Computer Science and Art: Then and Now[1]

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Abstract

In the second half of the 20th century, computer science entered the unsettled context of theories of art thanks to three scientists, who independently started using their computers for artistic purposes. The critiques raised by such attempts are the same as the ones moved against computer science in its beginnings, and deal with the impossibility of obtaining any original or surprising results from a computer. This work aims at investigating the relation between computer science and art to show that the actual situation is significantly different.

1. Introduction

If art is one of the oldest human activities (think of the Paleolithic paintings in the cave of Altamira in Spain, for example), computer science is much more recent: the first digital electronic computer was built by John Vincent Atanasoff in the 1930s at the Iowa State College.

In spite of its brief history, computer science has widespread in the last few decades to such an extent in so many aspects of our lives, that an encounter with art was inevitable. We can interpret such encounter in different ways: a clash between radically different disciplines, a temporary overlapping dictated by fashion and soon to be forgotten, an intersection between fields that makes us rethink some consolidated ideas and form new ones.

This work aims at shedding some light in this direction, not to provide answers, but conceptual instruments to tackle one of the freshest and most interesting debates in global culture.

2. The shaky foundations of computer science and art

To analyze how two disciplines affect each other in a proper way, we should diligently start by the fundamental concepts and their definitions to trace precisely the boundaries of the relevant contexts. We immediately bump into problems: "What is an artwork?" or "What is an algorithm?" are all but trivial questions and we may not be able to provide exhaustive answers.

This does not mean that it is impossible to study the relation between art and computer science, but surely such analysis will require that we zoom in and limit the context of our observations so that we can focus on more specific, and possibly easier, questions.

We may not solve the long-standing issues in computer science and art, but at least we will be able to have an overview on how the two disciplines are interacting in academia, in labs, and in museums all over the world.

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[1] This article is a rough translation of my work "Informatica e Arte: contraddizione, rivoluzione, evoluzione", *Mondo Digitale* n.57, April 2015.

2.1 Computer science or computational science?

You might already have noticed that some restrictions of context have already been applied in the introduction. Let us start with computer science because it is the least problematic discipline when it comes to fundamental definitions. It was somehow implied that computer science began with the first digital electronic computer, which seems to lead to the definition of computer science as the "science of digital electronic computers".

Is this a universal definition? The rigorous answer would be no because we can easily find examples of efforts that are fully fledged computer science results but do not have a direct connection with digital electronic computers: Charles Babbage's "analytical engine" was a project started in the first half of the 19th century, that is, an entirely mechanical calculator inspired by Jacquard's loom capable of the four basic arithmetic operations [1]; "Timsort" is a sorting algorithm created by Tim Peters in 2002 taking the best characteristics of two preexisting algorithms like "merge sort" and "insertion sort" [2].

These two examples clearly show how one can do computer science without electronic computers and, thus, the definition above seems to be too restrictive. It is more than legitimate then to ask what is the connection between digital electronic computers and Babbage's engine or Peters's algorithm, that is, what enables us to consider indisputably all these results as part of computer science: the factors creating such connection would be the best candidate for a general definition of the discipline.

We are speaking of the concept of computation: the analytical engine performs arithmetic operations, that is, it executes operations on numbers that yield numbers; the Timsort algorithm is a technique to sort values by means of a clever combination of comparisons between numbers; finally, digital electronic computers are comprised of circuits built in such a way that they respond to electric impulses with other impulses and such response follows the rules of arithmetic.

There is indeed a fundamental, even definitory link between computer science and computation. Let us not forget that one of the pioneers of computer science, Alan Turing, when writing about a "computer" in one of his most important works [3] meant a person who computes, just like "player" means a person who plays. In his article, Turing presents his vision on how to automatize by means of a machine what happens in the brain of a human while they are performing some computation. In the second half of the 20th century, when the pioneering efforts of Babbage, Atanasoff and Turing were followed by a number of success stories in the creation of such machines, the term "computer" lost its original meaning and acquired the one we are used to today, and the discipline dealing with computation and how to automatize it was called "computer science".[2]

Once they became aware that the name of the discipline takes the focus away from computation and puts it on the machines performing computation, a number of researchers involved in the debate on the disciplinary status of computer science put forward some renaming proposals, with the aim to stress the fundamental nature of this field, along side other hard sciences like physics and chemistry. Peter Denning, for instance, one of the most renown opinion makers in this context and de facto spokesperson for the Association for Computing Machinery (ACM), prefers the term "computing" over the usual "computer science" [5], and it is not by chance that the latest

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[2] In German and other languages like French and Italian, the term "informatik", contraction of "information" and "automatic" by German physicist Karl Steinbuch in the 1950s, took over [4].

and most complete book on the disciplinary status of this field by Matti Tedre is titled "The Science of Computing" [6].

