and 4 reduced to the bars O_AA and O_BB, while plane 1 features the distance $O_A\ O_B$ on the paper. Plane 1, the fixed plane or bar, is the frame, since it carries the motor shaft O_A and the pivot O_B. The important geometric property of Coupler plane 3 is the distance AB, also called a 'bar'.

At this stage, the assembly is the four-bar linkage of kinematics. If the total geometry is correct, that is, if the ratios of link lengths are proper (we will come to this criterion later), then link 2 can rotate completely about O_A and cause link 4 to oscillate or sway about O_B.

The rotating bar 2 (O_AA) is called a *crank* and the oscillating Bar 4 (O_BB) is known as a *rocker*; this kind of four-bar linkage is termed a *crank-rocker four-bar*, also *Class I four-bar*. Link 3 will reel about in drunken fashion, only two of its points, A and B, making predictable tracks on plane 1; point A will draw its circle, B will describe its circular arc. Any other point of the coupler plane 3 (a point such as C) will draw non-circular closed curves on plane 1, called *Coupler-point curves* or, simply, *Coupler curves*, curves of the types such as displayed in Fig. 1. Since a plane has an infinity of points and each point can describe a curve, there is an infinity of curves, no two of which will be identical in shape, although curves of neighboring points will have a resemblance.



(a) (b)

Fig. 3(a). *Four-bar linkage, in which plane* 3 *is the Coupler between planes* 2 *and* 4.

Point A is common to planes 2 and 3, and B is common to planes 4 and 3.

Fig. 3(b). *The four-bar linkage in schematic; arbitrarily chosen point C of the Coupler plane* 3 *traces a curve on plane* 1, *the paper.*

TO DRAW COUPLER-POINT CURVES: FULL-SCALE WORKING LINKAGE

The only feasible way to explore what is going on is to make a typical linkage, choose some coupler points of arbitrary location and let these points draw their curves on plane 1, the paper. Such a prototype linkage is shown in Figure 4; in it some arbitrarily chosen points of the transparent Coupler plane 3 present their curves, already familiar from Fig. 1. The chosen points are identified by the black blobs. As I remarked earlier, these coupler-point curves are non-circular but closed, repeating with each revolution of the crank O_AA (link 2). Technically, the curves (all of them) have been named *tri-circular sextics*, which means that they are of the sixth order, that is, describable mathematically by a sixth-degree equation. The practical meaning of all this is that they contain neither true circular arcs nor true straight lines, although approximations to such curve segments may be quite good and even satisfactory for some applications outside of my present concern. Fortunately, one can let coupler points tell their story directly by means of a simply constructed full-scale model.

The base for the model of Figure 4 consists of several layers of corrugated carton stock, cut a bit larger than the size of the paper 1 to be used, here $8\frac{1}{2} \times 11$ in. (216×279 mm); this material holds ordinary pins well and allows them to be withdrawn readily, an impossibility were a wooden drawing board used as a base.

For a schematic of the linkage we return to Figure 3(b) for identification of the parts. To insure that the demonstration model will be crank-rocker four-bar type with rotating input at O_A, the following link lengths are suggested:

Link 1, Frame, O_AO_B = 1·30 in. or 33·0 mm
Link 2, Crank, O_AA = 0·40 in. or 10·2 mm
Link 3, Coupler, AB = 1·15 in. or 29·2 mm
Link 4, Rocker, O_BB = 0·95 in. or 24·1 mm

Plane 1 is the paper stapled to the base; the two points O_A and O_B are 1·30 in. apart on a horizontal line (cf. Fig. 4); point O_A is located in the center of the paper. Links 2 and 4 (crank and rocker) are made from stiff cardboard strips $\frac{1}{6}$ in. (4 mm) wide. Link 3, the Coupler, is a sheet of thin transparent plastic about $5\frac{1}{2} \times 8$ in. (140×200 mm), with the distance AB set equal to 1·15 in.; point A is put at the center of the plastic sheet, with B on a line rising to the right. Points on the Coupler sheet were selected at random and were made as small holes to allow the insertion of a sharp pencil point or ball-point pen. To assemble, links 2 and 4 were pinned to the corrugated carton base at O_A and O_B, and the plastic sheet impaled on upward-pointing pins at

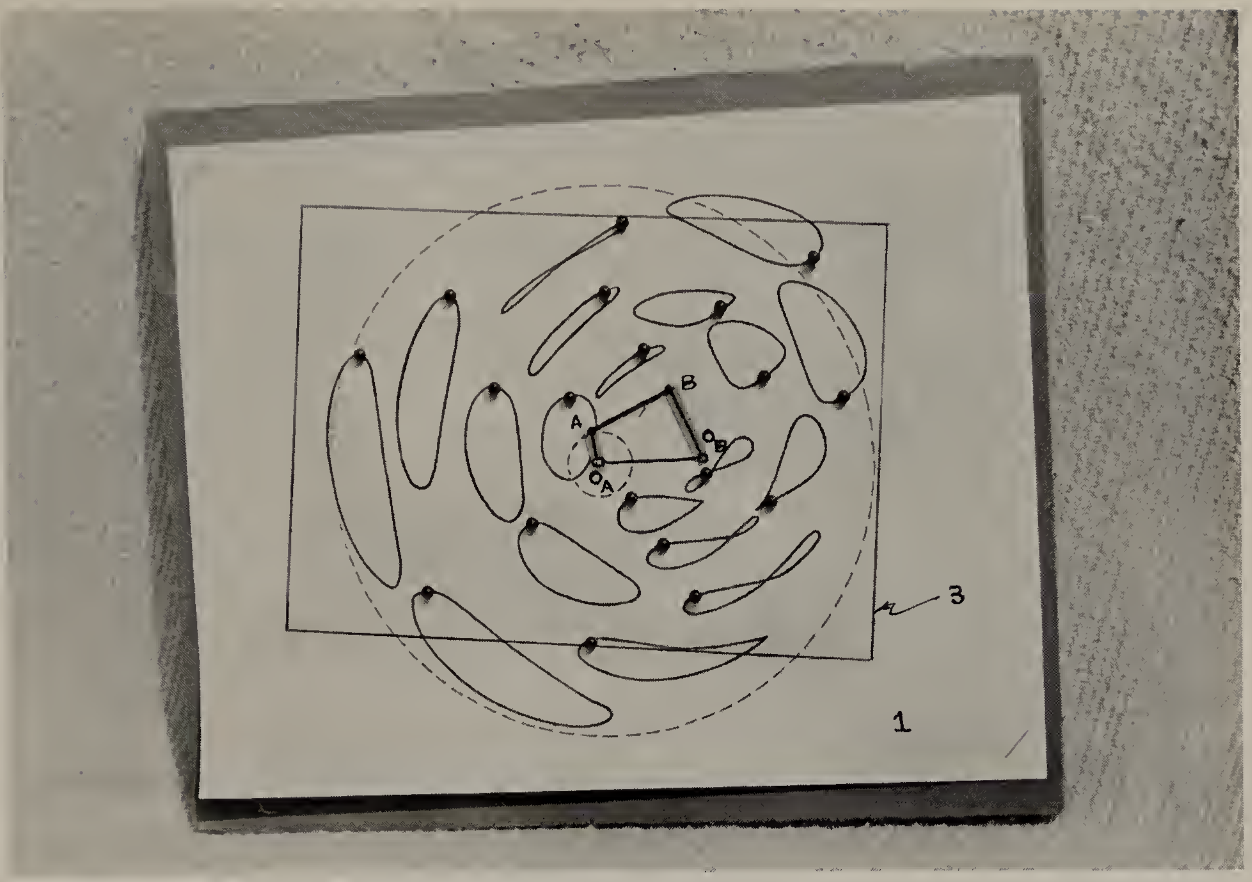


Fig. 4. *Photograph of model of crank-rocker four-bar linkage described in text and curves drawn by* 19 *points of Coupler* (*cf. Fig.* 1).

The curves on plane 1 are seen through the transparent plastic Coupler plane 3. The black blobs mark the Coupler points and show their positions on their respective curves at the same instant.

A and *B*. The Coupler plane is thus topmost, lying over links 2 and 4. If the pin at *A* is used as a crank, link 4 will be observed to oscillate over an arc of about 45°. At the same time, other points on the Coupler sheet perform complicated movements.

Drawing the coupler curves requires a bit of care and some patience because of the flimsiness of the model. It is helpful to 'crank' the mechanism using the pin at *A*, while otherwise 'driving' with the pencil at the selected Coupler point.

It is evident from the array in Figure 4 that coupler curves have as many shapes as points selected and that sharp curves, easy curves, crossovers, double points, 'straight' sections, cusps and so on are present. Furthermore, it may be observed that the points do not move along their curves at a uniform rate even though the crank is turned at a constant speed: the points will at times dart along, at other times proceed only slowly. (The dashed line circle in Figure 4 corresponds to a 7 in. (178 mm) diameter Rotor.)

The shape of the curves and their location depend upon the proportions of the linkage as much as on the choice of coupler point; if the length of but one link is changed, a new mechanism is produced and a new infinity of curves will result. To guarantee that a rotary input is possible at O_A by the shortest link requires the mechanism to fulfill the *Grashof* criterion: The sum of the lengths of the *shortest* and *longest* links must be less than the sum of the lengths of the other two links. To use the dimensions of our model, $0{\cdot}40 + 1{\cdot}30$ is less than $1{\cdot}15 + 0{\cdot}95$, thus satisfying the criterion for allowing O_AA to function as driving crank turning about O_A. (Our links were assembled in a certain order, giving a particular mechanism to discuss; were the order changed, a different mechanism (different Coupler and hence different points) would result. Either neighbor of the shortest link could be elected as the frame or fixed link.)

Curve shapes are independent of the scale of the linkage. For example, were a new model made from links that were twice as long as those of the original, then similarly located points would draw curves similar to but twice as large as those of our model and the whole would occupy four times as much area.

It may be observed that the relative motion of both crank and rocker with respect to the Coupler is rotation because of the direct pin-connections between *A* and *B*. If, therefore, crank and rocker were disks (cf. Fig. 3(a)) that might carry a design, they could be invoked to act as not only normal Lumidyne Rotors but also as local Rotors with respect to a design on the Coupler sheet: the mind boggles at the possible combinations in depth!

In the foregoing I have presented a rather sketchy treatment of the four-bar due to singleness of purpose. A broad view of crank-rocker coupler curves is given by Hrones and Nelson [2]; here over 7000 coupler-point curves are on display and, if a pleasing curve is found, the proportions of the associated linkage are immediately at hand. Theoretical treatments of the general four-bar linkage, as well as fields of application, are to be found in Hartenberg and Denavit [3], and in Rauh and Hagedorn [4].

