Quantum Genetic Algorithms for Generative 3D Creations

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Abstract

This article presents an experimental generative artistic work based on bio-inspired algorithms, more specifically quantum genetic algorithms.

1. Introduction

Since the discovery of fractal geometry by Benoît Mandelbrot(Mandelbrot & Mandelbrot, 1982), it has become clear that much of the world around us is better described by fractal geometry than by Euclidean geometry. This is true of trees, plants, mountains, rivers, clouds, the distribution of planets in the universe, human lungs, and so many other things that make up the world we live in. Other very interesting algorithms are used to better model the world, notably cellular automata, developed by a number of major researchers (Stephen Wolfram (Wolfram, 1984), John Conway (Conway, s. d.), Christopher Langton (Langton, 1984) in particular).

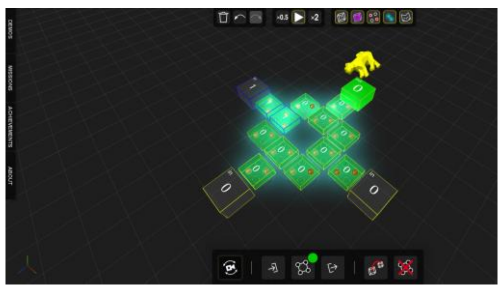

Figure 1 : Quantum Cellular Automata (Lioret, 2021)

The other great discovery that interests us here is that of quantum mechanics, which also gave us a new vision of the world at the beginning of the 20th century. Without going into too much detail, this new physics, which perfectly describes the microscopic world, is based on principles that are very confusing for humans: superposition of states (elementary particles can be in several places at once), entanglement (particles can be linked by instantaneous information systems, breaking the barrier of the speed of light), teleportation (information from one particle can be teleported to another particle). We will use these hypotheses to explore new avenues of computational creativity. Because with the advent of quantum computing, users and artists are now able to play with theories in very practical ways.

Here, we'll be experimenting with fractal art, quantum art, cellular automata art and some of the major scientific concepts that link these three worlds. And this will lead us on to some experiments in quantum fractal art and quantum cellular automata, which we find interesting from both a conceptual and aesthetic point of view. This article shows some generative experiments using Genetic Algorithms based on Quantum Cellular Automata (Arrighi, 2019), Quantum Fractals (Nottale, 1989), Cellular Fractal Automata (Willson, 1984) and Quantum Cellular Automata with Fractal Structures(Farrelly, 2020).

2. Quantum Genetic Algorithm

Genetic algorithms (GAs) are evolutionary algorithms inspired by Darwinian natural selection. They are heuristic optimization methods that use simulated genetic mechanisms like mutation and crossover, as well as population dynamics such as reproduction and selection. In the last decade, the concept of emulating quantum computers has led to a new class of GAs known as Quantum Genetic Algorithms (QGAs).

In the late 1980s, genetic algorithms gained popularity for optimization and machine learning. The Nobel Prize-winning physicist Richard Feynman proposed the concept of a quantum computer, which operates on the principles of quantum mechanics. The intriguing idea of designing a genetic algorithm to run on a quantum computer emerged but posed the question of its feasibility.

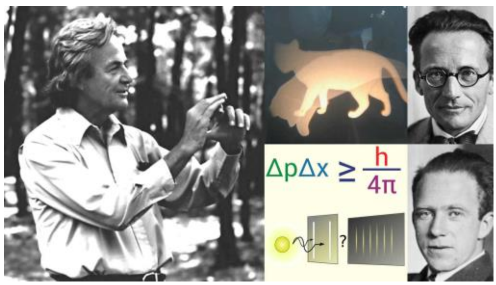

Figure 2 : Richard Feynman, father of quantum computing

Genetic Algorithms are search algorithms grounded in Darwinian natural selection and genetic mechanisms found in organisms. In a Simple Genetic Algorithm (SGA), solutions are encoded as chromosomes, which are arrays of information. Typically, the process starts with a randomly generated initial population of chromosomes. The algorithm then iteratively evolves this population to find an optimal solution.

Each generation of chromosomes is evaluated to determine their fitness, reflecting the quality of the solution they encode. The fittest chromosomes are selected as the "parents" for the next generation, simulating natural selection. The new generation is then produced through genetic mechanisms like crossover and mutation.(Lahoz-Beltra, 2016)

3. Comparison of Genetic Algorithm and Quantum Genetic Algorithm

It's interesting to compare a classical genetic algorithm with a quantum genetic algorithm. Zakaria Laboudi and Salim Chikhi, compares Conventional Genetic Algorithms (CGA) with Quantum Genetic Algorithms (QGA). Evolutionary computation, the basis for genetic algorithms, has been a part of computer science for over four decades, originating in the 1970s with John Holland. Quantum computation, combining information science and quantum physics, gained prominence with algorithms from Shor and Grover for factorization and database search, respectively. QGA represents a fusion of GA principles with quantum computing, aiming to enhance the exploration of search spaces.

