Entangled? Frieder Nake's Probabilities Versus Quantum Computing Artistic Research

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Abstract

Frieder Nake is one of the most prominent pioneer artists in computer art. Both carefully constructed and intertwined in a complex manner, his works are mainly based on the programming of drawing processes and the use of abstract geometrical forms. In the programs that he conceives, each visual character corresponds to variable parameters. The selection of these parameters uses random variables selected by computation of mathematical probability densities. Through statistical calculation, the artistic gesture becomes both open and determinant. The generative image is the realization of one of the many possible results. It is contingent – it belongs to an infinite class of probable images.

Quantum Computing is a relatively new field in informatics. It began in the early 1980s, when physicist Paul Benioff proposed a quantum mechanical model of the Turing machine. Richard Feynman and Yuri Manin later suggested that a quantum computer could perform simulations that are out of reach for regular computers. Quantum computing is the use of quantum-mechanical phenomena such as superposition and entanglement to perform computation. The essential difference with classical computing is the nature of information itself. Instead of a 0 or a 1, the unit of quantum computing, called the qubit, is based on the oscillation of its state between the two values.

In this paper, we are discussing the relations that can be traced between the generative probabilistic approach of Frieder Nake and few principles that are found in quantum computing, such as superposition of states and probabilistic operations on quantum information. At the beginning of computer art in the

sixties, the mathematical use of randomness played an essential role. If Frieder Nake found in classical computing and in such methods a new field for artistic research, what can we expect from investigating quantum computation with an aesthetic purpose? The paper explores this question moving from the present to the past and going back. It finally discusses the potentials of artistic research in the field of quantum computing.

1. Quantum Computing in visual art and creativity

Quantum physics has revolutionized our worldview for just over a century. Often misunderstood, and sometimes misused, quantum physics has led us in particular to quantum computing. It was in the 1980s that Richard Feynman [17] and a few other scientists [24][10] started talking about the quantum computer.

Now, 40 years later, slowly but surely, quantum computing is emerging. Beyond the advent of the quantum computer, new algorithms and new working methods are developed. The transition from bits to qubits is the important evolution, which above all enables an extraordinary creative capacity. Quantum physics is not to be confused with the resulting quantum computation. Today, as soon as the word quantum appears, it is fashionable to be wary.

However, quantum computing is indeed becoming real in our technological environments. Beyond all the extraordinary announced potentials, it is important to understand that this is a set of totally innovative methods for Information Technology. It is also important to understand that its value increases in the field of creativity. Quantum computing technology should not be considered superior to classical computing in the realm of computational creativity, but just different, with new types of algorithms.

Quantum computing is therefore gradually developing in several sectors, including the very important ones of cryptography, artificial intelligence, banking, biology and the army, of course. Quantum computing progresses both as a new digital machine and as a field of new algorithms and computer languages working on this machine.

We are interested here in the algorithmic part. Much has grown since its beginning, in particular the famous algorithms of Shor and Grover [26]. At the beginning of the 21st century, some interesting attempts were proposed by researchers for developing quantum algorithms in computer graphics and in 3D renderings especially. This is how Andrew Glassner [18][19][20], Marco Lanzagorta [21] and then Simona Caraiman [14][15] proposed the first quantum algorithms for 3D creation. These works are experimental. To our knowledge, outcomes are unsatisfactory. However, the idea of creating images with quantum computing was born.

Simultaneously, the first quantum artists or “researcher-artists” began to create the first quantum works. It is difficult to say who the first really was, because some are only using the concept to produce works while others really are starting to use quantum languages (mostly in Python, with librairies offered by Sympy, QuTip, and Qiskit – a module based on IBM computers, Rigetti Forest, etc.).

Among noticeable pioneer artists of quantum computer art, we can list Julian Voss-Andreae [35], Lynden Stone [33], Alain Lioret [4] [23] (Figure 1), Paul Thomas [34], and Libby Heaney [40]. Through their artworks or their papers, attempts to define a quantum culture [16] or a quantum aesthetic [25] are proposed.

All of these artists work with the inherently probabilistic aspect of quantum physics. It is not a question here of speaking of randomness, but of probabilities. Thus our world would be much less deterministic than we thought. And artistic creation can also make use of this profound property of our universe.