It is possible to design a four-bar linkage such that *one* coupler point will describe a curve with a unique property, for example, symmetry about a line, or containing two apparently straight lines in V-formation, or having one cusp or two, or showing one or two double points. All other coupler points will, however, not be subject to this control and will go their own way. Tao [5] gives no-nonsense graphical procedures for obtaining the special coupler-point curves.

SUMMARY

If it is of interest in kinetic art to have points move on non-circular paths of odd shapes, then the coupler-point motion of a four-bar linkage merits consideration. The mechanism is simple, having but three moving parts driven by a constant-speed motor, and for a kinetic painting the overall case dimensions would need to be no greater than those required to house the mechanism of the Lumidyne System.

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THE STUDIO OF WORD, SOUND, MOVEMENT OF THE JANÁČEK ACADEMY OF MUSIC AND DRAMATIC ART, BRNO, CZECHOSLOVAKIA

Bedřich Jičínský*

If we conceive modernity in art as the artist's creative ambition to resound in a new way to new reality, then it is the space and time of the stage that is a suitable complex medium for this purpose and that, at the same time, is an effective means for an anthropological-social response. The stage synthesizes, in the specific manner of its poly-dimensional, audio-visual activity and its immediacy of space–time impact on people, almost all of the authenticity and of the conventions of the creative arts. With the theatre's instinctively cleancut and wise feeling for craftsmanship, it is a unique example not only of the very effective co-existence of the variety of artistic materials and methods and of relevant contemporary technology but also of their fertile interaction.

The arts, with their deep roots in emotion and intuition, are a profoundly organic, inalienable component of the organization of this world. They are governed by the same laws of material, kind, system and behavior, structure, sign and function, communication and so forth. Just as in the natural sciences and in aesthetics, so too in artistic activity the centre of gravity is shifting to an engineering approach. It is shifting from the classical Archimedian sphere of energy and mechanics to the non-classical and more effective Pascalian sphere of information and communication. Contemporary life has been moulded in a revolutionary way by science and technology. Cognition and action, particularly as regards the creativity of the artist, are strikingly carried on now as intellectual abstractions of life and of the universe. It is natural, therefore, that the processes of artistic creation, of the interpretation of the works of artists and of the perceptions and reactions to art by consumers are receiving great attention.

The idea of the *Studio* is beginning to be realized at the Janáček Academy of Music and Dramatic Art in Brno, Czechoslovakia [1]. As a College of Arts, the Academy covers both practical and theoretical aspects of these arts, with special emphasis on the complexities of the processes of creativity and perception. In the relationships of both artistic and scientific processes, certain categories are dominant, such as work with word, sound and tone, with movement, with visual art elements, work with the body, the voice, musical instruments, technical apparatus and material. Associations, such as '*man:* voice–instrument–apparatus–material', '*body:* word–movement–sound–visual art element' and '*action:* control–self-control–inner discipline' are making themselves felt, all capable of objective observation, fixation and reproduction. Analytic as well as synthetic cognition on a technical, physiological and psychological experimental basis here opens up entirely new and unexpected possibilities of creative work with artistic expression and material, with the 'reason' of its technique.

Interdisciplinary co-operation is being put into practice by means of teamwork on the part of theoreticians, artists and technicians. It seeks its greatest measure of support from a complex audio-visual technique—sound and image recording and reproduction, sound and image production, stage and lighting equipment, and optico-acoustic apparatus equipment for research and experiment. This technique, applied to the methodological, pedagogical and artistic process on the scale of the whole Academy, is intended at the same time to further research activity with priority in the field of stage and platform interpretation and/or authorial art, which

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in this country has scarcely been touched by research.

The *Studio*, being incorporated into the existing college building, consists of a number of specially designed and equipped rooms arranged on two internal floors (Figs. 1 and 2). For stage productions, there will be available an adaptable hall space with a specially constructed stage and basic scenic equipment (Figs. 3 and 4). This will permit television production, cinematograph production of the 'polyecran' and 'polyvision' type, production of radio sound and of experimental music, either individually, in isolation or in any combination. In addition to these, there will be variable acoustic conditions of the hall space, a variable mirror wall in the back right-hand corner of the stage and several polyvisional objects. The expressional stage possibilities of the main hall, interconnected with auxiliary rooms, are thus considerably multiplied by those of radio, television, cinema and experimental music production.

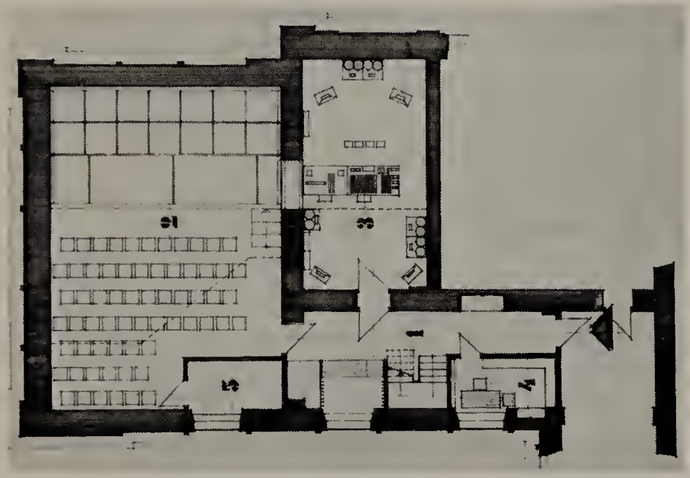

Fig. 1. *Plan of lower floor:* (1) *entrance passage with staircase and cloakroom;* (2) *main hall with stage* (*contains storeroom and part of gallery-room*); (3) *room for audio-visual recording and producing, and for experimental music productions;* (4) *archives;* (5) *storeroom.*

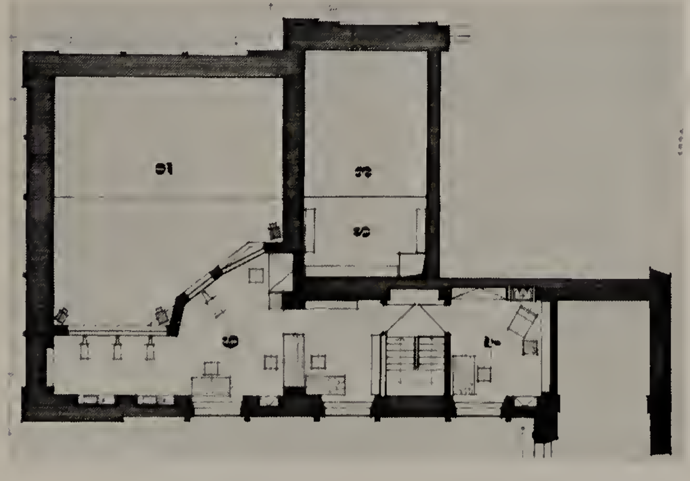

Fig. 2. *Plan of upper floor:* (6) *gallery-room* (*internally partitioned*) *for stage light operation, film projection and for laboratory work of engineer, psychologist and medical doctor;* (7) *laboratory of medical doctor* (*a phoniatrist, possibly an orthopedist*); (8) *small balcony for apparatus development.*

The stage activities will be realized here in the spirit of the distinctively *Musal* stage tradition of the avant-garde Czech theatre of the 1920's and 1930's, including its technological suggestions. (*Musal* is equivalent to the term *múzický*, signifying 'pertaining to the Muses', i.e. including the arts of theatre, music, dance and poetry.) One of the most significant of these was the theatre of light, which renders the medium of light a decisive element of scenic composition. The so-called *Theatregraph*, based on similar principles, enabled the simultaneous perception of actors, cinema film action and/or slides. Today's *cine-automat* (for activating audience participation) and *polyvision* (use of objects in motion) are based on ideas of that time. The Musal approach signifies synthetic polyphonic stage work involving relevant branches of art, such as literature, music, dance, visual arts, architecture, film and radio. Only developments of modern technology have made possible the practical realization of the expressional potential of these media and provided the conditions for a full expansion of the peculiarly Czech stage poetry to these branches. The artist of the stage transforms himself into a poet of the stage.

Our *Studio* carries on the Czech tradition of the theatre of poetry, which, as a kind of 'platform' art, goes even further back than the 1920's to the 'evenings' and 'academies' consisting of recitations, musical and dance numbers performed on a platform, i.e. a setting more or less visually designed for that purpose. In the late 1920's, the Czech theatre originated the remarkable 'voice-band' activity that entailed a very effective 'theatricalization' of the

Fig. 3. *View of front part of the main hall.*

Fig. 4. *View of back part of the main hall.*

word, in the sense of mingling literary and theatre elements with elements of music and 'expressional' dance. This fertile stage interaction of word, music, body and object was realized in the poetic, metaphorical and montage dimensions of a modern stage poem.

The artistic activities of our *Studio*, then, should be on the one hand an organic and creative expansion of native theatrical developments and on the other hand the concretization of present-day theoretical and artistic demands already dealt with above. Work with sound and image modulation (including computer techniques), work with light rays (including lasers) will be combined with the optical and acoustic expressional components of the human body and with static, kinetic (figurative and non-figurative) visual artifacts and architectural constructions—both material and camera projected.

Movement is seen here as an integral constituent of all stage activities, in the sense that kinetic principles are to give a feeling of the unification of the human body with objects, pictures with sound, sound with light rays and so on. It is even intended to investigate, on the basis of space–time kineticism, the possibility of seeing by sound, hearing by movement and obtaining a sense of movement from words.

The percipient of today is prepared to accept new rules of the stage game. He is beginning to accept art as a direct participant also in the dimensions of objectified scientific–technological creation. The mystery of living matter, with all the dynamism of human physique and psyche, is opening up in an ever more organic way to the expressional and creative mysteries of technique. Man, his own sensitive instrument of artistic effort, is step by step becoming fused with man, the no less sensitive operator of the expressional effort of technique, its technological creativity and poetry.

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NON-VERBAL 'DISCUSSION' USING MUSIC AND KINETIC PAINTING

Richard I. Land*

Abstract—*Using a new instrument, the author's* Chromara, *which 'paints' with lights on a translucent screen as a function of time, and a piano, two individuals composing on their respective instruments inter-related their efforts to provide a single unified experience. Throughout the period of simultaneous performance there was much evidence reported by each individual that a form of unplanned communication took place between them that influenced the musical and visual compositions they created. The only preparation made before the performance described was the previously developed competence of each artist with the piano and the* Chromara *instrument. This experiment provides, perhaps, further insight into the possibilities of communicating vast amounts of information without resorting to the complicated syntax and vocabulary of ordinary language.*

I. INTRODUCTION

The experience of non-verbal communication is common. The concert audience, viewers of the ballet, reaction to various natural phenomena, and the rituals and actions of love making are all instances where a definite experience of great elaboration is enjoyed without words being employed. In more specific examples, opera composers collaborate with librettists, choreographers and composers co-ordinate their efforts, song writing matches music with poetry and animated patterns have been designed to accompany musical compositions [1–3].

