The Computer is Not a Medium

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Abstract
Computer art embraces a resplendent diversity of expressive forms, including and exceeding those of traditional media such as painting, sculpture, film and video. Although it is sometimes referred to as another artistic medium, the computer plays a fundamentally different role in the activities of making and viewing art. A computer can output to many media, but its mode of operation is not the same as theirs. While an interface connects a computer to a medium, it also keeps it from becoming one of them. By studying the concepts of interface, interaction, and simulation, profound differences become apparent. A medium supplies physical material receptive to creative formation, while a computer offers conceptual agency capable of contentious discourse: it functions more like a creative partner than an expressive channel.

When visiting exhibitions of computer art it is not uncommon to encounter a baffling diversity of works including drawings, prints, paintings, photographs, sculptures, video, film, multi-media objects and performances as well as interactive installations. Faced with this plethora of creative expression, one cannot help but ask, "If the computer is a medium, which one is it?"

In examining the rich variety of computer art already produced in its short history, we are hard pressed to point out any genuinely new medium distinct from those which already existed when the computer was first applied to creative endeavors: there are still the same old paint, ink, emulsion, light, sound, words, etc. The computer is rarely present in the gallery, and when it is, it is not usually exhibited as an object in its own right. In fact it communicates with us through traditional media (if it uses media at all) and more often than not its physical presence is irrelevant. Its message is often recorded in a medium prior to the exhibition and carried in like any other art object. When it does calculate and communicate at the time of the show, it could be hidden in another room or even in another country, linked to a display in the gallery through telecommunications. Typically, the only time a computer is physically present is in real-time performances and interactive installations, where it does not usually function as a medium since its import lies not so much in the visual qualities of what it displays as in the development and discursive evolution through time of its interaction with us.

I should like to argue here that the computer is not a medium. The fact that computer art can be realized in any medium suggests that it is not one of them. It does not stand alongside traditional media as a
peer, but communicates through them remotely as an outside agitator bent on introducing foreign influences and conjuring up spirits from alien worlds. We can carry on a dialogue with a computer through media, and this interactivity, it seems to me, is prototypical of how the computer functions in an artistic environment. By examining some of its salient features we can learn how the use of a computer to make art differs from the use of media. What we find are not new media but rather media newly used—"intelligent" media which behave differently while still embodying visual meaning through the same old physical substrate. The point is often not the aesthetic presentation but the conceptual presence. A computerized oven still cooks a meal, but it does so with greater intelligence—it heats things up like its less savvy predecessors, but it knows enough not to burn the meal and to have it ready when you get home.

In our discussion it will be helpful to have before us an explicit understanding of what a medium is. Joseph Margolis supplies a relevant characterization: "a medium is a cultural instrumentality manifested in a physical material." There are at least three components to a medium so characterized which are relevant here. First, a medium is closely connected to a physical material. Second, the artistic message is not incidentally connected to that physical material, but is embodied in it in a way similar to the way minds are embodied. One cannot readily transport an artistic message from a painting into an opera since the meaning of any medium artwork is intrinsically bound up with its physical manifestation. Third, a medium is more than simple physical material: it is a culturally defined communication channel whose expressive possibilities are determined, at least in part, by the cultural conventions which delimit that channel. On each of these three salient points, we will discover that computers and media diverge. By examining the concepts of interface, interaction, and simulation, which are emblematic traits of computer art, radical differences become apparent. We shall examine how the computer relates to media through interfaces, how it functions differently as an interactive agent, and how it exceeds the circumscribed scope of any medium by simulating a wide variety of experiences and environments.

1. The Enchanted Forest

If Aspen.Spruce is a photograph, what is it a picture of (Figure 1)? Despite its appearance, it does not depict an actual forest or even a real model of one. It might, in some sense, represent what's in the artist's imagination; and in this sense any work of art reveals—we usually say expresses—the images and ideas an artist has. But this artwork also represents something of an entirely different sort which is completely outside the scope of traditional painting or writing. There is an important sense in which it is a picture of the contents of
A computer's memory: there is a direct correlation between the two. Aspen, Spruce is an example of one type of computer picture called a raster image. According to the raster model of a computed picture, an image is a visual representation of digital information contained in a frame buffer (also called image memory) which is that part of random access memory (RAM) where a computer stores numbers it interprets as pictures. A raster image is typically a two-dimensional array of picture elements (pixels), each of which is assigned a color based on a number in a particular location in the frame buffer which is correlated with the pixel. This 'representation' is not quite the same as the representation of a tree in a painting. For one thing, since numbers have no color, the correlation between the contents of RAM and colored dots in the picture is completely arbitrary and instantly changeable, although it is systematic. Yet each pixel in a raster picture is a translation into color of the value of a number which stands for that color and is situated in the memory location correlated with that particular pixel.

