COMPUTERS, SCULPTURE AND THREE DIMENSIONALITY

Course Notes for "Computer Graphics for Designers and Artists"

J. Michael O'Rourke

New York Institute of Technology
Computer Graphics Laboratory
Old Westbury, N.Y. 11568

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J. Michael O'Rourke

Introduction

As computer graphics capabilities become more sophisticated and at the same time more accessible to users, it is becoming increasingly possible for artists who are primarily concerned with three dimensionality to use computers in their artwork. It is fairly common to find architects using computer programs that allow them to define building-like shapes within the computer, reposition them interactively on the screen, and get some sort of hardcopy printout which records their efforts. [9] Choreographers are beginning to make first, tentative attempts to use similar capabilities of computers to help them sketch out and record dance movements. [7] And sculptors have also begun to find computers powerful enough and approachable enough to be able to make use of them in their artwork.

I am a sculptor. The great bulk of my artwork, sculptural and otherwise, is done with, in, around, thanks to and sometimes in spite of computers. This paper will describe some of my experiences in using computers to make sculpture. Various technical applications of the computer to sculptural processes will be discussed. In addition, some aesthetic issues which are raised by the use of computers in the sculpture making process will also be dealt with.

But first, let us begin by revising the concept of sculpture. Normally one thinks of sculpture as a very physical, very tangible thing. It is very much there–klunked down on the floor, lifted up onto a pedestal, precariously poised against the sky. It is often very heavy. The people who make it often have dirt under their fingernails. It is very "real".

But it need not be. The essence of sculpture, the heart of its matter, lies not so much in sculpture's physicality as it does in its conscious composition of three dimensional spaces and volumes. [10] An Egyptian granite figure and an aluminum Calder mobile are considered together as sculpture, not because they are both heavy. They're not. And not because they both rest on the earth. They don't. Nor do we classify them together because they are both physical, tangible objects. They are that, but so is an oil painting on a piece of canvas. We classify them together because they are both attempting to compose a three dimensional world. They may each be doing so for different emotional reasons and they may each be using very different approaches in doing so, but what binds them together, far more than any physical characteristics, is their common concern with three dimensional composition.

What is of primary significance as we look at the Egyptian statue is not what the material is made of or how heavy the material is or how this or how that the material is. These all, of course, play a contributing role if the piece is good. But what is of primary significance as we look at it is the set of three dimensional relationships that the various elements have among themselves and relative to the whole–where "three dimensional relationships" means, for example: what space they occupy, how they occupy it (filling it? "invading" it? sectioning it?), their orientation in the space, what spaces they *don't* occupy, etc..

When a sculpture consists of a coherent set of three dimensional relationships and when these have emotional significance for us, the sculpture has a pronounced presence, a reality of its own. It strikes us as being necessarily so.

With any sculptural medium that I have worked in, whether I have had clay under my fingernails, marble dust in my nostrils, or the hum of air conditioners in my ears, I have felt primarily concerned with composing three dimensional relationships. I suggest, therefore, that, to the extent to which sculpture can be defined, not in terms of its physical presence, but in terms of it three dimensional relationships, we can think of sculpture as being not necessarily "real" and physical, but also perhaps "virtual"–that is, defined, but having no physical being. The critical criterion is that sculpture be a conscious composition of three dimensional relationships.

Sculpture as I think of it and as I use the word here may be either physical sculpture or virtual sculpture. Physical sculpture is what we have grown up thinking of sculpture to be and is just what it says. Virtual sculpture is, like physical sculpture, a set of clearly defined and perceivable three dimensional relationships, but is sculpture without any physical being. This paper will deal with some applications of computer technology to both virtual sculpture and physical sculpture.

Physical Sculpture

Perhaps the connection which occurs most immediately to our minds when we think of computers and sculpture is to think of the computer as a tool to assist us in the design and fabrication of physical sculpture. The technology is advanced enough that using the computer in this way is quite possible, and indeed involves many of the same techniques that are used in standard industrial Computer Aided Design (CAD) and Computer Aided Manufacture (CAM).

For about a year now, I have been using a system of programs at the New York Institute of Technology as an aid in the design and manufacture of physical sculpture. The system is under development and, while not as complete as what one would find in, for example, a large automotive plant, is quite powerful. The approach has been to develop very generalized programs/tools and to avoid binding them closely to the modeling of specific kinds of shapes. The results of this approach have been quite satisfactory.[1]

The pieces I have worked on with this system are compositions which involve a number of discrete elements. That is, the pieces are not monolithic and the approach is primarily constructive, as opposed to subtractive. Having come up with some initial, very rough idea of the whole (usually a freehand sketch on paper) I model each of the component elements as a polygonal data base. For this stage, a real-time vector display device is used. These machines generate a wire-frame representation of the three dimensional shape and allow me to smoothly move and rotate the shape under the control of a

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[1] Credit for the software development in this system goes to Patrick Hanrahan and Jacques Stroweis for the modeling and spatial set operators, to Robert McDermott for the flattening software, and to Paul Heckbert for the rendering software.

joystick and a panel of dials. The techniques that might be used for modeling these elements come from the standard computer graphics repertoire. [1][3]
An outline, handrawn on a tablet, might be extruded to produce a block-like shape. Another outline might be used to generate a surface of revolution. Geometric primitives–for example, cylinders, cones, spheres–might be generated algorithmically. Finally, any of these elements might be added to or subtracted from any of other element using spatial set operators.

When the various individual elements have been modeled, they are combined–again in real-time on the vector device–to form the whole design. Doing this involves interactively positioning and scaling each of the various parts until the whole piece has taken shape. Figure 1 shows the result of these modeling efforts for one sculptural model up through this stage.

At some point, however, the wire-frame, skeletal representation that we have been using so far ceases to be sufficient for our purposes. As the composition is refined you find the need to see more precisely where things intersect, for example, or how they will look when solid and opaque, and the see-through representation of the vector machine no longer suffices. At such a point, the configuration can be rendered in frame buffers as a solid, shaded image (figure 2). With the additional information this provides, one can return to the vector representation and further change things–again pushing the parts around, changing their relative sizes, their locations, etc.

The advantage to the sculptor of using computers in this way lies in the ease with which he/she can make modifications to the design. Since there is no physical material involved yet, changing the size or location of a part can be accomplished by simply twisting a dial or pushing a joystick. Perhaps even more important, however, than the time and effort saved in this way is a psychological advantage. I have found that being able to try out ideas very easily while still retaining the ability to return at any moment to an earlier, saved version of the piece greatly increases my willingness to experiment with the ideas in the first place. In other words, the computer not only facilitates the realization of an idea, but also encourages the generation of different ideas.

