Early Computer Art and the Meaning of Information

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Introduction

Early Computer Art and The Meaning of Information gives a short introduction into the use of the computer in the arts during its early days. With this paper, I want to describe the beginnings of what is now called the 'Information Age' from a fine arts perspective. In order to understand what has happened not through our current conception, this paper employs predominately primary sources. 'What has happened' is, in fact, the unleashing of the new paradigm of information, which I will call the 'economy of information'. Through the research for this paper, it has become clear to me that although the term 'information' is in great use today, it is not always well understood. Information most certainly cannot be reduced to mere data. Data is only information's pragmatic relative.

Coming to terms with the *meaning of information*, therefore, is the major driving force for this paper. Although the concept of information is somewhat bigger than theories about computers and bigger still than theories about computer art, the study of the early approaches to computer art proves to be very helpful. The reason for this lies in the fact that the majority of early computer artists were, in effect, no artists at all. They were engineers or mathematicians involved with the development of computers and information theory in general. By studying their work, one actually studies computer knowledge in visual form. If at all, their work is used today only to illustrate the development of the computer or to introduce a section about computer art in an art book. It is not discussed as having any relevance to an understanding of the computer and its uses in the arts at present, or historically.

Art criticism is not the appropriate method to approach early computer art, although it can be applied to some artists. A historical method is definitely important, because much of the work reflects the research into information technology at the time, when it was carried out, and was used to demonstrate its achievements. As important as it is to ground computer artworks historically, they would be short-changed if they only illustrated the history of computers in general.

In the current paper I propose a system of four different categories. Although they appear in historical succession, it is their different approach to computed imaging, which is put to the fore. All examples are given to illustrate such an order, although I present them as historically ordered as possible.

The four categories are *Algorithmic Art*, *Generative Aesthetics*, *Image Processing*, and *Paint Programs*. Of some relevance is the development of bitmapped imaging that from the 1980s replaced vector based output devices. Image processing and paint programs are both rooted in the technology of bitmapped imaging. Paint programs like Adobe's

Photoshop have virtually fused both categories and it is not without sense to split the history into a pre- and post-paint era like Mike King proposes in his 'Digital Art Museum'[1].

Because of the predominately systematic approach, I have left out the work of many important artists in order to focus more in depth on systematic aspects. Therefore, this paper cannot be read as a history of early computer art. I have also focused on early *visual* computer art, although much work has been done on music and texts.

Preceding this systematic order of computer art, which is covered in the second section, are a few introductory pages on the computer in general. The concept of the all-purpose computer as the universal machine, that is the machine that can simulate any other machine, is important in any further investigation into computer art. Both, the first and the second sections of this paper are held very descriptive.

The third section of this paper develops the notion of information from the idea of randomness. The informational content of an image is perceived as being separate from its meaning. Randomised images could or could not carry meaning, but in both cases they carry information. The introduction of information as a second quality next to the meaning of an image is taken as a paradigmatic shift creating a rupture between information and the traditional understanding of meaning. Artistically, however, the majority of early computer artists did not live up to this challenge, a challenge that they themselves implicitly created by developing information technology.

Conceptual Art, on the other hand, coming from a different, artistic tradition drove the understanding of information further. For this reason, the fourth and final section of this paper follows Jack Burnham's claim that conceptual artists realised the importance of information technology for the arts. Burnham curated *Software, Information Technology: Its New Meaning for Art* in 1970, an exhibition that brought together technology and Conceptual Art and proved to be a unique approach to information technology.

Conceptual Art was not a monolithic movement. Especially artists realising their concepts or demanding their realisation offer yet another angle to the understanding of information. Information is best understood while it processes or is processed – while it is being *done*. Artists, who realise information in this manner, pose - and possibly answer - the question cornering the meaning of information.

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[1] Mike King, *Computers and Modern Art: Digital Art Museum*; available from http://www.dam.org/essays/king02.htm.

1. The Computer: The Universal Machine[2]

A computer is a machine. It is designed to perform a succession of calculational instructions called 'algorithms' usually to return values. The important point about computers is the fact that they are universal machines; that is, a computer can work out *any* possible algorithm[3]. Its universality stems from the fact that it is a device built in such a way that *any* algorithm can be fed into it, making the computer perform in the way the algorithm directs. Such algorithms are better know as 'programs' or 'software'; software in the sense that changing the algorithms does not mean physically changing any part of the computer (or 'hardware'). There is also a third notion, that of 'data'. Data is input into the computer in the same way as software, but data is the material the software performs its operations on.

Computational machines were dreamt of by many people, most famously Gottfried Wilhelm Leibniz (1646 - 1716) and Charles Babbage (1791 – 1871). However, since building such machines was technically impossible, their machines remained as dreams. Babbage succeeded in building only a small working model of his *Difference Engine* in 1822, but was never able to build the full scale machine. Moreover, all of these machines were mechanical and had the disadvantage of being constructed for specific purposes only. The British mathematician Alan Turing (1912 – 1954) was the first person to conceptualise an all-purpose computer by reducing algorithms not to their rules, but to the way they are applied. In this way, (hypothetical) machines could be constructed – later called 'Turing Machines' – to execute the algorithms. The universal computer, thus, is defined as that machine that can incorporate all possible *Turing Machines*.

To build a universal computer, it was necessary to leave mechanics behind and use electronics. But even in electronics there are two ways in which a universal computer could be realised, analogue and digital. The first designs were analogue. Analogue computers represent a value by the state of a medium, usually voltages; the higher a voltage the higher a computed value. Historically, however, digital computers proved to be more successful. Digital computers represent a value in binary (that is on- or off-states) and thus discrete form. The first universal digital computer, the *Z3* was built in 1941 by Konrad Zuse in Berlin. Ironically, Zuse's groundbreaking work was considered of low importance by the German officials at the time and found little support. In Britain, work

[2] Information for this section was predominantly taken from: Martin Davis, *Engines of Logic: Mathematicians and the Origin of the Computer*, (New York, London: Norton, 2001).

[3] This, however, does not mean that all mathematical problems can be expressed and thus solved as algorithms. On conceiving the universal computer, Alan Turing proofed that is was impossible to solve all mathematical problems algorithmically. This is known as Hilbert's *Entscheidungsproblem* first formulated by the mathematician David Hilbert (1862 – 1943).

on deciphering the German military's coded messages led to the *Colossus* in 1943. In the United States the *ENIAC* was developed in 1945 followed by the *EDVAC* in 1951. However, out of the three, only the latter is now considered to be truly general-purpose or universal.[4]

The first universal computers laid the foundations for what has been termed the 'Computer Revolution'. Since then reliability, speed, and availability of computers have improved enormously. Apart from Zuse's computers, which were developped privately, almost all other computers where developed by or used in classified military projects. Zuse tried to interest the German military in his work but this was largely rejected. Outside of the military, computers where accessible only for scientific research and only from the 1970s to the general public. This is one of the reasons why the foundations for computer art were laid by mathematicians and engineers working in or for the military[5].

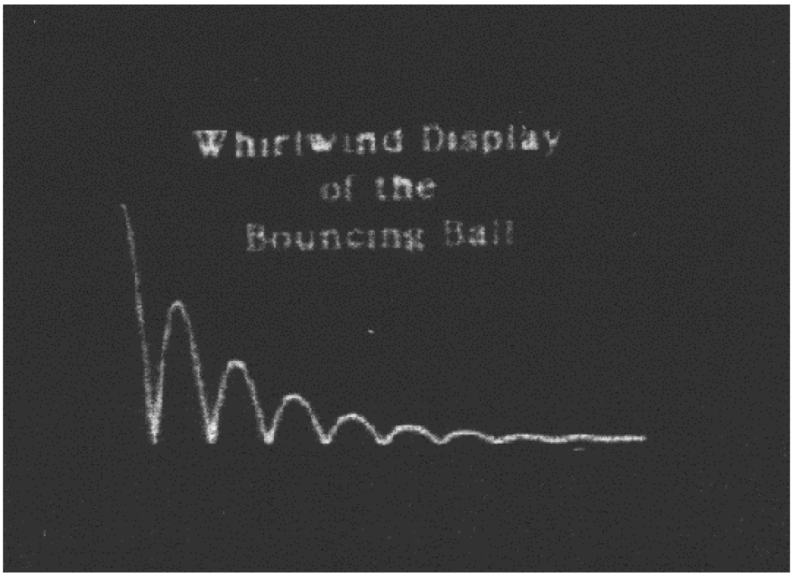

Fig. 1: Charly Adams' visualisation of a bouncing ball, 1949.[6]

Another important obstacle for the use of the computer by artists was the rudimentary tools available for artistic purposes. Although computers work with numbers, numbers by themselves are not of very important artistic value. Artists were – at least at the time - considered to work in vision and sound. The computer was only of interest to the artists

[4] It is remarkable, how little Zuse's work is featured in the Anglo-American histories of computing. Davis, who puts a lot of emphasis on the principle of universality of computers, does not mention Zuse once. Apart from a certain need for a linear history (in particular that of the victors), such a bias also emphasises the military's importance for the development of computers.

[5] *Stained Glass Window* of the US Army Ballistic Research Laboratory won the second price in a computer art contest of the magazine *Computers and Automation* in 1963. No individual artist was mentioned. See: Herbert W. Franke, *Computer Graphics - Computer Art*, (London: Phaidon Press, 1971), pp. 64 - 65.

[6] The image can be found at: http://www.first.gmd.de/persons/tj/diss/node11.html There, the image is referenced to: John T. Gilmore, *Retrospectives: The Early Years Is Computer Graphics at Mit, Lincoln Lab and Harvard*, in: Jan Hurst (Ed.), *Siggraph Panel Proceedings, Computer Graphics*, (1989), pp. 39 - 73.

insofar as its mathematics could be translated into these artistic categories. The first possibility of visually showing information was the display used in 1949 with a computer called *Whirlwind* at the Massachusetts Institute of Technology. This showed the first application, which was a bouncing ball gradually loosing height (fig. 1).

After this, it still took a considerable amount of time to develop the hard- and software that was needed to use computers for artistic purposes. The first scanner was introduced in 1957 followed by plotters in 1959. In 1963, the first interactive drawing programme, *Sketchpad*, allowed the user to draw directly on the screen using a light pen. The invention of Random Access Memory in 1970 allowed the storage of more data and with it the use of shapes rather than lines or text. Since the design of the frame-buffer in the early 1970s (that is memory space corresponding to the image on the screen) bitmapped images became possible and with them the development of paint applications.

However, all the developments that have made computers, peripherals, and software faster and more readily accessible have not changed anything about the fundamental concept of universal computers. If anything, advances in computer technology have obscured underlying principles. While artists working with the computer in the 1960s had to be mathematicians, today artists do not need to understand basic computing principles. With this in mind, it is fascinating to revisit the concerns and ideas of computer artists of the first generation, because in their work the production of images had to reflect the fundamentals of computing.

2. Early Computer Art

There exists no coherent description of what early computer art actually is. At best, computer art has been described as a certain, mostly experimental use of the computer within the traditional artistic practices of visual art, music, or poetry. A classification according to the different artistic disciplines, however, does not reveal the different ways the computer was used within these practices (i.e. as a tool for the production of an artwork or as its producer). Although similar categories can be applied to other artistic practices, the following discussion focuses on the use of the computer in the visual arts.

a. Algorithmic Art

Algorithmic art is the earliest and most fundamental artistic practice on the computer. This is not surprising since algorithms, as described previously, form the basic instruction sets of computers. The first practitioners of computer art were the programmers themselves, who at that time were predominantly mathematicians.

