A new revolution in physics

Russell K. Standish

March 5, 2001

Just over 100 years ago, Max Planck[10] published a paper that ushered in one of the biggest revolutions in science, known to us as *Quantum Theory*. Not that anyone knew it at the time — particularly Planck himself. In true millenarian spirit, perhaps its time for another revolution. What will science in the 21st century be like?

Whilst I humbly recognise that true revolutions are impossible to predict, I'd like to suggest a particular line of research, that if it lives up to its promise, will profoundly shape our understanding of physics.

Over the last decade, or so, it has become fashionable to posit a host of "parallel" universes. This was first done seriously as an interpretation of quantum mechanics, known as the *Many Worlds Interpretation* (MWI)[4]. Later, as the *Anthropic Principle*[1] was being developed, it was used as a way of explaining the observed fine tuning of physical constants without needing to appeal to a devine creator. The anthropic principle is normally expressed in two forms: the weak and the strong forms. The weak form says that the universe will be found to have properties consistent with our existence, but that it may well have had different properties, in which case we would be different. In the strong form, the universe must have precisely the values of physical constants it has in order for observers to exist at all. A number of well documented cases of this so called fine tuning can be found in [1].

The first person to start thinking of grander uses of parallel universes is probably David Deutsch[5]. In his book *Fabric of Reality*, he emphatically argues in favour of the MWI, and coins the name *Multiverse* to refer to set of all such parallel universes. Since his intention was that the Multiverse be described by a single "wavefunction of the universe", I shall use the term to refer to those universes obeying the laws of quantum mechanics. As we shall see later, it is interesting to examine the possibility of other worlds that obey different rules, or even no rules at all. Deutsch also speculates on the ingredients of a *Theory of Everything* (TOE), which he thinks will contain:

1. the Multiverse,

2. Darwinian evolution

3. Information theory and
4. Popperian epistimology.

The Multiverse turns out to have some very important implications for biological evolution[13], but interestingly, when viewed appropriately, the laws of physics turn out to have an evolutionary character. The Multiverse supplies the variation, upon which the Anthropic Principle acts as a selection process.

More recently, Max Tegmark[16] suggested that the TOE would be nothing other than an ensemble theory (the ensemble of mathematically consistent theories), but that only those mathematical theories admitting *self aware substructures* (ie conscious beings) are of interest. In other words, only those systems satisfying the Anthropic Principle are of interest for deriving physics as we know it. In his fairly lengthy paper, he reviews what constraints are already known to be due to the Anthropic Principle. The Multiverse is the result of unfolding one particular mathematical theory — namely that of Hilbert spaces. The Tegmark ensemble is already bigger than the Multiverse.

An alternative ensemble was proposed by Schmidhuber[11, 12], namely the ensemble of all programs, as interpreted by a particular universal Turing machine (UTM) (a sort of model abstract computer). If we interpret the Tegmark ensemble as the ensemble of all consistent formal axiomatic systems, then a formal system can be represented by a program that that enumerates all theorems of that system. However, not all programs will generate consistent formal systems, so the Schmidhuber ensemble is bigger again than the Tegmark one. A curious note is that Schmidhuber ensemble, with its associated UTM is a consistent formal axiomatic system, and so the Tegmark ensemble contains the Schmidhuber one as an element. The Schmidhuber ensemble is also known to contain itself.

The big advantage of the Schmidhuber ensemble is that it naturally admits a measure (called the *Universal Prior*). The reason this is important, is that if we're selecting elements at random from this ensemble, some elements are more likely than others. We would have to assume that the universe we inhabit is generated by a highly likely program, consistent with the existence of a self aware substructure, according to this measure. This principle goes by the name of the *self sampling assumption* (SSA)[2].

Making touch with ancient philosophical traditions, these ensembles of formal structures that are equally "real" are reminiscent of Plato's *ideal forms*. Hence we often use the term *Plenitude* to refer to one or other of these ensembles.

Just over a century ago, Ernst Mach founded a school which has become known to us as *logical positivism*. In effect, this asserts that all we can ever really know about reality is descriptions of that reality. These descriptions may have varying degrees of correspondence with what is known empirically, but poor descriptions tend to be weeded out in favour of good descriptions by a Popperian style evolutionary process.

Let us take a plenitude of descriptions, which can always be represented as a bitstring (possibly infinite in length). However, what do we take as our universal Turing machine? There don't appear to be any natural choices here. However, taking logical positivism to its extreme, there will always be at least one observer to consider. We assume that this observer has a finite number of mental states. The observer is mapping an infinite number of descriptions onto a finite set of states — a many to one mapping. Each description will be equivalent a fraction of the total number of descriptions, which gives a natural probability measure over the descriptions relative to that observer. It turns out that this probability is inversely related to the complexity of the description[14], hence Occam's razor[15]:

If you accept the creed of *computationalism* (ie all concsious entities can be simulated on a computer), then this plenitude is equivalent to Schmidhuber's with the universal prior.