The design process I have been describing so far is however, not without disadvantages. The possible shapes of the individual elements are limited by the kit of modeling programs available to me. There are some shapes which it would be impossible, or very tedious, for me to model. Also, in the case of the programs that I personally have been using, physical characteristics and constraints are not programmed into the system. I am not forewarned, for example, if my piece is going to protrude through the floor, or be off balance and topple over. Such constraints could, of course, be made part of a sculpture design system. And indeed, they should to the extent that you want to use your data directly to generate your final piece. [12]

Another disadvantage to be dealt with parallels, in reverse, the psychological advantage mentioned earlier. The easier it is to make changes in your design, the more important it becomes that the sculptor be able to sense which changes are for the better and which are gratuitous, which are taking the piece in a good direction and which are a dead end. It is very tempting to convince yourself that, since you've got ten variations anyway, all ten of them are good and each should be considered a final, distinct sculpture. In fact however, of the ten variations, perhaps only one or two might be considered worth preserving if you were to apply the same rigorous standards you would be applying if you had to physically and laboriously construct each of those variations.

Having come to some satisfactory composition, one wants somehow to begin building it. One wants to get from the digital information that describes the object to a physical object. The crudest approach is to work from the frame-buffer renderings, or perhaps from plotter drawings of the object as seen from several different points of view. In essence, this entails looking at a number of pictures of the object, using them as a guide, and "eyeballing" things to make your sculpture. There is obviously a lot of imprecision in this approach, and you will have stopped short of getting a physical, three dimensional representation of your ideas out of the computer Still, you will have used the computer's capabilities to very good effect to work out some initial design ideas.

An approach to using the computer as a manufacturing aid to produce a physical model is however, feasible with the system I have been describing. Each of the individual elements has been defined as a closed polyhedral figure. Having settled on a final composition, spatial set operators are used to calculate the intersections each element may have with any other element. The significant operator here is the Difference operator. This can be thought of as subtracting one part from another. If you have a cube and a cylinder occupying the same mathematical space, and the cylinder is subtracted from the cube, you will end up with a cylindrical hole in the cube. Doing this to each part gives you not only the shape of that part, but also the shape of any holes cut in it by any other parts.

At this point, each three dimensional, in-the-round part can be, as it were, "unwrapped"–flattened out so that all of its polygons now lie in the same plane. Imagine a cube-shaped cardboard box. Remove all the staples that are holding it together and flatten it out onto the floor. You will now have a flat, two dimensional pattern which, if you do it properly, you can then fold back up into its original, three dimensional cube shape.

Figure 3 shows a plotter drawing of several elements of one sculpture unwrapped and flattened out into a plane. The most easily recognizable of these shapes is probably the one in the upper right corner which, when folded back up, forms a cone. Note that the irregular shape in the left half of the drawing has a hole towards its own left side. When this element is folded back up properly, that hole will be the shape of the hole cut in this part by another part which touches it.

The farthest I have taken these techniques to date is to produce paper models of the sculpture. Each part is flattened and that flattened pattern then plotted onto paper. Each of these is cut out, folded up, and glued together. All of the various individual parts are then glued together to yield a small-scale paper maquette (figure 4). Having gotten to this stage, I usually find that there are further changes that I want to make to the composition. Sometimes these changes might send me back to the vector device stage for an additional complete pass through the process. Sometimes the changes may be made on the paper model directly.

I have not yet taken this technique all the way to its logical conclusion in full-sized sculptures fabricated of durable materials. Some possible approaches, however, are apparent. One is tc stop using the computer at this stage. One has, after all, already gotten a lot of very fast mileage out of the computer's three dimensional design capabilities. We have, presumably, gone through a lot of ideas very fluidly and quickly and have ended up with a physical model of our ideas. At this juncture we begin encountering the aesthetic problems that always arise when we transfer from one medium to another or move from one scale to another. It may be to the benefit of the piece to abandon the computer at this point and proceed as any sculptor who has several small maquettes in front of him and is working with traditional techniques might proceed.

It would also be possible, however, to continue making use of the computer right through the fabrication process, in ways similar to those used in industry. New York Institute of Technology has a numerically controlled milling machine and we are, in fact, in the process of working out procedures that will allow us to do this. Rather than plotting our flattened parts onto paper and gluing them together as we do now, we intend to send the data to the milling machine, instruct the machine to cut the patterns out of sheet metal and then weld them together. What new aesthetic problems this will raise and what solutions might be possible have yet to be encountered.

Virtual Sculpture

As mentioned in the introductory remarks, it is possible to conceive of sculpture that is not physical at all but is, rather, virtual. What makes a piece of sculpture sculpture is not the specific material from which it is made, nor even its materiality at all. It is its three dimensional composition. Certainly there have been sculptors before me who have felt as I do and who used the materials and technologies available to them at the time to make sculpture that reflected their feelings. The Constructivist sculptors, for example, worked at dealing directly with the composition of space, rather than of material. [2] In our current era, the computer and its new imaging capabilities have opened up to us new ways of dealing with these sculptural concerns.

A number of years ago, while at the University of Pennsylvania, I used a real-time vector device as both tool and final medium for a series of virtual sculptures.[2] I wrote a number of programs which ran on this machine and allowed me to define and then composite three dimensional configurations. Since there was no intention to ever go outside this machine with these compositions, these configurations consisted solely the kind of representation the machine was expecting and handled well–that is, lines drawn in space. There were no surfaces, colors or lights defined.

Having defined an initial three dimensional configuration of lines in space, I would then write a program to display it on this same device. This program was as much a part of the final piece as the original definition of the composition because written into the program were certain dynamic and interactive characteristics of the virtual sculpture. Neither the display of the composition nor the composition itself were static, but rather both were under the dynamic control (or partial control) of the viewer. (Figures 5-7).

To begin with, the viewer had the ability at any moment to change his/her point of view. He could move to the right or left of the object(s), in closer to them, around behind them. All this was accomplished with a three-axis joystick and the viewer quickly developed a close association between where he "wanted to be" and the movements of his hand on the joystick that would accomplish this change in point of

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[2] In the description of these pieces that follows I will often speak of them in the past tense. This is because the final pieces were extremely machine dependent. They were written to run on a specific machine under a specific operating system. As far as I am aware, they have never been run or seen by anyone since I left the U. of Pa.

view.[3] The immediacy of this association was important because it contributed to the viewer's send of the three dimensionality of the virtual sculpture. This, plus the various three dimensional perceptual cues of the display itself (intensity cuing, perspective, parallax) made one's perception of the three dimensionality of the composition very keen. If, in addition, the room lights were turned off so that you attention was very focused on the screen display, the sense of three dimensional space was even keener.

