



It, Bit, and Us

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Somewhat like the physicist with his field theory and his particle theory, we can have it both ways. To say that every right version is a world and to say that every right version has a world answering to it may be equally right even if they are at odds with each other. Moreover, talk of worlds and talk of right versions are often interchangeable.

Nelson Goodman, Starmaking.

1 Introduction

Clockwork analogies have played a strong role in the development of science and our understanding of it. So let's begin with a novel one: is the world like a Casio watch or a Rolex watch? That is, does it exhibit fundamental graininess and tick away in discrete steps, or does it flow smoothly? Is it digital or analogue? The analogy is a good one for our purposes because as with watches, at the root of the problem—"Is Reality Digital or Analog?"—is the issue of *representation*, and as with watches, it isn't clear whether there really *is* anything *in the world* being represented.

I'll argue that the question is a coherent one (once we have established the meanings of the terms), but one that quickly leads us into very deep metaphysical and epistemological waters, many of them standard problems of philosophy.¹ In particular, we face the mutual relationships between the physical world ('it'), our means of engaging with it ('bit'), and our own minds ('us'). We are able, however,

¹There is a sense in which the question, taken at face value, has a very obvious answer: reality is *both* digital and analogue. For example, it is well known that a Fourier transformation can map between discrete and continuous time, or between wave-like and particle-like descriptions. So presumably *neither* is fundamental: they are *dual*. However, this is too superficial a reading. In posing the question in terms of "analogue" and "digital" we are clearly directing the discussion at issues of information, not simply discreteness versus continuity.

to extract a coherent (if hard to stomach) view about the role of mind in the world. By way of scene-setting we begin with some prehistory of the problem.

2 Prehistory

Our question possesses a very rich history, with an ancestry tracing at least as far back as Pre-Socratic cosmology (see [13]). Atoms are the archetypical digital entities. They are discrete, distinct, identifiable, countable, individuals, of different shapes and sizes. The atomists, Leucippus, Democritus and Epicurus defended their *digital* worldviews on broadly philosophical, rather than physical grounds. That is to say, their atomism (or ‘digitalism’) was a *conceptual* one, implying that not even in thought could one conceive of dividing primitive atoms into more fundamental components. Their atoms were ‘without void,’ and without void it is not even metaphysically possible to have splitting: there is no way to turn *one* into *many*. However, though they espoused material atomism, their overall view was dualist, involving a continuous space and time in which the atoms moved. Diodorus Cronus went further in his atomism, arguing that there exist atoms of space and time too. In both cases, conceptual problems of infinity, motion, and change underpinned their theories.

The Stoics, by contrast, defended an *continuous* worldview, based on the idea that infinite division was at least a conceptual possibility. Aristotle too defended a similar position, though he also accepted into his inventory of ‘worldstuff’ discrete entities, such as those constructed as *limits* (e.g. boundaries of objects and instants of time bounding temporal intervals). The Stoics were, like the Diodorians, more thoroughgoing in their position, and outlawed all discreta from their inventory: boundaries and such like were penumbral, shadowy entities but no less continuous. Both models, continuous and discrete, were just that: attempts to represent the observable (and, by extension, *unobservable*) world via a coherent, consistent system of thought. The system of thought that results is a representation of the hypothesized features of the world, in the one case it will be natural (if one wants to closely mirror the purported nature of things) to employ a digital representation, in the other an analogue representation.

How have matters altered since these embryonic approaches? Now, of course, there is the claim that whereas earlier debates were metaphysical the question has since developed a more *scientific* basis and one at which the tools of mathematics can be directed. There are several ways to understand this: (1) as a claim about the discreteness (or not) of space, time, and matter; (2) about the *computational* nature

of the universe. The former extends the older debate mentioned already, and its ancestor is the debate between proposals that aim to discretise space, time, and matter versus those that view fields (on a continuum) as fundamental. The latter is a relatively recent addition, of course, since it required the introduction of computers and information theory—though we might treat Leibniz as espousing a kind of forerunner. Konrad Zuse is perhaps the first to apply digital computation to ontology, arguing that the universe is itself a giant finite-state automaton. But the most famous expression of the idea is encapsulated in Wheeler’s enigmatic phrase: “it from bit”. The idea is the same: ontology (‘what there is’) from information, rather than some ‘concrete stuff’. We turn to Wheeler’s view in §4; first we get to grips with the central terms.

