Five big questions with pretty simple answers

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Under the roof of one controversial assumption about physics, we discuss five big questions that can be addressed using concepts from a modern understanding of digital informational processes. The assumption is called ***finite nature****. The digital mechanics model is obtained by applying the assumption to physics. The questions are as follows:*

1. *What is the origin of spin?*
2. *Why are there symmetries and CPT (charge conjugation, parity, and time reversal)?*
3. *What is the origin of length?*
4. *What does a process model of motion tell us?*
5. *Can the finite nature assumption account for the efficacy of quantum mechanics?*

Digital mechanics predicts that for every continuous symmetry of physics there will be some microscopic process that violates that symmetry. We are, therefore, able to suggest experimental tests of the finite nature hypothesis. Finally, we explain why experimental evidence for such violations might be elusive and hard to recognize.

Introduction

At a symposium in honor of Heisenberg's 100th birthday, Frank Wilczek said: "Heisenberg's motivation for studying physics was not only to solve particular problems, but also to illuminate the discussion of broad philosophical questions" [1]. I'd like to share certain insights with regard to broad philosophical questions that are not yet in the collective physics consciousness. It is often said that around the turn of the century (19th to 20th), there was a crisis in physics. However, the "crisis" is not apparent from the physics literature of the period. There may be another such crisis today, but so far it hasn't caused significant concern. The crisis briefly stated is that the reasonably mature constructs of theoretical physics, dominated by differential equations, are basically incompatible with the brash and immature theories of digital computational processes in which the only formalism, automata theory, is of little use. What we mean by "incompatible" is that what we have so far learned about digital informational processes seems to imply that many accepted concepts and laws of physics are informational impossibilities. All of these conflicts are resolved if the finite nature (FN) assumption is valid.

Finite nature [2] encompasses the following assumptions:

- At some scale, space, time, and state are discrete.
- The number of possible states of every finite volume of space–time is finite.
- There are no infinities, infinitesimals, or locally generated random variables.
- The fundamental process of physics must be a simple deterministic digital process.

The progress of physics has been marked by a train of discoveries that various entities are discrete: atoms and

Note: The ideas in this paper were the basis of a talk presented in May 2003 at a symposium at the IBM Thomas J. Watson Research Center in Yorktown Heights, New York, honoring Charles Bennett on the occasion of his sixtieth birthday. The style and form of this paper have been brazenly borrowed from the written version of Frank Wilczek's talk "Four Big Questions with Pretty Good Answers" presented at a symposium in honor of Heisenberg's 100th birthday (December 6, 2001, Munich). In addition, parts of a few sentences are slavishly copied and themes are nearly plagiarized (except that credit is hereby given to Wilczek [1] for every such instance). Originality on the part of the author can be found in all of the new ideas presented here about physics. Whatever is wrong with this paper can be blamed on no one other than the author.

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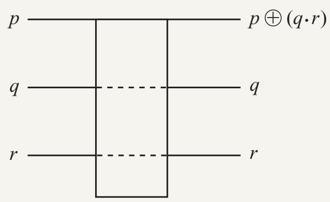

Figure 1

Landauer's reversible gate. If $p = 0$, the output is q AND r; if $p = 1$, the output is q NAND r. In either case, the bottom two gates go straight across. "⊕" means Exclusive-OR; "·" means AND.

particles, charge, light, spin, energy levels, etc. In effect, the FN assumption is that that process will reach its natural conclusion when space, time, state, and all other properties of physics are found to be fundamentally discrete. It is characteristic of digital mechanics (DM) models that the number of possible states of each point in space–time is a small integer; in this paper we assume it is 2.

The whole point of this paper is to suggest that there must be another branch of mathematics that deals with physical systems for which the FN assumption is valid; further, that this yet unfamiliar mathematics may be a key to understanding some of the most basic questions in physics. The problem is that trying to apply such a branch of mathematics to discrete physics is a primitive process. The novelty of the methodologies to which this paper pertains makes it difficult to communicate the power and scope of their applicability to fundamental issues in discrete physics.

The new mathematics is rooted in automata theory [3], but that fact doesn't give a clue as to what the new math is. It doesn't yet have a name. It has to do with models of digital informational processes that are physically realistic (in the microscopic sense). For example, all commercial computational devices rely on irreversible, dissipative circuits for many reasons; primarily to minimize the effects of noise. It was once common knowledge that, in practice or in theory, there was no other way to build computers. We now know that that common knowledge was incorrect. Nevertheless, until now, all of the computers that we use have been built using digital logic elements that are inherently irreversible.

We can make a model of a simple aircraft, such as a Piper Cub, where every part of the model and the airplane correspond to each other, one to one. That is not true of a computer model that includes such things as the Microsoft** Windows** operating system and merely represents the aircraft by a few numbers such as total mass, airspeed, and wingspan. DM implies that there is a computer-like model that has a bijective mapping, one to one, from states and function in the real world to states and function in the model. This imposes absolute requirements that the computer-like model be spatially organized like cellular automata, be reversible, and be computation-universal. The most fundamental processes in physics are reversible, and determining that computation is similarly reversible was actually an important problem in theoretical physics. The fact that we can build computers is proof that the fundamental process of physics is computation-universal. The author demonstrated in 1969 that non-*ad-hoc* cellular automata could be computation-universal [4], and in 1974 that fundamental computation was not inconsistent with conservation laws and reversibility by inventing the concept of conservative logic [5].

In his seminal paper in 1961, Rolf Landauer clearly connected the operation of digital logic elements (and thereby all of conventional digital computation) to the realm of physics [6]. In his thesis, Landauer postulates that every operation of a binary circuit has to dissipate an amount of energy no less than Landauer's constant, $\log_e 2kT$, for every bit that is lost in the irreversible operation of that circuit. The k is Boltzmann's constant, and the T is the absolute temperature. This put the most primitive theoretical elements of computation, such as the NAND gate, firmly into the category of thermodynamics. While thermodynamics is certainly a branch of physics, it's not the same as the simpler and more fundamental microscopic processes of physics that are reversible. Landauer had designed a three-input, three-output reversible gate (**Figure 1**) and used it as part of his very convincing (nevertheless wrong) argument that reversible computation was not possible. The so-called conservative logic gate[1] is also a three-input, three-output reversible gate (**Figure 2**) of a different design, and the author used it to show that reversible computation was possible and actually practical! Interestingly, the author just recently discovered that there is a simple circuit of Landauer gates that is fundamentally identical to a conservative logic gate. This shows that Landauer's gate could have been used to prove the opposite of what Landauer attempted to do, but the design of Landauer's gate was sufficiently awkward as to obscure the possibility.

In the early 1970s, first Charles Bennett and then the author independently found ways of demonstrating the counterintuitive result that there are models of universal computation that can be perfectly reversible. Charles Bennett showed that a Turing machine could be made reversible by adding an extra tape that could remember whatever was erased in the operation of a normal Turing

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[1] The conservative logic gate is commonly called a "Fredkin gate."

machine [7]. Similarly, Toffoli subsequently showed that cellular automata (CA) models of computation could be made reversible by adding an extra dimension to remember the states that would otherwise be lost [8]. Bennett and Toffoli demonstrated the falsity of the widely held assumption that universal computation had to be irreversible.

