Art of the Quantum Moment

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Abstract

For half a dozen years, the two of us have taught "The Quantum Moment," a course on the impact of quantum mechanics on culture and thought. The impact on art is one key topic of this course, and we discuss several different ways in which art of the quantum moment is intertwined with mathematics. Much of this has to do with various mathematical consequences of the fundamental quantum equation $E = h\nu$, which by various paths is responsible for complementarity, randomness, uncertainty, and alternate worlds, among other features that have shown up in art. Sometimes the connection to mathematics involves reimaginations, sometimes transformations and reconstructions, sometimes metaphors, and sometimes mere evocations. On the one hand there are incredibly precise and reproducible patterns, of which the earliest may have been spectrum of a hydrogen atom treated as a non-relativistic system. On the other hand, there are the random results of particle observations, such as the locations of strikes of individual photons in a diffraction pattern, which nevertheless in the limit of large numbers of photons becomes extremely precise and regular. Thus quantum mechanics, as well as the art it inspires, has a richness that invites us to expect a substantial future for artistic expressions of The Quantum Moment.

1. Introduction

In 2004-5 the New York Public Library hosted an exhibition entitled "The Newtonian Moment," consisting of manuscripts and other material illustrating the revolution in worldview brought about by Isaac Newton's work – its impact not on science but on culture and thought. The exhibition and accompanying catalogue, written by science historian Mordechai Feingold [1] among other things reveals the extraordinary impact of Newton's work on art. Characteristics of the "Newtonian Moment" include continuity, homogeneity, predictability and order throughout the universe (especially involving the applicability of differential equations), and these are strongly on view in the art. Many of the works consisted of portraits of Newton and Newtonians, of images of Newton's experiments, and of paintings inspired by light, gravitation, orbits, the spectrum, the rule of measure and order, and other Newtonian themes.

Figure 1: *"Newton," a monotype by William Blake, and "Newton Investigating Light," from The Illustrated London News*

The exhibition catalogue, for instance, includes several paintings and illustrations that mixed skyscapes and landscapes with graphs and other mathematical figures used to underline the continuity, comprehensibility, and predictability of the Newtonian world.

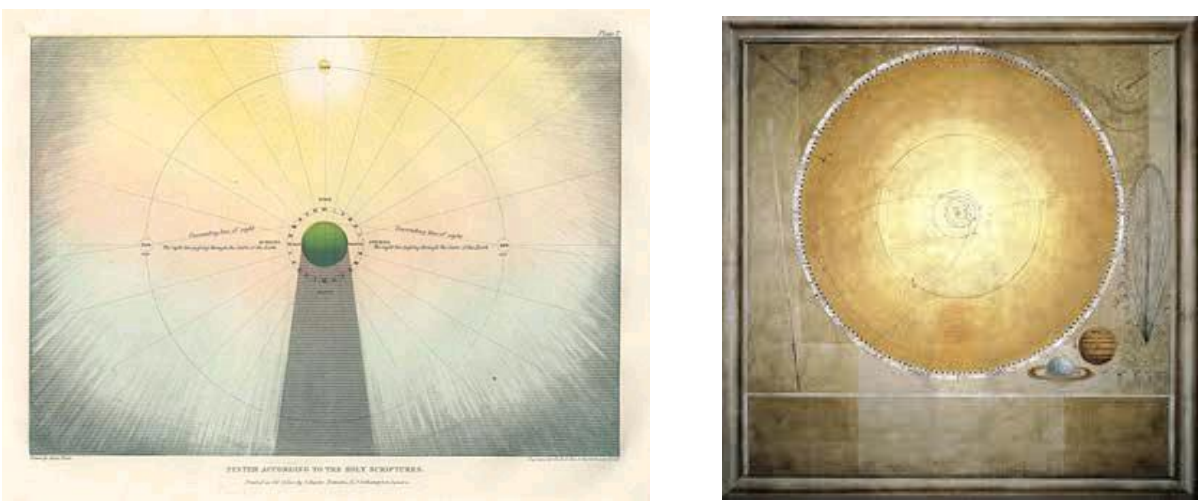

Figure 2: *Illustration from Isaac Frost, "Two Systems of Astronomy," of the Newtonian Sun-Earth-Moon system; and a fresco depicting the orbit of Halley's Comet at the Museo La Specola in Padua.*

The Newtonian Moment lasted for some 250 years, but was ambushed in the beginning of the 20th century by the discovery of the quantum. By the end of the 20th century's third decade, scientists realized that the implications of the discovery challenged many of the characteristics of the Newtonian Moment, including assumptions about continuity, homogeneity, predictability and order. Thanks to popularizations that began about 1927, the quantum came to exert its own impact on culture and thought. For half a dozen years now the two of us – one a philosopher, the other a physicist – have co-taught a course on this impact, which we call "The Quantum Moment." The impact on art is one topic in the course, and we want to talk about the various different ways in which this art is intertwined with mathematics.