In addition to controlling the point of view, the viewer also had a degree of control over the spatial relationships themselves. In each piece, there was one element that the viewer could elect to move around, re-orient or make smaller or larger. Some of these choices however, were subject to certain constraints. The artist (myself) had programmed into the piece certain limitations on the possible changes you could make. The idea was that artist and viewer both jointly determined the final composition. In effect, this meant that there was no "final" composition. Rather, one had to speak of the composition for a given viewer at a given moment. The compositions for different viewers at different moments would all be largely similar, because the initial composition provided by the artist was always the same. But because of the viewer's input, each would also be somewhat different than any other.

Each of these pieces was a virtual sculpture–a carefully developed and clearly perceivable set of three dimensional relationships without body They were developed on, stored in and viewed with the computer. They had no physical being. Nor was there ever any intention or desire that they should. On the contrary, it was precisely their virtual character that appealed to me and led me to produce them.

Because these virtual sculptures existed independently of the laws of the physical world, certain things were possible that wouldn't have been in a physical sculpture. One of the more obvious is the lack of gravity. These pieces need not rest on a ground, or be suspended from a ceiling. The whole thing, as well as each of the individual parts, could and did just float there in space. It was also possible, because there was no physical material involved, to go right through a piece and come out on the other side. As the viewer changed his point of view, moving around the piece this way or that, he could, if he chose, decide to approach, go into the composition and view it from the inside out.

Most dramatically perhaps, it was possible to program the sculpture such that elements could come into and go out of their virtual existence. The sculpture illustrated here involves this sort of temporality. Initially, there is only one of the box-like elements in the composition (figure 5). If he chooses to do so however, the viewer can hit a button and call into existence an exact duplicate of this element. This duplicate will appear in the same location as the original and begin very slowly drifting off from it, leaving the original behind. With a second joystick the viewer could now control the movement of the new element, moving it this way or that (figure 6). If he stopped moving it, it would resume its own slow, constant drift. After a certain definite, but from the viewer's point of view unpredictable, amount of time, the element's "life" would be over. Wherever it happened to be at the moment, it would glow, disappear, re-appear glowing very briefly in its starting location, and then be gone. Figure 7 shows the afterglow left behind just after the element has disappeared. If he wanted, the viewer could then reinitiate the cycle by hitting the button again.

This sort of sculpture proved very satisfying to me in my attempt to make

[3]The similarities between this system and video games is clear and will be pursued a bit later in the paper.

compositions that reflected not only the three dimensional patterns and relationships that we see in the world around us, but also the fact that these patterns are constantly changing, and that sometimes we have control over these changes and sometimes we do not. Sometimes more. Sometimes less.

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Having talked a bit about two very different types of sculpture that I have been involved with, it is worth discussing the issue of the influence one may have upon the other. I have always found it both enjoyable and valuable to be working simultaneously in several different media and from several different approaches. For example, while working with my more recent three dimensional virtual computer compositions, which I will be discussing in a moment, I have also periodically made sketches in clay and wire. The cross-fertilization that takes place when thinking about one set of ideas through different media is very helpful to me.

As an illustration of how the different approaches a single artist might take can be interconnected and how one's work in very different media can have cross-influences one upon the other, I'd like to briefly discuss a recent series of two dimensional compositions.

Given my three dimensional bias, it turns out that my two dimensional work succeeds best when it is related to, grows out of and feeds back into what I am thinking about three dimensionality. This series is an example of that close inter-relationship. The final product for each of the six images in this series is an edition of color photographic prints, one of which is reproduced in figure 8. They are very definitely intended to be static two dimensional compositions. Nonetheless, the first steps in arriving at these two dimensional compositions involved manipulating (again on a real-time vector machine) wire-frame representations of a three dimensionally defined model. By manipulating this representation of a three dimensional model on a machine designed to convey three dimensionality, but *deliberately* resisting the three dimensional cues and interpreting the result as a strictly two dimensional pattern, I arrived at an initial linear composition for each image. The color composition of each piece was then developed through a long series of purely two dimensional frame buffer modifications (frame buffer "hacking", in the parlance) on this linear composition. This was then combined with a three dimensional rendering of portions of the original model.

All of this grew out of my interest in what happens when we perceive a thing as two dimensional and what happens when we perceive something as three dimensional, which in turn developed out of my working with virtual three dimensionality. The intention is that the viewer will experience a tension between his tendency to view it as a two dimensional pattern and as a three dimensional "thing". The three dimensional object is rendered as if in front of a two dimensional plane, but that in turn is place as if suspended in a three dimensional space.

Notice, too, that part of the three dimensionally rendered object is very similar to the paper maquette we have already seen. This series of prints, as well as a model for a physical sculpture, as well as a video piece deriving from a related virtual sculpture–all developed simultaneously. Working with one influenced what I was doing with another, which then had an effect on my thoughts about a third, etc. Many of the compositional elements and issues that I was dealing with found their way into several of the pieces.

This kind of feedback is very stimulating to me.

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While I make an effort to always be working in several different media at any one time, and to be involved in making both physical and virtual sculpture during any one period, the majority of all the three dimensional work I have been doing at the New York Institute of Technology does involve virtual sculpture. I will describe and discuss some of that work now.

These pieces, like the earlier ones, are virtual. There is no attempt or desire to fabricate them of any physical material. They share many characteristics with the earlier pieces, but are significantly different in some ways.

On the positive side, these pieces (figures 9, 10) are visually more complex and subtle. They include, not merely the definition of monochrome lines in space, but also of surfaces, of light sources, shading, atmospheric color and density, and the definition of transparency and opacity–in short, most of the three dimensional modeling and rendering capabilities of contemporary computer graphics. While still retaining my interest in the composition of lines in space, I have now been able to also set up a tension between lines in spaces and solids in space, and then to modify this with a contrast between lines, "solid" solids and transparent solids in space. I have also attempted to establish a similar counterpoint with the tension between regular, geometric shapes and irregular, unpredictable configurations.

All of this grows out of my perception of these same sorts of patterns and rhythms in the world that we live in–whether these patterns be visual, temporal or emotional. For, ultimately, it is emotional and psychological patterns which I am after and which I attempt to deal with visually. By making a visual representation of these patterns in my virtual sculpture, I attempt to "handle" them and, by handling them, to understand them.

