DOES NATURE HAVE A DEFINITE INFORMATION CONTENT?

Dan Bruiger
Hornby Island, BC, Canada July 2012

Abstract

In contrast to conceptual systems, the notion of information bounds for physical systems is questioned. Several related assumptions are challenged: 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. By usual standards, this would imply that natural reality is not real, but ideal.

In fact, the unreality of nature continues to be a tacit assumption of modern science, deriving from traditions that influenced the emergence of natural philosophy from medieval European thought. The founding fathers of science were 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. This dovetailed with the ancient Greek notion that the world is ideal, a 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 several basic assumptions: that physical systems can be represented exhaustively; that they have a definite information content; that they are effectively identical to their mathematical representations; and that there is a bottom to the complexity of nature. In turn, such premises rest implicitly on an idealist thread within Western traditions: in a fundamental sense, nature does not possess its own indwelling reality, but only that bestowed upon it or defined by some outside agent, either human or divine, or that it is a mere shadow or projection of something more fundamental—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 scientific *models*. These correspond to aspects of nature that can be readily treated mathematically, to the possible exclusion of other aspects. Though the capacity for mathematical treatment has expanded with the computer, scientific focus lags behind because of underlying metaphysical assumptions.

For example, standard cosmological theory is a linear historical account—like the story in Genesis or the clockwork universe. It tends to disregard nonlinear processes of self-organization. Properties of matter are considered mere byproducts of fundamental equations acting “deterministically”. This imagined causal power of *laws* is an anthropomorphic and religious holdover from pre-scientific thought. It also reflects the computational limitations of an earlier age, when mathematics had to be done on paper.

In truth, physical laws are descriptive and essentially statistical, rather than prescriptive and precise, as equations would suggest. Differential equations express algorithmic compressions of observed data; they are convenient because they can be solved with known techniques. Even so, such equations still must be supplied with initial conditions, yielded by observation or experiment rather than theory. Yet, it is a common hope to eliminate this inconvenience, so that the evolution of the universe would be a matter of logical necessity, as the ancient Greeks had dreamed.

Real and Deductive Systems

Scientific realism is usually associated with a definite way that nature is, independent of how it is investigated. 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, organization, and causality 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 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 intentionally designed artifacts: deductive systems, logical constructs, machines, scientific models, etc. These are products of definition, in contrast to the natural systems they may model.

The natural world could be exhaustively modeled only if it were *deterministic*, with an intrinsically non-random structure. This, of course, was the classical assumption: the universe was deterministic because it was a machine. However, no deterministic system can generate a true random sequence. The problem of exhaustively modeling real systems amounts to finding an algorithm to express a random sequence, but no deterministic system (such as a computer) can be counted upon to do this.

Moreover, the concept of determinism trades on a double-entendre. For, to *determine* is an act of intent, such as programmers and designers engage in, which we have mistakenly projected upon nature as 'causality'. Nature itself is neither deterministic or non-deterministic, for we are not in a position to determine whether it is one or the other, except by projecting a preferred concept upon it—that is, by fiat. The *only* truly deterministic systems are deductive systems—in the broadest sense: machines!

Formalism

Understandably, but illogically, there is nevertheless a powerful incentive to assimilate nature to current technology, to consider nature itself to be nothing more than a (deterministic) product of definition. 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 or information processing, then it is necessarily well-defined. Yet, this is a metaphysical belief, not a scientific fact.

The idealist thread in science views matter as a mere abstraction, with only its defining properties. So to speak, nature is no more than its own blueprint, a formalism.

The Newtonian “world machine” was inspired by the literal machines of the day. It was deemed rationally comprehensible because it was conceived as rationally designed 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, being the realization of a formalism.

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, design, 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.[1] 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 idealized systems—formalisms—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 seems to be a basic assumption of contemporary physics, as expressed in the notion of ‘information bound’.

Physical vs. Mathematical Discreteness

While one knows that a real planet is not literally a mathematical idealization, quantum entities appear to actually *be* ideal. However, this appearance may not reflect reality so much as epistemic limits and logical and methodological constraints—the driving forces behind the quantum theory in the first place.

Nature obviously has discrete aspects at various levels. After all, a planet is a discrete object at a certain scale; yet it is resolvable into smaller objects, and so on. At the other end of the scale, one can only postulate (but never prove) that a “fundamental” particle is truly indivisible. Moreover, discrete states can often be regarded as manifestations of some continuous field concept—as in the case of wave harmonics and “eigenstates” [1][2] Macroscopic particle-wave interactions can demonstrate quantization and wave-particle duality [2]. Even at the quantum scale, apparent and relative *physical* discreteness is categorically different than the *mathematical* discreteness of integers or bits, which is definitional and absolute.