Quantum representation of the world has dramatically changed views for more than a century. Among great physicists and inventors of this new physics, we can mention the major works of Erwin Schrödinger, who beyond his famous cat, was one of the first to describe life as determined by quantum physics [30][31]. In *Mind and Matter* and then *What is Life?*, Schrödinger opens doors to a creativity model that would be quantum.

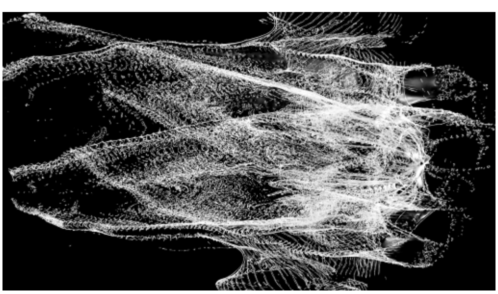

Figure 1, Alain Lioret, Galateia*, Quantum Image Creation.*

His work has inspired many authors and scientists who will go even further, including David Bohm who does not hesitate to relate particle physics to ways of thinking and therefore to creativity work [12][13] .

The emergence of a new form of art in relation to the evolution of science and computer technology has already a history. In the sixties, while first computers were introduced in university laboratories in Europe, young mathematicians saw an opportunity to pioneer new types of artwork. Already at that time, radical changes in the science, especially in the statistical physics of particles, gave an impulse for rethinking research in aesthetics. Randomness became both a scientific instrument and an artistic endeavor.

2. Randomness and probability in Frieder Nake's artwork

Computer art was made public in Stuttgart in 1965. Much influenced by cybernetician Norbert Wiener and the shift in statistical science [41], Max Bense, a physicist, a poet and a philosopher, founded the generative aesthetic with an exhibition in the Technical University of Stuttgart and a publication in the experimental *Rot* edition [42]. Influenced by Max Bense's theories, the computer graphic works of Georg Nees and Frieder Nake were shown together in 1965 in the Wendelin gallery in Stuttgart. For the first time, computers were involved in a process resulting in the making of artistic images. The detailed analysis of these early works enables a critical understanding in the relations between algorithms, randomness and art.

As a student in mathematics in the early sixties, Frieder Nake attended many lectures by Max Bense. From 1965 and on, Nake became an acclaimed artist in the emergent field of computer art. His works were shown in Germany and abroad, in important exhibitions such as *Cybernetic Serendipity* in London, or *Tendencies 4: Computers and Visual Research* at the New Tendencies Biennial in Zagreb. Both exhibitions were happening in 1968. In 1970 his works were then exhibited in the Venice Biennial. Later in 1971, Nake criticized computer art in a short essay: *There Should be no Computer Art* [43]. His critique focused on the commodification of computer art and the lack of perspective in this field of creation. He nevertheless remains one of the most prolific early computer artists.

Nake’s work is based on the programming of drawing processes resulting in abstract geometrical forms. Using lines, squares, hatchings, his works usually present two dimensional spaces that are both constructed and intertwined. The use of color is also a significant element in Nake’s work considering limitations of the time. During his early period, the programming of the drawing is usually followed by the use of a high-precision pen plotter. Within the programs conceived by the artist, the visual characters correspond to variable parameters. Played with probability distribution, randomness is at the heart of the program [2].