Laboudi focuses on comparing the computational capabilities of GA and QGA, particularly using the classic 0/1 knapsack problem as a test case. (Laboudi & Chikhi, 2012)

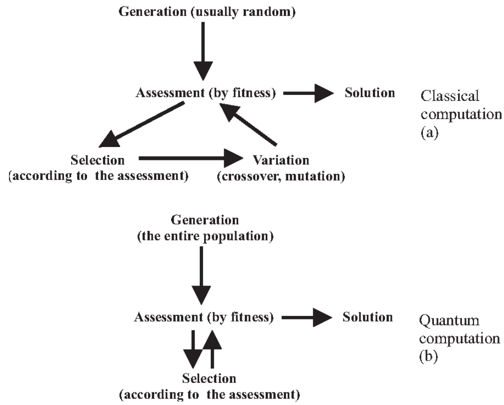

Figure 3 : Comparison of Classical Genetic Algorithm and Quantum Genetic Algorithm

4. RQGA : Reduced Quantum Genetic Algorithms

The Reduced Quantum Genetic Algorithm (RQGA) is a Python program demonstrating how to implement a 'true' quantum genetic algorithm, based on a fitness quantum gate and Grover's search algorithm. It is used for educational and research purposes. The RQGA was introduced as a fully quantum method to run genetic algorithms on a quantum computer, presenting a new methodology for this type of algorithms. As its name suggests, the RQGA aims to be a quantum version of the classical evolutionary process in a simplified setup. There has also been a proposal for a circuit level implementation of the RQGA using Python and Qiskit, with the main goal of analyzing the circuit complexity from various perspectives.

The Reduced Quantum Genetic Algorithm (RQGA) was proposed by Udrescu, Prodan & Vlăduţiu in 2006. Mihai Udrescu explores the application of genetic algorithms (GAs) within the quantum computing framework to solve the NP-hard graph coloring problem. Genetic algorithms, which are inspired by natural selection, have been adapted in the form of a Reduced Quantum Genetic Algorithm (RQGA). This adaptation leverages quantum computing's capabilities to potentially solve problems more efficiently than classical algorithms.

The RQGA specifically addresses both vertex and edge coloring of graphs and is also capable of determining the chromatic number, which is the minimum number of colors needed to color a graph without any two adjacent vertices sharing the same color. The authors propose a method that can solve the graph coloring problem in O(N1/2)O(N1/2) time, which is significant given that graph coloring is known to be a computationally intensive task.

Ardelean and Udrescu's implementation is tested in a quantum simulation environment. Their work details the algorithm's convergence and performance metrics, suggesting that the RQGA is a robust tool for tackling this class of problems. The research presents a compelling case for the application of quantum principles to evolutionary algorithms, potentially opening new avenues for solving other complex computational problems.

This work demonstrates the ongoing integration of quantum computing principles into broader computer science applications, highlighting the quantum genetic algorithm's potential to outperform its classical counterparts in specific instances. The study's findings contribute to the growing body of knowledge supporting quantum computing's role in addressing and solving NP-hard problems.(Ardelean & Udrescu, 2022)

5. Quantum Art

A number of artists have seized on quantum theories to experiment with their art. These include the work of Julian Voss-Andreae, Libby Heaney, Alain Lioret and Omar Costa Hamido (Hamido, 2021).

Some of these artists only used analogies with the principles of quantum mechanics, whereas more recently, the emergence of quantum computing has made it possible to work directly and practically with its concepts. This is how artist-researchers such as James Wootton (Wootton, 2020), Russell Huffman and Alain Lioret (Lioret, 2016) laid the foundations for the first true quantum artworks.

Figure 4: Quantum Sculptures by Julian Voss Andreae

6. Towards new experiments in computational creativity

We have embarked on a journey of artistic experimentation utilizing a quantum genetic algorithm. This advanced algorithm has been applied to the deformation of mesh structures, infusing them with new, unexpected forms. Moreover, we extended its application to fractal objects and shapes generated by cellular automata, exploring the boundary between algorithmic precision and creative expression. Below is the algorithm that we employed in our quest to meld science and art:

QGA Algorithm :

- Create a population of randomly initialized qubits by applying a Hadamard gate.

