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the further exploits of AARON, Painter

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C.P. Snow had a point. While it has not been the case that my own work, straddling the apparently disjoint fields of art and artificial intelligence, has been ignored, I have found few writers on art willing to exhibit their ignorance about technology, and as few in the science community able or willing to handle the art part: why we, on our side of the void, do the things we do. Into this rarefied space boldly strode Pamela McCorduck; her book, *AARON's Code*,1 published in 1990, remains the most serious attempt to show that my work on the AARON program has been a single endeavour, rather than a case of cultural schizophrenia. I will always be truly grateful for that understanding.

Books have a way of suggesting that the drama finished on the last page, however, and AARON is still very much on-stage four years later. Several authors have referred to more recent work, but, I am a touch chagrined to note, my own last published report was in a paper, "How to Draw Three People in a Botanical Garden," which I wrote in 1985. Clearly, I can always find things I would rather do than write (some of the things I ought then to have written about, for example) and I am grateful, in a perverse kind of way, when circumstances corner me. In this case I had said I did not think there would be any point in contributing an essay unless it could be adequately illustrated, and when the editors generously offered to print several pages of reproductions in color, I was stuck.

I must take advantage of this opportunity, then, to provide an overview of the past four years, during which time much has happened. This overview will be light on technical detail, necessarily; by this time AARON may be the oldest continuously-developed program in computing history.2 Since it has become virtually impossible to deal with its entire history in a single paper of reasonable length, however, I will start with a a brief pre-1985 recapitulation.

AARON began its existence some time in the mid-seventies, in my attempt to answer what seemed then, but turned out not to be, a simple question:

What are the minimum conditions under which a set of marks functions as an image?

On the simplest level it was not hard to propose a plausible answer: it required the spectator's belief that the marks had resulted from a purposeful human, or human-like, act--actions performed by a computer program possessing cognitive capabilities quite like the ones we use ourselves to make and to understand images. The earliest versions of AARON could do very little more than distinguish between figure and ground, closed forms and open forms, and perform various simple manipulations on those structures. That might not have been enough, however, had AARON not performed, as humans do, in feedback mode. All its decisions about how to proceed with a drawing, from the lowest level of constructing a single line to higher-level

issues of composition, were made by considering what it wanted to do in relation to what it had done already.

Both of these elements were necessary: while there was an obvious superficial payoff from this feedback-oriented drawing strategy--AARON's drawings had a distinctly freehand, ad-hoc look quite at odds with popular assumptions at that time about machines--I doubt whether freehand scribbling would have persuaded anyone that they were looking at anything more than scribbling. And to judge from the responses of art-museum audiences, AARON's marks quite evidently functioned as images (Figure 1).

figure 1.

San Francisco Museum of Modern Art, 1979. Mural in background, turtle making drawing in the foreground. Photograph: Becky Cohen.

Simple though the program was, one thing was thus established in its infancy: AARON would always need to know what it was doing, and the key to what it would be able to do would always be constrained by the ways it would represent, internally, what it had already done.

I had assumed, during this initial period, that I would continue to add cognitive primitives to AARON's repertoire, and that the program would continue to develop indefinitely. But by 1980 I was beginning to suspect that the human mind is remarkable more for the way it is able to orchestrate its use of a rather small family of primitives than for the size of the family, and, reluctantly, I was beginning to face the fact that the human cognitive system develops in the real world, not in the vacuum where AARON lived.

1980 marked a turning point, indicated by my examination of the scribbling behavior of young children, where I hoped to find some clue to further development. I concentrated, for two reasons, on the moment at which a scribble migrates outwards and becomes an enclosing form for the rest of the scribble; firstly, because this appears to be the moment at which the child becomes aware that the marks it makes "stand for" something in its world; secondly, because the geometry of enclosure, the physical relationship of the enclosing form to what is being enclosed, I found quite baffling.