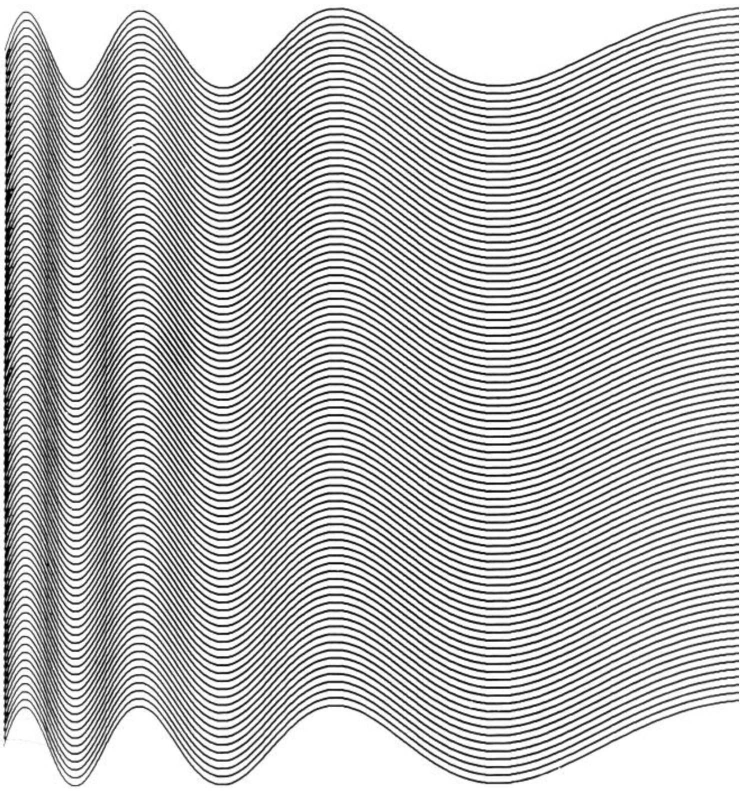

Fig. 2: A. Michael Noll, *Waveform*, 1965.[7]

[7] Franke, *Computer Graphics - Computer Art*, p. 67.

The first example of computer graphics and algorithmic art is the 1949 bouncing ball (fig. 1) on the *Whirlwind* computer. The bouncing ball was programmed using the physical laws of pendulation. Its decrease in height is the result of a calculation, visualised on the display. Another, much later example for algorithmic art is A. Michael Noll's *Waveform* from 1965 (fig. 2). The image shows 90 parallel sine waves with linearly increasing period.[8] Noll points out that many artworks that are categorised as *Op Art* (such as the works of Bridget Riley) utilise regular and mathematical functions in order to achieve their effect.

Algorithmic art is a visualisation of mathematical functions expressed in computer algorithms. In theory, it is possible to deduce the algorithm from its visualisation. Visualisations of algorithms have since served mathematicians as a means to gain insight into algorithmic patterns. Whereas in early computer graphics mathematics were employed to produce an optical effect or an artful decoration, they became increasingly accepted as tools for mathematical research, a field that has recently, according to Michele Emmer, been termed *Visual Mathematics*.[9]

Instead of looking at the artworks from a mathematical point of view, it is also possible to approach them through the history of art. Max Bill claimed in 1949 that "it is possible to evolve a new form of art in which the artist's work could be founded on quite a substantial degree on a mathematical line of approach to its content."[10] Bill refers in his work to the tradition of abstract art as it originated from Kandinsky, although it is possible to see algorithmic art also as part of the constructivist tradition.

The German artist Manfred Mohr discovered the computer in 1969. He was one of the first fine artists to use the computer in the early period of computer technology; his work consisting mainly of projections of cubes and hyper-cubes[11] onto two-dimensional surfaces researching, for example, the spatial relationships of the lines in the projection of a cube (an example is given in fig. 3).

In a 1975 text, Mohr explicitly refered to Marshal McLuhan's concept of technology as extending the human nervous system. Such technological "[b]reakthroughs in human development are always accompanied by radical changes of attitude towards the so-called

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[8] A. Michael Noll, *The Digital Computer as a Creative Medium* [1967], p. 159, in: Jasia Reichardt (Ed.), *Cybernetics, Art and Ideas*, (London: Studio Vista, 1971), pp. 143 - 64.

[9] Michele Emmer, *Introduction to the Visual Mind: Art and Mathematics*, p. 2, in: Michele Emmer (Ed.), *The Visual Mind: Art and Mathematics*, (Cambridge, Massachusetts and London: MIT Press, 1993), pp. 1 - 3.

[10] Max Bill, *The Mathematical Way of Thinking in the Visual Art of Our Time* [1949], p. 7, in: Michele Emmer (Ed.), *The Visual Mind: Art and Mathematics*, (Cambridge, Massachusetts and London: MIT Press, 1993), pp. 5 - 9.

[11] Hyper cubes are four-dimensional objects constructed from eight cubes, three of which meet at an edge. This is analogue to a cube, which is constructed of six squares. Although it is very difficult to imagine four-dimensional objects, they can nevertheless be projected into three or tow-dimensional space.

human values. […] It is evident that one should not create single forms and judge them by a traditional and subjective aesthetic, but build sets of form where the basic parameters are relationships between forms with no aesthetical value associated to any particular form in the set. It is possible within this context to ignore the former 'good' and 'bad', now allowing aesthetical decisions to be based on statistical and 'wertfreie' procedures where the totality represents a quality of a quantity."[12] Thus, the computer uses mathematical and algorithmic processes to produce artwork, which should not be judged by traditional aesthetic standards but rather by the idea itself they express.

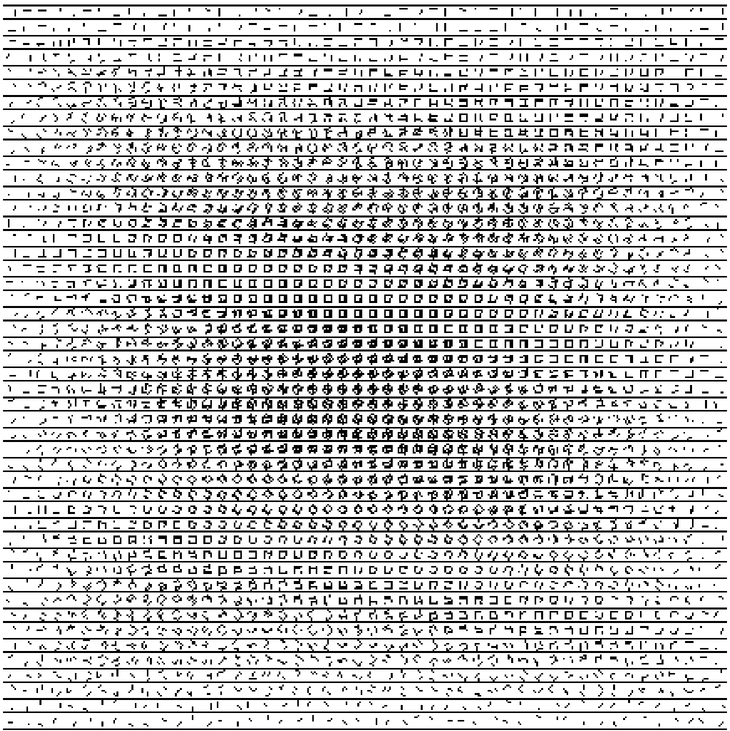

Fig. 3: Manfred Mohr, *P-159-R*, 1972.[13]

There are different ways to arrive at the sets of images Mohr talks about. The bouncing ball (fig. 1), for example, produces one and the same image every time the program is executed. It therefore does not create a set.[14] Mohr's *P-159-R* (fig. 3) is an example of a set of images that are created by the program. Each little image is a specific version of the cube, which also defines its position in the grid. No image dominates over the other one, whereas the totality of the set shows the quality of the algorithm. In both examples, the resulting images are identical whenever the algorithm is executed.

[12] Manfred Mohr, *[No Title]* [1975], pp. 94 - 96, in: Ruth Leavitt (Ed.), *Artist and Computer*, (New York: Harmony Press, 1976), pp. 92 - 96.
[13] Manfred Mohr's website is: http://www.emohr.com. *P-159-R* can be found at: http://www.emohr.com/mohr_cube1_159.html
[14] It is a set with one member only, to be precise.

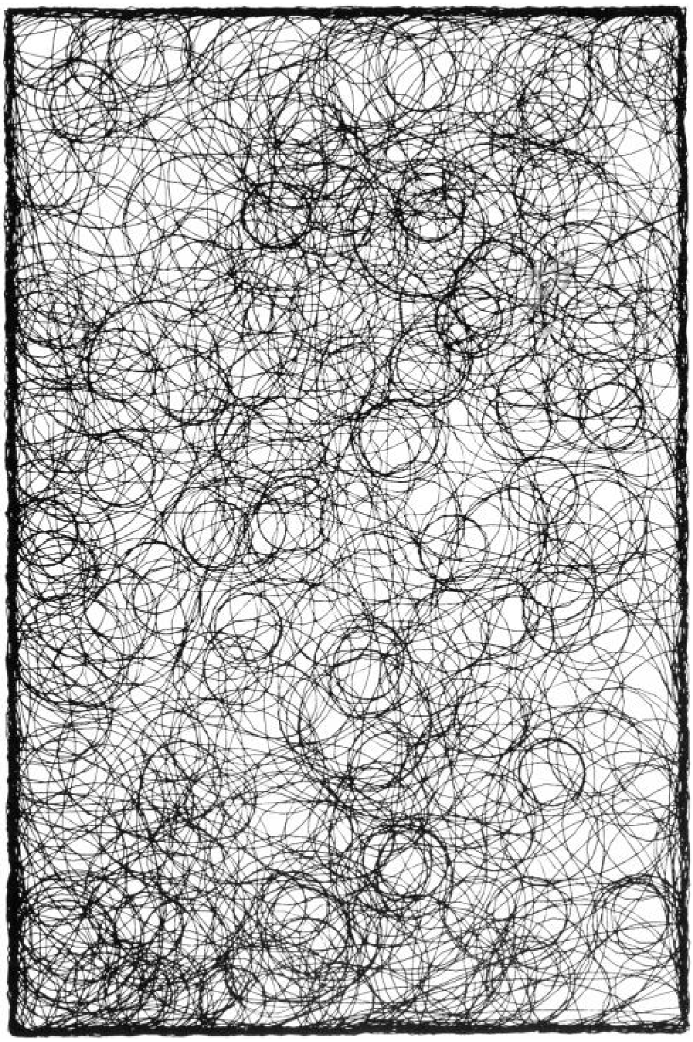

Fig. 4: Georg Nees, *Locken*, 1965.[15]

There is, however, a third option that many artists used, which is the incorporation of randomised algorithms. In this case, the set is produced with the help of random numbers, comprising all variations of a given algorithm. Georg Nees' *Locken* from 1965 is an example of this. *Locken* is constructed from interconnected circle segments where the radius and the length of a segment are calculated on the basis of two random numbers. The algorithm is put together in a way that, on approaching the edge of the specified area, the circles are deflected so they would never draw outside of the area.[16]

Mohr's idea of a set of forms could be applied in two ways for *Locken*. Each segment of a circle constitutes a form comparable to each individual cube in Mohr's *P-159-R*, with the exception that in *Locken* the circles are not arranged in a grid but rather chaotically. The second way to understand sets of images created with random generators is that every

[15] Franke, *Computer Graphics - Computer Art*, p. 66.
[16] For a description see: Karin Guminiski, *Kunst Am Computer: Ästhetik, Bildtheorie Und Praxis Des Computerbildes*, (Berlin: Reimer, 2002), pp. 101 - 02.

time an image is printed out it looks slightly different, since different random numbers are used for its construction. In Mohr's understanding applied to *Locken* each of these different *Locken* images is a member of a set which represents the capabilities of the *Locken*-algorithm.

With this image in particular another aspect of randomised algorithmic art can be illustrated, which contradicts Mohr's dictum. Nees had to stop the drawing of the image manually, whenever he felt the image was satisfactory. In the case of *Locken* this is said to have been due to a programming error, but other artists have reported a similar method. Some artists even physically interfered with the plotting of their images introducing an element of chance but also of choice into their images, which are outside of the algorithm. Such choices keep well below Mohr's aesthetic aims, in which all members of a set have the same aesthetic value and cannot be subjected to even the artist's choice.

Manfred Mohr formed with other artists[17] the *Algorists Group* 1996 to promote their ideas. Mohr is a member of a sub-group of the Algorists called *Plotter Artists*. These artists use plotters only (and no printers) to produce their work.

A particular branch of algorithmic art uses fractal geometry, a field of mathematics originally described by Benoit Mandelbrot in the 1970s. The birth of fractal geometry is a good example of how important visualisation in mathematics has become. "Fractal art [...] is indissolubly based on the use of computers. It could not possibly have arisen before the hardware was ready and the software was being developed"[18].