By delving even deeper into remote electronic recesses we discover that the trees themselves are unusual imaginary creations which can exist not only in the mind of an artist, but also in the mathematical structures which contain the information that defines what and where they are. Abstract systems of numbers determine the size and shape of each tree, its species, the exact placement of its branches and leaves, its location in the forest ... as well as what kind of day it is. A strictly numerical model of this enchanted forest can be submitted to the machinations of computational geometry to produce surprisingly realistic pictures of non-existent worlds. Borrowing a term from Jean Baudrillard, we might label this enigmatic digital realm "hyperreal" to capture the paradoxical reality of the fantasy worlds stored inside a computer. They bear the ontology of numbers: although not tangible objects, they are nevertheless manipulable entities and can be experienced as real things with resolute efficacy. A boy with joystick in hand is not flying a real airplane, but he is flying something (fantastic though it may be) whose movements are controlled by the palpable lever he grasps. Unlike her counterpart painter or novelist, the computer artist works with a hyperreal creation which stands behind the scenes as a kind of "meta-physical" object which prefigures the artistic expression.

The first problem we encounter with the notion that the computer is a medium is that the numbers which are the "substance" of computer art are not physical objects but conceptual ones. They need physical containers, but they can be stored equally well in many different formats and moved freely from one to another: graphite, electricity, magnetism, etc. Moreover, the physical basis of any particular hardware is also incidental to computed creations. When making computer art it is irrelevant whether the technology of the machine is based on tubes, transistors, integrated circuits, light fibers, or beads on a
string. The creative role a computer plays is conceptually and not physically based, although the efficacy of its role is closely tied to technological developments in computing. Unlike the concrete and implacable presence of light and pigment brought into the gallery through the agency of visual media, the computer's stance toward its creative sensory outlets is abstract and its influence on them remote. Numbers have a "meaning" independent of their expression in any particular medium because they are concepts, not objects or events. They are fundamentally unlike sounds or colors, and their abstractness is the basis of computations with them.

What color is a number; how big is a bit? We know how cadmium yellow looks and smells, what the pitch of middle C sounds like, and how a word should be spoken or written. It makes sense to inquire about the size and color of a blob of paint on a palette, but a bit has no characteristic look, sound, or smell because it is a concept, not an object. Duchamp may have stopped painting because he abhorred the smell of oil, but the antipathy many artists have toward computers cannot be based on any sensory aversions. Presenting an image as a file of numbers which can be lodged in a frame buffer is fundamentally different from presenting it as colored areas spread over a piece of canvas. A medium embodies its messages in an inseparable union of form and matter, but a computer encodes its information in an abstract sequence of bits with no intrinsic or favored physical manifestation.

Due to its numerical basis, computer art has opened up for artistic exploration elaborate abstract worlds of shapes and forms heretofore inaccessible due to their complexity or simply to the fact that no one has been able to think them up without the assistance of computed mathematical tools. The popular Mandelbrot Set (Figure 2) has become the paradigm of such imagery as legions of artists and mathematicians, as well as curious sightseers, have set upon their computers to catch glimpses of the intricate twists and turns of this mathematically defined object. Computers can reveal conceptual structures to us that exist outside media. They make it possible to examine abstractions visually by delivering them to us through media. Forays into these often intriguing domains have proven to be profitable not only for artists but also for scientists as well. They enable us to expand our vision for technical as well as creative purposes.