None of my attempts to simulate this early human drawing behaviour met with any measure of success, yet I became convinced that the range of forms AARON could generate would be greatly enhanced if its steering strategy could be made to find its way around a pre-existing "core figure," the equivalent of the way the child's initial scribble evidently determines, though not fully determines, the path it traces to enclose it. This conviction proved, in due course, to be justified, to a much greater degree than I could possibly have predicted. The construction of simple core-figures, plus a simple strategy for tracing a path around them, yielded forms of a complexity I could not have generated, if indeed I could have generated them at all, without substantially greater cost. This two-step strategy became AARON's standard mode for generating closed forms.

What I did not anticipate at all was the jump in the "thing-like-ness" of those forms, and with it the increasing illusion that AARON was drawing "from visual experience" of the outside world (Figure 2).

 figure 2.

Detail, One of the Young Ladies Grew Up and Moved to Washington. Mural for the Capitol Childrens Museum, 1980. The title was a reference to the Demoiselles d'Avignon, with which the artist thought he saw some affinities. Photograph: Becky Cohen.

Thus began a gradual slide downhill, or climb uphill, depending upon how you view it, into overt representation. By 1985 AARON had a set of trivial rules for the behavior of the outside world, and things moved rather quickly; later that year I succeeded in describing one particular figure, the Statue of Liberty, in enough detail to permit AARON to provide the final drawing for an exhibition on the history of images of the Statue (Figure 9).

figure 9.

Liberty and Friends, 1985. Ink and dyes on paper, 22x30 inches. Photograph: Becky Cohen.

Then came the provision of a physical ambiance for AARON's figures; a description of plant growth general enough to permit the generation of anything from a quasi-daisy to a quasi-oak-tree, and, in summary of what had been done up to that point, the paper mentioned above, "How to Draw Three People in a Botanical Garden." That phase provided a very large number of drawings, and for a series of paintings, the execution of which took me through to 1989 (Figure 3).

figure 3.

Meeting On Gauguin's Beach, 1988. Oil on canvas, 90x68 inches. Photograph: Becky Cohen. Collection: Gordon and Gwen Bell.

AARON's two-part representational strategy remained unchanged during this four-year period. It viewed the human figure as a complex of connected parts, and its postural rules referred to the way these parts articulated. Each part, arm, head, leg, was represented internally as an array of points with its origin at its articulation to the next part: hand to forearm at the wrist, forearm to upper arm at the elbow, and so on. The complete body could be accumulated in any of a rather limited range of poses from the appropriately transformed arrays of points. The core-figure for each part was generated by connecting these points, and AARON would then proceed to trace an enclosing form around each part. The single exception to this procedure was its handling of the one facial feature it represented; the nose was seen simply as a set of marks drawn within the bounding outline of the head, and it was used as a device to establish the head's orientation.

I think one would need to look rather closely at AARON's drawings of this period to spot the fact that its internal representation of the human figure involved only a symbolic three-dimensionality. It knew about perspective, to the degree that it could place figures into a spatial setting with things overlapping each other as they should. But the figures themselves were like cut-outs placed into this space, representations generated in two-dimensional terms directly. Viewed as an expert system, AARON's domain of expertise was drawing, not human anatomy; it did not need to construct a seated figure in 3-space for the thighs to appear foreshortened. AARON already knew that the thighs of seated figures should be drawn that way.

I did not view this two-and-a-half dimensionality as a limitation; I regarded it simply as a mode. Living as we do in a culture obsessed by appearances, saturated with photographic imagery for a hundred years, it comes as a shock to realize that 95%, at a rough guess, of all the images ever made follow other paradigms, exhibit virtually no interest in the reflection of light off the surfaces of objects, and direct the viewer's attention to abstractions, not to the appearance of physical objects. I have been much more aligned, as an artist, with this more general view of representation, and increasingly repelled by the fundamentally Eurocentric view (my own history!) that underpins the current version of Renaissance perspective rendering, computer graphics. AARON was not, and is not, a "solids modeling" program.

