It, Bit, and Something More

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"It from bit or bit from it?" Like so many other grand questions, this one is most useful to us if we begin by clarifying, analyzing, reflecting on alternatives, and probing implications. In the end, we might declare for one side or for the other. Or we might come to think that truth lies somewhere in between. Or perhaps we shall be led in a different direction entirely. In section two of this essay I shall also suggest that, in addition to "it" and "bit", we need to ponder the role of a third factor in the constitution of reality. The third factor is consciousness, which is the "something more" mentioned in the title.

The contrast of "it" versus "bit" seems to have been used in at least three ways. One of these is a distinction between continuity and discreteness. Because this was the subject for a previous essay contest, we do not consider it here. Secondly, there is a distinction between physical laws for matter and energy versus more abstract principles for information, entropy, and computation. Finally, John Wheeler, who first posed our question in its present form, gave considerable attention to a distinction between "the physical world" and "a very deep bottom". That "bottom" he associated somehow with "participation" and "communication".[1]

1. It and Bit in Nature.

We begin then with a contrast between physical laws ("it") and informational principles ("bit"). Nature appears to exhibit not one, but two, types of systematic and comprehensive order. One of these is built on dynamic laws of matter and energy. The second, which is rather more abstract, is centered on the concepts of information and computation. When we think about the first kind of order, we talk about such things as particles, fields, motion, force, gravity, electromagnetism, and so on. When we think about the second kind of order, we talk about such things as information, entropy, complexity, and computation. Many questions arise. Is one of these sets of factors more fundamental? Does one lead to or explain the other? If each is irreducible, then how is the world based upon both of them jointly?

One complication is that both forms of order make reference to time. Time appears to be a physical reality (an "it") rather than an informational one (a "bit"). Thus, the phrase "it from bit" generally does not mean quite what it says, but rather something more like, "the rest of it from time plus bit". In the following discussion I assume the reality of a rich and commonsensical form of time.

Another qualification to the question is that I shall focus on the universe in which we live. Our universe is a structure which began about 13.7 billion years ago. Because of expansion, the farthest parts which astronomers observe are now about 42 billion light-years away. This very sketchy description is perhaps sufficient to delimit the theater within which "it" and "bit" play their parts. Setting the limits is important, because the cosmic truth about "it" and "bit" may come to look very different if that *limited* truth is subsequently re-envisioned within a greater context. Many hypotheses now on the table do postulate more comprehensive realms of existence—many worlds, parallel worlds, one or more multiverses, and so on. One hypothesis of this sort, certainly relevant to our topic, is the idea, discussed by Nick Bostrom, that we are living in a computer simulation.[2] According to this view, our world, including us, would be nothing but bits through and through. This hypothesis obviously opens the door to questions about the higher levels, including of course questions about "it" and "bit" in those higher realms. As I said, there are many hypotheses about multiple, other, and larger worlds, all the way up to modal realism, which holds that all logical possibilities are real.[3] *Ultimately* we do not know the truth about "it" and "bit" until we comprehend their interplay across the totality of being, however vast and kaleidoscopic that may be. To begin, however, we shall try to understand the *apparent* truth about "it" and "bit" for one universe.

For present purposes, the physical principles belonging to "it" are clear enough so that we can proceed. About the "bit" side of the contrast, we might need to say a little. The two foundation stones for the "bit" aspect of natural order are information and computation. Both of these are defined quite abstractly. The quantity of information (in a message, or more generally in any item or state) is said to be equal to the logarithm of the number of possible alternatives to that item. This idea comes, of course, from the work of Claude Shannon in the late 1940s. For computation, the key concept is the notion of an algorithm. As with most important general concepts, a precise and comprehensive characterization is difficult. Very roughly, an algorithm is a step-by-step procedure that reaches a result by means of a finite number of steps. The lambda calculus of Alonzo Church provides a mathematical formalization. Alan Turing's idealized machines are the best-known explication. Much more could be said and should be said, but we have time for only one further remark. Bits connect information and computation in the sense that bits are the basic units, the common currency, for both.

Given this understanding of information and computation, we face two sets of questions. What role does information play in the content and structure of nature? What is the role of computation in the processes of nature? In what follows, I argue against the hypothesis that nature is generally computational, and then I take a more positive view about information.