In almost every instance the communication is one way. An artist creates in one discipline, and then a response is generated in another, or in the audience. Perhaps there have been occasions with ballet development where close mutual creation takes place, though this is rare. Most developments require one mind to initiate a succession of ideas, then some vocabulary is used to convey the creative effort, so that the collaborating artist may respond. As in the case of ballet, there are notations available to both musician and dancer, in addition to the common verbal communications. In cases of co-operative development, languages of one or more types are used in addition to the non-verbal art forms.

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II. THE CHROMARA INSTRUMENT

A new instrument, which I call the *Chromara*, uses light as a creative medium, and has simple manual controls to make observer-controlled kinetic 'painting' possible [4].

Colour, intensity and pattern, as well as some aspects of motion or rhythm,can be varied from a small manipulator box placed at a distance from the instrument producing the images. The *Chromara* uses a system of programmed forms, lights and optical effects to produce images on a translucid screen (Cf. Fig. 1). Successful control is easier than using the keyboard of the piano and is generally satisfying even in the most primitive usages. While the images produced range far short of the variety of shapes and arrangements that one can imagine, they are infinite in number with a chosen set of light reflecting and shadow producing elements. The artist at the controls only rarely feels frustrated in expressing himself within the instrument's capabilities. Thus, as with the limited tone, scale, intensities, pitches and control techniquçs associated with the piano, the *Chromara* is comparable. The *Chromara* cannot be classified as a machine, since it is an interpretive and expressive instrument for producing visual artistic experiences.

It should be observed that since the sense of sight is remarkably different from that of hearing, there is no direct correspondence between them. The ear responds only to the intensity of time variations of pressure. The eye, on the other hand, responds to variations of the wavelength and the intensity of light in space and with time. Thus seeing compared to hearing would be like a full colour T.V. picture compared to only one thin line of a black and white T.V. picture. Pitch does not correspond to form, tone only loosely corresponds to colour, harmony and pattern are perhaps remotely related and the two rhythm systems cannot, in general, correspond exactly.

Pleasing visual rhythms tend to be an order of magnitude slower than musical ones, perhaps because of the greater volume of information being assimilated. Generally, the relationship between the creation of visual images and of musical passages is interpretive and imaginative, rather than a simple logical association, as might be performed independently by a computer. Although elaborately programmed computers may produce relationships in specific instances, each program reflects a different interpretation that must withstand subjective judgment.

III. A 'DISCUSSION' BETWEEN PERFORMERS ON A PIANO AND A CHROMARA

The experimental arrangement I will discuss now consisted of the *Chromara* on top of a piano, the musician at the keyboard, and the painter behind him with the *Chromara* manipulator box. Each could fully see or hear what the other was doing. Both were familiar with the other's medium, both having independently played the piano and the *Chromara.* In addition, both had worked together in theatrical work as composer and designer, as well as having discussed the character of various creative activities. One might say there was a prejudicial friendship and a mutual understanding about styles of expression, but there were no specific agreements made beforehand. The limitations of the respective instruments were the only boundaries imposed on the performers.

There were two extended occasions of composition. At first, independent exploratory playing by both individuals took place for several minutes during which the images would change while the musician would just watch, then the images would stop changing and the music would be listened to by the painter. Then, by some undesignated process, both forms of expression began to change using rules which were devised as the experience progressed. Thus the first occasion, which lasted for nearly half an hour, began in silence with the screen dark, and developed into a mutual state of composition.

The remarkable situation which developed was that clearly first one then the other would be the leading 'form', often blending together as a single unified statement. A developing melody would be complimented by evolving patterns, the patterns would then influence the musical progression in such a way that directions were followed or changed as if by creative agreement. Certainly there were moments of frustration when the two forms would assume contradictory postures, but then they would resolve themselves again under the performers guidance.

When words are not used it is virtually impossible to describe, with words, the obvious results of communication that occurred. While visual and aural developments could be built, restatements made and intervals bridged together, the ending was imperfectly agreed upon, but it was not quite as indecisive as the beginning. The adjustment of rhythms between the two media was most difficult and the least satisfyingly co-ordinated. At the end there was a noticeable exhaustion as well as a feeling of exhilaration on the part of both participants. Only much later in the day was the experience repeated, resulting in perhaps greater co-ordination, but there was less inspiration.

It is hoped that the experiment will be attempted several times again, especially with the use of a special recorder that can record both artistic results. There are numerous musical variations and changes of image pattern structure that remain to be tried. Obviously, the range of possibilities is large and selecting a most fruitful approach is a major problem.

IV. CONCLUSIONS

I have reported on the results of two individuals communicating by means of sound and vision over an extended period of time, independently of words, just as two persons might in a conversation. The volume of information conveyed, I believe, far exceeded that which ordinary language could have handled during the same period. Having complete freedom within their respective media, the two performers shared in the creation of a visual and aural experience which was, I believe, more significant than either could have produced individually.

This experiment has implications in the general field of communications that go beyond the production of artistic experiences. There are several instances where large volumes of information need to be transferred, and present methods are either too slow or space consuming. Obviously a computer output using linear exposition of limited symbols in a complicated syntax is wasteful in the time its discernment takes, and ambiguity still remains. Astronauts are faced with thousands of instrument readings which cause capsule space to be wasted, confusion to be caused, and omissions to be unavoidable. While illustrational styles of computer communication are just now being developed and tactile signals are being suggested for instruments, perhaps there is an audio-visual 'vocabulary' which might be developed from the infinite possibilities available that will offer a significant increase in the information flux into men's minds. I have reported on only one example, which stands at the beginning of work I have currently under way.

The indispensable co-operation of Gregory Levin, the musician in this experiment, is most gratefully acknowledged.

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Fig. 1. *Example of picture produced by Chromara* I, 38 × 38 cm, 1964.

COMMENTS ON VISUAL FINE ART PRODUCED BY DIGITAL COMPUTERS*

Frank J. Malina**

I.

I have had no direct experience with digital computers either in applied science or in art, mainly because they were developed too long after I was born. I have read technical and philosophical studies of this intriguing device [1–5] and, as the editor of *Leonardo*, I have struggled with manuscripts by artists who have used the computer to aid them in producing visual fine art [6–11]. Furthermore, since I make kinetic art objects utilizing electric light and mechanical or electronic systems to provide motion, as well as traditional static images with paints and pen, I have a very critical attitude towards the output of computers instructed by artists.

For the purpose of my discussion, it is not necessary for me to go into the principles of operation of a digital computer, the differences between hardware and software, and the methods of programing. It is important, however, to stress that computers available today do what man tells them to do, provided the instructions are compatible with the computer's internal construction. The computer can imitate only a very limited part of the potential of the human brain. It does this at speeds vastly greater than is possible with our brains or our hands. Results that would have taken years to obtain two decades ago can now be achieved in a few hours or days.

Scientific and mathematical problems can now be solved with the aid of computers that before were put aside because of the enormous number of calculations that were required. Subjects such as meteorology and economics, which daily involve a great quantity of statistical analysis, may be expected to become more reliable in their power of prediction through the use of these machines. Astronauts have learned to depend on computers for the guidance and navigation of their space vehicles, although very reluctantly, for they at first feared that their skills as pilots were being taken over by a machine.

II.

The computer, in response to appropriate programed instructions, offers to the artist the following possibilities:

1. *Line drawings and compositions made up of typed symbols, in black and white or in color, on paper or a similar material, ready for framing*

Variations of these kinds of output of a computer can easily be made by changes in the instructions. One should bear in mind that these outputs can be produced without the computer, as far as the basic artistic conceptions of content are concerned. For example, the line drawings of a computer can be made by hand with a pen or pencil or by means of simple mechanical devices, such as the double pendulum [12]. Compositions of typed symbols can be made on a manually operated typewriter [7, 8, 11]. The advantage of computer graphic art is in the speed and quantity of copies that can be produced, perhaps at a lower price than by other traditional methods. This would allow a larger number of persons to purchase an example.

2. *Sculpture made by automatic machines controlled by a computer*

To make three-dimensional objects, a computer is provided with a program of instructions for conversion into commands to an automatic machine. A simple example is a symmetrical object turned in a wood or metal lathe. More complex cutting machines are available in industry for making irregular forms. Whether the traditional method in which the artist makes a prototype by hand, from which copies can be cast in plaster or metal, will be displaced by the new method is not obvious.

3. *Paintings made by an automatic machine controlled by a computer*

A computer would be used in the same manner as for making a sculpture, except that a special automatic machine would be required to apply paints to a surface. A painting machine is not at

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* Text based on a talk given at the *Décade: L'homme devant l'informatique* at the Centre Culturel International de Cérisy-la-Salle, Manche, France on 18 July 1970.

** American artist and astronautical engineer living at 17 rue Emile Dunois, 92-Boulogne sur Seine, France. (Received 25 July 1970.)

present available but perhaps a sufficiently flexible one could be constructed to give interesting results.

4. *Displays on a screen of a cathode ray tube*

A computer can be instructed to command the formation of black and white or colored, static or kinetic images on the screen of a cathode ray tube similar to that used in television sets. The images may be viewed directly or recorded on still photographs, cinema film or video tape. It is also possible to give a viewer the visual experience of three dimensions by stereoscopic separation of images through the use of auxiliary devices [6]. One can expect in the near future computer-produced visual art recorded on video tape for projection on the screen of a television set in the home, whenever desired. This kind of application of a computer may be the most promising one for the future of the visual arts.

5. *Compositions made up of a number of basic elements arranged according to a predetermined combinatorial principle*

A computer would provide instructions on the location of each basic element on a surface according to prescribed rules, for example, to avoid the same color in a part of an element touching the same color in neighbouring elements and to avoid the same shape in a part of an element touching the same shape in neighbouring elements. The artist (perhaps one should say craftsman) then takes the computer instructions and paints the composition or assembles previously prepared elements made to the desired scale. The computer only serves as a labor-saving device in arriving at combinations prescribed by the artist [10].

III.

By the time computers became available to them, artists had already used other means to make static and kinetic, two and three-dimensional visual art, including audio-visual kinetic art. Since a computer must be told what to do in detail, artists are forced to fall back on images with visual conceptions of content that have already existed before—the computer then makes imitations of them. It does permit the production of many variations of the components of the programed image or object—lines, areas, volumes and color, and time sequences, if they are kinetic, can theoretically be varied endlessly.