The relationship of computed art to its outward manifestation is not the same as it is in media. Media embody information in their physical basis, but the information in a computer flits elusively from one place to another and is never permanently fused with any particular material, although it can readily be transported into many different ones. Pictures of hyperreal worlds are realized through what is called an interface, which implements an automated correlation between numbers in RAM and colors on a slide, piece of paper, video moni-
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Another answer to the question what Aspen.Spruce is a picture of is "a Cathode Ray Tube (CRT)", since the image is a photograph of a video monitor interfaced to the frame buffer holding the information which constitutes the image of trees. Computers can interface promiscuously (though remotely) to virtually any medium, and they are not among the media they interface to. (They can also talk to each other through digital channels which are different, but related to, interfaces). Furthermore, we need to use interfaced media to communicate with computers since we cannot ordinarily receive information directly in the forms it assumes inside a computer. Aspen.Spruce is exemplary in this respect — a photograph is used to present a computer-generated image which exists independent of the film. This does not mean, however, that computer artwork is always in a medium; conceptual art has clearly demonstrated that art need not use media. Even when they speak to us through media, computers talk the language of numbers and concepts.

Media, on the other hand, cannot interface to anything. One might take a photograph of a painting, or paint a photograph, but one medium is simply providing the subject matter for another. The information stored in one medium is translated into another, and it never looks identical because different media possess different properties. So-called "computer-assisted" art is not a counterexample. When an artist uses, say, a computer-generated image displayed on a CRT as the basis for making a painting, the computer work is either a study for the painting, much the way a drawing might be, or else what we have is just another example of translation — this time from video to paint. The frame buffer does not function as an original against which interfaced images can be compared. Computer art is not a mixed medium either: it is not a mixture of two or more media since, when co-present with media, the medium remains pure and simply gets its information from a new source. This is why the computer need not be present for each computer artwork: the computer did its work, the information was interfaced to and recorded on film or paint, and it can then be moved into the gallery without carrying the computer along. Even when the computer is there, it does not mix with the medium as another material, but informs it through an interface.

An interface conveys information, media embody it. While moving messages from conceptual to physical repositories, the interface from computer to medium usually converts information stored in digital form to information stored in analog form (Figure 3). This distinction is characteristic of the difference between computer and media tools for artmaking. Let's examine some of its features:

a) Analog information cannot generally be separated from the medium in which it is created. When it is articulated, a physical impression is required: the painter's brush changes the canvas, and once imparted to the surface, the message is inseparable from it.
While one might try to produce a facsimile of a painting in a photograph, it certainly is not possible to make the substitute in sound. Digital information, on the other hand, can readily be transferred from electricity to magnetism to light to print to sound to ... whatever. Digital information can freely be moved about with little risk of corrupting the message it contains, but transferring analog information from one medium to another is risky: photographs, for example, notoriously fail to replicate important features of paintings.

b) Analog information is usually analogous to its source. The curve of the hand's movement over a canvas is analogous to the curve in the painted visual composition. But the digital information created when the same motion is made across a digitizing table bears little analogy to the movement itself. The information is just lots of numbers resulting from the computer's sensation of minute fragments constituting a kind of analysis of the movement.

c) When analog information is recorded or transmitted, a direct link is required: the painter's brush actually touches the canvas and we have to go to the gallery to see the result. Usually there is direct contact between the information and its storage medium. But digital information stands removed from the hand and is related to it indirectly by machinery. This difference constitutes part of the distinction between embodying and interfacing information.

d) Analog information is continuous and smooth, while digital information is discrete and choppy.

In general, I would say that media tend to use analog information, computers tend to use digital information, and that this is one of the dramatic differences between them.

A bit is not something culturally formed the way painting, a paint stroke, or a style are: Its definition is formal and mathematical. The concepts of a bit or of the number two are cross-cultural in a sense in which the pentatonic scale and easel painting are not. Numbers are concepts that don't inherently capture and reflect genres and styles the way a physical medium does. A musical or visual medium is defined by certain cultural conventions which could be different and typically are not the same in different cultures. The embodiment of information in the medium follows these conventions. Information in a computer is not embodied so much as encoded, and while the system of coding is conventional, it is also automated so that the rules of the conventions are not prescriptions for how to make art, but merely instructions for how to set up the interface. The instrumentality of a computer is mechanized, not conventionalized. An organized system of bits and numbers which constitute the substrate of computer art is simply stipulated and not culturally determined in the way a painting genre or operatic structure are. The notion of a 'bit' approaches the idea of information in a manner entirely different from that of media. A medium embodies information, which means that it is laden with
meaning through the enfranchisement of cultural practices which govern the creation and location of information in a formed object. But a bit is not inherently embodied in any medium: it is the basis of a science, and not simply an art, of information. The agreement that a painting will consist in what’s on the front of the canvas and not what’s on the back or the frame is different from the agreement that a bit is the atom of information or the stipulation that a certain arrangement of bits will store a raster image in a specified manner.