Computation. Is the universe a computer? No, it is not. In general, are natural processes computational processes? No, they are not. In section two below, I shall mention a few exceptions to these sweeping denials. Nonetheless, most of nature is not computational. An extreme version of computationalism would assert that natural processes are only computational. I intend to deny this. A less extreme computationalism would assert both that natural processes involve computations and that those processes exhibit other aspects as well.[4] I intend to deny the first half of this conjunction. Of course I know that we human beings (and perhaps other cosmic inhabitants elsewhere) can mobilize many aspects of the universe to do computations. I am also aware that we can simulate parts of nature by computations so as to produce "virtual realities". I concede that sometimes it is helpful to describe and understand parts of nature in informational or computational terms. But these capacities are beside the point. The issue is whether the universe *on its own* is doing something that amounts to algorithmic information processing. No, the universe is not doing that.

In order for there to be a genuine question here, we need to understand what a non-computational universe would be like. Unless we can describe an alternative to computation, then we do not know what we are trying to discuss. Indeed, lacking that understanding, we would have nothing to talk about. Nick Bostrom asks, "Are you living in a computer simulation?"[5] But first we must ask what would be the differences between a simulated (i.e., fake or virtual) universe and a real one? Stated less tendentiously, what would be the differences between a computational universe and a non-computational one?

Paul Davies explains what a non-computational universe would be like.[6] In that kind of world, natural laws would operate absolutely and to any degree of precision and complexity. The operations of nature would be subject only to laws and antecedent conditions. There would be no further constraints. By contrast, in a computational universe, there would be a further restriction, namely, the capacity of the universe to store and process information. In both kinds of universe, the details of a particular situation follow logically from natural laws and from relevant determining conditions. The relevant conditions normally include antecedent circumstances, constituent internal states, or both. In a non-computational universe, given the determining conditions, the consequent state "just happens". The laws are self-implementing. But in a computational universe, computation must intervene so that nature can "figure out" what is supposed to happen next.

We might say that there are three great questions about natural laws. First, why is the world subject to any laws at all? Second, given that there are laws, why does the universe obey the actual set of laws rather than some other? The problem about computation in nature arises with respect to the next question. Given that these particular laws obtain, how do they operate? On the computational view, the consequences are computed. On the non-computational view, such intermediation is unnecessary and does not happen.

Given this clarification of the distinction between a universe which is computational and one which is not, we can proceed to the main question in two stages. First, does the universe operate through "classical" computation; that is, through computation which does not reach into quantum processes for information storage and processing? And then, does the universe operate by mobilizing all of its resources, including quantum processes, for computation? The second refinement of our question is more interesting, and more difficult to answer, than the first.

Indeed, we have sufficient empirical evidence to say that nature does not achieve its effects primarily through classical computing. The storage and processing capacities are too meager. Most people seem to accept Seth Lloyd's calculations for the capabilities of the cosmic domain which I previously characterized as our home universe.[7] These limits are 10^{122} ops (i.e., elementary binary operations) since the big bang, working on 10^{92} bits, or 10^{122} bits if one includes bits "that can be stored using quantum gravity". Davies points out that an entangled quantum system containing 500 components requires for its description a wave function with 2^{500} components.[8] (For emphasis, I have substituted "500" for Davies's "400".) $2^{500} \approx 10^{150}$. Assume that each component of the wave function can be expressed in the minimum datum of one bit.

Clearly the cosmos could not contain the information describing such a small though intricate subpart of itself. Still less could the cosmos compute that description. Looking through Wikipedia's "Timeline of quantum computing",[9] I have to believe that quantum entanglements of sufficient size have already existed, or at least soon will exist. Clearly, the universe did not and will not *classically* compute what the laws of nature require in such circumstances. Lloyd is right when he asserts that "the universe is intrinsically more powerful than a classical digital computer."[10]

As quantum processes are taken into account, we can no longer rely on a straightforward argument about lack of capacity. Lloyd has shown "that a variety of quantum systems, including quantum computers, can be 'programmed' to simulate the behavior of arbitrary quantum systems".[11] I am not so sure, however, that the argument establishes that the simulator computes the behavior of what is simulated. Apparently, what would happen is that the simulator would mimic the behavior of the target system. Thus, the simulator would be like a scale model or a full-sized prototype, not like a virtual model inside a computer. Be that as it may, I want to explore other reasons to reject computationalism. We should move beyond doubts about possible lack of capacity.