The capability of a computer to produce easily variations of an artist's basic artistic conception may be a blessing for some artists. The artist in the past, in order to earn his livelihood, has been forced to make by hand a large number of art objects that are but minor variations of a given prototype. The pressures on the artist from the commercializers of art to make quantities of variants of a prototype bearing a clearly recognizable 'trade-mark' further aggravate the 'production' dilemma of the creative artist. This consideration is based on the conviction that only the prototype can be considered a significant creative act and that the artist becomes frustrated when he must make repetitions of the prototype with only minor variations. The fact that the works of an artist are divided into 'periods' can be blamed on the above considerations, although it is quite possible that the very nature of the human brain limits an artist to one or very few significant creative visual ideas during his lifetime.

No computer exists today that can be told to produce an image containing a specific content, say a reclining nude or a geometrical 'landscape', with an original visual conception of its own invention or *vice-versa* that will be aesthetically satisfying. If a computer is given instructions that exceed its capability, it may either come to a stop or make something classifiable only as 'garbage'. Furthermore, a computer can neither provide the artist with any new physical dimension beyond the two dimensions of drawings and paintings, the three dimensions of sculptures and constructions, and the added time dimension of kinetic art, nor make available new optical illusions.

In spite of the limitations of present day digital computers, artists will and, I believe, should make use of them. One cannot expect that, in the short time that a very few artists have had access to them, all of their possibilities have been explored. This exploration is severely limited by the high cost of computer time and by the reluctance of artists to learn the intricacies of computer operation and programing. Those artists who are interested in taking advantage of developments in modern technology generally look upon scientists and engineers as magicians who can do anything imaginable. From my experience, artists consider them as uncooperative because they tell the artist that their ideas violate the laws of nature, demand inventions that have not been made or would cost vast sums of money to be accomplished. There are, of course, scientists and engineers who mislead the artist by telling him that 'the difficult we will do immediately, the impossible will take a little longer'.

I believe the most important benefit to be expected from the use of computers by artists will be sociological. They will help to dispel the not uncommon view that computers are monsters rather than highly sophisticated devices that can serve man, if intelligently used.

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A CONVERSATION ON CONCRETE MUSIC AND KINETIC ART*

Frank J. Malina and Pierre Schaeffer*****

Malina. Audio-kinetic art has interested me for some time. I would like to know your views on the marriage of sound and image.

Schaeffer. I am not *a priori* against combining sounds with images, either static ones or those in motion controlled by sound, but what has interested me the most during our period of the discovery of what is sound is the fact that sound has been separated from visual images and that one can master sound in itself. I was led to this very naturally because my most active professional work coincided with the pioneering period of radio broadcasting. I worked as an engineer for 20 years with radio both as a program arranger and a composer. I combined the elements of sound and took a relatively new point of view of the relationship between a text, its accompanying music and 'noise'. I was forced to analyze the human voice and the medium we call radio.

It was around 1948, having had already considerable experience with texts and sound in radio, that I wished to go further, to do a program without words, with music entirely composed of 'noises', that is, sounds not made by musical instruments or by the human voice. I was up against a brick wall. When one wants to do something solely with noises, one has to make a drastic choice. For there are two possibilities: either one does or does not tell a story with noises; when one does not, one takes sounds for their intrinsic qualities and then the relationships between them give a kind of music. Actually, I did not then dare to call this 'music', for it was too unusual when compared to classical music. Therefore, I finally called it 'concrete' music to indicate it was not of traditional conception—instruments, notation, composing—but that it consisted of recorded sounds not produced by especially designed musical instruments or by voice (Fig. 1).

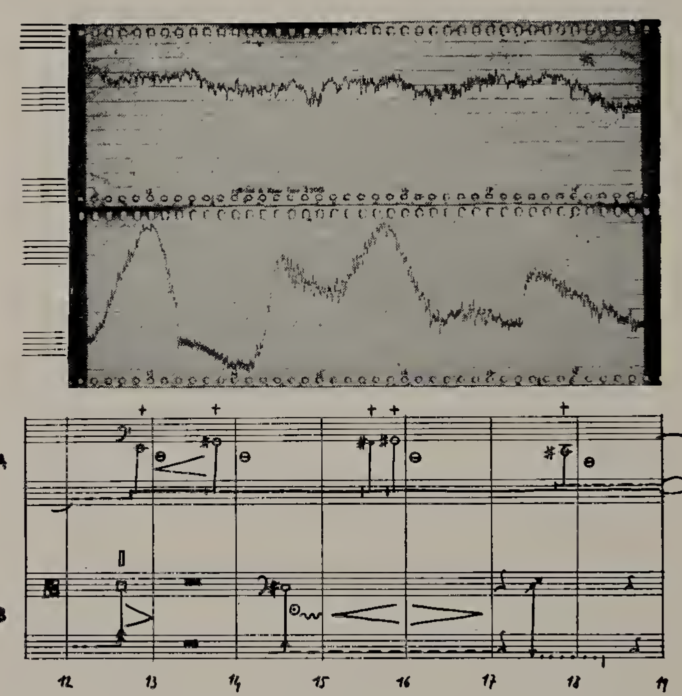

Fig. 1. P. Schaeffer, portion of a study for concrete music, 1958.

M. Listening for the first time to a record of your concrete music, I derived nothing from it. But after hearing it many times, I listened with more and more interest. This is a common experience. It was the opera that first introduced me to the problems of integrating sight and sound.

S. I am going to tell you a story that proves the importance of the absence of an image connected with sound that will help you to understand what I am talking about. A friend, Jerome Peignat, told me that the Greeks knew of this experience and called it *acousmatics*—the study of the meaning of sound and noise when their origin is ignored or unknown. In usual communication, when one hears something, its origin is usually easily verifiable (whether it be a bird singing, a violin playing or someone speaking). Acousmatics was the basis of Pythagoras' teachings. The Master had his disciples

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* This conversation was arranged and recorded by Madame Valérie Soudères at the Moulin de Dionval (near Chartres), France, on June 1970. (Based on the translation from French into English by Joyce Mandelbrojt.) (Received 24 July 1970.)

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listen to him without seeing him. Thus, they concentrated on what he said without his person visually distracting them. Vision can, indeed, be a distraction. When I listen to a violin being played, my attention is drawn to the gestures of the violinist and to the technical aspects of his instrument for producing sounds—my understanding of the music he makes is affected by what I see. But when I listen to the radio or recordings, I am forced to modify my listening, to penetrate into the sounds alone. This corresponds, in a way, to reasoning either by deduction or induction. Listening to live orchestral music is essentially deductive listening, it is strongly deduced from vision, whereas listening to the radio or a phonograph is inductive or acousmatic listening.

M. I suppose one needs to be trained to listen in an acousmatic manner. The technique I use to make kinetic paintings, which I call the Lumidyne system, is not visible to the viewer [1]. Most viewers at first want to know what the hidden system is like. Some are content to watch the painting without knowing how it is produced.

When I began making paintings of this kind, I found it very difficult to view the picture as an entity independent of the technique. I am sure a composer of piano music is not conscious of the interior mechanism for producing sounds because the piano is so well known to him.

S. New listeners to concrete music ask me: 'How do you do it?' The question always makes me angry, as I feel it is none of their business!

M. I am not sure the question is pointless—it is simply a normal manifestation of human curiosity, at least for those who do not just love to be mystified.

S. Classical musical instruments are so well known that they no longer strongly distract one's attention by wondering what they are. But, unfortunately, when a new instrument appears, attention is drawn to the instrument rather than to its sounds. One can say that sounds, like images, only carry aesthetic significance when they become sufficiently familiar so that the technical aspect of the production of their message is ignored. This differentiation is indicated by the terms 'sign' and 'index' that I used in my 'Traité des objets musicaux' ('Treatise on Musical Objects') [2]. The term 'sign' was introduced by Saussure in linguistics to bring out the fact that words refer to something and, thus, have meaning. A sign is supported by meaning. When I speak, you can analyse my words for their sound but, actually, you listen to them for their meaning. On the other hand, if you listen to my words to learn whether I have a cold, you do not pay attention to their meaning. Here a word serves as an 'index'. One searches for the cause of the particular sounds of the words. Since I understood these two characteristics of sound, I found it easier to synthesize sounds and to connect them than did many others interested in music made of such sounds.

A blending of sounds with images to obtain aesthetically satisfying results requires an understanding of each of their basic characteristics. I do not believe that, when sounds correspond naturally to images, one obtains a satisfying audio-visual art. But when sounds are combined artificially with images one might arrive at satisfying combinations.

M. It is reasonably obvious that audio-visual art poses difficult problems. The processes of hearing sounds and of seeing images are quite different. Listening to music is a differentiating process, whereas, viewing a picture is an integrating one. Furthermore, one can listen comfortably to a succession of sounds of a much higher speed than in the case of a succession of images.

S. I, also, have looked for a parallel between what can be seen by introducing the 'octave of colours' of electromagnetic vibrations of visible light and the 7 to 8 octaves of mechanical vibrations that can be perceived by the ear. This comparison is tempting to make.

The research that I did on this some years ago is completely out of date. The eye and the ear do react to vibrations but of a very different kind and many have been led to make a false comparison. The meaning of sounds and images has nothing to do with wave lengths. Although we are made up of atoms and molecules, it is not these atoms and molecules, as such, that determine our hearing and seeing; they are a part of a vast superstructure that makes up the eye and the ear.

M. I agree that attempts at correlating sounds and colors have been unproductive. There are conventions that can undoubtedly be established for such correlations but there do not appear to be physiological or psychological bases for them.

S. One could make the following experiment. Images of sounds can be produced easily on a television screen by using an oscilloscope. Each sound produces a very nice visual story on the screen. One cannot deny that this is simultaneous perception by ear and eye. What one sees does have a meaning, for the image is produced by what one hears. This demonstration has intrigued me a lot because it seemed to indicate a possible connection between hearing and seeing. This seems to contradict my preceding opinion that it is based on superstructures. What one actually sees and hears in this audio-visual experiment is not an explanation of causes but simply a correlation between simultaneous events: the image of vibrations is correlated to sound vibrations. This is simply a temporal correlation. When the sound seems very simple, the image may also be simple; when the sound is very complex, the image is sometimes also very complex. Here we are at the heart of the matter. In fact, an audio-visual causal relationship is realized here at the level of signs. Indices refer to complexity but remain distinct from signs. One hears a 'la' and one sees at the same moment, say, an ellipse. But an ellipse in no way means 'la' and nothing in the sound of 'la' signifies an ellipse. One must look for a connection in the signs (which are two similar vibratory phenomena) but not in the objects that produce them.

M. I have made an experiment with a kinetic painting on a translucent screen in which the images initiate sounds by means of photocells directed upon the screen (Figs. 2 and 3). When a light image passes in front of a photocell, the activated photocell causes an oscillator to sound a note. Eight photocells were directed at different areas of the screen to give an octave of notes. I wondered what one's reactions would be to the combinations of sounds produced by and correlated in time with the combinations of light images of the picture. One is, no doubt, intrigued by the recognition of the temporal correlations. I did not continue the experiment long enough to go to any depth into what I called kinetic-music or 'kusic'.

