The Best of Both Worlds:
why nature must be both analog and digital

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Abstract

When considering whether reality is fundamentally analog or digital, I can think of convincing arguments for each case, but feel that both answers are limiting, and that the fundamental nature of reality is far more interesting. I am firmly convinced reality is neither exclusively discrete nor solely continuous – as it must display both faces for either aspect to be manifested. The nature of reality is both analog and digital, rather than exclusively one or the other. Observable phenomena satisfy the constraints of both continuous and discrete natures at once. The attributes we observe appear discrete or continuous largely as a matter of choice. What information we choose to observe or preserve, and how we take in or process information, will affect what we see. Often the choice is automatic, as a single sub-atomic particle or atom acting as a localized observer can induce the appearance of classical variables and discrete entities, even though the global wavefunction remains coherent during local interactions. Nature is fundamentally unified however, regardless of all appearances, though any attempt to probe it finds discrete quanta of energy, information, and form. This paper proposes that reality is both analog and digital because nature finds the most effective or efficient means available to encode energy and information as observable form.

Introduction

The appearance of discrete quanta of matter and energy is undeniable, and is one of the most important discoveries near the start of the 20th century. It gave birth to the study of Quantum Mechanics, as a distinct branch of Physics. We observe a spectrum of bright lines and dark spaces, when we look at the sun or a sample of ionized gas through a prism or diffraction grating. And predictions of Albert Einstein that the corpuscular nature of light would be revealed by the photoelectric effect were verified by Robert Millikan, who also showed in oil-drop experiments that electric charge comes in discrete units. However; it is notable that Einstein had some reservations about his corpuscular light theory, as seen in a letter from Einstein to a friend, which was shown on a slide by Anton Zeilinger in a lecture I attended (at FFP11 in Paris). I also note two papers by decoherence theory founder H.D. Zeh, "Quantum discreteness is an illusion," [1] and "There are no quantum jumps, nor are there particles." [2] These individuals seem to share a belief that the appearance of separateness hides a deeper connection between the components of reality – a connection not admitted by conventional beliefs or the Copenhagen interpretation of Quantum Mechanics.

I propose that we start with the assumption that reality is a unified whole. Therefore; when asking whether reality is analog or digital, we must not exclude any part of the microcosm or macrocosm, nor limit the range of observable material and energetic attributes we consider. Let us assume that when speaking about reality, we mean everything. I will admit that we may be talking about a Multiverse rather than a simple Universe, but I am assuming that if there is an array of universes, there is some sense of order or hierarchal structure to the entire collection, which enables us to consider it as a unit. I also admit that the universe may be a cyclical or repeating phenomenon – rather than a one-shot deal. I don't need to make any assumptions about the relative laws of Physics in neighboring universes, or introduce other constraints to prove my point, as I am assuming that while some elements of the applicable Math may change from universe to universe, many of the basic laws of Mathematics will remain a constant, arising from yet more basic principles, as is found in the work of the constructivists among others. The local universe is my primary focus, when I use the term 'reality' in this paper. However; the majority of what I cover is applicable across a broader spectrum of possible universes. I note that my thesis suggests that if there are multiple universes, they would likely appear to exist in a discrete spectrum rather than in a continuous range, for any (temporally and spatially) localized observer.

The basic idea of this paper is simply that nature uses the most effective or efficient means to get the job done, wherever possible. This generalized statement of the principle of least action is also an explanation for conservation laws, as such. Nothing gets lost, and no interaction goes forward if it lacks one jot of the exact quota of energy and information or substance required to balance the scales. One might ask how such amazing precision might be achieved, and I propose that it is precisely because reality uses both analog and digital methods that what we observe is possible. Years ago, when discussing an engineering problem he encountered at work, one of my mentors, George Cann, suggested that what was easiest – or might work best – was a hybrid approach using both analog and digital technology. This was something I later got to see in practice, when it was my job to repair equipment using hybrid technologies for electromechanical control systems. The reason is simple; when the available digital technology is too primitive or too slow to act as a real-time control circuit, it is often possible to design an analog circuit which can do the job better. But in general, analog solutions are not quite as stable, nor as predictable in their action, and some circuits may require periodic calibration to function properly. So what makes the most sense is what my friend George said, that we should use analog circuitry for what it does better, and use digital for what it does best. In my opinion; this is what nature does too.