Nevertheless, I was experiencing some dissatisfaction with AARON's two-and-a-half dimensional world, though for reasons that might seem a little perverse. I had always colored some number of AARON's drawings; as the illustrations indicate, many of them had been turned into paintings and some half-dozen into murals. By 1986 it was beginning to seem inappropriate that a program smart enough to generate an endless stream of original drawings was incapable of doing its own coloring. I had no idea how to correct that deficiency, but I was beginning to develop some intuitions about what would have to be done. For example, I thought it would be unwise to take on the problem of color in the context of the elaborately detailed drawings of that time; I would stand a better chance with a simpler configuration of forms, something no more complicated than a torso-length portrait.

At the same time it seemed to me that while AARON's drawing served well enough in the context of its then-current work, it would be too blunt, the line of the enclosing form being inadequately articulated, to stand alone if enlarged up to the torso-length portrait I imagined. I thought the drawings would need the kind of visual complexity that results from the casual overlapping of one thing by another, the unexpected profile that emerges as a limb is rotated or a head lifted. AARON's two-and-a-half dimensional knowledge would not support that kind of complexity; in fact, the program had no way of placing an arm across the body, or breaking the outline of the head with an overlapping hand. As to the lack of articulation of the line itself; that was

not a problem of AARON's method for constructing the enclosing form around the core-figure, but rather of the sparsity of information contained within the core-figure itself.

So while I was completing the series of paintings based on the 1985-6 version of the program, I was also developing a new version involving a fully three-dimensional knowledge base. In effect, AARON became two interacting programs: the one applying a greatly enhanced rule-set governing posture to what was initially a small number of 3-space control points, generating "real-world" figures in a "real-world" environment; the other generating a two-dimensional representation of that "imagined" three-dimensional world.

This development marked the beginning of a far more "realistic" phase of AARON's output, and I need to stress the fact that it did not constitute a retreat into the Eurocentric world of surfaces. Neither at that time, nor at any time since, has AARON had any knowledge pertaining to the surfaces of things. Its data represented points within, not on, the figure; articulation points, muscular attachments, and, more generally, points designed to present an appropriate profile, in whatever posture and from whatever "viewpoint," to the outline-generating function (Figure 4).
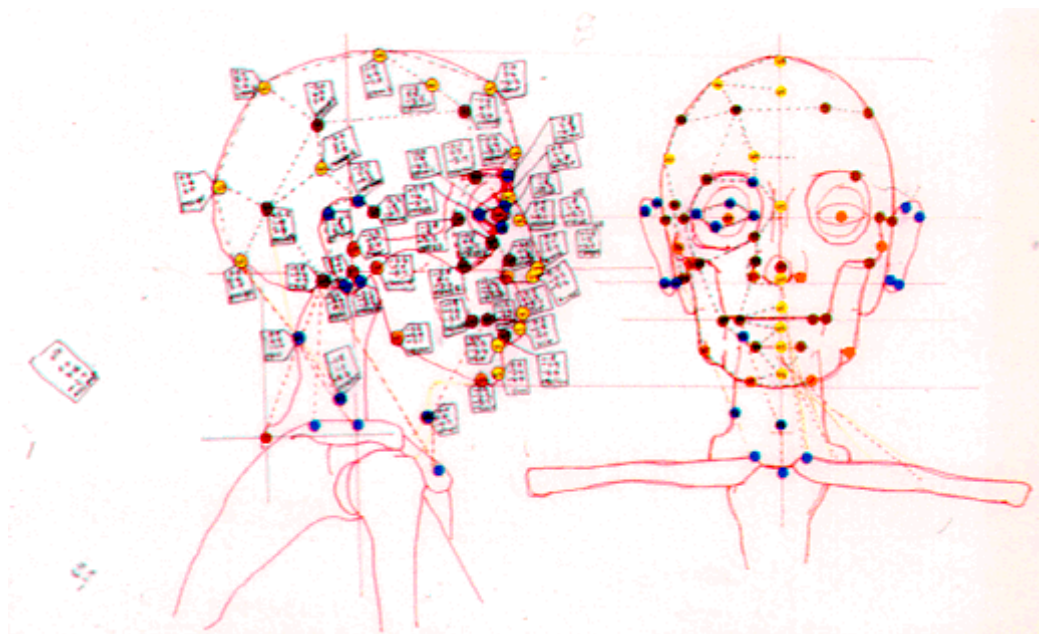

figure 4.

