Physics and the Problem of Change

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Physics, the science of change, has managed to discover and to explain a large number of qualitative and quantitative aspects of a large number of natural changes, but change itself remains unexplained since we first faced it, over twenty-seven centuries ago. This paper proves, in terms of transfinite arithmetic, that change is inconsistent within the infinitist framework of the spacetime continuum, were all solutions have been tried until now. It then proposes a consistent solution within the finitist framework of the discrete spacetimes of cellular automata like models, proving the factor that convert between continuum and discrete spacetimes has the algebraic form of the relativistic factor of Lorentz transformation, which could be reinterpreted as an operator to translate between a consistent discrete reality and an inconsistent continuous reality.

1 Introduction

Change is the most pervasive characteristic of our incessantly evolving universe. But change is also the most elusive and difficult question we have ever been faced with.* So elusive that no one has been able to explain how a simple change in position of a physical object occurs. So elusive that it could be inconsistent, as claimed at least since the time of Parmenides. But not only pre-Socratic authors as Parmenides, Zeno of Elea or Mellisus claimed the impossibility of change [12], modern authors as J.E. McTaggart also defended the impossibility of change [11]; and Hegel its inconsistent existence [8, p. 382]. If that were the case, the task of explaining the physical world in consistent terms would be impossible because the physical world is, essentially, change. And being physics the science of change, the science of the regular succession of events in Maxwell's words [10, p. 1], it should be concerned with the solution of this fundamental step in the understanding of physical reality.

It seems reasonable to assume that we model reality as a continuous system because we perceive it as a continuous system. The problem is that this perceived continuity is illusory. In fact, our brain takes a time greater than zero (≈13 ms [13]) to process each visual image (the base of the well known α, β, γ and δ movements, and of ϕ-phenomenon), so that *a continuum* of visual images is physiologically impossible. The same illusory perception happens with motion when observed in a film. And in the same way a film is a discontinuous sequence of images, natural motion could also be a discontinuous sequence of changes in position, which is perceived as continuous by our brains and our physical instruments. The discussion that follows addresses the problem a change from this discrete (discontinuous) point of view, proving it is inconsistent from the continuous perspective, and consistent from the discontinuous one. Surprisingly, the factor translating between both perspectives has the algebraic form of the relativistic Lorentz factor, which open the door to a discrete interpretation of special relativity, our main current theory on the continuum spacetime, the scenario in which change is so conflicting.

*for a general background see [12], [14] and the particular view of H. Bergson in [2], [3]).

2 Canonical changes

For the sake of simplicity, and in order to avoid unnecessary complications, we will discuss here the problem of causal changes in physical macroscopic objects. So, if O is one of such macroscopic objects, we will say O changes causally from the state S_a to the state S_b (including changes in position) if there is a set of physical laws L such that, under the same conditions C and as a consequence of those laws and conditions, the state of O is S_a at instant t_a and S_b at an ulterior instant t_b. In symbols:

$$\text{Causal change} \begin{cases} S_a \mapsto S_b \\ L(S_a, C, t_a) = (S_b, t_b) \end{cases} \tag{1}$$

The causal change $S_a \mapsto S_b$ can be direct, without intermediate states, in which case it will be said *canonical*. A causal change $S_1 \mapsto S_f$ can also be the result of a sequence of canonical changes:

$$\mathbf{S} : S_1 \mapsto S_2 \mapsto S_3 \mapsto \cdots \mapsto S_f \tag{2}$$

It is worth noting that every element S_n of $\mathbf{S}$ must have an immediate predecessor S_{n-1} (except the first of them S_1) so that S_n can be causally derived from S_{n-1}:

$$\forall S_{n>1} : \; L(S_{n-1}, C_{n-1}, t_{n-1}) = (S_n, t_n) \tag{3}$$

For this reason, a sequence of causal changes cannot be densely ordered. In fact, assume $\mathbf{S}$ is a densely ordered sequence of changes, and let S_λ be any element within the sequence. It is impossible for S_λ to result from a causal change of an immediate predecessor because no element of $\mathbf{S}$ has an immediate predecessor: between any two elements of a densely ordered sequence infinitely many other elements do exist. So, the causal change:

$$L(S_\mu, C_\mu, t_\mu) = (S_\lambda, t_\lambda) \quad (4)$$

is impossible, for all $S_\lambda, S_\mu \in \mathbf{S}$. In what follow all changes will be assumed to be causal changes as defined by (1), whether or not referred to as such causal changes.

