In a very large number of applications the computer is used for its ability to perform a set of pre-determined transformations upon a set of data, and this kind of use has become standard in 'computer art', where the data is some original provided by the artist. If the aim is to model human art-making behavior, rather than merely to use the machine as a tool! in this quite traditional sense, such a definition of the machine's functions is inadequate. Human art-making behavior is characterized by the artist's awareness of the work in progress, and programs to model such behavior will need to exhibit a similar awareness. Thus, 'behavioral functions' are defined here as functions which require feedback from the results of their actions as a determinant to their subsequent actions. Programs designed upon this specification will also require appropriate schema for the description of the work in progress.

The feedback systems employed in intelligent behavior might be pictured as the asking of questions about the perceptual world whose answers will be relevant to decision-making. For the machine, 'awareness' of the work is totally defined by this question-and-answer structure, and in this sense is equivalent to the human perceptual system. It is not clear what descriptions of the work will serve for a reasonable simulation of human art-making behavior, or what questions will need to be asked. They will not necessarily reflect the 'facts' of the human system, but it seems likely that the machine's feedback system as a whole will need to possess a comparable adaptiveness to permit of the fluently changing pattern of decision-making which characterizes the practice of art.
gone some part of the way towards realizing it, as I will try to show; far enough to suggest that the rest is attainable. But I should define my position more carefully, for the simulation of human perceptual processes arises as a result, rather than as a motive, for this work. Whatever other territories may appear to be invaded, I believe that my behavior in programming the machine to simulate human art-making behavior is, in itself, primarily art-making behavior, and I have proceeded by attempting to deduce from the requirements of the venture as a whole what perception-like abilities may be appropriate. The plausibility of the resultant structure must thus rest upon the success of the whole system in satisfying its purpose, rather than upon whether it appears to provide a satisfactory model of perception. If the whole system can autonomously generate art — autonomously, that is, in the obviously qualified sense used above — then we will know something more about ways in which art may be made, and conceivably something about the way in which human beings make it; but not necessarily about the specific mechanisms upon which human art-making rests.

The purpose of this essay, then, is to say something about the nature of the characterizations, or representations, of the work in progress which the machine will need to build; and about the constraints under which they are formulated. Unfortunately, so much confusion now exists in the interface areas between art and computers, thanks to the strange manifestation popularly known as 'computer art', that some clarification will be needed before I can get to my subject.

Evidently the power of image-making retains something of its primitive magic even in a society as familiar with images as our own; and, like the camera, the computer seems to exert a democratizing influence, making this power widely available, where it was at the disposal, previously, only of an elite with the skills and abilities to exercise it. Image-making is in the province of anyone with the price of an Instamatic and a roll of film; anyone with access to a computer and a little programming experience. The programmer starts with carefully digitized Snoopy drawings, progresses to rotating polygons, and by the time he gets to polynomial functions he is ready for the annual Calcomp Computer-Art Contest.

For most people outside of art, probably, art is directed primarily at the production of beautiful objects and interesting images; and who is to argue that a complicated and intricate Lissajou figure is less beautiful than an Elsworth Kelly painting or a Jackson Pollock; or that a machine simulation of a Mondrian is less interesting than the original it plagiarizes? To talk of beauty or of interest is to talk of taste, and matters of taste cannot be argued with much profit. The fact is that art is not, and never has been, concerned primarily with the making of beautiful or interesting patterns. The real power, the real magic, which remains still in the hands of the elite, rests not in the making of images, but in the conjuring of meaning. And I use the word meaning in a sense broad enough to cover not only the semantic content of the image itself, but all that is involved in the making of the image.

The particular kind of usage the computer has received in almost all 'computer art' offers some clue as to why 'computer art' can barely claim consideration as art at all. With a few notable exceptions the machine has been used as a picture-processor, which is to say that it is programmed to perform a number of transformations upon material previously defined by the artist. In this role it has something in common with other processes used traditionally by the artist, and yet it has failed to support the dynamic interplay we normally expect between a process, the art-making intentions which give rise to its use, and the formal results of that use. The cause of this failure may be the relative inflexibility of the processes available, but I am inclined to believe that it is dictated by the whole structure rather than by inadequate implementation of the structure. It should go without saying that it is beyond the power of a process to invest an image with significance where none existed before; that if you cannot draw without a computer — and by drawing I mean the conjuring of meanings through marks, not just the making of marks — it seems unlikely that you can draw with one. At all events, it is clear that the use of the computer as a tool in the sense that a camera is a tool represents the antithesis of autonomy, and is thus not my subject here.