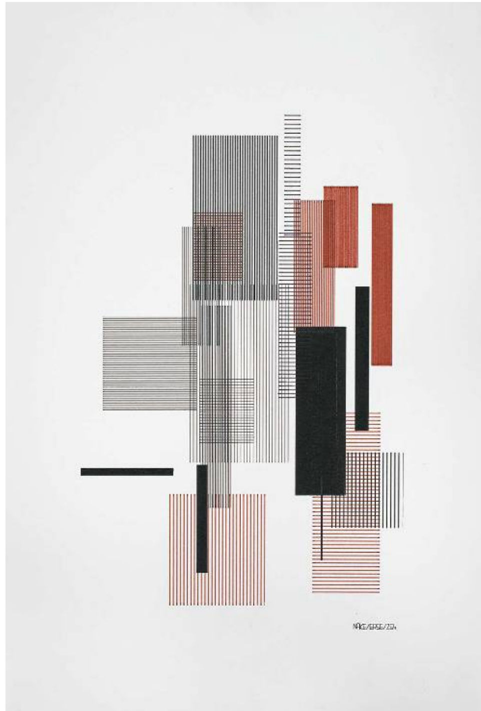

Figure 2. Frieder Nake, Rechteckschraffuren n° 3*, 1965, colored computer graphic, pne plotter with ink (black, brown) on paper, 19.2 x 29 cm, Bremen, *Kunsthalle*, Herbert W. Franke. Software : COMPART ER56 ; Hardware : Standard Elektrik Lorenz ER56 ; Plotter : ZUSE-Graphomat Z64.*

Rechteckschraffuren No. 3 [Rectangular Hatchings] (Figure 2) is an abstract and geometrical work in small format, based on the distribution of random values according to defined mathematical laws. It consists of a set of twenty areas of rectangular hatching that overlap or juxtapose each other. Densities of visual order: hatching density, positioning, dimensions and superimpositions of geometries – correspond to the calculation of probability densities. The resulting variations of visual densities create contrasts, depth and movement.

Although the image already offers to perceive certain programming issues, the non-visible part of the work cannot be approached solely from the visual description. Publications by Frieder Nake [1][2] and interviews with him provided necessary material for analyzing the algorithmic work contained in the software COMPART ER56, a program that Nake designed for various work of the same period.

With the exception of the size of the image, which is itself a variable that is determined randomly, all the values of the parameters of the work are obtained from a probability distribution function. In mathematical terms, a random value obtained with such function is an elementary event among a set of possible events. In the software COMPART ER56, a sub-program assigns the probability density for each of these events. A random generator is then used to select numbers that meet the densities devised by the user. Our study led to the programming of a simple algorithm using probability distribution for determining gray values (Figure 3).

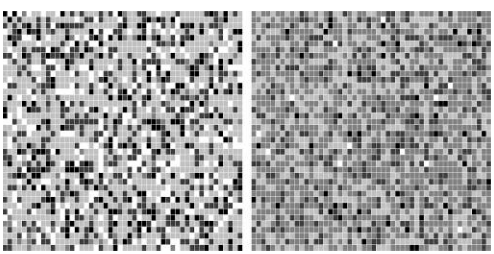

Figure 3. Probability distribution using a discrete approach: generation of a grid of rectangles of which gray value corresponds to the distribution. Five gray values are defined from black to white: black, dark gray, average gray, bright gray, white. For such a scale of gray, the right image probability distribution follows 10, 20, 5, 50, 15, and the left image probability distribution follows 3, 17, 50, 29.5, 0.1 (in %).

In his descriptions of the program, Frieder Nake does not specify the function that defines the probability distribution, nor how it affects precisely the visual results. But it is understood that each of the random variables responds to a probability distribution in which the distribution of densities can be of any type: "uniform, exponential, Gaussian, Poisson, and arbitrary discrete probability distribution functions" [46]. In our interview, Frieder Nake also testified to the use of probability distributions based on continuous functions [44].

In spite of its arbitrary appearance, the work presents a composition based on contrasts between various types of visual densities. Through statistical calculation, the artistic gesture becomes both determinant and opened. Many more works of Frieder Nake are programmed using randomness and probability distribution. As stated by the artist in recent publications [45], this algorithmic framework has strong conceptual implications. The image that has an experimental character is suspended; it is contingent – it belongs to an infinite class of image. It is a question whether such implications were followed in the later ages of computer art. The recent advances of research in quantum computing seem to renew interest in randomness and probability distribution in artistic research.

3. Randomness and probability in Quantum Computing and Quantum Images

Quantum mechanics is a theory which describes the nature of particles on the subatomic scale. It says that as we observe the world at a smaller and smaller scale, classical descriptions of particles and forces like those defined by Isaac Newton in the 18th century become less accurate and we must switch to different quantum descriptions driven by statistics and probability. For example the exact position of an electron around an atom cannot be predicted, we can only predict the probability of finding an electron in a given area around the atom at a given time [6].