The objective of our discussion will exclusively be canonical changes, be them or not forming part of a sequence of canonical changes. We will just begin by proving that if they form part of a sequence of canonical changes, that sequence can only have a finite number of steps. And the distance traversed, if any, by the corresponding object while performing the change can only be finite (think of a change in position). Indeed, let $S_1 \mapsto S_f$ be a change that takes place through a sequence **S** of canonical changes $S_1 \mapsto S_2 \mapsto S_3 \cdots \mapsto S_f$. This sequence has a first element S_1; a last element S_f; each element S_i has an immediate predecessor S_{i-1} (except S_1) and an immediate successor S_{i+1} (except S_f); no element exists between any two if its successive elements S_i, S_{i+1}; and any subsequence S' of S containing, for instance, S_v, will contain a first element preceding all elements of S' in the ordering of S, except itself: one of the elements S_1, S_2,... S_v. Therefore, **S** is a well ordered sequence to which an ordinal number ϕ can be assigned [5, p. 152]. The ordinal ϕ cannot be the least transfinite ordinal ω (the limit of all finite ordinals), because ω-ordered sequences have not a last element, while **S** has a last element S_f. Therefore, if the ordinal ϕ of **S** were a transfinite ordinal it would be greater than ω, in which case there would be a first element succeeding all elements S_1, S_2, S_3... indexed by the sequence of all finite ordinals 1, 2, 3,..., which can only be S_ω, the limit of all them [5, Theorem I, p. 158]. In consequence, there would be a canonical change $S_v \mapsto S_\omega$. But this canonical change is impossible because no finite ordinal v is the immediate predecessor of ω. So, ϕ can only be finite. We can, therefore, state the following:

> **Theorem of the finite evolution**.-In a consistent universe, the state of any of its objects at any instant of its past, present or future, can only be the result of a finite sequence of canonical changes.

We will prove now, by an argument similar to the above one, that in a consistent universe the distance between any two of its points is always finite. Recall first that a necessary condition to divide a line into infinitely many segments (a partition) is that the successive elements have a decreasing length. But what if they have the same finite length, except at most the last of them? Let us examine this possibility. Consider, for this, any two points A and B, the straight line AB, and the sequence **P** of all points of AB defined according to: $\forall P_{i\geq 1}$: iff $P_iB \geq AP_1$, take a point P_{i+1} separated from P_i by a distance AP_1. Let QB be a segment of AB whose length is just AP_1. It holds: $\forall P_\alpha \in \mathbf{P}$ and $P_\alpha \in AQ$ there is at least one point $Q' \in QB$ such that $P_\alpha Q' \geq AP1$. In consequence, there must be in QB one point P_ϕ of **P**, otherwise **P** would not contain all points P_i of AB such that $P_{i-1}Pi = AP_1$, which is not the case. So, the sequence **P** has a last element P_ϕ. The endpoints A and B and the sequence **P** define in AB a sequence **S** of successive adjacent segments: AP_1, P_1P_2, P_2P_3... $P_\phi B$ of the same length AP_1, except at most the last one $P_\phi B \leq AP_1$, all of them left-open and right-closed, except AP_1 that is closed. In the ordering **O** of **S**, there is a first element AP_1; a last element $P_\phi B$; each element P_iP_{i+1} has an immediate predecessor $P_{i-1}P_i$ (or AP_1), except AP_1, and an immediate successor $P_{i+1}P_{i+2}$ (or $P_\phi B$), except $P_\phi B$; no element exists between any two of its successive elements P_iP_{i+1}, $P_{i+1}P_{i+2}$; and any non-empty subsequence **S'** of **S**, containing, for instance, P_vP_{v+1}, will also contain an element that precedes in the ordering **O** of **S** all elements of **S'** except itself: one of the elements AP_1, P_1P_2, $P_2P_3, \ldots$ P_vP_{v+1}. Therefore, **S** is a well ordered sequence, to which an ordinal number can be assigned [5, p. 152]. In addition, **S** cannot be non-denumerable [4]. The ordinal of **S** cannot be the least transfinite ordinal ω because ω-ordered sequences do not have a last element, while **S** has a last element $P_\phi B$. So, if the ordinal of **S** were infinite, it would be greater than ω, in which case there would be a first element succeeding all elements AP_1, P_1P_2, $P_2P_3, \ldots$ indexed by the sequence of all finite ordinals 1, 2, 3,... which can only be the limit of all them $P_\omega P_{\omega+1}$ (or $P_\omega B$) [5, Theorem I, p. 158]. Take in AP_ω a point R at any given distance from P_ω less than AP_1. R could only belong to a segment P_vP_ω immediately preceding $P_\omega P_{\omega+1}$ (or $P_\omega B$). But P_vP_ω is impossible because there is not a last finite ordinal v whose immediate successor $v+1$ is ω. Hence, the ordinal of **S** cannot be infinite but finite. **S** can only have a finite number of elements. And being finite the sum of any finite number of finite lengths, AB has a finite length. This argument proves* the following:

