IS PHYSICAL REALITY REDUCIBLE TO THOUGHT?

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Hornby Island, BC, Canada January 2011

"Nature's independence *is* its meaning; without it, there is nothing but us."
—Bill McKibben[1]

Abstract

Physical reality is found, not made. Since it is not a product of definition to begin with, it cannot be exhaustively formalized. Nature is not virtual, nor merely 'mathematical', 'information', 'geometry', 'simulation', or 'computation'. Rather, it must be considered 'immanently real'. Moreover, there can be no final theory of everything. The computational metaphor is appealing for various psychological and historical reasons, including the certainty offered by deductive systems.

A Preliminary Remark The world has undeniable discrete aspects, interwoven with continuity. Since I view *analog* and *digital* as descriptive strategies, I will leave aside any question of the priority of one over the other, and focus rather on the notion that physical reality corresponds in some sense to digital computation. The fact that the world is obviously quantized in various ways implies no ultimate binary structure, much less that the world is, or reflects, some kind of computation, or is in some sense virtual.[2]

An Ancient Problem The theme of the discrete and the continuous is ancient. One wonders naturally of what parts something is composed. To limit regression, the ancients were led to posit indivisible particles as the ultimate basis of matter, even of continuous media like water. This strategy is equivalent to the assumption of axioms in a deductive system, another favored theme of the ancients.

Such particles might act upon each other through direct contact or across an intervening space or medium. However, nothing prevents further questioning the indivisibility of these 'atoms' or the composition of the space between them, inviting further analysis. In the face of this dilemma, the ancients were divided as to whether the world was a plenum, a void, or some combination.

Such niceties were later handled by the real number continuum, which provided a rigorous treatment of geometric space, the basis of the physics of differentiable curves and equations solvable with pencil and paper. Since this treatment applies only to idealized situations, it selectively influenced the types of phenomena studied. Geometricizing space and time, for example, resulted in the view of nature as comprised of reversible deterministic systems.

The digital computer expanded areas of study into non-linear processes, facilitating computation by brute force. It also influenced science in quite another way. The computer has become the latest expression of the mechanist philosophy, not only a new means to study nature, but the latest metaphor for nature itself. This is reflected in ideas like the Mathematical

Universe Hypothesis [1], the 'It from Bit' philosophy, and the notion that physical reality is somehow virtual—nothing *other* than information, mathematics, simulation, computation, or geometry [2]. Though mathematics so effectively describes and anticipates features of the world, it is a separate metaphysical assertion that physical reality is identical to mathematics, let alone to digital computation.

While dressed up in the latest technology, such idealist notions hark back to Plato and Pythagoras. It is no more plausible, however, that physical reality should correspond to the technology available to human beings in 21st century (computers, information grids), than that it should correspond to 18th century technology (steam engines, clocks). Though metaphor is an integral aspect of our thought, we should be conscious that such metaphors are necessarily parochial and human-centered, limited to a few centuries of consideration, to be taken with a grain of salt.

The Found and the Made I argue that the very meaning of natural reality lies in not being reducible to digital computation, to mathematics at large, or to any formalization whatsoever. Neither essentially digital nor analog, nature is what it is: an unknown that may be partially formalized, but is not ultimately reducible to thought. If this assessment is correct, there can be no final "theory of everything". A corollary, however, is that if nature *can* be exhaustively formalized, then it must be not real but artificial!