While there are some respects in which these compositions are more complex than the vector compositions, there are other respects in which I have abandoned some desired characteristics. Notably, these pieces are not, as were the earlier ones, viewed in real time and are not interactive. This is necessitated by the amount of time it takes to generate each given view, or frame of the virtual sculpture. In the vector pieces, a given view could be generated in 1/60 second. Thus the real-time updating. In these compositions, the additional image complexity is such that each frame takes several minutes to generate. Consequently the final product for these compositions has been video tape or film. What the viewer sees is a three dimensional configuration moving through space. Some of the elements of the composition are static and some are dynamic (just as in the earlier pieces). The patterns and rhythms of the movements of the dynamic elements are similar to the visual patterns established by the three dimensional shapes themselves. But in no case can the viewer interact with these compositions, as he did with the earlier, University of Pennsylvania, pieces.

This loss of interactivity is regretful to me. One's sense of the three dimensionality of an object is very severely limited if one cannot interact with it. The interaction may be very constrained, as it is for example, in the normal museum situation where our interaction with most sculpture consists simply of being able to walk around a static object. But even this is significant. By moving about, the viewer changes the content of his visual field. This is minimal interaction between viewer and object, but very important to our sense of the object *being* there in a real three dimensional space.

Of course, it is not necessary that compositions such as the ones I have been describing forever remain non-interactive and viewable only via pre-recorded tape. Raster devices which provide real-time updating of three dimensional imagery exist. If one had the proper equipment, these same virtual sculptures could be viewed on a real-time raster display device, in the same way that my earlier pieces were viewed on a real-time vector display device. The general availability and accessiblity of this kind of equipment is a matter of time.

There is a sense therefore, in which I consider these compositions to be an intermediate state. More complex and more refined than the vector compositions in some respects, more limited than these compositions in others, they can be thought of as steps along the way to creating real-time, fully-shaded, interactive raster display virtual sculptures.[4]

What I am after in the approach I have been describing can be thought of as a sort of video game. The point of this game however, is not to blow up one guy or avoid being blown up by another. The point of the "game" would be to examine, modifying it in certain ways as you do, a three dimensional configuration, and to come to understand its structures and meanings. The program which defines the virtual sculpture, including the possible interactions between it and the viewer, would be put onto a microchip and the sculpture displayed as arcade games are now–that is, not on a very expensive general purpose computer, but on a less expensive, special purpose machine designed for that specific game/sculpture. One box for one sculpture. For a series of related sculptures, perhaps one box for the series. Eventually, one could have in a gallery, home or museum a collection of these virtual sculpture boxes, just as one now has a collection of paintings or sculptures.

Conclusion

All of the above discussion of virtual sculpture raises some interesting philosophical questions. As we describe the progression from the early vector compositions to the video formated raster compositions and into what I foresee with the interactive raster pieces, we keep adding more, and more refined, perceptual cues. Linear perspective, shading, atmospheric density, viewer interaction. At what point, as we add and refine perceptual cues, do we cease to speak of the object as being "virtual" and just think of it as being real? If we can see a single view of what appears to be a three dimensional object, is it a "real" object? No, we say, because we can't walk around it. If we can "walk around it" by using a joystick to control our point of view, is it then real? Suppose the image is displayed to us not on a stationary monitor set on a table, but in a tiny head-mounted monitor that reads our body movements and updates the image accordingly, so that we can *physically* walk around "it". Is it then real? And if there are two images–a left eye view and a right eye view–so that we see the object in stereo, as our eyes normally do? Suppose we program into the definition of the object virtual

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[4] It is also possible, of course, to treat them as video *per se* and to work out the compositions, the animation and the editing with this in mind. I am in fact, working on a video piece along these lines.

tangibility,[5] so that we can "feel" the object–perhaps with a set of electronic gloves that would be to our sense of tactility as CRT monitors now are to our sense of vision. And if we add sound? And scent?

How many, and which, characteristics must the object have before we consider it real? Or before we become incapable of distinguishing between what is real and what is not? Or before we cease to care about the distinction?

[5] A. Michael Knowle did some experimental work a number of years ago at Bell Labs on this subject.

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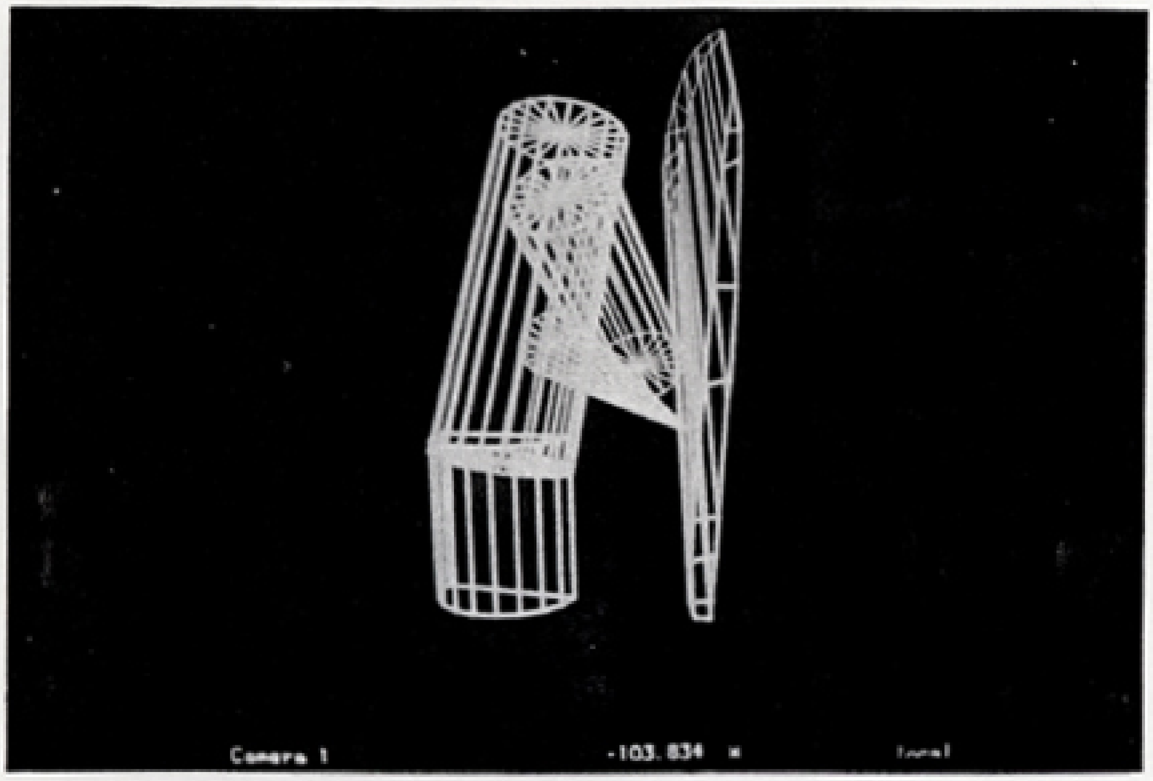