One problem is that, if nature is computing, nobody has any idea about the details of the computations. For one thing, we usually talk about bits, but have we really determined that nature computes in the binary system? We human beings can always use base-two coding to write down information about nature and to calculate the information capacity of parts of the universe and of the whole universe. But that is not the point. The problem is to determine what coding scheme or schemes nature itself uses, provided that nature is computing in some literal sense. For purposes of argument, suppose that nature does compute with a binary system. With this assumption, we open the door to many further questions. What data types are used? What mode of representation for each type? For instance, human beings have devised different ways to represent real numbers. Moreover, for real numbers there are always problems about precision and rounding off. If nature is genuinely computational, then nature must have solved these problems somehow. When we turn from data representation to data processing, we realize that, to accomplish a given task, such as dividing one number by another or sorting items on a list, alternative algorithms are available. If nature is computational, then we shall need to understand which algorithms are used for which purposes. So far as I can tell, researchers have not addressed these questions. But, if we take seriously the hypothesis that the universe works computationally, then the questions are legitimate.

A deeper problem is to distinguish in nature between explicit information and what we might call unsymbolized proto-information. An analogy can clarify this. Think about using a DVD to play a movie. We say that the movie is coded in bits on the surface of the disc. This is true, but not the whole truth. In order for the DVD to work as intended, the disc and the computer which plays it have to follow the same engineering specifications. These rules are not written on the disc, but are built into both the disc and the computer. Beyond engineering, there are facts which are fundamental to the world. For instance, linear order underlies both the one dimension of time and any one-dimensional spatial object. On the disc, the movie exists essentially in one spatial dimension (wound in a spiral around the center). Because of the common linear order, the immobile movie on the disc translates into a temporal sequence of images and sounds.

A similar analysis applies to the universe, if the universe is computational. I already suggested[12] that time is an aspect of the primordial cosmic computer, rather than a result of cosmic computation. There must be other such uncomputed factors. Collectively, they would be the "hardware" of the great cosmic computer. This way of looking at things does restrict the applicability of "it from bit". The bottom level would seem to be a substrate of "it". Resting on that substrate are processes of "bits". Then most of the familiar "its" of the world would result from the "bits". So this would be no more than an impure computationalism. The problem, however, is not this so-called "impurity", but rather the fact that such relevant questions have been left unattended.

Another thing to say about computationalism is that, if it be true, computations do not merely supplement what we now take to be the workings of nature. Instead, the computations would operate *instead of* natural laws. Natural laws would not directly determine that electric lights work, that tables and chairs stay solid, and that food nourishes. Instead, constituent parts of objects would compute how they should behave if they followed laws, and then, once results were obtained, the constituent parts would fall into line, and do what they were supposed to do. This might not be a falsifying consequence, but still it is an unsettling implication.

My last criticism of computationalism raises the issue of the status of consciousness. If my world is computed, am I computed too? Here, I think, is a dilemma for the computational hypothesis. Suppose the computationalist answers, "Yes. Conscious minds are computed aggregates, just like ordinary physical things." In that case, computationalism would fall prey to the difficulties that I discuss in section two below. On the other hand, suppose the computationalist answers, "No. Only physical things are computed, and conscious minds are not." In this case, computationalism would seem to commit itself to dualism, and thereby to take upon itself dualism's well-known problems. Furthermore, the motivation for computationalism would be significantly weakened. If important parts of the universe—namely, we ourselves—are admittedly not computational, then we might wonder why we should ever imagine that the rest of the universe must be computational.