Quantum mechanics, like all physics, has a theoretical and an experimental side. The theoretical side is expressed through mathematics. Indeed, we argue that it *is* mathematics – everything from number theory to algebra to geometry to differential topology to complex analysis. As such, quantum mechanics can be treated as a mathematical entity in itself. The concepts of quantum mechanics clearly are mathematical in nature, even when expressed in words rather than equations. This makes the inclusion of quantum-inspired art highly appropriate for this conference.

2. Varieties of Quantum-Inspired Art

Consider the following works by Harvard physicist/chemist Eric J. Heller. These were created from images of phenomena illustrating quantum principles – resonance waves and the superimposition of random waves. The mathematics – the equations of resonance in the first, of interference in the second -- structures the phenomena described, and therefore their reimagination in Heller's work. These reimaginations occur without significant structural transformations of the original images.

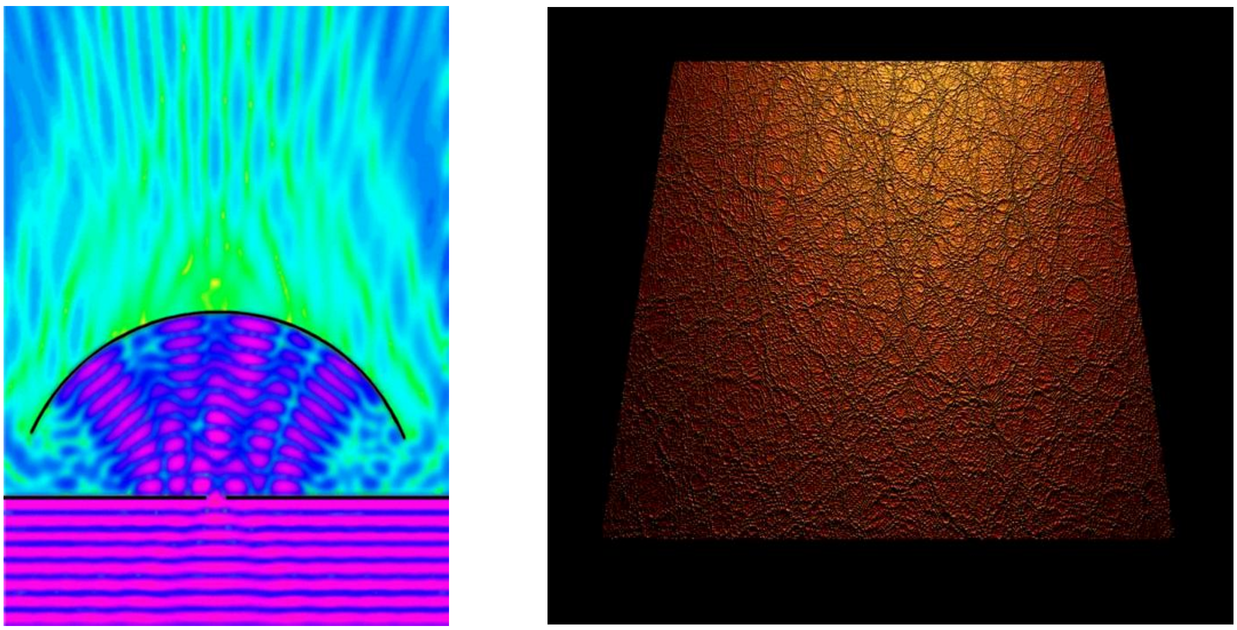

Figure 3: *"Resonator 1" and "Monolith," by Eric J. Heller. Courtesy Eric J. Heller*

A different kind of interaction between art and mathematics is involved in the work of Frédérique Swist, Senior Designer at the Institute of Physics Publishing in London. The artist describes her work so:

> In my art practice, I tend to find my source of inspiration in technical graphs and diagrams taken from scientific journals, I approach this material from a visual perspective and develop a particular aesthetics, with an emphasis on symmetry, harmony, colour and composition - I am particularly interested in the process of visual transformation and re-construction of imagery. But I also like to retain a link to the source, so I tend caption my work and provide the scientific background / source of inspiration. I'd like to think that it offers the viewer 2 dimensions to the work, the visual / aesthetic approach, and the underlying science it comes from.

