A TAXONOMY OF COMPUTER ART*

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Abstract:
There are various forms of computer art. This paper distinguishes the major categories, and asks whether the appropriate aesthetic criteria--and the locus of creativity--are the same in each case.

I: Introduction

Since the late-1950s, an ever-diversifying set of novel art practices has arisen which are still little known or discussed in aesthetics and art theory. (For a wide variety of examples, see: Krueger 1991; Wilson 2002; Candy and Edmonds 2002; Whitelaw 2004; Woolf 2004; Popper 2007.) As Jon McCormack, one of the artists concerned, has put it, "[Much of the innovation today is not achieved within the precious bubble of fine art, but by those who work in the industries of popular culture--computer graphics, film, music videos, games, robotics and the Internet" (McCormack 2003: 5).

The "precious bubble" of fine art is a (shifting) socially accepted norm. But artists often work outside the norm of their day, as famously illustrated by Marcel Duchamp and his readymades or John Cage's use of silence. And sometimes, the bubble eventually expands so as to engulf the previously maverick efforts. The Impressionists, for instance, no longer have any need for a *Salon des Refuses.* They don't even need a salon: their images assail us every day on calendars and chocolate boxes. Whether the innovations mentioned by McCormack will one day be included in the expanding bubble remains to be seen. Their fate, in this regard, depends partly on how people--both curators and the general public--respond to the controversial aesthetic and philosophical questions raised in Section IV.

The novel approaches involved here are closely inter-related, both theoretically and methodologically. So much so, indeed, that they are often all lumped together under one label: "computer art", "electronic art", "process art", or "generative art". This paper aims to clarify how they can be distinguished.

II: Origins and Inter-relations

From the theoretical point of view, this new art originated in cybernetics and general systems theory. The young painter Roy Ascott, later to be highly influential in the field, identified the novel activity as "a cybernetic vision" (1966/67; see also Mason 2008: ch. 4). And the exceptionally creative cybernetician Gordon Pask was a key influence. For besides producing and/or imagining some of the first artworks of this general type (in the 1950s), he provided much of the theoretical impetus that inspired the more philosophically minded artists in the field (Boden 2006: 4.v.e; Mason 2008: ch. 2).

Very soon, the "cybernetic vision" was bolstered by ideas about structure and process drawn from computer science. Ernest Edmonds, for instance, turned from paintbrush and easel to the computer in the 1960s: he thought he could produce more interesting art in that way (see Boden and Edmonds 2009: sectn. iii). At much the same time, music and visual art was produced which reflected AI's computational theories of mind. Indeed, Harold Cohen, a renowned abstract painter in 1960s London, deserted his previous working practices largely because he felt that doing computer art would help him to understand his own creative processes better (McCorduck 1991; Boden 2004: 150-166, 314f.).

Over the past twenty years, this artistic field has been inspired also by ideas about emergence, evolution, embodiment, and self-organization. These concepts are borrowed from various areas of cognitive science, and in particular from artificial life (A-Life). However, the theoretical roots (and the pioneering experiments) of A-Life reach back to mid-century cybernetics and automata theory (Boden 2006: 4.v.e, 15.iv-v). In short, the theoretical wheel has turned full circle.

The methodological wheel, meanwhile, has climbed an ascending spiral. For the art practices outside the fine-art bubble are grounded in technologies for communication and information processing whose power and variety have burgeoned over the last half-century. (Often, this means that the customary lone artist is replaced by a team, some of whose members may be computer scientists and/or tele-engineers.)

Most of them rely heavily on digital computing, and in particular on methods drawn from AI and A-Life. Specifically, they have employed both symbolic and connectionist computation, and--more recently--cellular automata, L-systems, and evolutionary programming too. This is an ascending spiral, not a linear ascent, because two of those "recent" methods were foreseen (by John von Neumann) in 1950s cybernetics, and all three had been mathematically defined by the 1960s (Boden 2006: 15.v-vi). But none could be fruitfully explored, by artists or by scientists, until powerful computers became available much later.

The resulting artworks are highly diverse. They include music, sonics, the visual arts, video art, multimedia installations, virtual reality, kinetic sculpture, robotics, performance art, and text. And whereas some of these outside-the-bubble activities

place ink or paint onto a surface, others involve desk-top VDUs or room-scale video-projection. Yet others eschew the virtuality of cyberspace, constructing moving physical machines instead.

The labels attached to these new art forms vary, and have not yet settled down into a generally accepted taxonomy. The names preferred by the artists involved include: generative art, computer art, digital art, computational art, process-based art, electronic art, software art, technological art, and telematics. All of those terms are commonly used to denote the entire field--and (although distinctions are sometimes drawn) they are often treated as synonyms.

With respect to the labels "computer art" and "generative art", that was true right from the start. These terms have been used in tandem, and more or less interchangeably, since the very earliest days. The first exhibition of computer art, held in Stuttgart in February 1965, was called "Generative Computergraphik" (Nake 2005). It showed the work of Georg Nees, who wrote the first PhD thesis on computer art, giving it the same title as the exhibition (Nees 1969). That thesis was widely consulted by the small but growing community, so harnessing the words *generative* and *computer* together in its readers' minds.

Their near-equivalence was reinforced in November 1965, when an exhibition (again, in Stuttgart) included both Nees' work and the early computer graphics of Frieder Nake. Both men applied the term "Generative" to their own work—and used this word to identify art that was produced from a computer program and, hence, was at least in part produced automatically. Others who were pioneering the activities outside McCormack's bubble also adopted the term. For example, when Manfred Mohr started producing drawings with a computer program in 1968 he termed it "generative art". And the philosopher Max Bense--who had composed the manifesto for the original Stuttgart exhibiton of 1965--was writing about what he called "generative aesthetics" (Nake 1998).

Today, the label "Generative Art" is still current within the relevant artistic community. Since 1998 a series of conferences have been held in Milan with that title (Generativeart.com), and Brian Eno has been influential in promoting and using generative art methods (Eno, 1996). The use of the term has now converged on work that has been produced by the activation of a set of rules (determined by the artist) *and* where the artist lets a computer system take over at least some of the decision-making.

With the recent appearance of art using methods drawn from A-Life (for examples, see Whitelaw 2004; Tofts 2003; 2005: 80-103; Popper 2007: 118-129), the label "generative art", as used in the community concerned, has acquired biological overtones. In biology, the key word is common in discussions of morphological development and growth in plants and animals, and in references to reproduction. One or both of those meanings is/are sometimes explicitly stressed by self-styled generative artists whose work focusses on emergence, self-organization, and/or

evolution. McCormack himself is one such example (e.g. Dorin and McCormack 2001; McCormack et al. 2004). Even so, the formal-mathematical sense remains a core aspect of the label's meaning.

(Despite the continuing assimilation of the terms "generative" and "computer" art, one shouldn't assume that these are exactly the same thing. According to the taxonomy given below, not all generative art involves computers. To the contrary, the generative processes involved vary widely in type--some of which were already used by artists hundreds of years ago: see Section III.)

Even in the 1960s, however, alternative tags for this general area were already being offered (and, as remarked above, more have been suggested since then). An influential discussion by the art historian Jack Burnham (1968), for instance, identified the new work, overall, as "process art"--a label that's still in use fifty years later.

Since Burnham's discussion, the "processes" involved have diversified hugely. As a result, and in addition to a variety of labels for the entire extra-bubble field, there are today many names for subfields. These more discriminating categories include interactive art, evolutionary art, video art, media (and new-media and multimedia) art, holographic art, laser art, virtual art, cyborg art, robotic art, telerobotics, net art ... and more. Again, however, the extension of these labels (the scope of the various subfields) is not always clear.

It's partly for that reason that "a satisfactory critical framework of new forms in art technology has yet to be developed" (Candy and Edmonds 2002: 266). The distinctions made in this paper should help towards such a framework.

There's a *caveat,* however. The definitions given here (in Section III)--for instance, of computer art, generative art, evolutionary art, robotic art, and interactive art--use words that are already being used by the artists in question. Indeed, this analysis may help readers to interpret these artists' discussions of their own work. But the aim is not to offer a report of common usage: as remarked above, such usage is not consistent. Rather, this new taxonomy is intended as a theoretical tool with which to highlight certain distinctions that have aesthetic and/or philosophical interest. As we'll see (in Section IV), judgments concerning creativity, authorial responsibility, agency, autonomy, authenticity, and (sometimes) ontology are even more problematic outside the precious bubble than inside it.

III: The taxonomy

Thirteen types of art are distinguished in the taxonomy given here. They are called Ele-art, C-art, D-art, CA-art, G-art, CG-art, Evo-art, R-art, N-art, I-art, CI-art, VR-art, and LC-art. (Table 1 lists some examples of artworks that fall under these terms, which are defined below.).

Some of these activities, having been located within the classification, are then ignored. In other words, there are certain types of computer art which are identified in the taxonomy but not further discussed in this paper--nor, for that matter, elsewhere in this book. Most of the attention is paid to the various forms of CG-art, because these raise the most interesting philosophical issues.

This "taxonomy" is a decidedly non-Linnaean structure. For one thing, the definitions given below, like most definitions, admit borderline cases—and even anomalous counter-examples. And for another, there's no neat and tidy hierarchy of genus and species within which these thirteen types can be located. Although there are some part-whole relations here, there are also untidy overlappings.

One type of overlapping concerns links with more traditional, or familiar, categories of art. Most cases of such art do not fall under this new classification at all. But some of the classifier concepts--namely: G-art, I-art, Evo-art, and R-art--cover artworks both inside and outside McCormack's "precious bubble". Admittedly, those which lie inside the bubble are relatively maverick examples, as we'll see. Indeed, some of them (produced by the 'conceptual' artists) were specifically intended to undermine the commonly accepted notion of "fine art" in terms of which the bubble is defined. In McCormack's usage, however, *all* examples of non-computer art are located inside the bubble.

A summary list of the relevant definitions is given at the end of this Section. Meanwhile, they will be introduced one by one, with illustrative examples of each category.

Let us start with electronic art, or Ele-art. This wide concept covers *(df.) any artwork whose production involves electrical engineering and/or electronic technology.* So it ranges from simple analogue devices of the 1950s and 1960s such as Pask's "Musicolour" and "Colloquy" (Pask 1971; Mallen 2005) and Edward Ihnatowicz's kinetic sculpture SAM (Zivanovic 2005: 103)--all pioneering examples of interactive art, or I-art--to the highly sophisticated man-robot integrations recently embodied by the performance artist Stelarc (Smith 2005). And along the way, it covers the whole of computer art and media art, including those examples which exploit the advanced computational techniques of virtual reality.

Ele-art does not include art that's *produced* only by humans but *published* by electronic means. So it excludes Japan's Keitai novels, for instance. These are stories published online, and downloaded from mobile phones. (Sometimes, they are so

popular--more than two million copies may be downloaded in the first week--that they are very quickly bought by traditional publishers, to be issued in book form. In 2007, half of Japan's top ten fiction bestsellers originated in this way.) By contrast, some of the Manga-art comics now being published for mobile phones do count as Ele-art: namely, those which involve animated graphics and/or interactivity. In some cases, there is a buzz from the phone when the reader comes to a tense moment in the action depicted on the screen. A Keitai novel could of course be adorned with such buzzes, so would then count as a marginal example of Ele-art--only "marginal", because these buzzes are merely superficial, and their loss (if the text were later published in book-form) would alter the reader's experience only minimally.

