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Finally Fresh Air: Towards a Quantum Paradigm for Artists and other Observers

By Julian Voss-Andreae and George Weissmann

Abstract: Quantum Theory, developed in the first quarter of the 20th century, has become the most widely applicable, successfully predictive theory of physics, but has long remained mysterious as a description of reality. What has been obstructing our understanding are deeply ingrained presuppositions about the nature of reality. Freed from these presuppositions, a new world view is emerging in which connectedness and consciousness play a fundamental role. Quantum Theory offers us glimpses of different ways of dealing with each other and with our world. Voss-Andreae's 'Quantum Sculptures' give expression to these emerging insights in their evolution from a literal analog to physics toward freely capturing key facets of the lessons learned through quantum physics. This article discusses this body of work in relation to Weissmann's work on an emerging 'quantum paradigm' in the hopes of inspiring new ways to transcend our current paradigm and helping to get these embryonic ideas out into the cultural mainstream.

Introduction

More than a hundred years have elapsed since the early 20th century Relativity-Quantum revolution of physics, but a malaise about its meaning, and a deep search for clarity persists. Quantum Theory (QT) works extraordinarily well in every of the countless fields in which it has been applied, with stunning accuracy and with no exceptions to its validity in predicting statistically the observed behavior of physical systems. But at the same time, it has stubbornly defied any conventional model of what a physical system could possibly ''be like" in order to exhibit such behavior. QT has defied any attempt to model what quantum systems "are". This predictive success of a theory without an accompanying single coherent and visualizable model of what entities the theory is about is a novel situation in science, and the time it is taking to make sense of it is a testimony to the monumental challenges we face in this endeavor. It is for this reason that QT continues to be seen as a weird, spooky, inexplicable picture of reality.

For many decades after the heady and exhilarating period 1900 – 1935 most physicists shied away from the fundamental questions and the philosophical inquiry of the founders, who had thought so profoundly about the meaning of QT and asked such penetrating questions. This was partly because of the seeming impasse this kind of inquiry had encountered. Another factor was that there was so much work to be done to apply QT to all kinds of phenomena, that the challenge of understanding the foundations receded. The focus on practical applications led to a "shut up and calculate"[1] mindset that became the motto of those times (approximately 1935 – 1970), characterized by great progress in applications to various fields of study and technology, but few new insights into the implications of QT for our understanding of the nature of reality. Then, in the 1970s, there came a renaissance of research into quantum foundations and quantum philosophy. Weissmann co-founded the 'Fundamental Fysiks Group' at the University of California, Berkeley, which played a role in kickstarting that renaissance[2]. That newfound interest in the theoretical foundations of quantum physics coincided with the emergence of a number of experimental groups that performed research driven by those fundamental questions. Today, a growing field of inquiry into the quantum foundations is producing important new insights, theoretically as well as experimentally, and appears to be preparing the ground for an emerging Quantum Paradigm. Books and other media, both technical and popular, are springing forth shedding light on many aspects of this[3]. The main obstacle impeding this thrust is the persistence of old presuppositions - unquestioned assumptions - and concepts built on these. Yet despite their shortcomings, in their totality these attempts bear testimony to the profound influence quantum insights are already having on our culture, even in the absence of a fully formulated, matured and consistent Quantum Paradigm.

The Classical Paradigm

Classical (or Newtonian) physics, the physics of the 16th to 19th centuries, is built on a set of unchallenged presuppositions, so self-evident that they are often considered 'common sense': The key presupposition of these is that I and the world are fundamentally separate, a concept known as *subject-object dichotomy,* made explicit by Rene Descartes in the 17th century. Accordingly, I, the individual "subject", experience myself as an actively knowing self which experiences a passively known, external, "objective" world outside and independent of being observed. The price of this Cartesian bargain was that the unity of being was sundered at the root of scientific thought. Initially, this did not seem to impede the development of science, which experienced 300 years of rapid growth, in a process of unification toward beautiful simplicity, accompanied by corresponding technological advances which greatly enhanced the control of humanity over nature, for better or for worse.

[1] David Mermin: "If I were forced to sum up in one sentence what the Copenhagen interpretation says to me, it would be 'Shut up and calculate!'"

[2] David Kaiser "How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival". W. W. Norton & Company, Jun 27, 2011

[3] Gary Zukav: "Dancing Wu Li Masters", Fritjof Capra: "The Tao of Physics", Nick Herbert: "Quantum Reality", Fred A. Wolf: "The Spiritual Universe", "The Dreaming Universe", Michael Talbot: "Mysticism and the New Physics" and "The Holographic Universe", Heinz Pagels: "The Cosmic Code - Quantum Physics as the Language of Nature", Itzhak Bentov: "Stalking the Wild Pendulum", Bohm and Hiley: "Implicate Order", Victor Mansfield: "Synchronicity, Science, Soulmaking", Carlo Rovelli: "Reality is not what it seems", Philip Ball: "Beyond Weird", Henry Stapp: "The mindful Universe" and "Quantum Theory and Free Will".

Moreover, the external world appears to consist of separate objects, which are thought to “exist” in a three-dimensional space. Their “existence” excludes the possible existence of other objects occupying the same space. These objects are considered to be existing continuously in every moment of time. A simple example is a ball flying through the air: Operating in the classical paradigm, we assume there is a ‘real ball out there’, and the light scattered off it and into our eyes, produces in our nervous system and brain the impression of a continually changing image of the same object at different points on its trajectory. But already the technology of a movie shows us that a series of discrete images (“frames”) slightly changing from image to image can produce the illusion of continuity. And TV technology shows us that the illusion of continuity can even be achieved through a fast succession of momentary events, such as an electron beam hitting fluorescent chemicals causing discrete, localized flashes of light on a screen. The ball flying through the air is an example of a perceptual-conceptual paradigm creating a familiar reality, namely an object, out of an underlying process, namely a discontinuous series of events. This can serve as an introductory metaphor of how the operation of our classical paradigm gives rise to our familiar world of objects and people from a very different underlying reality.

Another important presupposition of the classical paradigm is that “observation” or “measurement” is assumed to be a passive process, through which we merely find out experientially what the objective situation is. Measurement is assumed to allow the gathering of information without affecting the observed. It is imagined as an objective process, which can be carried out either by direct sensory perception and subsequent mental recording of the outcome, i.e. using our body and its sensory organs as a measurement device, or by an insentient measurement and recording device. ‘Objective’ refers to the assumption that the observer’s state of mind, for example his or her intent, are not assumed to play a role in the measurement.

The Classical Paradigm has no place for awareness, consciousness, mind or free will; it considers them as “epiphenomenal”, only simulated by corresponding behavior[4]. Devoid of existence or meaning, they are not considered to be legitimate categories of scientific discourse, but merely terms of ordinary discourse, remnants of pre-scientific thought. One of the implications is that my physical body is all there is to me, and that when I die, everything that is “me”, disappears together with my body’s biological functioning.

These presuppositions which form the core of the Classical Paradigm, together with a corresponding classical (Aristotelian) logic, are “embodied”, i.e. fully internalized and operating below the level of conscious thought. Our classical concepts, language and logic then keep us stably locked into this paradigm, and the resulting social consensus seals this confinement.

