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The Physical World as a Virtual Reality: A Prima Facie Case

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Not only is the universe stranger than we imagine, it is stranger than we can imagine

Sir Arthur Eddington

Abstract

This paper explores the idea that the universe is a virtual reality created by information processing, and relates this strange idea to the findings of modern physics about the physical world. The virtual reality concept is familiar to us from online worlds, but the world as a virtual reality is usually a subject for science fiction rather than science. Yet logically the world could be an information simulation running on a three-dimensional space-time screen. Indeed, that the essence of the universe is information has advantages, e.g. if matter, charge, energy and movement are aspects of information, the many conservation laws could become a single law of conservation of information. If the universe were a virtual reality, its creation at the big bang would no longer be paradoxical, as every virtual system must be booted up. It is suggested that whether the world is an objective or a virtual reality is a matter for science to resolve, and computer science could help. If one could derive core properties like space, time, light, matter and movement from information processing, such a model could reconcile relativity and quantum theories, with the former being how information processing creates space-time, and the latter how it creates energy and matter.

Key words: Digital physics, virtual reality, information theoretics

Online games show how information processing can create a virtual world with its own time, space and entity interactions, e.g. "The Sims". Yet the idea that *our* physical world is a virtual reality (VR) is rarely if ever considered as a scientific possibility. This concept will be presented in six parts, of which this is the first:

- *Part I, Introduction*, introduces a prima facie case for virtual reality theory.
- *Part II, Time and Space*, suggests how processing could create time and space.
- *Part III, Light*, suggests how light could be calculated.
- *Part IV, Matter*, suggests how matter could be calculated.
- *Part V, Relative Movement,* suggests how relative movement could occur.
- *Part VI, Discussion,* considers some of the implications of the above.

Each part asks whether a VR simulation could produce a world that behaves like the world we occupy. The idea that our world is virtual seems an outlandish suggestion, but the reader is asked to keep an open mind, as one should at least consider a theory before rejecting it. That an idea has little if any popular support is not a reason to reject it, as the history of science is littered with the wrecks of once "obviously right" theories, while some "obviously wrong" theories have later proved right. This paper argues that VR theory is not just logically possible but also theoretically useful. That our physical world is a virtual reality, normally a topic of science fiction, religion or philosophy, is here explored as a theory of physics.

Strange Physics

While virtual reality theory seems strange, so do other current theories of physics, e.g. the many-worlds interpretation of quantum physics proposes that each quantum choice divides the universe into parallel universes [1]. In this view, everything that can happen does in fact happen somewhere in an inconceivable "multi-verse' of parallel universes. This is a popular minority view, yet even relatively main-stream physics theories are quite strange. Guth's inflationary model suggests that our universe is just one of many "bubble universes" produced by the big bang [2]. String theory sees the physical world as having 12 dimensions, with eight of them "curled up" from our perspective. According to the M-theory our universe is a three dimensional "brane" that floats in time along a fifth dimension we can never register [3, p177-180]. The cyclic-ekpyrotic model postulates that we exist in one of two 3D worlds, connected by a hidden extra dimension, that collide and retreat in an eternal cycle [4]. Why does modern physics need such strange theories? One reason is the strange results of modern experiments, where time dilates, space curves, entities teleport and objects exist in many places at once, e.g. in relativity theory:

1. ***Gravity slows time***: An atomic clock on a tall building will "tick" faster than one sitting in the basement.
2. ***Gravity curves space****:* A ray of light traveling around the sun will be bent.
3. ***Speed slows time***. An atomic clock on a flying plane will go slower than one on the ground. For light rays traveling at the speed of light, time stops entirely!
4. ***Speed is relative***. If one could shine a torch from a beam of light the torch-light would leave the beam at the speed of light.

The above statements don't make sense to our normal reality concepts, yet they have been experimentally verified, e.g. in 1962 one of two synchronized atomic clocks was flown in an airplane for several days while the other stayed stationary on the ground. The result was, as Einstein predicted, less time passed for the clock on the plane. In relativity theory a young astronaut could leave his twin on Earth and return after a year's high speed travel in space to attend his twin brother's 80^{th} birthday. The space twin example is not considered as something that could possibly happen, but as something that could actually happen. Quantum theory introduces even more strangeness, e.g.:

1. ***Teleportation***. Quantum particles can "tunnel", suddenly appearing beyond a barrier they cannot cross, like a coin in a sealed glass bottle suddenly appearing outside it without the cap being removed.
2. ***Faster than light interaction***. If two quantum particles are "entangled", what happens to one instantly affects the other, even if they are light years apart.
3. ***Creation from nothing***. Given enough energy, matter can suddenly appear from an "empty" space (where there was no matter before).
4. ***Multiple existence***. Light passing through two slits creates a wave interference pattern. The interference continues if photons are shot through the slits *one at a time*, and *regardless of the time delay*. A quantum entity, it seems, can interfere with itself.
5. ***Physical effects without causality***. Quantum events like gamma radiation occur randomly, and no physical cause for quantum events has ever been identified.

Physics has developed equally strange theories to explain these strange findings.