Unlike mechanical art, such as Leonardo da Vinci's metal lion (who "after he had a while walked vp and downe, stoode still opening his breast, which was all full of Lillies and other flowers of diuers sortes"--Marr 2003: n.66), electronic art could not appear until the mid-twentieth century. But, as the previous paragraph implies, the technologies concerned have diversified richly since then. Accordingly, the highly inclusive label Ele-art is not very interesting for our purposes.

Surprisingly, perhaps, neither is the concept of computer art, or C-art. By C-art, I mean *(df.) art in whose productive process computers are involved.* This concept is apt for general art-historical purposes, because it covers every example that anyone might want to call computer art--including many that are commonly given other labels. It's less useful for us here, however, for two reasons.

First, it includes analogue as well as digital computers. Some of the earliest C-art work combined digital methods with specially-built analogue devices. Ihnatowicz' giraffe-like kinetic sculpture Senster is a case in point (Zivanovic 2005; Mason 2008: ch. 5). As for analogue computers as such, these were used in the early days. For example, in visual arts by Ben Laposky's work of the 1950s (Laposky 1969), and in the growth of electronic music at the same time, famously encouraged by the invention of the Moog synthesizer (Pinch and Trocco 2002).

Today, a few computer artists sometimes employ analogue *processes,* namely lectrochemical reactions like those pioneered by Pask. Some of their work, including Pask-inspired 'sculptures' by Richard Brown (2001, 2006) and Andy Webster (2006-ongoing), featured in a 2007 Edinburgh exhibition on "Gordon Pask and his Maverick Machines". (In addition, a video on this theme called "Tuning Pask's Ear" has been shown in several European art galleries: Webster and Bird 2002.) But analogue *computers* are another matter--and are very rarely used by artists today. Because of the huge flexibility that is afforded by the general-purpose nature of digital computers, it is those machines which underlie most C-art. Indeed, to speak of computer art is typically to assume that digital computers are being used.

In other words, computer art is (usually) tacitly classed as digital art, or D-art. D-art *(df.) uses digital electronic technology of some sort.* It includes not only artworks generated by computers but also digitally manipulable (but human-produced) music

and video. Common usage sometimes treats "digital art" and "computer art" as near-synonyms. In this taxonomy, however, they are analytically distinct--with most, but not quite all, C-art being included within D-art. (If the word "electronic" were removed from our definition, the nineteenth-century Pointillistes would count as D-artists; for their pictures were composed not of continuous brush-strokes or colour-washes but of myriad individual spots of paint.)

D-art is more wide-ranging than may appear at first sight. For instance, some C-artists use visual software that is *intuitively* analogue, and so relatively 'natural' to work with. (One example is continuous vector-mapping, used instead of pixel-editing: Leggett 2000.) But they are relying on methods/hardware that are digital at base. In fact, most people who said today that they are using an analogue method (i.e. an analogue virtual machine) would actually be working on a digital computer, used to simulate an analogue computer.

Similarly, most 'neural networks' or connectionist systems, whether used by cognitive scientists or by computer artists, are actually simulated on von Neumann machines. That's true, for instance, of Richard Brown's interactive *Mimetic Starfish,* a millennial version of the *Senster* that was later exhibited around the world, and was described by *The Times* in 2000 as "the best bit of the entire [Millennium] dome". The starfish was built by engineering visual imagery, not metal: it is a purely virtual creature (an image projected onto a marble table), which responds in extraordinarily lifelike ways to a variety of human movements. And it is generated by a self-equilibrating connectionist system, or neural network (programmed/built by Igor Alexander). In short, digital technology reaches further than one might think.

The second reason why the definition of C-art given above is too catholic for our purposes is that it includes cases where the computer functions merely as a tool under the close direction of the artist, rather like an extra paintbrush or a sharper chisel. Artists in the relevant community sometimes speak of this as "computer-aided" or "computer-assisted" art, contrasting it with what they call "computational" art--where the computer is more of a participant, or partner, in the art-making (e.g. Paul Brown 2003: 1). Let's call this CA-art, wherein *(df.) the computer is used as an aid (in principle, non-essential) in the art-making process.*

Consider video art and music videos, for instance. These popular outside-the-bubble activities qualify as CA-art in this sense. For the human-originated images and/or music are digitally stored and (usually) manipulated/transformed by the artist, using the computer as a tool. Other cases of CA-art include someone's doing a line drawing by hand on the computer screen, and then calling on a colouring program such as PhotoShop to produce a Limited Edition of identical prints--or, for that matter, a unique image. This is an upmarket form of painting-by-numbers, wherein the hues for each area are chosen by the individual artist. Yet other examples include visual collages composed from image-libraries, and computer music that's so called because it uses electronic synthesizers and 'virtual' instruments.

In practice, the computer "aid" may be necessary for the art-making. It's impossible, for instance, to alter video-images in certain ways except by using a computer. Similarly, some visual effects delivered by Photoshop could not have been produced by using oils, water-colours, or gouache. (The renowned artist David Hockney has recently described Photoshop as "a fantastic medium" accordingly: Hockney 2009.) And synthesized computer music exploits sounds that had never been heard before synthesizers were developed. Nevertheless, the computer is not essential *in principle.* The relevant visual/sonic effects are specifically sought by the human artist, and might conceivably have been produced in some other way. Much as a species with iron-hard finger nails would not need chisels, so our vocal cords (or wood, metal, or cats' sinews ...) might have been able to produce the sounds produced by synthesizers.

The sub-class of C-art that's of interest in the present context is the type where the computer is not used as a tool to effect some pre-existing idea in the artist's mind, but is in a sense (*just what* sense will be explored in Section IV) partly responsible for coming up with the idea itself. In other words, the C-art that's most relevant here is a form of generative art, or G-art. In G-art, *(df.) the artwork is generated, at least in part, by some process that is not under the artist's direct control.*

This is a very broad definition. It does not specify the minimal size of the "part". It does not lay down just what sort of generative process is in question. It does not say what counts as being outside the artist's direct control. And it is silent on the extent (if any) to which the processes concerned may have been deliberately moulded by the artist before 'losing' direct control. In short, this definition of G-art is largely intuitive. In general, it picks out cases of art-making in which personal control is deliberately diminished, or even wholly relinquished, and relatively impersonal processes take over.

Those impersonal processes vary greatly. They may be physical, psychological, sociocultural, biological, or abstract (formal). And if abstract, they may or may not be implemented in a computer.

For example, in the dice-music written by Haydn and Mozart the exact order of the pre-composed phrases was decided by throwing a die. Although a human threw the die voluntarily, he/she could not influence, still less determine, just how it fell. That was due to purely physical forces.

Such forces also influenced some visual generative art that pre-dated computers. One clear example is Kenneth Martin, whose 1949 abstract painting used basic geometrical figures (squares, circles, diagrams) and rules of proportion (Martin 1951/1954). Later, his "Chance and Order" and "Chance, Order, Change" series combined rule-driven generation with random choice. Although the basic forms were laid down by the rules that Martin had deliberately devised, chance physical events--such as picking a number out of a hat--determined the actual course of the work.

As for generative literature, this too may involve chance events dependent on physical processes. The various versions of Bryan Johnson's (1969) novel *The Unfortunates* are produced in this way. The novel was published as 27 separate sections in a box: all but the first and last were to be read in a random order, decided by shuffling or dice-throwing. Many other examples of interactive stories, part 'narrated' by the 'reader', have been produced since then (Montfort 2003). Most of these depend not on physical processes but on deliberate voluntary choices by the reader-author; however, some are part-generated by dice-throwing and the like.

Arguably, G-art produced by physical forces can be found *inside* McCormack's bubble, too. Given the phrase (in the definition above) "at least in part", one might say that Jackson Pollock's paintings exemplified G-art grounded in physics. For although he certainly was not throwing (still less, choosing) paint at random, he did not have direct control over the individual splashes--as he would have done over marks made with a paintbrush.

Even more control was lost, or rather deliberately sacrificed, when Hans Haacke, in the 1960s, began to exploit--and even to highlight--the physical behaviour of water/vapour/ice, of waves, and of weather conditions. He wanted to make "something which experiences, reacts to its environment, changes, is nonstable ..., always looks different, the shape of which cannot be predicted precisely ..." (Lippard 1973: 38, 64f.). He saw these works not as art *objects* but as "'systems' of interdependent processes"--which evolve without the viewer's interaction or "empathy", so that the viewer is a mere "witness". A few years later, Jan Dibbets placed eighty sticks in the sea, a few inches below the surface, and watched them oscillate in the water from fifty feet above: "That", he said, "was the work" (Lippard 1973: 59).

The Surrealists of the 1920s, by contrast, had exploited *psychological* processes--but their work counts as G-art since these were of a relatively impersonal kind. Inspired by Freud, they engaged in automatic writing and painted while in trance states, in order to prioritize the unconscious mind--which Andre Breton declared to be "by far the most important part [of our mental world]". Indeed, Surrealism was defined by Breton as: "Pure psychic automatism [sic] by which one proposes to express ... the actual functioning of thought, in the absence of any control exerted by reason, exempt from all aesthetic or moral preoccupations" (Breton 1969). The unconscious thought was taking place in a person's mind, to be sure, but voluntary choice and personal "preoccupations" (i.e. the reality principle and ego-ideals) were not directing it.

More recently, the conceptual artist Sol LeWitt was also recommending G-art when he said that art should be designed by some formulaic rule. The crucial idea, he said, "becomes a machine that makes the art," where "all of the planning and decisions are made beforehand and the execution is a perfunctory affair" (1967: 824). Once the plan has been chosen, "The artist's will is secondary to the [artmaking] process he *initiates* from idea to completion" (1969: item 7; italics added). He even added that "His wilfulness may only be ego". That artmaking process was nevertheless psychological,

in the sense that the implications of his abstract rules were discovered not by computers but by conscious reasoning.

Sociocultural processes--in the form of the United States postal system--produced Douglas Huebler's artwork called "42nd Parallel". Here, items were posted from 14 different towns spanning 3,040 miles on latitude 42, all sent to the Massachusetts town of Truro. The work, according to Huebler, was not the conception in his mind, nor the posted items, nor even the acts of posting. Rather, it was the widespread pattern of activity within the US postal system. But, he said, the work was "brought into its complete existence" through documents: the certified postal receipts (for sender and for receiver), and a map marked with ink to show the geographical relations between the 15 towns. Its nature as G-art is evident in his remarks "An inevitable destiny is set in motion by the specific process selected to form such a work, freeing it from further decisions on my part", and "I like the idea that even as I eat, sleep, or play, the work is moving towards its completion" (quoted in Lippard 1973: 62).

The artist Hubert Duprat turned to biology for constructing the work of art. He put dragonfly larvae into an aquarium containing not pebbles and pondweed but tiny flakes of gold, plus a few small pearls, opals, and sapphires--and left them to "sculpt" opulent little protective cases, held
together by caddis-silk (Duprat and Besson 1998). Some thirty years earlier, Haacke too had turned to biology. He experimented with the growth of grass and the hatching of chickens (as well as with water and weather), to make something "Natural", which "lives in time and makes the 'spectator' experience time" (Lippard 1973: 38). Mavericks though they were, both Duprat and Haacke were working inside McCormack's bubble.

Others have even exploited physical and biological *de-generation* to produce their G-art. The environmental sculptor Andy Goldsworthy sometimes highlights effects caused by undirected physical change: in his gradually melting ice-sculptures, for example. And in Gustav Metzger's "auto-destructive" art (notorious for the occasion on which an overnight gallery cleaner innocently threw Metzger's bag of rotting rubbish into the dustbin), the point of the exercise is to remind us of the deterioration that awaits all human constructions--and human beings, too (Metzger 1959, 1965). He was thinking not only of biological decay, but also of the terrible destructive power of the Cold War arms race. The artwork is usually assembled by a human artist (or sometimes, Metzger said, by machines in a factory). But it attains its final form, and its significance, through the natural processes of damage and decay.