But it was only a question of time before science would have to face the unrecognized limitations of its basic presuppositions. That moment came at the beginning of the 20th century, when classical physics ran into its terminal crisis with decades of irreconcilable paradoxes and confusion.

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[4] the basic assumption of behaviorism

Paradigms and the structuring of reality

The great wisdom traditions, for example Buddhism, Taoism, Vedic traditions, or Kabbalah, have investigated the nature and workings of human consciousness for millennia, and found that our experience is heavily conditioned by presuppositions. These presuppositions in their entirety determine a *paradigm*, an embodied world view within which the whole of life plays out. A paradigm, in this most fundamental sense, structures our experiential reality, including what we perceive and how we think. Our paradigms can have a severely limiting effect on us, a condition Buddhists refer to as “ignorance” and see as contributing to an unsatisfactory, alienated way of being, suffused by suffering, selfishness and conflict. The limitation is not so much the result of operating in a paradigm: it is the consequence of not being aware that we are operating in a paradigm, and what its presuppositions are. The traditions developed teachings and practices with the goal to lead the practitioners to free themselves of these limitations.

Presuppositions can be built on top of one another, which leads to a hierarchical structure of paradigms, with more specialized paradigms rooted in more general ones, and used for more specific domains. In general, the more fundamental a paradigm and its presuppositions are, the more unchallengeable these presuppositions seem. They may seem unchallengeable because they appear to be self-evident due to long term familiarity and habituation, making them not consciously noticed, and so not even subject to challenge at all. Thus, paradigms can form a “prison” that keeps our perceptions and thinking, our very sense of being, in tight limits. This is especially acute and problematic in the case of fundamental paradigms, which tend to operate at a conditioned, unconscious level, most especially since we are generally attached to them, i.e. “believe” them. The Classical Paradigm is an example of such a fundamental paradigm.

Einstein understood this and pointed out that our ‘*common sense’* presuppositions are nothing more than a culturally shared collection of prejudices, unchallenged assumptions programmed into the mind from an early age on. Every new idea one encounters in later years must combat this accretion of “self-evident” concepts. And it is because of Einstein’s unwillingness to ever accept any unproven principle as self-evident that he was able to penetrate closer to the underlying realities of nature than any scientist before him.

In the context of science, it was Thomas Kuhn, in his groundbreaking work “The structure of scientific revolutions”[5] who introduced the concept of a *paradigm* as “a comprehensive model of understanding that provides a field's members with viewpoints and rules on how to look at the field's problems and how to solve them”. By reviewing and analyzing the way science had historically developed, he showed that the traditional idea of science progressing through a steady accumulation of knowledge was inaccurate. Instead, science makes its greatest advances in discrete, revolutionary steps, so-called *paradigm shifts*, which are necessitated and prompted by the gradual accumulation of insoluble inconsistencies and other deficiencies within the old paradigm. A new paradigm then emerges by a stroke of genius, usually first resisted by the field but gradually gaining ascendancy and, in time, near-universal recognition. The new

[5] Thomas S. Kuhn "The Structure of Scientific Revolutions" University of Chicago Press, 1962

paradigm recontextualizes the whole field of knowledge to which it pertains, and opens up an explosion of new insights, research methods, and results. The phase of science between such revolutions, which Kuhn calls “normal science”, consists of filling in the details of the new map, until eventually it approaches its own limits.

Such scientific paradigms are of an intellectual, conceptual nature, more than of an embodied, experiential one[6]. Their explicit formulation is usually the task of philosophers of science. Such paradigms determine the concepts in which the theories are to be formulated, what is to be observed and how it is to be conceptualized, the kind of questions that can be meaningfully asked, the possible form of answers in relation to this field, and how the results of scientific experiments should be interpreted.

As such, paradigms are by their nature frameworks. They are not true or false; instead they can be more or less useful for specific purposes. All statements of fact are relative to a given paradigm, and their truth or falseness is therefore strictly relative to that paradigm, and not absolute. In fact, the same statement can sometimes be understood in completely different ways in different paradigms, or make no sense in yet another paradigm. This makes inter-paradigmatic communication challenging, and yet vital for our survival as a species. A basic openness, and willingness to listen, try it out, are necessary, but still not sufficient conditions for inter-paradigmatic communication. Metaphoric or poetic use of language, and art in general, can help bridge the gap.

A quantum physics experiment: Buckyballs reveal wave behavior and inspire art

George Weissmann and Julian Voss-Andreae met at the ETH Zürich’s *Cortona Week* in Italy in 1999 where Weissmann presented his research on *Quantum Physics and Parapsychology*. Voss-Andreae made his very first sculpture at this interdisciplinary workshop intended for natural scientists who want to explore beyond the confines of their fields[7]. Voss-Andreae was at that time a graduate student in physics participating in a seminal experiment[8] led by Markus Arndt in Anton Zeilinger’s research group in Vienna, Austria. Originally proposed by Roger Penrose[9], the experiment probed the wave aspects of the then largest particles to ever reveal quantum mechanical wave properties, Carbon-60 “Buckminsterfullerenes” or *buckyballs*. We will

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[6] However, when scientific paradigms are adopted, internalized, believed and embodied, they may, and frequently do, have experiential implications.

[7] Cortona Week was an annual seminar taking place in Cortona, Italy, during the years 1985-2017. Created to foster transdisciplinary and intercultural competence in natural scientists and engineers, the seminar extended their expertise to a much broader scope of other domains such as spirituality, literature, psychology, fine arts, bodywork, and intercultural knowledge.

[8] Arndt, M., O. Nairz, J. Voss-Andreae, C. Keller, G. van der Zouw, and A. Zeilinger. Wave-Particle Duality of C_{60} Molecules, Nature **401** (1999) <https://julianvossandreae.com/wp-content/uploads/1999/12/c60article.pdf>

[9] Markus Arndt, private communication

describe this experiment in some detail to illustrate how insights leading to the Quantum Paradigm are gained and how this experiment has inspired Voss-Andreae's artistic path.

While Newton assumed that light consists of particles, Thomas Young demonstrated in 1802 light's wave-like properties. His famous 'double-slit experiment' masks a beam of light to allow only two small portions of it, typically in the shape of rectangular slits, to fall onto a screen to allow observation of the resulting light pattern. Light imagined as consisting of a stream of bullet-like particles would be expected to create two separate areas of local brightness, the images of the two slits, but that is not what is seen when we perform the experiment. Instead, the light emanating from the slits creates a distinct striped 'interference pattern' with more than just two separate areas of maximum local brightness.

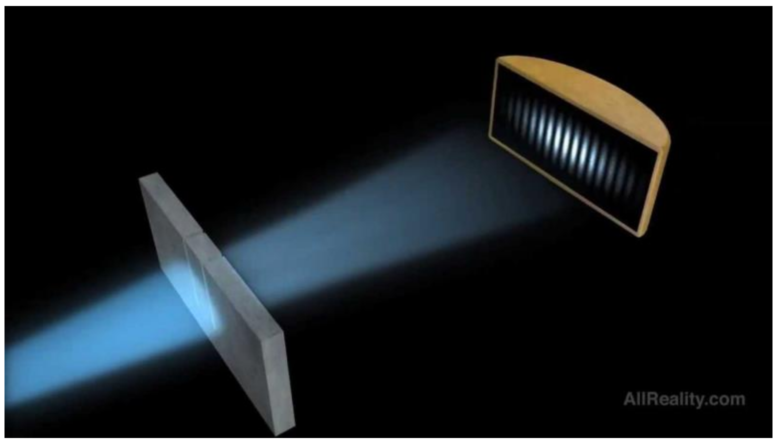

Fig. 1: The double-slit experiment. A light beam, coming from the lower left, penetrates the double-slit and the interference pattern is observed on the screen (top right).