Strange theories

Maxwell presented his wave equations in 1900. Einstein argued for relativity theory in 1905. Despite the hurdle of scientific skepticism, both theories have met every logical and experimental test their critics could devise. Their predictive success has surprised even their advocates, e.g. in 1933 Fermi's formulas pre-discovered the neutrino (a particle with no significant mass or charge) before nuclear experiments verified it in 1953. Dirac's equations predicted anti-matter before it too was confirmed. The theories of quantum mechanics and relativity *have never been shown wrong, and are the crown jewels of modern physics,* yet despite over 100 years of successful testing *they still just don't make sense*. As Kenneth Ford says:

"Its just that the theory lacks a rationale. "How come the quantum" John Wheeler likes to ask. "If your head doesn't swim when you think about the quantum," Niels Bohr reportedly said, "you haven't understood it." And Richard Feynman ... who understood quantum mechanics as deeply as anyone, wrote: "My physics students don't understand it either. That is because I don't understand it."" [5, p98]

For perhaps the first time in the history of any science, the scholars of physics simply don't believe what the reigning theories of their discipline are saying. They accept them as mathematical statements that give correct answers, but not as reality descriptions of the world. This is, to say the least, an unusual state of affairs. The problem is not lack of use, as these theories permeate most modern physics applications, from micro-computers to space exploration. By some estimates 40% of US productivity derives from technologies based on quantum theory, including cell phones, transistors, lasers, CD players and computers. However physicists use quantum theory because it works, not because it makes sense:

"*… physicists who work with the theory every day don't really know quite what to make of it. They fill blackboards with quantum calculations and acknowledge that it is probably the most powerful, accurate, and predictive scientific theory ever developed. But ... the very suggestion that it may be literally true as a description of nature is still greeted with cynicism, incomprehension, and even anger*." [6]

Such reactions call not for more mathematical proofs, nor for more applications, but for more understanding. Physicists "understand" the theories mathematically, but cannot connect them to their practical understanding of the world. They "know" the mathematics, but cannot interpret it to create meaning. Hence physics has theories that work but which make no sense, e.g. Feynman observed that an electron traveling from A to B acts like it simultaneously traverses all possible intervening paths. His "sum over histories" theory gives the mathematics to do just this, and predicts quantum outcomes well. Yet while most scientific theories add understanding, theories like this seem to take understanding away. It implies that a single electron travels many paths, but how can one electron simultaneously travel all possible paths between two points? The theory works, but contradicts a basic assumption of objective reality - that objects exist and move in a singular fashion.

It is interesting that not only do relativity theory and quantum theory contradict much of what we know (or think we know) about the world, they also contradict each other. Each has its domain - relativity describes macro events in space-time and quantum theory describes sub-atomic micro events. Each theory works perfectly within its own domain, but combining them creates contradictions, e.g. relativity demands that nothing can travel faster than light, but quantum wave function collapse occurs instantly over any distance, allowing entangled quantum particles to ignore light speed limits and affect each other from anywhere in the universe. Einstein objected to this "spooky action at a distance". As Greene notes:

"*The problem ... is that when the equations of general relativity commingle with those of quantum mechanics, the result is disastrous*." [7, p15]

Even after a century of successful use and testing, neither theory has percolated down to become routine high school subjects, perhaps because it is difficult to teach what one doesn't believe in. Meanwhile, physics has contained the problem by putting a mathematical "fence" around it:

"*… we have locked up quantum physics in "black boxes", which we can handle and operate without knowing what is going on inside*. (Preface, p x) [8].

Relativity and quantum theory today are effectively mathematical black boxes that physicists manipulate to predict the universe, but why they work is unknown. Some argue pragmatically that it doesn't matter, as if the mathematics works nothing else is needed. However others think that since these formulae describe the essence of physical reality an explanation is due: "*Many physicists believe that some reason for quantum mechanics awaits discovery."* [5, p98]

Nor can one relegate quantum and relativity effects to the "odd" corner of physics, as in many ways these theories *are* modern physics. Quantum theory rules the atomic world, from which the visible world we see emerges. Special and general relativity rule the cosmic world of vast space, which surrounds and contains our world. Between these two poles, everything we see and know about the physical world is encompassed. It is unacceptable that these theories, however mathematically precise, continue to remain opaque to human understanding.

We now consider another strange theory to explain this strange physics - that the physical world is a virtual reality. VR theory arises from the Sherlock Holmes dictum: "*…when you have excluded the impossible, whatever remains, however improbable, must be the truth*." It suggests that perhaps the answer to what modern physics means has been staring us in the face, but we do not want it to be true. Since modern physics finds the physical world not as objective as we once thought it was, let us now postulate the unthinkable: that our "real" world is a virtual reality.

The virtual reality axiom

While never commonly held, the idea that the world is a calculated reality has a long history. Over two thousand years ago Pythagoras considered numbers to be the non-material essence from which the physical world was created. Buddhism says the world is an illusion, and Hinduism considers it God's "play" or Lila, while Plato's cave analogy suggests the world we see "reflects" another more real world. Plato felt that "God geometrizes", and Gauss said that "God computes" (Svozil, 2005), both arguing that the divine mind appears as nature's mathematical laws. Blake's illustration "The Ancient of Days" shows God wielding a compass upon the world. Zuse first expressed the idea in modern scientific terms nearly forty years ago, arguing that space calculates [9], and since then others have discussed virtual reality in various ways [10-16].