However, such inside-the-bubble (albeit unorthodox) cases are not what the new artists normally have in mind when they refer to "generative art". Their phraseology is borrowed from mathematics and computer science, with which the maverick artists just named were not concerned. These disciplines see generative systems as sets of abstract rules that can produce indefinitely many structures/formulae of a given type, and which--given the Church-Turing thesis (Boden 2006: 4.i.c)—can *in principle* be

implemented in a computer. The GA-community outside the bubble put this principle into practice. That is, their artmaking rests on processes generated by formal rules carried out by computers--as opposed to physical, biological, or psychological processes, or abstractions personally discovered by conscious thought.

In other words, the instances of G-art which most concern us here are those which are also instances of C-art. They are computer-generated art: CG-art, for short.

A very strict definition of CG-art would insist that *(df.) the artwork results from some computer program being left to run by itself, with zero interference from the human artist.* The artist (or a more computer-literate collaborator) writes the program, but does not interact with it during its execution. In effect, he/she can go out for lunch while the program is left to do its own thing.

Such cases do exist. Cohen's AARON program (see below) is one well-known example. Nevertheless, that definition is so strict that it may be highly misleading. Most people working in, or commenting on, generative art allow a "compromise" in the core concept, so as to include interactive art (defined below). That is such a prominent subclass of what's called generative art that, even though the taxonomy given here does not aim to capture common usage, it would be highly anomalous to exclude it.

To be sure, the definition of CG-art given above does cover most interactive art, because it insists on zero interference from "the human artist", rather than from "*any* human being, whether artist or audience". However, it would be very easy for readers to elide that distinction--which, in any case, makes a questionable assumption about authorial responsibility (see Section IV). Moreover, the overly strict definition of CG-art excludes those cases (whether inside the bubble or outside it) wherein artists rely on their intuitive judgment to make selections during an artwork's evolution.

It's preferable, therefore, to define CG-art less tidily, as art wherein *(df.) the artwork results from some computer program being left to run by itself, with minimal or zero interference from a human being.* The word "minimal", of course, is open to interpretation. It necessitates careful attention to *just what* interference goes on, and *by whom,* in any particular case.

Most of what people call "computer art" is CG-art, in this sense. Indeed, the phrases "computer art" and "generative art" are often regarded as synonyms. Notice, however, that in our terminology not all C-art is CG-art. CA-art is not, because the computer is there used as a tool subject to the artist's hands-on control--and is of no more philosophical interest than a paintbrush or a chisel.

Admittedly, the distinction between CA-art and CG-art is not always so clearcut as in the CA-examples mentioned above. For instance, a program for simulating various painting materials and styles can be run either *more* or *less* autonomously (Colton et al. 2008; Colton 2012). More, and it counts as CG-art; less, and it's better seen as CA-

art--although even so, it relies heavily on CG-processes. In general, CA-art may involve AI "agents": programs called on by the human artist to aid him/her in specific ways during the production of an artwork (Boden 1994, 2006: 13.iii.d). The more that the ongoing direction is assumed by the computerised agents, not by the human being, the closer the project is to CG-art.)

CG-art is intriguing on two counts. First, the generality and potential complexity of computer programs means that the possible space of CG-artworks is huge, indeed infinite. Moreover, most of the structures in that space will be images/music which the unaided human mind could not have generated, or even imagined--as the artists themselves admit. (CG-literature can be ignored here: unless it is heavily interactive, it is much less successful, because the relevant knowledge of language and of the world is too rich to be implemented in computers.)

A sceptic might object that much the same is true of a trumpet, or a cello: not even the most skilled stage-impressionists could mimic these instruments plausibly. In short, human artists often need help from machines. Trumpets, computers ... what's the difference? Well, one important difference has just been mentioned, namely, the generality of digital computers. In principle, these machines can (and do) offer us an entire symphony orchestra, and an infinite set of visual images and sculptural forms--indeed, an infinite range of virtual worlds. McCormack (2003: 7) goes so far as to compare this infinite space of possibilities, way beyond our comprehension, with the Kantian sublime.

The second point is even more pertinent. Whereas there's no interesting sense in which a trumpet, or a cello, can be "left to do its own thing", a computer certainly can. And it is part of the definition of CG-art that this happens. As we'll see in Section IV, this aspect of CG-art raises some tricky problems concerning concepts such as autonomy, agency, creativity, authenticity, and authorial responsibility.

Especially well-known cases of CG-art are the successive versions of AARON. This is a drawing-and-colouring program developed over the last forty years by the one-time abstract painter Cohen (1995, 2002, 2007), and exhibited at venues all around the world--including the Tate Gallery. It has shown clear progression along various aesthetic dimensions. Indeed, Cohen (p.c.) describes the 2006 version as a "world-class" colourist, whereas he himself is merely a "first-rate" colourist: "I wouldn't have had the courage to use *those* colours", he sometimes says. (At earlier stages, colouring-AARON mixed liquid dyes and used 'painting blocks' of five different sizes to place them on paper; a later version printed out computer-generated colours instead of using liquids, but these colours too were 'mixed' at the program's behest. And the current implementation of AARON shows the development of the images in real time, projected onto an electronic screen.)

An almost equally famous example is Emmy, a computer-musician developed over much the same period by the composer David Cope (2001, 2006). This generates music in the styles of many renowned composers, and very convincingly, too--see

Hofstadter 2001: 38f. (Nevertheless, Cope has recently abandoned it, because of the prejudiced reactions of audiences: see Section IV.)

Both of those programs were based on methods drawn from what the philosopher John Haugeland (1985) dubbed GOFAI, or Good Old-Fashioned AI (see Boden 2006: chs. 10 and 13). However, the mature Emmy also uses connectionist AI (Boden 2006: ch. 12). More recent methods for constructing CG-artworks, as remarked in Section II, include cellular automata, L-systems, and evolutionary programming--all widely used in A-Life research (Boden 2006: ch. 15).

Cellular automata are systems made up of many computational units, each following a small set (usually, the same set) of simple rules. In such systems, surprising patterns can emerge from the simple, anodyne, base. Further variations ensue if another 'level' of rules is added to the system. Examples in CG-art include the tesselated visual constructs within Paul Brown's "Sandlines" and "Infinite Permutations", and other works by Paul Brown (Whitelaw 2004: 148-153; Tofts 2005: 85f.; www.paul-brown.com).

L-systems are automatically branching structures, used by botanists to study plant form and physiology (Lindenmayer 1968; Prusinkiewicz and Lindenmayer 1990; Prusinkiewicz 2004). In the hands of CG-artists, they have led (for instance) to McCormack's "Turbulence" installation (McCormack 2004; Tofts 2005: 80ff.). This generates images of un-natural yet lifelike vegetation growing in front of one's eyes--and in response to one's actions (thus qualifying as interactive art). Another example is the use of a "swarm grammar" based on L-systems to generate structures in (simulated) 3D-space, comparable to the decentralised yet organized constructions of social insects such as termites (Jacob and von Mammen 2007).

As for evolutionary programming, this has given rise to an important sub-class of CG-art: evolutionary art, or Evo-art. Examples include Karl Sims' "Genetic Images" and "Galapogos" (Sims 1991, 2007), plus many others (Whitelaw 2004: ch. 2). In Evo-art, the artwork is not produced by a computer program that has remained unchanged since being written by the artist. Rather, the artwork is *(df.) evolved by processes of random variation and selective reproduction that affect the art-generating program itself.*

Evo-art relies on programs that include self-modifying processes called genetic algorithms. To begin, a 'population' of near-identical artworks--or, to be more precise, the mini-programs that generate them--is produced by the computer. There can be any number: 9, or 16, or even more. In aesthetic terms, these first-generation artworks are boring at best and chaotic at worst. Next, each of these first-generation programs is altered ('mutated') in one or more ways, at random. Usually, the alterations are very slight. Now, some selective procedure--the 'fitness function' (decided by the artist/programmer)—is applied to choose the most promising candidate/s for breeding the next generation. And this process goes on repeatedly, perhaps for hundreds of generations. Provided that the mutations allowed are not too

fundamental (see Section IV), what ensues is a gradual evolutionary progress towards the type of structure favoured by the artist.

Occasionally, the fitness function is fully automatic, being applied by the computer itself. (If so, there may be scores, or even hundreds, of 'siblings' in a given generation.) This is a prime example of the computer's being "left to do its own thing". More usually, the selection is done hands-on by the artist--or by some other human being: a gallery-visitor, for instance--using intuitive, and often unverbalised, criteria. (In such cases, the population-size rarely rises above 16, because people cannot 'take in' more than a limited number of patterns at once.) In other words, and for reasons touched on in Section IV, there is usually no *programmed* fitness function. In such cases, the Evo-art also counts as interactive art, or I-art (see below).

One might argue that the suggested definition of Evo-art is faulty, on the grounds that evolutionary art need not involve a computer. It's certainly true that the very earliest G-art works of the sculptor William Latham, who later became famous as a *computer* artist, were drawings generated by repeated dice-throwing and hand-sketching. At that time, he had no idea that computers might be able to do the job for him--and do it better (Todd and Latham 1992). But that is highly unusual: virtually all art that's produced by an iterative process of random variation plus selection is computer-based. Indeed, there may be no non-computerized examples besides early-Latham. (Someone might suggest Claude Monet's water-lily series: but although these showed gradual improvement by way of small changes, those changes were far from random.) Even Richard Dawkins' simple "Biomorphs", which were hugely seminal for Evo-artists, were computer-generated (Dawkins 1986: 55-74). It is therefore acceptable to define Evo-art as a sub-class of CG-art, even though this excludes the early-Latham efforts.

Another sub-class of CG-art is robot art, or R-art. By R-art, is meant *(df.) the construction of robots for artistic purposes, where robots are physical machines capable of autonomous movement and/or communication.* This (happily!) is not the place for attempting to define "artistic purposes". As for "autonomous", the word may be understood intuitively here. At some point, however, it should be considered carefully--not least, because the concept of autonomy is closely connected also with agency and creativity (see Section IV).

(This definition covers all cases of C-art wherein robots are involved. However, robots may be constructed "for artistic purposes" where the focus of aesthetic interest is not--as is usual--on the robots themselves, but on drawings done by them: see (Boden 2010b). A narrower definition, that excludes such maverick cases, would be: R-art is *(df.) the construction of robots regarded as objects of aesthetic interest, where robots are physical machines capable of autonomous movement and/or communication.)*

Clearly, not all R-art is Ele-art. Indeed, R-art covers examples built many centuries ago. A few of these ancient machines could move as a whole from one place to

another--such as Leonardo's mechanical lion that "walked vp and downe" the room, or Daedalus' mercury-filled Venus which (according to Aristotle's *De Anima)* had to be tethered to prevent it from running away. Most, however, could move only their body-parts--like the moving statues of nymphs and satyrs in the grotto fountains at St. Germain, which enthused Rene Descartes as a young man (Boden 2006: 2.ii.d), or Jacques de Vaucanson's mechanical flute-player (Boden 2006: 2.iv).

Electronic R-art is highly varied (Whitelaw 2004: ch. 4). It includes Ihnatowicz's eerily hypnotic Senster, Stelarc's thought-provoking man-robot hybrids, and Ken Goldberg's early-1990s *TeleGarden*--wherein living plants are watered by a robot that is controlled by Everyman via the Internet. (For an archive of photos and videos, see www.telegarden.org/tg/; see also Popper 2007: 379-393).