All features of the interference pattern can be predicted by modeling the light as the sum of two electromagnetic waves, one emanating from each slit: in the center of the screen, where the distance to each slit is exactly the same, the two light portions arrive exactly in phase; whenever one wave's electric field is at its maximum so is the other wave's, and if one wave's electric field is at its minimum so is the other one's – the observed sum of the two contributions is an area of maximum brightness. If we, however, move a little bit to the left or right on the screen, away from the exact middle, we soon get to a point where the two wave trains are shifted by exactly one half of the light's wavelength with respect to each other. Now, whenever one wave is at its maximum, the other one is exactly at its minimum and vice versa – what we observe in such an area is the absence of light because the two oscillating electric fields of each wave cancel each other out exactly, at every moment in time. If we move away from the screen's center yet a little bit further, the situation is reversed again – the difference in length of the two wave trains is now exactly one whole wavelength so the waves arrive in phase yet again, resulting in another area of maximum brightness.

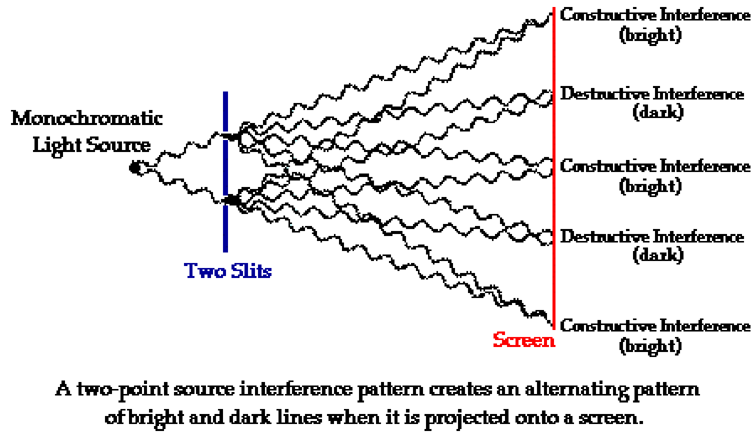

Fig. 2: How the wave property of light and matter explains the appearance of the interference pattern.

This experiment seemed to have settled the issue of whether light consisted of particles, as Newton had hypothesized, or had wave nature, in favor of the latter. But a hundred years after the double-slit experiment with light was performed for the first time, Albert Einstein established that even though it remains true that the propagation of light through space and time is perfectly modelled as a wave, its observation can only be modelled if imagined as a particle: If we replace the screen in the above experimental setup with an extremely sensitive light detector and dim down the light to almost darkness, we will observe discreet 'clicks' in the detector, each corresponding to the detection of a single photon, the particle of light. Even though the light can be so weak as to allow passage of an arbitrarily long time between the detection of each photon, the pattern that will be recorded over time will still satisfy the distribution of the same interference pattern – if we just wait long enough, the single photon detections will accumulate to create the same statistical pattern as seen on the screen in Fig. 1.

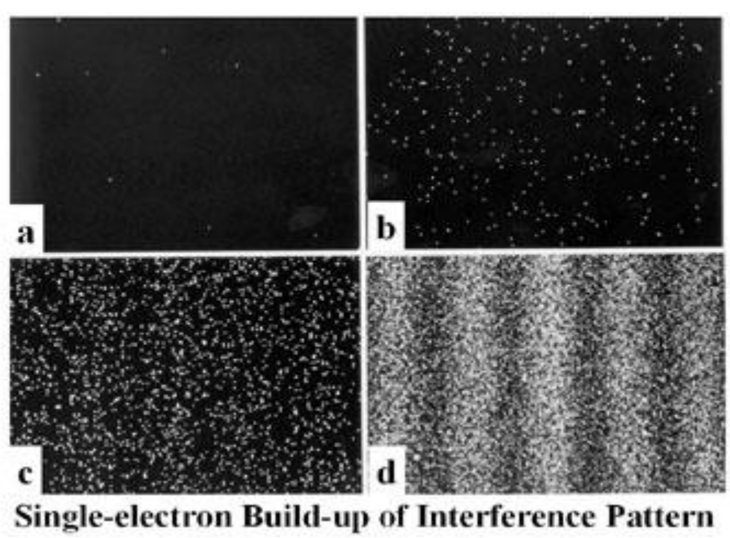

Fig. 3: Successive accumulation of observed particles (here electrons) shows that the individual 'events' (light dots) adhere to the overall probability distribution as predicted

by Quantum Theory. The individual events collectively create the interference pattern. QT does not, however, predict the exact position of each individual particle observation.

In the years leading up to the year 1999, the development of several atom optics techniques and advances in the field of semiconductor technology, as well as the unexpected discovery of Carbon-60 buckminsterfullerene all contributed to the possibility of using buckyballs to demonstrate quantum mechanical wave properties on that unprecedented scale, two orders of magnitude more massive than anything ever before. The buckyballs, soccer ball-shaped molecules consisting of 60 carbon atoms with a diameter of about 1 nanometer[10], were subjected to a double-slit-type experiment. The screen with the slits[11], about 1 m away from a source that evaporates a beam of hot buckyballs into a vacuum, has 50-nanometer wide slits, 100 nanometers apart from each other.

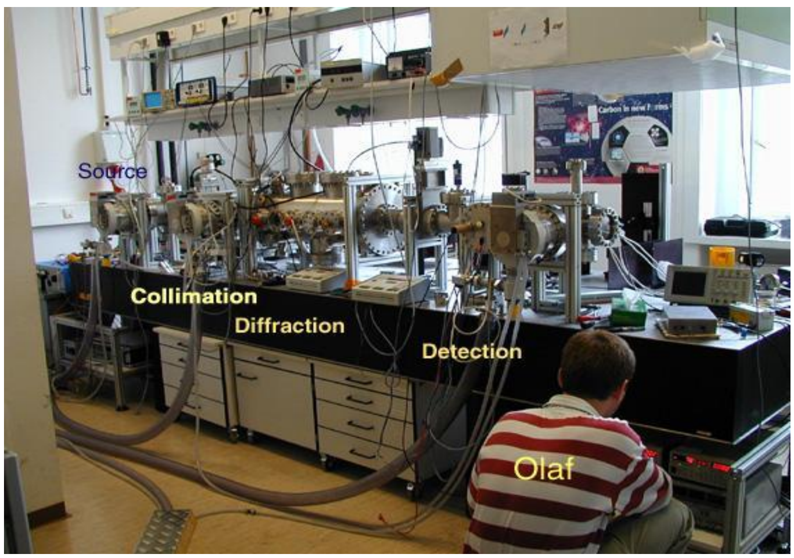

Fig. 4: Photo of the experimental setup used to reveal quantum mechanical wave behavior of Carbon-60 buckyballs (Vienna, 1999).