The conservative logic gate serves as a universal logic gate that is reversible while conserving all signaling quantities (1s and 0s). Conservative logic allows for the design and operation of practical reversible computers that do not necessarily have to dissipate heat, because bits are never lost. Through the use of conservative logic, it was possible to demonstrate what Bennett had anticipated, that one could achieve reversible computation in a practical sense without the need to store so many lost bits on a tape.

The author's motivation in demonstrating the possibility of reversible and universal cellular automata models of computation was very different from the apparent motivation of others. If physics (space, time, state, and all other quantities) is finite and discrete, then it should be capable of being modeled bijectively by some such computational process. In addition, fundamental physics is characterized by conservation laws, while the 1s and 0s in ordinary computers are certainly not conserved. When two 1s go into a NAND gate, a single 0 comes out! The so-called conservative logic gate (three inputs and three outputs) was invented to do two things: serve as a reversible gate which would allow for the construction of reversible computers, and at the same time operate in such a way as to microscopically conserve both 1s and 0s. Conservative logic showed that computational models were not inconsistent with time symmetry and the conservation laws that govern the simplest and most fundamental interactions in physics.

Conservative logic led the author to the billiard ball model of computation, based on a simple classical model of interacting billiard balls, with which all general-purpose computers can be implemented. The billiard ball model led to the Feynman–Ressler gate and was also used by Norman Margolus to create the first reversible universal cellular automata system that did not require an added spatial dimension. Additionally, Margolus invented the concept of a two-phase clock and neighborhood rules that were phase-dependent. These concepts have been extended and are an integral part of the so-called Salt model, which is briefly described later in this paper.

Before we get to the meat of the problem, we must explain certain aspects of physics related to digital informational processes as a key to understanding our answers to the five big questions. Imagine being given the task of explaining modern physics to people who have little understanding of mathematics. It is true that Hawking can write a book about physics with essentially no mathematics in it that becomes a best seller. It is doubtful that the few readers of the book (as opposed to the many purchasers) have a usable nonmathematical path to a real understanding of the physics as discussed in English and as presented with pictures. Here we have no choice; neither you, the reader, nor I, the author, understand the mathematics appropriate to the application of the FN assumption to physics because it hasn't been invented yet!

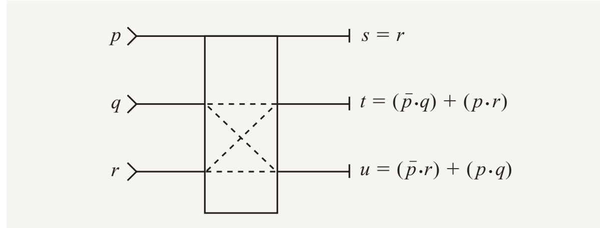

Figure 2

The conservative logic gate. If $p = 0$, q and r go straight across; if $p = 1$, q and r crisscross. In either case, p goes straight across; viz., $s = p$. "·" means AND; "+" means OR.

There is no doubt that information and even digital informational processes are subject to the laws of physics; however, these ideas are not usually incorporated into our thinking about physics or into our current mathematical laws of physics. This forces us to engage in an inordinate amount of hand-waving. We next must digress to introduce some of these new ideas.

Digital mechanics [9]

First, we must explain what is meant by the term *digital informational process* [3]. We borrow from physics the concepts of *state* and *closed system*. At any point in time, a computer[2] is in a particular finite state, which can be specified exactly by giving the state of every bit in the computer. A system made up of just a processor and a memory can be thought of as such a closed system. From some initial state, the memory evolves through a sequence of consequent states. To understand the temporal evolution of those bits, we must also know the design of the computer (or the rules of the cellular automata). What goes on inside the processor and memory of a computer is a digital informational process; it involves bits, some of which change state during finite steps of a computational process. However, computers as we know them are not the only kinds of hosts to digital informational processes.

[2] When we use the word *computer*, we normally mean an idealized computer consisting of a processor, a memory, and nothing more. We assume that the processor computes, causing the state of the memory to evolve in a series of discrete steps. A cellular automata system is a computer in which the processing and memory are co-distributed throughout some kind of discrete lattice.

Bits or binary digits are the most primitive elements of digital information: simple two-state systems. There are just two kinds of actions that a bit can be involved in: memory–communication and computation. From the perspective of physics, we must conclude that memory and communication are identical processes. The reason is that memory and communication differ by only a coordinate transformation. Thus, the difference is only in the subjective intent of the process. Whether it is memory or communication has to do with how one looks at it, and nothing to do with the physical process. To relate all this to physics, one can think of a particle as an element of memory–communication and the interaction of two particles as an element of computation:

$$R(B_{x,y,z,t'}) \Leftarrow S(B_{x,y,z,t}) \qquad \textit{Memory};$$

a bit is recalled at x, y, z, t' that was stored earlier at x, y, z, t.

$$R(B_{x',y',z',t'}) \Leftarrow S(B_{x,y,z,t}) \qquad \textit{Communication};$$

a bit is received at x', y', z', t' that was sent earlier at x, y, z, t.

Memory can be transformed into communication and vice versa by means of a coordinate transformation.

$$O_{x,y,z,t+1} \Leftarrow C(I_{x,y,z,t}) \qquad \textit{Computation};$$

a set of output bits, O, are the result of a computation performed on a set of input bits, I.

A more physics-like computation–interaction model that is reversible and conservative while also spatially similar to 3+1-dimensional physics is the second-order reversible universal cellular automata (RUCA) system:

$$F_{x,y,z,t+1} \Leftarrow [N_{x,y,z,t}](P_{x,y,z,t-1}) \qquad \textit{Computation–Interaction}.$$

The P, which consist of a few bits from the x, y, z, $t - 1$ spatial neighborhood (the immediate past state and for all values of x, y, and z) are involved in a second-order reversible, conservative computation—they are conditionally permuted into F at x, y, z, $t + 1$ (a permutation of the same bits, now the future state) as a function of N, which depends on a few bits from the x, y, z, t spatial neighborhood (N for *Now*, the present state). This means that bits in neighborhoods in the present time, t, determine how bits in neighborhoods in the immediate past, $t - 1$, are transformed into the future state, $t + 1$. The transformations are always nothing more than locally conditional permutations of neighboring bits, done simultaneously for all neighborhoods throughout the x, y, z space. Such systems are obviously conservative of 1s and 0s. Regardless of the choice of the function N, all systems that meet the prescription in this paragraph are necessarily perfectly reversible! However, only a subset of such models are computation-universal—an absolute requirement for all models of physics. At this time, the only mathematical facts that simplify thinking about such systems are conservation laws along with all their consequences. Given discrete representations of physical quantities such as angular momentum, momentum, and energy, we want the computational process to conserve the total energy and the vector sums of the angular momentum and momentum.