All the same it will be worth examining the notion of picture processing as a starting point in order to see how other possibilities relate to it. Diagramatically (Fig. 1) we might think of the processor as a black box, with a slot at the top through which original material is fed, and a slot in the bottom through which the processed material exits. The range of possible processes, or transformations, is fixed for any given configuration of the machine, but they may be selected and concatenated by the user, who also has a measure of quantitative control over their application — if he chooses to transform an image by rotating it, then he can specify how much it is to be rotated, for example. The actual number of processes which can be programmed is large, but, as one might almost anticipate, the few examples of exceptional quality which have occurred have tended to make use of
which run through neo-Pythagorean cosmology for some hundreds of years of European thought, and it is precisely the proportions of the figure which Csuri has chosen to manipulate.

From a processing point of view, the drawing (Fig. 3) by Kenneth Knowiton and Leon Harmon does no more than to replace small square patches within the original quite minimal processing functions, and instead of burying the original image, lay emphasis precisely on the metamorphosis itself. One such example would be Charles Csuri's manipulations of the Leonardo *Vitruvian Man* (Fig. 2), in which the figure retains its identity even after being distorted, rubber-sheet fashion, in a number of unlikely ways. The manipulations are effective for reasons of content rather than form, however, and are even part of that content, since the *Vitruvian Man* is a symbol for those notions about the proportions of the human body.

photograph with an alphabetic character, chosen from a range of different type faces, each with a proportion of white character to black space equivalent to the gray level in that patch. The processing function is a simple, one-step affair, and again, the interest lies behind the image itself, since Knowiton and Harmon are concerned primarily here with the nature of visual information; not only, WHAT is read, but, HOW it is read. Even so, the choice of original material is evidently by no means entirely neutral, since the text which is used for transfiguring the picture of the Vietnamese child is in fact the Declaration of Human Rights.

Processes may range from the simplest geometrical transformations to highly complex systems in which images of objects are not only rebuilt from the collection of three-dimensional coordinates which represent them,
but can be shown moving around in correct perspective, complete with the shading and shadows caused by any specified lighting conditions. In practice, the machinery for operating these transformational systems may vary enormously, and the wholly electronic nature of the more modern devices allows them to operate at speeds which give the illusion of a direct interaction between the user and the process. Rather than looking at the processed image drawn on paper, then resetting the parameters for the processing functions and starting again, the image can be displayed on a screen, and will change as fast as the knobs are twiddled (Fig. 4). (In fact, operated in this way, the processor inevitably takes on some curious affinities to musical instruments: one seems to be playing it, rather than playing the image with it, and the problems relating to the (outside of music) unresolved differences between improvisation and composition which have already appeared in the use of the video-synthesizer must arise here also.)

As far as the manipulation of the image is concerned, however, the speeding up of the system might induce a change of attitude, but does not represent a change of structure. What all these things have in common is their diagrammatic representation — the original going in at the top, the processed image coming out at the bottom, selective and quantitative control only over the process — and also the fact that at no point does the machine need to read back what it has done. By definition processing is a deterministic affair, and for any single run its functions are predetermined and invariant. Feedback from the result to the functions themselves has no part in this process. On the other hand feedback is clearly a part of the human art-making process, or indeed of any intelligent process, and if the only feedback possible within the computer environment is via the human user, then the computer is a tool in no essential way different from any other tool: and it is evidently capable, up to this point at least, of handling material of much less complexity, and in much cruder ways, than most of the artist's more fertile, and more traditional, tools.

Suppose, now, that we wished to modify this schema in some structural way, hopefully to arrive at something corresponding, in itself, more closely to human art-making behavior. What modifications would be possible, and what could we deduce in relation to them? We have already seen that increasing the number and range of the processes — adding more knobs and switches to the control panel, as it were — would make no fundamental difference: just as increasing the speed of the system would make no fundamental difference. Closing off the slot in the bottom of the box would simply render the system inoperative, in that there would be no result. If the slot in the top were closed off, could the system provide itself with original material upon which to function?