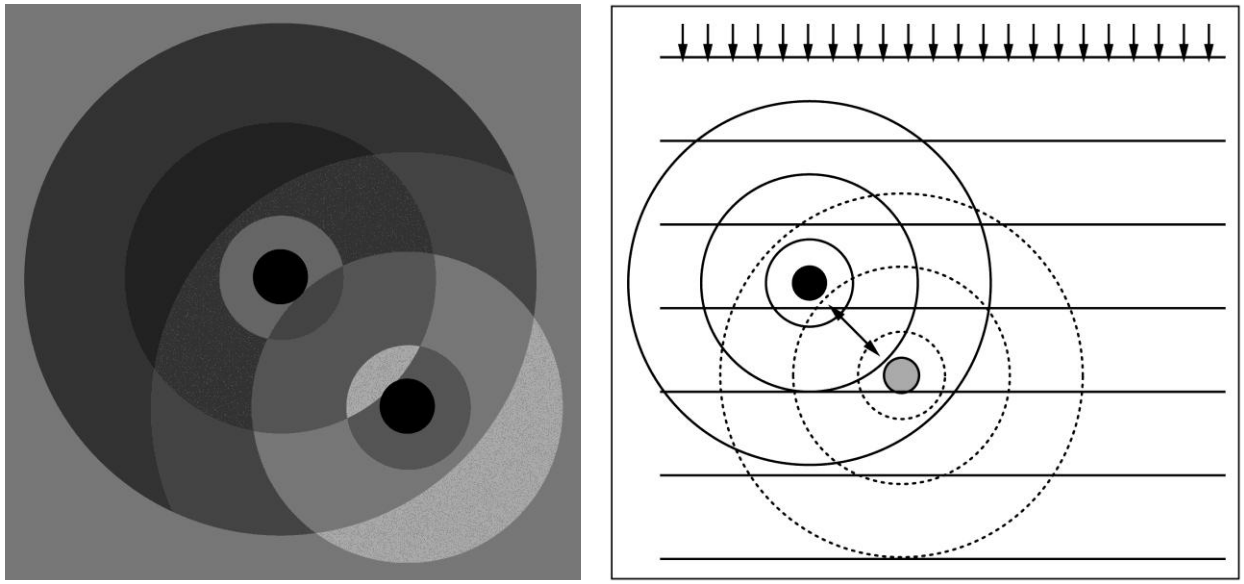

Figure 4: *"Quantum Obstacle," by Frédérique Swist, and the image that inspired it, from the article: "Multiple-path interferometer with a single quantum obstacle," H Schomerus, Y Noat, J Dalibard and C W J Beenakker 2002 EPL (Europhysics Letters) **57** 651–657. © 2012 IOP Publishing.*

The image on the left, "Quantum Obstacle" – used for the IOP's 2011 Christmas Card – was based on the drawing at the right, which accompanied a technical article in an IOP journal. Swist's work is unlike Heller's in that it does not involve the recreation of a phenomenon, but rather of a graph. In some ways the relation between art and mathematics is closer here, because the work is based on a technical graph, but in other ways it is looser, because the graph has been transformed and reconstructed.

We have also encountered other kinds of relations. One is what might be called metaphorical, when a painting represents in some way a quantum phenomenon. Another is what might be called evocative, when the word "quantum" is used in the title of paintings in a way that is unrelated to a particular phenomenon, or to mathematics -- and is also not metaphorical. In these cases the word functions principally to suggest vitality, glamour, and complexity; or to evoke some feature of the Quantum Moment such as discontinuity, randomness, and flux in a poetically suggestive way. We might call this kind of art *evocative*, by contrast with Heller's *reimagined* art, Swist's *transformed* art, and *metaphorical* art. Each involves a different kind of relation to mathematics.