The *Telegarden* was an early example of net art, or N-art, in which *(df.) the artwork is generated on the Internet, by multiple human interactions with the computer--and indirectly with each other.* So an N-artwork is not just a computer-generated artwork that happens to be put onto the Web by its human artist--not even if it can then be modified by other people. Rather, it is one for whose very existence the Internet is an essential condition. As Thor Magnusson has put it (p.c.), the immaterial property of interconnectedness is almost an artistic material, like clay.

Artwork that was comparable, to some extent, existed forty years ago (Edmonds 1975). In 1971, Edmonds exhibited "Communications Game", an electro-mechanical system of switches and lights controlled by six people sitting at individual stations linked by wires into three "networks". And in 1972, he exhibited "Rover", a rotating sphere driven, and partly lit, by three people operating joysticks. The aim was to enable an experience of communication and cooperation to arise, despite the absence of any direct communication between participants. These examples don't fit our definition of N-art, however. Since no computer was involved, they weren't even cases of C-art. Moreover, the Internet wasn't involved either--so the "multiple" human participants were a tiny number as compared with the numbers involved in N-art today (see below). But one might call them early prototypes, or anyway precursors. Indeed, Edmonds had also experimented with a few more participants and networks (unsuccessfully: people were overwhelmed by the larger number of signals); and he already had in mind the possibility of ARPAnet connections allowing for remote, and much more numerous, interactions.

Ten years later, Ascott conceived a work (*La Plissure du Texte*) that used the ARTEX computer network as the basis for the creation of a world-wide distributed narrative, or "collective global fairy tale" (Ascott 1983). The participants (or small participant-groups) were each responsible for improvising the actions of a different character in the story: witch, princess, beast, wise old man, and so on. They were drawn from eleven cities around the world, and the system was continuously online for twelve days at the Musee d'Art Moderne's ELECTRA 1983 exhibition in Paris. (The versions at different locations actually vary, though they should be identical; for a Toronto version, see <www.normill.ca/Text/plissure.txt>.)

This was much nearer to N-art than Edmonds' 1970s examples had been. But true N-art--generated by the interactions between hundreds or even thousands of people--is significantly different again. The word "multiple" in the definition (above) needs to be interpreted generously. Although N-artworks are sometimes confined to a relatively small and/or closed group, the general spirit of the N-art enterprise encourages not only extensive interconnection but also near-unlimited openness.

The pioneering *Telegarden* remains unusual, for only relatively few examples of N-art involve robotics. Most N-art is literary, visual, or musical (Bolter 1991; Becker 1995; Ascott 2003; Greene 2004). The rarity of *robotic* N-art is hardly surprising, since a robotic installation will require constant on-the-spot monitoring--if only to receive the friendly attentions of an oil-can. Goldberg's garden, for instance, was kept in operation and exhibition for nearly a decade by a team based in Austria's Ars Electronica museum (www.ieor.berkeley.edu/~goldberg/garden/Ars/).

Whether it should really be called "Goldberg's garden" is of course debatable (see Section IV). To be sure, it was his idea in the first place. But as with all N-art (by definition), its detailed nature at any time has depended on the individual choices of many other human beings. And "many", here, really does mean many. The number of participants/artists involved in the *Telegarden* had already reached 9,000 by the end of its first year online, and has mushroomed massively since then.

Huge numbers apply also to some of the non-robotic examples. The literary instances--of which Ascott's global fairy-tale was a forerunner—are multi-authored hypertexts. They include narratives composed by many hundreds of participants, offshoots of game-playing MUDs and MOOs (Montfort 2003). Their possibility was glimpsed long ago by Vannevar Bush, whose prescient "As We May Think" (1945), originally written as early as 1937, foresaw not only hypertext but search-engines such as Google, too (Bolter 1991; Boden 2006: 10.i.h).

In the cases of R-art mentioned above, only one robot is involved. Sometimes, however, groups of interacting ("distributed") robots are constructed. Usually, such groups employ the techniques of situated robotics, wherein the machines respond directly to specific environmental cues--here, Including *the behaviour of other robots* (Boden 2006: 13.iii.b and iii.d). Occasionally, they exploit self-organizing techniques whereby the system gradually reaches an equilibrium state. (Futuristic though they may seem, both these methodologies were first used by mid-century cyberneticians: Grey Walter and Ross Ashby, respectively—Boden 2006: 4.viii.) One example of the latter type is Jane Prophet's *Net Work* installation (Bird, d'Inverno, and Prophet 2007). One might think of this as a hi-tech version of Dibbets' oscillating sticks. But instead of eighty 'isolated' sticks, placed below the surface of the sea, *Net Work* consists of 2500 floating, and intercommunicating, buoys--each of which is colour-emitting and wave-sensitive. (More accurately, it *will* consist in 2500 such buoys: it has been tested in a 3X3 miniature on the Thames, but is planned to surround the pier at Herne Bay.)

Such mutually interacting robot-groups *do not* count as interactive art on the definition (of I-art) given below, unless they are also capable of interacting with the human audience. *Net Work* does have that capability: the audience can affect it by shining torchlight on the buoys, or by remote control over the Internet. Other examples of interactive (and interacting) robot-groups include Kenneth Rinaldo's works in what he calls eco-technology. His R-art (and I-art) installation called "The Flock" comprises three wire-and-vine robotic 'arms' suspended from the ceiling, which interact with each other and with the moving/speaking human audience. Similarly, his "Autopoiesis" has fifteen robot wire-frame 'arms' distributed around the room, which sense the observer's movements and communicate with each other so as to coordinate their behaviour in various ways.

This brings us to the tenth category: interactive art. In this genre, the human audience is not a passive observer but an active participant. Audiences are never wholly passive, of course, since art-appreciation involves active psychological processes. Indeed, Duchamp (1957) went so far as to say: "The creative act is not performed by the artist alone; the spectator brings the work in contact with the external world by deciphering and interpreting its inner qualification and thus adds his contribution to the creative act". Even for Duchamp, however, the spectator's contribution concerns only the work's "inner" qualification (its role, he said, is "to determine [its] weight on the aesthetic scale"). The work's perceptible nature--or, many would say, the artwork itself--does not change as a result. In interactive art, by contrast, it does.

In I-art, then, *(df.) the form/content of the artwork is significantly affected by the behaviour of the audience.* And in CI-art (i.e. the computer-based varieties), *(df.) the form/content of some CG-artwork is significantly affected by the behaviour of the audience.* Again, I am speaking intuitively here: worries about just what counts as "the artwork" are left to the next Section. The word "significantly" is needed, even though it is a hostage to interpretative fortune, so as to exclude performance art--for performance is usually subtly affected by audience reception. As for the word "behaviour", this must be interpreted with generosity. In CI-art it covers voluntary actions (such as waving, walking, touching the computer screen, and choosing a plot-line within a story), largely automatic yet controllable actions (such as the direction of eye-gaze), and involuntary bodily movements (such as breathing). It even includes arcane physical factors such as the radiation of body-heat.

(Occasionally, the 'interaction' involves not the audience but the physical environment: aspects of the weather, for example, or wave movements. Some installations in city squares respond to the ambient temperature and rainfall, a gentle drizzle causing changes different from those seen in a downpour; others focus on the changing patterns caused by waves on the sea. Strictly speaking, such cases fall outside CI-art as it is defined here, unless--which is usually the case—they *also* involve interaction with the human audience.)

CI-art is generative art *by definition.* But it is not "generative" in our strictest sense (above), as AARON is. For although the artist can go to lunch and leave the program to do its own thing, the audience cannot. However, it qualifies as CG-art in the broader sense, since the artist has handed over control of the final form of the artwork to the computer, in interaction with some other human being. The degree of control attributable to the audience varies: they may not realise that they are affecting the artwork, nor (if they do) just what behaviour leads to just which changes. We'll see later that this variability is an important dimension in the aesthetics of CI-art.

I-art is not an entirely recent phenomenon: remember Haydn's dice-music, for instance. But it became prominent in the mid-twentieth century. (This was often justified in political terms: I-art was seen as offering valuable *human-human* communication, in societies where the sense of community had been diluted--Bishop 2006.) It was made possible largely by cyberneticians such as Pask applying their theory of communicative feedback to art, and by the new electronic technology developed in World War II.

That's not to say that all these I-art efforts were examples of Ele-art. Many artists, indeed, eschewed such technology for (counter-cultural) ideological reasons: it was too strongly linked with the military-industrial complex. Even Ascott's first I-art had nary an electron in sight: it consisted of canvases with items/images on them that could be continually moved around by hand, so that the viewer of the resulting collages was their *maker* too (Mason 2008: 54-58). SAM and the Senster were early examples of I-art that did use electronics. But, as we have seen, they did not involve computers.

Today's I-art, however, is overwhelmingly computer-based. That's because the *generality* of digital computers enables them, in principle, to support an infinite variety of human-computer interactions.

The types of interaction explored in CI-art are already widely diverse--hence the inclusiveness of the term "behaviour" in the definition, above. The by-now-countless examples range from interactive CD-Roms viewed on a desk-top and altered (for instance) by touching the screen (Leggett and Michael 1996), to room-sized video or VR installations--such as Christa Sommerer and Laurent Mignonneau's "Trans Plant". In this case, a jungle gradually appears on the walls as the audience moves around the enclosure: grass grows when the viewer walks, and trees and bushes when he/she stands still; the plants' size, colour, and shape depend on the size and bodily attitudes of the human being; and the colour density changes as the person's body moves slightly backwards or forwards. "Trans Plant" is driven by the viewer's movements, but some CI-artworks are modified also, or instead, by the sound of human voices or footsteps. This is reminiscent of the Senster—but these computer-generated changes are much more varied and complex than those which could be engineered in the 1960s by Ihnatowicz.

Sometimes, the relevant interactions involve on-line access to the Internet. This is true of N-art in general, of course, wherein the artwork itself exists only by means of the Internet. But it is also true of cases where the artwork being shown/generated on the walls of a gallery is enhanced by the automatic incorporation of items that happen to be present on the world-wide-web at that particular moment. One example is "The Living Room", another installation built by Sommerer and Mignonneau. Unlike "Trans Plant", this CI-artwork does not undergo changes that depend systematically on what the viewer is doing. Instead, random images and sounds, picked up from the Internet, appear in the room as a result of the viewer's movements and speech.

It's usual, as in that example, for the change in the CI-artwork (whether systematic or not) to be near-simultaneous with the observer's triggering activity. In Edmonds' most recent CI-art, however (which was included within the 2007 Washington exhibition commemmorating the ColorField painters), the effects of the viewer's behaviour are delayed in time. Partly because of the lesser likelihood that the viewer will realise--and be able to control—what is going on, Edmonds speaks of "influence" rather than "interaction" in these cases. As we'll see in Section IV, whether mere "influence" can be aesthetically satisfying is controversial even *outside* the precious bubble.

Certainly, mere influence, as against instantaneous interaction, would not be enough for the nest category, namely Virtual Reality or VR-art. VR-art is the most advanced version of CI-art (for examples, see Popper 2007: chs. 4-6). Already foreseen in the mid-1960s, by Ivan Sutherland (1965), it was not technologically possible until the late-1980s (Boden 2006: 13.vi).

In VR-art, interaction leads to illusion--of an especially compelling kind. In other words, *(df.) the observer is immersed in a computer-generated virtual world, experiencing it and responding to it as if it were real.* One cannot pretend that this definition is clear: just what is it for someone to experience/respond "as if it were real"? Some relevant issues will be indicated in Section IV. Meanwhile, let's continue to rely on an intuitive understanding of such language.