Physical reality could only correspond perfectly to digital computation—or to mathematics at large—if it could be exhaustively formalized. This could only be so if it were a finite product of definition, which would mean that it is artificial. This would be the case, for example, if the Universe happened to be nothing other than a simulation in a brain or computer—a virtual reality. Or: if it were literally the divine creation people had supposed for ages. The Newtonian "World Machine" is rationally comprehensible because it was conceived as an artifact in the first place, inspired by literal machines. Even prior to that, the "Book of Nature" had been regarded as an alternative to Scripture [3][4][5], a divinely-authored *text* that could be read as a guide to the mind of God. The view of nature as an expression of divine will may reflect a more general human tendency to interpret experience in intentional terms. Its secular counterpart is the view that nature is reducible to human thought systems. Both may express, in turn, a universal need to appropriate the natural world to human terms, for understandable human reasons.[3]

According to Turing's thesis, a Universal Machine (which is both an artifact and a text) can simulate any other artifact. This says nothing, however, about its capacity to simulate natural reality. To assume otherwise begs the question of whether nature itself is artifactual. Unless one believes, with creationists, that the physical world is literally an artifact, nature presents itself, above all, as something *found*, not made.

Humans did make the human world, however, which includes theories and other intellectual constructs. All artifacts, physical or conceptual, are essentially products of definition. As such, they contain only information that is latent in their definitions. However, there is no guarantee that any product of definition corresponds fully to anything in nature. The natural world transcends the limits of definition in a way that parallels how thought itself is transcendent (as expressed, for example, in Gödel's theorems). The very drawing of a boundary defines a domain beyond it. The fact 'reality' contains *us*, both logically and physically, and not the other way around, means that it will always surprise us, can always present something that escapes or intrudes upon our definitions. Simply put, in addition to externality and observer-independence, this richness is what it *means* for nature to be *real,* in contrast to the poverty of artifacts. The hallmark of the artifact as a product of definition is that it is intensionally finite.[4] It is exactly what it has been defined to be. In contrast, nature is not a product of (our) definitions. Whether or not it is infinite in extent, it is for us intensionally ambiguous or unbounded. It that sense, it is an analog domain. A digital domain, on the other hand, is finitely specifiable.

A Note on the Dialectic of Analog and Digital The mercury in a thermometer expands and contracts continuously, while the graduated scale of markings is defined only at specified intervals. (The intervals themselves are not defined, unless by finer markings, and one is left to estimate any accuracy *between* marks.) The digital (the scale) is precise-by-definition—its utility in errorless information processing—while the analog (the mercury) is precise-in-fact. That thermometers can be read owes to the fact that there is no iteration involved to accumulate errors. Iteration, however, is the essence of digital computation.

The usefulness of such categories does not imply that nature corresponds strictly to either—that it is *either* analog or digital. Rather, these polarities describe aspects of natural processes on all scales, and tend to have a dialectical relationship. An analog domain emerges as a synthesis of propositional information, and may be searched again for propositional information in the emerging domain.[5] Far from implying that natural reality is a digital computation, its discrete aspects depend dialectically upon continuous processes or descriptions, and vice-versa.

Determinism or Deductionism? While the discreteness of the quantum realm may suggest the determinism involved in digital computation, its *statistical* aspect suggests that determinism is not the way of nature. Determinism is the hallmark of artifacts, not of natural systems. Machines are deterministic—in fact, the only truly deterministic systems are deductive systems! If one takes Hume at all seriously, what we think of as causal determination is ultimately logical implication; the precision we associate with determinism is the precision of definition. Otherwise, we are simply dealing with statistical patterns, with no bona fide "causal" basis. This is true on any scale; one simply disregards the spread of error in the classical realm, in order to imagine a precise link between cause and effect.

For Einstein, the objective existence of physical reality implied parameters knowable with certainty. This brand of realism, however, is actually deductionism: the faith that nature can be understood rationally because it consists of well-defined deductive systems. This belief is demonstrated by the insistence in the EPR paper [6] on the ideal of "completeness"—that "*every element of the physical reality must have a counterpart in the physical theory.*"[their italics] Such an arrangement is possible only in a deductive system, not in nature. Nature is real just because it cannot be exhaustively represented in any theory. No theory, therefore, *can* be complete in this sense.[6]

The probabilistic nature of nature, far from being an unsatisfactory state of affairs, is the very sign of nature's reality. Determinism, on the other hand, reflects the classical (and implicitly idealist) wishful thought that nature can be reduced to a deductive system. The significance of