Actually, at least when it comes to our objective, the conceptual debate on computation and computers is not particularly problematic. First of all, from an operational perspective any form of computation, even if originally conceived for a mechanical loom, can be performed on a digital electronic computer. Moreover, whether the heart of the discipline resides in the more abstract concept of computation rather than the more concrete artifacts implementing it is not critical when we analyze the relation between computer science and art because, as we see in the following, such link was born indeed when some computer scientists, mid-20th century, started making experiments with their digital computers. It was a new way to use a computer and not a new type of computation that opened the door to a possibly new kind of art that we want to deal with in this article: if we focused on the role of pure computation in art, independently from a computer, then our analysis should also include the wonderful geometrical patterns of Alhambra in Granada or the meticulous tilings of M. C. Escher, but they are out of our scope.

2.2 Art: function or institution?

Even if the debate on the disciplinary status of computer science has not reached a universally accepted result, at least the fundamental concepts such debate revolves around are not in discussion: for instance, it is true that there exist different technologies by which a computer can be built, but the characteristics that make an artifact a computer are the same and universally accepted.

The situation in the context of art is radically different: the debate on what an artwork is has been going on for centuries, and it became even more heated after the revolutionary proposals of the 20th century avant-gardes. The variety of ways in which one can perform computation (with a loom, with pencil and paper, with an electronic circuit, etc.) cannot even be compared with the width of the artistic landscape.

The impossibility of a comparison is not an exaggeration: on the side of computer science we have computers or, if one prefers, computation as the principal object of investigation, whereas on the side of art we lack any point of reference in terms of necessary and sufficient conditions that are universally accepted in the definition of a work of art. In other words: when we do computer science, we typically use a computer to perform computation; what do we do when we make art?

This question is very hard not for a lack but rather an excess of possible answers, all interesting but each failing at providing a universal definition of art. As we already said, the debate has been going on for a long time, and this article surely will not provide the definitive conclusion. A synthetic yet very effective overview is provided by Tiziana Andina [7], who helps us determine the main factors at play in the creation, presentation and fruition of objects and events when they are considered artworks: throughout the centuries several proposals have been put forward, each focusing on a particular issue.

The debate starts with Plato, according to whom art has the aim of imitating nature, which is, in turn, an imitation of the world of ideas, and goes onto more recent theories like the aesthetic theory of John Dewey [8], according to which an entity is an artwork only if it has been conceived by the author with the aim to provide the spectator with a sudden yet inexplicable sensation of inclusive wholeness and succeeds in it, or Randall Dipert's artefactual theory [9], which defines an artwork as an artifact without any practical purpose aiming at communicating something different than itself, or moreover the institutional

theory proposed by Arthur Danto [10] and perfected by George Dickie [11], according to which an object becomes an artwork the moment its value is recognized by a member of a non-official institution comprised of artists, experts and gallerists: the so-called "artworld"[3]. Please note that these art theories have not been presented in chronological order, apart from the big temporal gap between Plato and the rest, but rather in a decreasing degree of prescriptions on the content of a work of art: starting from the imitation of nature, we shifted to less and less directive definitions, ending up with a theory (the institutional one) that does not pose any restriction on the content, but only requires the approval of a group of people. Simply put, the institutional theory is in contraposition with all the other theories, which we may gather in one group of so-called "functional" theories, meaning that these theories ascribe to artworks at least one function (may it be imitative, aesthetics, etc.)

With the risk of being considered cynical, we could adopt the institutional theory and get rid of the task of justifying the existence of artworks with respect to some objective. However, such a move could not be considered a final result, especially because this theory is one of the more problematic from a philosophical point of view, since it features a dangerous circularity: it denies the existence of objective criteria that qualify an artwork, nevertheless it requires the intervention of a group of qualified people to whom such responsibility is delegated. Artworks are born when people who know artworks choose them: in other words, art seems to be born out of nothing.

In spite of its limitations, we believe that the institutional theory of art was met with significant success in the 20th century because it provided a rather simple explanation (the detractors would say "simplistic") to phenomena in the art world that were difficult to understand from any other perspective: we are obviously referring to the avant-gardes in the beginning of that century, among whom Marcel Duchamp is probably the most famous, thanks to his work "Fountain", shown at the first exhibition of the "Society of Independent Artists" in New York in 1917, consisting of a urinal bought in a ceramic store upon which the artist put the signature and date "R. Mutt 1917". Such a work hardly gets any confirmation by the above-mentioned functional theories, whereas the institutional theory qualifies it as a work of art simply because it was presented in an event of the "artworld".