Fractal geometry argues that traditional Euclidian geometry is not sufficient to explain natural phenomena like the formation of rivers, the growth of plants, or indeed the development of the universe. It utilises non-linear dynamic feed-back where the relationship between in- and output is not proportional.[19] Such systems can, in the long run, create 'deterministic chaos', a complex behaviour which appears to be random when in fact it is not. 'Non-deterministic chaos', on the other hand, is a complex behaviour that is open to random interferences from outside the feed-back loop. Fractal geometry is part of the wider field of chaos theory. One of the fundamental believes of chaos theory is that even very complex structures can be based on simple rules that are repeatedly applied.

The feed-back loop serves as an amplifier for the initial state, so that the final work appears very different, although initial states are similar. In the case of 'non-deterministic

[17] For information on the Algorists see: http://www.solo.com/studio/algorists.html
[18] Benoit B. Mandelbrot, *Fractals and an Art for the Sake of Science*, p. 11, in: Michele Emmer (Ed.), *The Visual Mind: Art and Mathematics*, (Cambridge, Massachusetts and London: MIT Press, 1993), pp.11 - 14.
[19] H.-O. Peitgen and P. H. Richter, *Frontiers of Chaos*, pp. 66 - 71, in: H.-O. Peitgen and P. H. Richter (Ed.), *Frontiers of Chaos: Computer Graphics Face Complex Dynamics*, (Bremen: MAP ART, 1985), pp. 61 - 91.

chaos' this is complicated by random interferences on different passes in the loop. The Brownian Motion can be seen as non-deterministic extreme, because in it the direction of every movement of a molecule is independent on its previous movement. Brownian Motion, therefore, is a process that can entirely be described stochastically in terms of a 'Random Walk'.[20]

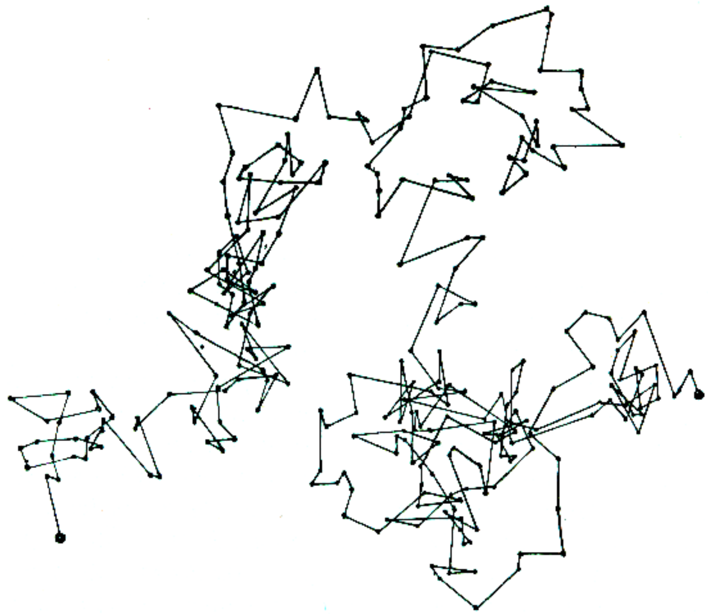

Fig. 5: Example of Brownian Motion.[21]

The depicted graph (fig. 5) shows the motion of a particle with measurements every 30 seconds. The points of measurement are joined by straight lines. It is easy to see, how such chaotic movement resembles the use of random numbers in computer art.

Mandelbrot himself describes fractal geometry as algorithmic art. He shares with the algorists the belief that the entire image must result from global algorithms without any detailed manipulation of the image by the artist. "To 'fix' an unsatisfactory corner of a piece by a local patch is not permitted."[22]

Generally, what I call algorithmic art is the visualisation of mathematical functions expressed in algorithms. Because of this, there is a direct relationship between the algorithm and the image. All parts of the image, fall under the rules of the same algorithms so that a sense of homogeneity is achieved.

[20] Benoit B. Mandelbrot, *Fractals: Form, Chance, and Dimension* [1975], (San Francisco: W. H. Freeman, 1977), p. 10 – 11 and pp. 86 - 87.
[21] Mandelbrot reproduced this figure from Jean Parrin's book Atoms [1909]. Ibid., p. 11.
[22] Mandelbrot, *Fractals and an Art for the Sake of Science*, p. 15.

b. Generative Aesthetics

Parallel to the development of computers, after Norbert Wiener's influential books *Cybernetics*[23] from 1948 and *Cybernetics and Society – The Human Use of Human Beings*[24] from 1950, a new science called *Cybernetics* developed. The subject-matter of cybernetics as described by W. Ross Ashby is "all possible machines"[25]. Cybernetics, therefore, can be called the science of the universal machine, that is the all-purpose computer as envisaged by Turing. The concept of cybernetics, however, is not restricted to computers, but can also be used to describe the behaviour of human beings and their relationships and communication. This can be validated, if it is possible to prove that a computer can be used to simulate human behaviour. The term 'Artificial Intelligence' has since been introduced to describe machines that show human-like, intelligent behaviour.

Naturally, it is much harder to prove that two things are the same, than to prove that two things are different. One way to compare the performance of the computer with that of a human being is offered by the *Turing Test*. In a *Turing Test* a person does not know if he or she communicates with a computer or a human being. After a certain amount of communication the person is asked to say if he or she believed to have communicated with a real person. Such information can be evaluated statistically to determine if a difference between the human and the computer can be perceived. [26]

While this paper does not discuss metaphysical concepts about the ontological status of computers and human beings, it is important to note that one element in the early phase of computer art was the belief that the computer can not only be used as a tool for artists but also as their replacement. Between these extremes a variety of positions was possible. Noll, for instance, saw himself as a technician who developed applications for artists. He believed his own artwork was for demonstration purposes only.[27] Mohr thought that the artistic decision could not be replaced by the computer, although the computer might be necessary as an aid for the development of more complex concepts.[28] Max Bense introduced the term 'Generative Aesthetics' to indicate that an aesthetical object can be generated with the help of the computer. This is, however, only the second step. "Any

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[23] Norbert Wiener, *Cybernetics or Control and Communication in the Animal and the Machine* [1948], (New York, London: MIT Press and John Wiley & Sons, 1961).
[24] Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society* [1950], (London: Free Association Books, 1989).
[25] W. Ross Ashby, *An Introduction to Cybernetics*, (London: Chapman & Hall, 1957), p. 2. The book is available online at: http://pcp.vub.ac.be/books/IntroCyb.pdf.
[26] Davis, *Engines of Logic: Mathematicians and the Origin of the Computer*, pp. 199 - 207.
[27] Jasia Reichardt, *The Computer in Art*, (London, New York: Studio Vista and Van Nostrand Reinhold, 1971), pp. 25 - 26.
[28] Mohr, *[No Title]*, p. 95.

generative aesthetics which leads to an aesthetic synthesis must be preceded by analytical aesthetics."[29]

Fig. 6: Piet Mondrian, *Composition with Lines*, 1917.

Fig. 7: A. Michael Noll, *Computer Composition with Lines*, 1964.[30]

A simple example might be Noll’s *Computer Composition with Lines* from 1964 (fig. 7), which was generated from an analysis of Piet Mondrian’s *Composition with Lines* from 1917 (fig. 6). Noll analysed Mondrian's image in terms of lengths of lines and their distribution and created an algorithm that within the analysed parameters randomly generated an image. Frieder Nake applied the same principles to paintings by Paul Klee (fig. 8)[31].

The accuracy, in which a generated image replicates the source that was analysed to produce the algorithm, is dependant on the amount and quality of measurements. If many measurements are taken, the resulting images can resemble the source image very much. On the other hand, if only a few measurements are taken, the images can loose any resemblance to the source image. An artistic style, as could be associated with Klee or Mondrian, thus encompasses the repertoire of the artist without over determining the result.

Noll’s *Computer Composition with Lines* was given to a hundred subjects to compare with Mondrian's *Composition with Lines*. The interesting, however unscientific, results showed that 59 per cent preferred Noll’s composition and only 28 could identify Mondrian’s

[29] Max Bense, *The Project of Generative Aesthetics*, p. 57, in: Jasia Reichardt (Ed.), *Cybernetics, Art and Ideas*, (London: Studio Vista, 1971), pp. 57 - 60.

[30] Noll, *The Digital Computer as a Creative Medium*, pp. 156 - 57.

[31] For a detailed description of Nake's work on Klee see: Frieder Nake, *Ästhetik Als Informationsverarbeitung: Grundlagen Und Anwendungen Der Informatik Im Bereich Ästhetischer Produktion Und Kritik*, (Wien and New York: Springer-Verlag, 1974), pp. 214 - 20.

composition[32]. Noll's 'Mondrian-Algorithm' was in fact closer to what people believed to be a Mondrian than the actual Mondrian itself.

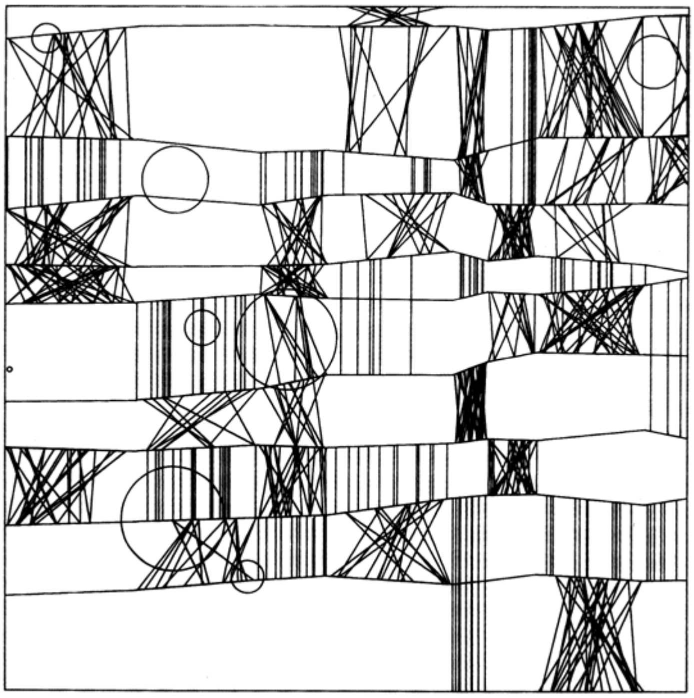

Fig. 8: Frieder Nake, *Klee*, 1968.[33]

Such a result does naturally not call the 'real' Mondrian into question. It gives, however, an indication that artworks created on the basis of generative aesthetics were able to achieve some sort of recognition insofar as they were able to produce something new on the basis of rules and chance. The method, with which this was achieved, is made explicit by Franke, in this instance talking about music: "The first task is to establish stylistic laws by means of a program. These might take the form of fixed instructions, perhaps a veto on the succession of certain harmonies, or else of probabilistic laws such as might indicate the frequency of the appearance of sound sequences. During the actual production phase, the random number generator offers one number after the other, and the program tests these for conformity to the stylistic rules."[34] The random number generator takes a crucial position in this concept, since without random numbers nothing new can be introduced into the algorithm. The random generator can thus be thought of as a novelty generator. The introduction of novelty into machines for artistic practice is indeed an important development, although it is arguable that to do something new or different is already a sign of intelligence or creativity as has been suggested by cybernetic reseach.

[32] Noll, *The Digital Computer as a Creative Medium*, pp. 156 - 57.
[33] Franke, *Computer Graphics - Computer Art*, p. 112.
[34] Ibid., p. 29.

In *Computer Graphics – Computer Art,* Franke sees the use of the random number generator as so decisive as to distinguish between computer art, where the artist uses the computer for his ends, and a "fully mechanised art", in which the artist is redundant.[35] According to Bense such generative aesthetics substitute even the uniqueness of an artist's individual artworks, since every work created with the help of a random generator is different.[36] The randomised algorithm's property to produce new and possibly unpredicted results can even work against the artist, when he or she wants to control the image to a greater degree, as Parslow and Pitteway report: "Every picture is an original. The computer never repeats itself, to the disappointment of an operator who on one occasion was unable to repeat a very effective surrealistic bull that was unfortunately produced under test conditions".[37]

According to the concept of Generative Aesthetics the algorithm produces a style which varies with the random numbers used. Although the algorithm does not determine the image in its detail, it is that piece of information that makes the artwork specific, whereas random numbers are unspecific and can be used in very different algorithms. While, in the 1950s the bad artist was the one whose variations were too predictable[38], by the 1960s and 70s the emphasis shifted to the rules as the place where the art lies. Instead of calling the artist the person who creates a very novel variation of a style, an artist is now seen as that person who invents his or her own rules. As Franke wrote in 1971: "As has been pointed out it is not the individual productions that are the real results of creative activity".[39] It is remarkable, that such an insight came on the last pages of his book under the heading "The Future of Computer Art". This shows how very recent in the development of the computer the rules and concepts guiding the applications entered the artistic realm.