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 the quantum realm, there are difficulties of principle involved in finding the set of all objects that correspond to the state-independent properties of a given type [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 properties, as we can in the case of planets or other macroscopic objects.[3] Yet, these physical restrictions on the epistemology of micro objects should not lead us automatically to conceive them as intrinsically mathematical objects. 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 conclude that planets are intrinsically mathematical or ideal 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 individuals can be identified by their state-dependent properties. But the former 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].[4] Furthermore, what is one to make of the fact that helium-4 atoms follow Bose statistics under certain conditions, while one would think of them as identifiable objects in other circumstances?

Some light is shed by likening the relation between quantum entities and detection events to the situation of money in a bank account [7]. A detection event (observation) is like the act of withdrawing funds; it occurs at a given time and place and bears a distinct record (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 depends on how one does the accounting. This aspect of the shell game of quantum physics depends on what one expects to find under the shell. Are waves and eigenstates "things" with individuating properties, or are they sums in bank accounts? While the evidence of Bell-type experiments confirms the statistical predictions of quantum theory, this in itself does not imply that quantum entities have precisely and only the properties defined for them by current theory.

Entropy

Structure, and therefore information and entropy, are ambiguous concepts. Structure may involve a relationship between identifiable things, but may also refer to a generic pattern—as in the spaces between atoms in a lattice. This ambiguity should bear 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 the world is divided up [7][8].[5]

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, and to that degree information cannot be considered purely objective. Though the entropy of information theory is routinely identified with thermodynamic entropy, ultimately even the latter concept cannot be dissociated from the purposes that shaped it, nor from the particular physical situations for which it is defined. The classical example of an expanding gas, for example, depends on a repulsive force between atoms to create a more dissipated state with higher entropy; whereas, the entropy in the situation of attractive forces (e.g. gravitation) is lower in the "dissipated" state and increases with clumping.

To some extent, structure, entropy, and information are in the eye of the beholder. They are matters of definition and circumstance. 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 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 so much a property of the physical system as of the experiments performed 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 and objectify the anthropomorphic aspect of the information/entropy concept, giving rise to the contemporary notions of 'information bound' and '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.[6] 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 presume they *have* found the ultimate constituents of matter and its deepest level of structure. Accordingly, one now 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."[7] However, such a conclusion depends from the outset on 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 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 information or 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 old metaphors updated in current technology and thought, whereas the natural world is not a product of technology or thought.

Structure or Mass?

Awkward questions arise concerning 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].[8] 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?[9]

Traditionally, information concerning physical systems implies real three-dimensional structure. 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 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. 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. 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. 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 effect 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 extreme 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 is grounded ultimately in the need to avoid infinities for the sake of mathematical calculation [13].[10] It suggests an ontological view of information as the fundamental constituent of the universe, on the double grounds of convenience and the discreteness of the quantum world. Yet, in the classical world, where h is zero and c is infinite, an information bound is 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 considered 'bits' to be 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 mysteriously appear to determine the reality *before* measurement [15].[11]

Whatever the explanation, Wheeler's catchy aphorism inverts the traditional understanding of information—as idealism generally inverts the materialist order of things. According to tradition, 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?[12] While an *organism* may need to model its environment, encoding it economically in its brain or elsewhere, there is no reason to think 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 it does turn out that apparently "inert" matter happens to encode information, this is a sign that it is not inert in the ways we have supposed! Moreover, information that any system encodes *for itself* would not necessarily correspond to the information that human agents would encode or find significant. The lesson to be gleaned from 'it-from-bit' is not that we can externally assign a definite information content to physical systems, but that no physical system is strictly 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. (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—the sort of whimsical behavior one expects of living agents rather than inert systems. 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, to query *nature* in this way produces a potentially non-terminating series. Even in the classical realm, 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, a definite *it*, can possibilities be restricted in such a way that a definite information content can be assigned. Accordingly, a science, a theory, or a model has a fixed information content, but nature and natural systems do not. If so, the physical world cannot be exhaustively modeled, and no complete or final theory is possible.