> **Theorem of the finite distances**.-In a consistent universe, the distance between any two of its points can only be finite.

3 The problem of change

Until now we have proved nothing on the possibility or impossibility for a canonical change to occur. We have only proved they cannot form densely ordered sequences, but finite sequences through finite distances, if any. We will prove now its most astonishing characteristic: canonical changes can only be instantaneous, i.e. of a null duration. This is an essential quality of change that is at the root of all classical and modern discussions on the general problem of change. And, as we will see, it is also the reason of its inconsistency in the spacetime continuum; and the reason of its consistency in discrete spacetimes. Consider any canonical change $S_a \mapsto S_b$ of any macroscopic object O. Assume its duration is $t > 0$, being t any positive real number. For every t' in the real interval $(0, t)$, the state of our object O will be either S_a or S_b. If

*The above argument obviates some basic Euclidean reasonings.

it were S_a then the change would not yet have begun and its duration would be less than t. If it were S_b then the change would have already finished and its duration would also be less than t. But O must be in one of those two states because $S_a \mapsto S_b$ is a canonical change. It could be argued that at t', O is in a sort of mixed state $S_a * S_b$, but this would pose the problem of change in terms of the change $S_a \mapsto S_a * S_b$, or in terms of a finite sequence of canonical changes of mixed states, and mixed states of mixed states, and so on and on. Although in this case, the "on and on" has not the infinitist escape of the ellipsis (...) because, according to above theorem of the finite evolution, a sequence of canonical changes can only be finite. And being canonical, each of these finitely many changes poses the same problem of its null duration. Consequently, the duration of a canonical change is less than any real number greater than zero. And being zero the only real number less than any real number greater than zero, a canonical change can only have a null duration, i.e. it can only be instantaneous.

The above canonical change $S_a \mapsto S_b$ of the physical object O would be instantaneous if O changes from S_a at t to S_b at t', were t' would be an hypothetical immediate successor of t, so that no time elapses between t and t'. But in the spacetime continuum this is impossible, because between any two of its instants t and t', whatsoever they be, *a time greater than zero always passes*: $t - t' > 0, \forall t' \in (0, t)$. Therefore, an instantaneous change $S_a \mapsto S_b$ in the spacetime continuum implies that S_a and S_b can only be two simultaneous states. In these conditions it would be inconsistent to establish a chronological order of precedence between both states, so that none of them can be the cause of the other. We must conclude it is impossible the existence of causal canonical changes (1) in the spacetime continuum. That is to say:

> **Theorem of change**.-Causal canonical changes are inconsistent in the spacetime continuum.