Figure 1

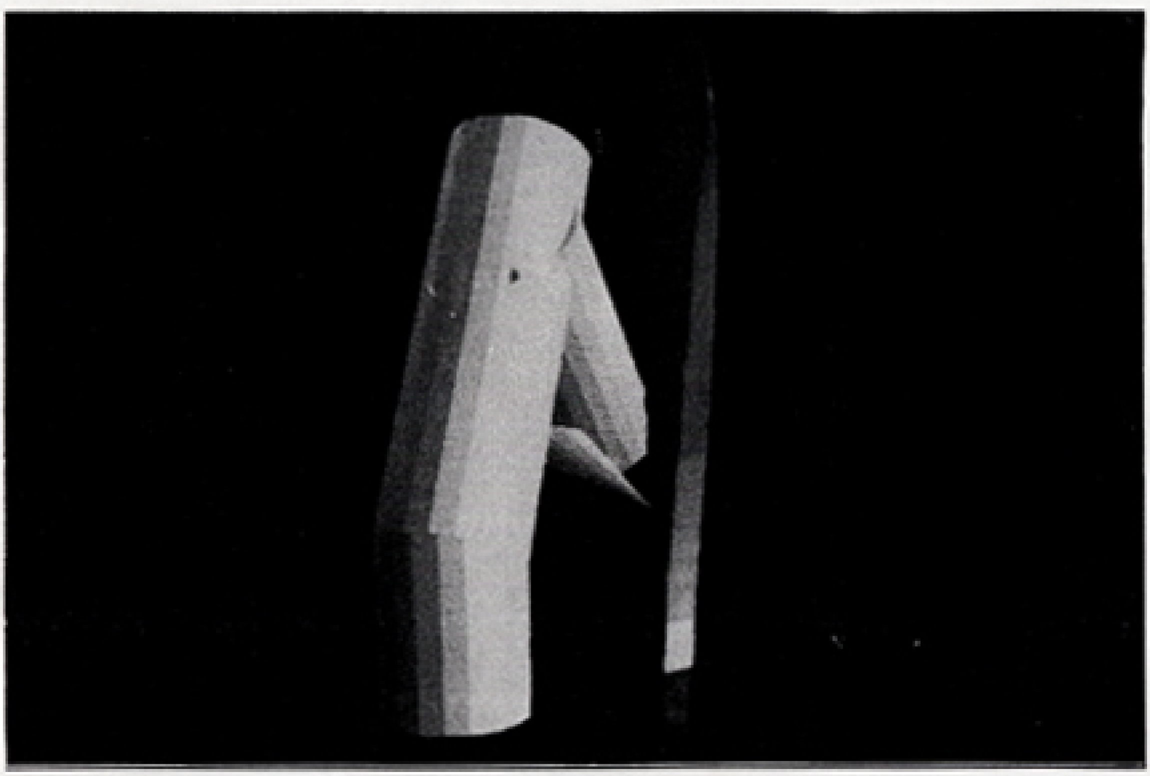
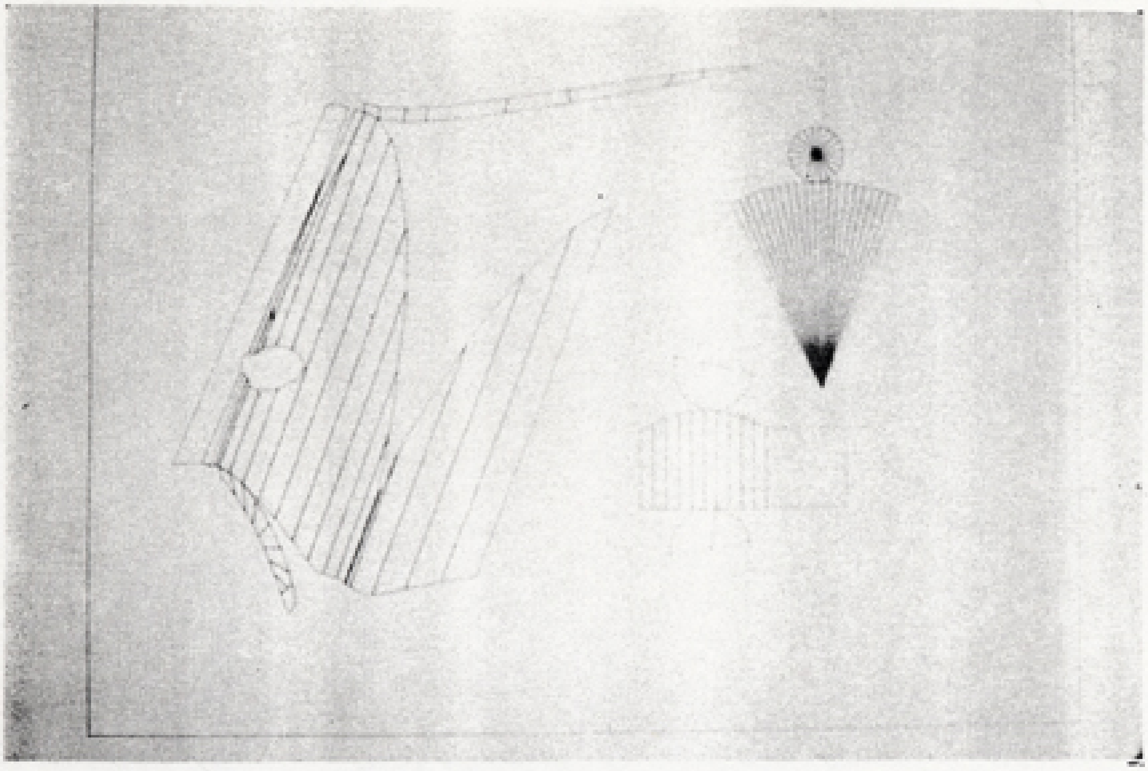


