IS NATURE REAL?

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Abstract

In contrast to conceptual systems, the notion of an absolute information bound for physical systems is challenged. Several assumptions are questioned: that there is a bottom to the complexity of nature, that physical reality can be exhaustively modeled, and that physical systems contain definite entropy or information.

Preamble

The dream to account for everything in a final unified theory can only succeed by exhaustively modeling the natural world. Yet, this is only possible to the degree that nature coincides with human thought systems—particularly with mathematical models. *Perfect* coincidence would imply that the cosmos *itself* happens to be a thought system, perhaps a simulation. By the usual standards of realism, this would imply that nature is not real. In fact, this continues to be a tacit assumption of modern science, deriving from religious and philosophical traditions that influenced the emergence of natural philosophy from medieval European thought. The founding fathers of science were, after all, religious men who believed that the laws of nature were divine decrees revealing the mind of God, and that the world was a product of divine creativity: a virtual machine. From the ancient Greeks we inherited the parallel notion that the world is an ideal or deductive system, inherently commensurate with rational thought. Together, these imply that the created world must be finitely complex, definitely knowable, and isomorphic to human definitions.

Introduction

This paper challenges the basic assumption that physical systems can be represented exhaustively, either conceptually or mathematically. This notion entails related ideas, such as a definite information content, the ability of mathematics to model natural reality, and a bottom to the complexity of nature. In turn, such premises rest implicitly on an idealist thread within Western traditions: nature, in a fundamental sense, does not possess its own immanent reality, but only that bestowed upon it by some outside agent, either human or divine. Or, alternatively: nature is a mere shadow or projection of something more fundamental that is an idealized product of definition. Such beliefs underwrite the assumed correspondence between nature and human thought that enables prediction and control, and therefore technology. As a consequence, the true objects of scientific study are not natural entities and processes but idealized scientific *models*. These correspond to aspects of nature that can be readily treated mathematically, to the exclusion of other aspects. Though the capacity for mathematical treatment has expanded with the computer, scientific focus lags behind, still influenced by underlying metaphysical assumptions.

For example, standard cosmological theory is a linear historical account, like the story in Genesis and the clockwork universe that followed. It tends to disregard inherently nonlinear processes of self-organization. Properties of matter are not considered causally effective in themselves, but merely byproducts of fundamental equations acting “deterministically”. This imagined causal power of laws is an anthropomorphic (or deity-morphic) holdover, but also reflects the mathematical limitations of an earlier age, when equations had to be solved on paper. Such equations still must be supplied with initial conditions, yielded by observation or experiment rather than theory. Yet, it is the hope of some theoretical physicists to eliminate this inconvenience, so that the evolution of the universe would be a matter of logical necessity, as the ancient Greeks had dreamed.

Realism and Deductionism

Scientific realism is usually associated with a definite way that nature is, independent of how it is investigated.[i] Yet, this notion of realism is paradoxical, owing to an unstated further assumption: the definite way that the world is can be definitely known through finite procedures. However, we come upon the natural world as something found, an unknown that does not necessarily correspond to our ideas or the information we have about it.

We are always only guessing at the parts and organization of natural systems, since we did not make them in the first place. Indeed, this elusiveness is an essential aspect of an opposing sense of what one *means* by the independent reality of nature. *This* independence implies that no aspect of nature is completely reducible to specified information or to any formalization whatsoever. Conversely, the only systems that *can* be exhaustively known are deductive systems—which include machines and scientific models. These are products of definition, in contrast to the natural systems they model. Understandably, but illogically, reduction has been a powerful incentive to consider nature itself to be nothing more than a product of definition, a machine. We witness this motivation at work in the computational paradigm, the penultimate expression of the mechanist philosophy. If the universe is a computer, or program, then its basic raw material must be digital ‘information’, of which there must be a definite and finite amount. If the universe is nothing but mathematics, then it is well-defined by definition, and hence guaranteed to be knowable.

