Quantum Art

Alain Lioret

INREV, Arts et Technologies de l'image
Universite Paris 8
Paris, France
alainlioret@gmail.com

Abstract

The use of quantum computing in the creation of art is proving to be very interesting since it allows both the exploration of digital work using new algorithms and of artistic creation based on new concepts. These new algorithms mainly rely on the use of qubits instead of bits to perform simple or complex operations, which are applied to the components of digital works: namely the pixels in an image, the frames of an animation, the vertices of a 3D object, the words of a text or the notes of a musical score. This article reviews the use of quantum algorithms, using various examples and particularly the new methods being applied in computer graphics.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques —

1. Introduction

Since the beginning of time, artists have been tasked with making representations of the world as we see it, or as it really is, or even as we cannot see it. Erwin Schrodinger in his paper [Sch92], on the quantum representation of the world, introduced a new way of representing the world as it is, ie based on quantum mechanics at microscopic scales. With this premise, we can examine the use of quantum principles in exploring and creating digital art. This article presents no new algorithms for quantum computing, nor is a complete history of the use of such methods in computer graphics. Rather, we review recent artistic explorations using research methodologies and creative techniques that involve new artistic tools in computational analysis and modeling of creative behavior, artistic image processing technology, image analysis styles, composition, visual balance, and layout.

2. Quantum algorithms

While a quantum computer does not yet exist, there are many quantum computing simulators in many languages, such as those found on the quantiki website [Qua16]. There are a number of quantum algorithms, and the most famous was developed by Grover to research large unsorted databases, whose calculation times challenge the best classical algorithms [Gro96]. The Peter Shor algorithm that effectively factorizes numbers [Sho94], and that of Deutsch-Jozsa that identifies correct answers in probabilistic predictions [DJ92].

3. First adaptations for computer graphics

A very well known adaptation for computer graphics was developed by Andrew Glassner [Gla01c, Gla01a, Gla01b] who was one of the first to propose the using of quantum algorithms in computer graphics applications. Marco Lanzagorta and Jeffrey K. Uhlmann [LU05, LGU03] the first to actually implement quantum algorithms in graphical applications used Grover algorithms for searching databases, which can be very useful for very large 3D scenes with millions of polygons that must be processed. These authors also used quantum cloning algorithms, especially for solving intersection problems. These algorithms have made it possible to achieve quantum computing, and their methods habe been applied to the traditional problems of Z-buffering, ray tracing, radiosity, and level of detail (LOD). The work of Lanzagorta and Uhlmann was continued by Simona Caraiman [Car, CM09] who later developed quantum algorithms for computer graphics. Caraiman and her team set up Quantum Computation Language (QCL) for applying quantum algorithms to adress the research problem highlighted by Grover's method. Further work has been conducted on the min/max search algorithm, which was implemented in QCL language. QCL is applicable to many problems, such as the visibility of polygons (using a Z-Buffer), and calculations for image rendering in ray tracing and global illumination techniques using photon mapping. To explore and describe the use of these quantum algorithms, Nielsen and Chuang [NC10] authored an important book in 2000 (reissued in 2010), which was served as the starting point of most current research. A more philosophical approach is taken in the excellent work of Scott Aaronson, which offers direction and research avenues with respect to the use of quantum algorithms [Aar13].

DOI: 10.2312/exp.20161072

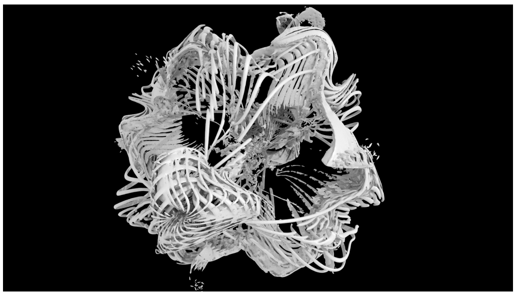

Figure 1: *Quantum Sculpture. Mesh generation with Bloch spheres representation of vertices.*

4. Quantum Philosophy and Art

Quantum philosophy and art leads the observer to see and think differently. Adapting the principles of quantum physics taps a very strong and deep source of creativity, that is inspiring many artists. The philosopher Michel Bitbol has attempted to describe these new worldviews [Bit11], defining the concept of quantum aesthetics as a philosophical one. In a recent article, Michel Caffarel and Monique Martinez [Mar13] opened what might be considered a new avenue in creativity. Gregorio Morales is also considered to be a pioneer in this field. For twenty years, artists have used quantum principles in different ways in their creative processes. Among the major artists Julian Voss-Andreae built beautiful quantum sculptures [VA11], and argued that "art such as the presented sculptures can indicate aspects of reality that science cannot and therefore has the potential to help liberate us from the deep impact the paradigm of classical physics continues to have on our every perception of reality." Lynden Stone also suggests that "translations of quantum concepts into visual art may assist in provoking such a revision of our ideas of reality." In her essay, she first introduces the concept of quantum superposition, notes its divergence from conventional perceptions of reality and then discusses how visual art might provide insight into quantum superposition [Sto13]. The work of Robert Crease and Alfred Goldhaber is also pertinent, and they state "Thus quantum mechanics, as well as the art it inspires, has a richness that invites us to expect a substantial future for artistic expressions." [CG*12].