In general, generative aesthetics uses the double structure of creation followed by a selection process. In the early period discussed above creation was nothing more than the creation of a simple random value. Apart from technical issues concerning the generation of random numbers, the work focused on algorithms used for selection often won through an analysis of existing artworks. It is important to note that the to-be-created aesthetic structure is accepted or rejected on the basis of accepting or rejecting the random values

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[35] Ibid., p. 57.
[36] Bense, *The Project of Generative Aesthetics,* p. 60.
[37] Robert Parslow and Michael Pitteway, *Computerart Panelling,* in: Jasia Reichardt (Ed.), *Cybernetic Serendipity: The Computer and the Arts,* (London, New York: Studio International, 1968), p. 90.
[38] As an example might serve J. R. Pierce: "[I]t is easy to agree that a truly bad poet never, or almost never, writes a good line. One might think that a good line would appear occasionally by chance. The trouble is that chance has no chance to operate. The bad poet is simply too predictable." J. R. Pierce, *A Chance for Art* [1950], p. 51, in: Jasia Reichardt (Ed.), *Cybernetics, Art and Ideas,* (London: Studio Vista, 1971), pp. 46 - 56.
[39] Franke, *Computer Graphics - Computer Art*, p. 122.

used to create it and not the structure itself that is the result. Such an approach, in a way, controls the outcome by the input possibly rejecting suitable outcomes without anticipating them. Especially when multiple random numbers are needed, and when these numbers are multiplied with each other on different levels of the algorithm, large amounts of objects can be created that appear essentially different.

One possibility is to introduce complex rules for the rejection of random numbers. The other possibility is to create the aesthetic object rejecting it *after* it has been completed. Rules for rejection can be applied by the computer, although such an approach makes it much easier for the artist to choose, since he or she chooses amongst aesthetic objects rather than numeric ones.

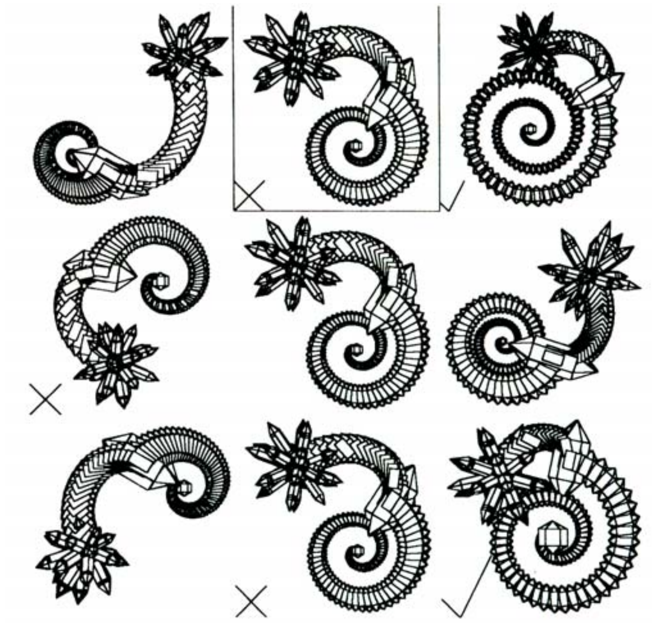

Fig. 9: Example of Todd's and Latham's *Mutator*.
The ticks and crosses indicate judgements the artist has made on the forms.[40]

An example for such an approach is Stephen Todd's and William Latham's practice, which they term 'evolutionism'. A program called 'Mutator' (fig. 9) produces families of shapes, which are presented to the artist for selection. It is close to the concept of evolution, "but with 'survival of the fittest' replaced by 'survival of the most aesthetic'."[41] Through such an approach artworks can be created were casual selection yields unexpected results. Given the fact that many possible families of shapes are rejected during the generation phase, 'evolutionism' can also be understood as a way of navigating through all possible shapes in a situation where the sheer amount of possible shapes exceeds human anticipation.

[40] Steven Todd and William Latham, *Evolutionary Art and Computers*, (London: Academic Press, 1992), p. 25.
[41] Ibid., p. 21.

Although this method was shared by Karl Sims, more recently he automated the selection process as well as the creation process. Sims replaced aesthetic rules by 'fitness measures' dependant on the preset goals. Because the artist is little involved in generating the shapes over a longer period of time, results are almost impossible to predict. Sims gives an interesting example for a goal defined as 'to move': "In this one example, the creatures got taller and taller and taller and would simply fall over. Instead of figuring out some clever way of walking, they would fall and generate horizontal velocity. [...F]alling was a perfectly reasonable solution as far as they were concerned. So this creature specialised in falling for as long as it possibly could, including doing a complete somersault."[42] (see fig. 10)

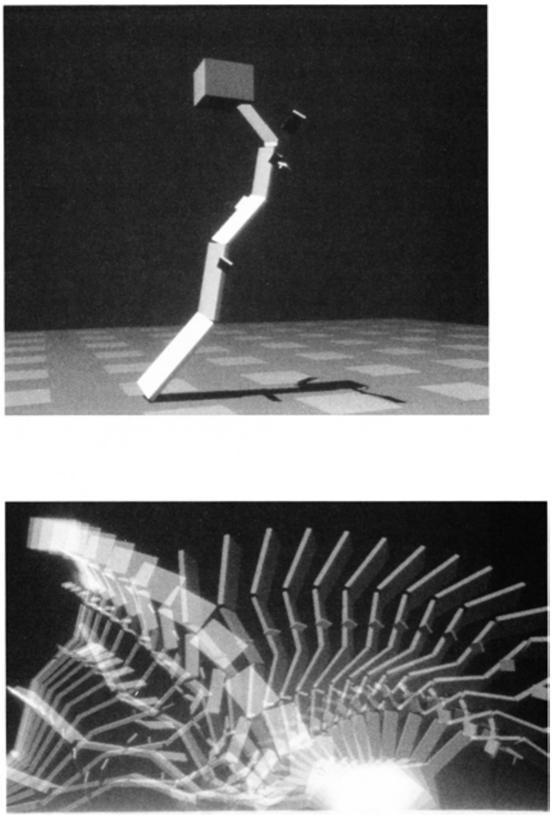

Fig. 10: Karl Sims, example of a moving figure.[43]

The last two examples are more recent developments (from the 1990s). I included them here to show that the future of generative aesthetics laid in systems of 'Artificial Life', rather than in more profound simulations of human creativity. The difficulty for generative aesthetics from the 1960s was the complete arbitrariness of aesthetic rules as means of selection. The use of modern art for generative aesthetics was replaced by a more speculative approach within the same rules of creation and selection.

[42] Steven Holtzman, *Digital Mosaics: The Aesthetics of Cyberspace*, (New York: Simon & Schuster, 1997), p. 94.
[43] Ibid., p. 95.

c. Image Processing

Unlike algorithmic art and generative aesthetics both of which create images, image processing works on existing images and became possible with the invention of the scanner in 1957. A scanner is a device which translates the analogue colour distribution of an image into numerical values held in the memory of the computer. To this end, the image is divided into a grid of cells (or pixels). The size of these cells is dependant on the resolution of the scan. The resolution indicates how many pixels per inch or centimetre the scan should read in. If the resolution is too low, details of the image are lost, because all image information within a cell is represented in a single number. Increasing the resolution of a scan allows to read-in more detail of the source image. To do so, more memory space is needed in the computer to hold the extra pixels.

A second factor that affects the computer memory needed to represent an image is the 'colour depth' of an image. The 'colour depth' indicates how much memory per pixel is used. If a colour depth of 1 bit per pixel is used, each pixel can only be in one of two colours (for example, black or white). If 2 bit are used, there are four possible colours, with 4 bit 16 and so on. The number of possible colours is equal to $2^{\text{bit-count}}$.[44]

Within the constraints of resolution and colour depth analogue images can be scanned in and processed. A simple image processing algorithm can be the decrease of the bit-per-pixel, which transforms an image of many colours into an image with less colours or even into a monochrome.

The scanner provides a device to read images into the computer. It was not until the 1970s, however, that adequate output devices for such images were developed. With the exception of the scanner, all early image computation was based on vector mathematics, which could suitably be represented with the first two output devices the Cathode Ray Tube (CRT) and the plotter. In both cases a shape is composed of line segments that are drawn onto the CRT by shifting the electron beam or onto paper by moving the pen of a plotter. In vector graphics the algorithm 'knows' how to construct an image and which line segments are used to construct a shape.

From the 1970s raster displays, in which the display is divided into many dots similar to television displays, and dot matrix printers allowed for the first time the direct output of scanned images. Such graphics were called raster, matrix, or bitmapped graphics to illustrate that the images were composed of an array of individual dots.

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[44] Charles Petzold, *Programming Windows*, (Redmond: Microsoft Press, 1999), pp. 643 - 44.

During the 1960s before the invention of bitmapped graphics, it was necessary to convert the image information held as a matrix of numerical values into images suitable for vector output. Such conversion posed a difficult problem, since individual pixels that are located next to each other in a matrix do not necessarily belong to the same line segment or shape. Instead of developing a complicated software that interprets bitmapped graphics as composed of vectors, programmers identified each pixel with one or more miniature vector graphics depending on the colour value of the pixel. Moreover, the plotters used at the time could only print in one colour (usually black). Therefore, it was necessary – similar to printed images – for these miniature vector graphics to be composed of a black and white pattern that resulted in the same average reflection than the tone itself.

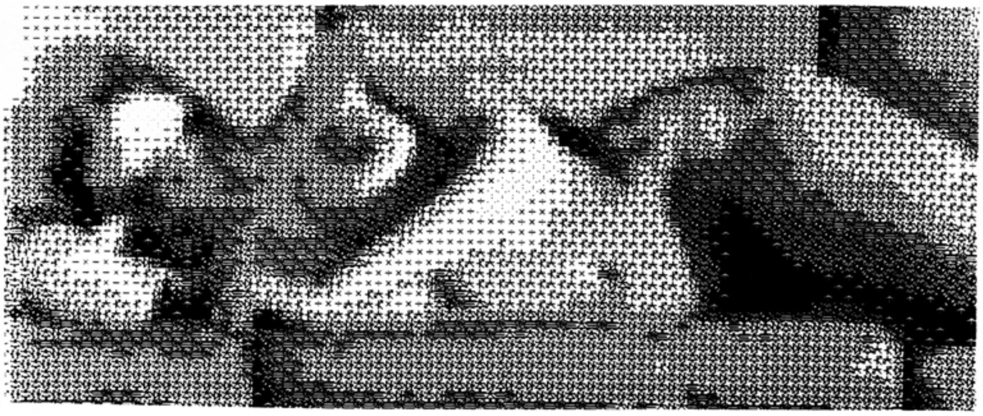

Fig. 11: K. C. Knowlton and L. D. Harmon, *Mural*, 1966.[45]

One of the first examples of images produced with this method is Kenneth C. Knowlton's and L. D. Harmon's *Mural* from 1966 (fig. 11). The image consists of 100 x 40 pixels. Each pixel can be represented in one out of 8 possible grey tones, which equals a colour depth of 3 bit. The pixels are mapped to 12 symbols, two for each level "to avoid monotony" (Knowlton and Harmon) out of which one is randomly picked at a time, plus black and white. The symbols used for *Mural* are symbols that are normally used for the design of electronic circuits (i.e. transistor, zener diode, vacuum triode etc.)[46]

Harmon and Knowlton distinguished three different viewing levels. "At closest view one can see the individual […] symbols. At the next level the sub-patterns are evident. Finally, at sufficiently great viewing distance […], the overall picture (original) becomes clear."[47] They compared these viewing levels with the raster of newsprint photographs, which do not have any symbolic meaning. Harmon and Knowlton, on the other hand, made choices

[45] Reichardt, *The Computer in Art*, p. 20. I was unable to verify, if the image is the right way around. Some reproductions show the nude lying from the left to the right.
[46] For a description of *Mural* see: Jasia Reichardt, *Cybernetic Serendipity: The Computer and the Arts*, (London: Studio International, 1968), p. 87.
[47] Ibid..

concerning the sets of symbols they are using for particular motives. *Telephone: Studies in Perception I* (fig. 12), for example, is composed of communication symbols (fig. 13). (In fact, one of the many symbols used is a telephone.) Such a choice illustrates how the image of the telephone is composed of our understanding of communication. As far as the choice of electronic symbols for the nude female body of the *Mural* is concerned, no further information is given.