Anatomical study, 1988. Photograph: Becky Cohen.

These points, many more of them than had been required by the earlier versions, were derived from large medical illustrations of the skeleton, each point being measured, and recorded as an xyz-triple, relative to the origin of the body-part involved.

It took more precise knowledge about the articulation of the body to take advantage of the potentially greater flexibility this new data offered, but not as much as I had anticipated. In gross terms, posture is controlled by a single variable: the physical relationship of the center of gravity of the torso, the heaviest part, to the placing of the feet, so that, for example, placing the center of gravity in advance of the feet results in a sense of movement.

A program does not just "possess" knowledge, however; the knowledge has to be represented within the program in computationally appropriate structures. I have always tried to have AARON specify its plans in terms of the highest level of

abstraction possible, leaving it to the lower levels of the program to generate instances of those plans. In effect, I wanted AARON only to have to specify "seated" at the topmost level in order to control the placing of the center of gravity with respect to the backside rather than to the feet. That meant designing a structure containing all the variables that controlled posture, supplying ranges of possible values for those variables, and specifying how to relate the selection of appropriate values to the abstraction.

Now AARON could, in principle, pose a figure in such a way that, from any "point of view," any part could be partially obscured by another part. In practice, it was not that easy.

I should clarify the notion of "point of view." As I have indicated, AARON's figures are posed, constructed, and placed in a virtual three-dimensional world. AARON places itself, its "eye," into this three-dimensional world also; in fact, its "eye" becomes the origin for a system essentially like the eye/picture-plane/object arrangement of Renaissance perspective. The xyz-triples representing the points of the figure are projected onto the picture-plane, and from that point on, AARON draws its enclosing forms from front to back and without erasing anything already drawn; the closest parts are drawn first, the furthest last.

In other words, while the data representing the figure are entirely three-dimensional, the construction of the representation of the figure is entirely two-dimensional; a duality that corresponds exactly to what happens when a human artist makes representations of the outside world.

If AARON had been a surface-oriented program there would have been no problem. There are off-the-shelf algorithms for hidden plane removal. But, as I have explained, AARON's primary representation of the "real" body exists as a cloud of points in space. Projected onto the picture-plane, these points had to be joined up, according to view-dependent rules, to make the core-figure for each part. Those parts, two forearms for example, might then overlap each other; but aside from the trivial case where both end-points of one part are known to be further away, in 3-space, than both end-points of the other part, there is no way of determining from the placement of the points on the picture plane which part occludes the other.

Not all the parts of the body have end-points in the simple sense of the fore-arms, and in any case it would be the not-yet drawn enclosing form, not the axis, that would be doing the occluding. In the absence of any straightforward mathematical solution to this problem, AARON was supplied with an extensive set of inference rules by means of which it could determine which part was in front of which on the basis of its knowledge of the figure. The problem was simplified by the realization that the hands move around much more than any other part of the body, and that a great deal could therefore be determined by examining the articulation of the arm. For example, if the left wrist is closer (in 3-space) than the left elbow, and the left elbow is closer (in 3-space) than the left shoulder, and the left wrist is to the right (in 2-space) of the left shoulder, and the left wrist is not higher (in 2-space) than the right shoulder, then the left arm will obviously obscure the torso, and will have to be drawn before the torso is drawn.

This is, of course, a deliberately over-simplified and under-specified example which assumes that the figure is more or less facing the viewer. Other rules would apply if the figure was facing right or left. Also, the "left arm" is actually composed of three articulated parts--upper arm, forearm and hand--for which the order of drawing is similarly dependent upon the relative positions of the articulation points. Things

become additionally complicated when, for example, the right hand overlaps the left upper-arm.