The molecules fly at typical airplane speeds[12] through the vacuum, one at a time[13], and fall about one millimeter in the gravitational field while traversing the apparatus, just as a macroscopic ball would at that speed. If we mentally scale up the experiment so that the buckyballs assume the size of normal soccer balls, they would be detected at the moon and the distance from one slit to the next would be about the size of a soccer field. What corresponds to the detection screen in Young's 1802 experiment is, in the 1999 Vienna experiment, a movable

[10] One nanometer is 10^{-9} m or one billionth (= 1/1,000,000,000) or 0.000000001 meter.
[11] The slits in our experiment are for technical reasons not just two, but a "diffraction grating" with many slits. The concept of the double-slit can be expanded in a straightforward fashion to a series of slits, not changing any of the reasoning above that leads to the interference pattern.
[12] Typical velocities of about 600-800 km/h corresponding to de Broglie wavelengths of about 3 picometers (3×10^{-12} m).
[13] The detected buckyballs are separated by a typical distance of 0.1 mm or 100,000 times their diameter.

stage that scans the width of the molecule stream with a laser beam pointing upwards along the direction of the slits.

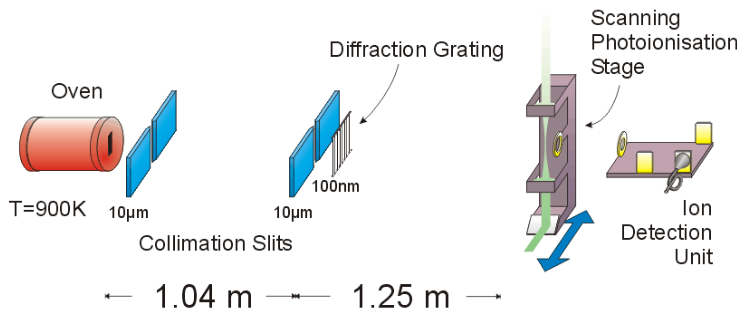

Fig. 5: Schematic of the Vienna experiment setup.

Focused to a narrow width of a few micrometers, the molecules passing through absorb the light and eject an electron in response. The now charged molecule can be controlled via electric fields and is accelerated into a particle detector to be counted individually. And the accumulated individual events indeed conspire to create an interference pattern that perfectly matches the predictions of QT.

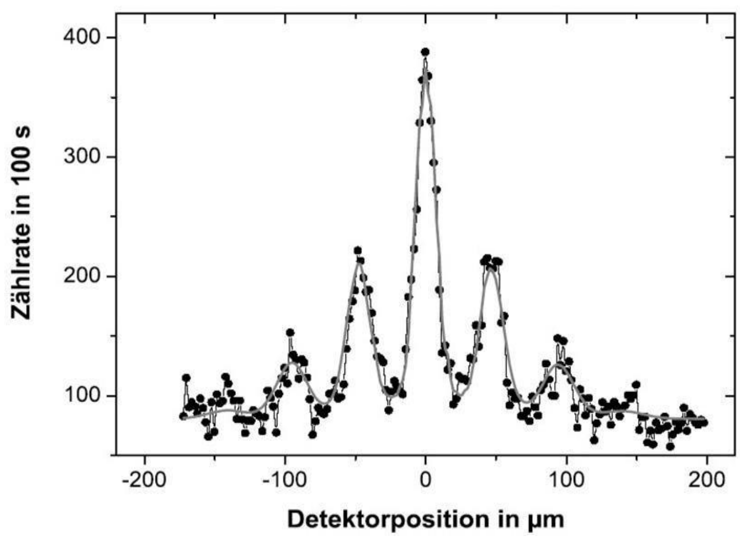

Fig. 6: The interference pattern of buckyballs[14].

The fact that the count rate drops down next to the central maximum and then goes up again is the telltale sign for wave interference. The only way to explain the experimental results in terms of the Classical Paradigm would be to conclude that a single buckyball (or, more accurately, the entity that is later detected as a single buckyball) goes through two openings at once - two openings that are a hundred times farther apart than the diameter of one buckyball.

[14] Image taken from: M. Arndt, O. Nairz, J. Petschinka and A. Zeilinger "High Contrast Interference with C_{60} and C_{70}" C. R. Acad. Sci. Paris, t.2, Série IV, p. 581-585 (2001).

The shape of the buckminsterfullerene, called ‘truncated icosahedron’ in mathematics, was first classified by Archimedes around 250 BCE and the oldest image existing today is a print from about 1500 AD by Leonardo da Vinci for a renaissance book on mathematics[15].

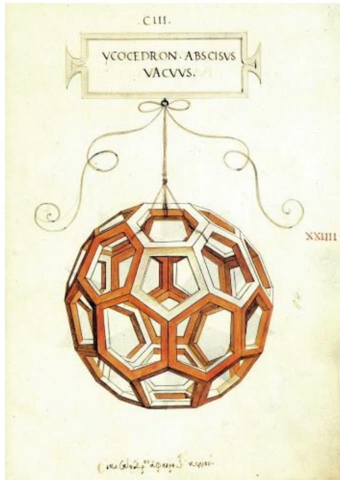

Fig. 7: The shape of the buckyball. A truncated icosahedron drawn by Leonardo da Vinci.

This image of a truncated icosahedron with open faces inspired the first sculpture Voss-Andreae made after graduating from art college in 2004: Recreating the structure from bronze sheet, the cutouts inside the faces were used to create a sequence of buckyballs of diminishing size, nested inside each other. The buckyballs where attached in place by running thin rods radially through the 60 vertices. Intriguingly, the resulting shape of “Quantum Buckyball” echoes the mathematical structure of the wavefunction encoding our knowledge of the potentialities of the buckyballs in the Vienna experiment: the wave fronts are a series of concentric spheres, moving outwards.

[15] Luca Pacioli “Divina proportione” (Divine proportion), composed around 1498 in Milan and first printed in 1509.

Fig. 8: Julian Voss-Andreae. *Quantum Buckyball*, 2004. Bronze with patina, diameter 24“ (60 cm). Location: Private Collection, Portland (Oregon).

A sculptural object occupying a considerable volume of space while consisting of comparatively little material is an apt metaphor for matter - the ephemeral energetic dance that gives rise to our experience of matter as solid, impenetrable and lasting. Voss-Andreae subsequently created larger buckyball sculptures from steel consisting only of the solid’s edges, culminating in a 30-ft (9-m)–diameter piece first installed in 2006. Now permanently sited in a picturesque private park in Oregon, the buckyball hovers above arm’s reach over a sloped terrain with a small creek running under it. Suspended by three majestic Douglas firs that grow through the structure, the buckyball’s orientation was chosen such that two opposing hexagons, one at the bottom and one on the top, are lying between the trees on horizontal planes. As of this writing, the sculpture has been at that location for over 10 years, growing slowly upwards together with the trees. The reason that such a basic shape succeeds as a piece of art is its placement within nature. Despite its considerable size, the structure’s visual impact is quite subtle due to the relatively thin 2-in (5 cm) tubing and the natural color of the corroding steel. The trees intersecting the buckyball dissolve the mathematical shape, symbolizing quantum physics’ revelation that our common-sense perception of matter as having well-defined boundaries is ultimately an illusion.