Information. We come now to information. Like computation, information belongs to the "bit" side of the contrast between "it" and "bit". Here I think the role of "bit"-like factors is essential in nature, although these factors also have to work together with the "it" aspects of things. To illustrate what I mean, we look again at the analogy of playing a movie from a DVD. While the movie is playing, it exists in four "versions", as we might call them. These four are (a) on the disc, (b) in the computer's processors, (c) at the screen and speakers, and (d) in photons and sound waves. (For our purposes, we had best ignore intermediates, parts of versions, interferences, imperfections, and so on.) This entire process works because the four versions share one informational structure ("bits"). Equally, however, each version realizes that structure in its own specific physical way (as an "it"). Both the abstract commonality and the concrete particularities are essential. My point is that both aspects are essential throughout nature.

Concretely, nature consists of matter, energy, space, and time. More abstractly, nature embodies an order which is in some sense simple and in other ways complex. Many people have had some sense of simplicity-and-complexity. Leibniz formulated the core notion. Our world, he said,[13] is, "at the same time the simplest in hypotheses and the richest in phenomena." Much recent work has been done to explicate complexity. I do not believe we should be either surprised or embarrassed by the number of items on Seth Lloyd's list of "Measures of Complexity".[14] Not all those items are applicable cosmically, but some of them are. This is not the place to present a cosmic vision of simplicity-and-complexity. One interesting suggestion as to how that might look is in Rudy Rucker's *Mind Tools*.[15] What I am saying here is that, in order to understand nature as fully as we can, we must take this abstract point of view and we must also describe nature more concretely. The abstract level of simplicity-and-complexity gives us important truth about our universe as contrasted with other universes (merely possible, or even actual, according to some multiverse theories). The concrete level of physical description tells us that we are dealing with a universe instead of some other type of simple-and-complex structure such as an artistic creation or a logical proof.

Fairly recently many researchers have come to see that "bit"-like considerations are more important than previously thought. Roger Penrose has asserted that the entropy of the big bang had to be extremely special.[16] Another issue has attracted more attention, however. I refer to some findings and ideas that are being collected under the heading of "the holographic principle".[17] (The reasons for this name are not relevant here.) For many regions of the universe, the maximum information content of those regions—or the maximum amount of information which would ever be needed to describe the contents of such regions—is proportional to surface area rather than proportional to volume. Obviously, this means that the informational capacities, or informational requirements, are much less than we would have supposed. The details are technical, and are not yet fully worked out. Nonetheless, there is something here highly relevant to our topic. At least in the present state of physical understanding, a principle of nature seems to be about information in the abstract, rather than about matter and energy more specifically. Raphael Bousso, summarizing some of his research, states that we should seek an explanation "in the number of fundamental degrees of freedom involved in a unified description of spacetime and matter."[18] If so, then discovering this explanation will be a very big deal. Furthermore, the explanation will be central to our subject. In order to understand the connection of information to matter, energy, space, and time, we need that deeper knowledge of nature.

2. Consciousness, Computation, and Complexity.

We come now to a second way in which Wheeler distinguished "it" and "bit". The relationship between "every item of the physical world" and "an immaterial source and explanation": what is that? The idea of any such relationship is hard enough to understand. A few other things that Wheeler says introduce more difficulty and leave me much more confused. First, if this relationship provides a topic, or perhaps several topics, I do not see what such issues might have to do with either "it from bit" or "bit from it". Yet, Wheeler asserted that "it from bit symbolizes" this very idea. Secondly, I would not be inclined to link "its" and "bits" with the notion of "a participatory universe". When we talk about "observer-participants", we are talking about conscious beings. The latter would seem to belong in a different inquiry. Yet, Wheeler lists "consciousness" as one of his five clues. Finally, however much we know about "it", "bit", and consciousness, we still do not know why something exists rather than nothing. When we investigate "it", "bit", and consciousness, we are studying things which we simply accept, unaccountably, as existing. Yet, Wheeler's primary aim was to answer the question, "How come existence?" With that question we are to end, or perhaps begin. "The supreme goal", Wheeler wrote, is to "*deduce the quantum* from an understanding of *existence*."[19]

Although I cannot ascertain Wheeler's intentions here, I think we do need to explore these large and admittedly somewhat amorphous issues. As I indicated at the beginning of the essay, this is the place to say a few things about consciousness. For ontology, the topic is important in its own right. Moreover, perhaps consciousness is a genuine clue on the track of "How come existence?" So, I propose to look at consciousness alongside "it" and "bit". Perhaps some insight can come from thinking about the three of them together. In order to do this, we shall revisit the topics of information processing and complexity, but this time we shall enlarge the discussion specifically to include consideration of consciousness.