A *virtual reality* is here considered to be a reality created by information processing. If a universe is a virtual reality then it does not exist independently in and of itself, as it depends upon processing to exist. If the processing stops, then the virtual reality ceases to exist. In contrast a universe is an *objective reality* then simply *is*, and does not need anything else to sustain it. This suggests two hypotheses:

1. ***The objective reality hypothesis:*** *That the universe exists as a reality in and of itself, that being self-contained needs nothing outside of itself to explain its behavior.*

2. ***The virtual reality hypothesis***: *That our physical reality is a virtual reality that depends upon information processing occurring outside itself to exist.*

Whatever one's personal opinion, these views clearly contradict. If the world exists as an objective reality it cannot be virtual, and if it exists as a virtual reality then it cannot be an objective one. That the world is an objective reality and that it is a virtual one are mutually exclusive. Each hypothesis has implications, e.g. objective reality suggests the universe as a whole is permanent, as it has nowhere to come from or go to. Physical realism also implies [17]:

1. *Object locality*: That objects exist in a locality that limits their event interactions.
2. *Object reality*: That objects have inherent properties that their existence carries forward from one moment to the next, and these determine their behavior independent of any measurement.

The rest of this paper explores some implications of the VR hypothesis. To illustrate the contrast between these two views, consider the primary axiom of Lee Smolin's book:

"***There is nothing outside the universe***" [18 p17].

The edifice of science itself is often assumed to rest upon this apparently self-evident statement. Yet VR theory contradicts this statement, and its prime axiom is the reverse of Smolin's, namely:

That nothing in our universe exists of or by itself.

This axiom arises because a VR processor cannot logically exist within the virtual reality its processing creates, i.e. it is logically impossible for a processor to create itself. The creation of a virtual world could not start if the processor did not initially exist outside it. Hence any VR world, by definition, *must* have existence dimensions outside itself. Current physics theories regularly suggest precisely this about our world, e.g. string theory needs 7-8 additional dimensions to be consistent. These are still assumed in the world, but just "curled up" to be invisible to us. In contrast, additional VR dimensions must be outside the VR world. Yet the difference between an unknowable dimension "in the world" and one "not in the world" is untestable, so the distinction is irrelevant to science, which then favors neither view. To postulate the world is virtual does not contradict science, but rather engages its spirit of questioning, as surely science is a method of asking questions, not a set of reality assumptions. If so, science does not need an objective world, only information to test theories against, which a VR can easily provide. Not only can science accommodate the virtual world concept, a virtual world can also sustain science.

Can a virtual reality be real?

Doesn't common sense preclude that the world, which appears so real to us, is a virtual reality? Philosophers, from Plato and before, have recognized that reality is not provable [19]. Dr Johnson is said to have reacted to Bishop Berkeley's idea that the world is created by our minds by stubbing his toe on a stone, implying that it is real enough. Berkley's solipsist perspective implies that a tree falling in a wood will make no sound if no-one is there to hear it. However VR theory does not imply this, nor does it say that a virtual world is unreal to its inhabitants.

If information processing in one world creates a second virtual world, VR events "unreal" to the first world can be "real" in the virtual world. If a virtual gun shoots a virtual man the latter may virtually die. That a world is calculated does not mean it has no "reality", merely that its reality is local to itself. Even if our world is a virtual reality, stubbed toes will still hurt and falling trees will still make sounds. What reality is depends upon the observer's substance, so to a virtual person, virtual objects are as real as it gets. By analogy, a table is "solid" because our hands are made of the same atoms as the table. Yet to a neutrino, the table is just a ghostly insubstantiality through which it flies (as is the entire earth), i.e. things constituted the same way are substantial to each other. Likewise physical reality depends upon the world it is measured from. To say a world is a VR doesn't make it unreal, it just makes its reality local to that world.

The science-fiction movie The Matrix illustrated a VR that was real to its inhabitants as long as they remained within it. This was because people in the matrix only knew their world from the information they processed, which is exactly how we know ours. Yet the matrix movie does not illustrate VR theory, as its computer-generated matrix was created by machines in a physical world, and when inhabitants escaped the matrix they returned to this "real" world, i.e. the physical world was still the "end of the line" for "realness". However VR theory does not assume the reality of physicality, or claim there is a reality behind our reality. It merely argues that our reality is a local. It does not argue that the world "unreal", only that it is not objectively real, and that if this were so, it need not be obvious - as Stephen Hawking says:

"*But maybe we are all linked in to a giant computer simulation that sends a signal of pain when we send a motor signal to swing an imaginary foot at an imaginary stone. Maybe we are characters in a computer game played by aliens."* [6, p131]

Yet to put the quote in context, the next sentence was "*Joking apart, …*" Though logically the physical world *could* be virtual, for some reason to imagine that our world *is* virtual can only be presented as a joke. The VR perspective contradicts neither common sense nor science, so why is the possibility discarded out of hand?

Approaching virtuality

Current theory seems to approach virtual reality using three hypotheses:

1. **Calculable Universe Hypothesis**: That our physical reality can be simulated by information processing that is calculable (halting).
2. **Calculating Universe Hypothesis**: That our physical reality uses information processing at the core of its operation to some degree.
3. **Calculated Universe Hypothesis:** That our physical reality is created by information processing based outside the physical world we register.

The calculable universe hypothesis states that physical reality <u>can</u> <u>be</u> <u>simulated</u> by information processing [14]. Calculable here does not mean deterministic, as processing can be probabilistic, nor does it mean mathematically definable, as not all mathematics is calculable, e.g. an infinite series. Many scientists accept that the universe is calculable in theory, as the Church-Turing thesis states that for any specifiable output there is a finite program capable of simulating it. If our universe is lawfully specifiable, even probabilistically, then in theory a program could simulate it, although this universal program could be bigger than the universe itself. This hypothesis does not say the universe *is* a computer, but that it could be simulated by one, i.e. it does not contradict objective reality.