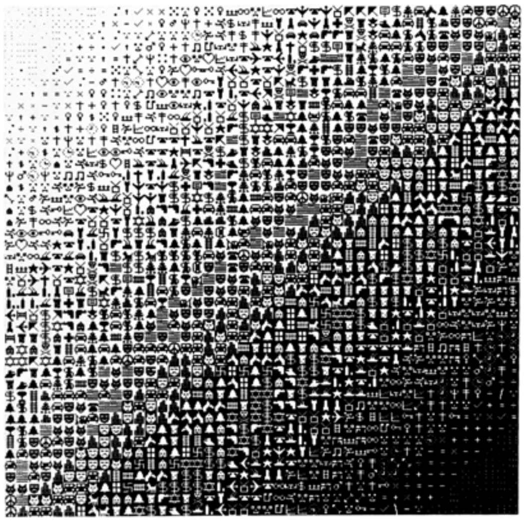

Fig. 12: K. C. Knowlton and L. D. Harmon, *Telephone: Studies in Perception I*, 1966.
Fig. 13: The set of communication symbols fig. 12 is composed of.[48]

Image Processing was amongst other activities also a concern of the Tokyo Computer Technique Group (CTG). Their practice exceeded the simple output of bitmapped information. Their re-working of an image of J. F. Kennedy in various forms can illustrate how transformational algorithms can be used on the same image information giving the resulting image a distinct look. In *Shot Kennedy No. 1* (fig. 14) lines, out of which a portrait of Kennedy is composed, are converging in a point above his right ear. This focal point of the image can be read as the point through which Kennedy could have been shot letting the dead Kennedy emerge from that centre. *Diffused Kennedy* (fig. 15) shows the same portrait of Kennedy more diffused the further away a point is from the left eye, making the portrait disappear or decompose into the ground. Finally, *Kennedy in a Dog* (fig. 16) shows an obviously different portrait of Kennedy superimposed on an image of a dog in profile.

In each of these cases, the image information was subjected to a transformation (which the CTG called "deformation"), which changed the meaning of the image. The image processing algorithm appears like an extra layer of meaning attached to the original image.

[48] Ibid..

The algorithm thus enhances or destroys certain features or, as the above examples show, interprets the image.



Fig. 14: CTG, *Shot Kennedy No.1,* [1968?].
Fig. 15: CTG, *Diffused Kennedy,* [1968?].
Fig. 16: CTG, *Kennedy in a Dog,* [1968?].[49]

Image transformation has greatly developed since the 1970s. This development is, however, seen more in terms of the technical development of algorithms used to transform images. The main goal has been to produce images that are as close to reality as possible. It is unclear how such 'realistic' transformations influence the meaning of an image. Today, especially in the advertisement industry, the meanings of images are shaped by subtle image transformations making, for example, colour *that* bit brighter or legs *that* bit longer while still maintaining a photographic representation of reality.

d. Paint Programs

Paint programs directly utilise the concept of bitmapped image representation. Whereas image processing algorithms manipulate the whole of an image or at least subsets of its pixels, paint programs are used to manipulate individual pixels by 'painting' right onto the memory space that holds the image. Although algorithms are used to perform this manipulation on the pixels, the change in colour values is due to the operator's choice of how each individual pixel should look like. To give an example, the operator can draw a blue line onto the memory space. Each colour value in the memory space that is covered by the blue line is replaced by a colour value representing blue. At no point, however, does the software construct a line. That is, the knowledge that the string of blue pixels represents a line is solely on the side of the operator.

[49] Ibid., pp. 75 - 76.

Such painting requires an interactive and graphic way in which the operator can paint on the memory space. As discussed above, one prerequisite is bitmapped images. To render bitmapped images interactive, a direct representation of the image on the screen is necessary. Consequently, frame buffers were invented that hold the image on the screen in a separate memory space. Changes in the frame buffer's memory directly result in a changed appearance on the screen. Additionally, it was important for the operator to physically be able to draw onto the memory, instead of using the keyboard to type in commands. *Sketchpad* was an early interactive device, in which an operator could paint onto the CRT using a light pen. In this case, the CRT itself functioned as memory. Since the 1980s, computer mice and graphics tablets have served as graphical input devices.

Fig. 17: Keith Haring, *Untitled*, 1983.[50]

According to Mike King, paint programs have since the 1980s revolutionised visual computer art.[51] This has various reasons. The shift to bitmapped images has liberated the production of images on the computer. In the bitmapped matrix, colour information sits next to each other independently. A change to one area of a 'classical' algorithmic image most likely affects all other areas of the image. In vector graphics, image information is linked together by the way the image is constructed. (The image is nothing more than the blueprint of a set of instructions to generate an image.) A paint program, on the other hand, offers exactly this possibility to alter a region of the image regardless. The artwork,

[50] Cynthia Goodman, *Digital Visions: Computers and Art*, (New York: Henry M. Abrams, 1987), p. 71.
[51] King, *Computers and Modern Art: Digital Art Museum*.

therefore, is much less under the control of the algorithm than under the control of the artist, who is able to change anything instantly.

Because of this, the computer screen can now be used very much like a painter uses the canvas. As Darcy Gerbarg reported: "Instead of mixing a palette of paint before beginning to paint, I mix light to create a colormap. Colormaps and palettes are very similar. Each contains a specific set of colors. When working with pigment, I would choose brushes of varing sizes according to my needs. On the computer I create the brushes I wish to use: thick ones, thin ones, multicolor ones."[52] Especially for artists who weren't so much interested in the materiality of paint on canvas, something the computer could naturally not provide, paint programs offered a good option. In 1984, Keith Haring criticised other artists in an interview in *Flash Magazine*, when he said: "Living in 1984, the role of the artist has to be different from what it was fifty or even twenty years ago. I am continually amazed at the number of artists who continue to work as if the camera were never invented, as if Andy Warhol never existed, as if airplanes, and computers, and videotape were never heard of."[53] Here, the computer's potential is almost experienced as normative, since it already defines reality in much the same way as modern air travel does. Haring also references Andy Warhol, whose work stands for a paradigmatic shift in the history of fine art.

Fig. 18: Andy Warhol, *Deborah Harry*, 1986.[54]

[52] Goodman, *Digital Visions: Computers and Art*, p. 63.
[53] Ibid., p. 71.
[54] Ibid., p. 89.

Warhol himself started to use the computer from the mid 1980s. *Deborah Harry* from 1986 (fig. 18) is an early example of Warhol's use of the computer. Images like these could be done in minutes that look "astonishingly like those it normally took him weeks to produce."[55] The computer's speed suited Warhol's industrial approach to the art very well.

Deborah Harry could also be used to illustrate how early experiments with image processing can be seen as close to the visual language of Pop Art. Reichardt gives an example of how M. R. Schroeder reproduced half-tone images on a black and white microfilm plotter. Schroeder superimposed various layers of microfilm exposed with only these areas of the image that were above a defined brightness threshold. The resulting image (fig. 19) is similar in image processing to an algorithm that reduces the colour depth to approx. 2 bit.

Fig. 19: M. R. Schroeder, [no title, before 1971].[56]

In contrast, *Deborah Harry* is made up of colours rather than of grey tones. For this reason, the colour depth, however, need only to be approx. 4 bit, with the colour of the hair mapped to a light green and the colour of the skin to blue. Processes like these are well within the realm of image processing. What is different, however, is the probable manual selection of areas to be mapped to a specific colour, as well as Warhol's direct painting onto the image, most prominently the thin green line that circles the face and Warhol's signature in the bottom left corner. (The image actually holds a third level of production of meaning, which is the software itself, expressed by the name of the software along the upper border of the image and the cross-shaped pointer towards the upper right corner.)

Paint programs did not only bring the computerised reality into painting and the reality of the artist into the computed image, they also brought the reality of the photographed (or

[55] Ibid., p. 86.
[56] Reichardt, *The Computer in Art*, p. 28.

filmed) image into the reach of the painter in a very direct way. A considerable part for the success of paint programs is that they have in fact merged with image processors allowing the photograph to replace the blank canvas and the artist not to start from nothing. Image processing can also be used as a post-production tool for computer painted images.

Naturally, algorithmic art could still be done in the 1980s and even within paint programs, but the use of the computer started to suggest that any artwork could at least be manipulated in the sense that there were no simple algorithms that the image represented. Moreover, the result did not tell the difference between a painted shape and a calculated shape. The majority of vector graphics we see today are in fact vectors projected onto the bitmapped memory space with the optimal resolution of the output device chosen.

For algorists such a potential was threatening because early computer art was equal to algorithmic art, whereas now they had to declare that they had not used paint programs.[57] For others, like Haring or Warhol, paint programs proved to be the breakthrough of the use of the computer in the visual arts. Such liberation did not only mean that artists did not have to be mathematicians anymore (or at least work closely with mathematicians). It also meant that the different approaches of algorithmic art, image processing, and paint programs could be mixed in a single image.

At the same time when paint programs were developed software in general had become so sophisticated that artists did not have to understand basic computing to do their work. Frame buffers, bitmapped images, and the graphical use of the computer have removed mathematical implications so far from the artist that with paint programs any image the artist wants to produce can now actually be produced. The all-purpose computer has become the all-purpose imaging tool.

[57] See above how in 1990, 30 years after the first algorithmic computer images some artists found it necessary to form a group that was defined through algorithmic art. See also Mandelbrot's insistence on fractal images being generated without any later manipulation.

3. Randomness and Information

Following this brief introduction into early computer art, I would like to focus once more on the theme of 'randomness', this time from a less pragmatic and more theoretical angle. This section will develop an understanding of how the concept of randomness is essential to an insight into 'information'. Information's dependence on randomness will be seen as a crucial break up from traditional concepts of meaning. Firstly, however, I will give a brief introduction into the special status of randomness in computing.

It is not difficult for a computer programmer to create a program that executes a command like: "Return the sum of 2 and 5.", whereas a command like "Return a number between 1 and 6." poses more complicated problems. The difficulty lies in the fact that the return value of the first command is unequivocal (namely 7), whereas the second is not (namely 1, 2, 3, 4, 5, *or* 6). To create random numbers, programmers have designed a special type of algorithm called 'random generator'. Random generators can produce random numbers only when fed with a 'seed'. A seed is a number taken from somewhere *outside* of the algorithm (usually the time, the temperature of the processor, or other sources accessible to the algorithm).

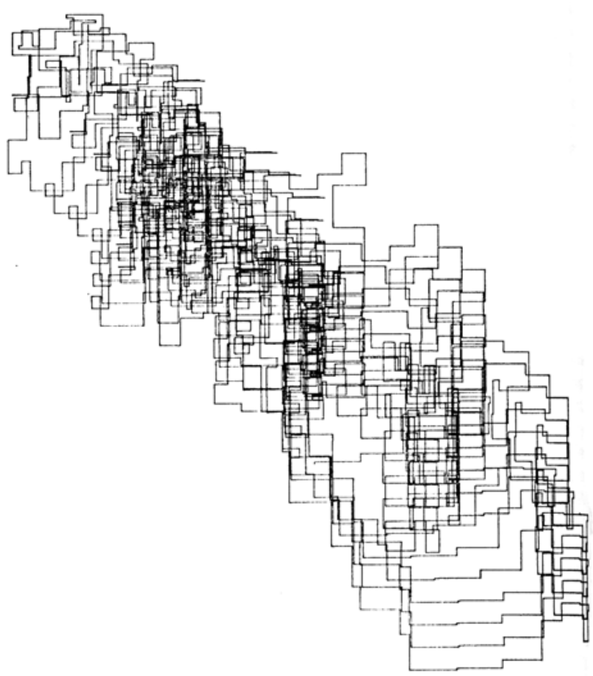

Fig. 20: Georg Nees, *Maze*, [before 1971].[58]

True random numbers based on external seeds were difficult to obtain in the early years of computer art. To work around this problem so-called pseudo-random numbers were

[58] Franke, *Computer Graphics - Computer Art*, p. 29.

introduced. These are calculated on the basis of irrational numbers (numbers that cannot be expressed as a fraction, thus having an infinite number of decimal places without ordering themselves into periodic sequences). For pseudo-random numbers an algorithm is used that is powerful enough for the numbers to appear as being random. However, pseudo-random sequences eventually start repeating themselves.