Fig. 9: Julian Voss-Andreae, *Quantum Reality (Large Buckyball around Trees)*, 2007. Steel and trees, diameter of the steel structure 30 ft (9 m). Location: Private collection, Portland (Oregon).

Special Relativity associates a specific amount of energy with each portion of matter[16]. QT assigns this energy a specific frequency[17] which, by virtue of relativity, becomes a wave when moving. Therefore, any portion of moving matter is mathematically described as a wave, with a specific *de Broglie wavelength*[18]. Anton Zeilinger once remarked jokingly during one of the weekly meetings of his research group in 1999, that the fact that the de Broglie wavelength associated with a walking person of fairly typical mass and velocity happens to be approximately the Planck length[19], cannot possibly be a coincidence. Zeilinger's remark highlighted a yearning, often expressed in the group's discussions, to understand what the unobserved wavefunction 'really is' and how it feels like – "it would be great" was an often-heard wish, "to send a philosopher though the double-slit experiment". The philosopher could, after diffraction and subsequent detection, tell us what exactly happened in there. While completely out of current technological reach, this wish led to the idea of using larger biomolecules as probes in future experiments. Voss-Andreae spent some time researching viruses and proteins

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[16] $E = mc^2$

[17] $\omega = E/\hbar$ from $E = \hbar\omega$

[18] $\lambda = h/(mv)$ from $p = \hbar k = h/\lambda$

[19] A very small distance (1.6×10^{-35} m) generally assumed to be of fundamental importance in physics.

as potential candidates for such a follow-up experiment[20] and, getting excited about protein structure, he embarked two years later on his career in art by creating sculptures based on these molecular building blocks of life[21,22]. Soon after that, the old dream of sending a person through the double-slit, to experience for oneself what it feels like to fly through space as a delocalized wave package in a ghostly superposition with oneself, inspired Voss-Andreae to dream up such a sculptural metaphor. Modeled on the shape of a stylized human walker, “Quantum Man” consists of numerous vertically oriented parallel slabs of steel with constant spacing reminiscent of the wavefuntion’s mathematical structure[23,24]. Like a quantum-age update of classical, monolithic and solid sculpture, this style creates an impression of a three-dimensional topological map, evoking the fundamental scientific act of the measurement, imposing the Cartesian coordinate system onto the organic structure of the world. The slabs are connected with short cylindrical pins of steel. These seemingly irregularly positioned pins between the regularly spaced slices evoke the random-appearing, indeterminate events encountered in quantum physics.

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[20] Frank Grotelüschen: "Die Quantenwelt wird sichtbar. Anton Zeilingers physikalische Experimente stoßen an die Grenzen des Vorstellbaren" Berliner Zeitung (Wissenschaft - Seite W01) December 6, 2000 <https://julianvossandreae.com/wp-content/uploads/2000/12/2000_12_6_BZ.pdf>

[21] J. Voss-Andreae: "Protein Sculptures: Life's Building Blocks Inspire Art" Leonardo **38** 1, 2005 <https://julianvossandreae.com/wp-content/uploads/2005/01/Leonardo_38_1_Protein_Sculptures_I.pdf>

[22] J. Voss-Andreae: "Unraveling Life's Building Blocks: Sculpture Inspired by Proteins" Leonardo **46** 1, 2013 <https://julianvossandreae.com/wp-content/uploads/2013/01/Leonardo_46_1_Protein_Sculptures_II.pdf>

[23] Ph. Ball: "Quantum objects on show" Nature **462**, November 26 (2009) <https://julianvossandreae.com/wp-content/uploads/2009/11/2009_11_26_Nature.pdf>

[24] “Dual Nature,” Science **313** (2006) p. 913 <https://julianvossandreae.com/wp-content/uploads/2006/08/2006_08_18_Science.pdf>

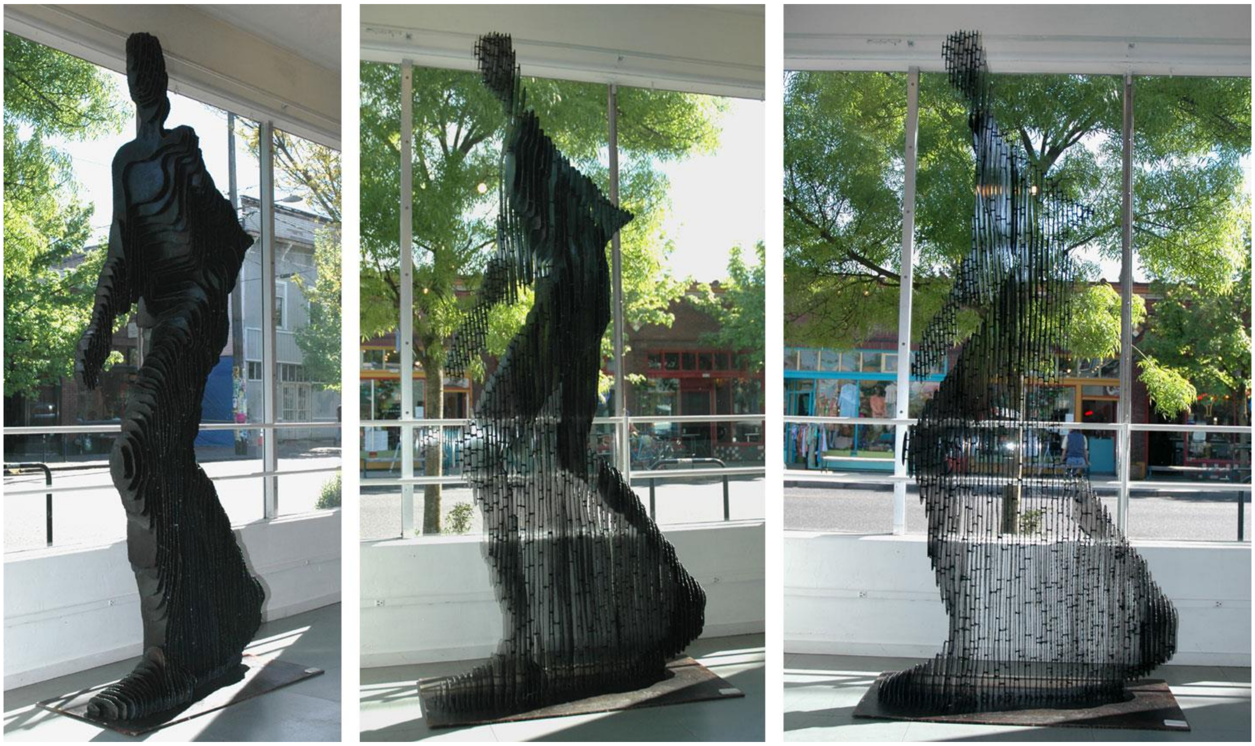

Fig. 10: Julian Voss-Andreae, *Quantum Man*, 2006. Steel with patina, 100 × 44 × 20 in (2.50 × 1.10 × 0.50 m). Public collection of the City of Moses Lake, Washington.