The first answer would seem to be that it could. In fact, of course, the machine works on a description of the original rather than on the original itself, and although I have tended to write as though the description were always given as a set of points — that is to say, as a digitized version of an original — there are other ways of describing pictures. For that matter, sets of points could be included in the program which defines the processor rather than entering them after the program had been set up, although doing so would be merely a device, and would severely limit the versatility of the system. Other kinds of description, like the use of mathematical equations to describe curves, probably could not be entered conveniently after the program was set up, and would more properly form part of the program itself. Here, too, versatility would be seriously limited, since there is a relatively low limit on the number of kinds of curves which one might realistically hope to describe by means of mathematical functions. In any case, what becomes clear is that the question more usefully to be asked is not whether the machine could function with its input slot closed, but whether its program could actually GENERATE material, as opposed to being given it as it needs it on the one hand, or being given it in advance on the other.

Note that, although it is factually true that a mathematical function can generate a set of points, I have treated it as a storage device rather than a generator, precisely equivalent to the list of points it will generate. I have done so for the reason that a curve is fully described by its equations, just as it is fully described by the set of points of which it is comprised. But suppose we were to find some way of writing a program that required no preliminary input, no 'original', that did not make use
of mathematical functions in place of input; that none-
theless succeeded in generating a graphic result; would it
not then be true that the program as a whole fully de-
scribed the image? That it was, in effect, exactly equiva-
lent in that respect to the mathematical function?

The answer I will give to this question is that programs
can be written which do not fully describe the images
they generate in the same sense that a mathematical func-
tion does. But we should examine the implications behind
this answer with some care, since it appears to involve
the question of whether a machine might be capable of
non-deterministic behavior. I have some doubt whether
any definitive answer can be given to this question:
whatever more rigorous definitions of the term 'non-
deterministic' might be available in other disciplines, it
seems to me that here it relates to what we think human
behavior is like at least as much as it does to what we
think machine behavior is like. Thus it seems to become
a problem of definition rather than a problem of identi-
fication, and my own question was proposed as a more
meaningful alternative to it. And in answering this ques-
tion more fully, I will try to demonstrate the possibility
of what I will term behavioral functions, which differ
from mathematical functions in that they require feed-
back from the image — the image in progress, that is —
and contain the necessary feedback mechanisms within
their own structures (Fig. 5). It would seem reasonable
to say of such functions that they do not fully describe
the images they generate in the sense that mathematical
functions do.

Before going on to describe programs of this sort, and
to talk about the nature of the feedback, and of feedback
interpretation, I should deal more thoroughly with the
initial premise; the notion, that is, of a machine which
can provide itself with its own original material. This
innocent-sounding suggestion reveals itself to be even
more troublesome than the idea of non-deterministic
behavior, or perhaps simply a more troublesome formul-
ation of the same idea: since what appears to be implied
is nothing less than the machine initiating its own perform-
ance, and initiating formal material. Once again, the
question is heavily colored by our beliefs concerning the
nature of human behavior. But to what extent could we
reasonably maintain that the human mind initiates?
Concepts are formed on the basis of prior concepts,
decisions are made on the basis of feedback from the
environment and from the results of previous decisions.
The probability is that, if one could identify the starting
point for an artist's whole life's work, one would find
a set of concepts completely formulated if not completely
digested, given to him and not initiated by him. We
habitually speak of the artist 'beginning to find himself
at some date much later than this starting point: the
artist himself will tend rather to speak of his life and his
work as a continuous self-finding process.

Thus the question of starting points and starting
material is misleading in relation to the machine's per-
formance, not because the machine could or could not
initiate material, but because the idea of the machine
being loaded with a program, running the program, and
stopping, forms a discrete unit which has no real parallel
in human behavior. What we would need to imagine to
establish a reasonable parallel is a machine equipped with
an archival memory, running a self-modifying program
not once, but hundreds or even thousands of times, modi-
fying future performance on the basis of past performance
(Fig. 6). In this state, the nature of the initial input might
be of no more importance to the final outcome than the name and style of an artist's first teacher.

I do not believe that the existence of such a machine is around the nearest corner: and there is no doubt that before we get to it, and to other machines which, like it, would profoundly challenge man's thinking about his own identity, there will be emotional roadblocks of significant proportions to be taken down. But, of course, it has already been demonstrated that machines can learn, given appropriate criteria for performance: and conceivably the idea that no such criteria can exist in art will prove to be simply one of the roadblocks.