Bell-type experiments actually conducted, as physical versions of the EPR thought experiment, lies less in confirming quantum theory (which needs little further empirical confirmation) than in confirming that nature is not a deductive system or artifact. While a deeper level of analysis might be possible (in terms of 'hidden variables'), an exhaustive account capable of "certainty" is not. The ideal of deterministic certainty ironically contraindicates reality.[7]

Idealization of Nature and the Nature of Idealization Scientific thought attempts to model complex phenomena in simplified, idealized terms. But there is more than streamlining involved. There is a qualitative shift from the real natural thing, as the object of study, to a conceptual artifact that is, in essence, a product of definition. In other words, formalization involves a shift from empirical to *de dicto* truths, from found to made. Equations define and describe abstractions, not the natural things they only approximately fit [7]. The equations and the models they describe may well be isomorphic to each other, being expressions of the same abstraction. But neither is strictly isomorphic to the real process it simulates.

Geometricized space and time, and the closed reversible system, are such idealizations. A 'system' can be isolated in the sense that it involves no exchange of mass, energy, or information with an environment. But it can also be *logically* closed, in the sense that nothing within it refers to anything outside its definitions. A system closed in this second sense is a deductive system—a conceptual machine. It may be reversible simply because time is irrelevant in deductive systems, since every theorem is eternally latent within the axioms. It is the fact that reality is *not* a deductive system that allows time, direction, irreversible processes, entropy growth, and the unknown. Time's arrow implies that the world is real, not ideal. For, no part of the real world is either logically closed or absolutely isolated; there is always a real background—as opposed to an artificial reference frame—measured against which change is irreversible.[8] The basic laws of dynamics are time-reversible because they describe fictions, *deductive* rather than physical systems.

It should come as no surprise that we cannot move backward in time, since in truth we cannot move backward in real space either. Motion through space seems reversible only in terms of an idealized reference frame, with background change defined out of it. Intuitively we recognize that the flow of events, though measured by the clock, refers ultimately to an environment of other events in the rest of the world, not just to a regular process that is defined as a standard. Clocks may run backward, but the Universe as a whole simply does what it does. Similarly, one may move forward or backward relative to an unchanging "rigid" ruler or metric; but the Universe itself is not unchanging, nor a mere product of definition. The ancients recognized that one cannot step twice into the same river. Neither can one traverse the "same" space twice, if referents defining the space are in flux or incompletely known.

Simulation and Replication While the flight of airplanes imitates the flight of birds only metaphorically, a model airplane that actually flies effectively simulates a genuine airplane because it *is* one, though reduced in size. A model bird or insect, however, even should it fly, is not a genuine creature, but an artifact. One artifact may exhaustively simulate another, but whether any artifact can exhaustively simulate *any* natural reality, is another question.

Nevertheless, the implicit faith behind the computational metaphor, the dream of perfect simulation, and theories of everything, is that each and every property of a thing can be fully represented with precision—the classical ideal of determinism. A 'property', however, is a construct, an assertion that disregards infinite other possible assertions. The collected properties of a natural thing do not constitute the thing itself; rather, they constitute a separate artifact. Any list of properties that could practically be assigned would be finite. It could not exhaustively describe a natural thing, which has indefinite properties, but it could exhaustively describe a made thing. Information is the encoding of such properties. It may be finite for an artifact, but is indefinite for natural things, which have only artificial boundaries.

An organism's genetic code, for example, is in some sense a set of instructions on how to make the organism. They are instructions to the natural world, however, not to human engineers. To assume that the organism's 'program' can be hacked is to fatuously believe that all resources can be allocated to build it from scratch, securing the cooperation of other organisms, etc., exactly as nature does. In contrast, one *can* exhaustively know an artifact and reproduce it. This happens every time you copy a cd or print text from your hard drive. One *can* know all that there is to know about Juliet, her fictional balcony, or her thoughts about Romeo. Shakespeare's character can be reproduced onstage. But, such knowledge is skimpy, compared to the nuanced reality of the living actor. Enumerating the current equations of physics may allow one to know all there is to know about *physics* as it stands, which may be a far cry from all there is to know about the physical world.