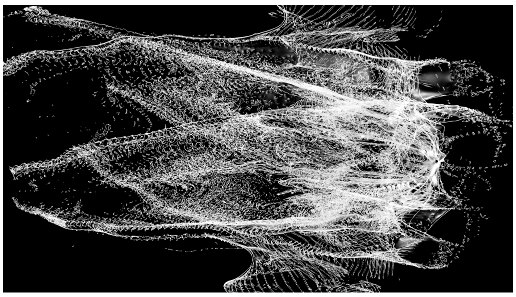

Figure 2: *Evalo 20M : image generated using qubits representation and Continuous Time Quantum Walk computation.*

5. Theoretical Creations

As described above, quantum principles can be used on many creative levels. Artists can use quantum philosophy to create works that simply follow its main theoretical principles. This is what occurred in the first prototypes that explored digital creativity, which were constructed with conventional tools and algorithms. The recently published work by Lioret [Lio14, Lio] explores the different possibilities of temporal space travel in the respective areas of work, images, films, 3D objects, music and text.

6. Practical Creations

Real quantum calculations can also be used along with some basic formulas to enter into a new world, where the methods and algorithms are completely different from the conventional. A good example is the use of Bloch spheres, which provide good representations of qubit states. One of the earliest experiments was to consider each vertex of a 3D polygon object as an elementary particle that can be represented by a Bloch sphere [Blo16]. It is easy to imagine aggregations of particles, all arranged on a fictional 3D mesh, and projected into a space with atomic dimensions. This technique as produced some amazing creations that possess considerable aesthetic qualities. Beyond these, this technique can be used to open new lines of thought with respect to digital creation, which, while not yet very advanced, remains well within the reach of many digital artists. In our own work, we have used some libraries in Python, for our creative achievements, wich offer most of the standard basic functions of quantum algorithms: QuTip [QuT16] and sympy [Sym16] are two excellent libraries that explore the possibilities of quantum methods. Another avenue is to explore logic gates, including the famous gates of Hadamard. Interesting creations made using quantum logic gates includes those based on quantum cellular automata (QCA), which were first proposed by Jonathan Scraping and Pablo Arrighi [AG12], and which have since been adapted by a number of other authors [BCM12].

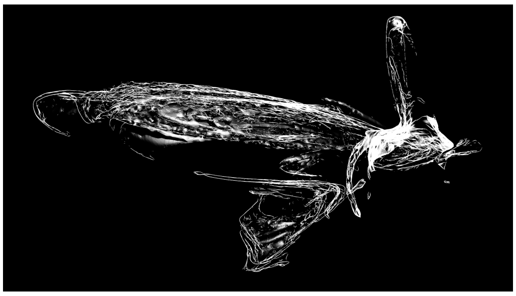

Figure 3: *Quantum Swan: Mesh generation with Bloch spheres representation of vertices.*

7. Quantum exploration of digital works

Viewing art from another perspective is a particularly exciting adventure. Each work can be imagined as a space to explore, whether it is presented as an image, a movie, a 3D object. Digital work has a very important property: as virtual entities, there is no fixed or correct scale. As such, the art may be considered at the macroscopic as well as the microscopic scale. It is quite legitimate, therefore, to project a digital creation on a microscopic space, even below the scale of the famous Planck constant. At this level, as determined by the greatest physicists of the last century, it is quantum mechanics that governs all behavior.

7.1. Exploration of an image

Consider that an image is a two-dimensional plane universe, populated by a pixel population. If each of these pixels is considered as an artificial being, we can note some of its properties, i.e., its position with respect to the x and y axes, its RGB color components, and its alpha transparency value. Then, imagining each image as Abbott designed Flatland [Abb15], if a pixel is introduced to the image, an exploration of the new image can provide a stunning vision. No quantum calculations are needed to achieve this result, but certain principles of quantum physics can be further applied. For example, the concept of quantum teleportation becomes interesting to the extent that an artist can suddenly arrive elsewhere in the image. More spectacularly, the concept of ubiquity enables the travelling pixel to have two positions at the same time in the image space. By linking these capabilities to the usual composition functions, very interesting results can be obtained. However, the visual results can be poor, since as in Flatland, the observer is positioned at the location of a pixel. Thus, we see only colorful lines. The results become more attractive when the observer is positioned outside the plane of the image, at a distance that allows observers to see an image of the pixels' universe.