When approached from the front or back, “Quantum Man” seems to consist of solid matter, but when seen from the side it virtually disappears because only a small fraction of material can be seen at this angle. The visual effect this style produces is striking and echoes quantum physics' paradoxical nature and its critical dependence on the observer's point of view. The effect is even more pronounced in the second version, using laser-cut stainless-steel slabs: the light zig-zagging between the polished slices lets the viewer perceive moving objects behind the sculpture even at angles where no direct line of sight exists. In addition, the light reflecting off the laser-cut edges draws the sculptural volume into space. Through its highlights and shadows still clearly reading as the depicted body[25], the sculpture becomes a ghostly ‘after image’ of the body, now completely unified with its surroundings[26].

Voss-Andreae experimented with different ways of representing the human figure through parallel slices, including more realistic rendering as well as exploring other slicing directions[27]. In 2012, he made his first work in a series that continues to endure to this day, rendering the human body naturalistically and in vertical slices oriented along the direction of the gaze.

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[25] This effect even allows to clearly discern faces and facial expressions despite the drastic reduction of visual information this approach entails.

[26] A good visual introduction can be found at <https://www.facebook.com/thisisinsiderart/videos/719258618244705/>

[27] J. Voss-Andreae: "Quantum Sculpture: Art Inspired by the Deeper Nature of Reality" Leonardo 44 1, 2011 <https://julianvossandreae.com/wp-content/uploads/2011/11/QuantumSculptures_VossAndreae_44_1.pdf>

This orientation results in the sculptures' disappearing exactly when the viewer crosses the figure's 'line of sight'. Instead of a literal analogy to the mathematics of quantum physics, this new body of work, while using the same formal device of creating a solid body from thin parallel slabs of metal, now speaks to the conscious mind observing his or her world. It is not enough to look at a static image; the viewer must actively experience the work by surrounding it and allowing the full image of the work to emerge through continued observation. A 2014 installation for the University of Minnesota's Physics and Nanotechnology Building titled "Spannungsfeld" (literally "tension field"[28]) places two monumental figures in meditative kneeling poses, a man and a woman, facing each other. Sliced in the same direction of their gaze the two figures emerge as a pair of polar opposites, like manifestations of a single underlying oneness, a 'quantum field', as it were. Object and subject appear as symmetric, as merely different sides of the same coin.

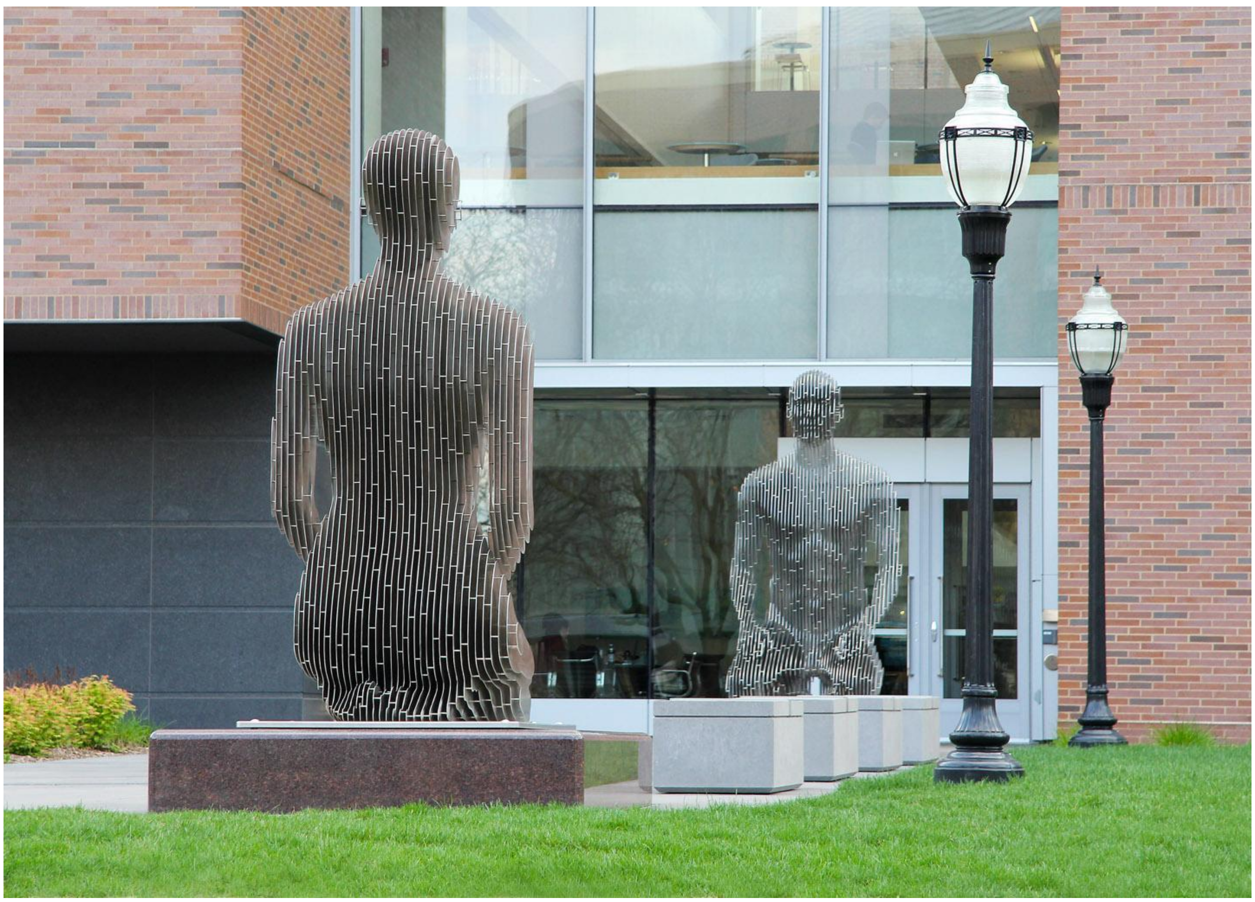

Fig. 11: Julian Voss-Andreae. *Spannungsfeld*, 2014. Stainless steel and granite, 12' x 70' x 6' (4 x 21 x 2 m). Physics and Nanotechnology Building, University of Minnesota (Minneapolis, Minnesota). The two figures manifest as a pair of polar opposites from an underlying oneness. Object and subject are merely different sides of the same coin

[28] The German title of the installation originated in physics but is used in contemporary German almost exclusively in a metaphorical sense, implying a dynamic tension, often between opposites, that permeates everything in its vicinity.

Voss-Andreae's 2018 work "Elective Affinities"[29] takes the next step toward symbolizing our underlying connectedness by merging two human bodies into one. A standing male and female figure leaning against and pushing each other, in a pose suggesting opposition as much as attraction. The hands, pushing into the opposite figure, seem to merge with the other body. The heads morph into one, with the faces touching, sharing common metal slabs which makes full visual separation of the two bodies impossible.