Waves and particles – localizing energy and information

While particles and atoms are largely localized entities, waves are extended in space and over time. Wave-like phenomena can be studied a number of ways, where what is learned by creating waves in a water tank can be applied to electromagnetic phenomena, and so on. We can even recreate the double-slit experiment in a water tank, to show how quantum path interference will produce alternating light and dark bands. But with the normal double-slit experiment, the same result is observed – even when the light is so feeble that only one photon at a time comes through the apparatus. We have a hard time imagining that a single quantum can behave like a wave, in effect passing through both slits or interfering with itself, rather than occupying a discrete location throughout the experiment. And the position of any one photon, when it strikes the target, is more or less random. When enough have gone through to create the whole picture, however, what is seen are the familiar alternating light and dark bands. In my view, this is because energy is fundamentally a wave-like phenomenon, and it retains this property even when it is observed as encapsulated into units such as photons, sub-atomic particles, or atoms. According to the writings of H.D. Zeh, Erich Joos, and other proponents of decoherence theory [3], the appearance of discrete transitions like spectral lines, and discrete entities like photons or particles is induced (through decoherence) by the localized nature of the observer or detector involved.

We must remember that, whenever we make observations and measurements, we are observing the universe from a platform which is comprised of macroscopic molecular matter, rather than free energy – as radiation. Any collection of atoms or an aggregate of molecules tends to behave as a localized object, and in fact the atoms in macroscopic objects tend to be localized too, where their quantum indeterminacy is small. But particles, individual atoms, and small molecules which are free floating are often found in eigenstates, exhibiting a superposition of multiple unique quantum states coherently. This leads some to assume that quantum mechanics is only about very small entities, but it is not so. In his FFP11 lecture, Zeilinger said that it is wrong to imagine that quantum mechanical effects are limited to the extreme microscale of size or temperature. He showed that experiments with C60 molecules (Buckyballs) demonstrated robust 'quantumness' from a few degrees Kelvin to several thousands of degrees. So; something large enough to be a macroscopic observable object can still be entirely quantum mechanical, over a range from well below to well above prevailing temperatures on Earth. Other experiments show that quantum effects can span larger distances, as well. Zeilinger's research team recently demonstrated quantum entanglement for photons separated by 144 km, in an experiment performed using the Tenerife observatory and a workbench on La Palma in the Canary Islands. [4]

But one does not need elaborate and expensive equipment to demonstrate quantum weirdness. One simple experiment I like is the Mach-Zehnder interferometer. It uses two half-silvered (lightly coated) mirrors, two more mirrors that are ordinary or fully-reflective, a light source, and a pair of detectors. The first and last mirrors encountered are half-silvered, and split the beam of light. The four mirrors are placed at the corners of rectangle, and rotated 45 degrees from perpendicular to the beam of light, which enters at one corner and is directed along one edge of the rectangle. When the light hits the first mirror (which is half-silvered), part of it goes straight, but part is deflected 90 degrees. When the next mirrors are struck they direct the beams to the mirror in the far corner (also half-silvered).

If the detectors are placed just past the opposite corner, and the apparatus is carefully adjusted to make the path lengths exactly equal, we observe that only one detector is activated, showing that light behaves like a wave. When something is placed in either path to block the beam, however, both detectors are activated instead. This experiment also works with feeble light, where only single photons traverse the apparatus at any one time. So again; we have individual quanta behaving like waves, rather than a particle. That is; we are forced to assume that each photon is wave-like from the time it enters the apparatus, and then coalesces or becomes particle-like at the last corner to enter the proper detector. In my view; this is because the special fine-tuning of the path lengths allows the 'quantumness' of an entering photon to be preserved throughout its transit. So; while in a double slit experiment one must imagine a photon chooses both of two closely-spaced parallel paths, in the Mach-Zehnder interferometer, we see that the photon chooses both of two perpendicular paths – and that parallel path segments can be separated by several meters or more. Each photon acts like a wave that propagates down both paths, to navigate the apparatus. This shows that the concept of photons as a kind of object – even one which is always moving at the speed of light but takes a unique path to get somewhere – is erroneous. Instead of a discrete entity, we can show that a photon is merely a single cycle of a continuous wave.