In practice, it is not possible to run a program from scratch without providing initial material. You cannot tell the machine, "draw some circles", you have to tell it how many circles you want drawn, as well as specifying a general program for drawing circles, how big you want them, and where they are to be placed. But it is possible to have the machine itself decide these things, and the programmer can make use of the machine's random number generator for this purpose. You tell the machine "draw some circles — anything from ten to thirty will do. I want them not less than an inch in diameter, and not bigger than three inches" ... and so on. We should not be too impressed with this ability: it is no more indicative of intelligence in the machine to make decisions randomly than it is for a human being to make his decisions by tossing coins. Intelligent human beings make their decisions this way only when the outcome does not matter, and what is at stake here is the programmer's tacit declaration that his program will function to give satisfactory results regardless of whether it has fifteen circles or twenty-five to work on. What we might anticipate from the hypothetical learning machine is that parameters would be initially set as random choices over very wide ranges, and that the machine would itself narrow those ranges down to the point where specific values could produce specific results.

Let us turn now, finally, to the question of feedback, and of what kind of programs one might imagine could be built up given appropriate feedback structures. Any complex, non-organic system must make use of feedback structures to keep it in a stable state, just as any organism does. In the computer there will be such mechanisms functioning at electronic level, but these are not the ones under consideration since they are operating regardless of what the machine is doing, just as the body uses feedback to control its temperature regardless of what the mind is thinking. Similarly, organisms have feedback structures to control their physical movements, and while something of the sort may be built into a computer program, they do not come high enough in the scale of activities for organisms or for mechanisms to be considered intelligent. The program which generated the drawings in Fig. 12, for example, has at its lowest level a sub-program which draws lines between pairs of points which have been determined higher up in the program. The sub-program uses a sort of homing strategy: it wants to wander freely as if it had no destination, but at each step it corrects its path, so that it arrives at its destination nevertheless, without overshooting and without needing to spiral in as a moth does around a candle flame. While the feedback structure is more sophisticated than the moth's, equivalent perhaps to those we might employ in driving a car, it is of essentially the same order, and the structures exhibited higher up in this program are of a different kind. I will return to these in a moment.

I use the term 'feedback' in the most general sense, to denote, within a system, the passage of information back TO a function FROM the result of the operation of that function, such that the operation tends subsequently to be modified. In intelligent systems, we might thus characterize feedback, in a rough ad hoc sort of way, as the asking of questions relevant to continuing operation, and might even describe the complexity of the feedback system in terms of the number of questions the continuing operation requires.

This is not to say, however, that the complexity of the result necessarily depends upon the complexity of the system. One of the most amazing examples of an apparently simple system yielding complex results is the 'Game Of Life', which has received enough attention recently not to require further description. In this matrix-manipulating program, the asking of the same single question for each cell in the matrix — how many of its neighboring cells are live and how many are dead? — is enough to provide for the generation of a rich set of patterns often possessing remarkable characteristics. If I would exclude the 'Game Of Life' from the class of systems I am discussing it is because, although it appears to be asking its question of the result of an operation, the operation itself never actually changes at all, and the result of one application of the operation simply becomes the input, the original, for the next application of the same operation (Fig. 7). In other words, the system should properly be considered as an iterative processor of ingenious design, in which the complexity of the result stems from the iteration rather than from the process itself.

In practice, it is quite difficult to avoid the appearance of this processing structure in computing, since the whole methodology of programming is built upon the notion of
iteration. But to say that processing structures are embedded in a program is not the same as saying that the program itself functions as a processor. The distinction becomes important if we pursue the idea that feedback complexity may be measured by the number of questions which need to be asked in order to determine subsequent operation, for clearly the total number of questions to be asked within the whole program to provide a single unit of information will depend upon a number of issues, not least of which is the availability of that single piece of information. We might imagine an artist having a piece of work made by telephone, updating his mental image of the piece by asking questions. "How many lines are there in the drawing now?" he might need to know: and he has no interest in whether the person on the other end will need to go and count them yet again, or whether he has been smart enough to keep an updated record. For our purposes we would say that only one question has been asked. Similarly (Fig. 8), the computer program could be considered as a two-part affair, in which the upper part — the 'artist', as it were — accesses the work in progress by interrogating the lower part about it. Our measure of feedback complexity is then given by the number of loops between the two levels, and is not concerned with how complex are the functions occurring within the lower part, many of which will certainly appear as processing functions in the sense we have already discussed. In many ways, then, the upper part might be thought of as using the lower part as the human user uses a processor.