Someone might want to argue that VR-art was initiated centuries ago. For pseudo-realistic mimetic worlds have been depicted in various forms of *trompe l'oeuil* (including 'realistic' panoramas) for many centuries, and even appeared in some of the wall-paintings and architecture of Classical Rome. But there's a crucial difference between the relevant aesthetics in times ancient and modern. As Oliver Grau (2003: 16) has pointed out, the "moment of aesthetic pleasure" in *trompe l'oeuil* comes when the viewer consciously realizes that they are *not* experiencing reality. In VR-art, by contrast, the enjoyment lies in feeling as though one is really inhabiting, and manipulating, an alternative world. The longer the awareness of its unreality can be delayed, the better. In other words, the experience of past forms of mimetic art was based only on illusion, not on immersion. Although one can say that the viewers were invited/deceived into responding to the art *as if* it were real, that "as if" was much less

richly textured, much less sustained, and therefore much less persuasive, than it is now.

(Cinema is a half-way house--Grau 2003: ch. 4. It often elicits an emotional/narrative 'immersion' in the filmgoer, and sometimes--using special screens and techniques--leads to near-veridical experiences of inhabiting the cinematic world. These tend to exploit our reflex bodily responses to visual images that suggest falling, or imminent collision: so roller-coasters, white-water-rafting, and tigers leaping towards us out of the screen are familiar favourites. But there's little psychological subtlety in this 'inhabitation', and no detailed interaction with the alternate world--still less, any physical manipulation of it.)

In general, VR-art aims to make the participants (often called "immersants") feel as though they are personally present in the cyberworld concerned. Normally, this world is visual or audio-visual, being presented on a VDU screen or projected onto the walls/floor of a real-world room. (McCormack's "Universal Zoologies" VR-artwork is an exception: here, the images/sounds are projected onto two large 'talking heads', in an attempt to provide a realistic illusion of human conversation--Tofts 2005: 81f.) But sometimes, VR-art leads also to convincing experiences of touch, pressure, and motion by providing the observer with special gloves and other equipment (Boden 2006: 13.vi). Sometimes, too, the observer experiences utterly *unreal* capacities, such as being able to fly or to activate highly unnatural causal chains within the virtual world.

Even when the viewer is not presented with such shockingly unfamiliar experiences as those, something about the virtual world will be perceptibly *unlike* the real world. And this is deliberate. For VR-artists are not aiming to achieve a fully detailed mimesis: what would be the point of that? Rather, they use near-mimesis to cast some aesthetically/conceptually interesting light on our usual experiences and assumptions.

Detailed mimesis may be appropriate for other purposes, of course. For instance, a VR-brain used in training neurosurgeons provides nicely realistic sensations of touch and vision when the trainee's virtualized surgical tool prods, pinches, or cuts different parts of it (Wang et al. 2007). Given that brains are very soft (compared with hearts, for example), the visual/haptic information at issue here is highly complex. So each of the different types of "touching" (prodding, pinching, cutting) has its own distinctive material and perceptual effects. Such highly realistic effects would be appropriate in an *artistic* VR-work only if they prompted thoughts about matters beyond the practical exigencies of brain surgery--the physical vulnerability of all human flesh, perhaps, and (by extension) of human plans.

The final category is live-coding, or LC-art. This is a new type of CG-art, dating from the turn of the century (Collins et al. 2003). In LC-art, *(df.) the form/content of some computer-generated artwork is affected by coding being done live by the artist at the time of presentation.* The "artist" may in fact be two or more *artists.* If so, they may

concentrate and/or alternate on different aspects of the music, and cooperatively undertake distinct coding tasks.

Since this is happening in real time, LC-artists don't have the luxury of writing lengthy instructions, nicely constructed to achieve highly specific results. Instead, they must rely on special programming tricks (e.g. short-cuts) and strategies. A number of criteria have been suggested for choosing/writing generative processes suitable for use in LC-practice. According to one account, the processes should be: "succinct and quick to type; widely applicable to a variety of musical [or other artistic] circumstances; computationally efficient allowing real-time evaluation; responsive and adaptive by minimising future commitments; and modifiable through the exposure of appropriate parameters" (Brown and Sorenson 2009: 17). The last of these means that the mini-algorithms for repeating a phrase, or changing an instrument, or ... should not be written in a highly condensed (and ordinarily more efficient) way, but in a more "descriptive" fashion, so that the relevant code-items can be easily accessed and altered. Even so, the coded descriptions must not be too full: only *mini*--algorithms can be satisfactorily dealt with on the fly.

Clearly, LC-art involves intensive interaction between human and computer. And one publicly available LC-tool is therefore described by its author as an "interactive" programming environment for music-making (Sorenson 2005). Nevertheless, LC-art is *not* an example of CI-art, as defined above. Within this taxonomy, CI-art involves interaction between the computer and the human *audience*--where the latter need not even know what effect, if any, they are having (automatically) on the computer's behaviour. In LC-art, by contrast, both the base program and the live coding are directly attributable to the artist, not to the audience. Even if the live coding were to be influenced by the audience's response (or, as sometimes happens, by the behaviour of cooperating live-coders), that influence would have been consciously selected and deliberately transmitted by the human performer.

Although LC-art is not CI-art, the audience is invited to be engaged rather more actively than it is in most (non-CI) cases of computer art. For the LC-artist's intention is not only to produce an interesting artwork, but also to allow people to experience it developing moment by moment as a result of the coding being done before their eyes. Ideally, then, the audience don't merely recognize that there are two sets of changes going on simultaneously: one in the artwork, and one on the screen displaying the code that's being written. Nor do they merely appreciate that changes in the code are correlated with, and presumably cause, changes in the artwork. Rather, they understand why it is that *this* perceptible change happens when *that* line of code is written. Ideally, too, the LC-artist takes pains to enable this structural matching to happen--for instance, by using a programming language that is exceptionally easy for non-specialists to understand.

Typically, the "perceptible change" in the artwork is an auditory one. In other words, LC-art is overwhelmingly concerned with music. The base (compare: the canvas) is a piece of music being generated at the time by the background computer

program. But the live coding causes temporary changes and/or additions to the pre-existing generative rules. So it is a kind of improvisation, or meta-improvisation, on the CG-base.

Specific sounds can be triggered directly, if desired. But it is much more efficient for the new code to represent new generative rules, which will be automatically followed by the developing CG-program until they are modified or negated by some future coding episode. Some of the musical changes that are effected by the coding include: changing speeds; changing volumes; adding or changing instruments; and adding or changing a melody. As this list suggests, some code-fragments produce an ephemeral change, whereas others produce a change that persists for an appreciable time--possibly, until the end of that entire presentation.

The listeners are assumed to be musically experienced. If they were not, they could not recognize the musical changes going on, still less match them up with specific lines of code. At present, the type of musical experience that's most relevant is not familiarity with Bach or Chopin but with electronic music of various kinds. The reason is that most LC-musicians (of whom there are still relatively few) have their roots--and find their most appreciative audiences--in the electronic music community. In principle, however, any musical genre can be approached by live coding.

The "listeners", of course, are also "viewers" (of the screen displaying the newly-added code). Hearing and vision must work in tandem in experiencing LC-music. Rarely, LC-art also involves graphics; for instance, the LC-duo Called *aa-cell* sometimes generate visual images alongside their music. In principle, LC-art could deal also with visible changes in the real world--such as the choreographed movements of robots (thus counting as a form of R-art). It might even involve changes in verbal text: a form of concrete poetry, perhaps, being constructed before one's very eyes. The problem with all those (mostly unrealized) possibilities is that vision would be needed for perceiving both sets of changes--in the code, and in the artwork. Only if the changes were made extremely slowly would it be feasible to compare two sets of (very different) simultaneously changing structures. Text would be especially challenging, because mental effort would also be required to interpret the words being displayed.

In sum, the thirteen definitions in this taxonomy are as follows:

(1) Ele-art involves electrical engineering and/or electronic technology.
(2) C-art uses computers as part of the art-making process.
(3) D-art uses digital electronic technology of some sort.
(4) CA-art uses the computer as an aid (in principle, non-essential) in the art-making process.
(5) G-art works are generated, at least in part, by some process that is not under the artist's direct control.
(6) CG-art is produced by leaving a computer program to run by itself, with minimal or zero interference from a human being.

NB: The stricter definition of CG-art (art produced by a program left to run by itself, with *Zero* interference from the human artist) was deliberately rejected, as explained above.

(7) Evo-art is evolved by processes of random variation and selective reproduction that affect the art-generating program itself.
(8) R-art is the construction of robots for artistic purposes, where robots are physical machines capable of autonomous movement and/or communication.

NB: Cases of C-art that use robots, but where the artistic focus is not on the robots themselves, would be excluded by defining R-art, instead, as the construction of robots regarded as objects of aesthetic interest.

(9) N-art is the generation of artworks on the Internet, by multiple human interactions with the computer--and indirectly with each other.
(10) In I-art, the form/content of the artwork is significantly affected by the behaviour of the audience (or, sometimes, by purely physical causes)
(11) In CI-art, the form/content of some CG-artwork is significantly affected by the behaviour of the audience.
(12) In VR-art, the observer is immersed in a computer-generated virtual world, experiencing it and responding to it as if it were real.
(13) In LC-art, the form/content of some computer-generated artwork is affected by coding being done live by the artist at the time of presentation.

IV: Questions for Philosophical Aesthetics

Various aesthetic and/or philosophical problems arise with respect to CG-art in general, and others with respect to particular varieties of it. None of these can be explored at length here. (For fuller discussions, see: Boden 1999, 2004, 2006: 13.iii.d-e and 16.viii.c, 2007(a,b), 2010(a,b); Cornock and Edmonds 1973; Costello and Edmonds 2007; Edmonds 2006, 2007; Muller, Edmonds, and Connell 2006.) Instead, this Section merely indicates the wide range of puzzles that attend the consideration of generative art.

One obvious question can be put like this: Is it really the case that a computer can ever *do its own thing?* Or is it always doing the programmer's (artist's) thing, however indirectly?

To answer that question seriously requires both general philosophical argument and attention to specific aspects of particular CG-art examples—in the underlying program, as well as in the observable artwork. That sort of attention is not appropriate in cases of G-art that are not computer-based. For the physical, psychological, or biological processes in which they are grounded are not specifiable in detail--not even by scientists, let alone by artists. Computer programs, in contrast, are so specifiable.

That's why one can make sensible comparisons between the extent to which different CG-art programs are or are not "under the artist's direct control", and the extent to which, and the points at which, they are subject to "interference from a human being". However, one can do this only if one knows something about how the program and/or installation works. Merely observing, or even participating in, the resultant artwork is not enough.

Whether it *appears* to participants that the program/installation is independent, or autonomous, is of course another question--one which may not be easy to answer, in practice.

Even the programmer may be misled, here. In the longer paper on which this one is based (Boden and Edmonds 2009), Edmonds pointed out that step-by-step programming (i.e. writing a program as a sequence of explicit instructions) "feels" more directive than rule-based programming (i.e. defining a set of constraints--for instance, that "Z should always be bigger than Y", or "X must never equal W"--that the computer must follow, without stating how this will be effected by the machine). In the latter case, one might say that the artist leaves the computer to do its own thing without knowing *just what it is* that the computer will be doing. The computer-art community usually regards it as important that the artwork is generated from a set of rules, or constraints, rather than from a step-by-step algorithm. But this is more a matter of taste than anything else. For even when a programmer has written explicit step-by-step code, he or she does not necessarily--or even usually--know the outcome.