The Appeal of the Computational Metaphor Why, then, is the computational metaphor so appealing? Perhaps what makes perfect simulation seem plausible is the feature of our language-dominated thought, whereby 'a rose is a rose is a rose' and all flying things exhibit 'flight'. But, there are many varieties of rose and every individual flower is unique. In particular, an artificial flower is not a real one and an aircraft is not a bird. The concept of simulation, however, rests on obscuring such distinctions by conflating all that can pass semantically under a given rubric.[9] The algorithm, program, or formalism is the bottleneck through which the whole being of a phenomenon must pass in order to be simulated. Thus, one thing is said to simulate or model another when they *embody a common formalism.* This can work well for two artifacts, such as the airplane and its model, which are alternative constructions from the same design. However, the being or behavior of a natural thing is not exhausted in a formalism abstracted from it, nor is this then a blueprint for its reproduction. Paley's watch notwithstanding, the natural thing is a found object, not an invention constructed from design. It does not come with a blueprint, which is imposed after the fact through a structural analysis that can never be guaranteed complete. The mechanist fallacy—of reverse-engineering natural systems—fosters the belief that it is possible to perfectly emulate a natural thing, by first formalizing its structure and behavior and then constructing an artifact from that as a design. The artifact *will* instantiate the design, of course. But it will *not* replicate the natural object, any more than an airplane replicates a bird.

Granted such common sense, it seems all the more remarkable to opine that nature could be assimilated to a computer program, consist literally of 'information', or in some sense be virtual. This is less surprising when we recall that science originated in a religious tradition that considered the world to *be* an artifact. This tradition in turn had embraced the Greek ideal of deductive knowledge, on the model of Euclid's *Elements*. The early natural philosophers melded classical deductionism with the creationism of their religion. The good Lord had set in motion the machinery of the world, which dutifully "obeyed" his rational laws. In keeping with the ideal of the ancient geometers, these laws were logically necessary, modally governing, and derivable from first principles by rational beings made in his image. The Book of Nature was as fixed and searchable as the Bible, since they were both finite texts; prediction and prophecy were of a kind. Yet, the early scientists were understandably also concerned to preserve divine freedom of creativity against the fatalism of logical necessity [8]. Their particular compromise was to hold the laws as necessary and leave the details (which we now call 'initial' conditions) to divine whim (which we now call 'chance'). Is this not where physics stands today—expressed in terms of equations and boundary conditions, or computer programs and inputs?

A computer is nevertheless a machine that requires to be set in motion. Whether God or the physicist is the programmer, there is a dualism of passive inert system and external agent. The computer metaphor continues to ignore the most obvious fact of physical reality, which is that it is not organized by our intelligence, but is somehow self-programming. Mechanism, at least as the classical result of top-down design, is the very thing that *cannot* explain physical reality as a self-organizing process.

Of course, self-organization is now a rich field of study, in no little part *because* of the computer, which can model complex non-linear processes. Accordingly, one anticipates a more sophisticated mechanist metaphor. If advanced machines can self-organize, then why not a less naively mechanistic cosmos? An ongoing dualism of hardware and software, however, allows no explanation how 'it' can emerge from 'bit'. Certainly, computers as presently conceived cannot compute themselves into existence. Their output is a different sort of thing than their own physical being. Even so, one can imagine machines whose primary output—like that of organisms—is themselves. One may not currently be able to picture how the cosmos as a whole could bootstrap itself into existence, yet its apparent example serves as a proof of possibility.

Self-organizing machines would be beyond human control or even definition. They would in fact be *self*-defining. One may continue to view nature mechanistically, in terms of increasingly complex and self-referential 'systems', which may be necessary if one hopes to account with present tools for the capacity of nature to self-organize. But it is not sufficient. For, unlike the machine, computer, or system, nature did not begin as a known product of definition. Not only organisms, but the cosmos at large must be considered not only self-organizing but self-defining. We should not be too impatient that our little brains do not yet understand creation ex nihilo.