Figure 2



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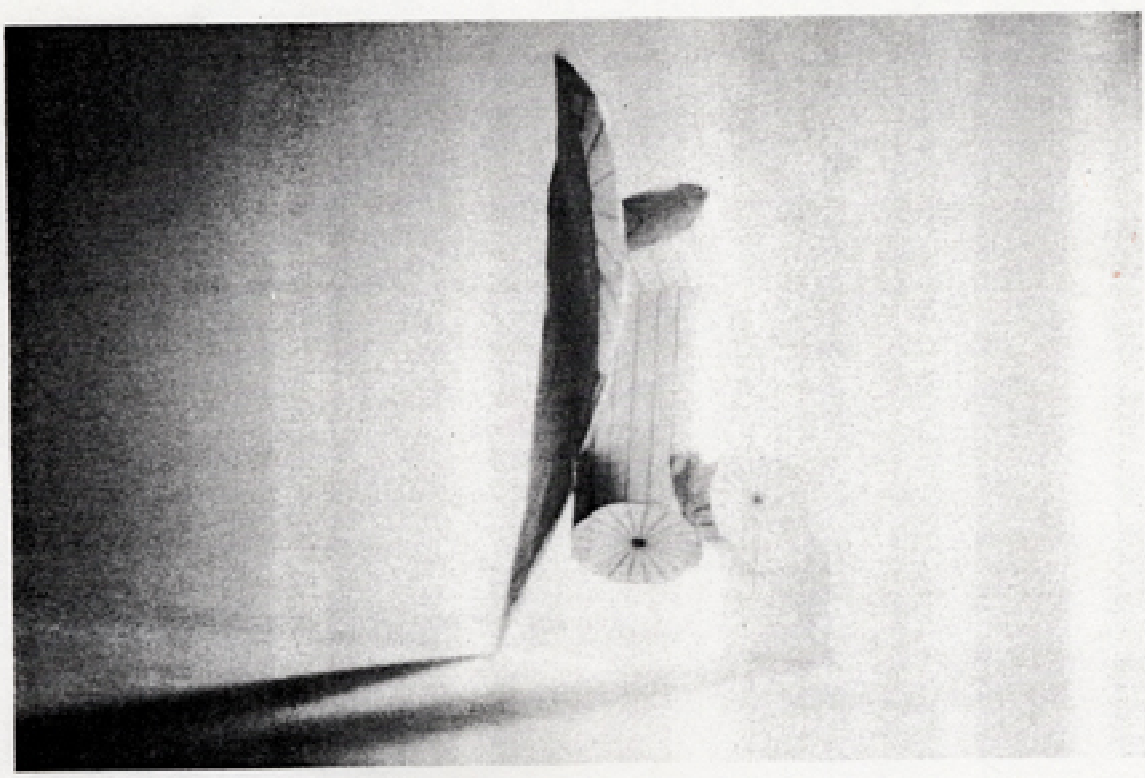