S. Temporal correlation is about the only thing that we know how to do. But what people do not understand either is that, if one looks for connections between sounds and images, one might have connections at various levels. There is not a unique type of relationship. The most elementary relationship one can demonstrate is a correlation in time. One can have a common rhythm between phenomena that are completely unrelated otherwise. Time and the way things vary with time are very important, of course.

Here is an amusing example that illustrates exactly the opposite. We filmed images obtained with light projected through lined glass to give luminous colored lines advancing in close rows, marching in perfect order. Our technician in charge of sound dubbing, Jeannette Berton, provided a military march to go with the film. At once the image was interpreted: it was the 14th of July parade in Paris!

Fig. 2. F. J. Malina, 'Musical Cylinder', No. 936/1963, *kinetic painting, Reflectodyne system*, 28 × 40 cm, 1963.

Fig. 3. F. J. Malina, 'Passing Planets, III', No. 989/1966, *kinetic painting, Reflectodyne system*, 28 × 40 cm, 1966.

It would be interesting to find some important structural relations in images, similar to, for instance, intervals in music and a relationship between intervals. We constantly add sounds to images and images to sounds in the cinema and in television: and it works. When one wants music to go with a film sequence, one searches for a piece of music already composed or asks a composer to write it. The music should reinforce the meaning of the film sequence and there should be a correlation of rhythms. But if one takes a film and dubs in haphazardly any music from records or tapes, experience shows that the spectator will still find a significant correlation between them. Sounds always reinforce images in one way or another. Ridiculous or comic effects are easiest to produce. The combination of sounds and images gives more to a spectator than either of them alone. Of course, very loud sounds often are used to distract the spectator's attention from the poor quality of the visual material.

M. There is no unique combination of an image with a sound. One has enormous freedom of choice. In concrete music, where there are no musical stereotypes for gaiety, tragedy, comedy etc., it is perhaps easier for listeners to avoid looking for them and to exercise their own visual imagination. Thomas Wilfred, an early pioneer of kinetic art with light images on a translucent screen, although at first he used his Lumia technique in connection with music, later became strongly opposed to the idea of combining his Lumia works with music.

S. It seems useless to protest against anthropomorphic interpretations, even of concrete music. Perhaps they are unavoidable.

M. What do you think of music using sounds made by an electronic synthesizer rather than traditional musical sounds or recordings of natural sounds?

S. Probably sounds made by violins, pianos etc. form the nucleus of the best sounds, a little like in the mathematics of geometry where Euclidian geometry is easiest for us to comprehend because it corresponds to common experience. I think that this nucleus of sounds possesses, at the same time, specific and abstract qualities. They are easily heard, they provide tones that are well within the range of the seven octaves of the vibrations that we can hear, their duration can be controlled to correspond to the duration of human movements. When one leaves the natural world of sound and one hears a new sound with which one is not acquainted, the tendency is for it to be called wonderful. But I believe that we should not be pleased too easily. Because a sound is new does not mean it is significant. As I pointed out earlier, one may only be intrigued by the technique used to produce it.

Synthetic sounds are not necessarily easy to hear; they can be too complicated or too poor, lifeless.

I reply to your question by saying that neither synthetic electronic sounds nor the sounds that we have been looking for in nature (noises, animal cries etc.) are to be rejected. But one must make a choice of them to conform to the archetypal habits of the ear—sounds that contain neither too much nor too little information, sounds that have a 'life' of their own. Most synthetic sounds do not have 'life' because they do not vary from the moment they start till they end.

With computers one can try to make very elaborate combinations of sounds or else program an electronic synthesizer to imitate natural sounds. I speak of 'imitation' as a 'model' and not in the sense of 'doing the same'. Since after the long period of the evolution of our ear most people find the sounds of a violin beautiful, it must mean that the ear is especially attuned to such sounds. Among those who make artificial or synthetic sounds there are two main trends. In one, the use of calculation is believed to have virtue (but no one knows on what factors to base these calculations); in the other, our experimental school at the ORTF in Paris has been influential, for example on Knut Wiggen of Stockholm.

There is an old war between the electronic school of sound and myself because I have always refused to calculate sounds *a priori*, saying that one could calculate them only by analogy from the knowledge we have of natural sounds. But our paths unavoidably cross because with a synthesizer one can make all the sounds one wishes to make. Still, the question arises: What sounds does our ear want to hear? I have pointed out in my 'Traité des objets musicaux' [2] that it is necessary to translate the physical nature of sound into its psychological qualities. We are now at the inter-disciplinary stage of finding a language to express mathematically the psychological characteristics of sound.

M. It is interesting to note here that what you say applies to kinetic art and also to static images. I am often asked if I use mathematics when I make geometrical abstract paintings. My reply is negative, for in art I do not believe circles, ellipses, hyperbolas and more complicated shapes need be accurately drawn. After all, a painting is not used as a plan from which something will be constructed for utilitarian purposes or a diagram for the mathematics of geometry. There is no doubt an element of personal psychology involved, also of chance effects, that leads to a richer artistic result. We still have very little information available on aesthetics from the point of view of the psychology of perception.

S. Calculations have no virtue in themselves. It is strange that many artists think that calculation means science. But they forget that physicists have never considered mathematics as anything else than a tool to help them. Just because something is mathematically correct does not mean that the result is physically true.

M. We, as engineers, know this very well. By the way, I started out as a musician. There are now many discussions on the relationships between science and the visual fine arts. As engineers, we make approximations all the time. I agree that mathematics is a language that may allow one to analyse complex situations more easily. I am aware of the fact that discussions on the relationship between science, mathematics and music are also taking place.

S. Naturally, since certain contemporary musicians consider that music has a wide mathematical basis and that it is even an audible expression of mathematics. Again one thinks of Pythagoras. But one must be on guard against these ideas. The structure of sound is one of the most amazing traps that nature has ever invented to make man believe that music has a mathematical basis: octaves correspond to the powers of two, harmonics are like the set of integers, there is the cycle of fifths (except that the cycle of fifths is not quite closed and our ear does not notice it). This cycle of fifths is called 'temperament' and leads to the *tempered* musical scale but one quickly forgets this little detail about the tempered scale; one forgets that one has cheated with mathematics, in the West, at least.

One of the ideas that I have not had time to carry further but which seems to me very important, is the following. The tempered scale was established and accepted around the time of Bach. The summit of Western music began with this scale because of the fact that our music was faced with the stupendous possibilities of harmony. From this coexistence of sounds, forming repetitive ensembles, the West was led to formulate a theory, for harmony belongs to the West. I always asked myself why in other parts of the world music developed differently, to the point that the West believes that real music belongs to them (and, if it were true, it would be due to the shameless mathematical cheating, even though the cheating leads to a good psycho-physical approximation). I have always denounced this belief. But I should say also that the West has excuses because its music has developed in a remarkable way and it is only in Western music, in this very special system, that such an elaborate construction of sounds is possible. One can give two explanations for this phenomenon, according to whether one refers to Hindu or to African music, which are less developed from a technological point of view. In countries of low technological development there are neither materials nor instruments that would lead to a tempered scale. Music remains a rather floating affair. There is, however, harmonic music. But this harmonic music in some way is already ultra-modern, because it does not rely on do, re, mi, fa, sol, la, ti, do or on exact fifths. The result is that a lot of African or Chinese music verges on some contemporary music. What happens in Hindu music and in music of other peoples when very precisely made instruments do not exist, with which one cannot cheat, is that the instruments are so well tuned that the cycle of fifths is no longer closed. The result is that they can play only melodies because, if they play harmonies as we do, they would sound false. They use only the exact series of harmonics starting from a tonic. As you know, in the cycle of fifths the last of the cycle leads to a sound that is very close to the tonic. Western tempered instruments require their identification, that is, acceptance of a physical approximation.

It is here that our technology joins, as it were, the philosophical and religious inspiration at the base of Hindu music. Hindu music is played primarily for religious purposes. When they play their instruments, they repeat over and over the tonic (as we play: do, sol, do, sol, do, sol) to envelop all of the music, while the solo instrument plays notes that are exclusively harmonics in accordance with this envelopment. Our type of harmony from the tempered scale could not originate from their tonic and from their harmonics.

With regard to your question on using mathematics in art, what I have just said is an example of how music differs very much according to whether one has or has not made an approximation of the cycle of fifths. This shows that 'exact' music has had difficulty in developing and that it has been forced to restrict itself to melodies situated 'outside' our harmony. Instruments that have sacrificed exactness to approximation permit a set of sounds to be made that form chords.

The snag of all this is that, basically, sound is the most simple thing in the world. It is much simpler to grasp than images. The difference between hearing and seeing lies not only in the difference between the seven octaves of mechanical vibrations and the one octave of perceptible electromagnetic vibrations. The eye is confronted with an infinite variety of stimuli, say in a painting, and the role of the eye is to select from them a topography, a geometry, with colors intervening only from a qualitative point of view. The ear, on the other hand, establishes relationships between all mechanical vibrations that impinge upon it.

M. Do you think that our world of technology and science has had an effect on music from a conceptual viewpoint—that at least some modern composers are consciously inspired by our technological life—not as regards designing sound-producing devices but from the viewpoint of echoing the kinds of new sound combinations we hear? I am convinced the 'new' landscapes provided by science and technology are at the bottom of what we call 'abstract' art.

S. I am not going to deny that there is a connection between the artist's inspiration and the scientific new look at the world, which is altogether different from the old look of the naked eye on nature, but I wonder if this is not just a chance affair. I believe the painters of abstract art made this kind of art independently of technology.

M. A good case can be made that modern abstract art was provoked by the invention of the camera in the 19th century. It seems to me that the camera had two effects upon artists. First, they began to wish to make images that were not easily produced by the camera. Second, from this time onward, artists were more and more bombarded with new kinds of 'landscapes' that cannot be seen with the naked eye. In countries with a low level of scientific and technological development, abstract art in the form of objects for contemplation rather than for decoration were not and still are not made, except by replication. (I am ruling out abstract sexual symbols.)