Information Processing. In the previous section I argued that the processes of nature are not in general algorithmic computations. Nonetheless, particularly in living organisms, there are some important kinds of processes which do seem to involve what we might view as information processing. One obvious example is the complex of reproduction, development, and genetics. Here one set of relatively small things (DNA, RNA, and proteins) correlates systematically with a collection of larger items (bodily structure, function, and behavior). Another obvious example is found in brains and nervous systems. We might also think of immune systems as doing some information processing.

Since human brains and the brains of various other animals do computations, the question is unavoidable whether consciousness itself might be a kind of computation. Despite much effort spent in trying to establish such a picture, the hypothesis that consciousness is a form of computation seems as implausible as ever.

From the 1960s into the 1980s concepts and analogies about software, algorithms, and Turing machines were not infrequently used to explain thinking and mental experience. The first thing to notice is that such an approach to mind is at variance with a more comprehensive computationalism about the world. An important task in philosophy of mind is to ascertain what makes mentality so different, or at least apparently so different, from the rest of the world. So, in this game, we can play the computer card only once. If everything is really "it from bit", then we shall have to find some other and more specific way to differentiate between the "bits" of mind and the "bits" of everything else. On the other hand, if we start by characterizing mental activity in terms of algorithms, information processing, and software, then the distinctiveness of mentality will be hard to maintain when we then proceed to try to explain all of existence in the very same terms.

Computation does take place in the brain. However, the properties of actual experience—for example, seeing or hearing—are different from the properties of neural computational processes. Therefore, the experience and the underlying computation cannot be the same thing. The details of this argument are well-known, and need not be repeated here. But I would like to reply to the criticism that what I call “actual seeing” is in reality merely information processing plus an illusion of something more. To this critic, somebody like Daniel Dennett or Douglas Hofstadter perhaps, I would say that the illusion which the critic requires me to have is just as experiential as the qualitative original which I thought happened and which the critic denies. So, the critic has not been able to remove experience from the world. To do that, the critic would have to assert that I have only an illusion of an illusion of seeing—well, only an illusion of an illusion of an illusion of seeing. And so on. In my view, the unavoidable regress is as futile as it is false to the facts of experience. Conscious experience is not a kind of information processing.

Complexity. In the previous section I also endorsed the belief that concepts of complexity, and of simplicity, are important for our understanding of the cosmos. Ideas from complexity theory, like ideas from computer science and information theory, have over the last several decades been given two different jobs in philosophy. On the one hand, both kinds of ideas have been brought forward to help us understand things in general. On the other hand, both kinds of ideas have found work in purported explanations or descriptions of the essential character of mental phenomena. Some people have said that the brain is an especially complex structure—“the most complex thing known in the universe”. Therefore, also according to some people, that is why the brain thinks. Similarly, neural activity is an especially complex sort of process, and that is why (some of it) rises to the level of consciousness.

In fact, however, complexity is not the distinctive trait of consciousness. Complexity might be part of the explanation for consciousness, but it cannot be the whole of the explanation. Is a human brain more complex than all the rest of a human body? When a person is conscious, some of that person’s neural activity underlies consciousness, but most of the neural activity is involved with other things. Is the consciousness itself, or its associated neural processing, more complex than all the other activity in the brain? Suppose that for a period of time—perhaps for fifteen seconds—a human being concentrates on the fact of being conscious. (The reason for this unusual thought-content might be a desire to make a philosophical point.) Is that consciousness, or the brain activity correlated with it, more complex than what is happening in Google’s computer network during the same time span?

To each of these three questions, the answer is “No”. Some non-conscious processes are more complex than conscious ones. This is so, on any reasonable explication of the concept of complexity. Therefore, consciousness does not arise mainly because of amount or kind of complexity. Complexity per se neither constitutes consciousness nor explains it.

What we have learned, I think, is that consciousness is not a phenomenon of “bits”. Specifically, consciousness is not a computational process, and it is not a product of complexity per se. If there is a unified world-picture, consciousness belongs to it in some other way.