To Be or Not to Be Indefinitely Complex is (perhaps) Not the Question Does nature have an ultimate irreducible structure? If so, can this be taken as an axiomatic structure that renders nature effectively a deductive system, a computable program?

Let us begin with the fact that only a deductive system can have zero entropy. Entropy is the inverse of probability—a measure of uncertainty, of what can be known of a system. Yet, absolute certainty is possible only of deductive systems. Thermodynamic entropy is also held to reflect real structure in a physical system, a measure of "complexity". Both thermodynamic and Shannon entropy depend, however, on how a system is partitioned—in terms of possible 'states' or 'degrees of freedom.' While the difference between these entropy concepts is considered a matter of convention [9], their historical distinction suggests that thermodynamic entropy is an objective physical property, while Shannon entropy (information) pertains to communication between agents. Perhaps it is through their mathematical equivalence that the two entropies have alike been objectified, which might in part account for the current belief that 'information' is a plausible ontological basis for reality.[10]

A bottomlessly complex nature, even if finite in extent, implies limitless information. The Bekenstein bound, however, denies this possibility, placing a limit on the information that can be "contained" in a given region for a given mass [10]. However, the Bekenstein bound is effectively a version of the Heisenberg uncertainty relation, adapted to entropy and gravitation. If Heisenberg uncertainty represents a limit on knowledge, one is yet at liberty to question whether Planck's constant represents an ontological ultimate structure or "merely" an epistemological limit—owing, nevertheless, to real physical circumstances—which could conceivably be overcome.[11] To reify either uncertainty or entropy may simply reflect a universal tendency to objectify relationships that involve the observer—to make verbs or adjectives into nouns.

Eliminate Non-Computable Functions? The discovery of the Mandelbrot and similar sets might seem to renew the promise to capture nature's complexity in simple algorithms. Patterns generated by these formulae, however, are but more sophisticated idealizations. Their detail is not truly random, but prescribed by algorithm; it is made, not found. If nature is bottomlessly complex, there is no hope of capturing it in any algorithm whatever, even one capable of generating endless detail. While this does not prevent such equations from being highly useful in computer-generated films and image enhancement, the danger lies in the assumption of verisimilitude. (Simulation may be valid enough for entertainment, while not for theory.) Furthermore, indiscriminately mixing computer images with traditional photography blurs an essential distinction and creates the misleading impression that we are viewing reality, not artifact. Reality may then be mistaken for a species of artifact.

The truly random, in contrast, can be associated with the so-called non-computable reals [11]. Computable numbers can be named, described, counted as distinct individuals. But, they are infinitely outnumbered by other numbers that cannot be so identified [12]. The real numbers as a totality correspond with the continuum of geometrical space—the analog domain—which may or may not correspond to real space. However, prediction and computation require computable numbers. It might seem a boon to physics if it could be re-formulated to avoid non-computable numbers. Yet, such a reduction would amount to treating nature as a deductive system. In the computer age, it is all the more tempting to imagine that this is how the Universe really is: a deterministic place after all, generated by computable algorithms, just as a virtual reality is.

Maker's Knowledge I suspect that there are even deeper reasons than our religious and classical heritage for the bias toward deductive systems. One such reason was suggested, at the dawn of the scientific era, in the 'maker's knowledge' concept of Giambattisto Vico. This was the idea that one knows *bes*t what is humanly made. On this basis, Vico proposed human institutions as the natural focus of study, rather than nature. A stronger version of his dictum[12] is that we know *only* the made: the only certain knowledge is of deductive systems, whose foundations are tautological. Hence, the most reliable scientific knowledge is not knowledge of nature but of scientific constructs. *A priori* truths are simply *de dicto* truths. Understandably, the attractiveness of theoretical certainty appeals understandably not only to the religious, but also to the scientific mind.[13]

In Vico's time, of course, *everything* was understood as made, either by Man or by God. The early scientists were creationists, after all. The idea of nature as self-existing, self-creating, with an immanent reality of its own, did not register with the Christian imagination except as pagan heresy. No doubt, science could only have developed by treating nature as a passive artifact, and the world as inherently rational, even mathematical. Nevertheless, the time may have come for physicists to take more seriously the hint, first intimated by the irrationality of the quantum realm, that nature is immanently real and the cosmos self-creating.