So far, our *Theory of Everything* is little more than Feynman's spoof[6, §25-6]. He said that he had a theory of everything (not that he used that term) that could written down as a single equation $U = 0$, where U is *unworldliness*. What is unworldliness? How does one compute it? Suppose one takes the law $F = ma$ and rewrite it as $F - ma = 0$. Then the term $U_1 = (F - ma)^2$, which should of course be zero, can be a measure of the "unworldliness" of mechanics. Similarly, $U_2 = (F - Gm_1m_2/r^2)^2$ could be called the unworldliness of gravitation. Sum all these possible terms together to get U.

What is needed is to apply the Anthropic Principle to whittle out those descriptions likely to be observed. Unfortunately, this is skating dangerously close to the problem of consciousness, which has proved a quagmire of intellectual debate. The Anthropic Principle has been quite rightly criticised[3] as a non-predictive, wishy-washy handwaving explanation, perhaps little better than invoking deities and mysticism, for this very reason.

So lets try a physicist's approach, which is to assume a few, fairly uncontroversial things about consciousness, without pretending to know the full story, and see how far this gets us. Let us assume two things in particular — that the observer *observes* by selecting a partial description from the ensemble, and that there is a psychological experience of time in order to do the observations. If one additionally assumes the standard axioms of probability theory, and then crank the handle, Schrödinger's equation pops out, along with most of the structure of Quantum Mechanics[15]!

Surprising as this result may be, two other scientists have independently come to similar conclusions, each with a slightly different set of starting ingredients. Bruno Marchal[8, 9] started by assuming a particular form of computationalism, as well as what he calls *Arithmetic Platonism* (essentially a plenitude structure like above), and strong form of the *Church Turing thesis*, and ended up predicting that the observers knowledge should obey quantum logic. Roy

Frieden[7] started with an observer embedded in 4-D Minkowski space-time, and asked what happens out of game where nature tries to hide its true reality from the observer. Probability theory enters through the concept of *Fisher Information*. In the most general form of the problem, he ends up with the Klein-Gordon equation, a covariant form of the Schrödinger equation. It is as if, in the words of Marchal, “Physics is but a branch of (machine) psychology”. Even though each of these efforts are tentative, and the details differ, there does seem to be an “elephant” that blind men are discovering.

The observer was seen to be an integral part of physics as a consequence of quantum mechanics. Do we have the courage to complete the journey and realise that the physics is defined by the observer?

References

[1] J. D. Barrow and F. J. Tipler. *The Anthropic Cosmological Principle*. Clarendon, Oxford, 1986.

[2] Nick Bostrom. *Observational Selection Effects and Probability*. PhD thesis, Dept. Philosophy, Logic and Scientific Methods London School of Economics, 2000. http://www.anthropic-principle.com/preprints.html.

[3] Marcus Chown. Out in the cold. *New Scientist*, 166(2242):32, 10th June 2000.

[4] Bryce de Witt and R. Neill Graham. *The Many Worlds Interpretation of Quantum Mechanics*. Princeton UP, 1973.

[5] David Deutsh. *The Fabric of Reality*. Penguin, 1997.

[6] Richard P. Feynman, Robert B. Leighton, and Matthew Sands. *The Feynman Lectures on Physics*, volume 2. Addison Wesley, 1964.

[7] B. Roy Frieden. *Physics from Fisher Information: a unification*. Cambridge UP, Cambridge, 1998.

[8] Bruno Marchal. *Calculabilité*. PhD thesis, Université de Lille, 1998. http://iridia.ulb.ac.be/~marchal/.

[9] Bruno Marchal. Computation, consciousness and the quantum. *Teorie e Modelli*, 3, 2001. to appear.

[10] Max Planck. *Annalen der Physik (4)*, 4:553, 1901.

[11] Jürgen Schmidhuber. A computer scientist's view of life, the universe and everything. In C. Freska, M. Jantzen, and R. Valk, editors, *Foundations of Computer Science: Potential-Theory-Cognition*, volume 1337 of *Lecture Notes in Computer Science*, pages 201–208. Springer, Berlin, 1997.

[12] Jürgen Schmidhuber. Algorithmic theories of everything. Technical Report IDSIA-20-00, IDSIA, Galleria 2, 6928 Manno (Lugano), Switzerland, 2000. arXiv:quant-ph/0011122.

[13] Russell K. Standish. Evolution in the Multiverse. *Complexity International*, 7, 2000. http://life.csu.edu.au/ci.

[14] Russell K. Standish. On complexity and emergence. *Complexity International*, 2001. submitted. arXiv:nlin.AO/0101006.

[15] Russell K. Standish. Why Occam's razor? *J. Theoretics*, 2001. submitted. arXiv:physics/0001020.

[16] Max Tegmark. Is "the theory of everything" merely the ultimate ensemble theory. *Annals of Physics*, 270:1–51, 1998.