When I say that "sequences start repeating themselves", I actually imply that a specific rule becomes apparent that can be used to construct future sequences. The rule provides a shortcut to the sequence, that is a shorter way to construct the sequence than following one number after the other. The informational content of that rule is shorter (and thus requires less memory space) than the actual sequence itself. The relationship of the sequence to it's shortest expression is, according to Kolmogorov, a measure for the randomness of the sequence.[59] If the quotient is 1 it means that the shortest way to express a sequence is the sequence itself. Such a sequence can be considered to be absolutely random.

If, however, a sequence is not absolutely random an image created on its basis shows patterns that reflect the non-random structure of a sequence. Georg Nees' *Maze* (fig. 20) is created using an imperfect pseudo-random generator. Repetitive patters are clearly visible.

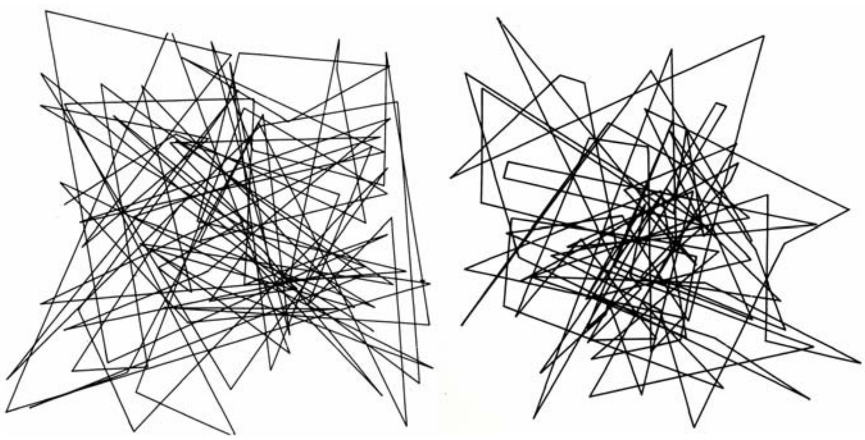

Fig. 21: A. Michael Noll, [no title, before 1971].[60]
The image on the left shows a uniform distribution of random coordinates linked with lines, the one on the right uses normal distribution that creates a higher density around the centre of the image.

Another element controlling the appearance of an image is the distribution of random numbers. In the same way as repetitive structures of pseudo-random numbers bring in

[59] Deborah J. Bennett, *Randomness*, (Cambridge, Massachusetts and London: Harvard Univesity Press, 1999), p. 163.
[60] Noll, *The Digital Computer as a Creative Medium*, pp. 150 - 51.

deterministic ingredients to a image, the distribution of numbers also shapes the appearance of an image (fig. 21).

Nees' and Noll's examples show how images can be influenced by the way random numbers are generated. Yet, they still show to a much greater degree their choices of how to plot lines according to the numbers obtained. Both, for instance, chose to use lines instead of circles or colours. An absolutely random artwork could in fact show anything.

Claude Shannon has argued in *A Mathematical Theory of Communication* from 1948 that such a random artwork[61] contains a maximum of information. This counter-intuitive argument becomes more understandable if one accepts the hypothesis that an artwork not only consists of information but also of redundant elements. Something is redundant if it does not add any further information to an artwork. Shannon claims, for instance, that approx. 50 percent of letters are redundant in the ordinary English language, that is, a text containing (the right) 50 percent letters less than its original could still be reconstructed.[62]

Redundancy, thus, reduces the informational content of an artwork. It, however, increases its comprehensibility for the human, who perceives the artwork. This is due to the fact that the information a human can register in a given time span is limited to, according to Abraham Moles, 16 bit per second[63]. An artwork that requires an information intake above this value contains too much information and is too complex. However, if it requires significantly less, it is considered banal, because it hardly gives any new information (respectively, because the image's content is mainly redundant).[64]

Entropy is the measure Shannon introduces for the quantity of informational content. The sum of redundancy and entropy equals 1. That is, all of that in an artwork, which is not information, is redundant with the same right that all that is not redundant is information.[65] However, this equation also states that everything (1 = 100%) in an artwork can be seen as either entropy or redundancy but nothing else.

The absolutely random artwork, to follow the above lead, is most likely some kind of 'white noise' comparable to the left image (fig. 22). For information theorists like Moles, such an artwork does not contain *no* information but rather *too much* information. "The lack of any spontaneous interpretation is from a theoretical point of view linked with too

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[61] Information theory generally deals with messages. In the context of this theory, works of art are considered to belong to the greater class of messages. For the purpose of this paper, I have replaced the term 'message' by 'artwork' in order to keep the text as specific as possible.
[62] Claude E. Shannon, *A Mathematical Theory of Communication*; available from http://cm.bell-labs.com/cm/ms/what/shannonday/shannon1948.pdf.
[63] Abraham A. Moles, *Kunst & Computer* [1971], (Köln: M. DuMont Schauberg, 1973), p. 18.
[64] Ibid..
[65] Shannon, *A Mathematical Theory of Communication*.

much informational content, whereas following the common psycho-aesthetic view it is linked to a lack of structure, inner organisation" [my translation M. Sc.].[66] For this reason entropy has been linked to disorder: the higher the entropy the more evenly information is spread out and the less obstructed this spreading of information is by a structure (the house in fig. 22 right).

Current algorithms for image compression (with no data loss) could be seen as a simple example to illustrate this. The more ordered information is put down on the image the smaller the resulting file size is. This is due to the replacement of repetitive structures by memory-saving calculations, a process similar to Kolmogorov's measure of randomness (see above). The more random an image (or a number, for that matter), the more information is needed to express it.

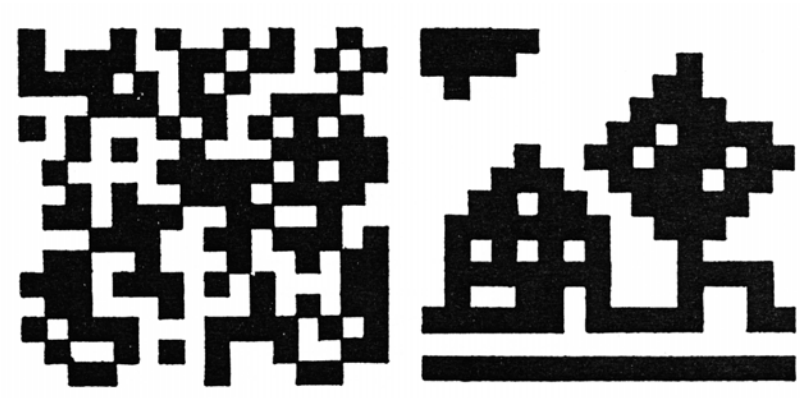

Fig. 22: Relation between the complexity of information and redundancy.
Moles uses the image on the left comprises more complexity, the one to the right more redundancy. Both images consist of the same amount of pixels.[67]

In summary, the informational approach to artworks locates two contradictory and supplementary properties in any work: redundancy and entropy. Information is identified with entropy and thus with randomness and disorder. Order, on the other hand, is a structure that is represented by an artwork's redundant elements. For humans, redundancy is necessary for the understanding of information.

The claim that the informational elements of an artwork would be located in its disorder provoked a response by Rudolf Arnheim in his essay *Entropy and Art* from 1971. If an artist, according to Arnheim, draws a line, it is this line that has informational value. Information has to be located in the structures of images. Still, according to Arnheim, both the artist and the information theorist follow the same economic principle. "Any predictable regularity is termed redundant by the information theorist because he is committed to

[66] Abraham A. Moles, *Informationstheorie Und Ästhetische Wahrnehmung* [1969], (Köln: M. DuMont Schauberg, 1971), p. 93.
[67] Moles, *Kunst & Computer*, p. 17.

economy: every statement must be limited to what is needed. He shares this commitment with scientists and artists"[68] Both, however, follow different economies. By rejecting information theory's approaches to art, Arnheim nevertheless accepts the validity of information theory. Arnheim argues that even the amount of repetitions in an artwork can be very important for the meaning of even the smallest unit. As Arnheim demonstrates with the drawing of a child (fig. 23), the meaning of the image changes if all windows of the house are drawn or if they are reduced into an instruction for their repetition.

Fig. 23: Child's drawing from Arnheim, *Entropy and Art*.[69]

For Arnheim the meaning of a work of art is what the work has to give, with what it informs. Such information is bound to an inner structure and not a random meeting of separate pieces. The image in fig. 22 on the right could haven been produced intentionally by drawing a house. It could also have happened by an unlikely chance event. For Arnheim the grid like structure of the image would already symbolise parts that are stuck together to form a house rather then elements that belong together.

Concerning the arts, Arnheim does not want to separate information from meaning. Information theorists like Warren Weaver, on the other hand, radically distinguish information from meaning and are only concerned with the informational elements of things. For Weaver the term 'information' has to be kept distinct from the term 'meaning'. "In fact, two messages, one of which is heavily loaded with meaning and the other of which is pure nonsense, can be exactly equivalent, from the present viewpoint, as regards information."[70] For Arnheim's understanding of art, on the other hand, both message are clearly different.

[68] Rudolf Arnheim, *Entropy and Art: An Essay on Disorder and Order*, (Berkeley, Los Angeles, and London: University of California Press, 1971).
[69] Ibid..
[70] Warren Weaver's preface to: Shannon, *A Mathematical Theory of Communication*.

The two 'economies' (to use Arnheim's term) that can be identified are the *economy of meaning* and the *economy of information*. Arnheim's essay can be seen as a response to the socio-cultural shift towards an understanding of art as message, which can be split into its informational components. To understand the economy of information, it is important to see that meaning plays only a secondary role. Information does not exclude meaning. However, it receives its validity not from the meaning as Arnheim maintains, but from the randomised originality and the entropic character of the message. The possibility of meaningless information in both understandings as pointless and as devoid of meaning might be the reason for the historical success of the paradigm of information, which has led the world into the 'information age'. Fig. 23, for example, shows details of fig. 12. The David's star, the Dollar sign, and the swastika are taken by Knowlton and Harmon for their informational value (the relationship between black and white in the icons) and not for their meaning. The three signs have actually been used interchangeably in *Telephone* without making any informational difference. Stripping the icons bare of their meaning is significant for the way information is used in the economy of information.

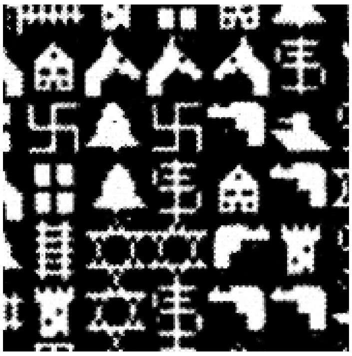

Fig. 24: Magnification of fig. 12

The economy of information can, to give another example, be traced to the foundations of modern statistics. Statistics generally deal with measurements collected from the 'real world'. In order to obtain a finding relevant to the 'real world' the collected data is tested against the possibility that the finding is due to random errors of measurement or chance alone. For this reason the measurements have to be taken randomly (random sampling).[71] If data is not collected randomly, a finding can result from sample selection biases. The randomness of the sample ensures the informational quality of a finding. The finding gets its meaning, however, only when re-applied to reality. (For instance, the knowledge, that the average age is, say, 70 has relevance for me only when compared to my age.)

[71] Bennett, *Randomness*, p. 110.

This theoretical result can practically be traced in some of the artwork examined in section 2. Here, I will focus on Noll's work on Mondrian and Nake's work on Klee as discussed in Section 2b. Both artists (Noll and Nake) developed algorithms that simulate the style of Mondrian and Klee. The algorithms produced variations of these styles with the help of random numbers.

The algorithm (that is the style expressed in mathematical terms) orders random numbers offered by the random number generator. This order was pre-established by the analyses of given artworks. Although the order might interpret these and create something new in comparison to the original Mondrian or Klee images, the order represents the static and therefore redundant elements across the sets produced. The random numbers is the only things that is new in each image. This newness gives them their informational character, since information was understood as that that does not repeat itself and is therefore not redundant.