"Fountain" is perhaps the most famous example of a series of works that have put to discussion the foundations of art even before they were defined in a clear way (if that is ever possible): other groundbreaking works are the rusty iron with nails by Man Ray ("Gift", 1921) or the boxes of soap pads by Andy Warhol ("Brillo Box (Soap Pads)", 1964). Still, of all people who defied art's traditional canons back then, Marcel Duchamp is to be considered the most significant, at least in the context of this analysis of art and computer science, because he is the reference artist of Frieder Nake, one of the pioneers of the so-called "Computer Art".

3. Computer Art: new works, old controversies

To trace the early stages of Computer Art, that is, of the first works made with a computer with an artistic purpose, is rather simple thanks to Nake himself, who has always been accompanying his activity as a computer scientist/artist (or "algorist", as the pioneers of this field called themselves sometimes) with a thorough work of chronicle and

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[3] Readers who are experts in aesthetics may wonder why philosophers like Baumgarten or Kant have not been mentioned here: we are not dealing with what is beautiful (object of study of aesthetics) but with what is art. Such distinction, which has lead to the birth of philosophy of art as a discipline independent of aesthetics, has become more and more marked through the 20th century.

philosophical analysis, brilliantly summarized in a recent paper [12], in which, as said before, Nake takes Duchamp as a point of reference in the analysis of the theory behind the use of computer science in the artistic field. Since Nake relied on Duchamp's thought to defend the earliest works in Computer Art, let us first check what these works were like and how their authors were criticized.

3.1 The dawn of Computer Art

We can trace the beginning of Computer Art back to the 1960s, when three computer scientists began, almost at the same time and independently from one another, to use their computers to create geometrical designs: George Nees at Siemens in Erlangen in Germany, Michael Noll in the Bell Labs in New Jersey, and Nake himself at the University of Stuttgart, Germany. Curiously, all their surnames start with the same letter; hence they are jokingly known as "the three Ns" of Computer Art. Actually, there had been already other experiments in the 1950s that dealt with computers used for artistic purposes, but we consider the three Ns to be the true initiators of the discipline for at least two reasons: they were the first to use digital computers (whereas those used in the previous decade were analog systems combined with oscilloscopes) and their works were the first to be shown not in the laboratories where they were created, but in real art galleries instead. The works of Nake, for instance, were shown together with some works by Nees in the gallery "Wendelin Niedlich" in Stuttgart in November 1965.

The first letter of their surname was not the only common trait of the three algorists: the works they proposed are all extraordinarily similar, to the point that it is almost impossible to believe that they were developed independently. They all consist in graphical compositions with broken lines with a random orientation to form closed or open polygons. Nake himself provides a convincing explanation, quoting Nietzsche who wrote in 1882 to his secretary Köselitz about a typewriter with only upper case letters that "our writing instrument attends to our thought," to state that even a very free kind of thought like an artist's creativity follows guidelines determined by the instrument chosen for the creative process. In the case of the three Ns, such instrument was a digital computer of the 1960s with its very limited graphical capabilities, which included little more than a function to trace segments between two points. Nake states that anybody with some artistic ambitions and such an instrument at disposal would have arrived at results like the one shown in figure 1, titled "Random Polygons".

Before analyzing Nake's work and its revolutionary aspects, let us take a look at the criticism that it raised, including a controversy that has accompanied Computer Science since its beginnings, even before the birth of Computer Art. Such controversy might indeed find a solution in Computer Art itself.

Figure 1: F. Nake, "Random Polygons" (1965), plotter on paper.
Courtesy of the digital archive of the Victoria & Albert Museum.

3.2 Criticism and contradictions

A criticism against Computer Science and, in particular, Artificial Intelligence (i.e. the subfield that aims at reproducing by means of a computer the reasoning and information processing mechanisms that are typically human) was moved ante litteram in 1843 by the English mathematician and aristocrat Ada Lovelace, when she translated the essay of Italian mathematician Luigi Federico Menabrea on Babbage's Analytical Engine and added some personal notes [13]. In such notes, Lovelace showed an exceptional insight into the possible future applications of machines similar to Babbage's and added some methods she conceived to solve a number of mathematical problems, so that she is considered the first programmer in history: the programming language "Ada", born in 1980 and still in use today after some revisions, was named after her. Lovelace also wrote that one should not expect any originality from the Analytical Engine: it can execute whatever we are able to order it to execute, but it is not able to anticipate any analytical relation or truth.