Being change so omnipresent in the physical world, the above theorem of change could be indicating that the spacetime continuum could be inappropriate to represent physical space and time. Space and time could be, in fact, of a discrete nature. And, as we will see in the next section, instantaneous changes are possible in such discrete spacetimes.

4 A discrete model: cellular automata

Cellular automata like models (CALM for short) provide a new interesting perspective to analyze the way the universe could be evolving. It provides a discrete spacetime framework that makes it possible a new analysis of some of the apparently unsolvable problems and paradoxical situations in modern physics, as the problem of change, or quantum entanglement. In effect, as we will see in the next discussion, twenty seven centuries after it was posed, the old problem of change could find a first consistent solution in the discrete spacetime of CALMs. In these models, space is exclusively composed of indivisible minimal units called cells, here referred to as *geons*. Time is also composed of a sequence of successive indivisible units: *chronons*. No extension exists between a geon and its immediate successor in any spatial direction. Similarly, no time elapses between a chronon and its immediate successor.

Each geon of a CALM can exhibit different states each of them defined by the current values of a certain set of variables, the same for all geons. The states of all geons of a CALM change simultaneously at each successive chronon in accordance with the laws driving the evolution of the automaton. Once changed, the state of each geon remains unchanged for one chronon (in what follows we will assume this is the case, although in the place of one chronon, the state of each geon could also remain unchanged for a certain (natural) number of chronons). Let u, v, $\ldots z$ be the set of variables defining the state of each geon of a certain CALM $\mathbb{A}$. Let us represent the nth state of each geon γ_i by $\gamma_i(u_n, v_n, \ldots z_n)$, where u_n, $v_n \ldots z_n$ are the particular values of the state variables at the nth chronon t_n. Finally, let L be the set of laws driving the evolution of $\mathbb{A}$. L determines the way in which each geon γ_i changes from a chronon t_n to the next one t_{n+1} taking into account the state of γ_i as well as the state of any other geon with which it interacts, which may include all geons. All these current states define the conditions C_i under which the laws L of $\mathbb{A}$ operates and changes the state of each of its geons γ_i. The automaton engine changes the state of each geon at each chronon and maintains it just for one chronon. Thus we can write for each particular geon γ_i:

$$L(\gamma_i(u_{i,n} \ldots, z_{i,n}), C_n, t_n) = (\gamma_i(u_{i,n+1} \ldots, z_{i,n+1}), t_{n+1})$$
$$L(\gamma_i(u_{i,n+1} \ldots, z_{i,n+1}), C_{n+1}, t_{n+1}) = (\gamma_i(u_{i,n+2} \ldots, z_{i,n+2}), t_{n+2})$$
$$L(\gamma_i(u_{i,n+2} \ldots, z_{i,n+2}), C_{n+2}, t_{n+2}) = (\gamma_i(i, u_{n+3} \ldots, z_{i,n+3}), t_{n+3})$$
$$\vdots$$

This behaviour of a CALM resembles the way a computers works, each chronon being a pulse of its clock and each geon an indivisible position of its memory. Being both space and time discrete, each chronon t_n has an immediate predecessor t_{n-1} and an immediate successor t_{n+1}, so that no other chronon elapses neither between t_{n-1} and t_n nor between t_n and t_{n+1}. Or in other words: no time passes between any two successive chronons. This simple characteristic of CALMs suffices to solve the problem of change: in a discrete spacetime instantaneous changes are possible. Indeed, the state $\mathbb{A}_n$ of the CALM $\mathbb{A}$ at chronon t_n changes to the state $\mathbb{A}_{n+1}$ at the next chronon t_{n+1} so that no chronon elapses between t_n and t_{n+1}. And this is possible because the state of each geon is updated at each chronon and maintained just for one chronon. So, in CALMs, the problem of change does not arise. Obviously, a CALM is a simplified model of a discrete reality of which we know practically nothing on its functioning. It would be new paradigm of reality. But one in which change is consistently possible, which makes it more attractive.