If they did, there would be no bugs (except those due to typing mistakes and punctuation errors). Despite the difference
between the "feel" of the two programming approaches, there is no distinction at the most fundamental level: in all but the very simplest cases, both types of program are unpredictable by their programmer. Rule-driven systems merely *appear* to have a greater degree of autonomy, relative to the conscious decisions of the human artist.

Autonomy, of course, is a concept that's closely connected with art-making in general. (John Ruskin, for example, made much of it in his theory of aesthetics.) But does it ever make sense to ascribe autonomy to a computer?

If so, how much? Irrespective of the artist's phenomenology while writing the program, and/or of the participants' phenomenology when experiencing it, do some categories of CG-art have more autonomy than others? What of Evo-art, for instance: does the self-modification involved, and the automatic selection (in cases where that happens), mean that evo-programs are more autonomous than (say) AARON? With respect to AARON, can we ascribe at least a minimal level of autonomy to the computer, given that Cohen has no hands-on control over what picture will be drawn, or how?

Insofar as a program is "doing its own thing", does it take on the *authorial responsibility?* (Let us ignore the fact that "authorial responsibility" is often unclear here anyway, since most CG-art is produced by a team, not a lone artist.)

For instance, did AARON generate those magnificent "world-class" coloured drawings, or did Cohen do so? He admits, after all, that he himself "wouldn't have had the courage to use *Those* colours". On the other hand, he says he is happy that there will be more of "his" original artworks appearing well after his death (Cohen 2002). Is he right, or is he deluded? The answer will depend not only on one's philosophy of the self but also on one's views as to whether any computer program can be seen as an author/artist. Douglas Hofstadter, for example, interprets "the self" in such a way that he would be content to ascribe the posthumous works to Cohen himself--and would even deny that they are in the fullest sense *posthumous* (Hofstadter 2007). However, if he was emotionally moved by them, he would also resist ascribing authorship to the computer (Hofstadter 2001).

Does Evo-art leave more room, or less, for human authorship than AARON does? That is, does the artist's choice of fitness function suffice to give him/her the authorial credit for whatever artwork emerges after many generations of random (i.e. undirected) change? Is the credit greater, or less, if instead of relying on a programmed fitness function the artist does the selecting 'by hand'?

One reason for the Evo-artist's choosing to do the selection by hand is in order to produce only works *in his/her own style.* This is also the reason why the mutations that are allowed are usually very slight. For an artistic style is a sustained pattern of activity, lasting over time (Boden 2010b). In Evo-art that allows radical mutations

(and which does not 'ration' them to once every 2,000th generation, for instance), no pattern can be sustained for long--not even if the human artist is trying to shape the results by making the 'fitness' selection at each stage. On the contrary, huge structural changes can occur in a single generation (cf. Sims 1991). This leads to fascinated amazement on the part of the gallery audience. Nevertheless, Evo-artists do not normally allow such mutations. They prefer to explore a stylistic space which, despite many surprising variations, remains recognizable as 'theirs' to someone with an experienced eye. In other words, they are primarily engaged in *exploratory* creativity, not transformational creativity (Boden 2004).

There are some exceptions. The CG-artist Paul Brown recently instigated an Evo-art project whose aim was to evolve robots that will make aesthetically acceptable drawings which *do not* carry Brown's general style, or 'personal signature' (Bird et al. 2006). Thus far, his hope hasn't been satisfied. And perhaps that's not surprising: Brown, after all, was setting the fitness functions at all stages of the work. It's not clear whether it's in principle possible for his artistic mark to be lost as this project proceeds, nor whether the robots might be able to develop a 'personal' signature of their own (Boden 2010b).

This example raises questions also about the relation between CG-art and *embodiment.* Many philosophers of mind discount AI/A-Life in general (as models of mind or life) for being concerned with virtual, body-less, systems. However, these R/Evo-art creatures are robots moving in the real world, and are therefore subject to physical forces. It's known that truly fundamental changes--i.e. new types of sensory receptor--can evolve in robots as a result of unsuspected physical contingencies (Bird and Layzell 2002). (Compare the biological evolution not of a primitive eye into a better eye, but of a light-sensor where no such sensor existed before.) In principle, then, a fundamentally new style [sic] might develop in this way, whereas (arguably) that could not happen in a purely virtual, programmed, system.

Similar puzzles about authorial responsibility arise in CI-art in general, of which 'hand-selected' Evo-art is a special case. Just where, in the man-machine system concerned, is the true author?

That worry affects all I-art, of course--but is there any extra difficulty where CI-art is concerned? (For present purposes, let us ignore Duchamp's suggestion, quoted above, that *all* art is multi-authored.) And what difference, if any, does it make if—as sometimes happens (see Chapter 9)--the audience provides feedback during the construction of the CI-work, so that its final form depends not only on the decisions of the artist but also on the reactions of the audience/s who encountered it in its prototype stage? Perhaps the distinction between "decisions" and "reactions" is crucial here, debarring the audience from earning any 'extra' authorial credit in such cases?

To speak of a "worry" here, however, is perhaps to counteract what CI-artists are trying to do. Despite its sturdy roots in cybernetics and computer technology, CI-art

has attracted favourable notice from post-modernists precisely because of the ambiguity of authorship involved. The pioneering Ascott (2003), in particular, has always seen the value of CI-art as its democratising ability to engage the viewer/participant *as creator.* In his words, "creativity is shared, authorship is distributed..." (1990: 238). If authorship is deliberately distributed, then to worry about its locus (about ascribing the status of *author*) is to miss the point.

(For all the heady talk of creative participation, some CI-art is fairly limiting: Kahn 1996. That's so, for instance, where the possible changes in the artwork are explicitly pre-set by the artist, as opposed to their emerging from the program's "doing its own thing". The limitation is especially great where they are selected by the participant's choosing from a Menu.)

Another way of putting questions about authorial responsibility is to ask where the *Creativity* lies. But what, exactly, do we mean by creativity?

It certainly involves *agency*--which is why considerations of autonomy and authorial responsibility are inevitable. But what is agency? The interacting 'arms' and floating buoys identified above as examples of R-art are typically described by the artists and technicians concerned as agents--a word borrowed from AI/A-Life research on distributed cognition. But does that research misuse the concept? Even if it does, does it include 'agents' of interestingly different types (Boden 2006: 13.iii.d-e), some of which are more deserving of the name than others? If so, should we at least reserve the term--and the ascription of creativity--for those cases of CG-art where the agents involved are of the more plausible variety? Again, such questions cannot be answered without careful attention to the details of the programs and communications involved.

It's commonly assumed that creativity--and art, too—involves *unpredictability.* But what is its source? Is it merely lack of computational power on the part of human minds? We have seen that CG-art, like complex programs in general, is indeed unpredictable for that reason. But CI-art and Evo-art are unpredictable for other reasons as well. CI-art, because the artist cannot predict the sequence of interactions that will take place, even if he/she can predict what would happen at a given moment if *that* audience-movement were to occur; and Evo-art, because of the many *random* changes to the program, and because of the choices made at successive generations by the artist. Does the unpredictability of traditional art have any deeper source? And if so, is this something which cannot be ascribed to, or even simulated in, computers? Answering these questions requires one to distinguish different types of unpredictability very carefully (see Boden 2004: ch. 9).

Another set of questions concerns *ontology,*
namely what counts as the *artwork.* How can e identify "the artwork" when an artist's computer program generates countless unique images, or musical compositions, none of which have been

seen/heard by the artist? Is each image/music pro uced by AARON or Emmy an artwork--or is the artwork the program which generates them? In Evo-art, does one and the same artwork exist at differing levels of sophistication at different generations? Or does every generation produce a new artwork--or, perhaps, a new population of (sibling) artworks?

What counts as the artwork when the uniqueness is due not only to a richly generative computer program but also to the contingent (and ephemeral) behaviour of a participatory human audience? Perhaps the familiar concept of artwork is well-suited only to the unchanging artefacts that form the overwhelming majority of the cases *inside* McCormack's bubble?

A traditional artist can fully comprehend the painting or sculpture that they have executed so carefully (although whether this applies to the G-art dimension of Pollock's paintings is questionable), but CI-artists cannot fully know the CI-artwork that they constructed with equal care. This is not merely a matter of the unpredictability of detail: in sufficiently complex cases, it's not even clear that they can recognize the general potential of their own work. With regard to CI-art, then, perhaps we should speak not of the "artwork" but of the "art system"--where this comprises the artist, the program, the technological installation (and its observable results), and the behaviour of the human audience? (And perhaps, if the concept of the "artwork" falls, then that of the "artist/author" falls too?)

Or maybe we should think of each occurrence of CI-art as a performance, and the program/installation as the score? If so, then philosophical discussion of what counts as an artwork in music is pertinent (e.g. Goodman 1968). But the 'performance' is more like a jazz improvisation than the playing of classical music, for it can vary considerably from one occasion to another. Even if the form of each particular human-computer interaction can be completely determined by the artist (which is not so, for instance, when the computer's response can be modified by its memory of the history of previous interactions), the *sequence* of such events cannot.

Yet another problematic area concerns *aesthetic evaluation.* Are entirely novel aesthetic considerations relevant for CG-art in general, or for some subclass of it? And are some aesthetic criteria, normally regarded as essential, utterly out of place in CG-art: authenticity, for instance?

The devotees of CI-art, in fact, do not use the familiar (inside-the-bubble) criteria to judge different interactive installations. Or insofar as they do, these are secondary to other considerations (Boden 2010a). The criteria they see as most appropriate concern not the nature of the resulting 'artwork' (the beauty of the image projected on the wall, for example, or the melody and harmoniousness of the accompanying sounds), but the nature of the interaction itself. There's general agreement on that point. But there's significant disagreement on just what type of interaction is the most aesthetically valuable.

Some CI-artists, especially those engaged in VR-art, stress the disturbing sense of unreality involved, and the participant's new 'take' on everyday experience that ensues. Many value the participant's conscious control of the artwork; others aim to highlight their sense of personal embodiment; while yet others stress the audience's disconcerting experience of unpredictability triggered by their own actions. All of those criteria concern the participant's *experience*--but difficulties arise if one asks how that experience can be discerned, or 'logged', by anyone other than the individual participant. (As remarked in Section III, if the observers can never come to realize that they are affecting what happens, then the "I" in "CI-art" might better be thought of as the initial letter of "influence", not of "interaction".)

There are some especially jagged philosophical rocks lying in wait for VR-artists. The concept of virtual reality has been defined in various ways (Steuer 1992). Most, like the definition of VR-art given in Section III, refer to the participant's experience of being immersed in a real world, and reacting accordingly. This notion seems to be intuitively intelligible, especially if one has actually encountered a VR-installation. But just what it means, whether in psychological or philosophical terms, is very difficult to say.

It's not even clear that it is coherent (Boden 2006: 16.viii.c). Several leading philosophers of mind have addressed this hornet's nest of questions in writing about the film *The Matrix* (see especially the papers by Hubert Dreyfus and Andy Clark on the Warner Brothers website: http://whatisthematrix.warnerbros.com). That's not to say that *The Matrix* counts as VR-art, for it does not. Nevertheless, it raises some of the same questions that would attend highly plausible instances of VR-art. (Whether these would also be highly successful instances is another matter: we have seen that VR in art, as opposed to science or surgery, typically highlights some *unreal* dimension of the experience.)

As for *authenticity,* this is a tricky concept. There are several reasons, of varying plausibility, why someone might argue that it is not applicable to any instance of CG-art (Boden 2007a). And CG-artists have suffered as a result.