To make things even more complex, the Copenhagen Interpretation of quantum mechanics devised by Niels Bohr and Werner Heisenberg states that quantum systems do not have definite properties prior to being measured, but exist in all possible states simultaneously in a principle known as superposition. It is only when the system is observed that the superposition collapses and the system exists in a single definite state. This is known as the observer effect. Taking the example of the position of an electron, we can predict a probability that an electron will be present in a particular location at a particular time, but before that measurement the electron exists in all possible positions around the atom. During the measurement the electron will reveal itself to be in one place, but by observing and measuring the electron we have altered its state and cannot determine other properties like momentum due to the uncertainty principle [7].

This interpretation of the quantum world understandably shook the physics community at the time, and is debated to this day. Albert Einstein refused to believe that reality is governed by probability and famously said "I, at any rate, am convinced that He (God) does not throw dice”.

Like it or not, Quantum theory remains our best understanding of the subatomic world and has been developed into the heart of an all new type information processor. Quantum computers rely on the ability for quantum particles to exist in a superposition of multiple states at once to perform calculations. Since quantum computers can manipulate the superposition of particles which are governed by probability, we can use them as a tool to harness the nature of the quantum world and build a true random number generator (i.e. a random generator based on subatomic properties of matter).

Randomness and other properties in probability distribution found in quantum computing bears strong implications in the field of quantum algorithmic images.

Quantum image processing methods, such as that proposed by Yao et al. [38], are emerging in the field of quantum computing. We do not include here works illustrating the quantum phenomena, which are quite numerous, but rather those using quantum algorithms, with quantum gates and entanglement effects, superposition of states, etc.

In his image processing work, Alain Lioret uses representations of qubits on Bloch spheres to create 3D structures (Figure 4). The representation of qubits on Bloch spheres thus enables a very interesting creative potential, which can be edited using rotations in 3D space with quantum gates.

The images of *Galateia* (Figure 1) and *Quantum Swan* (Figure 4) presented in this article were produced from the probabilistic representation of qubits, which can be formalized in Bloch spheres. Starting from basic 3D objects (a sphere or a cube in particular), each vertex of these objects has been represented by a qubit. Once the qubit is randomly initialized, a photograph taken at a time *t* of all the qubits gives the result obtained on these images. This is a probabilistic randomness as it really works at the subatomic level.

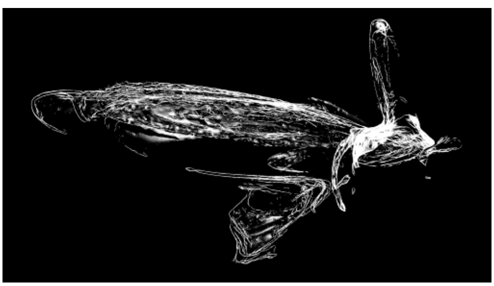

Figure 4. Alain Lioret, Quantum Swan*, Quantum Image Creation.*

This article cannot describe in detail the operations leading to these image creations. However, these images and the majority of what is found in the literature relies on the use of the following:

- Qubits which are the basis of all quantum computation. Qubits having the great peculiarity of being able to be in multiple states at the same time (superposition of possibilities, factoring creativity).

- Quantum gates, which are used to apply probabilistic operations on sets of qubits. These quantum gates (notably the most famous, those of Pauli, Hadamard, Toffoli, Cnot, etc.) make it possible to produce computer calculations in a whole new way, breaking away from the computational methods of classical computing [26].

4. Artistic research in the field of quantum computing

Are the efforts in creative quantum computing entangled with the work of Frieder Nake? As a prominent pioneer in computer art, Frieder Nake based an important part, if not the entirety, of his work – on randomness. More specifically, his exploration of probability distribution gave birth to a new conceptual framework envisioning the artwork as a class of images. The visible work is only an instance of an infinite set of possibilities. As he states it:

> A class of objects can never itself, as a class, appear physically. In other words, it cannot be perceived sensually. It is a mental construct: the description of processes and objects. The work of art has moved from the world of corporeality to the world of options and possibilities. Reality now exists in two modes, as actuality and virtuality. [45]