Observation, Perception, and Cognition

Part of what motivates me to write this particular paper is my observation that our cognitive faculties have evolved to enable perception by allowing what is received by the senses to be cognized. My belief is that nature equipped us with complex hierarchal brains out of a need to cognize an intricately complex world, and thus to give us a survival advantage which enabled our species to continue evolving. It is therefore likely we can glean some insights into what is real by studying the perceptual apparatus which allows observations to be cognized. My own research has revealed that there are some exciting connections with the field of Physics, which are revealed by examining the latest findings and insights of cognitive and neurological researchers. A Scientific American article by Alison Gopnik [5] explains that very young children are like little scientists, who create theories and then devise experiments to test those theories – all in the process of simply playing. And this 'theory theory' idea, explored by Gopnik and her colleagues, lends credence to my own insights about an important landmark in human cognitive development.

An earlier article by Judy DeLoache, describing developmental steps leading up to our capacity for symbolic thought [6], led to an insight that acquiring this capability depends upon our ability to determine the dimensionality of objects and our surroundings. That is; it seems especially important that we are able to distinguish between a given 3-dimensional object and a 2-d representation or scale model, which can serve as a symbol for the fully dimensioned version. Once it is grasped, that we can have correspondence of variables across dimensional boundaries; a whole new world is opened up to us through symbolic thought. Compare this with the revolution in theoretical Physics brought about by the insight of Gerard 't Hooft, when he posted a paper on "Dimensional Reduction in Quantum Gravity" [7] that swiftly became the most downloaded paper on the Physics arXiv. This led to papers by Susskind [8], Maldacena [9], and others – who generalized 't Hooft's conjecture to a large class of systems and dimensional boundaries of all sorts. And this crucial insight, which has come to be called the Holographic Principle, guides our attempts to unite Relativity and Quantum Mechanics through theories of Quantum Gravity. So, we see that sometimes important advances in Science recapitulate the landmarks in cognitive development, by which we acquire the capacity to perceive and express their core ideas.

Another recent Scientific American article, by MacNeilage, Rogers, and Vallortigara, [10] focused on the evolutionary developments which may have led to lateralization of the brain, as lateralized brains appear in creatures much more primitive than humans, and it is reasoned that there must be evolutionary advantages to having lateral specialization. The ideas expressed in their article inspired me to re-examine insights I have had about lateralization, which led to some correspondence with the authors and to additional research on my part. This matter is profoundly important to the question of whether reality is analog or digital, because the answer we get is largely dependent on which side of the brain we ask. The left and right hemispheres have very different views of the world, you see. Neuro-Physiologist Jill Bolte Taylor recounts her personal experience of having her left brain go off-line during a stroke, in a book entitled "My Stroke of Insight." [11] Having her left-brain completely shut down gave her profound first-hand knowledge of how the right hemisphere operates, and of how different the character of its world-view is from that of the left-brain, which is the dominant hemisphere for most humans. Her description of the right brain's view of the world closely matches the observations about reality made by H.D. Zeh (with a more rigorous technical treatment) in the papers I mentioned earlier.

Simply put; the right-brain perceives reality as unified, connected, and fluid, rather than being made of distinct, disconnected, and solid entities. In Doctor Taylor's view, it is important for us to acknowledge that the right-brain's unified view of reality is every bit as valid as the fragmented outlook of the left-brain. Zeh and Joos go further, and assert that the appearance of separateness is induced by decoherence due to observations by or interactions with localized entities, and that the continuous evolution of the global wavefunction is a more fundamental reality. Re-stating this; reality is by nature a unified whole, but its unity is wave-like and/or energetic – rather than material – which makes the unified field or global wavefunction essentially non-local. When a localized observer or probe interacts with this unified reality, components of the global wavefunction will decouple from the main wave, and become identified with the local system instead. Similarly; the ocean remains a unified whole, with waves moving across it, but the crest of each successive wave delivers a definite amount of water to the shore. Clearly; each individual wave is a discrete event or entity, which only delivers its payload once it has crested (completed a cycle), and yet nobody would say that the ocean is broken into pieces by this action.