In summary, there are variants of the microscopic actions and overall organizations of computers that have a close connection to microscopic physics. Instead of the standard logic elements of ordinary computers, such as the D flip-flop or the NAND gate, we use some form of conservative logic. Finally, the computers we call "cellular automata" have an organization and connectivity reminiscent of the space–time of physics [10]. Unlike mathematical models, whose symbols and formulae (e.g., differential equations) represent facts and laws of physics, CA models actually undergo temporal evolution, as do physical systems. We have observed that such digital informational processes can also have many more physics-like properties, such as particles and fields.

Since a cellular automaton [11–13] is a space–time volume of cells with integer space–time coordinates (i.e., x, y, z, t), every such system has natural units of length and time. The designs of such systems can be made more or less physics-like by the choices of various characteristics. It is now easy to define such systems, which are computationally universal[3] and reversible. Further, it is now easy to have such systems, in which various attributes that can be associated with physical quantities are conserved perfectly and exactly. Thirty years ago, all of the things called "easy" in this paragraph were generally thought to be impossible. Very few have been aware of these issues, and even fewer have knowledge of the progress that has been made or of its significance.

The so-called "Salt" model is one of a broad class of digital informational processes based on conservative, reversible, universal second-order systems. Salt is a cubic space–time lattice made up of two face-centered cubic sublattices. Every cell has four integer coordinates, x, y, z, t, and $x + y + z + t$ is always even. At odd points in time, bits in the chloride subarray might evolve, and at even instants of time, the bits that might evolve are in the sodium ion subarray.

The tyranny of computation universality appears to tell us something about whatever bright ideas we might think up as potential principles guiding choices in digital

[3] Throughout this paper the word *universal*, as in *universal computer* or *universal computation*, is used to describe a computer or computation that can exactly emulate the behavior of any other computer that has slightly less memory. Thus, every PC is universal. There are many kinds of cellular automata that are universal computers, and these are the kinds of computers that digital mechanics is based on. A conventional universal computer requires slightly more memory than what it emulates in order to use the extra memory to contain an emulation program. The early, old-fashioned use of the term *universal* in this context made the unnecessary assumption of infinite memory.

mechanics. We might be able to demonstrate that an ordinary computer model of physics is sufficient, but we cannot normally show that it is necessary. The reason is that any and all models of finite nature can be replaced by equivalent computational models based on any universal computer. This is somewhat similar to the situation regarding mathematical proofs: There are an arbitrarily large number of correct proofs for every correct theorem, but we prefer those that are most concise and elegant. When we say that we have a computer model of some system, we normally mean that a subset of the data in the computer can be mapped onto the system being modeled. For example, if we are modeling the exponential decay of voltage in an R-C circuit, a number in a memory location in the computer represents the voltage, and another number in another location represents the time; these binary numbers can be mapped, in a complex manner, onto the physical system. The other billions of numbers in the computer, some playing an essential role in the modeling process, cannot be mapped onto the real variables. Obviously, there are a very large number of different ways to create the same kind of ordinary computer model. However, what we want (in digital mechanics) is a digital-informational model that has a bijective map, one-to-one onto physics! That is why it was necessary to prove that there are reversible and conservative models of computation that also have the spatial–temporal connectivity of physical space. The beauty of the one-to-one mapping onto restriction is that it delivers us from the apparent tyranny of computation universality. It is unlikely that there will be more than one such correct model other than those that are merely simple symmetries of each other.

A two-state physical system, such as a fermion that is either spin-up or spin-down, can represent a bit of information. We can, with a great risk of possible confusion, call such physical two-state systems "bits." Spin $\pm\frac{1}{2}\hbar$ is a very reasonable choice for such physical bits. This means that the physical bit is represented by a conserved quantity, angular momentum. This poses no problem in computation. The concept of *bit* is independent of how it is represented; digital information has to do with the meanings inherent in the arrangement of things and is not related to what the things are.

The temporal evolution of state according to the laws of physics and the evolution of bits that represent state in a computer are two examples of temporal processes. Both can be thought of as having, at one instant of time, a state. Both can be thought of as transitioning from that state to another state at a later point in time. In conventional physics, that transition is often thought of as continuous and in concert with the laws of physics; in a digital informational process, that transition is in concert with the "laws" as described in automata theory; they correspond to some kind of automaton truth table or computer program. In the case of physics, we normally represent the laws by mathematical formulae, such as a conservation law. The evolution of state in physics is implied by a set of correct mathematical laws. However, the laws cannot be used directly to implement physics. Laws are static, written down; there is no direct path that takes the laws and causes physics to run. This is a slippery concept; it can be made clearer by considering some examples.

If we write a computer program to model a physical experiment, we can put the program and initial conditions into a computer and the computer model of the experiment runs. It undergoes temporal evolution. If we set up a physics experiment, we can put matter into motion and the system can undergo temporal evolution. If we simply look at the mathematical laws or at a computer program, it is like looking at the five characters in the formula $E = mc^2$. Looking at the formula does not convert matter into energy. The point is that the mathematical laws of physics are static representations of various relationships, which can be static representations of dynamic processes, but the mathematical laws are not dynamic; they are a static collection of symbols that represent relationships between physical quantities and time.

On the other hand, when we write a computer program to simulate a dynamic physical model, we have a different situation. The model can be put into motion or temporal evolution by loading the program and the initial conditions into a host (a computer) and letting it run. Such a model can have a very close relationship to a simple idealized physical process. Both can evolve in similar ways from similar initial conditions. We can ask ourselves "What are the limits that govern the behavior of such computer models?" The answer is that there is no finite process that cannot be modeled exactly by any universal computer with enough memory. This is a consequence of Turing's argument. This leads one to a new kind of equivalence principle: "Every finite physical process can, in principle, be exactly modeled by some finite digital informational process." With respect to discrete systems such as physics, there are two kinds of such models under the finite nature assumption. First, there is the normal kind of computer model, in which some of the bits in the model can be interpreted so as to correspond to the physical quantities being modeled. Then there is the DM style of modeling, in which every bit, trit, or other n-state symbol in a correct model can be mapped directly one-to-one onto every such n-state quantity in the simulated physics.

We cannot make progress in this discussion without assuming that physics is always locally finite. We do not intend to argue that point, even though we do not know the nature of how or why it might be true; we assume that it is true. This is, of course, part of the FN assumption. A consequence of finite nature is that every finite volume of space–time can be in only one of a finite number of states. At this point we don't care whether the space is 3+1-dimensional or configuration space. We don't care if the graininess of space shows up at Planck's length or at a Fermi. It doesn't matter whether we are thinking Newtonian mechanics or thinking of the evolution of the wave function. Given the FN assumption, it is tautologically true that a finite digital computer can run an exact model. Of course, this is contingent on having the exact initial conditions and boundary conditions, along with a correct program for the computer. Further, it should be possible to eventually find an informational process model that maps its bits or n-state variables directly one-to-one onto the corresponding quantities in the physics it is modeling.