This observation, which has then become known as the Lovelace objection to any attempt to create something original by means of a computer, was reprised a century later by Turing in his article "Computer Machinery and Intelligence" [14], in which he proposes the famous test to evaluate a machine's intelligence: anticipating criticism based on the abovementioned objection against his vision of future machines able to converse like human beings, Turing affirms that the English mathematician would have changed her mind had she been exposed to the possibilities of computer science in the 20th century.

Actually, it might have been Turing himself to change his mind, had he been still alive 20 years later, seeing Computer Art pioneers deal with the same objection. To be more precise, the criticism the three Ns were facing was more specific than the original one by Lovelace, as it was referring to the context of art. A typical complaint was as the following: since machines simply follow orders, one cannot expect any creativity from them, hence the works of algorists, if they are the result of a creative process, must entirely come from the algorists' minds; algorists are mathematicians or engineers (there were no official computer scientists at the time) but not artists, so their works are spawned from a process that is not artistic and cannot be considered artworks.

The discourse is complex because there is an overlap between at least two distinct issues: the one in Computer Science on the capability of computers to create artworks, which can be seen as a specialization of the Lovelace/Turing debate, and the one in Art on the essential nature of artworks. Let us begin with the latter because it is the one marred with a contradiction that shows us yet another shortcoming of the institutional theory of Art.

We have already shown the circularity of this theory, but the controversy surrounding the three Ns' works sheds light upon another problem, more pragmatic than logical: many artists dismissed Nake's and his colleagues' works as simple mathematical games printed on paper, but in fact there were German and American gallerists who decided to show these works in their spaces. In other words: how does one consider works that trigger opposite reactions within the "artworld"? The institutional theory does not provide any answer, while Nake treasures Duchamp's words: "All in all, 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 qualifications and thus adds his contribution to the creative act." [15]

Moving beyond the limitations of the existing theories, Duchamp for the first time ascribes the spectator a primary role in the creation of an artwork. If many artists have decidedly rejected such an idea, Nake embraced it fully in responding to the critics stating that "Random Polygons" and similar works were "only created by mathematicians and

engineers": the works by the three Ns are indeed simple because only mathematicians and engineers had access to computers and were able to use them to design. Of course, if people with an artistic background had tackled programming to create their works, much more interesting Computer Art works could have been produced.

Nevertheless, continues Nake, if the value of a work is established also by the audience, then it does not matter whether the first Computer Art works were created by mathematicians or more traditional artists, because the spectators would have surely appreciated the undeniable revolutionary content of these lines plotted on paper. A revolution that is not only technological but, as we shall see, cultural.

4. The computer revolution: randomness and authorship

We have not forgotten about the Lovelave/Turing indirect controversy on the possibilities to obtain anything original from a computer, which specialized into the question whether computers can be endowed with any kind of artistic creativity after the advent of the algorists. This problem is tightly connected with a strong contrast between the fundamental principles regulating the workings of a computer and those that deal with human creativity: the rigor of the mathematical rules on one side and the absolute freedom of art, especially in the light of the bewildering works of Duchamp, Ray and Warhol, on the other.

In this context, one can argue that, as computers are machines for automated computations comprised of electronic circuitry, it is impossible for them to be creative in the way human beings are, who are sentient biological creatures with a growing experience of the world on their back. This may sound like a conclusion, but instead it is our starting point.

4.1 The compromise on randomness

Since computers are automatic machines, they work in a deterministic way, that is, after the completion of each operation what to do next is already established because, differently from a human being, a computer is not able to choose how to move on in solving a problem. A person can make decisions on the basis of past experiences in situations similar to the current one; a computer, obviously, cannot.

Since each operation by a computer is determined before its execution, the action flow is entirely established since the beginning, and the only variations one can have depend exclusively on the input data, which in any case need to be in the planned range. To have an example from everyday life, one can think of the computer managing an ATM, which can receive only a restricted set of input data (shown on the ATM's screen) and deterministically responds in accordance with the choices of the customers, unless there is a failure. From this perspective, there is no significant difference between the ATM's computer and the most advanced super computer at NASA.

Obviously, in the deterministic working of a computer there is no room for any random phenomenon: determinism and randomness are mutually exclusive. We are thus facing two limitations: in its operations a computer cannot be creative nor act at random.