3 Us and Bit

“Digital” roughly corresponds to “discrete,” though digital has further representational connotations: the digital states *mean* something. For example, traffic lights constitute a digital system, with three possible states (in the UK at any rate), that have the meanings ‘Stop,’ ‘Go,’ and ‘About to change’. It is, however, perfectly possible to model a continuous process or system using a digital model, and likewise, a discrete process using an analogue model. Analogue representation usually proceeds by using a physical magnitude to do the representing. One might think here of the distinction between a digital processor and a neural network. Analogue models are usually dense: between any two states there will be another state, and for any state, there will be no *next* state. But, again, I might easily provide an analogue model of a discrete process. The traffic lights might be represented by a dial that has to move over some space to get between ‘Red,’ ‘Green,’ and ‘Amber’. Moreover, as cellular automata models indicate, we can model continuous processes, such as avalanches, using discrete models. Often the assumed denseness of an analogical model is parasitic on the assumed dense nature of the process or object functioning as the model.

Following Nelson Goodman [6], John Haugeland [8] focuses the definition of digital on *distinguishability* and *reproducibility*.² On this view chess is digital since configurations can be distinguished and perfectly repeated, at least in the abstract

²Nelson Goodman distinguished between digital and analogue representations by characterising the former as a system that is “differentiated” (it can be ‘marked’) while the latter is not, being dense. David Lewis [9] later showed how Goodman’s distinction failed to latch on to the standard understanding of discrete and analog, since he was able to show how there can be analogue representation that are differentiated and non-dense. See [10] for more on this debate.

sense (there might be slight differences in the exact positions of the pieces on the board). But this example requires that we have agreed on the *rules* of chess, and that the configuration (and the pieces and their relationship to the squares) *means* something. To be digital is to encode something meaningful and communicable. There is no such thing as digital *simpliciter*. This is just to repeat what I said previously: the question “Is reality digital or analogue?” concerns representation, and representation involves intentional systems (of which the human mind is but one example). We turn now to what lies ‘beyond’ the representation, it’s (or the mind’s) supposed target.

4 It and Bit

It from bit. Otherwise put, every ‘it’—every particle, every field of force, even the spacetime continuum itself—derives its function, its meaning, its very existence entirely—even if in some contexts indirectly—from the apparatus-elicited answers to yes-or-no questions, binary choices, bits. ‘It from bit’ symbolizes the idea that every item of the physical world has at bottom—a very deep bottom, in most instances—an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes-no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a participatory universe. ([16], p. 5).

Ontology, as philosophers use the term, is about *what there is*. They usually mean this in a deeper sense than most scientists, who might simply mean what is contained in our physical universe. Like physicists, philosophers might worry about whether there are quarks, and whether they are truly elementary, but they will also worry about whether there are numbers, possibilities, past and future events, and so on. They need to worry about these things since we often speak about *mathematical truths*, about *what might have been*, and about what *was* and *will be*. Usually if something is true or false, there is something that *makes* it so. So ontology includes thinking about these ‘truth makers’. What Wheeler is considering, however, is the idea that we often have a hand in this truth making enterprise, at a deep level supposed out of bounds by most scientists, and even most philosophers. For Wheeler, in an important sense, epistemology precedes ontology: bit precedes it.

How are we supposed to get from bits to its? Recall that a bit is the standard unit of information: the amount of information one can extract from a ‘Yes/No’ question. This is a particular type of digital system, a binary one, that maps nicely

onto truth values—a matter that was essential to Wheeler’s view. ‘It from bit’ was part of a larger overarching scheme stemming from a radical understanding of the Copenhagen interpretation. For Wheeler, in order to bring about physical reality, one *needs* an observer. The universe is born out of a participatory relationship. Before measurement by an observer, there is no physical reality: there is no such thing as a no phenomenon until it is an observed phenomenon.³ His delayed choice experiment exposed this feature in a vivid way [15]. The idea is that until an observation (a choice) is made, past events are not definite. When a decision is made, then it *becomes* the case that the past takes on a specific value. This is somewhat different from the Copenhagen Interpretation since according to that it does not make sense to speak of the state of a system prior to measurement. Here, it does, so long as one has made an appropriate measurement choice: histories are ‘constructed’ by choices. But the ability to ‘construct’ here is not unrestrictedly pliable: the extent is firmly circumscribed by the rules of QM.⁴

One can find several versions of this position in the literature. Of particular note, in terms of the digital aspects of Wheeler’s position, is Carl von Weizsäcker’s [14] theory of ‘Ur-elements’, based directly on the view that the predictions of physics (and science in general) can be reduced to such atomic binary alternatives. He too conceived this in terms of ‘atoms of information’—pre-qubits I might add. In terms of the ‘participatory aspects,’ Arthur Eddington is a clear forerunner. In his brief, though penetrating study of ‘Eddington’s Principles,’ Edmund Whittaker describes Eddington’s view in a way that has much in common with Wheeler’s “participatory universe”:

The fact that changes in our material universe can be predicted—that they are subject to mathematical law—is the most significant thing about it, for mathematical law is a concept of the mind, and from the existence of mathematical law we infer that our minds have access to something akin to themselves that

³Schrödinger puts the same point in slightly weaker terms: “The most perfect record, when not inspected, tells us nothing” [12].