Occlusion, the obscuring of elements in the visual field, the T-junctions that form when the edge of one object breaks off at the edge of another object, provides one of the strongest clues in depth perception, and it is unlikely that any coherent system of representation could exist that did not pay attention to it.

AARON's method for implementing occlusion, as opposed to knowing simply what occludes what, has not changed fundamentally since its earliest days. Part of AARON's internal representation of its "imagined" 3-space world is a two-dimensional matrix of a size equal to the resolution of the workstation screen. As the lines comprising a core-figure is drawn, the cells through which the lines pass are marked. The fundamental algorithm for enclosure operates in relation to these marked cells, and the enclosing line it generates is similarly mapped onto the matrix. Once this now-continuous boundary of marked cells is complete, each cell inside it that has not already been claimed by a previously drawn form is marked to identify it as belonging to the current form. Only those areas of the matrix that remain unmarked are available for drawing through and filling.

Since at this stage AARON was drawing only, it was enough to use small integers as cell-markers serving to differentiate between one part and another, and between filled parts and ground. As we will see, coloring introduces new requirements, in relation to which the simple differentiation of parts by number is quite inadequate.

From the first use of three-dimensional knowledge in 1988 until some time in 1990, the size and complexity of the knowledge-base increased relatively little. AARON was now doing the simpler drawings I had wanted, and I thought they exhibited the characteristics for which I had hoped. I turned my attention to the building of a prototype painting machine, a small robot arm carried on a large flatbed xy-plotter. It was in operation by the end of 1990. But building a machine did not solve the still-intractable problems of color, and AARON never got beyond making a few black-and-white brush drawings with its new toy.

I was beginning to feel that AARON's usual two-step procedure for generating closed forms was in need of attention, in order to bring it more into line with our own perception of things. Since it viewed each of the body's parts as articulated but separate, it drew each of them with its own outline. Our own perception is less simple. We view the shoulder as an area of transition between upper arm and torso, for example, rather than as a boundary between the two. We know that faces have noses, but we do not think of the nose as being enclosed within its own outline.

During 1990 I had finessed that problem by allowing the unbroken enclosing forms to serve at the junctions of parts as if they delineated clothing, while I was obliged to leave out facial features entirely. That was obviously a cheap fix; the problem was really solved in 1991 through a modification to the underlying strategy. AARON continued internally to represent body parts as closed forms, but in drawing them it would leave out appropriate parts. The modification, simple in principle, proved to be extensive in its implementation, for the reason that the part to be left out would change as the angle of view changed. Unless the deleted part of an outline could be guaranteed not to become the bounding outline for the entire figure it would be all too easy to find an incomprehensible gap in the drawing: a hole where the shoulder should be, a head with a void instead of a nose.

Since the information that generated the outlines was contained in the core figures, and the core figures were responsive to angle of view, guarding against missing

shoulders and non-existent noses involved generating a slightly different core-figure for each part, for each segment of possible angles of view; a great deal of work and a large potential increase in code. I could not face doing this for every possible angle of view, and the task never went further than a fairly narrow range of more-or-less frontal positions (Figure 5).

 figure 5.

Two Friends with Potted Plant, 1991. Oil on canvas, 60x84 inches. Photograph by Becky Cohen.

I continued through 1991 and into 1992 to work on other aspects of the program in what I thought of as jockeying for the right position from which to move, finally, into color. I was beginning to sense that we use colors in different ways for different purposes, and while I had succeeded in providing a nice, simple format, I was no longer sure that I wanted to deal with color in an exclusively representational context. With this in mind I spent some weeks developing a functional description of decoration, general enough to allow a relatively small body of code to generate a rather wide range of decorative motifs. This decoration, applied to the wall behind the figure, sometimes within a frame, sometimes covering the entire available space, re-introduced a level of complexity in the series of paintings that followed (Figure 6).

figure 6.