S. Well, as long as countries with a low level of technology are not disturbed by our analytical civilization, their synthetic type of civilization integrates art into their overall mode of life. In the great examples, for instance Negro art, one knows very well that what we call an art object for valuation as art has for Africans primarily religious value. In these objects, there is a mixture of utility and taste, whether figurative or non-figurative elements are combined. Indeed, these objects were made to represent more than simple resemblances, as in the case of masks. But I agree that abstract or non-figurative art for contemplation, which came after the discovery of the camera, was perhaps provoked by its discovery. With regard to sound, I can give you a more enlightened reply. I shall speak of absolute coincidence. For while traditional music was marking time at the end of its development in this century, notably with the work of the serial school, which finally did not know what to do with its notes, a technology coming from elsewhere that had nothing to do with music (the technology of broadcasting was a technology of telecommunication) taught us how to capture sounds and to condition them for another purpose. Sounds were torn out of their ephemeral existence and transferred on to tapes—just like the images that are transferred by the camera on to a support. At this moment, the two manifestations of sound met, the downfall of traditional Western music (for its inspiration had withered) and the sudden arrival of this mass of new sounds. I think that it is the same as what happened with visual art: the meeting of two movements in history. Painters who did non-figurative work may not have been directly influenced by the camera although the camera existed in their time.

M. This is a very important question. Either an artist can create an image from his brain uninfluenced by the external world or he makes images that are a reflection, perhaps distorted and modified by invention, of the external world. I favor the second hypothesis. A good test is to ask an artist to draw an animal that in appearance is unrelated to any animal he has ever seen alive or in an image. I have yet to see an example of such an original animal. Do you really think that music came about without any influence from the external world that surrounded the pioneering composers?

S. I truly think that *dodecaphonic* music is quite independent of the microphone. In fact, I do not recommend that one search for historical explanations, as, for example, whether or not the Vienna school was inspired by the microphone. But there is perhaps something more general, cosmic, that made the school of Vienna want to create music different from the old school. For example, for a little piece of Webern, which lasts one or two minutes, there are two explanations. In the first place, it is music based on a row of twelve tones and their permutations etc. And for the traditionalists, it is twelve-tone music. When I analyze this music, I am not interested in the permutations. I do not hear them. But Webern indicated little tremolos, exquisite glissandos, all very well constructed.

Perhaps I can explain what I mean in terms of concrete music. Here is music known to be the most 'abstract' in the world, which it is from the dodecaphonic point of view; but I deny, absolutely, that it would be interesting to base oneself on the twelve-tone scale. This is nonsense. Why do we find these pieces based on this scale interesting, seducing and so well made? Because they are little jewels of concrete music. Because in this music there is not a note that exists for itself. Because the composer found something that we were to find elsewhere much less refined, much rougher, from another direction. There is something fascinating in this meeting of twelve-tone music and concrete music.

M. It is strange, is it not, that the rupture between classical and new music came about at the same time as the introduction of abstract art?

S. Visual art tends to be almost fifty years in advance of music. One must remember that the cinema at first was silent. This proves that the eyes of men are a dominant sense because vision is essential for survival and for the existence of science and technology.

The school of twelve-tone music came later than abstract painting. The world of images is much more abundant than the world of sound and music is much less interesting from the point of view of utility. In spite of this delay between them in prosaic chronological order, music often catches up with visual art on the poetic plane and, in my opinion, leads more directly to the self-knowledge of man.

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GLOSSARY

ACID. A substance having in it hydrogen exchangeable for a metal or a metal-like base forming a salt and which gives up H^+ ions when put in water. A complex substance having a tendency to give up protons. (See *Base, pH indicators, Salt.*)

ADDITIVE. A substance mixed with another to give it a desired property, such as color.

ALPHA BRAIN WAVES. Rythmic changes of electrical potential of the brain that can be recorded from the skull by means of an electroencephalograph. These waves occur during the normal conscious state of the brain and range from 8 to 12 cycles per second. Under stimulation, by flashing lights on the retina, for example, the number of cycles per second can range from 4 to 60. (See *Electroencephalograph.*)

ANALOG COMPUTER. A computer which represents variables and constants by physical analogies. Thus, any computer which solves problems by translating physical conditions such as flow, temperature, pressure, angular position or voltage into related mechanical or electrical quantities and uses mechanical or electrical equivalent circuits as an analog for the physical phenomenon being investigated. In general, it is a computer which uses an analog for each factor and produces analogs as output. Thus, an analog computer measures continuously whereas a digital computer counts discretely. (See *Digital computer.*)

APPARENT MOTION. Motion perceived through simple observation, when there is actually no motion, as is made clear by observation with instruments or by reasoning.

ARMATURE. (See *Modulator.*)

AUDIO-FREQUENCY. A frequency between 20 and 20,000 Hz. If it is a pressure oscillation in air (acoustic waves), it is audible. Electrical oscillations in this range of frequencies can be transformed into acoustic waves by means of an audio-oscillator. (See *Audio-oscillator.*)

AUDIO-KINETIC SCULPTURE. A kind of sculpture incorporating real motion that is controlled by ambient sound, such as music and speech. Sound intensity or frequency is converted into mechanical motion, for example, by means of electronic devices that control the direction of rotation of electric motors. Also a kind of kinetic sculpture whose motion produces sounds by means of appropriate auxiliary parts.

AUDIO-OSCILLATOR. An electrical circuit for generating audio-frequency currents that can be heard when applied to a transducer (loudspeaker). (See *Audio-frequency.*)

AUDIO-SIGNAL. An electrical current that oscillates within the range of audible frequencies. (See *Audio-frequency.*)

AUDIO-VISUAL. Pertaining to forms of instruction, entertainment and fine art that make use of hearing and sight, such as films with sound, television, theater, opera, and audio-kinetic art forms.

AUTOMATION. A term popularly used to describe or suggest the advanced mechanized performance of complex tasks, both mental and physical, that traditionally require the effort or attention of human beings.

BASE. A substance which undergoes a reaction with an acid forming a salt and water, and which gives hydroxyl (OH) ions when dissolved in water. A compound having a tendency to take on protons. (See *Acid, Salt.*)

BATCH-PROCESSING. A method of computer operation in which complete programs and related data are processed without external interaction, so that one batch may follow another at the computer's speed. (See *Off-line, On-line.*)

BIO-FEEDBACK. Feedback is the phenomenon whereby a small part of the output of a system is used to control the input to the system. Biofeedback occurs, for example, when voluntary control of Alpha brain wave frequency is used to affect body functions, such as heart rate and blood pressure. (See *Alpha brain waves.*)

BIREFRINGENT MATERIAL. A material which splits a wave of light into two waves that propagate through the material with different velocities, thus giving rise to interference effects which, when polarized light is used, produce colors.

CAM. A rotating piece of irregular shape, such as a notched disc or an elliptical cylinder, adapted to impart an alternating or variable motion to another piece by rolling or sliding contact.

CAPACITOR OR CONDENSER. A device for storing electricity made up of two or more parallel plates close together, separated by a nonconducting material.

CATHODE-RAY TUBE (CRT). An electronic device in which electrons strike a phosphor screen to produce a visible trace, as in a television set and in an oscilloscope.

CENTRAL PROCESSOR UNIT (CP). The part of a computer that acts as its 'brain'. It executes all logical operations required by the program and directs information to other components of the computer. (See *Computer.*)

CHAIN-CODE GENERATOR. A binary sequence generator whose sequences are governed by the binary code.

CHEMICAL LIGHT SHOW. A type of light show produced with an overhead type projector that projects light through colored liquids. (See *Light show.*)

CHROMARA. A kinetic art device of the Lumia type developed by R. I. Land. Optical techniques of light refraction and reflection and shadows produce a kinetic picture on a translucent screen. The colors, patterns and motion in the pictures can be controlled automatically or by an observer.

CHROMATIC ABSTRACTOSCOPE. A kinetic art device developed by C. Martinoya and N. Joël for projecting on a screen or a wall a continuously varying colored picture. The device makes use of light-polarizing material (Polaroid) and shaped birefringent material, for example colorless cellophane, attached to transparent revolving disks to produce changing shapes and colors by the interference of polarized light.

CLOCK CIRCUIT. An electrical circuit that produces trigger pulses at regular intervals. (See *Trigger or initiating pulse.*)

COLOR ORGAN. A kinetic art device, analogous to a pipe organ in music, that projects colored forms in motion onto a screen. An operator controls the forms and colors by means of a keyboard.

COMPUTER. A device capable of accepting information, applying prescribed processes to the information and supplying the results of these processes. It usually consists of input and output devices, storage, arithmetic and logical units, and a control unit. (See *Analog computer, Digital computer.*)

COMPUTER ART. The output of a general purpose computer classified as art. It may be hard-copy, drawings from a plotter, black and white or color kinetic images on a television-type screen or pictures thereof, resulting from a program supplied to the computer.

COMPUTER GRAPHICS. A term designating anything relating to the pictorial output of a computer. It covers programming techniques, plotting, displaying, filming and other active output forms.

CONDITIONAL STATEMENT. A statement in a computer program offering a choice of alternatives in the processing.

CONVECTION CURRENT. A current in a liquid or a gas whose motion is caused by different conditions of density in different parts and the action of gravity, especially the moving up of a heated part and its replacement by a colder part.

CRYSTAL. A solid substance having a definite geometrical arrangement of its atoms, ions or molecules that repeats in space periodically to form a three-dimensional lattice. Crystals are characterized by a definite external form.

CYBER. A programmed kinetic construction incorporating electric light, sound, smell and smoke effects devised by the Russian 'Movement' Group for installation in their Cybertheater. (See *Cybertheater.*)

CYBERTHEATER. A large park-like area designed to produce an environment of aesthetic fantasy demonstrating relationships between man and machines. Spectators follow designated paths through and around giant Cybers, water pools and pyrotechnic displays. (See *Cyber.*)

DEGREES OF FREEDOM. Any of the independent ways in which a body or system may undergo motion. For a solid body of fixed form, for example, there are six—straight-line motion in any one of three directions of space, as given by three lines at right angles, and a turning motion about any of these three lines.

DIAPROJECTION. The projection of one or more series of photographic transparencies by means of a manually operated or automatic projector in a predetermined manner to give the feeling of objects or of forms in motion.

DIGITAL COMPUTER. A computer which processes information represented by combinations of discrete or discontinuous data, as compared with an analog computer for continuous data. More specifically, it is a device for performing sequences of arithmetic and logical operations, not only on data but on its own program. It is a stored program computer capable of performing sequences of internally stored instructions, as opposed to calculators, such as card programmed calculators on which the sequence is impressed manually. (See *Analog Computer.*)

DIODE. An electrical device that allows current to flow only in one direction. It may be a two-electrode vacuum tube or a semi-conducting material that in a circuit produces a direct current from an alternating one. (See *Rectifier.*)

ELECTROENCEPHALOGRAPH (EEG). An instrument that measures electromagnetic waves, such as Alpha brain waves. (See *Alpha brain waves.*)

ELECTROLUMINESCENCE. The emission of light from a material when its atomic structure is stimulated by electrical energy but not only as a result of heating the material.

ELECTRO-MAGNET. Any electrically powered device producing a magnetic field, generally a current-carrying coil of wire whose field strength may be enhanced by an iron core.