7.2. Exploration of several images

By extending these concepts to a series of images, it is possible to jump from one universe to another and from one image to another, much like through a wormhole between two parts of the universe. This technique can become a travel tool in the image creation process if multiple versions of the same work can be made at different creation times.

7.3. Exploration of a movie

The use of quantum simulation tools can also very impressive in the exploration of film and video, because in addition to playing with the space, the artist can also navigate through time. An enduring fantasy of the human mind, we have the opportunity to time travel fairly simply by considering that a film is like a large three-dimensional box, that can move in unconventional ways. As such, while we can explore a cinematographic work simply as a mere spectator, we can also explore it as a quantum being, who can move to the heart of a lively set of images which has become organic matter.

8. Quantum Art Creation

Beyond the huge potential for further exploring digital work, quantum calculations can be used to create images, 3D objects and movies. Most artists working now inspired by quantum principles do not carry out real quantum calculations to produce their work, based on the pretext that the quantum computer does not yet exist. We believe that artists must be part of the community of quantum work precursors, and thereby enjoy all the simulation tools available to produce artistic works in different ways. The first simple experiments involved the use of qubits to encode images and 3D objects, and logic gates (rather than the usual addition, subtraction, multiplication, and division operators). In quantum computing and specifically, the quantum computation circuit model, a quantum gate (or quantum logic gate) is a basic quantum circuit operating with a small number of qubits. Qubits are the building blocks of quantum circuits, just as classical logic gates are the building blocks of conventional digital circuits. Quantum algorithms provide a number of standard logic gates, of which the best known are the Hadamard and Toffoli gates. A simple example is that we can perform image processing with qubits. Several studies have recently been conducted toward this end, including that by Phuc Q. Le, Abdullahi Iliyasu, Fangyan Dong, and Kaoru Hirota [LIDH11], to provide a representation of images on quantum computers that capture information about colors and their corresponding positions in the images. We also note the excellent work of Mario Mastriani who used the representations of Bloch spheres in most of the necessary calculations of an image [Mas14]. Finally, among the many possibilities associated with the use of qubits to encode images, Madhur Srivastava [SP13] proposed a novel method for image representation in quantum computers, which uses quantum states to locate each pixel in an image using row-location and column-location vectors. This method unlike many others, uses only quantum calculations to work with images. In addition, some studies have also adressed techniques for working with 3D objects. Mesh segmentation methods developed by Mathieu Aubry, Schlickewei Ulrich and Daniel Cremers [ASC11], that rely on the use of a wave kernel signature to divide 3D objects into multiple parts. Mathieu Aubry and his team are also recognized as leading experts in the field of 3D shape analysis using quantum methods. Many examples are possible here, but the key is to understand that mankind is the dawn of a new algorithmic era, in which the use of quantum calculations will gradually revolutionize most creative tools.

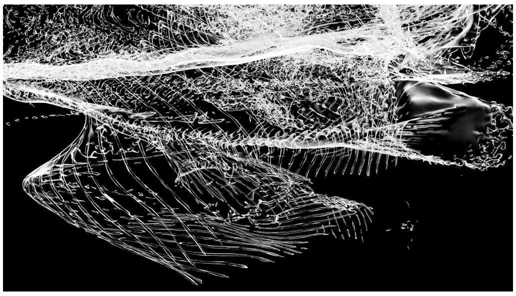

Figure 4: *CDV 1212 : image generated using qubits representation and Continuous Time Quantum Walk computation.*

9. Artistic technical experiments

It may be noted that there are many ways to work with quantum algorithms. However, everyone can worry about the complexity of the methods to be used and many users may find themselves lost in front of so unusual working methods. For our part, we began to realize some creations using existing libraries and with relatively simple functions. To produce the images illustrating this article, we used the Python language, with Sympy, QuTip, and PyCTQW libraries. These libraries have allowed us to use qubits and basic methods like Bloch spheres and Continuous Time Quantum Walk. Bloch spheres were used to represent each vertex of an object, with an appropriate scale projection, which has been used for Figures 1 and 3, using a Fresnel Shader in Blender.