However, it is only possible to exhaustively analyze products of definition—deductive systems. Exhaustive analysis of *nature* would be possible only if nature had an intrinsically non-random structure, which would be the case if it were merely a product of definition. For, the problem of exhaustively modeling real systems amounts to finding an algorithm to express a random sequence. Nature is *not* deterministic because only machines are deterministic; the only deterministic systems are deductive systems. No deterministic system can generate a true random sequence, nor can it be counted upon to find a version of it that is shorter than the (infinite) random sequence itself.

Artifact and Formalism

Nevertheless, the idealist thread in science views matter as a mere abstraction, with only the properties assigned to it. So to speak, nature is no more than its own blueprint. The Newtonian “world machine” was inspired by the literal machines of the day. It was deemed rationally comprehensible because it was conceived as an artifact in the first place. Mechanism continues to be the dominant metaphor in Western thinking because it assimilates everything to human intention. The modern "computational universe" tacitly embraces this motivation, for only an artifact is *necessarily* comprehensible.

One thing is equivalent to another if they share a common definition. One *artifact* is informationally equivalent to another if they embody a common *design*. However, it is circular reasoning to assume that the being or behavior of a *natural* thing is exhausted in a human definition or a formalism that has been abstracted from it in the first place. Nevertheless, the quest for a final theory assumes implicitly that each and every property of a natural system can be formally, fully, and exactly represented. A 'property', however, is an assertion that disregards endless other possible assertions. While any finite list of properties could exhaustively *define* an artificial thing, it does not *constitute* a natural thing, whose properties are indefinite.

Information, and definite information content, are concepts that apply only to deductive systems, which are well-defined and finite. A scientific model or theory, for example, contains definite information, since it is a product of definition. However, there is no a priori reason to believe that any *natural* system has a definite information content. Yet, this is a basic assumption of contemporary physics. Just as classical physics explicitly assumed an idealized system of point masses (for example, the solar system), so the paradigm of contemporary physics is the idealized quantum system. One knows that a real planet is not literally a mathematical idealization. Unlike planets, however, quantum entities appear to actually *be* products of mathematical definition. However, this appearance may not reflect reality so much as epistemic limits and methodological requirements—the driving force behind the quantum theory in the first place.

Physical vs. Mathematical Discreteness

Nature obviously has discrete aspects at various levels; after all, a planet is a discrete object at a certain scale. At another scale, its integrity is resolvable into smaller objects, and so on. Moreover, discrete states can often be regarded as manifestations of some continuous field concept—as in the case of wave harmonics and "eigenstates" [1].[ii] Even at the quantum scale, apparent and relative *physical* discreteness is conceptually a different affair than the *mathematical* discreteness of integers or binary numbers, which is definitional and absolute. Physical integrity should not be confused with mathematical integrity. One can at least imagine physical entities resolved in further detail, whether or not they can be in practice; in contrast, the integrity of mathematical entities is a matter of definition.

Like macroscopic objects, quantum entities may have state-dependent properties, such as position and momentum, and state-independent properties, such as mass and charge, which define their kind. Two objects are qualitatively identical if they share all their state-independent properties (that is, if they share a common definition); they are numerically identical if they share their state-dependent properties as well [2]. In quantum physics, there are difficulties of principle involved in finding the set of all objects that correspond to the state-independent properties of a given type of particle [3]. It is merely assumed that elementary particles have no other properties than those that currently define them. While theory based on qualitative identity works for statistical prediction, we think of particles as identical when we cannot point to them or to individuating detail, as we can in the case of planets or other macroscopic objects. Yet, these are physical restrictions on the epistemology of micro objects, which should not be construed to mean that such objects are merely products of definition. Even the identity of new planets consists in little more than the sort of detection events encountered with elementary particles. In both cases, statistical accounting operates at the limit of observational resolution, yet we do not think that planets are intrinsically mathematical objects.