Conclusion: How Come This Existence?

Discussions of topics like ours are sometimes faulted for reaching no conclusions. However, we do have some results. Nature is not in general computational. Two informational concepts, complexity and information, are important for understanding the world, but only along with more concretely physical ideas, according to current understanding. On the role of information, however, further work is necessary. Finally, consciousness is not a computational process, and consciousness is not to be identified with complexity.

But still, how come existence? We recall that Wheeler took this perennial question for the keynote of his first essay about "it" and "bit". We seem no closer to answering it. I would like to suggest, in words somewhat reminiscent of Wheeler's "clues", that perhaps we have made some progress. Here is the clue: Look for how come in how. Stated more prosaically, this means that facts internal to the world, that is, facts about the world's contents and structure, are linked to the primal fact that the world exists. If so, then we can move toward insight about why there is anything at all ("How come existence?") through a deeper understanding of what there is.

[1] "Information, Physics, Quantum: The Search for Links", pp. 311, 320-321. Originally in *Proc. 3^{rd} Int. Symp. Foundations of Quantum Mechanics*, Tokyo, 1989, pp. 354-368. Text and page numbers here cited from <http://jawarchive.files.wordpress.com/2012/03/informationquantumphysics.pdf>.

[2] "Are You Living in a Computer Simulation?" Originally in *Philosophical Quarterly*, 53 (2003), pp. 243-255. Available at Bostrom's Web site, <http://www.nickbostrom.com/>.

[3] David Lewis, *On the Plurality of Worlds* (Oxford: Blackwell, 1986); *Philosophical Papers* (New York: Oxford University Press, 1983), esp. pp. 21-25. See also Brian Weatherson, "David Lewis", section 6, in the online *Stanford Encyclopedia of Philosophy*, at <plato.stanford.edu/entries/david-lewis>. See also Robert Nozick, *Philosophical Explanations* (Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1981), pp. 115-142. See also Max Tegmark, "Parallel universes" in John D. Barrow, Paul C. W. Davies, and Charles L. Harper, Jr., eds., *Science and Ultimate Reality* (Cambridge, U.K.: Cambridge University Press), 2004), pp. 459-491.

[4] Roger Penrose, "Forward" to *A Computable Universe*, p. 11-12. Available at <http://matrioshkaworld.blogspot.com/2012/06/roger-penrose-forward-to-computable.html>.

[5] See footnote 3 above.

[6] "Universe from bit" in Paul Davies and Niels Henrik Gregersen, eds., *Information and the Nature of Reality* (Cambridge, U.K.: Cambridge University Press, 2010), pp. 65-91.

[7] *Programming the Universe* (New York: Alfred A. Knopf, 2006), pp. 165-166.

[8] "Universe from bit" in *Information and the Nature of Reality*, pp. 84-86.

[9] <http://en.wikipedia.org/wiki/Timeline_of_quantum_computing>

[10] *Programming the Universe*, p. 53. See pp. 51-53.

[11] "Universal Quantum Simulators", p. 1073. Originally in *Science*, N.S. 273 (August 23, 1996). Available at <http://research.physics.illinois.edu/DeMarco/lloyd%2096%20paper.pdf>.

[12] pp. 1-2 above.

[13] *Discourse on Metaphysics*, trans. George R. Montgomery, revised by Albert R. Chandler, secs. V, VI; in Monroe C. Beardsley, ed., *The European Philosophers from Descartes to Nietzsche* (New York: The Modern Library, 1960), p. 255.

[14] Available at <http://web.mit.edu/esd.83/www/notebook/Complexity.PDF>.

[15] Boston: Houghton Mifflin Company, 1987.

[16] *The Emperor's New Mind* (New York: Oxford University Press, 1989), pp. 302-347. *The Road to Reality* (New York: Alfred A. Knopf, 2005), pp. 686-734.

[17] Raphael Bousso, "The holographic principle", at <http://arXiv:hep-th/0203101v2>. Jacob D. Bekenstein, "Information in the Holographic Universe", *Scientific American*, 289 (August, 2003), pp. 58-65.

[18] "The holographic principle", p. 1.

[19] "Information, Physics, Quantum: The Search for Links", pp. 309-311, 320.