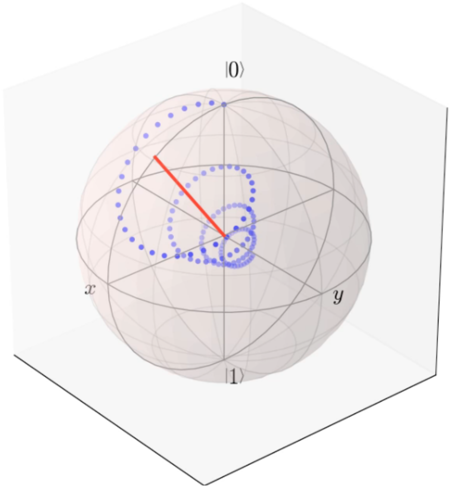

Figure 5: *Bloch sphere vector computing.*

Algorithm 1 Bloch Sphere Vector

```
Select Object = O
Set Scale = Sc
for v in list(vertices from O) do
    Compute Bloch Sphere Vector (v) = BSV
    Set BSV=BSV*Sc
    Set PositionXYZ(v) = PositionXYZ(v) + BSV
end for
Render(O)
```

Note that working with Bloch spheres is inspired by Qutip documentation. Figures 2 and 4 were produced with a similar method, but instead of using Bloch spheres, we conducted a Continuous Time Quantum Walk (use PyCTQW). Each vertex is considered as a particle, to which is applied a Continuous Time Quantum Walk on a 3-Cayley tree (inspired by documentation of PyCTQW [IW15]).

Algorithm 2 Continuous Time Quantum Walk

```
Select Object = O
for v in list(vertices from O) do
    Compute Continuous Time Quantum Walk = QW(add 9 new
    points)
    for p in QW(9) do
        Set PositionXYZ(p)
    end for
end for
Render(O)
```

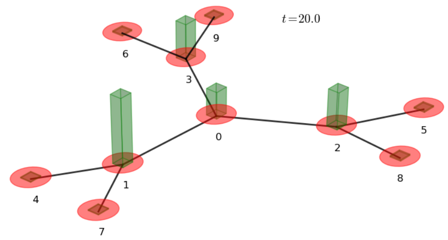

Figure 6: *propagation of a 1 particle continuous-time quantum walk on a 3-Cayley tree.*

10. Next, Quantum Algorithms for Computer Graphics

From the research work of Glassner, Lanzagorta and Caraiman, we know it is possible to implement quantum computation processes for use in 3D rendering systems (ray tracing, radiosity, Z-Buffer), but we need not limit ourselves to this application. We can also take advantage of algorithms that are as efficient as that of Grover to accelerate work with large databases. There is no lack of large databases. In particular, Grover's algorithm may be used to treat motion capture data, as well as large particle systems, or simply scenes with millions of polygons. One of the most interesting approach is that of Quantum Evolutionary Algorithms, which build genetic algorithms that work, not with bits, but with qubits and logic gates, and which are called Q-Gates. This method presented by Han Kuk-hyun and Kim Jong-Hwan [HK02], and Gexiang Zhang [Zha11], opens wide horizons in research and creativity, and is based on the concept of the Quantum Cellular Automaton (QCA).

11. Conclusions

In this article, we have discussed a broad panorama of new possibilities in artistic creativity, using both quantum calculations and conventional principles of quantum mechanics. The opportunities are vast and have burgeoned in the last five years. We have reviewed research approaches and associated creative outputs in our exploration of these new methods, which rely on the use of qubits, Bloch spheres, wave functions, logic gates, algorithms by Grover, Shor and others, quantum cellular automata, and evolutionary algorithms inspired by quantum methods. The possibilities are wide open and digital artists today are called to begin to explore these tools of tomorrow. New gates (logic) are open to all, artists and explorers, the adventure is just beginning...

References

[Aar13] AARONSON S.: *Quantum computing since Democritus*. Cambridge University Press, 2013.

[Abb15] ABBOTT E. A.: *Flatland: A romance of many dimensions*. Princeton University Press, 2015. 3

[AG12] ARRIGHI P., GRATTAGE J.: Intrinsically universal n-dimensional quantum cellular automata. *Journal of Computer and System Sciences 78*, 6 (2012), 1883–1898. 2

[ASC11] AUBRY M., SCHLICKEWEI U., CREMERS D.: Pose-consistent 3d shape segmentation based on a quantum mechanical feature descriptor. In *DAGM-Symposium* (2011), Springer, pp. 122–131.

[BCM12] BLEH D., CALARCO T., MONTANGERO S.: Quantum game of life. *EPL (Europhysics Letters) 97*, 2 (2012). 2

[Bit11] BITBOL M.: *Mecanique Quantique: Une introduction philosophique*. Editions Flammarion, 2011. 2

[Blo16] Bloch sphere. "https://quantiki.org/wiki/bloch-sphere", 2016 (accessed February 8, 2016). 2

[Car] CARAIMAN S.: Quantum computer graphics algorithms.