The indirect dispute between Lovelace and Turing seems to over with a victory of the former. Still, one of the works by Nake is titled" Random Polygons". Is this title a deceit? Not exactly. We need to analyze more in detail how Nake conceived and created his work.

From the perspective of creativity, interpreted as the complex mental processes that brought some computer scientists in the 1960s to use their computers to create geometrical designs, we can only acknowledge that the graphical capabilities of the machines back then might have affected the 3 Ns' choices. Computers indeed had an active role, but only after such choices had been made: those deterministic machines did nothing more than executing the commands given by the human programmers who had indeed chosen to have polygons drawn.

From the perspective of the execution of the idea, instead, computer science provides a very interesting instrument that might look like a trick at first glance, but that poses interesting epistemic questions: pseudorandom numbers. Nake did not program his computer with instructions that explicitly specified the coordinates of all the vertices in his work: such coordinates have been computed on the basis of rather complex mathematical functions parameterized with respect to several numerical values inside the computer such as the hour and the minutes in the clock, so that although resulting from a deterministic computation, they appear to be random to the human user. This is the trick: a computer is not able to generate random numerical values, but aptly programmed it can create figures that look random.

Nake had a rather precise idea of the drawing he was going to make, but could not exactly foresee the positions at which the vertices of the polygons would have been placed because he was not able nor he was willing to do the math the computer was going to do to establish such positions. Thus, once the work was completed, the artist was looking at an unexpected result, at least in part. Turing, in his reply to the Lovelace objection, wrote that he was positive that computers were not entirely predictable, and they had the capability to surprise us, in particular thanks to results that human beings would not be able to obtain immediately; the works based on pseudorandom numbers seem to agree with him. The field that exploits pseudorandom numbers to create artworks is called Generative Art and it is named after the generative character of this kind of process.

Surely there are several other ways to create randomness (or something that looks like it) without using a computer. In fact, the mathematical functions that yield pseudorandom results could be computed by hand, or one could simply throw some dice. There exists a truly remarkable art catalogue featuring works based on randomness, including the one by French artist François Morellet titled "40,000 carrés (40,000 squares)": a series of 8 silkscreen prints derived from a painting comprised of a grid of 200 x 200 squares, to each of which the artist had associated a number read from a family member from the local phonebook; squares with an even number were painted blue, those with an odd number red. The entire process took most of 1971 for completion.

This may be a bizarre example, but it clearly shows the advantage of working with computers: the ongoing evolution of digital electronic technology allows for better performance every year, that is, shorter completion times even for the most complex of works. Let us not forget that in 1965, the year of "Random Polygons"[4], a computer with what was considered a reasonable price like the IBM 1620, which came with a price tag of 85,000 US dollars, needed 17,7 milliseconds to multiply two floating-point numbers, whereas today (January 2015) one only needs little more than 900 US dollars to build a machine with an Intel Celeron G1830 processor and an AMD Radeon R9 295x2 graphical card (endowed itself with a processor) able to execute more than 11,500 billions of floating-point operations.

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[4] Interestingly, 1965 is also the year of publication of the famous article by Gordon E. Moore, co-founder of Intel, who foresaw that the number of transistors in a processor would double every year: a rate known as "Moore's law" [17]. The prediction was later revised to a doubling every year and a half.