A corollary is that if the FN assumption is valid and we have a theory of physics that cannot be modeled exactly by a computer, that theory cannot be a true or correct model of physics. This is a very interesting observation. The reason it is interesting has to do with the fantastic success in physics of the mathematics of continuous variables. If the FN assumption were valid, most of the laws of physics that rely on continuity would be no more than good approximations! It is well known that continuous models work well for systems with discrete quantities (for example, in hydrodynamics or electrical engineering). When those discrete quantities, such as electrical charge, are conserved exactly, continuous models can be exactly correct only when the appropriate variables happen to be integers. These observations do not diminish the beauty or utility of mathematical laws based on the calculus or on differential equations; rather, our appreciation of them should be increased. While we take note of the fantastic success of the calculus at accurately modeling all kinds of processes in physics, we see no reason to assume that that success offers any evidence against the finite nature assumption.

This is the end of the informational digression.

What is the origin of spin?

"That a question makes grammatical sense does not guarantee that it is answerable, or even coherent." In the spirit of Wilczek's paper, let us also begin with a critical examination of the question posed in this section: What is the origin of spin? The following paragraph is an example of the author's use of paraphrased sentences from Wilczek's paper [1].

In classical mechanics, angular momentum appears as a secondary concept: linear momentum times length. It might have been a mistake for the founders of classical mechanics to fail to treat angular momentum as a primary concept. In Newton's laws of motion, momentum appears as a basic property of matter in motion, while little is said of angular momentum. Of course, angular momentum is closely related to linear momentum, which Newton thought of as a basic property; hence Newton's $F = d(mv)/dt$ (using Leibniz's notation). What Newton wrote was "The change of motion is proportional to the motive force impressed . . . ," where in this context the meaning of "motion" is the same as the contemporary meaning of "momentum." Any extended object without angular momentum would not know what to do about its angular motion. Of course, the parts of an object without angular momentum would have to lose their linear momentum. The instantaneous angular momentum of an extended body can be thought of as a consequence of the instantaneous linear momenta of all of the parts of that body. In any case, Newton discovered the laws that govern the manifest properties of matter in motion. Despite reportedly heroic efforts, he was left with no explanations for the processes of gravity and of massive objects in motion. Thus, in the Newtonian framework, angular momentum is just what it is.

Later developments in physics make the concept of angular momentum seem more irreducible. That process started in earnest with the Planck theory of radiation. The famous equation

$$E_\lambda = \frac{8\pi hc}{\lambda^5} \times \frac{1}{\exp(hc/kt\lambda) - 1}$$

is Planck's law for the energy E_λ, where λ is the wavelength. The appearance of the constant h may have started with Planck's equation, but it didn't end there. We have $E = h\nu$, $\alpha = e^2/4\hbar c$ (where $h/2\pi = \hbar$), and, finally, the realization that particles have spin and that they can be divided into bosons and fermions based on whether they have integer or half-integer spin. Particles with integer spin $(\ldots 0, \pm 1\hbar, \pm 2\hbar \ldots)$ are bosons; an example is the photon. Particles with half-integer spin $(\ldots \pm\frac{1}{2}\hbar, \pm 1\frac{1}{2}\hbar, \pm 2\frac{1}{2}\hbar \ldots)$ are fermions; an example is the electron [1].

It is clear that, along with c, the speed of light, $\hbar$ is one of the most fundamental of physical constants. Further, it is a natural unit of angular momentum. Currently, there is no known natural unit of mass [1]. Planck's mass seems to have no relationship to common particles. Conventional physics rules out natural units of energy or momentum.

Angular momentum has to be promoted from its current position as a composite quantity, ML^2T^{-1}. First of all, along with the speed of light, it is one of just two very basic natural units in physics (excluding gravitation). Second, there are the amazing facts: $\hbar/T$ is energy, $\hbar/L$ is momentum, and then there's the relationship between $\hbar$, c, e and the fine structure constant. For these and other reasons, it is a principle of DM that mass is demoted to being $M = \hbar TL^{-2}$, or with $c = 1$, $M = E = \hbar/T$. We argue that spin is not just a property of particles, but rather it is a consequence of a discrete space–time process and of the laws of physics. In DM we simply define the bit (B) as a two-state system in which the two states are $\pm\frac{1}{2}\hbar$: plus $\frac{1}{2}$ unit of spin or minus $\frac{1}{2}$ unit of spin. In DM there are only three basic dimensions or units: B, L, and T, and each is a natural unit.[4]

CPT symmetry must be a property of space and the laws of physics, since particles promoted from the vacuum are consistent with it. While we know that $B = \pm\frac{1}{2}\hbar$ in SI units, we define it in DM units as ± 1. We do not yet know the SI values of L or T, but we define the DM units as $T = 1$ and $L = 1$. The definitions of the unit of length and time should maintain the ratio $L/T = c$. The consequence is that with three natural units, B, L, and T, we have a complete system capable of representing all dimensioned quantities in physics.[5] That is why we believe that energy is the temporal frequency of bits (binary digits), B/T, and momentum is the spatial frequency of bits, B/L. From dimensional analysis, electrical charge is $\pm\sqrt{(B\,L/T)}$. CPT symmetry tells us that the sign of the charge must be related to the phase of the spin. This is a consequence of the observation that time reversal requires charge and parity reversal for the laws of physics to be consistent. From a very basic point of view, the only thing that can be directly reversed when time is reversed is some kind of motion, spatial or purely temporal motion.

Bits (binary digits) can make waves in space that have a wave number or spatial frequency. The smallest part of such a wave is two neighboring cells in opposite states. These two cells constitute an atom of a momentum vector. Similarly, a temporal wave has a frequency. This can also be thought of as the number of times per unit time that cells change state. Therefore, B/T (a cell that is in a different state than it was at the prior point in time) is an atom of energy. Since B, L, and T are natural units, in DM there are natural units of energy, momentum, force, and so on. Just as c, L/T is a natural unit of velocity while being the highest possible velocity for a particle, B/T represents the highest possible instantaneous energy in one cell. B/L represents the greatest possible momentum in two adjacent cells. The energy of a particle would be the total average energy in the volume associated with the particle, minus the average vacuum energy of a similar volume. The total momentum of any particle would be equal to the total vector sum of all the momentum atoms associated with it. Since the momentum information must accompany the particle when it moves, the total energy of motion of a particle includes the energy of the moving momentum bits. Classically, the number of momentum bits that have to move is proportional to the momentum (a unary representation of the information); therefore, the energy of motion must be proportional to v^2. To clarify, the number of bits that specify the motion must be proportional to the speed, and must be moved at that speed. Thus, the total amount of kinetic energy associated with a moving mass must be proportional to v^2, and the total momentum must be proportional to v.