The usual interpretation of the Bose-Einstein statistics is that the particles concerned are indistinguishable and so must be tallied differently than in classical statistics, where state-dependent properties can be identified for individual particles. But such a statistics could also result if the particles were distinguishable but connected by some force that tends to put them in the same state. In contrast, the Fermi-Dirac statistics usually assumes distinguishable particles, which then appear to have a repelling force acting between them, such that no two can occupy the same state within an atom [4]. From a certain point of view, it turns out that indefinitely many statistics are theoretically possible between the extremes of Bose and Fermi statistics [5].[iii] Moreover, what are we to make of the fact that helium-4 atoms follow Bose statistics under certain conditions? That is, atoms one would normally think of as identifiable objects are in other contexts indistinguishable.

Some clarity is gained by likening the relation between quantum entities and detection events to the situation of money in a bank account [6]. A detection event (observation) is like the act of withdrawing funds from a bank account; it occurs at a given time and place and bears a record with a distinct place and time (withdrawal slip). The money itself, however, is merely quantitative; it does not consist of *specific* dollar bills. Similarly, though energy is quantized, it makes no sense to speak of identifiable individual quanta of energy. However, even in this analogy, identifiable properties of individual dollars *can* make a difference under certain circumstances—for example, if they are counterfeit bills or collector's items in a safe-deposit box. Whether a "dollar" is an object with individuating properties beyond a defining set of properties depends on how we do the accounting. A=B can be an assertion of numerical identity, or even qualitative identity, where A and B are identifiable "objects"; but it can also mean quantitative equivalence, where A and B are quantities rather than objects. Accounting in quantum physics is something like a shell game: it depends on how attentive you are and what you expect to find under the shell. Are waves and eigenstates like "things" with individuating properties or like dollars in bank accounts? It depends.

While the evidence of Bell-type experiments confirms the statistical predictions of quantum theory, this in itself does not imply that quantum entities are mere products of definition, or have precisely and only the properties defined for them by current theory.

Entropy

Structure, and therefore information and entropy, are ambiguous concepts. A structural relationship may exist between identifiable things, but can also refer to a generic pattern—as in the spaces between atoms in a lattice. This ambiguity should have some effect on how information is calculated, as it does in the statistics of "particles". Distinguished from meaning or content, information is supposed to refer to real structure in the world, which gives it an objective flavor. However, this does not imply that information so defined exists independent of intentional agents. While a sensible concept of information must involve correspondence to physical structure, physical structure depends on how we divide up the world [7] [8].[iv]

Information gains further cachet by association with the physical concept of entropy. This was suggested by the formal resemblance of the equations involved in two distinct disciplines, communications theory and thermodynamics. As a measurable quantity, the information in communications originally referred to the transmission rate and storage capacity for coded binary messages. A message, however, reflects human purposes or those of other agents. To the degree that information is an anthropomorphic concept, it cannot be considered purely objective. Though the information of information theory is routinely identified with thermodynamic entropy, ultimately even latter cannot be dissociated from the purposes that shaped it.

To some extent, structure, entropy, and information are in the eye of the beholder. Yet, contemporary physics seems to have ignored the caveats of E.T. Jaynes regarding the nature of entropy [9] [10]. Jaynes cautioned that there is no such thing as *the* entropy of a physical system, since any given *physical* system corresponds to many possible *thermodynamic* systems. He reminds us, on the one hand, that entropy measures our degree of ignorance about the true microstate of a system, when we know only its macroscopic thermodynamic parameters. On the other hand, entropy measures the degree of experimental control over the microstate, when only macroscopic parameters can be manipulated. It's not a property of the physical system at all, but of the experiments one chooses to perform on it. While it is unclear how experiments can be performed on the universe as a whole, Jaynes' admonitions only served to spur on efforts to transcend the subjective or anthropomorphic aspect of the information/entropy concept, giving rise to the contemporary notions of 'information bound' and the 'holographic principle'.