The calculating universe hypothesis states that the universe <u>uses</u> <u>information</u> <u>processing</u> as it creates reality, e.g. quantum mechanical formulae. Supporters of this view are a minority, but include mainstream physicists like John Wheeler, whose phrase "*It from Bit*" suggests that objects ("it") somehow derive from information ("bit"). Now information processing does not just *model* the universe, it *explains* it [20]. While a computer simulation *compares* its output to the physical world, in a computer explanation information processing *creates* reality, i.e. the latter is a theory about how the world works. Now the world is not just *like* a computer, it *is* a computer.

The calculated universe hypothesis goes a step further, stating that physical reality <u>is created by</u> external information processing. Now the physical "real" world is the computer *output* rather the computer *process.* Supporters of this "strong" virtual reality theory are few [10], with none in the physics mainstream. One can make the idea that the *reality we see* is created by *another reality we cannot see* more palatable by saying that both are still "in the world". This is how string theory presents its "curled up" dimensions. Yet whether the processing that calculates a VR universe is considered "in" or "out" of "the world" is just semantics. It is irrelevant to the core concept that a VR world must be processed from outside itself. The calculated universe hypothesis equates to the VR hypothesis presented earlier.

The above three hypotheses cumulate, in that each requires that the previous be true. If the universe is not calculable, it cannot actually operate by calculating, and if it cannot operate by calculating it cannot be a calculated reality. It is also a slippery slope, as if one accepts that physical reality is *calculable*, then perhaps it has a *calculating* base, and if it has a calculating base then perhaps it is *calculated*, i.e. virtual. On the surface the calculating universe hypothesis seems the best of both worlds, as it combines a physical universe and an information processing source, e.g. Deutsch says:

"*The universe is not a program running somewhere else. It is a universal computer, and there is nothing outside it.*" [21]

However if the physical world is a universal computer, *what is its output*? What is the "output" of, for example, the solar system? The brain may input and output information like a computer, but most of the world does not [20]. On the other hand if the physical world is the computing output, what is doing the processing? That the universe is computing the universe creates a circular paradox [22]. That physical processing based in the physical world is creating that physical world is an entity creating itself, which is illogical. A universe can no more compute itself than a computer can output itself, so the physical universe cannot be both a universal computer and its output. If the physical world is produced by information processing, as the centrality of computation in modern physics implies, that processing cannot operate in the physical world. If it occurs elsewhere than the physical world, then the calculating universe hypothesis collapses to the calculated reality hypothesis.

A criticism of the calculated universe is that we *"…have no means of understanding the hardware upon which that software is running. So we have no way of understanding the real physics of reality.*" [23]. The argument is that virtuality implies an unfalsifiable reality, and so is unscientific and should be dismissed. However VR theory postulates no "hardware" in another dimension. It is a theory about *this world,* not some other unknowable world, and its hypothetical contrast is that *this world* is an objective physical reality. Speculations about other virtual universes [24], or that the universe could be "saved" and "restored" [11], or that our virtual reality could be created by another VR [25], are unprovable speculations that fall outside the scope of VR theory as proposed here. It should also be noted that:

1. In this comparison, the idea of objective reality seems equally unprovable, so it is inconsistent to dismiss virtual reality as unprovable if objective reality is in the same boat.
2. The calculable hypothesis is falsifiable, as one could easily disprove it by demonstrating some incomputable physics. If reality does something that information processing cannot, then the world cannot be virtual and so must be objectively real. Yet while mathematics has many incomputable algorithms, all known physics is held to be computable.

The collapse of the calculating universe hypothesis suggests there are only two alternatives – objective reality or virtual reality.

Virtual reality requirements

If one were to create a VR that behaves like our world, what are the requirements? To proceed it is necessary to assume ***information constancy:*** *that information processing operates the same way in a virtual world and its source.* For example, our information processing involves discrete input/output, a calculable algorithmic process, and must avoid memory overloads and calculation infinities. We assume that any VR processing works the same way. Other requirements include:

1. ***Finite processing***. *That the processing that creates a VR that behaves like our world is finite*. While the processing power to run our universe is enormous, if it were infinite, why is our universe expanding? An infinite capacity does not need to expand. As we have no concept of what "infinite" processing means, it is reasonable to assume that the processing creating a VR is finite. As Davies notes: *"...recent observations favor cosmological models in which there are fundamental upper bounds on both the information content and information processing rate*." [26 ,p13] Such processing is not inconceivable, as Bostrom argues that all of human history would require roughly only 10^{33} to 10^{36} calculations to simulate, while a planetary size computer could provide 10^{42} operations per second [25]. Finite processing implies that every entity, event and section of space-time contains a finite amount of information.

2. ***Information conservation***. *Once started, a VR that behaves like our world must run without further information input.* Most human computer simulations require regular data input to run. In our world, such external data input would constitute a "miracle", and miracles are at best rare. This VR simulation must run itself without miracles. If the system inputs no information after it starts, it must also not lose the information it has, else it will "run down". Our universe has not run down after 14+ billion years and an inconceivable number of microscopic interactions. If it is made of information, then it must conserve it, i.e. operate without gaining or losing information.