ELECTRONIC ABSTRACTION. (See *Oscillon.*)

ELECTRONIC MUSIC. A type of music composed of sounds produced by, and characteristic of, certain electronic devices.

ELECTRONICS. The study that deals with the emission, behavior and effects of electrons in vacuums and in gases, especially with reference to technical and industrial applications.

EPOXY RESIN. A variety of synthetic resin containing oxygen attached to two different atoms already united in some other way (the epoxy group). A substance used chiefly in coatings and adhesives.

EXOTHERMIC REACTION. A chemical reaction which takes place with the production of heat.

FANTASY MACHINE. A term coined by T. Hunkin for machines designed to produce amusing and aesthetic visual and sound effects.

FLIP-FLOP CIRCUIT. An electrical circuit consisting of a pair of interconnected amplifiers that is able to remain indefinitely in either of two stable states and can be induced to make a quick transition from one state to the other by means of a trigger pulse. (See *Shift register* and *Trigger or initiating pulse.*)

FLUORESCENT LAMP. A tubular electric lamp coated on its inner surface with a fluorescent material such as phosphor. It contains mercury vapor whose bombardment by electrons from the cathode provides ultraviolet light which causes the phosphor to emit visible light.

GARBAGE. A useless output of a computer because the machine is faulty or it has received faulty data or programs of instructions.

GEIGER OR GEIGER-MÜLLER COUNTER. An instrument used for detecting the presence of ionizing radiation, from radioactive substances or cosmic radiation, for example.

HALOGEN. Any of the elements fluorine, chlorine, bromine, iodine and astatine.

HARDWARE. The physical components of a vehicle, such as a spacecraft, or of a machine, such as a computer. (See *Software.*)

HELIUM. The second lightest gaseous element known, hydrogen being the lightest. Because it is noninflammable, it is used in arc-welding of reactive metals.

HORIZONTALLY ORIENTED ROTATING PAINTING. A type of kinetic art developed by R. Henry in which a painted surface is suspended horizontally from a ceiling by means of strings about which the painting rotates by winding and unwinding.

INCANDESCENT LAMP. An electric lamp whose light is produced by incandescence of some specially prepared material, such as the filament of an electric bulb.

INDICATOR. A substance which, when put into a liquid, indicates by its color if the liquid is acid or alkaline. Indicators are used in chemical light shows for their color properties.

INFUSOR. A term coined by D. R. Wier for a tool used for the infusion of additives and the production of currents in starting solutions. It is made of a section of rubber hose, one end of which is fastened to a rubber syringe. (See *Starting solution.*)

INPUT. Information and instructions in the form of data and programs on, for example, magnetic tapes or punched cards for directing the operations of a computer. (See *Output.*)

INTERFERENCE. The phenomena occurring when wave trains of the same or nearly the same frequency mix in such a way that amplitudes add, subtract or cancel to produce a new wave train. In the case of light, interference causes the appearance of colored rings, alternating light and dark bands or fringes. In the case of sound, interference may cause beats to be heard.

KERR CELL. A device for rotating the plane of polarized light. The light passes through certain clear substances across which an electric potential difference is acting.

KINETIC ART. A form of visual fine art which incorporates real motion and changes of color with time in a completed work. There are three major types of kinetic art: the first includes three-dimensional or constructional artifacts whose motion is caused by clockwork systems, air currents, electric motors, etc.; the second uses variations of the cinema technique to project a light picture in motion on a screen or a wall; and the third consists of devices (called Lumia by T. Wilfred) provided with a translucent screen upon which a light picture in motion is produced by means of reflectors, light filters and painted transparent elements in motion in the path of a light source within the device.

KINETIC PAINTING. A fine art form of the Lumia type. The term refers especially to kinetic art devices which produce a picture in motion on a translucent screen by passing light through transparent materials that have been painted with transparent and opaque paints.

KINOPTIC SYSTEM. A kinetic art system developed by V. Caloutsis for projecting a changing colored light image on a screen or a wall. The light beam from an electric lamp passes to a fixed reflecting surface and then to a rotating reflected surface from which it is projected outward.

KRYPTON. A gaseous element used in a variety of incandescent and fluorescent lights. In fluorescent tubes, krypton emits a pale violet light when electric current passes through it.

KUSIC. The term coined by F. J. Malina for combinations of sounds produced by audio-oscillators controlled by inputs from photoelectric cells directed at moving light images on the translucent screen of a kinetic painting. (See *Kinetic painting.*)

LASER. An acronym for Light Amplification by Stimulated Emission of Radiation. A laser device produces light beams whose coherence, collimation, monocromicity and intensity are far greater than light from any other source.

LIGHT PEN. A photosensitive pen-like device for interacting with a cathode-ray tube display. Lines may be drawn or moved or commands may be generated by pointing at displayed images. (See *Cathode-ray tube.*)

LIGHT-POLARIZING MATERIAL. A material that polarizes light, such as Polaroid plastic sheet and certain crystals.

LIGHT SCULPTURE. A kind of sculpture incorporating electric light within a structure of transparent or translucent materials.

LIGHT SHOW. A form of kinetic art in which a projector is used to project light through an intervening medium to create pictures of changing composition and color on a screen or on a wall.

LISSAJOU'S FIGURE. A curve representative of the motion of a point moved by two simple harmonic motions acting at right angles to one another, for example, that at the end of a pendulum suspended from another pendulum moving at right angles to it.

LUMIDYNE SYSTEM. A system developed by F. J. Malina for producing a kinetic painting (a fine art form of the Lumia type). The picture in motion on a translucent screen is produced by electric light transmitted through a painted transparent element in motion and through a static painted transparent element. A three-component Lumidyne system has no translucent screen. Opaque and transparent paints are used. Motion is obtained by means of electric motors.

LUMINOUS MOBILE. A term coined by N. Calos for a fine art form of the Lumia type using a Lumidyne system for the production of a picture in motion on a translucent screen. (See *Lumidyne system.*)

MAGNETIC TAPE. A thin ribbon of paper or plastic, one side of which is coated with particles of iron oxide that form magnetic patterns corresponding to the electromagnetic impulses of a tape recorder.

METAFORM. A term coined by E. B. Weill to designate static photographic images or slides or cinematographic images of trajectories of specially designed mobiles in motion.

MICRO-SWITCH. A very small, highly sensitive electrical switch.

MOBILE HYDROMURAL. The term used by G. Kosice for a mural form of kinetic art incorporating flowing water and electric light beams in motion.

MODULATION. The combination of waves of different frequency so that the information from one is contained in the amplitude envelope (AM) or the frequency variation (FM) of the other.

MODULATOR. Term used by R. I. Land to designate the object placed in his Lumia kinetie art instrument between the light source and the translucent screen to produce specific images on the screen. A modulator that rotates about a fixed axis he calls an armature. (See *Chromara.*)

MOOG SYNTHESIZER. An electronic instrument that is used to imitate musical sounds or form new ones. The operator depresses a key on a keyboard producing a voltage wave of a fixed frequency. The wave form is fed in directly to a speaker after having been modified first by passing it through a series of voltage-controlled filters and amplifiers.

NEON. A gaseous element. When an electric current is passed through neon confined in a glass tube, it becomes ionized, producing a reddish orange glow. It is widely used in advertising signs.

OFF-LINE. Descriptive of a system and of the peripheral equipment of devices in a system in which the operation of the peripheral equipment is not under the control of the central processing unit. (See *On-line.*)

ON-LINE. Descriptive of a system and of the peripheral equipment or devices in a system in which the operation of such equipment is under the control of the central processing unit and in which information reflecting current activity is introduced into the data processing system as soon as it occurs. (See *Off-line.*)

OP ART. A form of visual fine art in which an object (usually consisting of clearly defined geometrical images) is designed to produce a strong visual effect. The means for producing the effect may be simultaneous contrast, illusionary images (including moiré) or metallic reflections.

OPTICO-SPATIAL MOBILE. A kind of kinetic art developed by H. Gabriel consisting of a string-suspended construction incorporating effeets of visual illusion.

OSCILLON. An art form developed by B. F. Laposky consisting of electron oscillograms (images) composed on the screen of an oscilloscope in black and white or in color, in motion or at rest, that can be viewed directly or reproduced photographically.

OSCILLONICS. A term invented by B. F. Laposky for the technique of making Oscillons or electronic abstractions. (See *Oscillon.*)

OSCILLOSCOPE. An instrument in which the variations in a fluctuating electrical input appear temporarily as a visible form on the fluorescent screen of a cathode-ray tube.

OUTPUT. The results of processing data according to a program supplied (input) to a computer, usually in the form of graphs and tables in printed form or on magnetic type. (See *Input.*)

PASSBAND. The range of frequencies permitted to pass through a filter.

PENDULAR. Characterized by motion resembling that carried out by a pendulum.

PERSPEX. (See *Polymethyl methacrylate.*)

pH INDICATORS. Substances used for indicating whether a chemical solution has excess hydrogen ions, H^+ (acidic), or excess hydroxyl ions, OH^- (alkaline). They are used in chemical light shows for their color properties. (See *Chemical light show.*)

PHOTIC STIMULATION. The reaction of the brain to stimulation from light flashes.

PHOTOCELL OR PHOTOELECTRIC CELL. An electronic device whose electrical properties are modified by the action of light.

PHOTO-DETECTOR. A device that produces an electrical signal in response to light falling on its sensitive surface.

PLASMA. A state of matter whose electrical properties determine its dynamic behavior. It is usually an ionized gas in which a significant proportion of atoms is split into free electrons and positive ions. Plasmas are produced, for example, within fluorescent and neon tubes.

PLEXIGLAS. (See *Polymenthyl methacrylate.*)

PLOTTER. An instrument provided with a pen to plot points or to draw lines on paper guided by the output of a computer.

POLARIZED LIGHT. Light whose vibration pattern shows a preference in orientation. In ordinary light, the vibrations are supposed to be in all directions perpendicular to the ray; in polarized light, the paths of the vibrations may be straight lines, circles or ellipses.

POLYETHYLENE. A polymer of ethylene widely used in the manufacture of film for the wrapping of tubing, electrical insulation, molded objects, etc.

POLYMETHYL METHACRYLATE. A plastic material that is the polymer of methyl methacrylate. It is commonly used in coatings and in the form of sheets, tubes and rods. The latter are available under the trade names Lucite, Perspex, Plexiglas, etc.

POTENTIOMETER. A device for measuring electromotive forces. It is also used for varying a fixed voltage.

PROGRAM. (1) The complete plan for the solution of a problem, more specifically, the complete sequence of machine instructions and routines necessary to solve a problem. (2) To plan the procedures for solving a problem. This may involve, among other things, the analysis of the problem, preparation of a flow diagram, preparation of details, the testing and developing of subroutines, allocation of storage locations, specification on input and output formats, and the incorporation of a computer run into a complete data processing system. (See *Computer, Input, Output.*)

QUADRATIC. Pertaining to a square. An equation of the second degree.