Elements of an emerging Quantum Paradigm

The wavefunction

All the measurement information which an observer has gained about a physical system through past measurement interactions is encoded in a mathematical object called the wavefunction[30]. All physical questions the observer could ask within the context of QT about his[31] possible future measurements can be answered from knowing this wavefunction. Let us exemplify this with the simplest case of a quantum system, a single particle such as the buckyball in our experiment described above. The "wavefunction of this particle"[32] is the quantum mechanical equivalent of the function describing the motion of the center of mass, in Newtonian physics an infinitesimally small point. In QT, the wavefunction is not point-like but spreads out over space, giving it for example the ability to penetrate two neighboring slits in our experiment. But QT does not tell us what the system's ontic[33] properties are, if such even exist. The wavefunction cannot be considered to be representing what the system itself "is", only how it manifests to an observer via its interaction with him. The common shorthand notion of the wavefunction being the "wavefunction of a particle" is misleading, suggesting that such a particle exists even when not observed. It creates a false duality between observer and observed and imputes properties to a particle which that "particle" in fact only "has" when it is observed. The idea that the particle exists, in and of itself, and has definite properties "between" observations, is incompatible with QT. What the wavefunction does do, however, is to inform the observer what values a possible measurement can yield, and what probabilities to expect for these values to be measured.

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[29] "Elective Affinities" (German: "Die Wahlverwandtschaften") is a novel by Johann Wolfgang von Goethe, published in 1809. The title is taken from a scientific term once used to describe the tendency of chemical substances to combine with certain other substances in preference to others. The novel is based on the metaphor of human passions being governed or regulated by the laws of *chemical affinity*.

[30] The general term is 'state vector'.

[31] Or 'her'. Let us assume, for the sake of brevity and without loss of generality, that this and the other hypothetical observers we use in this article, identify as male.

[32] representing its position, the so-called "center-of-mass-wavefunction"

[33] real, or factual existence

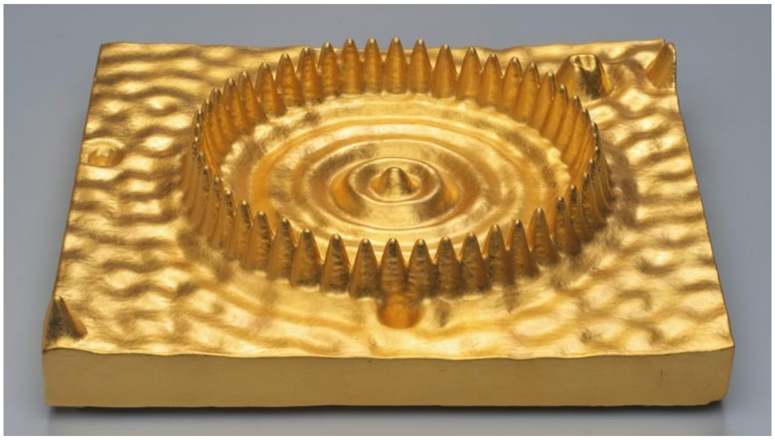

Fig. 12: Julian Voss-Andreae. *The Well (Quantum Corral)*, 2009. Gilded wood, 3” x 13” x 12” x (6 cm x 34 cm x 31 cm). This object was made by using data from a 1993 landmark experiment[34] arranging single atoms into a circle.

Measurement problem and information

One of the paradoxes of QT that has doggedly bedeviled a self-consistent interpretation of QT, namely the so-called “measurement problem”, is based on the fact that a measurement instrument is just another physical object like any other and should be treated as such by QT. Then why does the wavefunction of a quantum system S evolve continuously in time according to the rules of QT, while when S interacts with a measuring instrument, its wavefunction “collapses”, i.e. changes discontinuously? According to the laws of QT, the wavefunction of S becomes correlated with that of the measuring instrument when they interact but should never collapse. That would, however, entail that a measurement, with a determinate outcome, is not possible. But since measurements obviously do occur, and have determinate outcomes, the collapse had to be postulated as an *ad hoc* rule in QT. Most physicists who thought about these issues felt uncomfortable with this “measurement problem”; that there should be two kinds of time evolution of the wavefunction, a continuous evolution dictated by the Schrödinger equation ‘while no one looks’ and a discontinuous ‘collapse’ if a measurement is performed - despite the fact that any measuring instrument is in all other respects just another macroscopic quantum system.

But if we interpret QT within the Quantum Paradigm, where the wavefunction is regarded as a mathematical construct encoding past measurement information and not an ontological objective reality, then each new measurement calls for a substitution of the previous wavefunction with the current one encoding the new information gained by the measurement. The mysterious “collapse” is now recognized as simply an information update. This understanding of the wavefunction as representing *information*, and therefore of QT as a theory of information, is now considered by most researchers in quantum foundations the most promising and practically useful interpretation of QT. But most of them still don’t take the final logical step and relate information to experience; when the fullness of experience is reduced to

[34] M.F. Crommie, C. Lutz and D. Eigler, “Confinement of Electrons to Quantum Corrals on a Metal Surface,” Science 262 (1993) pp. 218–220.

conceptual abstractions, then experience reduces to information, void of meaning. The informational interpretation which is becoming dominant as an interpretation of QT, while close, is still one crucial step removed from the Quantum Paradigm, from making contact with existential reality.

In this, and many further examples which we elaborate elsewhere[35], the Quantum Paradigm solves the foundational inconsistencies and paradoxes of QT that result from interpreting it classically, in particular with the presupposition of objectivity. What all this implies existentially is that the world is not "out there" with us (our mind) being "in here". The classical dualism between external objective reality and our internal subjective experience of it is generated by the inappropriate application of the Classical Paradigm.

Relationality

The second fundamental "paradox" of QT when interpreted within the Classical Paradigm with its Cartesian subject-object split is the "Wigner's friend paradox"[36], a scenario involving an indirect observation of a quantum measurement. In QT, an observer O treats not only the system S that he is observing, but also any other observers (along with their measuring instruments) as quantum systems. If we analyze the quantum treatment of a situation where a second observer O' is observing O in the process of observing S, and apply the usual quantum rules, it turns out that O' and O end up with different wavefunctions for S[37]. This "paradox" is inevitable, given the rules of QT for construction of wavefunctions on the basis of data. As long as we are trying to interpret QT within the Classical Paradigm, which regards the wavefunction as objectively given, this is indeed a paradox, because the wavefunction should then be unique, and not observer-dependent. The conclusion from the above considerations is that the wavefunction is always relational, i.e. relative to a given observer. There is no objective or absolute information about S itself, and in fact, the assumption that there could be (possibly as yet unknown) objective properties[38] of S is irreconcilable with observed quantum behavior. This simple and elegant resolution of the "Wigner's friend paradox", discovered in the 1990's by Carlo Rovelli and others, is a generalization of the relativity of space and time which Einstein discovered and formalized in his special relativity theory.

The Observer-Participator

The purely passive observer of classical physics, who just observes what was already the case before the observation, is in QT elevated to the observer-participator[39] who plays an active role in creating the event history of the system, and in the process, of himself. John A. Wheeler used the suggestive terminology of question and answer: The observer asks a question of the

[35] George Weissmann, Cynthia Sue Larson: "The quantum paradigm and challenging the objectivity assumption" Cosmos and History: The Journal of Natural and Social Philosophy, vol. 13, no. 1, 2017
[36] also known as the "second observer" paradox
[37] For a time at which O has already observed S but O' has not yet, only the wavefunction belonging to O has yielded measurement results for S that are definite.
[38] other than conserved ones
[39] a term introduced by John A. Wheeler

universe[40] by means of his measurement operation, and the universe answers this question by yielding the outcome of the measurement. This process of question and answer creates something genuinely new in the universe and is therefore truly ‘creative’; the observer has the freedom of choice what question to ask, and the outcome of the measurement is in principle not predictable from the state of the system before the measurement[41]. The observer is thus a co-creator of his reality.