2. The Magic Mountain

An artist who is uncertain how rugged to make the mountains in a landscape can enlist the aid of a computer which, on simple commands, will increase and decrease the number and sharpness of peaks, displaying a variety of alternatives from which the desired result can be chosen (Figure 4). Similarly, by changing the parameters of a formal language designed to generate plant-like objects, one can get the computer to display a variety of species (Figure 5). The artist makes a request or takes an action (by turning a knob, typing a message, moving a stylus, etc) and the computer responds with information and advice. A dialogue takes place between person and machine, and its outcome could just as easily be frustration or enlightenment as the production of art.

Unlike a medium, a computer is not a communication channel characterized by culturally defined protocol that specifies how a message should be formed. It is rather the kind of thing that appears at one end of such a channel: an entity with powers and agencies which can be manifested through media. Like a person, it uses media to communicate, embodying messages via interfaces which function as the machine’s hands and eyes.

Media and computers delineate two different pathways for artistic expression. A medium like painting cannot interact, but only react to what an artist does. It also takes a fixed and relatively passive stance toward the audience in a gallery. A computer, on the other hand, can function as an interactive partner in both the creative process and the artistic experience. The artist has no privileged position in making mountains move: that power can be put into the hands of the viewing public so that the artwork and not merely the making of it is an interactive adventure.

When painting a canvas, an artist’s imagination is expressed in the medium through a one-way channel in which the hand attempts to deposit ideas and images on the canvas. The artist may then use what is seen as a further stimulus to the imagination to refine and clarify the visual goal: this is the whole point of making sketches (Figure 6). But in this feedback cycle of progressive refinement, the medium remains passive. It cannot respond with anything beyond what the
artist deposits in it. Once it is finished and installed in a gallery, the painting speaks to its audience in a similarly unresponsive one-way communication. People who touch or talk to art on the wall are usually viewed with suspicion.

A computer, on the other hand, can be actively responsive to the words and movements of the artist, who might even choose to extend this somewhat anthropomorphic experience to the audience as part of the artwork. A computer is active: it computes. Its purpose is not primarily to store information, but to process it; indeed, it usually "forgets" the information you give it as soon as it is turned off. It is not an information channel, a passive medium, so much as an information manipulator — dare we say a thinker? A computer can sense where the artist's finger points and react by choosing a color or registering a stroke or moving a mountain. The information flows in two directions. The computer receives input from the user, processes it, and responds in like kind (Figure 7). What makes this possible is the interposed world of numbers specified by the artist and manipulated by the computer. It is through this shared conceptual realm that people and machines communicate.

This communication bears the marks of intelligent conversation, and the computer's interactive tools are sometimes said to have intelligence. What does this mean? I suppose one thing it means is that they are more partners than tools: they supply not only efficacy but agency. Differences from the tools of media emerge in some of the characteristic ways their abilities exceed the capabilities of physically manifested instrumentality.

One hallmark of interactivity with an "intelligent" machine is the ability to discourse in generalities and dispense with the need to delineate all the specifics: we can tell the computer to adjust properties of objects or images without delineating each and every detail as a painter must in manipulating pigment. Since the computer understands concepts, we can tell it to make the mountains rougher without saying exactly how it is to be done. This makes it possible for the artist to work at a higher level of generality. A media artist must conceive a creation with some determinateness and then execute it in all its meticulous detail in order to create a work: although the painter may conceive an image in generalities, every rock and blade of grass is painted in by hand with deliberate execution. A photographer can capture a whole scene at one snap, but the scene is seen before photographed, its details are knowable in advance. The medium artist must either create or find each detail. But the computer artist might simply say something like "Put a grove of aspen over here and a spruce forest over there with a meadow in between and bathe the whole setting in a warm afternoon sun." The computer will then determine all the necessary details: where each aspen leaf, spruce needle, and blade of grass is placed and how it reflects the light. The artist discovers these
details almost as a viewer and can typically be just as surprised at the result. The computer has the "intelligence" to figure out the details if you give it the general picture. With such a talented assistant, the computer artist can produce individuated things by describing them in general terms. To react with this apparent cognitive behavior, the computer system must be appropriately configured with hardware and software: a naked machine with empty chips is no more communicative than a sleeping person. Thus, when I use the term 'computer' here, it refers to a complete system with the ability to interact. Originally a "computer" was a person who does calculations. When discussing the cultural role of computing machines, we need to consider not only the hardware (the "body"), but also the software that animates it (the "mind"). I suppose one could say the hardware is the "medium" in which the computation happens (i.e. on which the software is run), as one could say the brain is the "medium" in which thinking takes place. But I believe this sense of 'medium' is rather different from its paradigmatic artistic use.