To have a more concrete idea of the effects of this technological evolution, let us take a look at a work by a contemporary generative artist, Matt Pearson, author of a book aptly titled "Generative Art" [18]. The work, called "Tube Clock", is shown in Figure 2. By zooming in enough, one can realize that the tubular structure depicted in the work is comprised of thousands of elliptical shapes, drawn very close to each other. The basic idea of the artist to draw a series of ellipses along a circular path is affected by a discreet turbulence provided by the pseudorandom noise slightly altering the coordinates of the centers and the dimensions of the shapes. The issue of performance must be taken into account again: even if it could be possible to obtain a design like Nake's without the aid of a computer, a work like Pearson's is not achievable only with manual instruments. It is not only a matter of time (even with the patience of the Morellet family), but also a matter of precision and dexterity.
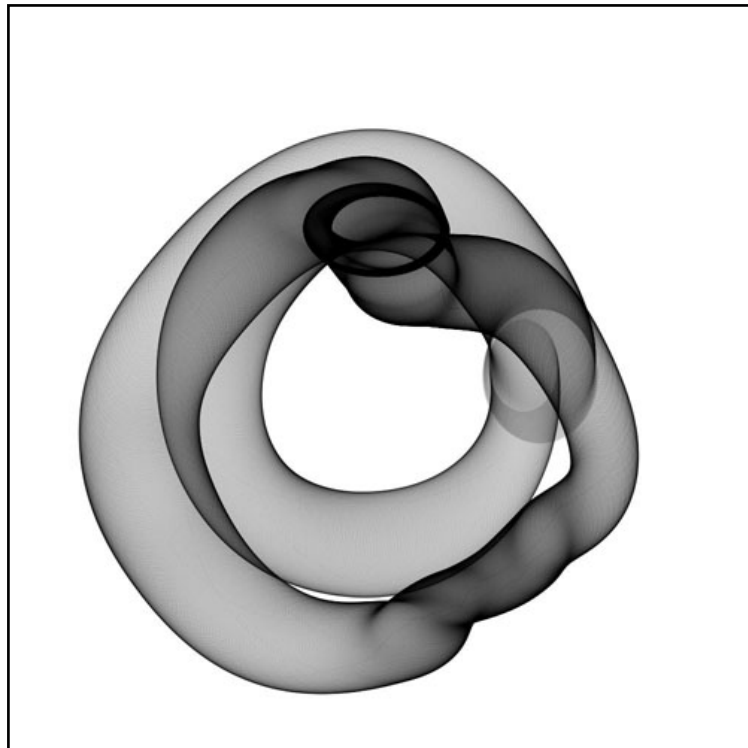

Figure 2: M. Pearson, "Tube Clock" (2009), rendering on screen. Courtesy of the artist.

4.2 A new kind of authorship

The traditional role of the artist fully in control of the creative process seems to have been changed by the introduction of an instrument like the computer, which, even if lacking completely human creativity, is indeed endowed with characteristics a person is missing: as said before, computing power. If pseudo randomness makes the artist lose the sharp vision of the final results of their effort, the dramatic increase in computing performance not only has made such vision even more blurred (the more pseudorandom operations per second, the more variability in the final result), but it has also disclosed new, otherwise unreachable landscapes. Artists like Pearson create artworks that are possible only by means of a computer: must we then admit that man has given up power to the machine? Should Pearson share credit with the computers he used? Actually, the final and most important decision is still in the hands of the human artist: which of all the possible results of a pseudorandom computation is the one to be shown to the public? Which one qualifies

as an artwork? A computer is able to explore in a short amount of time the vast space of the possible solutions, but the last word is the artist's and there is no way to delegate such decision to the machine. To do so, one would have to write a piece of software encompassing and encoding all the factors affecting the artist's decision (i.e. their upbringing, their cultural background, their taste, the zeitgeist they are in, etc.), but philosophers have stated again and again throughout the years with rather convincing arguments that any attempt to build an exhaustive and computable list of all the relevant aspects of the human thought is doomed to failure [19], [20].

It is important to remark that an artist's dependence on a computer for the creation of an artwork is not an essential characteristic of Computer Art: just think of a pianist's dependence on their piano, or a painter's on their paintbrushes. From this point of view, a computer is simply a new type of instrument, technologically very advanced, that has been recently added to the wide range of tool at our disposal to make art. The true revolution of artistic authorship that Nake discovered with his pioneering work was not about an issue of computing performance (which was rather limited in 1965), but it was about an issue of abstraction, in the form of a shift from the execution of a material act to the construction of a mathematical model of such act, and that construction was indeed possible and exploitable thanks to computers. In his writings, Nake stresses the distinction between an instrument and a machine, stating that the latter is a much more complex entity, comprised of an internal state that evolves through time and is able to keep track of those changes. By means of a computer, an artist does not draw a line between A and B anymore, and a description takes the place of such action, in the form of a program instruction, which is by its own nature parametric: it does not refer only to one specific action, but to a scheme of which such action is just one instance. As said before, the artist is still in charge of the creative process, but they move away from traditional artistic gestures, shifting from a material to a semiotic dimension: the working space does not include brushes and colors anymore, but symbols instead, the symbols computers are used to process automatically.

The radical change brought by computers in Art is that artists do not create one artwork anymore, but a whole class of artworks: even without relying on pseudorandom numbers a program can be seen as an instance of a more general set of programs, and a change in one of its numeric parameters will allow for the exploration of such set. These considerations have a universal character and do not depend on the evolution of technology: they were true at the time of Nake's first steps as an algorist and they are true also today. In fact, when we asked Pearson to send us a high-res image of his "Tube Clock" for this article, the artist kindly sent us another image "produced by the Tube Clock system", different from the one shown on his website, whose high-res version got somehow lost in the meantime.