[CG*12] CREASE R., GOLDHABER A., ET AL.: Art of the quantum moment. *Proceedings of Bridges 2012: Mathematics, Music, Art, Architecture, Culture* (2012), 307–314. 2

[CM09] CARAIMAN S., MANTA V. I.: New applications of quantum algorithms to computer graphics: the quantum random sample consensus algorithm. In *Proceedings of the 6th ACM conference on Computing frontiers* (2009), ACM, pp. 81–88.

[DJ92] DEUTSCH D., JOZSA R.: Rapid solution of problems by quantum computation. In *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* (1992), vol. 439, The Royal Society, pp. 553–558.

[Gla01a] GLASSNER A.: Quantum computing. 2. *Computer Graphics and Applications, IEEE 21*, 5 (2001), 86–95. 1

[Gla01b] GLASSNER A.: Quantum computing. 3. *Computer Graphics and Applications, IEEE 21*, 6 (2001), 72–82. 1

[Gla01c] GLASSNER A.: Quantum computing, part 1. *IEEE Computer Graphics and Applications*, 4 (2001), 84–92. 1

[Gro96] GROVER L. K.: A fast quantum mechanical algorithm for database search. In *Proceedings of the twenty-eighth annual ACM symposium on Theory of computing* (1996), ACM, pp. 212–219. 1

[HK02] HAN K.-H., KIM J.-H.: Quantum-inspired evolutionary algorithm for a class of combinatorial optimization. *Evolutionary Computation, IEEE Transactions on 6*, 6 (2002), 580–593.

[IW15] IZAAC J. A., WANG J. B.: pyctqw: A continuous-time quantum walk simulator on distributed memory computers. *Computer Physics Communications 186* (2015), 81–92. 4

[LGU03] LANZAGORTA M. O., GOMEZ R. B., UHLMANN J. K.: Quantum rendering. In *AeroSense 2003* (2003), International Society for Optics and Photonics, pp. 128–136.

[LIDH11] LE P. Q., ILIYASU A. M., DONG F., HIROTA K.: A flexible representation and invertible transformations for images on quantum computers. In *New Advances in Intelligent Signal Processing*. Springer, 2011, pp. 179–202.

[Lio] LIORET A.: Time beings: Quantum beings for art exploration and creation.

[Lio14] LIORET A.: Quantum computing for art exploration and creation. In *ACM SIGGRAPH 2014 Studio* (2014), ACM, p. 2. 2

[LU05] LANZAGORTA M., UHLMANN J. K.: Hybrid quantum-classical computing with applications to computer graphics. In *ACM SIGGRAPH 2005 Courses* (2005), ACM, p. 2.

[Mar13] MARTINEZ MICHEL C. M.: Esthetique quantique : Un regard croise arts et sciences. *Science, Fables and Chimeras: Cultural Encounters* (2013), 257.

[Mas14] MASTRIANI M.: Optimal estimation of states in quantum image processing. *arXiv preprint arXiv:1406.5121* (2014).

[NC10] NIELSEN M. A., CHUANG I. L.: *Quantum computation and quantum information*. Cambridge university press, 2010.

[Qua16] Quantiki. "https://quantiki.org/", 2016 (accessed February 8, 2016). 1

[QuT16] Qutip : Quantum toolbox in python. "http://qutip.org/", 2016 (accessed February 6, 2016). 2

[Sch92] SCHRODINGER E.: *Physique quantique et representation du monde*. Editions du Seuil, 1992. 1

[Sho94] SHOR P. W.: Algorithms for quantum computation: Discrete logarithms and factoring. In *Foundations of Computer Science, 1994 Proceedings., 35th Annual Symposium on* (1994), IEEE, pp. 124–134. 1

[SP13] SRIVASTAVA M., PANIGRAHI P. K.: Quantum image representation through two-dimensional quantum states and normalized amplitude. *arXiv preprint arXiv:1305.2251* (2013).

[Sto13] STONE L.: Re-visioning reality: Quantum superposition in visual art. *Leonardo 46*, 5 (2013), 449–454. 2

[Sym16] Sympy. "http://www.sympy.org", 2016 (accessed February 6, 2016). 2

[VA11] VOSS-ANDREAE J.: Quantum sculpture: Art inspired by the deeper nature of reality. *Leonardo 44*, 1 (2011), 14–20. 2

[Zha11] ZHANG G.: Quantum-inspired evolutionary algorithms: a survey and empirical study. *Journal of Heuristics 17*, 3 (2011), 303–351.