If we seek to find or explicate a unified view of reality, it seems we will need to acknowledge the ways in which nature already is unified. And it appears that this aspect of the universe is something we can all cognize, but most of us filter out instead. However; during her stroke – which knocked out the portions of the brain that do the filtering – Jill Bolte Taylor reported that she "could no longer perceive things as things that were separate from one another," and saw that "Instead, the energy of everything blended together." I should mention that, throughout the ages, mystics and sages have reported the experience of being as one with the universe, have asserted that separateness is an illusion, and have taught that the true nature of reality is an ocean of pulsating energy. Dr. Taylor's experience suggests that this awareness is part of the natural function of the right-brain, which makes it something to which we all have access. But in general; people are strongly inclined – and fiercely guided by human society – to identify with the view of the left-brain, which creates the impression of our individuality as a separate self, and depicts all objects as separate entities. Interestingly; this left-brain centered outlook is also strongly connected with our sense of moving forward through time, and specifically with our separation of past, present, and future – into different categories of events.

In a paper soon to be published [12]; I assert that the two halves of the brain function similarly, but tend to operate on information in opposite directions of time. While the left-brain is well-equipped to take a watch apart and to note the details of all the individual pieces, the right-brain is better able to assemble those pieces into a functioning whole watch. Taken to the limit; it is easy to see how these two complementary modes of operation result in two very different views of the world, where all the left-brain sees are separate pieces having a specific form and function, and all the right brain sees is connections which denote how all the separate pieces are interrelated – and comprise components of a unified whole. One could say that the left-brain is a staunch reductionist, while the right-brain is an integral thinker. This tends to foster a world-view that is largely discrete or digital for the left-brain, and an outlook that is far more continuous or analog in the right brain. This extends to the perception of time itself, where the left-brain lives in the sequential time of a succession of individual moments, where the right-brain tends to perceive a continuous flow subsumed into an eternal now – which is encompassing. In other words, the right-brain perceives a timeless reality, rather than having sequential time with a distinct past, present and future.

Generalities and Specifics

While it is nice to realize that nature is unified, it is important to acknowledge that Physics is the study of observable reality and its causes, rather than an open-ended exploration of realities which cannot be observed. The act of observation is itself founded on the possibility of separation, as distance provides the perspective to allow it. Consider how different a circle would appear if you were standing in its center, or on the edge, rather than looking at it from above – as it normally appears on the printed page. But to some extent; we are constrained to watching Quantum-Mechanical reality from the shore, where each wave is seen as a discrete entity, rather than having the view from the open ocean that corresponds to being pure energy as radiation. To see the quantum wavefunction as it is, we would need to be energy riding the waves – rather than having a localized frame of reference which is identified with particle-like or material nature. Thus; even though the evolution of the quantum wavefunction is continuous, all any localized observer can see are distinct entities and discrete transitions. Therefore; it was certainly justifiable for the scientists who devised and adopted the Copenhagen interpretation to do so. After all; Physics is a Science studying observable reality. However; adopting a standard interpretation which disallows any consideration of the energetic mechanisms that give rise to material reality may prevent us from ever understanding what is fundamentally real.

To an extent; all of theoretical Physics is an exercise in discovering the generalities which result in the specific array of observables we find. And in some manner; the efforts of all theoretical physicists are an attempt to discover how nature itself moves from generalities to create the specific details which make up the universe we now observe. But if the quantum wavefunction is a more fundamental reality, creating the appearance of both discrete entities and Classical variables, the Copenhagen interpretation is a roadblock to progress. In my view, all material substance is comprised of energy, and this means that the properties of energy are generalities contributing to the specific properties of all material entities. Energy is motive by nature, rather than fixed or static. Instead of being a local entity, it is a mover. It tends to induce or embody motion, to propagate, circulate, oscillate, or otherwise create variations. Energy tends to spread out from any localized concentration, if it is unconstrained, and it will flow into adjoining regions of lower potential. Energy will also vibrate or undulate, assuming extended wave-like configurations in order to travel through space. Although energy can be bound into forms like protons which persist for millennia, these forms retain many of the attributes possessed by energy as radiation, as the energy they embody never stops being what it really is. This readily explains why not only photons, but even entities as large as C60 molecules behave as non-local waves, rather than sharply defined and localized objects. However; this leaves us with the impression that reality is both analog and digital

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