5. After Duchamp: Interaction and evolution

It is time for some clarification to avoid making the reader believe that there exists only one kind of Computer Art, that is, pseudo-randomness-based Generative Art, and that the evolution of technology plays an interesting yet not significant role in this context.
These statements are both false and we only need one work by one artist to prove it.

5.1 The boundaries of interactivity

Scott Snibbe was born in New York 4 years after "Random Polygons" was shown to the public, so he belongs to a later generation than the 3 Ns, but nevertheless he can be considered a pioneer in his own way, as he was one of the first artists to work with interactivity by means of computer-controlled projectors. In particular, one of his most famous works of this kind is "Boundary Functions", presented for the first time at the "Ars Electronica" festival in Linz, Austria in 1998 and then several other times around the world, ending in 2008 at the Milwaukee Art Museum, in Wisconsin, USA [21]. The work consists of a projection of geometric lines from above onto a platform on the floor, separating the persons on the platform from one another (see Figure 3).

Figure 3: S. Snibbe, "Boundary Functions" (1998), here depicted at the NTT InterCommunication Center in Tokyo, Japan in 1999. Image provided with GFDL license at http://en.wikipedia.org/wiki/Scott_Snibbe

The lines are traced in accordance with the positions of the participants, and they draw the relevant Voronoi diagram on the floor, that is, the boundaries of the regions of positions that are closer to one person than any other. The projected diagram is dynamic: the lines change as people move to always keep a line between any pair of persons on the platform. Snibbe wants to show by means of an artwork that, although we think our personal space entirely belongs to and is completely defined by ourselves, its boundaries are indeed defined also with respect to the people around us, and they often undergo changes that are out of our control. It is meant to be a playful way to stress the importance of the acceptance of others: a message even more charged with meaning, if one considers

that the title of this artwork is inspired by the title of the PhD thesis in Mathematics of Theodore Kaczynski, also known as Unabomber.

Meaning of the work aside, it is clear that "Boundary Functions" is an example of non-generative Computer Art: there is no pseudo randomness involved because a Voronoi diagram is obtained by a known computable procedure and, given a certain configuration of people over a platform, the artist is able to foresee the result of such computation. In terms of the Lovelace/Turing controversy, there are no surprises by the computer for the artist.

The surprise is indeed all for the audience that takes part in this work: such participation undoubtedly makes a significant difference between Snibbe's work and those by Nake and Pearson. This is another kind of Computer Art, born from the interaction with the audience, namely Interactive Art. The concept of interaction is so general that some specification is needed. Obviously, it is always possible for the audience to interact with an artwork, even a traditional one: an observer can look at a painting from different points of view and obtain a different aesthetic experience every time; moreover, artworks with mirrored surfaces like Anish Kapoor's "Cloud Gate" in Chicago (also known as the "Bean") do invite people to interact with them, in a game of ever-changing deformed reflections.

The interaction of an Interactive Art work is different, though, because it is necessary for the existence of the work itself: if "Cloud Gate" can be enjoyed also from a distance, without any self-reflection on its surface, there is no experience at all, let alone aesthetic, when nobody is standing on the platform of "Boundary Functions". It is when two or more people walk around on it that the work comes to life.

Let us remind the words of Duchamp reprised by Nake to defend Computer Art made by mathematicians and engineers; it is easy to recognize that Interactive Art grants the audience an even bigger role than what prescribed by the "Fountain" artist: the spectator is not required to establish the value of an artwork, but to build, together with the artist, the artwork itself.

5.2 The necessary evolution

In the context of Interactive Art it becomes clear that one needs adequately performant computers. Let us indulge in a mental experiment: imagine we want to create "Boundary Functions" without computers. How would we proceed? One solution could be to enhance the platform technologically by means of small scales and LEDs: the scales should be organized in a matrix-like structure so that each scale transmits the weight on it to the surrounding scales; the LEDs of the scales in a state of balance should turn on to mark the boundaries between the people. Another solution could consist in exploiting some assistants who, by means of some flashlights that have been modified to project only segments of light, can skillfully trace the boundaries around the people from above.

Not only these solutions appear to be extremely tricky, but surely they would not ensure the accuracy and the aesthetic experience provided by the actual "Boundary Functions", whose interactivity is made possible by devices that, thanks to their computing power, are able to project the lines of the Voronoi diagram relevant to the audience members currently walking around the platform.