What atoms are associated with a particle? The digital process that moves the particle must do so in accord with the information that represents its velocity. Since the particle has inertia, that process must move the velocity information along with the particle without changing that information. The bits of information that must be moved along with the particle are said to be associated with the particle. A field (or an absorbed or emitted photon) accelerates a particle by changing the information that represents the momentum and energy of the particle. In the unary representation of the information, where the number of atoms determines the magnitude of the quantity represented by the atoms, the process of absorbing a photon is very simple; all of the momentum and energy atoms in the photon that is absorbed are added to the momentum and energy atoms of the particle that absorbed the photon. Obviously, the momentum atoms add as vectors. It's all too simple, which is the nature of discrete process models. Keep in mind that every detail here is simply an example as to how DM might work. There is little doubt that the details of the truth, when we know it, will be different; but what is being offered here is a conceptual framework that might, with many different details, be a model of fundamental processes in physics. As an example, in the 1970s the author developed a similar model (the octahedron particle) in which the momentum information was represented in binary. That model included the process of particle–photon interaction. But, as in all models so far, problems exist. The reason we favor the unary representation of quantities over the binary representation is that the unary one has fewer problems.

There are rules for such processes, as described in Sections 12 through 23 of "An Introduction to Digital Philosophy" [14], in which the Salt model is described. Salt can be thought of as being 10-dimensional; viz., 3+1-dimensional space–time, where time has six distinct phases. This results in all fundamental motion having an

[4] See Chapters 19 and 20 in *Introduction to Digital Philosophy*; *www. digitalphilosophy.org/*.

[5] All of DM is completely and exactly characterized by eight constants; B, L, T, P, D, R, A, and I. B, L, and T, the bit, length, and time, are all equal to 1. Each time step T is made up of P substeps. P is the number of time phases and is equal to a small integer; in the Salt model, $P = 6$. D is the number of spatial dimensions, $D = 3$. R is the rule, something we should eventually be able to know exactly. We already know the age of the universe approximately; A is the age in units of T. I is the initial conditions, when $T = 0$; learning something about I will require luck. Unlike the ≈23 constants of the standard model, these eight constants exactly define absolutely every single fact about physics; in addition, they exactly determine every past and future state of the universe, macroscopically and microscopically. See [14].

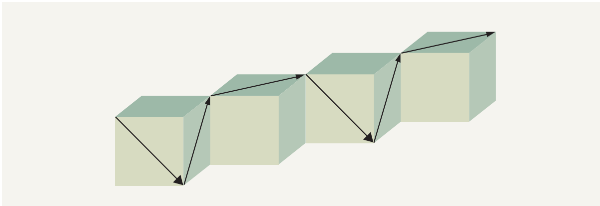

Figure 3

Illustrative microscopic translation path.

angular momentum component. During each time phase, the motion of bits is restricted in spatial orientation (direction). The result is that all motion, at a most microscopic level, has an orbital component. For example, consider the following three steps: (Δx, Δy), (Δy, Δz), (Δx, Δz). In **Figure 3**, we can see the orbital component of the path. In this particular kind of model, all spin is orbital; there is no rotation. There are other DM models that have been worked out where the most basic action is a rotation group of three bits. In those kinds of models, spin is closer to being rotational.

Thus, for every particle, at least one bit is swapped six times in every time cycle, regardless of the velocity of the particle. The result is that spin is an absolutely intrinsic part of every particle. In DM, a spin zero particle must have some arrangement like a ($+B$, $-B$) swap that occurs while another, associated ($-B$, $+B$) swap occurs so that the net spin is zero. While it is obviously possible to come up with rules for a DM model that exactly conserve spin (and angular momentum), it is also possible to have rules that conserve linear momentum and energy. Linear momentum is represented by two spatially nearest neighbors in the opposite spin state: ($+B$, $-B$) at the same time: $\rightarrow B/L$. Energy is represented by two nearest temporal neighbors (in the same place) in opposite spin states: $\rightarrow B/(PT)$. Actually, in the Salt model it is more informative to say that the unit of energy is $(2B)/(2PT)$, since the smallest change in state is always two bits, separated by two phase steps.

Why are there symmetries and CPT?

For a while, physics suffered from what Wigner, Weyl, and others once called the "Gruppenpest." The question as to why group theory applies to hadrons found part of its resolution in the more microscopic particles of quantum chromodynamics (QCD). We look beyond particles to a more microscopic and fundamental process to understand the basic source of symmetries and CPT.

Rotational symmetry, space translation symmetry, and time translation symmetry are all symmetries of our world. These symmetries are often thought of as the most basic properties of physics. Noether's theorem allows us to derive conservation laws based on these symmetries. It is well known that Noether's theorem is itself symmetrical. It allows symmetries to be a consequence of conservation laws. A variant of Noether's theorem states that for every microscopically conserved discrete quantity, there is an asymptotically continuous symmetry. A good example of a discrete conservation law is conservation of charge. If our microscopically discrete, finite physics exactly conserves angular momentum, momentum, and energy, then at a scale sufficiently above the granularity of the discrete space and time, the symmetry of rotation (angular isotropy), space translation symmetry, and time translational symmetry will be asymptotically continuous! Thus DM unseats these symmetries as most fundamental and replaces them with more fundamental conservation laws. The apparently continuous symmetries arise asymptotically—as one scales up above the space–time lattice—and they have fooled us into believing in the reality of physical continuity. Despite the plethora of negative results, it is the author's thesis that future experiments[6] will show violations of symmetries of rotation, translation, time, and all other continuous symmetries.

We often regard momentum as being associated with a spatial wave for which the momentum is equal to $\hbar/L$, the spatial frequency. Since the models we are considering are quantized to two states, a wave must be characterized by the number of spatial state transitions. This means that the most microscopic part of such a wave would be two spatial neighbors that are in different states. This would constitute a kind of atom of momentum. A similar situation involving two temporal neighbors (in the same place) that are in different states would be an atom of energy.

It is possible to design cellular automata with rules that result in the following:

1. The bits are conserved exactly.
2. Bits that are spatial neighbors in different states obey simple rules.
3. Bits that are temporal neighbors in different states obey simple rules.

If all of this is true, the following physical laws can be consequences:

1. Exact conservation of spin (and angular momentum).
2. Exact conservation of momentum.
3. Exact conservation of energy (or exact on average).

[6] See the epilogue at the end of this paper.

Then, by a variant of Noether's theorem, we get the following:

1. Asymptotic continuous rotational symmetry.
2. Asymptotic continuous translational symmetry.
3. Asymptotic continuous time translation symmetry.

Instead of assuming the symmetries (without understanding the underlying reasons for them), we assume a discrete process which exactly conserves certain quantities, and the apparently continuous symmetries arise asymptotically as a direct consequence. Of course, we expect that every apparently continuous symmetry in physics will correspond to a conserved quantity in the DM model. The fact that the DM process is computation-universal while having a set of conservation laws puts it into a computational class outside common experience. This is discussed further in the section titled "Can the FN assumption account for the efficacy of quantum dynamics?"

In a second-order CA, even and odd time steps are distinguished. In such systems, charge is undoubtedly a temporal-phase-sensitive process involving a bit, a velocity (L/T or c), and a temporal process $\pm P$, so that $(\pm P)^2 = 4\alpha Bc$.