3. ***Consistent self-registration***. *A VR that behaves like our world must "register" itself in a locally consistent way.* Most human computer simulations are designed to output data to an outside viewer, i.e. us. However we see our world from within, and register "reality" when light from the world interacts with our eyes. For a virtual reality to "register" itself as a constant reality, its internal interactions must be consistent with respect to each local "observer". In this case "reality" is an interface, just as a screen is, that arises whenever VR entities interact, i.e. an interface between the processor and itself.

4. ***Calculability***. *A VR that behaves like our world must at all times be calculable*. A finite processing source must ensure that no calculations tend to infinity, e.g. the processing demands of some many body calculations explode to incalculability. Calculability requires a simulation that is guaranteed to avoid infinities.

These major requirements constrain any VR model of our world. A prima facie case is now presented that a virtual reality model could explain some of the strangeness of modern physics.

A prima facie case that the physical world is a virtual reality

One of the mysteries of our world is how every photon of light, every electron and quark, and indeed every point of space itself, seems to just "know" what to do at each moment. The mystery is that these tiniest parts of the universe have no mechanisms or structures by which to make such decisions. Yet if the world is a virtual reality, this problem disappears. Other examples of how a VR approach could illuminate current physics issues include:

1. ***Virtual reality creation***. A virtual world can come from nothing, as the big bang theory says our universe does (see next section).

2. ***Digital processing***. If a world is virtual, everything in it must be digitized. Digital processing has a minimum amount of 1, so a virtual space-time must be discrete at the lowest level, i.e. quantized. Plank's discovery that light is quantized, as photons, would then extend not only to charge, spin and matter, but also to space-time. This avoids the mathematical infinities of continuous space-time, as loop quantum gravity theory argues [18] (see Part II).

3. ***Maximum processing rate***. The maximum speed a pixel in a virtual reality game can cross a screen is limited by the processing capacity of the computer running it. In general, a virtual

world's maximum event rate is fixed by its source processing capacity. In our world, the fixed maximum that comes to mind is the speed of light. This absolute maximum for our world could reflect the maximum rate of its information processing (see Part III).

4. ***Non-local effects***. The processing source that creates a virtual world is not limited by the space of that world, e.g. a CPU drawing a screen is no "further" from any one part of the screen than any other. All screen points are equidistant with respect to the CPU. If VR processor effects can ignore screen distance, they can be non-local. If our universe is a three-dimensional "screen" whose processor is equidistant to all points in the universe, the non-local collapse of the quantum wave function could be a non-local processor effect (see Part IV).
5. ***Processing load effects***. On a distributed network, nodes with a high local workload will slow down, e.g. if the local server has many demands, a video download from it will play slower than usual. If a high matter concentration constitutes a high processing demand, a massive body could slow down the information processing of space-time, causing space to "curve" and time to slow. Likewise, if relative movement requires processing, speeds near light speed could affect space/time, causing time to "dilate" and space to extend. Relativity effects could then arise from local processing overloads (see Part V).
6. ***Information conservation***. If matter, energy, charge, momentum and spin can be expressed as information, all the conservation laws could reduce to one. Einstein's transformation of matter into energy ($e=mc^2$) is then simply information going from one form to another. The only conservation law required would then be the law of information conservation.
7. ***Algorithmic simplicity***. If the world arises from finite information processing, it is necessary to keep the calculations relatively simple, as the core mathematical laws that describe the world are. As Wigner notes: "*The enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious and there is no rational explanation for it*." [27] VR theory suggests that the laws of the universe are simple because they actually have to be calculated.
8. ***Choice creation***. Information requires choosing between choice options, and a VR processor random number function could provide such choices. Einstein never accepted that quantum events could be truly random, i.e. that no prior world events could predict them. That a radioactive atom decays by pure chance, whenever "it decides", was to him unacceptable, being a physical event not predicted by any other physical event. He argued that one day quantum randomness would be predicted by as yet unknown "hidden properties". In contrast VR theory suggests that the source of quantum randomness is outside the physical world, and so no hidden variables will ever be found.
9. ***Complementary uncertainty***. In Newtonian mechanics one can know both the position and momentum of objects, but for quantum objects Heisenberg's uncertainty principle means one cannot know both at once. Knowing one property with 100% certainty makes the other entirely uncertain. This is not measurement "noise", but a property of reality - measuring particle position displaces its momentum information, and vice-versa. This is strange for a physical reality, but virtual reality "screens" are typically only calculated when they need to be viewed, i.e. when an interaction occurs [12]. If complementary object properties use the same code or memory location, the object can *appear* as having either position *or* momentum, but not both at once.
10. ***Digital equivalence***. Every digital symbol that is calculated by the same program is identical to every other, e.g. every "a" on this page identical to every other one because all arise from the same computer code. In computing, objects are "instances" of a general class. Likewise

every photon in the universe is exactly identical to every other photon, as is every electron, quark, etc. While every object we know has physical properties that identify it individually, quantum objects seem all pressed from identical moulds. VR theory suggests that this is so because each is created by the same digital calculation.