⁴Note that this is not something that can only occur on small timescales. Wheeler himself conjectured a ‘cosmic double slit experiment’ in which the photon is making its way from the early universe, and engaging in various interactions. One can even envisage the use of planetary masses as diffraction gratings, enforcing superpositions of just the right kind. This way, too, given the interplanetary distances, one can be sure that there is no possibility of communication between particles, screens, and grating. One can imagine millions of light years of separation, translating to many million years in our pasts. Still, our experimental decision will determine the particle’s entire history back to the grating. (The free will theorem of Kochen and Conway is a version of this, showing that a particles’ response to a certain type of experiment is not determined by the history of that part of the universe to which they have access.)

is in or behind our universe. ([11], p. 230)

Eddington labeled his position *selective subjectivism*, a view grounded in “the operation of observing acting upon something objective”. This is a heavily Kantian view of the nature of physical theories that puts human experience at the root of physical theories and scientific knowledge of the world. As he puts it, “[t]he [logical] starting point of physical science is knowledge of the group-structure of a set of sensations in a consciousness” [2]. The knowledge so generated is entirely *structural*, and this structure marks the limit of what we can know. But note that the structure comes essentially from us: we have selected what to focus on, filtering out other possibilities.

I believe that Eddington, Wheeler, and von Weizsäcker share the same core vision, and this is one of an intensely human (or at least *intentional-system-centric*) element to knowledge of the physical universe. Though not in the sense of so-called “social constructivists,” whereby there is enormous plasticity in the possible constructions that one can envisage; rather, in a highly constrained sense. Just as our eyes are highly selective, on account of their adaptation to a relatively narrow, though optimal band, so are our theories. Theories about the physical world inescapably bear our imprint; they are constructed to account for *our* experience.

5 Us and It

In his much maligned *Relativity Theory of Protons and Electrons* Eddington writes the following passage, sure to make most present-day physicists wince:

An intelligence, unacquainted with our universe, but acquainted with the system of thought by which the human mind interprets to itself the content of its sensory experience, should be able to attain all the knowledge of physics that we have attained by experiment. ([4], p. 3)

Though it seems to smack of anti-empiricism, one can see through this, and when one does, it becomes *ultra*-empiricist. The passage expresses the idea that our theories constitute systems of thought ultimately devised to account for what we observe. Thus understood it is almost a platitude. Physical science constructs a ‘physical universe’ to account for the results of observations, experiment, and measurement. The physical universe consists of physical *quantities* and it is precisely these that are grounded in observation. Eddington [3] defended a view whereby one can learn an awful lot by inspecting not the world, but our means of

engaging with the world: our sense organs and our ways of thinking. He thought we could derive the fundamental constants (or rather their ratios: pure numbers) *a priori*. Repeating his “intelligence” story above, he writes:

[T]here is nothing in the whole system of laws of physics that cannot be deduced unambiguously from epistemological considerations. An intelligence, unacquainted with our universe, but acquainted with the system of thought by which the human mind interprets to itself the content of its sensory experience, should be able to attain all the knowledge of physics that we have attained by experiment. He would not deduce the particular events and objects of our experience, but he would deduce the generalisations we have based on them. For example, he would infer the existence and properties of radium, but not the dimensions of the earth. ([4], p. 327)

Since these constants can determine Length, Mass, and Time, they can determine all physical quantities (since physical quantities can be re-expressed as combinations of L, M, T). Hence, for Eddington we can derive the whole physical universe from pure thought. Moreover, since G , c , and h are involved in a crucial way (and must appear together), quantum and gravity (continuity and discreteness) were inextricably linked for Eddington.

We model to get a *grip* on the world. Our models can often do so well that we think that the model is a perfect match, so that features of the model are features of the world. But physical theories are always approximations, and there is always inference involved. Digital and analogue models can both serve to represent the physical universe. Whether they have a target in the world is something that cannot be discovered by empirical science. We saw in §3 that the digital or analogue nature of a model or theory cannot be relied upon when it comes to determining the nature of its target. However, the nature of empirical science, and our best theories, *do* seem to contain inevitably discreteness, and this goes back to features already seen in our discussion of Wheeler and Eddington. We finish with a brief discussion of this aspect, which highlights an inevitable digitalisation in the ‘It-Bit-Us’ link.

