Why do we live in a quantum world?

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Anybody who has ever studied quantum mechanics knows that it is a very counter-intuitive theory, even though it has been an incredibly successful theory. This paper aims to remove this counter-intuitiveness by showing that the laws of quantum mechanics are a natural consequence of Konrad Zuse's and Edward Fredkin's digital universe hypothesis combined with classical Newtonian mechanics. We also present a possible way to test the digital universe hypothesis.

1 Introduction

The great and famous physicist Richard Feynmann once said, "I think I can safely say that nobody understands quantum mechanics." [4] He said this not because he thought scientists were incapable of understanding how to apply the laws of quantum mechanics to make predictions about experiments, but because quantum mechanics is a very counter-intuitive theory; there are many paradoxes associated with quantum mechanics [2] and many ways to interpret quantum mechanics as well [3]. The aim of this paper is to completely remove counter-intuitiveness from quantum mechanics by showing that the laws of quantum mechanics are a natural consequence of Konrad Zuse's and Edward Fredkin's digital universe hypothesis combined with classical Newtonian mechanics. We also present a possible way to test the digital universe hypothesis.

2 Digital physics

Zuse's and Fredkin's digital universe hypothesis can be summarized with four laws [5]:

1. Information is conserved.
2. The fundamental process of nature must be a computation-universal process.
3. The state of any physical system must have a digital representation.
4. The only kind of change is that caused by a digital informational process.

So in a nutshell, the digital universe hypothesis is that all of our universe is the output of a computer program. This is a radical departure from contemporary physics, which is based on the assumption that space-time is continuous, not discrete. As Edward Fredkin said, "From a Digital perspective, contemporary models of fundamental physics are a bit like looking at an animated cartoon while assuming that it is reality; that the images are moving continuously." [5] So if our universe is the result of a computer program, then Who is the programmer? Digital physics does not address this question.

If the digital universe hypothesis is correct, does this imply that all of contemporary physics is wrong? The answer to this question depends on one's definition of "wrong": If "wrong" means that the equations of contemporary physics do not completely describe our universe, then yes, contemporary physics would be wrong if the digital universe hypothesis is correct. But if "wrong" means that the equations of contemporary physics do not predict the results of experiments done in the real world, then no, contemporary physics would not be wrong, since contemporary physics does a great job of predicting the results of many experiments done in the real world.

3 Classical physics on a computer

The position and momentum of particles play a central role in classical Newtonian mechanics, as we can see from Hamilton's equations,

$$\frac{\partial H}{\partial x_i} = -\frac{dp_i}{dt}, \tag{1}$$

$$\frac{\partial H}{\partial p_i} = \frac{dx_i}{dt}, \tag{2}$$

for $i = 1, 2, 3$, where H is energy, t is time, (x_1, x_2, x_3) is position, and (p_1, p_2, p_3) is momentum. Suppose that our universe is a digital universe which attempts to simulate the laws of Newtonian mechanics as best as it can, given the limitation that it would only have a finite number of bits available to specify the position and momentum of each particle. There is no reason why the computer which generates such a universe would not be able to borrow bits associated with the momentum of a particle to specify its position with greater precision or to borrow bits associated with the position of a particle to specify its momentum with greater precision. On such a computer, precision in position would be inversely proportional to precision in momentum.

Hence, we would obtain the following inequality, where Δx is uncertainty in position, Δp is uncertainty in momentum, and $\hbar$ is a constant:

$$\Delta x \cdot \Delta p \geq \hbar/2. \tag{3}$$

If the reader hasn't noticed already, this inequality is Heisenberg's Uncertainty Principle. Now consider the fact that in 2001, Michael Hall and Marcel Reginatto derived Schrödinger's equation,

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{m}\nabla^2\psi + V\psi, \tag{4}$$

from an exact version of Heisenberg's Uncertainty Principle combined with the assumptions of classical Newtonian mechanics [7]. Then since Schrödinger's equation is the fundamental equation of quantum mechanics, we have completely removed counter-intuitiveness from quantum mechanics by showing that the laws of quantum mechanics are a natural consequence of Zuse's and Fredkin's digital universe hypothesis combined with classical Newtonian mechanics.

Can the hypothesis that our universe is digital be tested or is it just a nice way to remove counter-intuitiveness from quantum mechanics? The answer to this question is "possibly, yes". To understand how, we must understand the concept of *quantum computing*.

4 Quantum computing

A quantum computer is any computing device which makes direct use of distinctively quantum mechanical phenomena, such as superposition and entanglement, to perform operations on data. As of today, nobody has ever built a large-scale quantum computer; however, much is known about the theoretical properties of quantum computers. For instance, quantum computers have been shown to be able to efficiently solve certain types of problems, like factoring large integers, which are believed to be very difficult to solve on a classical computer, e.g., a desktop computer or a Turing machine [6]. The *extended Church-Turing thesis* is the assertion that any mathematical function that is efficiently computable in the natural world is efficiently computable by a classical computer. Therefore, if a large-scale quantum computer ever gets built and it is indeed impossible to efficiently factor integers on a classical computer, then the extended Church-Turing thesis would be false. And if large-scale quantum computers are impossible in principle to build, this would mean that quantum mechanics needs to be modified. The quantum computer expert Scott Aaronson summed it up as follows: "Either the Extended Church-Turing Thesis is false, or quantum mechanics must be modified, or the factoring problem is solvable in classical polynomial time. All three possibilities seem like wild, crackpot speculations - but at least one of them is true!" [1]

Many scientists are of the opinion that building a large-scale quantum computer is impossible; in fact, the great complexity theorist, Leonid Levin, wrote: "QC of the sort that factors long numbers seems firmly rooted in science fiction. It is a pity that popular accounts do not distinguish it from much more believable ideas, like Quantum Cryptography, Quantum Communications, and the sort of Quantum Computing that deals primarily with locality restrictions, such as fast search of long arrays. It is worth noting that the reasons why QC must fail are by no means clear; they merit thorough investigation. The answer may bring much greater benefits to the understanding of basic physical concepts than any factoring device could ever promise. The present attitude is analogous to, say, Maxwell selling the Daemon of his famous thought experiment as a path to cheaper electricity from heat. If he did, much of insights of today's thermodynamics might be lost or delayed" [8].

Can a large-scale quantum computer that can efficiently factor integers ever be built? According to quantum mechanics, the answer is "yes, in principle". But according to the hypothesis of a digital universe, the answer is "no", assuming that it is impossible to efficiently factor integers on a classical computer. So in principle, there is a way to test the digital universe hypothesis, if it is impossible to efficiently factor integers on a classical computer: If one successfully builds a large-scale quantum computer, then the digital universe hypothesis is false and the extended Church-Turing thesis is false. And if one does everything possible build a large-scale quantum computer but is still unsuccessful in building one, then the digital universe hypothesis is confirmed, and the laws of quantum mechanics are only a useful approximation to the real world that do not always hold true.

References

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