- Measure and evaluate its correspondence with the desired result

- Retrieve the N best elements according to their correspondence with the desired result

- Mutation of previously selected elements using a flip on the X-gate and the application of a Hadamard gate

- Repeat for the defined number of generations

- Recovery of the best elements

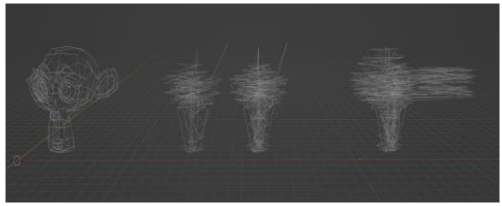

Figure 5: Genetic quantum deformation of a mesh made with QGA

In our continuous exploration of the intersection between technology and art, we have implemented a variant using the Reduced Quantum Genetic Algorithm (RQGA). This cutting-edge algorithm has been adeptly adapted to manipulate mesh deformations, introducing a novel dimension to our digital sculptures. Furthermore, we have employed this variant to shape fractals and patterns emerging from cellular automata, pushing the envelope of generative art. This initiative harnesses the RQGA, integrating its sophisticated mechanisms into our creative toolkit:

RQGA Algorithm

- Initialize a circuit containing n qubits

- We set each qubit in superposition state with a Hadamard gate

- We modify the state of each qubit starting from a random angle between 0 and pi / n, (pi / n can be increased if we wish a slower evolution between each

generation), modifying the state of our qubits in a random way allows us to observe the evolution of other genes than the one we wish and thus observe a more natural evolution.

- We apply Grover's algorithm to select the gene we want our population to evolve towards

- We observe the result after 1 generation; if required, we can apply Grover's algorithm several times to simulate evolution over several generations.

We present here a collection of creations crafted with both the quantum genetic algorithm and its variant, the RQGA. These pieces represent a fusion of algorithmic complexity and artistic vision, showcasing the transformative power of mesh deformation and the intricate beauty of fractal and cellular automata-generated objects. Each creation is a testament to the seamless synergy between advanced computation and the boundless realm of art, illustrating the rich possibilities that emerge when these two worlds collide.

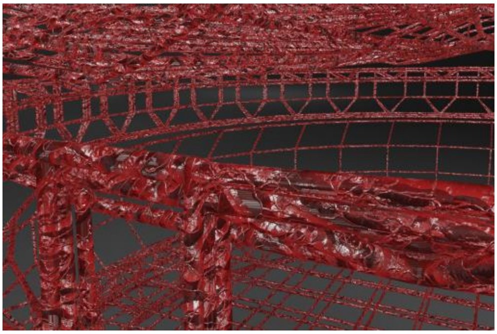

Figure 6 : quantum structure of a Burger

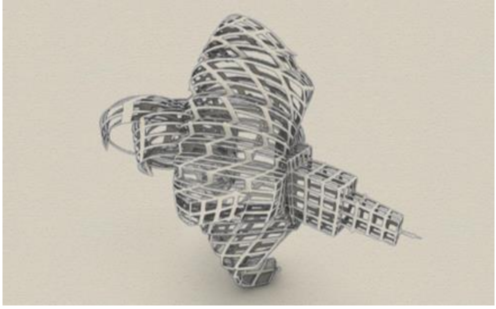

Figure 7: Quantum Fractal Creation made with QCA Algorithm (2023)

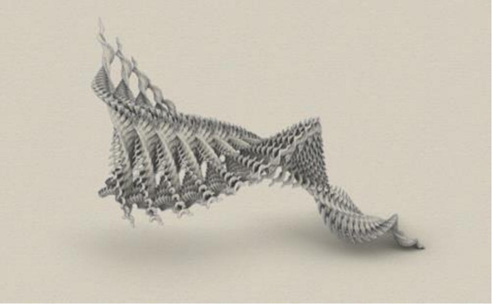

Figure 8: Quantum Fractal Creation made with RQCA Algorithm (2023)

Figure 9: Quantum Mesh Creation made with RQCA Algorithm (2023)

Figure 10: Quantum Mesh Creation made with QCA Algorithm (2023)

7. Future Works

These first quantum genetic algorithm experiments are very interesting and enable us to create 3D generative forms with innovative creation processes. The method used here remains fairly simple, and it would be very interesting to introduce Machine Learning concepts to further explore the possibilities offered by complex space computations where bio-inspired algorithms and quantum computation meet.

Looking ahead, we envision future works where animation becomes a central element, bringing our algorithmic creations to life. By incorporating motion, we aim to explore the temporal evolution of forms, where meshes unfold and fractals breathe, all orchestrated by the RQGA. This dynamic layer will add a new dimension of interactivity and realism, inviting viewers to witness the dance of pixels and vertices, a choreography guided by the sophisticated rules of quantum genetics. These animated artworks will not only captivate the eye but will also stir contemplation on the fluid nature of digital artistry.

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