6 A Tale of Two Measurement Problems

A pure quantum world would be dead.

Blanchard and Jadczyk

Quantum mechanics is standardly presented in terms of the probabilities of experimental outcomes. The pure quantum algorithm does not have actual, definite events, though we seem to *experience* these. This is the measurement problem in capsule form. It is clearly a problem involving the relation between it, bit, and us. Position measurements do not measure the position that a particle was existing at, but in some sense ‘creates’ a correlation between a particle and a detector. Such discrete events form the foundations for theory-building. Rudolph Haag [7] has argued that objects as continuants (things that continue exist over dense intervals of time, that *persist*) are largely inferential. They constitute what he calls “causal ties” linking the discrete events that form the real data of our experience and that breathe life into the quantum world. Theory, according to Haag, consists in finding models for predicting the properties of such events (in the future) from the properties of other events (in the past). In this sense, fields are inferences just as much as particles.

All we have to go on in science (once we abstract the contribution of our qualitative experiences or ‘sensates’) is pointer-readings, the record of some interaction, and the relationships between such entities. These take the form of coincidences, say of the bringing into coincidence of the origin of a ruler and some other mark on the ruler and some object. This is a basic feature of science. Even the notion of a single object, with properties independent from some coincidence, is purely inferential. We must always invoke some other object if we wish to observe it. Hence, what is observable is, strictly, a coincidence or correlation between at least two objects. In fact, as Eddington pointed out, though a coincidence between two things constitutes an observable, a “measurable” requires four. We also have relations between distinct observables (such as measurements) and between distinct measurements (and more complex groupings). These form the basis of the pattern-finding aspect of science. This combined system is a coincidence quantity. It is invariant and primitive, and it has the properties of an event. The links between pointer readings form the data for physical laws. Again, laws are inferences (in this case of a radical kind, covering infinitely many unobserved cases).

All physical theories are, in this sense, approximations: they go beyond what is observed (namely, discrete events). Expecting more of them (expecting them to provide literal descriptions of reality) is what leads us into difficult paradoxes. Beyond these events, all else is inference. We can infer a model of the world that is able to unify a varied jumble of data, bringing it into order. Or a model that can predict what will happen to some pointer-reading. We can impose other conditions on the kinds of models we want, such as beauty, simplicity, and so on. But in the end it is inference.

There is a related measurement problem in the context of the gauge theories, forming our best theories, and the nature of quantities in such theories. Observables here are those functions that are gauge-invariant (i.e. invariant under a variety of operations known as ‘gauge transformations’). Other gauge-variant quantities can be formulated in an abstract sense, but will not form part of what is measurable, for a measurable demands another (gauge-variant) quantity that is brought into some correlation with the original, and this *bringing together* relation forms a gauge-invariant quantity. Hence, as in quantum mechanics, so too in gauge theories: the basic elements are discrete events involving observations. But to go from this to the view that ‘the world beyond’ these events shares the same characteristics is a bridge too far: we select this discrete structure in virtue of our means of interacting with the world. Inasmuch as we are engaging directly with the world, it is via its relational structure. Perhaps, then, if one desires a theory that is able to describe *it* without *us*, then one will have to jettison the standard empirical methods of science and the baggage it carries; but one will also have to jettison *bit*, which also bears our traces.

7 Conclusion

At the heart of everything is a question, not an answer. When we peer down into the deepest recesses of matter or at the farthest edge of the universe, we see, finally, our own puzzled faces looking back at us.

John Wheeler⁵

The physical world, in the sense of that which matches the description provided by physical theories, is as digital or analogue as the theories themselves. Since there is no logical necessity either way, both are possible, and it seems perfectly possible for reality to be described by a dual system. ‘Reality itself,’ by which I mean whatever it is that physical theories try to latch on to, might be either or, more likely, something inscrutable: it seems unlikely that intentional-system-centric notions would have counterparts in reality, independently of minds. Inasmuch as our minds *are* capable of latching physical theories onto reality, the best that can be hoped for is a purely structural/relational matching and in this sense reality *is* digital, for our linchpins are precisely discrete, identifiable events, be they the elementary bits of Wheeler, or the elementary correlations of gauge theory.

⁵Cited in John Horgan, *The End of Science*, p. 84 (Little, Brown & Company, 1998).

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