If I were to write a program which packed equal sized circles into a hexagonal array, no feedback at all would be required, since I could calculate in advance where all the centers would need to be, and would know without looking that there would be no overlapping. A program which sought to pack the same circles over and around an irregular projection (Fig. 9) would be a different matter, however, since the space available for each new circle could not be known until the previous circle had been
drawn. Similarly, a program which caused a number of loosely distributed circles to grow irregularly, amoeba-like (Fig. 10), until all the available space had been absorbed,

would need to ask, for each new development of each developing shape: what is the current state of its boundary? What shapes lie in the direction of the proposed development, and what is the state of THEIR boundaries? Has this developing shape reached those existing boundaries yet? The end-state of the whole development (Fig. 11), which has been managed entirely by the program, has thus evolved from a unique set of events, and the large set of drawings which actually resulted from a long run of this program exhibited wide variety without any change in the operating parameters.

A more recent program of mine ran continuously for a month during a museum exhibition, and, again, required no human intervention in making over three hundred drawings (Fig. 12) beyond changing the sheets of paper on the drawing machine and refilling the pens. The feedback in the current version of this program is more complex than in the previous example, but not by much, since to draw each new line the program needs only to know which of many possible destinations may be reached without crossing an existing line, and, of them, which is the nearest and which the furthest away. But the program is structured in such a way that more particularized decisions may now be reached on the basis of more extended information requiring more complex feedback — which of the possible destinations will result in the straightest lines? Which is closest to the center of

Fig. 10

Fig. 11. Harold Cohen, "Labeled Map" (1969), 102" x 192", oil on canvas.

Fig. 12A

Fig. 12B
the picture? Which is in the densest part of the picture, and so on: with even greater variety of output than we have at the moment.

But this brings me now to the central issue in this enquiry. I suggested before that feedback complexity might be measured by the number of questions which needed to be asked about the current state of the drawing, not by how difficult it would be to answer them. Consider the question: is the pen currently inside a closed shape? (Fig. 13). If the lower part of the program had been keeping up a running index of closed shapes, updating it every time a new closure was made, the question might be answered immediately. If not, it might not be able to give an answer at all within any reasonable time. Obviously one would not want to write a program which asked unanswerable questions: or to put the matter the other way around, one would certainly want to be sure that the lower part was in a position to answer the questions one knew the upper part would need to ask; that the required information was either explicitly available, or easily derived from what was available. What may not be equally clear is that as far as the machine is concerned its awareness of the picture exists solely and exclusively in terms of this information, and it is by no means mandatory that this information be visual, in any sense which might seem to apply to human perceptual behavior, and which makes the recognition of closed shapes a trivial human problem. I am not in a position to judge what the relationship actually is in human perception between the outside world and the internal representation: my experience in teaching students to draw suggests that the internal representation of the visual world is certainly not exclusively in visual terms, and indeed that visual information may be a good deal harder to retain than information of other sorts. As far as the machine is concerned, the internal representation similarly need not be equivalent to a complete view of the picture — such as might be given by a television scan of the picture itself, or by a fine matrix in which each cell records the presence or absence of a mark in the drawing — and for many purposes such a representation would yield up the required information very poorly. Actually, they might be better regarded as transcripts than as representations. The need to model the machine's internal representation in terms of the upper program's special preoccupations is not merely a matter of efficiency, since once it is established it places an absolute limit on what the upper program will be allowed to do. There will always be a line beyond which the upper program will
not be able to go, questions in answer to which it will be
told — sorry, we don't know anything about that.

There is, of course, no mode of internal representation
of the work in progress which could be described,
meaningfully, as 'natural' to the machine, and no single
universal mode to satisfy all possible requirements. Pres-
umably the same could be said of human internal re-
presentations of the real world, since we do find it neces-
sary from time to time to build new models, or at least
to modify old ones, pushing back the line and finding
ways of asking new questions. Whatever else it is, art is
primarily a model-making activity. Thus unless we were
limiting the aim to simulating the work of a particular
artist at a particular time (a human process known as
plagiarism, not as art) it would be obviously simplistic
to think in terms of the machine's upper program needing
to ask the same questions about the work in progress
that the human artist would ask, and of the lower pro-
gram building representations of the work very much like
those the human artist would build. The nature of art
is not to be characterized in terms of specific sets of
questions and representations, since these will be, by
definition, in flux for any given artist and even perhaps
peculiar to a single artist only. The interface between
the questions and the representations, permitting fluid
change in both, might reasonably be thought to possess
more general properties, since art does change, at least
within our own Western tradition. Thus I would con-
clude that the machine's autonomy rests upon developing
total systems, in which the feedback structures linking
the decision-making processes above with the character-
izations below are sufficiently flexible, or adaptive, to
support the changes which must occur in both; not upon
pinning down particular characteristics of human per-
ception, or particular formal aspects of human art.