The classical assumption was that physical variables must *have* precise values, even when measurements are imprecise. The fact that the *mathematics* worked precisely, despite the limits of measurement, was taken to mean that *causality* worked perfectly behind the scene [18]. But 'physical variables' are idealized mathematical constructs, and the equations are products of definition. *They* are precise by fiat, and their presumed identity with physical reality is merely an assumption based on a functional and approximate correspondence. Equations are deterministic, but this does not mean that nature is. Yet, to say that nature is *non*-deterministic means only that human concepts cannot be made to correspond perfectly to it—not that it possesses a "property" of indeterminacy.

On the other hand, to assume 'indeterminacy' *because the natural world eludes definition* might lead to new avenues of thought and research outside mechanistic paradigms. For example, the apparent "fine-tuning" of the universe might turn out to be a result of active self-organization, rather than of highly unlikely coincidence, as it is held to be in the present view of matter as passive. Self-organization may be the norm of matter, since it maximizes the rate of entropy production [19]. A working hypothesis that natural systems do *not* have a definite information content, that information bounds are only tentative, and that there is no intrinsic bottom to the complexity of nature, could lead to a different view of the constitution and history of 'matter'. At this stage, science can only benefit by questioning assumptions behind the traditional identification of natural systems with their theoretical counterparts.

Endnotes

[1] This concept 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.

[2] Cf. F J Tipler [1]: "…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."

[3] See [18], p 158: "The idea of complete loss of individuality is very difficult to comprehend, because the very act of imagining the behaviour of such 'objects' restores to them the individuality which in theory they do not possess.

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

[5] Cf. Barbour [8], 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 [9], 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…"

[6] "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]

[7][12] op cit

[8] See [13]: "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. Another "awkward question" that occurs to me as a non-physicist is how to reconcile the escape of gravitons as a form of radiation?

[9] 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?!

[10] For example, Sorkin [14] 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.

[11] Cf Stoica, [16]: "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)."
12 For example, Lloyd, [17]: "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".

References

[1] F. J. Tipler "The structure of the world from pure numbers" Prog. Rep. Phys. 68 (2005) p897–964
[2] A. Eddi, J. Moukhtar, S. Perrard, E. Fort, and Y. Couder "Level Splitting at Macroscopic Scale" Phys. Rev. Lett. 108, 264503 (2012)
[3]P. Teller "Quantum Mechanics and Haecceities" in Elena Castellani, editor, *Interpreting Bodies: classical and quantum objects in modern physics*, Princeton University Press, 1998 [p116]
[4] M. L. Dalla Chiara, R. Giuntini, D. Krause "Quasiset Theories for Microobjects: a comparison" in Elena Castellani, editor, *Interpreting Bodies: classical and quantum objects in modern physics*, Princeton University Press, 1998 [p149]
[5] H. Reichenbach "The Genidentity of Quantum Particles" in Elena Castellani, editor, *Interpreting Bodies: classical and quantum objects in modern physics*, Princeton University Press, 1998 [p71]
[6] "Anyon Superconductivity?" Science, 23 March 1990: p1410.
[7] P. Teller, op cit, p119-20
[8] Julian Barbour, "Bit from It" [http://www.fqxi.org/data/essay-contest-files/Barbour_Wheeler.pdf, 2011]
[9] Luciano Floridi "Against Digital Ontology", preprint of article for *Synthese* 2009
[10] E. T. Jaynes "Gibbs vs Boltzmann Entropies" Amer. J. of Physics, Vol 33 No. 5, May 1965, p396-98
[11] S.F. Gull, "Some Misconceptions about Entropy", 1989 [http://www.ucl.ac.uk/~ucesjph/reality/entropy/text.html]
[12] Jacob D. Bekenstein "Information in the Holographic Universe" Scientific American Aug 2003 [p60]
[13] Raphael Bousso "The holographic principle" [arxiv: hep-th/0203101v2 2002]
[14] Rafael D. Sorkin "Ten Theses on Black Hole Entropy" 2005
[15] John A. Wheeler, "Information, physics, quantum: The search for links", in W. Zurek, ed., *Complexity, Entropy, and the Physics of Information* Addison-Wesley, 1990
[16] Cristi Stoica, "'Bit from It' vs. 'It from Bit'" [http://www.unitaryflow.com/2011/02/bit-from-it-vs-it-from-bit.html, Feb 2011]
[17] Seth Lloyd, "The Computational Universe" Edge 2002 [http://www.edge.org/documents/day2/day2_lloyd_index.html.]
[18] Jonathan Powers *Philosophy and the New Physics* Methuen 1982, p140
[19] Rod Swenson "Spontaneous Order, Autocatakinetic Closure, and the Development of Space-Time" Annals New York Academy of Sciences, vol. 901, pp. 311-319, 2000