Like Nietzsche's typewriter shaped his way of thinking, many artists have their inspiration enriched by the computing possibilities provided by computers: it is reasonable to think that nobody at the times of "Random Polygons" could have conceived a work like "Boundary Functions", not because the mathematical concept of a Voronoi diagram did not exist (it existed) or there was no algorithm to compute it (it existed, too), but because the

computing instruments available at the time would not have allowed even to imagine that a computer would have been able to compute in real time the boundary lines among a group of people moving on a platform. From this perspective, even more respect is due to visionaries like Turing, who more than 50 years ago imagined computers performing operations that are not possible even today (e.g. conversing with a human), in spite of all the doubts that characterize every prediction on the future.

6. Conclusion

Whatever the future of computers in general, and computers in Art in particular, it is a fact that today there exists a new discipline at the intersection between Computer Science and Art that was made possible by the birth of computing devices powerful enough to ensure real time interaction between persons and machines. Interactive Art has quickly gained a primary role in the artistic landscape: art historians like Katja Kwastek have recognized its potential for a significant support to the search of an adequate art theory and proposed an aesthetic of interaction with digital instruments [22]; philosophers of art like Dominic McIver Lopes have even promoted the concept of interaction to an essential and definitory characteristic of Computer Art in general [23].

In spite of the problems in recognizing universal criteria that define Art, Interactive Art, with its focus on technology and persons, seems to be the discipline that embodies the zeitgeist best, and it surely has the remarkable merit of having given us, on the foundations laid by the pioneers of mid-20th century, a new kind of artworks that are not achievable in any other way than the most recent computing technology. The fundamental role of the interaction between the spectator and the artwork is a break with the past that may be compared to what brought by at the beginning of the 20th century by Duchamp.

Considering what happened in the following years in terms of evolution of Art, Technology and everything in-between, we cannot help looking forward to what awaits us in the 21th century.

Extra: Computer Arts

In this article we have talked about Computer Art in general to mean a form of art in which works are created with the fundamental support of a computer. Depending on how this device is used, artworks can be classified in a more specific way: we have seen that when one uses pseudorandom numbers one makes Generative Art, while when an artwork requires the active intervention of the audience and changes in accordance with their actions we are dealing with Interactive Art.

There are several other ways to make Computer Art. Here is a non-exhaustive list of the most common subfields, which are not to be considered mutually exclusive, but rather possibly overlapping perspectives from which one can study an artwork. Moreover, several of these fields are affected by some conceptual issues.

New Media Art uses new types of communication media. We could take for granted that "new media" means computers, but from the point of view of some art historians even the use of TV sets in installations is to be considered new. Hence, not all New Media Art is necessarily Computer Art.

Multimedia Art is based on the use of multiple communication media at the same time. Computers have been traditionally linked to the concept of "multimedia" because they are versatile instruments able to manage contents in different formats (text, audio, video), but as in the previous case we cannot take for granted that a Multimedia Art work features a computer.

Digital Art is based on the concept of digital encoding, that is, the transformation of information into a finite sequence of discrete numbers. This is the most general definition possible, because it involves the fundamental principle every digital computer is built upon. It may be even too general: from this perspective, any picture taken with a digital camera could be considered Digital Art.

Virtual Art can be enjoyed only through instruments that grant access to computer-generated virtual worlds. Such tools are man-machine interface like helmets, visors, gloves, etc. (the Oculus Rift is the latest example) that enable users to observe and possibly interact with the artworks in the simulated environment.

Cybernetic Art aims at creating works inspired by cybernetics, a transdisciplinary approach mainly based on system theory, the analysis of system endowed with signal circuitry that ensures some form of a feedback loop between the system itself and the environment. The signals are usually (but not necessarily) encoded by means of a computer.

Internet Art, also known as Net Art, creates works that exploit the Internet, either simply used as a distribution channel opposed to the traditional art gallery system, or as a fundamental part of the artwork itself, when it is based on telecommunication services like websites or email, or it prescribes interaction between physically distant people and objects.

Software Art is the subfield of Computer Art in which artworks are software programs. We have seen a definition of Art according to which an artwork is an artifact without a practical purpose: from this perspective works of Software Art are different from other software because they do not solve any problem but are only meant to provide an aesthetic experience.

Video Game Art may be considered a special kind of Software Art whose works are videogames. In reality, Video Game Art does exploit videogames, but only to provide an aesthetic experience that is clearly distinct from a game experience. The use of videogames can be at a superficial level, by reusing images and sounds from such games, or at a deeper level, by copying and modifying pieces of game code. Whether videogames should be considered artworks is a question we will tackle in our future research.

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