For example, Cope (2006) has been continually disappointed by people's failure to take his music seriously--not because they dislike it on hearing it (sometimes they *refuse* to hear it), but simply because it is computer-generated. Even when they do praise it, he has found that they typically see it less as "music" than as "computer output"--a classification which compromises its authenticity. For instance, even though each Emmy-composition is in fact unique, people know that the program could spew out indefinitely many more tomorrow. (The fact that human composers die, says Cope, has consequences for aesthetic valuation: someone's oeuvre is valued in part because it is a unique set of works, now closed.) As a result of this common reaction, Cope has recently destroyed the data-base of dead composers' music that he had built up over the last twenty-five years, and used as a crucial source in Emmy's functioning. (Emmy's successor will compose music only in Cope's own style; whether audiences regard this as being significantly more authentic remains to be seen.)

Finally, what of the claims made by many CG-artists to be exploring the nature of *life?* It's clear from Rinaldo's choice of the titles "Autopoiesis" and "The Flock" (plus the rest of his oeuvre--Whitelaw 2004: 109-116), for instance, that his R-art works are not intended as mere fairground toys but as meditations on significant aspects of life. He's not alone in this: many of the CG-artists who have been influenced by A-Life see their work in that way. Concepts such as emergence and self-organization, and of course evolution, crop up repeatedly in their writings and interviews--as does the key concept of life itself.

One may well agree that their work throws light on, or anyway reminds us of, important--and puzzling--properties of life. But one need not also agree with the claim sometimes made by these CG-artists, that purely *virtual* life (a.k.a. strong A-Life) is possible--and that their work, or something similar, might even create it. Indeed, one should not accept those claims, because physical metabolism (which is much more than mere energy-dependency) is essential for life but is denied to computers (Boden 1999).

Perhaps the most obvious philosophical question of all is this: "Yes, it can help to while away a Sunday afternoon--*but is it art, really?"*

Whatever "art" may be (a topic on which gallons of ink have been spilled), many people feel that computers are the very antithesis of it. Indeed, some philosophers argue this position explicitly (e.g. O'Hear 1995). On their view, art involves the expression and communication of human experience, so that if we did decide that it is *the computer* that is generating the 'artwork', then it cannot be an *art* work after all--no matter how decorative, or even beautiful, it may be.

A closely related worry concerns emotion in particular: if computers are not emotional creatures then--on this view—they cannot generate anything that's properly termed "art" (Hofstadter: 2001). Another common way of discrediting computer art in general is to argue that art involves creativity, and that no computer--irrespective of its observable performance—can *really* be creative (for a discussion, see Boden 2004: ch. 11). Furthermore, a person's aesthetic approval of an artwork is sometimes instantly renounced on their discovering that it is, in fact, a CG-artwork. Cope was so disturbed by this reaction, as we've seen, that he destroyed the data-base on which Emmy's--or should one rather say "his"?--CG-music rested.

Despite these (fairly common) views on the relation--or lack of it--between art and computers, there are undeniable continuities between CG-art and non-computer art. Several of these were mentioned in Section III, which showed that some of the twelve taxonomic categories include examples drawn from both inside and outside McCormack's precious bubble. And those categories which apply only to CG-art cover many individual cases that are aesthetically related to traditional artworks.

Moreover, the art world itself--however suspicious it may be of computers in general, and however dismissive it may be of particular CG-art efforts--does sometimes award these new activities the coveted status of art. Sometimes, this happens in a specialised corner of the art world: for instance, London's *Kinetica* gallery (opened in 2006), which is devoted to interactive, robotic, and kinetic art. But there are also cases where major 'traditional' galleries clearly accept that traditional and CG-art are players in the same cultural ballpark.

Two such instances were mentioned above: the Tate's one-man show of Cohen's AARON, and the Washington exhibition featuring Edmonds' work as a development of that of the ColorField painters (Mark Rothko, and the like). The latter example is especially telling, precisely because it was not a show celebrating only CG-art. On the contrary, this 60th-anniversary exhibition was putting CG-art alongside the precious bubble--or even inside it. In reply to the sceptical challenge "But is it art,. *really?*",what more persuasive answer could there be?

References:

Ascott, R. (1966/1967), 'Behaviourist Art and the Cybernetic Vision', *Cybernetica,* 9 (1966), 247-264; and 10 (1967), 25-56. Reprinted as ch. 3 of Ascott 2003: 109-156.

Ascott, R. (1983), *La Plissure du Texte*.
http://alien.mur.at/rx/ARTEX/PLISSURE/plissure.html

Ascott, R. (1990), 'Is There Love in the Telematic Embrace?', *Art Journal* (College Arts Association of America), 49: 241-247. Reprinted as ch. 15 of Ascott 2003: 232-246.

Ascott, R. (1998/2003), 'Technoetic Aesthetics: 100 Terms and Definitions for the Post-Biological Era', in Ascott 2003: 375-382. First published in Japanese, trans. E. Fujihara, in R. Ascott, *Art and Telematics: Toward the Construction of a New Aesthetics*, (Tokyo: NTT Publishing Co.), 1998.

Ascott, R. (2003), *Telematic Embrace: Visionary Theories of Art, Technology, and Consciousness* (London: University of California Press).

Becker, H. S. (1986), *Doing Things Together: Selected Papers* (Evanston, Illinois: Northwestern University Press).

Becker, H. S. (1995) 'A New Art Form: Hypertext Fiction'. Online in M.Bernstein (ed.), *How to Read a Hypertext* (Cambridge, Mass.: Eastgate Systems), and on Becker's home page.

Bird, J., d'Inverno, M., and Prophet, J. (2007), *'Net Work:* An Interactive Artwork Designed Using an Interdisciplinary Performative Approach', *Digital Creativity*, 18(1): 11-23.

Bird, J., and Layzell, P. (2002), 'The Evolved Radio and its Implications for Modelling the Evolution of Novel Sensors', *Proceedings of Congress on Evolutionary Computation,* CEC-2002, 1836-1841.

Bird, J., Stokes, D., Husbands, P., Brown, P., and Bigge, B. (forthcoming), 'Towards Autonomous Artworks', *Leonardo Electronic Almanac*. (Available from jonba@sussex.ac.uk.)

Bishop, C. (2006), *Participation* (Cambridge, Mass.: MIT Press).

Boden, M. A. (1994), 'Agents and Creativity', *Communications of the Association for Computing Machinery: Special Issue on Agents* (ed. D. Riecken), July 27th: 117-121. Reprinted in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press, 2010), ch. 8.

Boden, M. A. (1999), 'Is Metabolism Necessary?',

British Journal for the Philosophy of Science, 50: 231-248. Reprinted in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press, 2010), ch. 12.

Boden, M. A. (2004), *The Creative Mind: Myths and Mechanisms* (London: Routledge). 2nd edn., expanded/revised.

Boden, M. A. (2006), *Mind as Machine: A History of Cognitive Science* (Oxford: Clarendon/Oxford University Press).

Boden, M. A. (2007a), 'Authenticity and Computer Art', *Digital Creativity,* 18(1): 3-10. (Special Issue on Creativity, Computation, and Cognition, ed. P. Brown.) Reprinted in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press, 2010), ch. 10.

Boden, M . A. (2007b), 'Stillness as Autonomy', in S. Worden, L. Green, and P. Thomas (eds.), *Proceedings of Computers in Art and Design Education (CADE) Conference,* Stillness (Perth), September 2007. Published as a CD-ROM (ISBN 1 74067 530 4). A longer version is in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press, 2010), ch. 9.

Boden, M. A. (2010a), 'Aesthetics and Interactive Art', in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press), ch. 11..

Boden, M. A. (2010b), 'Personal Signatures and Computer Art', in M. A. Boden, *Creativity and Art: Three Roads to Surprise* (Oxford: Oxford University Press), ch. 6.

Bolter, J. D. (1991) *Writing Space: The Computer, Hypertext, and the History of Writing* (Hillsdale, NJ: Lawrence Erlbaum).

Brown, A. R., and Sorenson, A. (2009), 'Interacting with Generative Music through Live Coding,' *Contemporary Music Review*, 28(1): 17-29.

Brown, Paul. (2003), 'Generative Computation and the Arts', *Digital Creativity*, 14(1): 1-2. (Special issue on Generative Computation and the Arts, ed. P. Brown.)

Brown, Richard. (2001) *Biotica: Art, Emergence, and Artificial Life* (London: RCA CRD Research).

Brown, Richard. (2006), 'The Electrochemical Glass', *Strange Attractor Journal Three*, available from the Strange Attractor Shoppe, <http://www.strangeattractor.co.uk>

Breton, A. (1969), *Manifestoes of Surrealism* (Ann Arbor: University of Michigan Press). Trans. R. Seaver and H. R. Lane. (Includes several manifestoes, the first published in 1924.)

Burnham, J. (1968), *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of this Century* (London: Allen Lane).

Bush, V. (1945), 'As We May Think', *Atlantic Monthly*, 176 (July): 101-108. Reprinted in R. Packer and K. Jordan (eds.), *Multimedia: From Wagner to Virtual Reality* (London: W. W. Norton, 2001): 135-153.

Candy, L., and Edmonds, E. A., eds. (2002) *Explorations in Art and Technology* (London: Springer).

Cohen, H. (1995), 'The Further Exploits of AARON Painter', in S. Franchi and G. Guzeldere (eds.), *Constructions of the Mind: Artificial Intelligence and the Humanities.* Special edn. of *Stanford Humanities Review,* 4 (2): 141-160.

Cohen, H. (2002), 'A Million Millennial Medicis', in L. Candy and E. A. Edmonds (eds.), *Explorations in Art and Technology* (London: Springer): 91-104.

Cohen, H. (2007), *AARON's World: 20 de Junho--28 de Julho 2007* (Lisbon: Antonio Prates, Arte Contemporanea).

Collins, N., McLean, A., Rohrhuber, J., and Ward, A. (2003), 'Live Coding in Laptop Performance,' *Organised Sound,* 8(3): 321-330.

Colton, S. (2012), 'The Painting Fool: Stories from Building an Automated Painter', in J. McCormack and M. d'Inverno (eds.), *Computers and Creativity* (Berlin; Heidelberg: Springer): 3-38.

Colton, S., Valstar, M., and Pantic, M. (2008), 'Emotionally Aware Automated Portrait Painting', *Proceedings of the 3rd International Conference on Digital Interactive Media in Entertainment and Arts (DIMEA),* (ACM): 304-311.

Cope, D. (2001), *Virtual Music: Computer Synthesis of Musical Style* (Cambridge, Mass.: MIT Press).

Cope, D. (2006), *Computer Models of Musical Creativity* (Cambridge, Mass.: MIT Press).

Cornock, S., and Edmonds, E. A. (1973), 'The Creative Process Where the Artist is Amplified or Superceded by the Computer', *Leonardo,* 6: 11-16.

Costello, B., and Edmonds, E. A. (2007), *Playful Pleasures: A User Evaluation of Three Artworks* (University of Technology, Sydney: CCS Report 2007-1).

Dawkins, R. (1986), *The Blind Watchmaker* (Harlow: Longman).

Dorin, A., and McCormack, J. (2001), 'First Iteration/Generative Systems (Guest Editors' Introduction)', *Leonardo,* 34(3): 335.

Duchamp, M. (1957), 'The Creative Act', in M. Sanouillet and E. Peterson (eds.), *The Essential Writings of Marcel Duchamp* (London: Thames and Hudson, 1975), 138-140.

Duprat, H., and Besson, C. (1998), 'The Wonderful Caddis Worm: Sculptural Work in Collaboration with Trichoptera', *Leonardo,* 31(3): 173-182.