In the "Quantum Moment" course, we found different kinds of quantum-inspired art that were often (though not necessarily) related to a specific characteristic of the quantum world involving a different mathematical path, so to speak, from the basic quantum equation $E = h\nu$. Examples of such paths include complementarity, randomness, uncertainty, and alternate worlds.

3. Complementarity

We start with a category familiar to this audience, thanks to an article in the Bridges 2010 proceedings by Julian Voss-Andreae [2]. "Complementarity" was Niels Bohr's neologism for the fact that particle and wave behaviour are simultaneously necessary yet mutually incompatible in the quantum world ('wave-particle duality'). This puzzling feature, Bohr thought, sprang from the fact that human beings have to be both actors and spectators when observing the microworld, and that the instrumental conditions under which a quantum phenomenon is observed affect -- up to a point -- what is observed.

In the Newtonian world, particles and waves had two descriptions under which each phenomenon was both observable and predictable. In the quantum world, the wave lost its observability, and the particle its predictability. The wave equation is thoroughly predictable but unobservable, but makes only probabilistic statements about particles. The particle is observable, but cannot be handled within the same kind of predictive scheme as in classical mechanics. How much the quantum phenomenon is wave-like and how much particle-like depends on the instrumental conditions set up to measure it. Again, this is all a by-product of the fundamental equation E = hν.

In his Proceedings paper, Voss-Andreae showed slides of work that exhibited the varieties of quantum-inspired work mentioned in #2 above. “The Well (Quantum Corral),” for instance, was a reimagined piece based on data from a scanning tunneling microscope, rendering visual quantum mechanical matter waves, while “Night Path” transforms Richard Feynman’s path integral diagrams.

Figure 5: *Two views of “Quantum Man,” by Julian Voss-Andreae (used with permission)*

“Quantum Man” is an example of what we call a metaphorical work. It is composed of parallel steel slabs arranged so that the work appears as a virtually solid piece of steel from one perspective, and all but disappears from another angle. The work is not mathematically based on the mathematics of complementarity – the mathematics of the perspective change on an object would be described better by a kind of group theory. Instead it is a kind of “metaphor,” as Voss-Andreae said, for wave-particle duality; that is, for the way in which one form morphs into another depending on how the observer is “positioned” with respect to the phenomenon. Voss-Andreae’s “Self-Portrait on the Brink of Detection,” on the other hand, is a more “evocative” work, suggesting what the author might look like under the stochastic conditions implied by quantum mechanics, during a short time when only a few photons are available.

4. Order Emerging from Randomness

Visitors to London cannot miss *Quantum Cloud* when passing the park next to the Millennium Dome or taking a cruise along the Thames. It rises about 30 m above a platform on the banks of the river, and from a distance looks like a huge pile of steel wool. As you draw closer, you can make out the hazy, ghost-like shape of a human being in the center. It is a sculpture, by the British artist Antony Gormley, made from steel rods about a meter and a half long that are attached to each other in seemingly haphazard ways. Framed by the habitually grey London sky, it does indeed look cloud-like.

Figure 6: *"Quantum Cloud XXI,' by Antony Gormley, 2000. Stainless steel bar, 4.76 mm x 4.76mm, 230 x 143 x 116cm, 35 Kg. Permanent installation, River Thames, Greenwich Peninsula, London, UK. Photograph by Stephen White, London. © the artist*

Gormley has written about the work: "It represents a shift in my work, from a preoccupation with mass, volume and skin to a concern with air, energy and light. Hovering above the cast-iron caissons that were bequeathed to us by the industrial revolution, the work alludes to the transformation of classical physics and its concern with the building blocks of matter to a new quantum reality: that everything is in flux and that solid objects are an illusion."

Quantum Cloud thus falls in the category of a metaphorical work, owing its name to an analogy with the way forms emerge from chaos in the quantum world. More evocative is *Quantum Sheep*, the brainchild of Valerie Laws, a writer who lives in the north of England. In 2002 she spray-painted words onto the fleeces of sheep from a nearby farm. As the flock milled about, the words rearranged and a new "poem" was created every time the sheep came to rest. A spokesperson for Northern Arts, which provided £2000 of funding for the project, said that the result was "an exciting fusion of poetry and quantum physics". Here is one of the resulting "Haik-Ewes":

Clouds graze the sky
Below, sheep drift gentle
Over fields, soft mirrors
Warm white snow

Talking to the BBC at the time, Laws explained why she felt the project was worth pursuing. "Randomness and uncertainty is at the centre of how the universe is put together, and is quite difficult for us as humans who rely on order," she said. "So I decided to explore randomness and some of the principles of quantum mechanics, through poetry, using the medium of sheep."