RAND TABLET. A surface on which each point located under the tip of a special pen may be accurately sensed by a computer.

RASTER. A predetermined pattern of scanning lines that provides substantially uniform coverage of an area on a television or on an oscilloscope screen.

REACTIVE. Having the power or, especially, a strong tendency to chemical reaction.

REAL-TIME PROCESSING. A method of computer operation in which the results of the operation on data are available as the data is being produced. For example, one sees displayed a drawing being formed at the same time as the input of points is made. This technique is useful when human decisions are required during the processing of the program before final results are obtained. (See *Batch-processing, Off-line* and *On-line.*)

RECTIFIER. A device for changing an alternating current into a direct current.

REFLECTOR. A flat or shaped part with a mirror-like surface that is used to reflect light in art devices.

REULEUX'S FIGURE. A geometrical non-circular figure of constant diameter drawn from any regular or irregular odd-sided polygon.

ROBOT-PAINTER. A system developed by P. K. Hoenich for producing kinetic pictures. Reflectors, moved by wind, are used for projecting sunlight on a wall, or on an opaque or translucent screen. Since the motion of the reflectors is irregular, the pictures produced at any moment are not predictable. The basic forms and colors that decide the style of the picture can, however, be chosen. (A simpler version of this system, in which the reflectors do not move, is called by Hoenich a Robot-picture. The pictures vary only with the position of the Sun. In this case, a yearly program of pictures can be planned.)

RORSCHACH PATTERNS. Patterns made of ink blots that the viewer interprets in terms that reveal intellectual and personality factors to a psychologist.

SALT. Any substance of the sort produced when a metal ion takes the place of one or more hydrogen ions of an acid. (See *Acid.*)

SHIFT REGISTER. A chain of interconnected flip-flop circuits that is capable of storing binary numbers. (See *Flip-flop circuit.*)

SKETCHPAD. A technique of manipulating drawn elements on a computer output display to permit computer-aided design. Relationships between parts of an image can be developed as a design is being created on the display.

SOFTWARE. The non-structural features of a machine such as the program for a computer. (See *Hardware.*)

SPACE-TIME CONTINUUM. The four-dimensional blend of three-dimensional space and time that resulted from the theory of relativity. To specify where and when an event occurs, three length coordinates are needed for the 'where' and a time coordinate for the 'when'.

STARTING SOLUTION. The initial liquid, made up of water and other chemicals, into which reactive chemicals are infused to produce color changes and motion for a chemical light show.

STEREOSCOPE. An apparatus which, by the use of lenses or mirrors, makes two pictures of the same thing taken from different points of view come together so as to seem like one to the eye, giving a three-dimensional effect.

STORAGE TUBE. A monochromatic cathode-ray tube that retains an image until an erase instruction is given. (See *Cathode-ray tube.*)

STROBE CIRCUIT. A device for producing pulses at regular intervals, which can be used to produce light flashes.

STROBOSCOPIC. The term used to designate rapid periodic lighting produced by a stroboscope. The device is made in the form of a revolving disk with equally spaced holes around the edge for chopping the light beam or in the form of an electronically operated light source.

SURFACE TENSION. A condition that exists at the free surface of a body (as a liquid) by reason of intermolecular forces about the individual surface molecules and is manifested by properties resembling those of an elastic skin under tension.

SYNCHRONOUS MOTOR. Alternating current electric machines turning at a rate in step with the frequency of the current.

THERMAL INTERRUPTER. A device for interrupting or periodically making and breaking an electric circuit, operated by the expansion of a metal bar heated by the electric current of the circuit.

TRANSISTOR SWITCH. A voltage controlled switch that, in the open position, allows no current to flow and, in the closed position, allows all the voltage to appear across the load in an electrical circuit.

TRIGGER OR INITIATING PULSE. A voltage wave form that is usually applied to a circuit to induct a change. (See *Flip-flop circuit.*)

TORUS. A surface in the shape of a doughnut.

WAND. A device that makes it possible to read the three dimensions of a point in space as an input to a computer.

WATERFALL EFFECT. A visual illusion caused by looking for a while at a rotating or steadily moving field of lines or of shapes and then seeing an after-image of an apparent motion in the opposite direction. (See *Apparent motion.*)

WET SHOW. (See *Chemical light show.*)

XENON. A heavy colorless, inert, gaseous element used in thyratrons and specialized electric lamps.

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Some illustrations from an article by Michael Thompson
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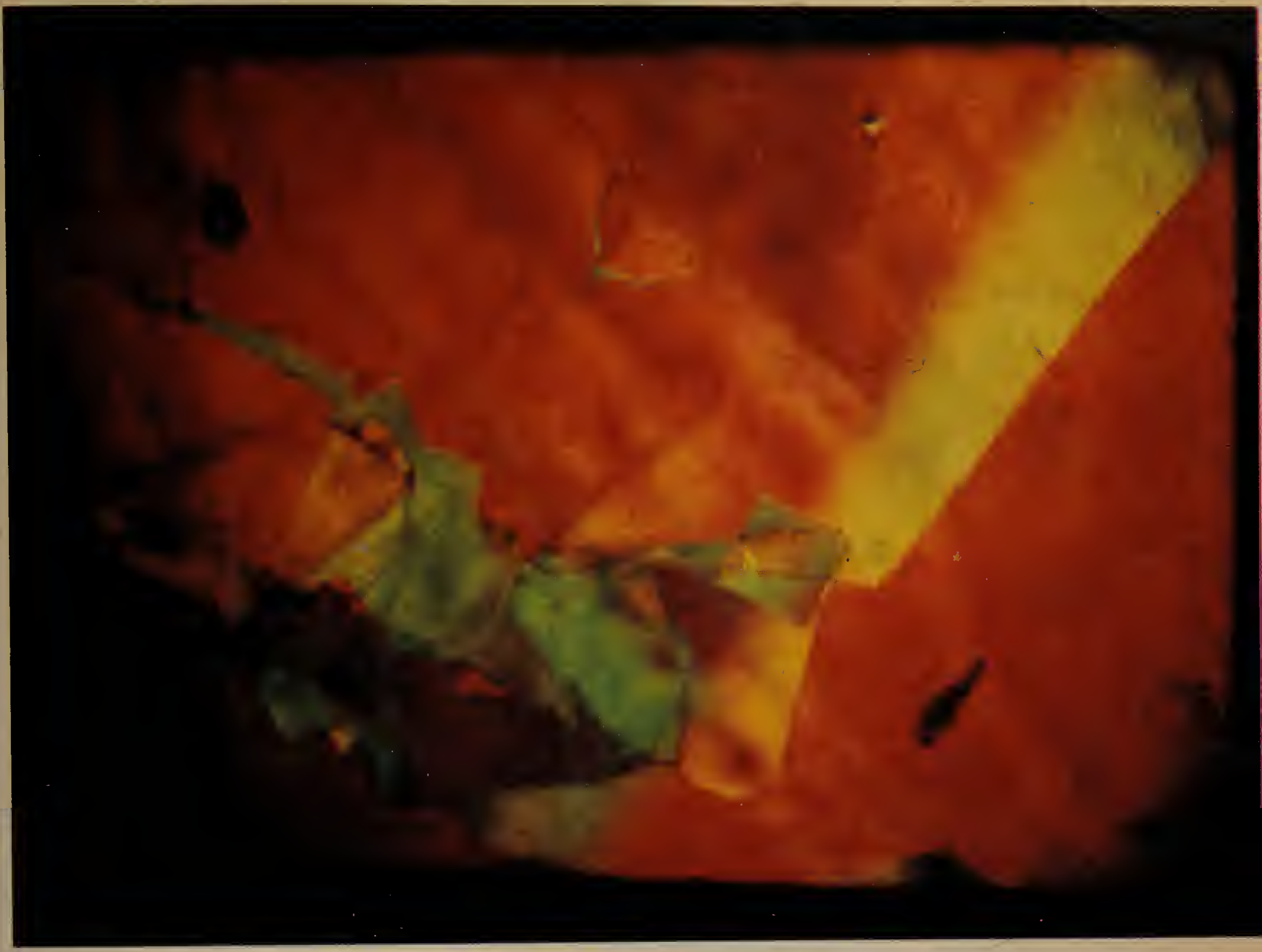

Three Compositions projected by Chromatic Abstractoscope, by Carlos Martinoya and Nahum Joël. See Article 8, "The Chromatic Abstractoscope: An Application of Polarized Light".

KINETIC ART: THEORY AND PRACTICE

EDITED BY
FRANK J. MALINA

From Thomas Wilfred's first Lumia experiments in the early years of the twentieth century, kinetic art has grown into a rich artistic field with great cooperation between artists and technicians and work that is increasingly more sophisticated. Sculptures that move, pictures closely linked to music, mechanical, electrical and chemical systems, constructions involving lasers, and computer hardware have all proved their worth as useful modes of artistic expression.

In this collection of 44 articles from *Leonardo, the International Journal of the Contemporary Artist,* artists and engineers talk about their own work and about the history, theories and general resources of kinetic art. Plexiglas and light sculptures, light shows, lumia systems (including the lumidyne, the chromatic abstractoscope, the kinoptic system, and kinetic art with sunlight) are all included along with audio-kinetic systems, photic-stimulations of alpha brain waves, computer art, oscilloscope-generated art, visual displays of sound, and information on subjects relevant to kinetic art, such as health and safety hazards, cybernetics, the theory of space and time, kinetic art theory, holography, and other potentially potent methods and materials. Among the artists who discuss and comment on their own work are Nino Calos, Valerios Caloutsis, Robert Henry, P. K. Hoenich, Richard I. Land, Frank J. Malina, Timothy Hunkin, Charles Mattox, Stephan Von Huene, Jim Hill, Milton Howard, Ben F. Laposky, David Smith, Joël Stein, and S. R. Wagler.

Artists, teachers, designers and others interested in the possible joining of art and technology will find this book to be stimulating for the descriptions of vital work being done today. Since the artists themselves are writing, the articles tell much about the possibilities and probabilities of kinetic art in the near future. Classes and individuals who are working with kinetic art will find here a book that will serve as a solid source of information and lead to the best resources as well as the best works and workers in the field today.

Original Dover (1974) publication. 44 articles reprinted from *Leonardo*. Introduction, glossary, and index prepared specially for this edition by Frank J. Malina. References. 163 photographs. 60 other illustrations ix. + 244pp. $8\frac{1}{8}$ x 11.

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Oscillon 1206 by Ben F. Laposky. See Article 29, "Oscillations: Electronic Abstractions".

Paths in Space, by Frank J. Malina. See Article 7, "Kinetic Painting: The Lumidyne System".

Cover designed by Theodore Menten