Noll's and Nake's work shares two major characteristics. The first is their use of algorithms. The algorithms define a style that in their cases is oriented by works of modern artists. These algorithms mainly consist of the construction of redundant structures. These structures are, following Arnheim's opinion, the site where meaning can be attached. Secondly, however, the algorithms are open to random numbers. The images, in a way, show the random numbers through the algorithms. Information can be seen as visualised through redundancy. Meaning breaks away from information, since one has to look through meaning to see the information. In this way, meaning is a secondary concept.

Both artists have, in fact, focused their work on the relationship to style (Modrian's, Klee's, or their own) in order to produce images that could be aesthetically compared to their sources or as an artwork in its own right. They have not followed Mohr's dictum that criteria of 'good' or 'bad' cannot be applied anymore (see section 2a). Because of this, they did not display variations of their algorithms that would have allowed a better understanding of the image's informational dimension. Moreover, both artists displayed their work next to the 'original' Mondrian or Klee, emphasising the redundant aspects of their work.[72] This can be seen as mixture between the economy of meaning and the economy of information. The informational character of the work is apparent, but it has yet to break free.

In his book *Ästhetik als Informationsverarbeitung* from 1974 Nake contemplated a "simple algorithm […] that could create all objects of a class by going through all possible

[72] See: Noll, *The Digital Computer as a Creative Medium*, pp. 156 - 57. And: Nake, *Ästhetik Als Informationsverarbeitung: Grundlagen Und Anwendungen Der Informatik Im Bereich Ästhetischer Produktion Und Kritik*, p. 215.

combinations. Such an algorithm would be as simple as it was useless. Because, in the face of the gigantic size of these classes it would take thousands of years before a first 'interesting' object was created." [my translation M. Sc.][73] What Nake calls 'useless' is in fact the absence of redundancy caused by the aesthetical implications of an algorithm that imposes a style and a shortcut to interesting images.

Twenty-five years later John F. Simon created *Every Icon* (fig. 25), a web application that consists of a 32 by 32 pixel grid, in which each pixel can be either white or black. In time *Every Icon* will literally have created every possible icons (there are 2^{1024}) giving each icon the same significance. Simon estimates that it will take several trillion years to display all possible icons.

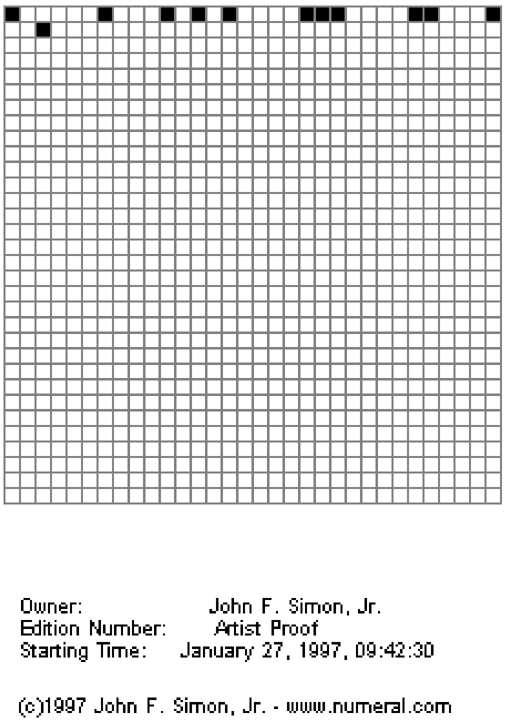

Fig. 25: John F. Simon, *Every Icon*, 1997.[74]

Simon embarked exactly on the mission Nake though fruitless. The "simple algorithm" Simon uses to display all possible icons is indeed a very simple one: it counts! In the above example (fig. 25) *Every Icon* has counted to 9868694593. 9868694593 is the decimal value of the binary term 1001001100001110000101010001000001 as which fig. 17 can be read when every black pixel is expressed as 1 and every white pixel as 0. The upper left corner, that is the start field, is the last digit of the binary term. Once the end of the first line is reached, *Every Icon* starts the second line from the pixel furthest left. Instead of having a

[73] Nake, *Ästhetik Als Informationsverarbeitung: Grundlagen Und Anwendungen Der Informatik Im Bereich Ästhetischer Produktion Und Kritik*, p. 104.
[74] *Every Icon* is accessible online at: http://www.numeral.com/everyicon.html

32 by 32 matrix, one actually has a 1024 spaces long string as a result when all 32 lines are glued together. (For the number given above, I have omitted all white fields (=0s) after the last black field.)

Counting is indeed devoid of any aesthetic structure or artistic style. The icons are assembled not in regard of their meaning but as a pure calculational possibility. In the press review for *Every Icon* written by Matthew Mirapaul for the *New York Times'* website *Arts@Large* in 1997, Simon is quoted saying: "There was a lot of talk at the end of the 80's when post-modernism was emerging about how we've reached the end of imaging, and I wanted to show that even in a simple 32-by-32 space, the possibilities for imaging were vast." Mirapaul adds: "Most of the images will have no value, a realization which in turn deepens one's appreciation for the range of choices that artists must confront and discard daily."[75]

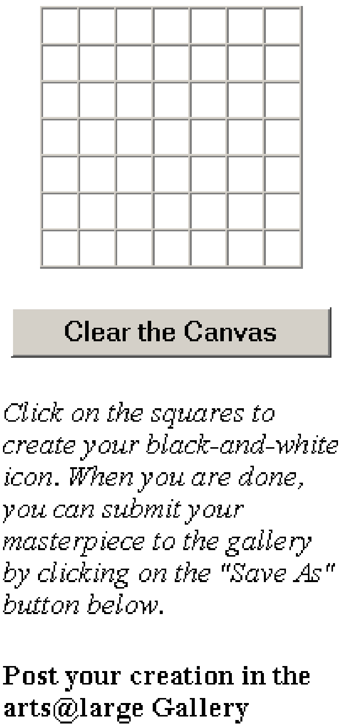

Fig. 26: Part of Arts@Large website, 1997.[76]

In the economy of information the artist is not understood as creator, but as selector who is immersed in a sea of possibilities. These possibilities are pre-created by the economy of information, which offers single possibilities for meaningful approval. The economy of

[75] The review is not online at the *New Nork Times* anymore, since they have taken down their Arts@Large website in 2000. A copy of the article can be found on Simon's site. Matthew Mirapaul, *In John Simon's Art, Everthing Is Possible*; available from http://www.numeral.com/articles/041797mirapaul/041797mirapaul.html.
[76] See previous footnote.

meaning that is secondary in this example discharges the majority of images as having "no value" (Mirapaul).

When *Arts@Large* was still online, it offered readers the service to create their own 9 by 9 icon, which could be uploaded onto the online gallery (fig. 26). By producing a miniature version of an icon, the reader was asked to simulate *Every Icon* that simulates every icon. In remembrance to the creation of meaning, the reader's icons could be published as a "masterpiece" in the online gallery.

With the example of *Every Icon*, I described the economy of information in two ways. Firstly, the artwork itself uses exclusively informational criteria (calculation) to produce images. Secondly, the media event of *Every Icon's* review in the *New York Times* informs us about the artwork. Simon's and Mirapaul's attempt to re-inscribe meaning into the images, by allowing the readers to create their own icon and by interpreting *Every Icon* as contribution to the understanding of the process artists go through when creating meaning, shows how helpless the search for meaning in the economy of information.

In this section, I reflected on the uses of randomness in early computer art. Randomness proved to be suitable for the introduction of the concept of 'information', which has to be held separate from that of 'meaning'. As an example, I showed how early computer art had not radically embraced the informational paradigm that has become more apparent since. By introducing a much later example of computer art and part of its reception, I highlighted the relationship to meaning that is at stake when art becomes "Information Art".[77]

[77] See: Stephen Wilson, *Information Arts: Intersections of Art, Science, and Technology*, (Cambridge, Massachusetts and London: MIT Press, 2002).

4. Conceptual Art and Beyond

Instead of focusing on the dichotomy between meaning and information, I would like to follow a different path. What interests me is not so much art that opposes the economy of information by caving itself into a paradigm of meaning, but rather art that responds to the challenge information theory poses.

Some Conceptual Art can be seen as such an art. Lucy R. Lippart and John Chandler in their essay *The Dematerialization of Art* from 1967 agree on Arnheim's (later) position that meaning is a property of order, which the artist bring into a work when they say: "Order itself, and its implied simplicity and unity, are aesthetic criteria."[78] However, they only agree in order to reject art "that is an end in itself"[79]. For them, dematerialised art offers a "post-aesthetic" option in the historical sense of the term. To paraphrase their point, it can be said that for them aesthetics are redundant rather than information. It should, however, be noted that such a historical perspective uncritically subscribes to a progressive model of knowledge.

Post-aesthetic art draws its inspiration from an idealised end state of disorder and randomness, which, in an a-historical move, is taken as current reality and as a challenge to understanding and artistic production. Reality is believed to be in a disordered and chaotic state. According to Lippard and Chandler, reality has to be held separate from realism and other formalist varieties of art. Conceptual Art does not screen reality believed to be arbitrary. It assists the viewer in his or her quest for reality, thus repositioning the artwork. Only by dematerialising it can the art-object become a function of reality. In this way, Conceptual Art repositions the triangle of viewer, art, and reality.

According to Sol LeWitt, in Conceptual Art "[t]he idea becomes the machine that makes the art."[80] The artistic focus shifts from the set of images as countable objects to the production of images as an active process. In his "Sentences on Conceptual Art"[81] from 1969 LeWitt describes that "new experience" (sentence 3) is made when an idea is applied methodically (sentence 29) to the end (sentence 22). The concept, however, that is carried out by the ideas has to link the ideas illogically (sentence 11) or draw irrational conclusions from them (sentence 3.) The ideas have to be followed through, if new

[78] Lucy R. Lippard and John Chandler, *The Dematerialization of Art* [1967], p. 48, in: Alexander Alberro and Blake Stimson (Ed.), *Conceptual Art: A Critical Anthology*, (Cambridge, Massachusetts and London: MIT Press, 1999), pp. 46 - 50.
[79] Ibid., p. 49.
[80] Sol Lewitt, *Paragraphs on Conceptual Art* [1967], p. 12, in: Alexander Alberro and Blake Stimson (Ed.), *Conceptual Art: A Critical Anthology*, (Cambridge, Massachusetts and London: MIT Press, 1999), pp. 12 - 16.
[81] Sol Lewitt, *Sentences on Conceptual Art* [1969], in: Alexander Alberro and Blake Stimson (Ed.), *Conceptual Art: A Critical Anthology*, (Cambridge, Massachusetts and London: MIT Press, 1999), pp. 106 - 08.

experience is to be achieved (sentence 6). Ideas can, in fact, be seen as algorithms since they form the mechanical elements of Conceptual Art. Following LeWitt's view, computer art can be seen close to Conceptual Art.

Edward A. Shanken has highlighted this proximity in his article *Art in the Information Age: Technology and Conceptual Art* by focusing on the exhibition *Software, Information Technology: Its New Meaning for Art* curated by Jack Burnham in 1970. Shanken stresses, that for Burnham the term 'software' "parallel[ed…] the aesthetic principles, concepts, or programs the formal embodiment of actual art objects, which in turn parallel 'hardware'.[82] Especially the conceptual artists shown in the exhibition have played with the notion of software and information outside of their application in computer technology.

Fig. 27: Les Levine, *Systems Burn-Off X Residual Software*, 1969.[83]

Les Levine, for instance, contributed *Systems burn-off X Residual Software* from 1969. Levine scattered around 1000 x 31 photographs of one of his earlier exhibitions, *Earth Works*, a show that attracted much public attention. The photographs are the residues of an information spectacle, which was his show. In his artist's statement, Levine writes: "The experience of seeing something first hand is no longer of value in a software controlled society […M]ost of the art that is produced today ends up as information about art."[84] The term 'software', in this understanding, describes control mechanisms on a larger scale as long as these are not biologically or otherwise determined factors but rather socio-cultural realities. Society is compared to a computer that functions following a set of immaterial instruction and produces information. Levine's installation adds an extra layer to this

[82] Edward A. Shanken, *Art in the Information Age: Technology and Conceptual Art*, *Leonardo* 2002, p. 434.
[83] Image is taken from: http://www.c3.hu/collection/koncept/images/bekekepek.html [The image has still to be verified M. Sc.]
[84] Quoted in: Shanken, *Art in the Information Age: Technology and Conceptual Art*, p. 434.

concept, since it incorporates the photographs as information in order to create new information. As Shanken puts it: "*Systems Burn-Off was art as information about information about art.* [Shanken's italics]"[85]

Joseph Kosuth contributed his *Seventh Investigation (Art as Idea as Idea) Proposition One* (1970) to Burnham's exhibition. *Seventh Investigation* consists of a set of six propositions, which were shown on advertisements, billboards, newspapers, and banners.