Entanglement and Wholeness

Let us consider a “composite” quantum system consisting of two separate subsystems S_1 and S_2 described by a common wavefunction. We measure the observables of each subsystem separately. If S_1 and S_2 are not interacting, then a measurement of one subsystem will not affect the portion of the wavefunction describing the other one; the two systems can be thought of as independent. But if the two subsystems do interact, then the wavefunction will become an inseparably connected wavefunction of both subsystems. A measurement of the observables of one of the subsystems will in that case also affect the expected measurement probabilities of the other one. Even if S_1 and S_2 are far enough from each other to exclude any causal influence between them[42], a measurement of one system will affect the other one's measurement outcome. S_1 and S_2 are called ‘entangled’. Every time two quantum systems can interact, they become entangled, even if they were initially not entangled.

Entangled systems cannot be considered to be separate, since their respective observables are mutually correlated. Quantum systems have an aspect of wholeness which would not be classically suspected on the basis of being “separate, independent particles”. This wholeness extends to any quantum system, even the whole observable Universe. Separateness thus turns out to be a classical illusion, rendering the concept of reductionism, the assumption that a whole is nothing but a sum of its parts and that the behavior of complex systems can in principle be understood by considering their separate components and interactions, obsolete. Separateness and reductionism are replaced by holism, the recognition of wholeness as a basic feature of reality.

[40] The whole observable universe is ultimately one large quantum system.
[41] and cannot even be thought of as determined at all, a property of QT called *contextuality*
[42] Causal influences cannot spread faster than the speed of light.

Fig. 13: Julian Voss-Andreae. *Elective Affinities*, 2018. Stainless steel, 89" x 82" x 26" (226 x 209 x 66 cm). Private collection (Palm Springs, California). Two human bodies merging into one symbolize our fundamental connectedness - our apparent separateness is an illusion.

Quantum Indeterminacy, Randomness and “Psi”

All the laws of classical physics are deterministic. Once the configuration of a classical system is given at one moment in time, its whole past and future is completely determined and in principle calculable. For human existence this seemed to imply a complete lack of free will: human and animals were just automatons, with completely pre-determined reflexes. Full embodiment of such a worldview would obviously have grave consequences for human societies, for then no one is responsible for their actions. Quantum theory demolishes this determinism: knowing all that can be known about a system now, namely its wavefunction, does not allow us to predict, even in principle, the outcome of the next measurement. While the probability of any possible outcome is determined by QT, the outcome of any specific measurement we make, is not (see Fig. 3 for an example). The only regularity we can predict is that if we repeat the same experiment, measuring the same observable many times, then the average outcome will be the one predicted by QT. There is no other regularity or order in the individual measurements. This *quantum indeterminacy* is characterized by the impossibility of influencing the probability of measurement results by any causal means. This indeterminacy is typically interpreted as randomness, i.e. any pattern or predictability is thought to be absent from the sequence of individual measurement outcomes. But randomness is not the only alternative to determinism, as can be seen by considering the concept of free will: An action caused by free will, as we usually understand it, is neither causally determined, nor is it random.

Let us consider an experiment, where a quantum system is prepared in the same way every time and a specific observable is measured every time. An example would be the measurement of the spin of electrons in a beam, which has a binary result: spin 'up' or spin 'down'. Randomness of quantum events in this case would mean the absence of any pattern or predictability in the sequence of measured 'ups' and 'downs'. Quantum indeterminacy denies the possibility of any causal influence on individual measurement outcomes. Randomness implies there is no pattern in the sequence of repeated measurements, causal or not. If there are any (non-causal) factors that influence such a pattern, then that would contradict randomness, but not quantum indeterminacy. There are a number of very carefully executed experiments, by a number of different researchers, who have set up such an experiment but, in addition, asked participants to "influence" the outcome of the binary sequence and to somehow temporarily "shift" the pattern of 'ups' and 'downs' away from the, say, 50:50 probability, the ratio expected for very long experimental runs. It turns out that the presence of a person with focused intent can make a statistically significant impact[43]. Here, like in most other fields, some people are better at it than others - interestingly often people skilled in activities such as meditation, yoga or martial arts. Physics tells us that there is no causal mechanism to explain such "psi" phenomena - but our conscious mind co-creates the world, and the quality and specifics of that co-creation are at least in part of our own mind's making[44].

Embodying the Quantum Paradigm

Understanding the Quantum Paradigm intellectually does not, in and of itself, transform our experience. In order to achieve that, the new paradigm must be embodied, so that it structures our experience and informs our actions.

What does it mean to live as a quantum being in a quantum world? By reintroducing us to the centrality of experience, it will awaken us from the trance of living in a reductionist world of concepts into the fullness of life; by its insights into the oneness underlying the apparent separateness it will sensitize us to our kinship with all of life and Nature, where compassion and commitment to the common good becomes the foundation of all ethical behavior. It will re-introduce us to the aboriginal but now long-lost realization that the Universe is alive, and sacred. We would recognize the deeper truth of the ancient insight that "Life is a dream": all manifestation, all beings, the whole world, are seen as the dream of one Cosmic Consciousness.

[43] A good starting point to explore this interesting topic outside the current scientific mainstream are the books of Dean Radin. "Entangled Minds" and "The Conscious Universe", for example, present exhaustive meta-analyses of the existing literature.

[44] The phenomenon of such "non-causal co-occurrences" was studied in a collaborative research by one of the great founders of QT, Wolfgang Pauli, and the renowned psychologist Carl G. Jung, who named them "synchronicity" - meaningful coincidences.

Fig. 14: Julian Voss-Andreae. Quantum Buddha, 2016. Bronze, 25" x 19" x 11" (62 x 47 x 28 cm). Private collection (Taipei, Taiwan).

Conclusion

Most of us, scientists as well as laypeople, are unaware of the deeper layers of presuppositions that underlie our own experience. Through the rise of classical science this materialistic-reductionist, deeply internalized worldview has given us great powers and put us, at the same time, at great risk. The urgent need for a paradigm shift is most obvious in our reckless attitude toward our environment; we are jeopardizing our future by rapidly making our planet uninhabitable. The global crisis we are collectively creating calls for a revisioning of our reality, for a refocusing of our energies towards the common good, grounded on an embodied knowledge of our fundamental connectedness. This connectedness has been recognized by the world's great spiritual wisdom traditions, but in our current age, with (classical) science having become the ultimate arbiter of truth for many, this insight no longer holds sway over us. It is intriguing that through the natural progression of that very same human endeavor, the natural sciences, those ancient insights now appear in a new light, imbued with renewed meaning, which will be of crucial help in changing our way of being.

Before our future unfolds, we have dreamt it up. The central place where we, as a collective mind, dream up our future, is in art. Therefore, art has an important role in harnessing the transformative powers we need to get to the future we want. Like the Quantum Paradigm, art is holistic in its very essence. Artists and other keen observers tend to have a natural affinity toward the elements of this emerging worldview and there are many examples of art, including the sculptures presented here, that offer glimpses into this view, helping us to intuit its qualities. Our hope is to plant these seeds into the cultural mainstream to help transcend the paradigm of old, such that science, spirituality and art can become partners, rather than foes, in the dream of discovery and illumination.