Edmonds, E. A. (1969) 'Independence of Rose's Axioms for m-valued Implication', *Journal of Symbolic Logic,* 34: 283-284.

Edmonds, E. A. (1975) 'Art Systems for Interactions Between Members of a Small Group of People', *Leonardo,* 8: 225-227.

Edmonds, E. A.,(1988) 'Logic and Time-based Art Practice", *Leonardo,* Electronic Art Supplemental issue (Oxford: Pergamon Press): 19-20.

Edmonds, E. A. (2003) 'Logics For Constructing Generative Art Systems'. *Digital Creativity,* 14 (1): 23-38.

Edmonds, E. A. (2006), 'New Directions in Interactive Art Collaboration', *CoDesign,* 2(4): 19-194.

Edmonds, E. A. (2007), 'Reflections on the Nature of Interaction', *CoDesign: International Journal of CoCreation in Design and the Arts,* 3(3): 139-145.

Eno, B. (1996) 'Generative Music: Evolving metaphors, in my opinion, is what artists do.' Available at: http://www.inmotionmagazine.com/eno1.html

Generativeart.com, http://www.generativeart.com/

Goodman, N. (1968), *Languages of Art: An Approach to a Theory of Symbols.* (Indianapolis: Bobbs-Merrill).

Goodstein, R. L. (1951), *Constructive Formalism, Essays on the Foundations of Mathematics* (Leicester: University College Press).

Grau, O. (2003) *Virtual Art: From Illusion to Immersion* (Cambridge, Mass.: MIT Press).

Greene, R. (2004), *Internet Art* (London: Thames and Hudson).

Haugeland, J. (1985), *Artificial Intelligence: The Very Idea* (Cambridge, Mass.: MIT Press).

Hiller, L. and Isaacson, L. (1958) 'Musical Composition with a High-Speed Digital Computer,' *Journal of the Audio-Engineering Society,* 6(3): 154-160.

Hockney, D. (2009), 'Drawing in a Painting Machine', at <www.lalouver.com/resource/hockney>. See also 'David Hockney Swaps Oils for Pixels', <timesonline.co.uk/news> March 22 2009.)

Hofstadter, D. R. (2001), 'Staring Emmy Straight in the Eye - And Doing My Best Not to Flinch', in Cope 2001: 33-82.

Hofstadter, D. R. (2007), *I Am a Strange Loop* (New York: Basic Books).

Johnson, B. S. (1969), *The Unfortunates* (London: Panther).

Kahn, D. (1996), 'What Now the Promise?', in M. Leggett and L. Michael (eds.), *Burning the Interface, Exhibition Catalogue on International Artists'* CD-Rom (Sydney: Museum of Contemporary Art), pp. 21-30.

Kowalski, T. L. and Levy, L. S. (1996), *Rule-Based Programming* (Amsterdam: Kluwer Academic).

Krueger, M. W. (1991), *Artificial Reality,* 2nd edn. (Reading, Mass.: Addison-Wesley).

Laposky, B. (1969), 'Oscillons: Electronic Abstractions', *Leonardo,* 2(4): 345-354.

Leggett, M. (2000), 'Thinking Imaging Software', *Photofile: Photomedia Journal,* 60: 28-31.

Leggett, M., and Michael, L., eds. (1996), *Burning the Interface*<International Artists' CD-Rom (Sydney: Museum of Contemporary Art).

LeWitt, S. (1967), 'Paragraphs on Conceptual Art', *Artforum,* 5(10): 79-83. Reprinted in K. Stiles and P. Selz (eds.), *Theories and Documents of Contemporary Art: A Sourcebook of Artists' Writings* (London: University of California Press), 822-826.

LeWitt, S. (1969), 'Sentences on Conceptual Art', *Art-Language*, 1: 11-13. Reprinted in (Lippard 1973), 75f., and in K. Stiles and P. Selz (eds.), *Theories and Documents of Contemporary Art: A Sourcebook of Artists' Writings* (London: University of California Press), 826-827.

Lindenmayer, A. (1968), 'Mathematical Models for Cellular Interaction in Development, Parts I and II', *Journal of Theoretical Biology,* 18: 280-315.

Lippard, L. R. (1973), *Six Years: The Dematerialization of the Art Object from 1966 to 1972* (New York: Praeger). Page-references to the 1997 reprint (London: University of California Press).

McCorduck, P. (1991), *AARON's Code: Meta-Art, Artificial Intelligence, and the Work of Harold Cohen* (New York: W. H. Freeman).

McCormack, J. (2003), 'Art and the Mirror of Nature', *Digital Creativity,* 14(1): 3-22. (Special issue on Generative Computation and the Arts, ed. Paul Brown.)

McCormack, J. (2004), *Impossible Nature: The Art of John McCormack* (Melbourne: Australian Centre for the Moving Image).

McCormack, J., Dorin, A., and Innocent, T. (2004), 'Generative Design: A Paradigm for Design Research', in J. Redmond, D. Durling, and A. de Bono (eds.), *Proceedings of Futureground I* (Melbourne: Design Research Society.

Mallen, G. (2005), 'Reflections on Gordon Pask's Adaptive Teaching Concepts and their Relevance to Modern Knowledge Systems', in L. Candy (ed.), *Creativity and Cognition 2005.* Proceedings of the Fifth Conference on Creativity and Cognition, 12-15 April, Goldsmiths College (New York: ACM Press): 86-91.

Marr, A. (2003), '"He Thought it the Deuil, Whereas Indeede it was a Meere Mathematicall Inuention": Understanding Automata in the Late Renaissance', paper given to the Workshop on the History of AI/A-Life, Stanford (October). A later version was published as: A. Marr, 'Understanding Automata in the Late Renaissance', *Journal de la Renaissance,* 2 (2004): 205-222.

Martin, K. (1951/54) 'Abstract Art', *Broadsheet No. 1: Abstract Paintings, Sculptures, Mobiles* (London: Lund Humphries, 1951), AIA exhibition catalogue; also in L. Alloway, *Nine Abstract Artists, Their Work and Their Theory: Robert Adams, Terry Frost, Adrian Heath, Anthony Hill, Roger Hilton, Kenneth Martin, Mary Martin, Victor Pasmore, William Scott* (London: Tiranti, 1954).

Mason, C. (2008), *A Computer in the Art Room: The Origins of British Computer Arts 1950-80* (Hindrigham: JJG Publishing).

Metzger, G. (1959), 'Manifesto Auto-Destructive Art', reprinted in C. Mason, *A Computer in the Art Room: The Origins of British Computer Arts 1950-80* (Hindrigham: JJG Publishing), p. 59.

Metzger, G. (1965), *Auto-Destructive Art* (London: Destruction/Creation). Expanded version of a talk at the Architectural Association, updating the manifesto of 1959.

Montfort, N. (2003), *Twisty Little Passages: An Approach to Interactive Fiction* (Cambridge, Mass.: MIT Press).

Muller, L., Edmonds, E. A., and Connell, M. (2006), 'Living Laboratories for Interactive Art', *CoDesign: International Journal for CoCreation in Design and the Arts,* 2(4): 195-207.

Nake, F.(1998), 'Art in the Time of the Artificial', *Leonardo,* 31 (3): 163-164.

Nake, F. (2005), 'Computer Art: A Personal Recollection', in L. Candy (ed.) *Creativity and Cognition 2005.* Proceedings of the Fifth Conference on Creativity and Cognition, 12-15 April, Goldsmiths College (New York: ACM Press): 54-62.

Nees, G. (1969), *Generative Computergraphik* (Berlin: Siemens AG).

O'Hear, A. (1995), 'Art and Technology: An Old Tension', in R. Fellows (ed.), *Philosophy and Technology* (Cambridge: Cambridge University Press), 143-158.

Pask, G. (1971), 'A Comment, a Case-History, and a Plan', in J. Reichardt (ed.), *Cybernetics, Art, and Ideas* (London: Studio Vista), 76-99.

Popper, F. (2007), *From Technological to Virtual Art* (Cambridge, Mass.: MIT Press).

Pinch, T., and Trocco, F. (2002) *Analog Days: The Invention and Impact of the Moog Synthesizer* (Cambridge, Mass.: Harvard University Press).

Prusinkiewicz, P. (2004), "Art and Science for Life: Designing and Growing Virtual plants with L-Systems', in C. G. Davidson and T. Fernandez (eds.), *Nursery Crops: Development, Evaluation, Production and Use.* Proceedings of the XXVI International Horticultural Congress, Acta Horticulturae, 630: 15-28.

Prusinkiewicz, P., and Lindenmayer, A. (1990), *The Algorithmic Beauty of Plants* (New York: Springer-Verlag).

Sims, K. (1991), 'Artificial Evolution for Computer Graphics', *Computer Graphics,* 25(4): 319-28. See also <http://www.genarts.com/karl/genetic-images.html>

Sims, K. (2007), 'Galapogos Interactive Exhibit' <http://www.genarts.com/galapogos/index.html>.

Smith, M. (ed.) (2005), *Stelarc: The Monograph* (Cambridge, Mass.: MIT Press).

Sorenson, A. (2005), 'Impromptu: An Interactive Programming Environment for Composition and Performance,' *Proceedings of the Australasion Computer Music Conference 2005,* Brisbane, ACMA: 149-153.

Steuer, J. (1992), 'Defining Virtual Reality: Dimensions Determining Telepresence', *Journal of Communication,* 42 (4), 73-93.

Sutherland, I. E. (1965), 'The Ultimate Display', *Proceedings of the International Federation of Information Processing* (New York), 2, 506-508 and 582-583. Washington, D.C.: Spartan books. Reprinted in R. Packer and K. Jordan (eds.), *Multimedia: From Wagner to Virtual Realit y* (London: W. W. Norton, 2001), 232-236.

Todd, S. C., and Latham, W. (1992), *Evolutionary Art and Computers* (London: Academic Press).

Tofts, D. (2003), 'Avatars of the Tortoise: Life, Longevity, and Simulation', *Digital Creativity,* 14(1): 54-63. (Special Issue on Generative Computation and the Arts, ed. Paul Brown.)

Tofts, D. (2005), *Interzone: Media Arts in Australia* (Fisherman's Bend, Victoria: Craftsman House).

Wang, P., Becker, A. A., Jones, I. A., Glover, A. T., Benford, S. D., Greenhalgh, C. M., and Vloeberghs, M. (2007), 'Virtual Reality Simulation of Surgery with Haptic Feedback Based on the Boundary Element Method', *Computers and Structures,* 85(7-8): 331-339.

Webster, A. (2006-ongoing), *Solar Stacking.* (An electrochemical sculpture.) See <http://www.andywebster.info/solar/>

Webster, A., and Bird, J. (2002), *Tuning Pask's Ear.* Video (7:26) exhibited in several galleries.

Whitelaw, M. (2004), *Metacreation: Art and Artificial Life* (London: MIT Press).

Wilson, S. (2002), *Information Arts: Intersections of Art, Science, and Technology* (Cambridge, Mass.: MIT Press).

Woolf, S. (2004), *Expanded Media: Interactive and Generative Processes in New Media Arts* Unpublished DPhil thesis, Dept. Informatics, University of Sussex.

Xenakis, I (1971), *Formalized Music: Thought and Mathematics in Composition* (Bloomington, Indiana University Press).

Zivanovic, A. (2005), 'The Development of a Cybernetic Sculptor: Edward Ihnatowicz and the Senster', in L. Candy (ed.), *Creativity and Cognition 2005.* Proceedings of the Fifth Conference on Creativity and Cognition, 12-15 April, Goldsmiths College (New York: ACM Press): 102-108.