Figure 4

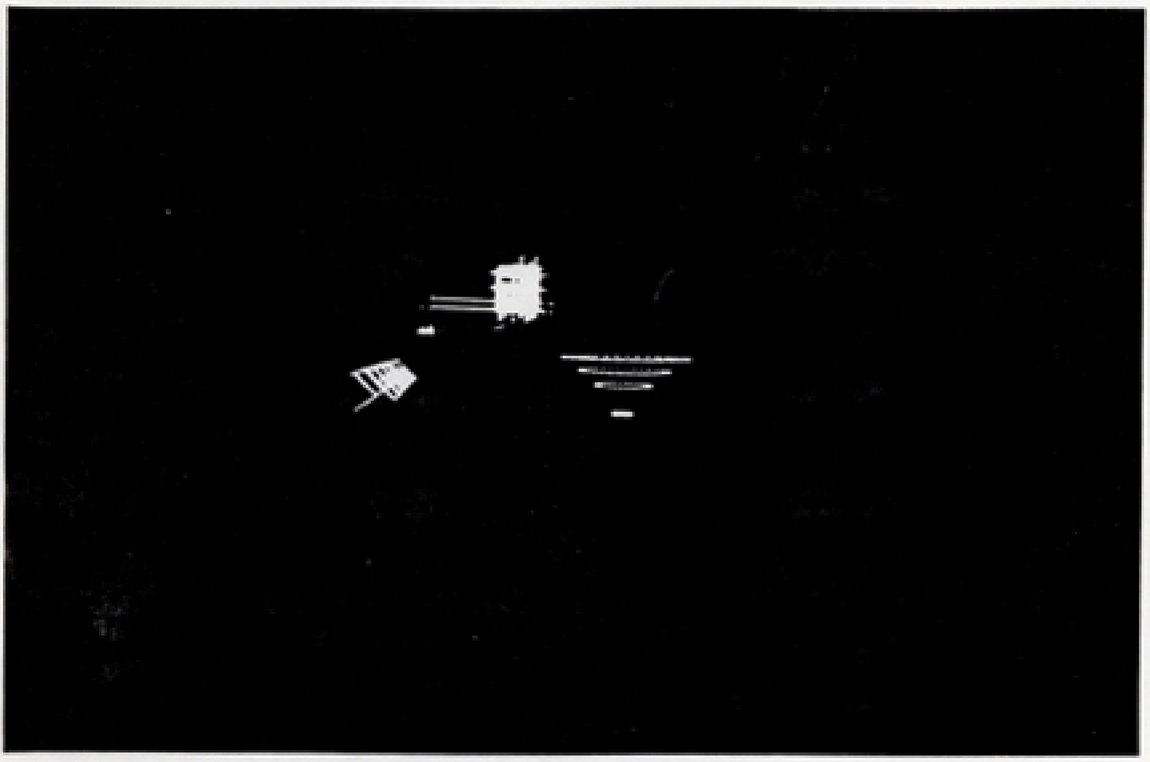

Figure 5

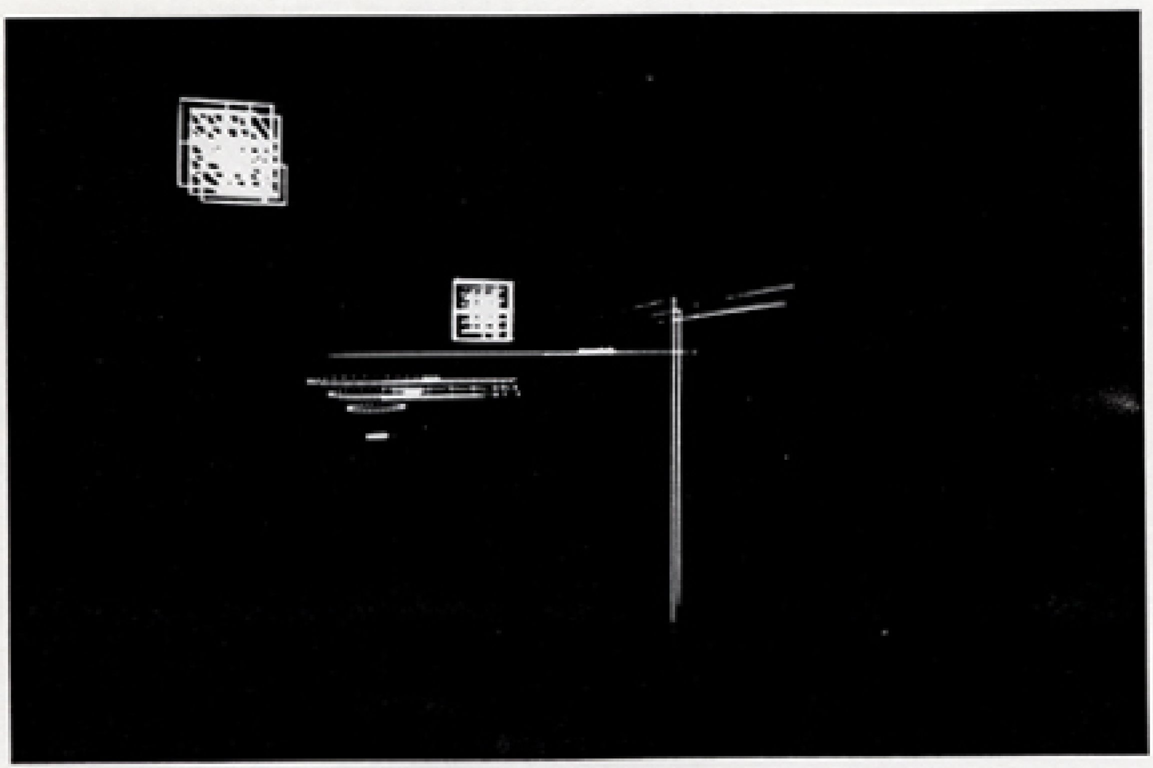

Figure 6

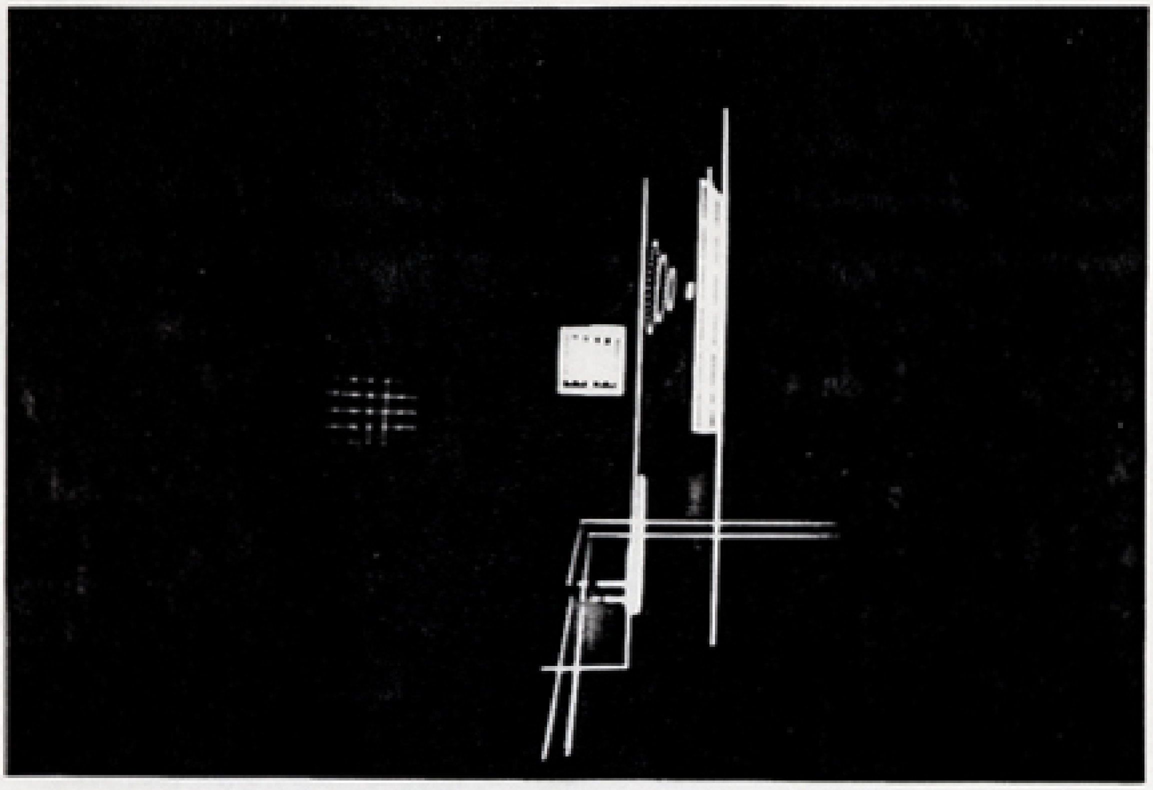