Concluding Remark Medieval maps were largely symbolic, idealized, and decorative, following tidy pre-conceived schemes. Hence, the three continents of the old world represented the Trinity.[14] As exploration provided better data, not only did maps become more accurate and literal; there was also a profound realization that the world was vaster, different, and deeper than suspected. Perhaps this is how science generally works: first guided by esthetic principles, corrected and refined by observation. This brings one full circle to the dialectic of analog and digital—and perhaps to further realizations that nature is deeper than we suspect or can ever finally know.

ENDNOTES

1. Bill McKibben *The End of Nature* Random House NY 1989, p58
2. Hence, my short answer to the question, 'Is reality digital or analog?': No, but it is *real!*
3. See my book, *Second Nature: the man-made world of idealism, technology and power* Trafford/Left Field Press 2006
4. 'Intension' refers to defining characteristics, while 'extension' refers to those things satisfying the definition.
5. As when a visual representation emerges in the brain as an integration of the signals from individualretinal receptors. In turn, this "image" may be searched for (higher-level) propositional information—cognizable features. On the other hand, the optical image falling on the retina is an analog domain that emerges in the first place from incident quanta of light.
6. It is interesting to speculate that Einstein's campaign against the "completeness" of the existing quantum theory might have been influenced by his friendship with Kurt Gödel. [Rebecca Goldstein *Incompleteness: the proof and paradox of Kurt Gödel* Atlas Books (Norton) 2005] The implication of Gödel's theorems is that not all of *mathematical* truth can be formalized. It seems Einstein stopped short of concluding that, in a parallel way, *physical* reality must transcend any given theory.
7. EPR [6] continues: "*If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.*"[italics theirs] However, a 'probability equal to unity' characterizes *deductive* systems, not natural ones, which always demonstrate a probability *less* than one.
8. Not to mention the "internal" events within a brain or psyche, which constitute another "background," for subjective time.
9. Yet, one cannot deny the creative utility involved. Leonardo's first (and unsuccessful) efforts to produce a flying machine were modeled literally on the flight of birds. Only after he embraced a more abstract concept of flight did his inventions come to resemble modern aircraft. I am examining here the other side of the coin: the hazards, rather than the advantages, of abstraction.
10. The tendency to hypostasize in scientific thought, and to search for ontological solutions, may reflect a general pattern based on an ancient linguistic division of Indo-European and non-Indo-European languages [Leslie Dewart *The Evolution of Consciousness* U. of Toronto Press, 1989]
11. If somehow, for example, a medium of communication were discovered that is finer-grained (and perhaps faster) than light, the values corresponding to c and h would be different, affecting the present limits they represent.
12. *verum ipsum factum* (the true is the made)
13. In fact, 'theory' and 'theology' come from the same Greek root.
14. See the McGill Univ. project, "Making Publics", or the CBC Ideas series based upon it, "Origins of the Modern Public"

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[7] Cf. Cartwright’s ‘nomological machine’: Nancy Cartwright *The Dappled World: A Study of the Boundaries of Science* Cambridge University Press 1999
[8] David C. Lindberg *The Beginnings of Western Science: the European scientific tradition in philosophical, religious, and institutional context, 600 B.C. to 1450 A.D.* Univ. of Chicago Press 1992, pp198ff
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[10] Jacob Bekenstein “Black Holes and the Second Law” *Lettere al Nuovo Cimento* **4** 737 (1972)
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