It seems convenient to recall at this point that our sensory perception of the world is continuous. This is why we always think in terms of a spacetime continuum. So far, our only way of thinking about reality. All our models of the physical world assume it is a continuous world. It is then almost inevitable to extrapolate this way of thinking to any new discrete paradigm, which would be catastrophic. To think in (physical) discrete terms will surely require a long process of reeducation. The state of an electron, for example, could be S_1 at instant t_1, and S_2 at a posterior instant t_2, without ever being in any intermediate state between S_1 and S_2 (quantum jump). It is therefore a canonical change. In the spacetime continuum the interval (t_1, t_2) must always be greater than zero, and during that time the electron cannot be neither at S_1 nor at S_2, nor at an intermediate state between S_1 and S_2. During that time the electron could not exist. It must disappear at t_1 and reappear at t_2. In the digital spacetime of a CALM all we have to do is to consider two successive chronons, t_1 and t_2. At t_1 our electron would be in the state S_1 and at t_2 in the state S_1. By way of example, assume that:

- The universe has 2.66×10^{185} geons (for example of a Planck volume).
- The universe contains 10^{80} elementary particles.
- Each particle is defined by p variables
- Each particle is, somehow, present in each geon.
- Each geon is updated at each successive chronon (for example of a Planck time duration).

Let $\mathbb{U}$ be a 3-dimensional CALM of 2.66×10^{185} geons in which the state of each geon is defined by $p \times 10^{80}$ state variables. If it were possible to simulate $\mathbb{U}$, perhaps we could observe the self-organizing and evolution of an object similar to our universe, whenever we know the whole set of physical laws driving its evolution. $\mathbb{U}$ would be incomparable less complex than, for instance, any matrix of infinite elements (which are usual in mathematics and theoretical physics). Colossal as it may seem, our CALM model $\mathbb{U}$ would be a finite object and then composed of a number of elements incomparably less than the number of points ($2^{\aleph_o}$) of, for example, a lineal interval of Planck length in the spacetime continuum. In addition, while points and instants of the spacetime continuum have no physical significance (they are primitive concepts), each geon of our $\mathbb{U}$ model would be plenty of physical meaning: the current values of its defining variables, which could be sufficient in order to define physical objects of any size in terms of sets of linked geons that evolve and move through the whole fabric of $\mathbb{U}$'s geons. On the other hand, to simulate does not means to reproduce the exact history of the universe: recursive interactions between geons and the resulting non-linear dynamics open the door to unexpectedness and diverseness. At least, we could use $\mathbb{U}$ as a theoretical reference to grasp the essence, magnitude and possibilities of real universes of a discrete nature in which change is consistently possible.

5 Discrete relativity

We have developed several discrete (digital) geometries in which the continuum space plays no significant role. We have also developed computational geometry, whose main objective is the construction of algorithms oriented to represent in graphic terms geometrical objects (see, for instance [7], [6]). But we know nothing on the type of the discrete geometry required by a CALM. Notwithstanding, some elementary conclusions can be logically drawn from the own concept of discreteness. For instance, integer numbers should play in CALMs the same role as the real numbers in the spacetime continuum; the distance between two geons should be an integer number of geons; the interval between two chronons an integer number of chronons; the number of geons of the hypotenuse of a right triangle should be equal to the number of geons of its greater leg (Pythagoras digital theorem); nothing can move a distance less than one geon; nothing can last less than one chronon; speed should be defined as the ratio of the integer number of geons an object traverses to the integer number of taken chronons; there would be a maximum speed of one geon per chronon. In addition, if a CALM is isotropic, as physical space seems to be, its geons should be anyway isometric.