Assuming the validity of the FN assumption, it is possible to devise a simple and straightforward six-phase automaton rule which has the property that the proper reversal of CA time results in charge conjugation and parity reversal. DM can have a wonderful kind of T symmetry. In the Salt model, if time is reversed by stopping time and then starting time up in the opposite direction, where the last step in the forward direction is repeated as the first step in the backward direction, then in a simple, perfectly clear manner T goes to $-T$, charge is conjugated, and parity is reversed! In Salt, time reversal is physically correct, causing the resulting physics to have CPT symmetry. One such system is described in [14].

Every particle must have part of its structure in both of the Salt subarrays. However, those two substructures may not be exactly symmetric (with respect to the two subarrays). In all such nonsymmetric substructures, there can be two mirror-image particles that differ only as to which subarray each is associated with. Such pairs are a particle and its anti-particle. This model is fundamentally correct in explaining the Feynman view that an anti-particle can be viewed as a particle moving backward in time.

What is the origin of length?

In classical mechanics, length appears as a primary concept. It was a very great step for the founders of pre-geometry mensuration to isolate the mathematical concept of length. It was natural for the founders of classical mechanics to embrace the concept of length. In Newton's laws of motion, length (and area and volume) appear as irreducible, intrinsic properties of space and of the objects in space. An object without length could not have a size. It would not know, from one moment to the next, where in space it is supposed to be or how much space it has to occupy. Concepts such as velocity and acceleration are meaningless without clear concepts of length and time. Thus, it is difficult to imagine, in the Newtonian framework, what could possibly constitute an "origin of length." In that framework, length just is what it is [1].

Later developments in physics make the concept of length seem less irreducible. The undermining process started in earnest with the theories of relativity. The constant c, the speed of light, united length and time in a wholly unexpected manner. Physics knew of no basic constant of length. Physics knew of no basic constant of time. Yet the most fundamental constant of physics relates length and time! The very idea that the ratio of length to time possesses a fundamental constant, c, while neither length nor time does, should be thought of as a philosophic mystery [1].

Much of what we do know about length has to do with objects in space. We ascribe length (area and volume) to different objects, and we assume that it is a symmetry of nonrelativistic space; the properties of length belonging to a stable object are possessed of translational and angular symmetries. The length of an object is independent of position and orientation. However, it is not independent of the relative velocity of an object and an observer. An important philosophical question has to do with space. Is length a property of space, or only a property of objects in space? There are many reasons to suppose that length is an intrinsic property of space. Empty space allows for the propagation of light and other particles and for the possibility of particles promoted up from the vacuum. There is no reason to suppose that space requires material or energetic content in order for length to exist.

So far, we may have said nothing new or even interesting. The subject becomes interesting when we introduce the assumption of finite nature into the physics of length. This results in length being unable to represent more than a finite amount of information. Further, there must be a unit of length. We can then measure lengths longer than the unit and also measure lengths with more precision than the unit. We define a unit of length in the following way. Since a finite volume of space–time can contain only a finite amount of information, the unit of length should have some simple relationship to the distance between two points which are as close as possible while having two distinct informational states [1].

Having a unit of length does not imply that we cannot have observable phenomena more microscopic than that unit. Because of the nature of a particle in a DM model (as a complex extended structure), it is capable of representing its position with much greater resolution than the unit of length. This means that physics experiments can return measures of length many orders of magnitude smaller than the unit of length.

In a DM model, a photon is a complex, extended object in that it has an informational structure that represents its energy and direction of motion. The total information carried by a particle may consist of hundreds or thousands of bits. This information may be spread out over a very large volume of bits. Further, that structure must be involved in an informational process that moves the photon, with all its associated information, in the direction so represented. There are many processes that, in a given reference frame, change the direction of motion of a photon without changing the energy of the photon. While a photon has momentum, it may be more logical from an informational viewpoint to speak of the *energy* and *velocity* of the photon as opposed to the *momentum* of the photon.

The kinds of geodesics and lengths that we use in physics can be thought of as being defined by the path of a photon and by the time it takes for the photon to traverse that length. When there are very strong gravitational fields, the laws of general relativity (GR) and the paths of photons define what we think of as our physical space–time. Under benign conditions, the DM lattice (essentially Cartesian) is a close approximation to our space–time. When we need to take GR into account, it is best to think of the lattice as a computational substrate in which the results of the computation (which determines the paths of photons) define the geometry of the local physical space–time. Under such extreme conditions, the mapping between the lattice and the space–time of physics would be determined by GR as the lattice remains Cartesian, while the space of physics, as determined by what particles do, would conform to the laws of GR.

What DM dictates is that there is a natural unit of length, L, and it should have a very simple relationship to the distance between two nearby neighboring cells. Similarly, the natural unit of time, T, should have a very simple relationship to the fundamental clock of the underlying cellular automata. Finally, L/T should equal the speed of light.

We can speculate that the mass of an electron might involve a compact 13-cell pattern (a cell in an fcc lattice with its 12 nearest neighbors, the smallest possible *sphere*). Thus, the size of each cell would be determined by a calculation similar to that used to calculate the Compton wavelength of the electron, namely, $2\pi\hbar/m_e c \approx 2.42631 \times 10^{-12}$ meter. Thus, an overly simplistic calculation of the unit of length L would be $13\hbar/m_e c \approx 5.02007 \times 10^{-12}$ meter, and another overly simplistic calculation of it would be $2688\hbar/m_{\text{muon}} c \approx 5.02009 \times 10^{-12}$ meter. This would mean that a muon would have a 2688-cell pattern (a larger *sphere* with a small *spherical* void). At this stage of DM theory, such calculations are little more than numerology.

While the core of the muon would be much larger than the core of the electron, the additional spatial information in the muon would allow for higher-resolution interactions with other particles. Thus, experimentally, the muon would appear to be smaller (actually, it would be more localized) than the electron. The startling consequence would be that the unit of length might be much greater than a fermi (10^{-15} meter). DM restores the common-sense notion that heavier structures (such as a muon) ought to occupy a greater volume than lighter structures (such as the electron).

What does a process model of motion tell us?

A process model differs from the mathematical equations of physics in that it is capable of being put into a computer and then running. If we assume that the FN assumption is valid and then create a process model of particles in inertial motion, we discover that we cannot do it without it being the informational equivalent of a process model that refers all motion to a single fixed reference system. In other words, no matter how we try, there is no way to write a program that models motion in accord with the contemporary picture of physics. We believe that there is a law of physics that states "That which cannot be programmed to run on a universal computer cannot be consistent with physics!"

Within the kinds of DM models that are based on the FN assumption, it is natural to think of a particle as some kind of little machine that works itself in some direction, while carrying along its velocity information. Of course, it also has to bring along all other facts, such as its charge, spin, and total energy. It should be obvious that the things we are describing are already at odds with our contemporary concepts of physics. Imagine that somewhere in or near a particle, some combination of its velocity, energy, or momentum information must be written down along with other state information! Some process looks at all that information and moves all of it accordingly! A field or particle interaction must appropriately change the information that is written down! The implication in all of this is that there must be a single fixed reference system for such information. What else could the written-down information refer to? While it is natural to assume that the information is written down in the same local space–time in which the particle exists, there are a number of facts that support that conclusion.