There is a world of difference between *Quantum Cloud* and *Quantum Sheep,* between the steel-wool-resembling sculpture on the Thames and poetry created by Scottish farm animals. Still, both works were motivated by the special role of randomness in quantum theory: the former case in the creation of form out of chaos, the second evokes the quantum as a symbol of irreducibly random processes.

The earliest source of this role for randomness in quantum theory may be Einstein's paper of 1916, which installed probability at the heart of quantum theory for the first time by deriving Planck's radiation law $E = h\nu$ with the use of probability transitions similar to those used in radioactivity.

5. Uncertainty

Figure 7: *"Abedecary," by Spencer Finch. Courtesy Spencer Finch*

The basic equation of Heisenberg's uncertainty principle is instantly recognizable and almost an icon: $\Delta p \times \Delta x \geq h/4\pi$. In "Abecedary," Spencer Finch reimagined, not the mathematics, but the text of an article in which Heisenberg described the uncertainty principle. Finch used an idea by the novelist Vladimir Nabokov, involving an alphabet that synesthetically connects each letter of the alphabet with a specific color, to "rewrite" Heisenberg's text. The resulting painting is a literal reimagining of the text and evokes the equation it describes by playing with inexactitude of perception.

Another example of an art work evoking uncertainty is an often-reproduced image, patterned after Roy Lichtenstein, of a split cartoon in which "Bob," speaking over the phone, says to "Alice:" "Oh Alice … you're the one for me," to which she replies, "But Bob, in a quantum world, how can we be sure?" Furthermore, various artists of the 1930s and 1940s wrote articles and manifestos invoking quantum mechanics as an inspiration or even as a collaborator in their revolutions. To mention one example, the Austrian-Mexican painter Wolfgang Paalen wrote that "the crisis of causality in science," involving the recognition of the loss of causality in the microscopic domain, was "the same revolution" as "the crisis of the subject in art" associated with the loss of connection of things like light and shade and "the appearance of the given things" [3] -- though using what artists say about their work is notoriously risky.

6. Alternate Worlds

The Copenhagen interpretation of quantum mechanics is sufficiently strange to have inspired deniers, who insist that nothing collapses the information or wave function; all the "superimposed" worlds exist. This is the "parallel" or "many-worlds" interpretation of quantum mechanics, one of the most logical, bizarre, and ridiculed ideas in the history of human thought. The many-worlds idea was introduced by Hugh Everett III (1930--1982). In his 1957 PhD thesis, written at Princeton under the supervision of John Wheeler, Everett proposed that the encounters that appear to evaporate the wave function do not; they simply split the system into different worlds, each of which may continue to branch, bush-like, in subsequent encounters with the classical world.

Figure 8: *Publicity Poster for "Another Earth" (used with permission)*

The many worlds interpretation has been the inspiration for many a science-fiction story, and numerous movies including "Another Earth" (2011).

7. Conclusion

Classical mechanics inspired many beautiful structures, well beyond what we mentioned briefly at the beginning. For example, there are maps of self-similar systems associated with a relatively recent branch of mechanics, chaos theory. However, for quantum mechanics there is a much richer variety, only lightly sampled here. The fundamental source of that variety is the enormous range of possibility in quantum mechanics. On the one hand there are incredibly precise and reproducible patterns, of which the earliest may have been spectrum of a hydrogen atom treated as a non-relativistic system. On the other hand, there are the random results of particle observations, such as the locations of strikes of individual photons in a diffraction pattern, which nevertheless in the limit of large numbers of photons becomes extremely precise and regular. Thus quantum mechanics, as well as the art it inspires, has a richness that invites us to expect a substantial future for artistic expressions of The Quantum Moment.

References

[1] M. Feingold, *The Newtonian Moment: Isaac Newton and the Making of Modern Culture*, New York: Oxford University Press. 2004
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[3] Wolfgang Paalen, "On the Meaning of Cubism Today," *Dyn* 6 (1944), p. 7.