11. ***Digital transitions***. When one views a digital animation it looks continuous, but in fact it is a series of state transitions, e.g. a movie is a series of still frames run together fast enough to look like a smooth event. Yet if the projector is slowed down, one sees a series of still pictures. Quantum mechanics describes quantum interactions in similar terms, as state transitions. These transitions explain quantum tunneling, where an electron at A suddenly appears at C without moving through the intervening area B which is impenetrable to it. While this is strange for an objective reality, in VR theory all object movement must be by state transitions.

Individually none of the above short points is convincing, but taken together they constitute what a court calls circumstantial evidence. They present a plausibility argument not a proof, but make the case that the virtual reality concept is worthy of further consideration. Two problems that VR theory explains but objective theories do not are now given in more detail.

Where did our universe come from?

The traditional view of our universe is that it is an objective reality that “just is”, and so has always existed. While its parts may transform, its total is in a “steady state” that always was and always will be. The alternative view is that the universe did not always exist, but arose at some specific point, which also created space and time. During the last century these two theories have battled it out for supremacy on the stage of science. Steady-state theory proponents included many respected physicists, who found the idea that the entire universe expanded from a point singularity a highly unlikely theory.

However Hubble’s finding that all the stars around us are red-shifted suggested that the entire universe is indeed expanding at the speed of light. Now an expanding universe has to expand from somewhere, so scientists could trace the expansion to its source, a “big bang” that began our universe about 15 billion years ago. The discovery of cosmic background radiation, left over from the big bang, has largely confirmed the theory today in the minds of most physicists.

Big bang theory sidesteps questions like: “What existed before the big bang?” by answering: “There was no time or space before the big bang, so the question is faulty” However if time and space suddenly “appeared” for no apparent reason at the big bang, could it equally suddenly disappear? “What caused the big bang?” is a valid question, even without time and space. If nothing in our universe is created from nothing, how can an entire universe come from nothing? That the universe arose from nothing is not just incredible, it is inconceivable. One does not need mathematics to state the problems:

1. What caused the big bang?
2. What caused space to begin to exist?
3. What caused time to start up?
4. How can the big bang be caused without a time/space for the cause to exist in?
5. How can space be caused if there is no “there” for a cause to be in?
6. How can time be started if there is no time flow for the starting to occur in?

Such questions seem beyond any theory that assumes the universe is objectively real, as how can an objective reality, existing in and of itself, be created not only out of nothing but also without space or time existing? The failure of the steady state theory of the universe removes a cornerstone of support for the objective reality hypothesis.

However if the world is a virtual reality, the big bang is much easier to explain. No virtual reality can have existed forever, since it depends upon a processor to create it. All virtual realities come into being, or "start up", at a specific moment of time. They typically begin with a sudden influx of all the information necessary to initiate the virtual world. Whenever one starts a computer game, or even boots up a computer, this happens. From the perspective of the virtual world itself, this creation is always from "nothing", as before the virtual world startup there was indeed no time or space *as defined by that world*. There was nothing relative to that world, because the world itself did not exist. VR theory predicts that any virtual universe will come into existence at a specific point that initiates its space-time fabric. Note that in a virtual world there is no logical reason why all initiating information cannot initially "point" to a single arbitrary location. In this view then, the big bang was simply when our universe was "booted up".

The big bang illustrates an accepted aspect of modern physics that VR theory accommodates but objective reality perspectives do not. More importantly, it illustrates that such arguments can be resolved by an appeal to experimental data *from this world*. Just as the steady state versus big bang theories of the universe were resolved, so can the virtual vs objective theoretical contrast be resolved, even though neither is absolutely provable.

Why does our universe have a maximum speed?

The author's interest in the concept of virtuality began with a simple question: *"Why does our universe have a maximum speed?"* Einstein deduced that nothing travels faster than light from the way the world works, but stating this does not explain why the world is that way. Why cannot an object's speed simply keep increasing? Why is there a maximum speed at all?

If light is a wave, then a classic wave's speed depends upon the elasticity and inertia of the medium it travels through. If the medium light travels through is space, its speed should depend upon the elasticity and inertia of empty space. What then is empty space? Initially it was thought to be a luminiferous "ether" which objects move through as a fish swims through water. However water provides a fixed reference frame for a fish's movement, and in 1887 Michelson and Morley showed that space didn't work that way. In 1905 Einstein showed that the speed of light was the real absolute, and discredited the spatial "ether" idea.

However this left empty space, the medium of light transmission, as "nothing". The mathematical properties of empty space, like length, breadth and depth, give no basis for elasticity or inertia. How can a vacuum have properties that imply a maximum light speed? Some mathematicians deal with this by making the speed of light define the elasticity of space, but this argues backwards, that an outcome determines a cause. The nature of space should define the rate of transmission through it, so the speed of light should conclude the argument, not begin it. If space has no object nature its object properties are "null", but then how can it be a "medium" whose properties limit the speed of light? How can "empty space", devoid of object properties, not only transmit light but also limit its speed?

The paradox again arises from assuming an objective reality. Any theory that assumes objects exist in and of themselves must also assume a context for them to exist within. The ether's proponents assumed space was an "object" like the objects it contained, e.g. both fish and water are physical objects. Einstein showed that space, which contains objects, cannot also itself be an object, else it would exist in itself, which is impossible. Yet while Einstein made space and time relative, he replaced them by an equally absolute space-time concept:

"…*absolute space-time is as absolute for special relativity as absolute space and absolute time were for Newton* …" [7, p51]

Einstein merely replaced the old object context (space) with a new object context - space-time. He assumed, like Newton, that *objects exist of themselves,* and it was this that put him at odds with quantum theory's non-local equations. Any theory that assumes objects exist independently must also assume an existence context for them, whether space or space-time. Such an assumed existence context cannot have properties precisely because it is an assumed context. String theory has the same problem, as it also assumes a space-time context. In contrast virtual reality theory assumes nothing about reality except that it is created from information. While objective reality must assume space, time, or both, virtual reality theory does not need to assume a space-time.