> (1) to assume a mental set voluntarily
> (2) to shift voluntarily from one aspect of the situation to another
> (3) to keep in mind simultaneously various aspects
> (4) to grasp the essential of a given whole; to break up a given whole into parts and to isolate them voluntarily
> (5) to generalize; to abstract common properties; to plan ahead ideationally; to assume an attitude towards the 'mere possible' and to think or perform symbolically
> (6) to detach our ego from the outer world[86]

Although Kosuth himself did not make explicit reference to Burnham's concept of software, his *Seventh Investigation* can be understood according to it. The subtitle Kosuth gives the work 'Art as Idea as Idea' parallels Levine's multiple layers of information. The *Seventh Investigation* is a set of instructions (first level of ideas) that has to be followed through to produce ideas (second level of ideas), which function as art.

With Conceptual Art the paradigm of 'information' has been absorbed into the arts. According to Burnham, "[t]he conceptualists have objectified the dissemination of art information [...]. This is the result not of centering interest on content but, as in information theory, on the nature of information itself."[87]

Conceptual Art as Burnham presented it in his *Software* exhibition as well as in his writing can indeed be aligned with information theory. That is, firstly, because the aesthetical order of the material object is made redundant, secondly, because concepts can be broken down to a set of instructions similar in function to computer algorithms, and finally, because information itself forms the centre of attention.

Taken by this bare bone, Conceptual Art represents a shift out of the art world's traditional economy of meaning into the new economy of information that formed around the same

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[85] Ibid.
[86] Cited in: Ibid., p. 435.
[87] Jack Burnham, *Alice's Head: Reflections on Conceptual Art* [1970], p. 218, in: Alexander Alberro and Blake Stimson (Ed.), *Conceptual Art: A Critical Anthology*, (Cambridge, Massachusetts and London: MIT Press, 1999), pp. 216 - 19.

time. Within Conceptual Art there are, however, various different approaches some of which additionally engage into a critical discourse with and about information from within.

Sol LeWitt's emphasis on the completion of an idea to its end has already been mentioned. His approach implies the execution of the concept, which might result in "new experiences". Although the concept does not have to be materialised, it has to be realised and gone through until its end. In Kosuth's case, even more pronounced than in Levin's, the artwork emerges from an activity, which is directed or triggered by the artist. Although the trigger or the directions are materialised, the resulting artwork is not, although it needs to be realised by the spectator.

The increased activity for the spectator that Lippard and Chandler find symptomatic of Conceptual Art[88] resembles the procedural character of the computer. In Kosuth's *Seventh Investigation*, the conceptual artist is comparable to a programmer. In other cases, the artist can also be compared to the computer itself when he or she methodically follows (his or her own) instructions. There is a number of conceptual or non-conceptual artists, who are manually performing operations, which the computer could perform. I have mentioned Bridget Riley in section 2a already, when Noll compared her work to be close to algorithmic art. Other examples include the work of Hanne Darboven, who frequently uses the act of writing, or the drawings of Wendy Smith, who uses simple patterns she repeatedly copies onto the paper to form a complicated figural image. In any of these cases, the activity of *making* the artwork seems to add a different quality.

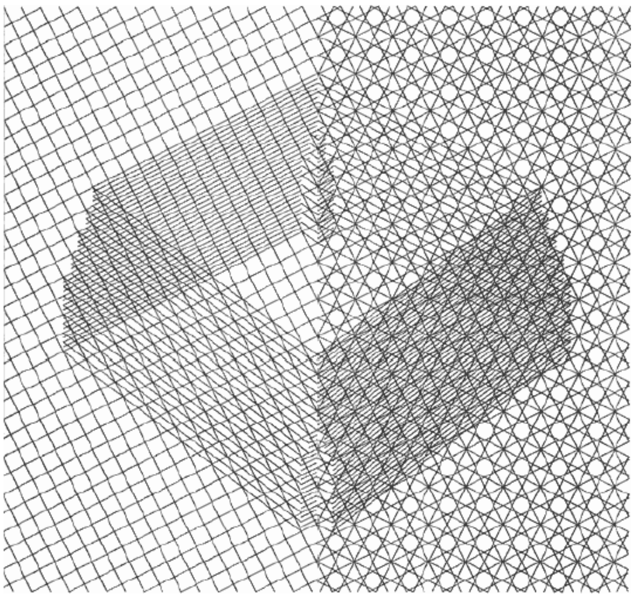

Fig. 28: Wendy Smith, *Verso / Recto VI* [no year][89]

[88] Conceptual artworks "demand more participation by the viewer". Lippard and Chandler, *The Dematerialization of Art*, p. 46.
[89] The image is taken from http://www.domobaal.com.

When concepts are realised on the computer they presumably have little effect on it. In the case of the artist or the spectator, the process of realising the artwork is accompanied by experience, or as Shanken writes, concerning Kosuth's *Seventh Investigation,* the propositions "demand that the viewer examine the process of processing information, *while in the process of doing so* [Shanken's italics]."[90]

It can, however, not be said that the making of an artwork, be it as immaterial as possible, is necessary for Conceptual Art. In fact, one ways to determine if an artwork is conceptual or if it just uses conceptual aspects is to question if the realisation of the artwork is unimportant for the artwork. I believe that for a critical engagement with the economy of information the effect the realisation of a work has on whoever realises it is more important than the art object's ontological status.

Based on this, one can say that the majority of computer artists, whose work I have discussed in section 2, never *really* made their images – that the images never were made *real*. The computer artist in general merely creates the potential for the work. He or she delegates its execution to the computer. The need for an execution moves the character of the computerised artwork away from the materialised object and towards the temporal creation of images, which emphasises the algorithm's active potential to generate. It, however, also emphasises the image's mode of being, that of a possibility striving towards reality.

[90] Shanken, *Art in the Information Age: Technology and Conceptual Art*, p. 435.

Conclusion

In this paper, I have traced the origins of computer art by exploring four different uses of the computer in artistic practice. This categorisation gives a systematic view over the most fundamental ways computers can be used with a particular focus on visual practice.

Algorithmic Art is the most basic practice. It can be understood as the visualisation of computer algorithms. Based on this, *Generative Aesthetics* developed as a way to employ algorithms to substitute at least part of the artist's role in the creative process. With *Image Processing* computer art moved outside of the mathematical domain, since this allows existing images that are not expressed in mathematical terms to be fed into the computer. *Paint Programs* directly utilise this non-mathematical approach to image production and allow direct manipulation of selected areas of the image.

I have based this classification on a very brief history of computing, which focuses in particular on the computer as a universal machine. Any of the different approaches of image-making discussed, utilises the concept of the computer as the universal machine. In fact, the machines used for imaging are a subset of all possible machines. As we know today, the computer has enjoyed similar developments in all areas of human activity.

In imaging, the computer can indeed be seen as the universal image generator. Only with image processing and paint programs, however, has the computer come of age. This is partly due to the shift from the constructed image to the image as pixelated data, and partly due to the advance of sophisticated software that could shield the artist from underlying mathematical procedures.

The historical step between algorithmic art and paint programs was so big and so permanent that algorithmic art is, at least in the public opinion, non-existent, whereas paint programs rule the desktop. It is partly for this reason that I have focused more on the algorithmic side of things. A better overview over the specialities of paint programs and in particular the way in which these influence artistic practice, is still outstanding.

In section 3, because of this limitation, I have developed an understanding of 'information' based on algorithmic considerations and not so much on information as data, as is primarily discussed today. Therefore, information is derived from a technical background in great contrast to a more cultural conception. It is my current understanding that such restrictive views, paralleled perhaps by the closely related practice of generative aesthetics, have greatly lost currency in the present debate. I am certain that a deeper understanding of the reasons for the scientific shift away from early theories of information technology would prove very helpful.

It is possibly both, my lack of understanding of these theories as well as a shifted cultural framework, that make this third section such a hard read. There is clearly something counter-intuitive in the radical split between information and meaning. On the other hand, I am very much intrigued by the idea that such a split could have liberated the new paradigm of information, of which hardly anything was heard of before the 1960s and that since has dominated our cultural debate.

This split is not so much counter-intuitive seen from the discourse of meaning, but from that of information itself, which links information with the presumed emptiness of complete chance. It is difficult to see what we really do learn from a throw of dice. It is, however, also difficult to see what we learn from Simon's *Every Icon* or other art that Stephen Wilson has recently termed 'Information Arts'. Seen superficially one has to admit to an increased emptiness of information, which is possibly not only due to its current inflation, but also to its more essential quality, which is beyond meaning.

I have used Rudolf Arnheim's *Entropy and Art* to introduce the art into this context of information, but also to develop the term 'economy of information'. Arnheim, in fact, does not criticise the paradigm of information as an impossible tearing apart of meaning and information, he only criticises its application to art. There was, however, not much space in the context of this paper to develop any profound theory of such an economy. Unfortunately, this has to be left as an open end.

It would be fruitful to link the 'economy of information' with Mark Poster's reading of Baudrillard, Foucault, Derrida, and Lyotard, who he brings together under the term 'mode of information.'[91] I have deliberately left out as many references as possible to more philosophical and also more contemporary work, in order to understand information from its birth rather than through information age's digest, an aspect which will also need to be left for a later date.

When I brought in more contemporary references, it was generally in the context of artistic practice. I used these examples to magnify particular areas of interest for the later application of the computer, in particular chaos theory and evolutionary computing. These, however, were meant as pointers to allow the link between earlier ideas and 'state of the art' approaches. The one example that I do follow through is Simon's *Every Icon*, with the help of which I linked *Algorithmic Art* to the 'economy of information'.

Every Icon was used to exemplify the radical future of an art emptied of meaning. I used it also, however, to shed a brief light on the reoccurrence of 'meaning' in a very naïve and

[91] Mark Poster, *The Mode of Information: Poststructuralism and Social Context*, (Cambridge: Polity Press, 1990).

almost cynical sense when the economy of information represented through the New York Times' website on the one hand admired the suffering of the contemporary artist confronted with trillions of years' worth of information and on the other hand invited their readers' hands-on production of "masterpieces" (that is, 'meaning') with the help of a simple paint program. Unfortunately, the gallery has been taken off-line since, which I would like to take as further indication for the futile battle between meaning and information in aesthetic terms.

I very briefly sketched the way out of such aesthetic considerations in the fourth and final section when I introduced Conceptual Art as the art form that has stepped in the ring to allow a critical discourse about life in the 'economy of information'. I could not name a single relevant piece of work today that does not take a loan from Conceptual Art, although Conceptual Art in the radical sense is clearly a thing of the past.

The conceptual way in which something is done today, replaces the question of computer or not computer. The biggest criticism of computer art today has to be the conceptually poor use of the computer. To say it with Sol LeWitt: "Banal ideas cannot be rescued by beautiful execution."[92] Standards have to be developed that allow to compare the concept with its technological demand. Occam's fashionable razor has to come into play again to cut off any excess that is due to a lack of understanding of the meaning of information.

I am still hunting for a copy of the catalogue for Burnham's *Software* exhibition. Following Shanken, it must have been an exciting brief time when Conceptual Art met Information Technology on the highest level. This meeting must have shaped an understanding of the meaning of information until today.

As concluding remarks, I would like to position this paper in the context of my research project *Image Automation: Photography and Computed Images*. A now better understanding of early computer art makes me believe that the two notions of 'manipulation' and 'automation', which I have so far developed, should not only be seen against the concept of technology but also against that of information. Do we actually understand the meaning of the term 'Information [pause] Technology'?

[92] Sentence 32 in: Lewitt, *Sentences on Conceptual Art*, p. 108.

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