Figure 7

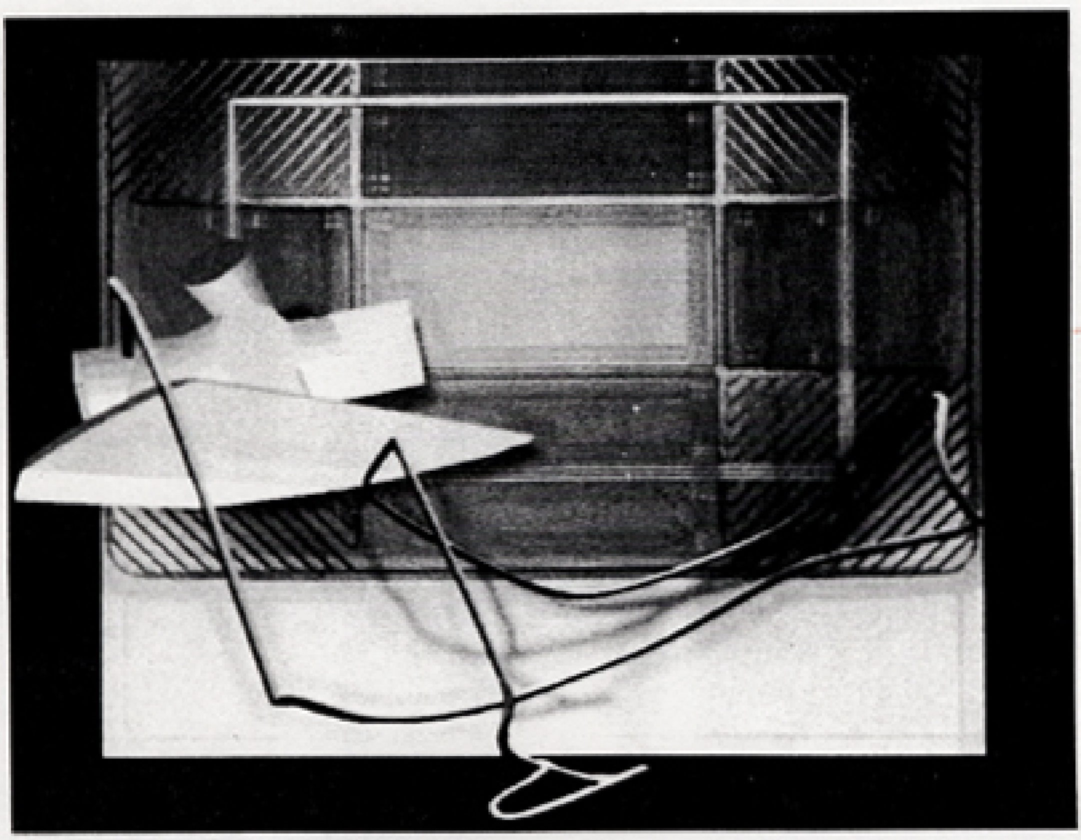

Figure 8

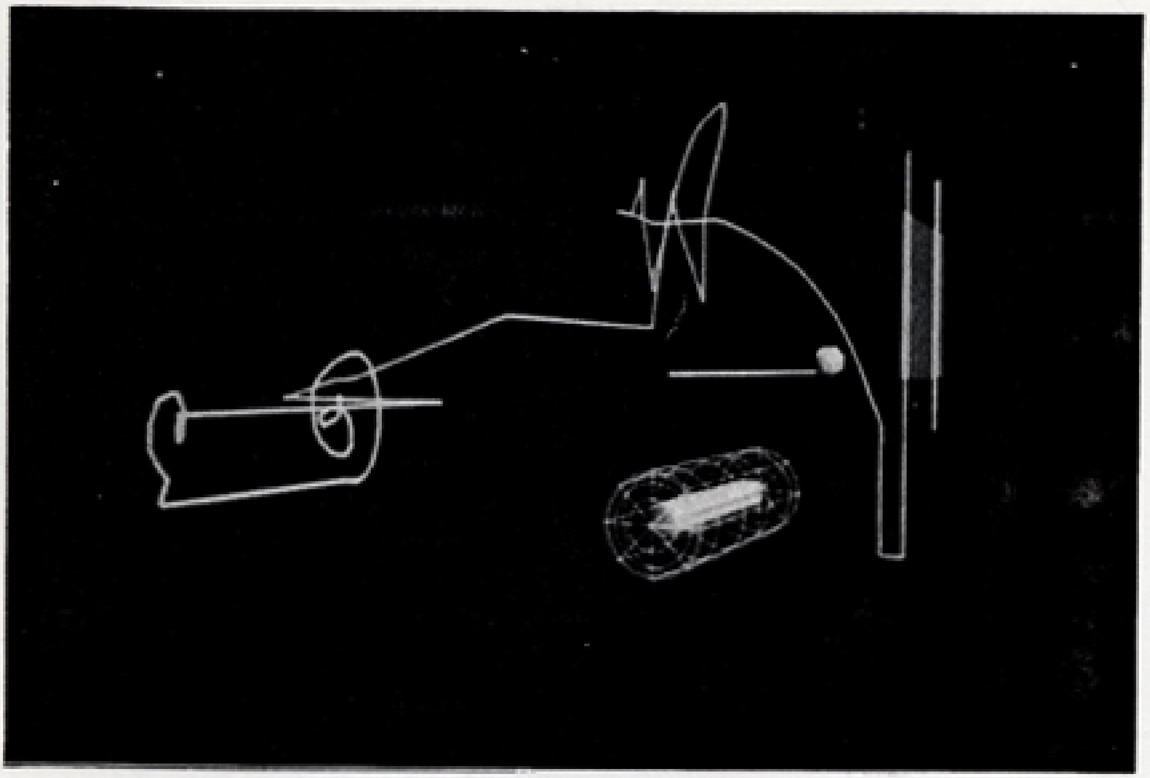

Figure 9

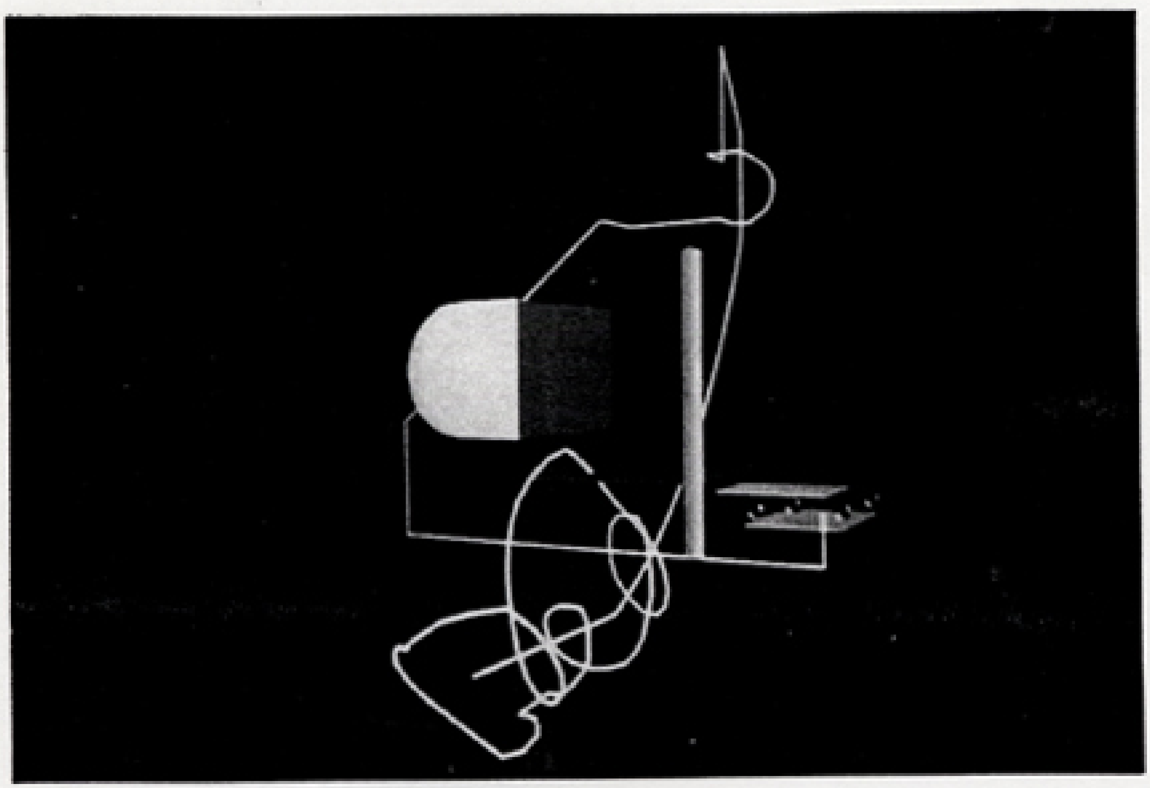

Figure 10