Information Bounds

The Bekenstein bound, defined in terms of Planck's constant, *h*, implies that the amount of information in any physical system is finite, and proportional to a surface area rather than a volume.[v] When this reasoning is applied to the universe as a whole, it is then held to imply a limit on the total structure and information that can exist. However, Bekenstein himself reminds us that information-theoretic entropy and thermodynamic entropy are two very different concepts, even quantitatively. Furthermore, echoing Jaynes, he acknowledges that "There could be more levels of structure in our universe than are dreamt of in today's physics… One cannot calculate the ultimate information capacity of a chunk of matter or, equivalently, its true thermodynamic entropy, without knowing the nature of the ultimate constituents of matter or of the deepest level of structure…" [11]

Yet, theorists in every age tend to believe they *have* found the ultimate constituents of matter at its deepest level of structure. Accordingly, the current generation takes seriously the notion of an absolute bound to the information content of any physical system, including the universe as a whole. Reasoning about the properties of black holes has led to the further conclusion that "our universe, which we perceive to have three spatial dimensions, might instead be 'written' on a two-dimensional surface, like a hologram."[vi] However, such reasoning effectively limits information by assuming from the outset a bottom to the complexity of nature, a discrete ultimate structure.

It is only because of the peculiar definition of information as digital, along with the physical assumption of discreteness, that a calculable absolute information bound appears inevitable. (The dimensional reduction is actually gratuitous, since a limit—albeit bigger—would be implied even for volumes in a world already presumed to have an absolute discrete bottom.) An information bound rests on assumptions about the degrees of freedom of a system. These depend crucially on how the system is defined. Entropy (and hence information) is defined in statistical mechanics in terms of discrete states—of molecules, for example. This fits nicely with digital computation and a definition of information that is explicitly digital. However, it does not imply that the universe *itself* is digital, much less that it consists of computation! Nature does not have well-defined "hardware" components, as a computer does, nor is it well-defined in the way that theoretical models are. Physical laws are not "software" that "compute" information digitally, so that nature "obeys" them in the way that a computer is driven by a program. These are simply metaphors based in current technology and thought, whereas the natural world is not a product of technology or thought.

Structure or Mass?

Awkward questions arise in relation to information and black holes, at least for interested outsiders to contemporary physics. In some ways, the situation appears to parallel the infamous "measurement problem". Instead of a "collapse of the wave function" there is a collapse of the entropy when matter passes the event horizon [12].[vii] In that situation, one may ask, what is the relationship between information (entropy) and real structure? With what structures shall information be identified within black holes, where all structure is presumed destroyed or inaccessible?[viii]

Traditionally, physical information implies real three-dimensional structure—both regarding what it refers to and how it is stored. A real surface would occupy a physical volume (e.g. a spherical shell one atom thick), and storage of information on a real surface would still involve three dimensions of space plus one of time. Yet information is also treated as a dimensionless abstraction, free of physical details, or confined to two dimensions on an event horizon. The holographic idea seems to conflate two notions of information—one physical and one mathematical or geometrical.

Furthermore, entropy is thought to increase with mass, inside or outside of a black hole. While the *structure* of matter may disappear inside a black hole, its *mass* does not. Outside a black hole, where structure can exist and be identified, a greater mass normally corresponds to a greater number of particles and their possible states, or to greater energy. Yet, inside, this identification cannot be made. Mass then becomes like other macroscopic thermodynamic variables, such as temperature and pressure, which disregard microstates. Whatever the state of the matter inside the black hole, its gravitational effect continues to be felt outside, defining the event horizon. To say that the entropy of a piece of matter falling into a black hole "disappears" can mean one of two things: either its structure has been destroyed or altered, or information about it has become inaccessible. Yet, mass (or equivalently energy) is conserved. Inside the black hole, entropy continues to be proportional to mass, but can no longer be associated with structure—nor, therefore, with microstates or information.