Information, as a universal constituent, avoids physical realism's problem that a substance cannot contain itself, because information processing can "stack", i.e. processing can create processing. That VR objects are created by information processing does not contradict that space itself is also created by processing. The concept of space-time as a virtual processing network that both processes information objects and itself arises from processing is explored in Part II. That a virtual space is empty of "objects" does not make it empty of structure, as an idle network still has protocols and connections to maintain. This supports the modern view that empty space is not "empty". Space as a virtual network also allows a property – the maximum network processing rate. In our world, the Lorentz transformations limit the maximum rate objects move through space-time, e.g. for a photon moving at the maximum rate through space, the rate of change of time is zero, i.e. time stands still. That space and time trade-off their rates of change is explained if both arise from a fixed amount of information processing, i.e. the sum total of space and time processing cannot exceed a fixed maximum. That our universe has a maximum speed again illustrates a fact of physics that VR theory explains but which objective reality does not.

Evaluating virtual reality theory

Possible responses to this prima facie case for the world as a virtual reality include:

1. *Spurious*. One can satisfy the requirements of any world by appropriate assumptions, so a VR model can always be found to match our world. This response is less likely if the model's assumptions are few and reasonable.
2. *Coincidence*. The matches between VR theory and modern physics are fortunate coincidences. This response is less likely if the matches found are many and detailed.
3. *Useful*. Seeing the world in information processing terms may open up new perspectives in physics. This response is more likely if VR theory explains well.
4. *Veridical*. Our world in all likelihood actually is a virtual reality. This option is more likely if VR theory covers what other theories cannot, and adds value to them.

While it the reader can decide their own response, virtual reality is a logical option that deserves consideration alongside the other strange theories of physics. The view that the essence of the universe is information may not be correct, but it gives a unique view on some perennial issues of physics. However can science evaluate if a world is a virtual reality from within it? Suppose one day that the computer code that creates "The Sims", a virtual online world, became so complex that some Sims within the simulation began to "think". Could they deduce that their world was a virtual world, or at least that it was likely so? If a simulated being in a simulated world acquired thought, would it see its world as we see ours now? A virtual entity could not *perceive* the processing that creates its world, but it could *conceive* its possibility, as we do now. It could compare how a virtual reality would behave and how an objective reality would behave, with how its world actually behaved. While it could not "know" it could deduce a correctness likelihood, which is all science aims to do anyway.

However science warns against selecting data to support a theory, and so requires unbiased data that is not selected by the researcher (to fit their case). It is not enough to find that *selected* computer programs, like cellular automata, mimic *selected* world properties [13], as the researcher is choosing what is being explained. There is no need for "a new kind of science" when the old kind still works, i.e. one must not select the parts of a reality one's theory will explain. One way to avoid this trap is to *derive the reality from first principles*, i.e. begin with nothing but information processing, and derive essential properties like space, time, light, energy, electrons, quarks and movement from first principles. Now what is explained is not just a selected subset of the world, but its operational basics, i.e. it is not selected by the researcher. This means developing a VR specification that explains our world. The approach is to assume the theory of virtual reality is true, and "follow the logic" until it fails. If the world is not a virtual reality, attempting to go down this path should soon generate implications inconsistent with observations. If the world is a virtual reality, this approach should consistently account for facts that objective reality theories cannot. Ultimately, if a virtual reality model behaves exactly as our world does, then even if the world is not a virtual reality it may as well be.

Discussion

A VR model considers all physical entities, all events acting on them, and even the context of space-time itself, to arise from information processing. Nearly a hundred years ago Bertrand Russell dismissed this concept using Occam's razor (that a simpler theory is always preferred):

"*There is no logical impossibility in the supposition that the whole of life is a dream, in which we ourselves create all the objects that come before us. But although this is not logically impossible, there is no reason whatever to suppose that it is true; and it is, in fact, a less simple hypothesis, viewed as a means of accounting for the facts of our own life, than the common-sense hypothesis that there really are objects independent of us, whose action on us causes our sensations*." [28]

Yet today, that objects are independent of our interaction with them is by no means certain, and that information is the basic underlying "stuff" of the universe is not so easily dismissed. Given the big bang occurred, what is simpler, that the universe was created out of nothing, or that it represents a virtual reality start-up? Given the speed of light is a universal maximum, what is simpler, that it depends on the properties of empty space, or that represents the maximum information processing rate of our reality? Similar questions can be asked for each of the points summarized in Table 1. Modern physics increasingly suggests that virtual reality is a simpler theory, i.e. that Occam's razor favors virtual reality over objective reality.