Aaron, with Decorative Panel, 1992. Oil on canvas, 72x54 inches. Photograph by Becky Cohen.

By this time I had very little reason, beyond my own inability to see how to proceed, to prevent me from coming face to face with the problem that had eluded me for three years. Circumstances came once more to my rescue. My dear friend Jerome Rothenberg was about to celebrate his sixtieth birthday. Another friend, Pierre Joris, decided to publish a small volume to commemorate the occasion, and I was asked to produce the cover.

Having been so recently involved in decoration, I thought I could provide an attractive decorative cover without difficulty. Then I started to wonder whether AARON could not be persuaded to produce a recognizable likeness of the poet. As a result, for almost two months I found myself developing AARON's knowledge of the structure of heads and faces. The number of data points involved grew from a few dozen to several hundred, though this increase in numbers alone gives little idea of the structural development of the program. The points were organised into parts; upper mouth, lower mouth, beard, forehead, eyelid, lower eye and so on, in such a way that the individual parts could be scaled and moved, three-dimensionally, at will.

The fine-tuning by hand that was required to produce the likeness was a bit like playing with a police identikit, except that in this case the manipulated data was three-dimensional; once I had a likeness, the likeness would hold as the head turned and the facial expression changed.

Along the way, however, AARON was generating make-believe people, many of them looking distinctly like people I knew; that I found interesting (Figure 8). By the time the exercise was done, AARON's much-extended data base represented a prototype figure only, and the program had enough knowledge to generate from it a varied population of highly individualized physical and facial types, with a range of haircuts

to match. It was now in the second half of 1992, and I began in earnest to develop a functional description of color and rules for its deployment.

 figure 8.

Theo, 1992. Oil on canvas, 34x24 inches Photograph by Becky Cohen.

Let me try to clarify what my intentions were with respect to color, and to explain why I had so much difficulty in finding a starting place.

In the first place, I do not much like the quality of electronic imagery, and I have never had a taste for the ephemerality of images produced in the medium. I like art to stay around long enough to unfold. Thus, while I am by no means a technology freak (my friends are much amused by the fact that I do not use money-dispensing machines and never learned to program my VCR), I could see no alternative but to build a machine that would allow the production of large, colored images in the real world. And while I have built a number of drawing machines and had already made a prototype painting machine, I had no idea how long it would take to build the fully-functional version, nor, for that matter, whether I could build it at all with whatever resources I could muster.

In making the pragmatic decision to proceed with the problem on a computer workstation I knew I was facing a number of obstacles related to the control of the device itself. Firstly, I was aware that there is a fundamental, perhaps irreconcilable, difference between the three-color additive mixing that these devices use, and the subtractive mixing of the fifteen or twenty dyes I have long used myself and proposed to have AARON use. I still do not know for sure how coherently knowledge gained in the one domain will map onto the other.

Secondly, I needed to provide knowledge about color control, and I was struck by the fact that most of what we think of as color theory covers a range of topics: color measurement, color perception, ways of describing color space, but little of it

constituting a theory of color use. What there is, Albers, for example, is bound so tightly to a single image that it does not extrapolate. An apple green used to color a square band in an Albers painting will not generate the same response if it's used to color a face: imagine how differently the color would be read on a face in a German Expressionist painting and on a face in an Italian Renaissance painting.

I was not looking for anything off the shelf, I was perplexed by the fact that there did not seem to be anything of the sort on the shelf. We do not even have an adequate vocabulary: names for individual colors, a couple of descriptors for comparing one color with another; one is lighter than the other, we say, this one is more vivid that that one, but we have no way of discussing in detail anything as complex as a color scheme. Isn't that surprising, considering how much we appear to value our experience of color, and how good some artists are at manipulating it?

I concluded that color is one of those things that we do not exactly "think" about; what I mean is that we have ways of manipulating it in the head, but the manipulation does not follow the more regular traffic of externalization into verbal constructs. I am comfortable with the conclusion that not everything that goes on in the head is thinking, but how does one write a computer program to manipulate material one cannot even describe in English?