It happens that the surface area of the black hole's event horizon *also* increases with mass, precisely because of the effects of gravitation. It is therefore no surprise that the increase of entropy is thought to be proportional to an increased surface area. Volume is simply not an appropriate correlate of entropy (or structure or information) in a situation of indefinite gravitational collapse. However, the proportionality of entropy to mass does not require the holographic principle as its explanation, which is rather a separate metaphysical thesis. The real question (which I do not propose to answer) is how entropy should be defined in certain conditions.

While mass/energy is the traditional measure of what is physically real, the ontological status of entropy/information remains in doubt. The holographic paradigm is a vogue in physics that may or may not prevail. It is grounded ultimately in the need to avoid infinities for the sake of mathematical calculation [13].[ix] It argues for an ontological view of the universe as fundamentally information, on the double grounds of convenience and the discreteness of the quantum world. Yet, in a classical world, where h is zero and c is infinite, an information bound would be infinite or undefinable. In alternative worlds, where h and c had arbitrary finite values, an information bound calculated on their basis would be finite but different in each case. At the least, it seems ill-advised to objectify information as something calculable in an absolute sense.

The Game of *Twenty Questions*

The expression "it from bit" was coined and popularized by the noted physicist, John Wheeler. Wheeler himself acknowledged that 'bits' are answers solicited from nature to yes-no questions posed by physicists via detector events [14]. He describes the situation in quantum physics, where knowledge cannot be clearly distinguished from the objects of knowledge. In particular, choices about what to measure appear to determine the reality *before* measurement [15].[x]

Wheeler's catchy aphorism simply inverts the traditional understanding of physics—as idealism generally inverts the materialist order of things. According to the traditional understanding, information is implicitly abstracted or gleaned from physical reality to begin with. From this point of view, information cannot logically then be recycled as the basis from which physical reality springs. However, by assuming that such legerdemain is endorsed by quantum weirdness, one then has *carte blanche* to imagine that the universe is nothing but a computation or simulation, a virtual reality, a branch of mathematics, or a lengthy message from aliens. Some thinkers see information "encoded" or "registered" everywhere, without asking: by whom and for what purpose?[xi] While an *organism* may need to model its environment, encoding it economically in its brain or elsewhere, one has no reason to imagine that physical reality at large registers or processes information, or has any need to encode or represent aspects of itself. Information is encoded, registered, or processed by intentional agents. If apparently "inert" matter does happen to encode information, this is a sign that it is *not* inert in the ways we have supposed. Information it encodes *for itself* would not necessarily correspond to the information that human agents would encode or find significant. The lesson to be gleaned, from regarding the universe as bits of information, is not that we can externally assign a definite information content, but that the universe is not an *it*!

As Wheeler intimated, the information-theoretic view of nature renders the scientific process rather like a party game, in which the science community asks a series of yes-no questions regarding a natural phenomenon. The number of questions required to pin down the answer constitutes the information content of the phenomenon concerned. (A question comes down to whether something falls in a given category or not.) In the actual party game of "Twenty Questions", the contestants are to guess a pre-established answer by a process of elimination. The series of questions converges to a known answer, and so terminates.

While the actual party game metaphorically represents classical realism, Wheeler modified it to represent the situation in quantum physics. In his "surprise" version, there is no fixed answer, which may change with each query so long as it is consistent with past answers. Yet, this extension to the quantum realm only undermines the notion of a definite information content, since the answer in the modified game is a moving target, influenced by the question. In *either* the quantum or the classical case, furthermore, to query *nature* in this way produces a potentially non-terminating series. Even in the classical case, there is no predetermined answer regarding what a natural phenomenon is. The number of categories may be infinite, so that the universe, or any part of it, potentially contains an infinite amount of information. Or, rather, it does not "contain" definite information at all! Information is not generated by physical reality, but by the process of inquiry; it is stored and managed by the inquirers. It is supposed to correspond to real structure, of course, yet structure is indefinite both in the macro and the micro worlds.