When a particle passes through a small hole or a narrow slit, some of the directional information of the particle is lost. When a photon accelerates an electron, it is because the photon arrives in the close vicinity of the electron, which absorbs it. If the information is local to the particle, and if there is a process that uses that information to move the particle and its associated information, it becomes compelling to conclude that the velocity information must refer to a local fixed reference system. Interestingly, such an assumption does not violate a single mathematical law based on experimental data. What it does violate is the concept that there is no preferred, single, fixed reference system, a law adopted voluntarily. Nothing compels us to adopt such a principle, other than the embarrassment of looking for and not finding such a reference system. Finally, it is rather easy to show how an informational process based on a uniform, fixed, single Cartesian lattice can easily model Newtonian relativity and general relativity. One must remember that the physical properties of our space–time are not directly determined by the lattice; rather, they are determined by the paths particles take as they move through the lattice; it is their motion that has to conform to the laws of physics. Since the Cartesian CA is computation-universal, it is a tautological fact that such a lattice can support rules that produce particles and fields for which the motions of the particles are in accord with both special relativity and general relativity. Naturally, the same is true for relativistic particles for which their masses and internal clocks must obey the laws of special relativity.

So far, there have been a great many diverse experiments that have all failed to detect a common fixed reference frame. However, there have also been an even greater number of experiments that failed to detect symmetry violations of time, or of charge, or of parity (left- or right-handedness),[7] or of charge and parity combined, etc. (In the past fifty years, we have learned that certain obscure experiments show us that symmetries of time, charge, parity, charge and parity together, etc., are all violated!) It is also true that we can crudely measure absolute motion through the CBR. We believe that much better experiments are possible to detect both absolute velocity and absolute angular orientation. We believe that there are experiments that can measure the unit of time, T, or the unit of length, L; and since $c = L/T$, we will then know both. We have already learned the hard way that despite a hundred years of careful experiments, with each showing that a symmetry holds, we can wake up one day and discover that it is violated. Once we know that a symmetry is violated, it is forever violated; all prior experiments are shown to have been deficient. Measuring a thousand things that show the symmetry is far from a proof that no other experiment will show that it is violated. We have explained why first-order, continuous rotation and translation symmetries can arise asymptotically out of a discrete model that does not have these symmetries, because of exact conservation of momentum, angular momentum, etc., as shown by the variant of Noether's theorem. It is the author's thesis that new experiments will show the violation of every continuous symmetry of physics—demonstrating that the FN assumption is valid. Further, the FN assumption implies that we should eventually be able to measure absolute angular orientation and absolute speed through the universal reference system, determine the units L and T, and finally, discover the rule that governs the operation of the fundamental automata process.

What is inescapable is that the contemporary scientific concept of motion is an informational impossibility. In other words, today's concepts as to the physical mechanism of motion must boil down to magic, since there is no possibility of making a sensible informational model of it. At the end of this paper, we put forth a number of possible experimental tests of the FN assumption and the DM model.

Can the FN assumption account for the efficacy of quantum mechanics?

The FN assumption implies that physics is a digital informational process. This means that the laws that we know from automata theory apply to physics. The most important of these has to do with computational universality. The simple fact that we can build computers implies that the most fundamental processes of physics must be computation-universal. But there are two computer science *theorems* that may enable us to see quantum mechanics in a new light: the "speedup theorem" and something related to Wolfram's computational irreducibility [10a] that might be called "computational semi-irreducibility." The speedup theorem states approximately the following: "Given various computations, each taking a number of steps to get to the answer, there is no way, in general, to do the same computations in a smaller number of steps." The key to understanding the effect on physics has to do with the part that says " . . . in general . . . ." Obviously, if your computer is busying itself with nothing other than counting from 1 to 10^{16} (which ought to take about a year), we can arrange for another computer to count up by 10s and get the job done in about a month.

[7] Many molecules can be optical isomers (levo or dextro), existing in both left-handed and right-handed versions. Many such molecules found in living things seem to violate P symmetry in that only one of the two versions is present. This is not the kind of thing that implies that P symmetry violation is a property of fundamental physics. P symmetry violation, as a fundamental property of physics, was first suggested almost fifty years ago, and subsequently proven true experimentally.

Wolfram states:

> "In traditional science it has usually been assumed that if one can succeed in finding definite rules for a system then this means that ultimately there will always be a fairly easy way to predict how the system will behave.
>
> "Several decades ago chaos theory pointed out that to have enough information to make complete predictions one must in general know not only the rules for a system but also its complete initial conditions.
>
> "But now computational irreducibility leads to a much more fundamental problem with prediction. For it implies that even if in principle one has all the information one needs to work out how some particular system will behave, it can still take an irreducible amount of computational work actually to do this.
>
> "Indeed, whenever computational irreducibility exists in a system it means that in effect there can be no way to predict how the system will behave except by going through almost as many steps of the computation as the evolution of the system itself."

The kinds of CA systems that we are proposing as models of physics are basically very simple. Nevertheless, they are all computation-universal, which means that they are capable of any degree of large-scale complexity. It is perfectly understandable that, aside from things like conservation laws, there are many aspects of the behavior of regular universal CAs that are not subject to simple formulas that allow short-cut computation of exact future states. However, it is important to understand the novelty of a complex universal computation as envisioned in DM, where a number of fundamental quantities are conserved exactly or exactly on average. We have pitifully few experiences with such kinds of universal, reversible cellular automata that adhere to strict conservation laws for certain quantities. This changes the nature of the consequences of the speedup theorem and computational irreducibility, since we can and do know all future results of the computation exactly, but only in regard to the conserved quantities! At the level of QM, we have a marvelous mixture of apparently probabilistic behavior that cannot be predicted other than statistically while things still obey the laws of physics with regard to the conserved quantities. At the level of classical physics, the microscopic uncertainty due to the computational complexity fades into the background, and we are left with the consequences of the exact conservation laws.

For QM, Wolfram's idea of computational irreducibility is insufficient because it does not take into account the role of conserved quantities. Computational semi-irreducibility forces a kind of intermediate formalism, sandwiched between a CA model at the bottom and classical physics at the top, that can allow for the kinds of calculations we are able to do in QM.

Because the CA underlying DM is regular and simple despite being computation-universal, it is not surprising that there are mathematical shortcuts beyond conservation laws that partially escape from the dictates of the speedup theorem and computational irreducibility. Because we never have complete microscopic information as to the exact present state of any physical system, we cannot predict the outcomes that are not constrained by what we do know. The randomness we see in microscopic QM is easy to understand in a DM model as the influx of information orthogonal to the process we are measuring. As to Heisenberg's uncertainty principle, our bit is $\pm\hbar/2$; what could be simpler? DM models that use the Salt space–time framework also appear to give a natural basis for the complex amplitudes of QM.