It is interesting and immediate to convert between continuous and discrete hypotenuses. For this, let λ be the length of a geon, and h, x and y the respective number of geons of the hypotenuse and legs of a right triangle. Assume $x < y$. In the discrete geometry of CALMs we will have: $h = y$. In classical Euclidean geometry the length of the hypotenuse will no longer be $h\lambda$ but $h'\lambda$, being $h' > h$, because it is greater than the length $y\lambda$ of its greatest leg (note that while h, x and y are natural numbers, λ and h' are real numbers). According to classical Pythagoras theorem, we can write:

$$(h'\lambda)^2 = (x\lambda)^2 + (y\lambda)^2 \tag{5}$$

$$y = \sqrt{h'^2 - x^2} \tag{6}$$

The ratio between the continuous and the discrete hypotenuse can be written:

$$\frac{h'\lambda}{h\lambda} = \frac{h'}{h} = \frac{h'}{y} = \frac{h'}{\sqrt{h'^2 - x^2}} = \frac{1}{\sqrt{1 - (x/h')^2}} \tag{7}$$

were the last term on the right side of (7) as the algebraic form of the relativistic Lorentz factor γ. Let us rewrite it as:

$$\frac{h'\lambda}{h\lambda} = \frac{1}{\sqrt{1 - (x\lambda/h'\lambda)^2}} \tag{8}$$

Assume now a photon ϕ moves through a vertical distance $y\lambda$ in the rest frame RF_o of its source. If ϕ moves the same vertical distance $y\lambda$ from the perspective of another inertial frame

RF_v while RF_o moves with respect to RF_v the horizontal distance $x\lambda$ at a uniform velocity v parallel to X_v for a time t_v, then ϕ moves along the hypotenuse of a right triangle whose legs are $y\lambda$ and $x\lambda = vt_v$, We will have $h'\lambda = ct_v$. And then (8) can be written:

$$\frac{h'\lambda}{h\lambda} = \frac{1}{\sqrt{1-(x\lambda/h'\lambda)^2}} \quad (9)$$

$$= \frac{1}{\sqrt{1-(vt_v/ct_v)^2}} \quad (10)$$

$$= \frac{1}{\sqrt{1-(v/c)^2}} = \gamma \quad (11)$$

which proves the ratio between the continuous hypotenuse and its corresponding discrete alternative is the relativistic Lorentz factor γ. This result suggests that a discrete interpretation of special relativity could be possible. Special relativity could be, in fact, the consequence of explaining a discrete, discontinuous, world in terms of the continuous mathematics the spacetime continuum. Or in other more expeditious words: the result of explaining a consistent discontinuous reality in terms of an inconsistent continuous reality. Strange as the new discrete paradigm may seem, let us end by indicating some of its possible advantages:

1. The problem of change would no longer be a problem, and a consistent understanding of the physical world would be possible, which until now is not the case.
2. The Second Principle of relativity would not be necessary because in a discrete spacetime there is an insurmountable velocity of one geon per chronon.
3. The flow of time and its irreversible directional arrow, enigmatic from a spacetime continuum perspective, is naturally explained in CALM terms. The slippery concept of *now* could also be easily explained in CALM terms.
4. While points and instants of the continuum spacetime are primitive concepts devoid of physical meaning, and then hard to link with physical reality, geons and chronons are plenty of physical significance.
5. All known physical objects and magnitudes, just except spacetime, are discrete, with indivisible units. In CALMs there is no exception, space and time are also discrete.
6. Quantum entanglement and related questions could be naturally explained in terms of the synchronized evolution of geons.
7. The incessant quantum activity of free space (vacuum) could be better explained in terms of CALMs than it is in terms of the points and instants of the assumed spacetime continuum.
8. General relativity and quantum mechanics would have a new discrete opportunity to meet each other [1].
9. Being finite in time and size, a CALM is simplest than any other infinitist alternative, as the continuum spacetime.
10. Physics would no longer depend on the consistency or inconsistency of the Axiom of Infinity. After all, an axiom is an axiom, and in this case one suspicious of being inconsistent [9]. Getting rid of (the teoplatonic) infinities would be good news for everyone, particularly for physicists.

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