Well, of course, there are some things one can describe. The key to progress came, finally, with the realization that I knew what some of them were. For many years I have been insisting to my painting students that brightness is a far more important component of color than hue is; that it is more important to control how light or dark things are in a painting than where they fall on the spectrum, given that the eye functions primarily as a brightness detector.

Why it took me so long to bring into focus something I have known and used for half of my life I cannot say. Once it was in focus, I was able to proceed quite rapidly. I still did not know enough to provide a complex rule-set for color control, but it turned out that I did not have to. Before we pay much attention to how an artist performs we look to see what he, she or it believes to be worthy of performing, what issues are thought to be worth consideration. Evidently it was enough for AARON's almost exclusive preoccupation with brightness to give its coloring a kind of simple authority, and by the end of 1992 I could see AARON functioning, on the screen, as a modestly able colorist.

The rules became more complex, obviously, and AARON more able and varied in its performance, as I continued to work on the program. I devised a notion of color chords, ways of choosing colors in various spatial relationships from the entire color space, and AARON was able to construct these color chords, rather than control the brightness of more-or-less randomly selected hues, as a way of controlling the overall color structure of the image. Even so, the importance of brightness remained central; the structure of a chord, as I had designed it, demanded that all its components, however selected, retain some required level of vivacity as they became lighter or darker.

By the summer, I found I was able to use AARON's coloring to determine my own coloring decisions in making paintings, by hand, from its images. Rather than enlarging up a slide made from a laser-print, my assistant now worked directly from a slide shot off the workstation screen. It was like working from a color sketch, something I had never done before. Of course, there's a big difference between a 35mm slide and a seven-foot painting, and while in some cases I departed little from AARON's original (Figure 7), in others the color changed a good deal, which is not to

say that it necessarily got better, as the painting proceeded. In any case the old head-scratching system of color choice was over: just ask AARON.

 figure 7.

Standing Figure with Decorated Background, 1993. Oil on canvas, 78x54 inches. Photograph by Becky Cohen.

By this time my painting machine was in construction, and I had to confront what proved, unexpectedly, to be the most difficult single problem I have faced in twenty years of programming.

AARON's images are represented by a two-dimensional matrix of cells at the resolution of the workstation display, currently 1280 by 1024. Each part is mapped onto this matrix, but, of course, rarely ends up there as a single bounded shape. This is of no consequence when the coloring is done, raster fashion--row by row, top to bottom--on the screen. Each cell is scanned, its identifier points to the part to which it belongs, the data attaching to that part says what color is to be generated, and the cell is "painted" by the correct combination of the three gun values.

But I did not go to the trouble of building a painting machine merely to reproduce a boring, mechanical way of filling in shapes. The machine is designed to use brushes, and on the assumption that it would be able to use those brushes in a more "natural" way. This means that AARON has to be able to isolate and deal seperately with an arbitrary number of patches, all of which belong to the same part and consequently require the same color. It also means that AARON has to be able to cope with the filling of arbitrarily complex shapes once it has located them, under the overall constraint that it should attempt to keep a wet edge moving forward; as far as possible, it should not leave an edge to dry in one part of the shape while it is working in another part.

Let me try to give some sense of the nature of the problem. Look at the nearest potted plant: make a drawing in which you outline every patch you see, whether its boundary is determined by the edge of the leaf to which it belongs, that of other occluding leaves, or, most likely, both; and whether it is a part of a leaf or part of the background. Now assign a number to each patch, being sure that the same number is assigned to every patch belonging to any single leaf. Having got this far, try to categorize the many strange shapes you will have drawn: entirely convex, partially concave, long and thin, short and fat, lobed, torus.... Finally, try to devise a strategy for filling each of these many shapes that will function for every category of shape. It has to be a strategy that does not draw attention to the shape as an isolated event, but allows it to be seen as part of the object to which it belongs.