The challenge in media of conceiving and executing a work of art is supplemented in computer art by the enterprise of displaying and choosing alternatives. This gives rise to dilemmas of surfeit. Where the problem in media is to create the work, to get the message embodied, the problem in computer art is often to make a meaningful selection from an overabundance of alternatives playing out an endless sequence of permutations. Dismayed at such a prodigious sea of possibility, the issue of making the right choice can often confuse an artist accustomed to the struggle for hard-won individuated expressions in media. The very notion of a correct choice becomes suspect. An assistant is probably not best used by requesting myriad permutations in hopes a masterpiece will be chanced upon. Solving the problem of finding the jewel among reams of output is not a diminutive detour around hard creative work. It is easy to lose sight of the forest for the trees. The modi operandi of a computer artist are different at least in some respects, from those of a painter; and for all their new potential, they bear equally novel dangers and distractions.

The versatile interactive tools of the computer artist are also distinguished by the wide range of effects that can be wrought with similar creative techniques. Radically different looking results can be produced from the same mathematical tools adjusted to slightly different settings. Marble can be turned to clouds by changing a program slightly. Furthermore, similar inputs can result in quite different consequences. A sweep of the hand over a tablet might produce a single red line, multiple multicolored lines, or perhaps just a change in the color of an imaginary pencil, depending upon how the computer interprets the motion. The machine can usually tell what the user intends by context, just as another person can know the correct homonym in conversation.
These characteristic features of computer art all stem from the nature of the insubstantial numerical material which provides the intangible milieu in which it operates. Herein lies a profound difference between creations in media and in machine memory. As a user addresses a computer, the features of imaginary mountains are adjusted, and not just properties of pictures of them. These mountains are described by collections of numbers and formal techniques for manipulating numbers. When the mountains are smoothed, roughened, or changed in some other way, this description changes. So the computer artist is working in a fantasy world populated by creatures of his or her own imagination whose appearance is discovered by interfaces which convey this world in RAM to media outside. The computer therefore supplies artists with more direct and tangible access to products of the imagination than that proffered by media, where changes in a fantasy can only be manifested through newly crafted images of it. The imagination is oddly objectified, and this is probably one of the most important new capabilities the computer bestows upon creative artists.

Baudrillard's notion of "hyperreality" denotes this peculiar realm which supports the somewhat paradoxical combination of real activity on the part of the artist in an imaginary space which is only as real as its mathematical description, but in which the artist's actions have efficacy. This mechanized formal existence makes something possible with a computer which cannot be contemplated in any medium: one can make a picture of something by first modelling it in an imaginary world and then asking the computer to produce a picture of it according to various parameters placed in that created world. The interposition of hyperreality between the artist's imagination and the visual display makes interaction possible. What the artist interacts with resides in that world. Media cannot interact, in part, because of the inseparability of information and physical material. In an interactive video display it is the computer, not the video, that is doing the interacting. Yet interactivity is the hallmark of even the simplest computer paint systems. Most artistic software tools in use today are interactive.

The scope of interactivity extends even further to suggest new artistic frontiers. Myron Kruger's work is a good example of art which encompasses a new dimension by interacting with the viewer. In his "Videoplace," a little "critter" has the ability to sense an individual person's shapes and movements and respond to them in a gallery installation where a computer is linked to a video system. I suspect this work is a harbinger of even more radical artforms to come.

3. The Virtual Camera

Although the computer is not a medium, it can pretend to be any one
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of them. Precisely by virtue of what distinguishes it from media, a computer can be programmed to simulate them. Computer art has no characteristic look or behavior, but like a chameleon it can be made to take on the feel and appearance of a multitude of old and new tools. Notions of medium specificity are presented a serious challenge when confronted with an art-making environment which is not only capable of interfacing to any medium but also of casting a ruse for each one. 