Conclusion

Only by *redefining* a natural system as an idealized model can the possibilities be limited in such a way that a definite information content can be assigned. Accordingly, a theory can have a fixed information content, but nature cannot. If so, the natural world cannot be exhaustively modeled and no complete or final theory is possible.

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[i] This concept of realism was paradigmatically expressed by EPR in the definition of a complete theory, in which every 'element' of a physical system is to be represented in the theory.

[ii] Cf. F J Tipler "The structure of the world from pure numbers" Prog. Rep. Phys. 68 (2005) 897–964: "…even though quantum mechanics yields integers in certain cases (e.g. discrete eigenstates), the underlying equations are nevertheless differential equations based on the continuum. Thus, if we consider the differential equations of physics as mirroring fundamental reality, we must take the continuum as basic, not the integers."

[iii] Particles exhibiting these statistics are generically called "anyons". However, they exist only in two-dimensional space.

[iv] Cf. Barbour [7], p 7-8: "A 'bit' is not a single-digit 'atom of reality' as 'it from bit' implies. A dot on a screen is not the unadorned answer to a straight question. A 'bit' has no meaning except in the context of the universe… Just because the overall conditions of the universe enable us to observe them in carefully prepared experiments, dots on screens are no proof that at root the world consists of immaterial single-digit information. For we have no evidence that the dots could exist in the absence of the world and its special properties… Abstraction creates the impression that the world is made of qubits, but humans make qubits, just as they make coins." Cf. also Floridi [8], p26: "…the search for the unconditioned mistakes time and space and complexity/granularity for features of the system instead of realising that they are properties set by (or constituting) the level of abstraction at which the system is investigated…"

[v] "In physics, the Bekenstein bound is an upper limit on the entropy S, or information I, that can be contained within a given finite region of space which has a finite amount of energy—or conversely, the maximum amount of information required to perfectly describe a given physical system down to the quantum level." [Wikipedia: Bekenstein bound]

[vi] [11] op cit

[vii] see [12]: "From an outside observer's point of view, the formation of a black hole appears to violate the second law of thermodynamics. The phase space appears to be drastically reduced. The collapsing system may have arbitrarily large entropy, but the final state has none at all. Different initial conditions will lead to indistinguishable results." Bousso argues—circularly, I believe—that since the reduction of information defies "unitarity", the entropy must have been proportional to area all along, corresponding to the Bekenstein bound.

[viii] The dictum that "black holes have no hair" acknowledges that black holes resemble elementary particles, with no observable detailed structure and only a few externally observable properties. That is, they are "unitary" and therefore in a "pure" quantum state, in contrast to thermal systems. Hawking's black hole paradox is that they nevertheless emit thermal radiation, putting them in a mixed state. If so, might this contradiction work the other way, to suggest that elementary particles are similarly able to radiate "classically," in the prohibited way that gave rise to quantum physics in the first place?!

[ix] For example, Sorkin [13]argues for a discrete "spacetime" structure from the mathematical need for a "cut-off" to avoid infinite entropy, much as the original quantum theory was based on the need to eliminate infinities of energy in classical models of radiation. Cf also Tipler [1] op cit: "But if we take the continuum as fundamental, we are faced with the infinities of quantum field theory, and the curvature singularities of general relativity.

[x] Cf Stoica, [15]: "We can think that there is an ontology behind the outcomes of our measurements, as in the classical world. But the 'delayed choice experiment' shows that the 'elements of reality' depend of the future choice of our measurements…This is why [Wheeler] was led to the idea that the state of the universe (it) results from the observations (bit)."

[xi] For example, Lloyd, [16]: "Every physical system registers information, and just by evolving in time... processes that information." Lloyd goes on to argue that the fact that digital computers exist demonstrates that the universe is "capable of performing things like digital computations".