Because of conservation laws at the CA level and conservation laws at the level of QM, we are assured of conservation laws at the level of classical physics. However, the path from bits swapping places at the CA level up to particle interactions at the QM level can be dominated by the randomness whose source is that constant influx of information orthogonal to the local process. While the CA is totally deterministic and is reversible and universal, particle interactions within the CA can follow the laws of QM. Further, such synchronous CA models can easily exhibit the kinds of long-range correlations and somewhat mysterious processes we see in QM.

Thus, in finite nature, the role of quantum mechanics is exactly as described years ago by 't Hooft:

> "Quantum mechanics is not a theory about reality, it is a prescription for making the best possible predictions about the future if we have certain information about the past."

When working with CAs it is surprising how often behaviors are seen that strike one as resembling the kinds of things seen in quantum mechanics. We do not yet have a CA model that leads to QM; however, it is obvious that the models we do have today are closer to that possibility than earlier ones.

The development of QM has had an interesting history. From today's perspective, with knowledge of all the experimental results and theoretical progress of the last 100 years, we can see that the vast majority of all papers ever published in the general field of QM have fatal flaws. In the week following the discovery of the J/psi particle, it is my recollection that 150 papers were submitted to *Physical Review Letters*, and that 150 of them were wrong. The reason is that figuring out QM, quantum electrodynamics (QED), and the Standard Model are not the same kind of tasks as Einstein working out special and general relativity. It's a very good thing that there was not some kind of physics oracle present during the last hundred years reviewing papers. He could have discouraged almost all authors of 100 years' worth of QM papers (many of which contributed significantly to the advancement of QM) by pointing out that, in some respect, they didn't get it right.

Epilogue

Any proposed new physics has to address the issue of experimental verification. We believe that there are a number of kinds of microscopic symmetry violations that can be tested by experiments: violations of rotation symmetry, space translation symmetry, scale symmetry, etc. These violations would be similar in character to T symmetry and CP symmetry violations. This means that, despite the lack of apparent violations under almost all conditions, some experiments, often bizarre experiments, should be able to detect the violations. In the case of rotation symmetry, decay particles initially moving in certain preferred angles (in terms of the celestial coordinates, right ascension and declination) might be associated with probabilities differing from what is obtained at other such angles. For example, to detect violation of absolute (celestial) angular isotropy in the decay of the K^0 particle, the probabilities associated with the angular coordinates of the particles would have to be analyzed after transforming the data associated with these events from laboratory coordinates to celestial coordinates. One might look for variations in the probabilities of decay modes as a consequence of the absolute celestial orientations of particle paths going into or coming out of the region of a collision in an experimental apparatus.

New experiments may not be needed because additional analysis of existing data may be sufficient. To the author's knowledge, the kinds of analyses of experimental data contemplated here are seldom done. As for the detection of violation of translational invariance, this might be facilitated by being able to conduct brief experiments in what is called PTM space (space that is in pure translational motion); see pp. 242–243 of [14]. PTM is unaccelerated, irrotational motion along the path that a particle would take in the absence of a field. The fact is that ordinary physics experiments are conducted under circumstances that tend to hide or obscure the detection of these two symmetry violations. The complex motions (continuously changing spatial accelerations and rotations) of a laboratory on earth (or of a satellite in earth orbit or even anywhere in the solar system) combined with the averaging of data contrive to hide and obscure subtle symmetry violations. Once we understand such processes, it should be possible to build devices that easily measure absolute motion and absolute orientation regardless of the complexity of its motion. While the decay of the K^0 particle seems promising, there are other possibilities such as differences in the decay of the B and the anti-B particles or even β decay, in which a neutron decays into a proton, an electron, and an anti-neutrino. For reasons that are explained in the *Introduction to Digital Philosophy*, Quark jets (especially with $\frac{1}{3}e$ electrical charge) along with other high-energy events, may be fertile ground for the search for violations of rotation symmetry (angular isotropy).

When some experiments are done, expecting certain results, the experimenter often adjusts the apparatus until a clean signal is obtained, showing the expected results. Many times, averaging noisy data is part of that process. Such experimental procedures may hide effects due to symmetry violations. The angular orientation of a laboratory is changing in a rather complex manner as the earth rotates, moves in its orbits around the earth–moon center of gravity and around the sun. Further, lunar and solar tides complicate the picture. This complexity shows up both in absolute angular orientation and in deviation from what we are calling PTM. Laboratory devices can be built that maintain PTM (including absolute angular orientation) for periods of time from a few seconds up to a minute or two. The task of constructing and operating a large facility of this type would be somewhat simplified if the laboratory were precisely located at the earth's South Pole.

There are experiments that could initially be conducted in a PTM reference frame that might allow the measurement of the basic unit of time, and hence the unit of length. For example, a small perfect piezoelectric crystal might show a change in impedance (or some other anomalous effect) when its absolute orientation, driven frequency, and atomic spacing were properly related to the underlying space–time lattice. The atomic spacing could be adjusted over a small range by subjecting the crystal to a range of pressures. The main problem has to do with the large space to be searched. It might make sense to run a large number of such crystals in parallel. Such experiments are much more feasible if we already understand the nature of the symmetry violations involved.

In contemporary physics today, there is no competence with regard to guessing the likely size of the unit of length in a DM model of physics. Most would immediately suggest Planck's length, 10^{-35} meter. Some would cite experimental evidence as to why the unit of length must be less than some value, such as 10^{-22} meter. What is not generally understood is that there is no experimental evidence that strongly hints that the unit of length of a DM model should be much less than 1/100 of a fermi (10^{-17} meter)! It certainly could be as large as 100 fermi (10^{-13} meter)! A DM model is capable of yielding experimental results that imply distances many orders of magnitude smaller than the cell-to-cell distance because the particle is an extended structure involving many cells which can represent a great deal of high-resolution position information.

Understanding various consequences of the finite nature assumption has been slow and difficult. The remaining tasks may not be as complex as the development of quantum mechanics, but they will undoubtedly require more people and more mistakes along the way than did the development of SR and GR. Today, it is still very easy to point out that physics based on the finite nature assumption is incompetent at explaining many properties of physics. That is not the point. It already explains a few things that contemporary physics can't touch [15]. It makes predictions that are subject to experimental tests. Definite progress has been made, no matter how much more progress remains to be made. There are still many problems in conventional physics that are dealt with by ignoring them. It's no more true today that " . . . now we know everything" than it was 100 years ago. We have to imagine what physics might become and not just cling to what it is. With luck there will be a great many more surprises. Finite nature and all it entails might be one of those surprises.

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1. The author was motivated by reading Frank Wilczek's "Four Big Questions with Pretty Good Answers" (*http://arxiv.org/abs/hep-ph/0201222/*). Various sentences, sentence fragments, and styles of exposition in this paper were copied from that paper. We have tried to identify most paragraphs where such instances occur. The content of this paper has little to do with the content of Wilczek's paper. However, the author has found following the framework of Wilczek's exposition to be useful in overcoming some of the obstacles the author encountered in trying to express his ideas. We thank Wilczek for granting an indulgence; allowing our use herein of paraphrased and copied fragments of his good work.
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Received April 28, 2003; accepted for publication August 5, 2003

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