I would like to put forth what may initially seem an outlandish claim. You cannot draw with a computer. I think of drawing as something that happens when a person uses an object to make a mark of some sort on a surface. One hopes this is not what happens when people make computer art: a gouge in the surface of a digitizing tablet is bad form.

A computer is not a drawing instrument (and maybe not really a tool at all). If you can't see the monitor, an artist's empty motions over a small plastic surface must seem like some rather peculiar habits of an obsessive-compulsive. The hand moves in one place, the creative result is stored in another place, and the visual display comes out in yet a third place. This is not drawing. Instead, it is a computer simulation of the activity of drawing. Most artists find it takes a while to get used to moving the hand on the tablet while looking somewhere else at the CRT. The creation occurs in a hyperreal world of digital information. In this world, drawing feels a little like how it feels with pen and paper, but it can be quite different since the computer can interactively manipulate numbers in many surprising ways. The intelligent machine is a great pretender. It can make believe the artist holds a brush of any size or color when in fact nothing more than a dry slender cylinder is in the hand. But the scope of its simulation capabilities extends far beyond the cultural conventions delimiting the artistic exercise of media. It possesses a protean pliability which transcends any particular physical basis.

Kruger's work was featured in a recent Newsweek article entitled "Now, Artificial Reality" which examined the variety of simulators currently being used or developed for flight, medicine, war, art and a host of other human endeavors. Computer systems can be made to simulate a wide variety of environments, and this is becoming one of their most important uses today. Whether one agrees with Baudrillard's sometimes sinister view of simulation, he certainly is correct in emphasizing its significance for contemporary and future cultures.

In their well-known text on computer graphics, Foley and Van Dam call the computer a "synthetic camera" constituted by numbers in a world whose other denizens share a similar ethereal existence. Exploring this analogy will help us understand something about the possibility and nature of using the computer for graphic simulations. It is illuminating to look at the two algorithms by which perspective
pictures are made using media on the one hand and computers on the other. A real camera embodies formulae for producing images which differ radically from those employed by the virtual camera concocted inside a computer to simulate the behavior of its real counterpart.

An algorithm is a set of step-by-step instructions for accomplishing a task. Information that can serve as instructions — that can be used to do things — functions quite unlike information in media that just sits there in storage, and also differs from the data stored in RAM as an image. Algorithmic information supplies a how-to-do vs a how-it-is, and it is an essential ingredient in making machines appear to think. The importance of information in a computer lies primarily in its active form as instructions (knowing how to do things), and not simply in its passive form as data (knowing that such and such is the case). Information storage in media can effectively depict the real world; but the exercise of algorithms in a computer can function to simulate an imaginary one.

The geometric algorithm practiced so effectively by Renaissance artists (and mechanized in cameras) is a loosely defined set of passive instructions which the painter can follow to render a scene in perspective (Figure 8). The algebraic algorithm utilized by computer renderings, however, actively produces an image automatically without the need for an artist to figure anything out except what is to be pictured and from where (Figure 9). The former functions in the concrete space of the real world using a physically defined point and plane for the eye and the picture plane; the latter performs its task in the hyper-real world of a coordinate system where points and planes are nothing but numbers and equations. Leonardo constructed his perspective renderings using the time honored techniques of Euclidean geometry, while a computer artist asks the machine to compute its results using analytic geometry of a more recent origin. The results of the construction are delivered directly onto the picture surface, but the results of calculation must be appropriately interfaced to a medium to make the perspective picture visible. Even though the camera obscura automated the geometric algorithm and eventually evolved into the modern camera, it still functions today by the same concrete rules.

The computer is not a medium because it does not embody meanings in a physical substance according to cultural conventions. But if it is not a medium, what is it? What we've got here is a new polymorphous beast whose effects on human culture are not yet well understood, although they clearly will be profound. So I don't have any easy answers to this question. And furthermore, I think others may have been led to believe it is a medium because they don't have any good answers to this question either. The best I can do now is to proffer the somewhat lame metaphor: creative partner. But this does at least capture the radically different role computers are playing in artmaking when compared to the one traditionally occupied by media.
Notes


2 Joseph Margolis, "Film as a Fine Art," Millennium 14/15 (Fall/Winter, 1984-85), p. 95. One could argue that this definition is not suitable for describing literature since words are not made of physical materials. Margolis defends his definition, but the discussion at hand need not turn on whether one is convinced by his defense. It is sufficient simply to agree that words, whatever else they may be, are not concepts. In the arguments that follow, painting is the paradigm of a medium that I have in mind; however I believe the fundamental points being made apply to any artistic medium.