I cannot describe my solution to these problems without going into more technical detail than is appropriate here. I tried, and abandoned, a number of methods which looked good as far as they went but then failed to make it to the end. The whole thing took the greater part of a year, not the two or three weeks I had thought it would need, but now I am able to watch, on the screen, while AARON generates what appears to be a good simulation of what will happen in the real world (Figure 10). Interestingly, the final, successful, solution rides upon extensions to methods that have been fundamental to AARON since its first inception.

figure 10.

Two Women with Decorated Background, October 1994. Image taken from screen. The variations in the colored areas indicate the path taken by the simulated brush in the filling algorithm.

A great deal remains to be done before AARON opens at the Computer Museum in Boston April 1995. But, as I write, the painting machine is in the final stages of "training;" learning where everything is, picking up and putting down brushes, dispensing and mixing dyes, parsing the files which AARON will send it. Another couple of weeks (he says, optimistically), and this article might have included the first published illustration of the first fully machine-generated and machine-executed work of art in human history.

On those rare occasions when I make the time to write, I tend to focus, as I have in this piece, upon what the program does; showing it as a series of events that can be shown to have occurred and what needed to be done to enable them to occur. In part, this is because I recognize that I am uniquely placed in being able to give such an account, and because such accounts are a good deal more rare than I think they should be. It is also because, without such an account being given, one is reduced to talking in abstractions.

Abstractions are properly challengeable for their appropriateness to the events, but if the events are not available the discourse becomes meaningless. The reader will note that I did not say that AARON was exhibiting intelligence with respect to the potted-plant example, I said that it "has to be able to isolate and deal separately with an arbitrary number of patches...to cope with the filling of arbitrarily complex shapes..." Does that capability constitute intelligence? It does not constitute *human* intelligence.

It is easy, in short, to assert that machines think, and equally easy to assert that they do not. If you do not know exactly what the machine did, both are equally fruitless in carrying our knowledge, including our self-knowledge, forward.

I am quite sure that if it had been proposed to Herbert Dreyfus twenty years ago that computers might do what AARON is doing today he would have produced something resembling an argument to deny the possibility. We know how it would have gone: art is an activity requiring self-awareness; computer programs cannot be aware of themselves; therefore computer programs cannot make art.

That is a definition, not an argument. If Dreyfus, Searle, or Penrose believe that art is something only human beings can make, then for them, obviously, what AARON makes cannot be art.3 That's nice and tidy, but it sidesteps a question that cannot be answered with a simple binary: it is art or it is not.

AARON exists; it generates objects that hold their own more than adequately, in human terms, in any gathering of similar, but human-produced, objects, and it does so with a stylistic consistency that reveals an identity as clearly as any human artist's does. It does these things, moreover, without my own intervention. I do not believe that AARON constitutes an existence proof of the power of machines to think, or to be creative, or to be self-aware, to display any of those attributes coined specifically to explain something about ourselves. It constitutes an existence proof of the power of machines to do some of the things we had assumed required thought, and which we still suppose would require thought, and creativity, and self-awareness, of a human being.

If what AARON is making is not art, what is it exactly, and in what ways, other than its origin, does it differ from the "real thing?" If it is not thinking, what exactly is it doing?

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Notes

1 Pamela McCorduck, *AARON's Code* (New York: Computer Science, 1991).

2 Readers who would like to know more about the internals of the program might begin by referring to the several earlier papers which I am currently making available on the Internet by anonymous FTP from wendy.ucsd.edu. My intention is to make

more technical reports similarly available, but I can see how this intention might not be taken too seriously.

3 See Hubert Dreyfus, *What Computers Can't Do* (New York: Harper, 1967; ed. 1979), and *What Computers* Still *Can't Do* (Cambridge, MA: MIT Press, 1992); Roger Penrose, *The Emperor's New Mind* (Oxford: Oxford UP, 1989); and John Searle, "Minds, Brains, and Programs," *The Behavioral and Brain Sciences*, vol. 3 (1979) rpt. in Douglas Hofstadter and Daniel Dennett, *The Mind's I* (New York: Basic, 1981).