Because the artwork virtually exists in multiple states, Nake's theory seems to echo the principle of superposition property found in quantum computing and used in quantum image processing. It also tells that the reception of the artwork doesn't only rely on actual aspects. This argument might parallel the role of measurement in quantum computing, where measurement terminates states superposition. In a way, Frieder Nake has not only pioneered computer art, he also has prepared sustainable concepts for artistic research in the current technological epoch. Nevertheless it is necessary to underline that although in continuity with prior approaches, the computability of the artwork in quantum computing radically changes in nature. If Frieder Nake found in classical computing a new field for artistic research, what can we expect from investigating quantum computation with an aesthetic purpose? What are the potentials?

Quantum computing gives us a great opportunity: to put into form what were until now only theories. It is quite easy to summarize in one sentence the potential of this new computational creativity:

> We are moving from bit-based computer systems (2 possibilities, 0 or 1) to systems working with qubits (quantum bits) (an infinite number of theoretical possibilities)! [36]

A priori this tenfold principle results in an exponential field to explore, that is if artistic research in the field considers itself informational only, something we hope to discuss in a later research. Conceiving creative systems as the exploration of a space of possibilities, Geraint A. Wiggins asserts that creative behavior might not be described and captured by just classic Artificial Intelligence search:

> In standard state space search, we normally operate on one mode (which might indeed represent a partial solution) at a time. In my formalization, at least, traversal of the space may arise through simultaneous consideration of (and hence consideration of the relationship between) more than one of the modes in it which have already been discovered. Thus the search pattern produced is not a tree, but a lattice. [36]

At an epistemological level, the renewal of searching methods opens to new considerations in the way artistic research could be conducted, more specifically in generative art. The artistic field that remains to pioneer in quantum computing also calls for thinking and visualizing computing in new ways.

Cellular automata have been powerful tools of computational creativity since their creation (Conway, Langton). In recent years, several authors have developed quantum cellular automata. We can notably mention those proposed by Arrighi and Grattage [9], Bleh [11] or Lioret [23] (Figure 5). These operate on the basis of quantum gates and no longer on binary logic gates, which increases their potential tenfold, using probability with true random numbers .

Quantum Cellular Automata, for instance, is a project developed in collaboration with students from Université Gustave Eiffel, IMAC engineer program. The idea here is to use the probabilistic capacities of each qubit and to combine them with the use of quantum gates in order to create quantum circuits. While offering a ground for training, this process also provides the user with new creative tools.

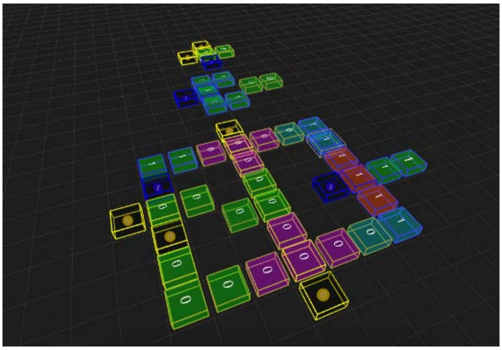

Figure 5. Alain Lioret, Maximilien Pluchard, Baptiste Montovani, Pierre Gabory, Valérian Daul, Quantum Cellular Automata*, 2019. Project developed with students from Université Gustave Eiffel, IMAC engineer program.*

Quantum cellular automata give shape to new types of algorithms in the quantum computing field, enabling the user to grasp the complexity of such algorithms. It is also worth to notice that large efforts are made in the developments of libraries like Qskit to trace the circuits involved in the programming of qubits. In itself, the logical circulation of information and its behavior also seems to lead to a new type of aesthetic, neighboring the aesthetic of code. Moreover the field of video games is very prolific in terms of quantum creation. Many quantum video games have been developed in recent years, a history of which is proposed by James Wooton [37].

Quantum computing seems to be synonymous with a new technological age. It is an opportunity to critically reflect both on computer art historicity and the relation between artistic research and computability. With his modern approach in art, Paul Klee also opened a way for *Exact Experiments* that is useful to remind: “We construct and keep on constructing, yet intuition is still a good thing. You can do a good deal without it, but not everything.” [47]

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