3 Jean Baudrillard, Simulations (New York: Semiotext(e), 1983).

4 Jay Barchrach accuses me of functionalism because of statements like this one. I'm not sure how to plead, but it might help to clarify what I'm getting at here. It is possible to follow "by hand" (and "by mind," to be sure) the processes which lead up to a computer-generated picture. One could write down the numbers and do the calculations with pencil on paper, and then use a box of crayons to put colored dots on graph paper to create a "hand-made" raster image (much like "paint by number"). The fact that a silicon-based computer can do the same thing a million times faster is not merely a quantitative difference, but gives rise to qualitative differences as well. So the constitution of hardware is important in many ways, but it does not affect the basic relationship between numbers and colors in a raster image.

5 Benoit Mandelbrot is responsible for the relatively simple but extraordinarily fecund definition of this set of numbers in the complex plane. He has also developed a new kind of "fractal" mathematics which has proven to be useful not only in making computer images, but also in articulating scientific theories. See The Fractal Geometry of Nature (New York: W. H. Freeman, 1983). For more examples of rich imagery based on mathematics, see H. O. Peitgen and P. H. Richter, Eds., The Beauty of Fractals, (Berlin: Springer-Verlag, 1986). See also Heinz-Otto Peitgen and Dietmar Saupe, Eds., The Science of Fractal Images (New York: Springer-Verlag, 1988).


7 As David Fisher has pointed out, literature may pose a general problem for this discussion since it works in a medium that is digital and creates things that are more like concepts than objects. However, it seems apparent that regardless of how one analyzes the "substance" of the medium of literature, there are two fundamental ways in which it differs from computer creations. One is that by describing the objects and events in a novel, there is no sense in which one is actually creating a model of them that can be inhabited and manipulated through simulations. The other is that literature cannot interact.

8 Noel Carroll has criticized beliefs in medium specificity from a somewhat different perspective. See his "Medium Specificity Arguments and Self-Consciously Invented Arts: Film, Video and Photography," Millennium 14/15 (Fall/Winter, 1984-85).
February 9, 1987, pp. 56-57. Gene Youngblood characterizes this type of environment as one where context supersedes content as the creative focus: I think this is a useful way to understand one aspect of how interactive art differs from its passive predecessors.


The two algorithms are discussed more fully in my article, "Computed Space," Proceedings of the National Computer Graphics Association (1987), Vol. III.

Earlier versions of this paper were read at meetings of the National Computer Graphics Association, the Pacific Division of the American Society for Aesthetics, and the New York City ACM/SIGGRAPH. I am grateful to Linda Ashley, Ken Glickfeld, Jay Bachrach, David Fisher, and a number of other respondents for useful comments which helped mitigate the folly.
Figure 1. Aspen, Spruce. By Bill Reeves, from Alvy Ray Smith, "Plants, Fractals, and Formal Languages," Computer Graphics V. 18, No. 3 (July 1984), pp. 1 - 10.

Figure 2. Mandelbrot Set. In this image from an animated sequence, the two-dimensional set is mapped onto a sphere by John Simon, Jr.
Figure 3. *Interface*. Digital information can be experienced by using a digital-to-analog converter to express it in a medium.
Figure 4. The Magic Mountain. Three versions of the same terrain with different ruggedness by Richard Voss. Published in Benoit Mandelbrot, The Fractal Geometry of Nature (New York: W. H. Freeman, 1983).

Figure 5. Bushes. Alvy Ray Smith, "Plants, Fractals, and Formal Languages," Computer Graphics V. 18, No. 3 (July 1984), pp. 1 - 10.
Figure 6. The Expressive Pathway Using Media.

Figure 7. The Expressive Pathway Using Computers.
Figure 8. The Geometric Algorithm. Albrecht Dürer, *Designer of the Lute*, 1535.

Figure 9. The Algebraic Algorithm. Tomà, 1985.