While VR theory barely changes the mathematics of physics, it drastically changes its meaning, as *if the universe is virtual then so are we.* The world as a virtual reality reduces our significance significantly. To be pixilated avatars in a digital world hardly flatters the human ego, but then again, we have been here before:

"*Since our earliest ancestors admired the stars, our human egos have suffered a series of blows*." [14]

Copernicus found that the Earth is not the center of the universe, and we now know that our tiny planet circles a mediocre star two-thirds of the way out of a million, million star galaxy, itself within a million, million galaxy universe. Darwin found us not the center of things biologically either, and since over 99.9% of every species that ever lived is now extinct, our absence would

Table 1. Virtual properties and physical outcomes

Virtual Property	**Physical Outcome**
Virtual reality creation. Virtual worlds begin with an information influx out of "nothing" that begins the VR's time and space.	*Physical reality creation.* The universe was created out of nothing by a "big bang" at a single event that also created time and space.
Digital minima. All events/objects that arise from finite digital processing must have a minimum quantity or quanta.	*Quantum minima.* Light is quantized as photons and matter, energy, time, and space may be the same, i.e. have a minimum amount.
Maximum processing rate. Events in a VR world have a maximum rate limited by the processor.	*Maximum movement rate.* The speed of light is a fixed maximum for our universe, and nothing in our space-time can move faster.
Non-local effects. A computer processor is equidistance to all pixels on its screen, so its effects that are "non-local" with respect to the screen interface.	*Non-local effects.* The collapse of the quantum wave function is non-local, as entangled photons on opposite sides of the universe may instantly conform to its requirements.
Processing load effects. If a virtual processing network is overloaded, its processing outputs will be reduced.	*Matter and speed effects*. Space curves near a massive body and time dilates at high speeds.
Information conservation. If a stable VR is not to gain or lose information it must conserve it.	*Physical conservation.* Physical existence properties like matter, energy, charge, spin etc are either conserved or equivalently transform.
Algorithmic simplicity. Calculations repeated at every point of a huge VR universe must be simple and easily calculated.	*Mathematical simplicity.* Core physical processes are describable by relatively simple mathematical formulae, e.g. gravity.
Choice creation. Information implies choices and a random number function in the processor could provide such choices.	*Quantum randomness.* The quantum "dice throw" is to the best of our knowledge truly random, and unpredictable by any world event.
Complementary uncertainty. Calculating one property of a self-registering interface from its source may displace a complementary form that uses the same data.	*Heisenberg's uncertainty principle.* States that one cannot know a quantum object's position and momentum both at once, as knowing either property makes the other unknown.
Digital equivalence. Every digital object created by the same code is identical.	*Quantum equivalence.* All quantum objects, like photons or electrons, identical to each other.
Digital transitions. Digital processes simulate event continuity as a series of state transitions, e.g. the frames of a film.	*Quantum transitions*. Quantum mechanics suggests that reality is a series of state transitions at the quantum level.

hardly be missed. Even the matter we are made of is only about 4% of the universe, with the rest being dark matter (23%) and dark energy (73%) [5, p246], and over 99.9% of that "solid" matter is the empty space round the atom nucleus. Freud found that our sub-conscious has more impact than our conscious, and neuroscientists find the brain "split" at the highest (cortical) level [29], suggesting our unitary "self" is an illusion [30]. Further disillusionments seem imminent in areas like dreams, genetics and consciousness, but the trend is clear: science finds us to actually be less than we imagine, and we imagine ourselves to be more than science finds we are. So would one more ego blow be a surprise, say if we found that our reality didn't exist objectively at all?

For a century physicists have tried unsuccessfully to make sense of modern physics using traditional objective reality concepts. Quantum experiments on Bell's theorem flatly contradict both the locality and reality assumptions of physical realism [17]. Perhaps it is time to try something new. Yet even physicists who call for a radically new view of reality balk at the idea of virtual reality. Modern physics implies a calculated world, but such a world offends us. Yet that we cannot imagine something is so, or that we would wish it not so, are not reasons why it cannot actually be so. Ultimately, whether our world is virtual or real is not our choice, as one must accept one's reality whatever form it takes.

This leaves theoretical physics in a conundrum. On the one hand, mathematical speculations about unknowable dimensions, branes and strings seem increasingly pointless and untestable. On the other hand, objective realism seems to face paradoxes beyond its capacity, which it will never, ever, solve. This paper suggests another option: *virtual reality as a hypothesis about this knowable world*. This introduces the methods of computer science and information systems to support the mathematical theorizing of physics. However the assumption of objective reality is currently blocking the serious development of a virtual reality model, as it limits our thinking about space, time and the objects and events within them. It is a barrier to progress in physics.

In contrast, the virtual reality approach could open up new ideas, as virtual objects do not need to have inherent properties, or to exist at fixed locations. Virtual objects have no inherent properties or locations beyond those embodied in the calculations that create them. A virtual reality could reconcile the contradiction between relativity and quantum theory, if the former is how information processing creates space-time, and the latter how it creates energy, matter and charge. It could also solve the quantum measurement problem, as if our reality is in effect a processing interface, viewing it could indeed create it. When one views a virtual computer world on a screen, the entire world is not shown on the screen. The computer only calculates for view what the viewer chooses to view, i.e. the screen interface is calculated as required. What we call reality could be an 'interface" similarly calculated only as required. The virtual reality viewer may be no more aware this than a virtual game player is, as everywhere they look, the world exists. In this case, reality would only be calculated when we looked or "measured" it. However there is a twist, as if our world is a virtual reality, we are viewing it from within not without. In a computer game, the viewer exists outside the processing that creates the interface. However in the case of our world we are within it, so the processing that creates the interface also receives it. If the real world is such a recursive interface, then it is like no other that we know.

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