Space-time: Reality and information as indistinguishable entities.

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Abstract

Space-time is a structure that reveals the indistinguishability between reality and information. For this we analyze the models of classical physics, relativistic physics and new theories created for the purpose of unifying forces, such as string theory and M-theory. In all these models space-time appears as an abstract structure in which physical phenomena take place, providing no justification for its true nature, so that its observation or measure is always indirectly realized through mass-energy. The analysis of the mentioned models shows a clear structure of irreducible functional layers of increasing complexity, which may have no end, and in which a fundamental premise is the formal consistency of the models in which the information process is an element of reality. The analysis also shows how finally space-time can be the most complex physical object, since it is where all physical phenomena take place and in which, although it may seem something totally natural, there is only one temporal dimension, which should be a subject of study. Finally, the principle of reality is postulated, so that any consistent structure of information processing can be an element of reality.

Keywords: Space-time, classical physics, general relativity, string theory, M-theory, reality, information, indistinguishability, layered structure, irreducible functionality, principle of reality.

Introduction

The hypothesis that reality and information are the same entity has led, from the point of view of computer theory and information theory, to establish that its thesis is an undecidable problem and therefore reality and information are indistinguishable entities [1]. This means that any observable system can be described by a formal model underpinned in the information process, so that both entities in their context will be indistinguishable. At this point it is necessary to emphasize that the term information corresponds to the axiomatic process of information according to the concepts of the Turing machine or the algorithmic information theory.

We can test this thesis in any realm of reality: social, individual, biological or physical, for which we can find two types of problems that hinder this task. The first is the lack of a formal model to describe reality, so that conclusions cannot go much further than intuition itself. The second problem is related to the complexity of the specific case of study, since, according to information theory, there are structures that can only be represented by themselves and that due to their enormous complexity is not easy to extract or formalize behavior patterns. An example illustrating this situation is the description of the Universe as a whole, which, assuming the hypothesis that nothing beyond it can be posed, can only be represented by itself.

Examples can be shown where it is very complex to establish formal models. This is the case of the phylogenetic tree that establishes the evolutionary relationship of species and which consists of a taxonomy based on species, genus, family, etc. If we consider the number of known species that exceed one million, as well as those not discovered in the fossil record and those that have left no trace, we can get an idea of its enormous complexity. If we add that evolutionary biology [2] states that evolution is determined fundamentally by chance at various levels, such as genetic mutations or geological and astrophysical events, we can conclude that it is not possible to establish an evolutionary model, simply we have to conform to the results offered by the evolution and its description is the information that represents such evolution. Even so, it is possible to perform a structuring, grouping the organisms into categories, resulting in a phylogenetic tree in which the bifurcation is a characteristic pattern resulting from the dynamics of deterministic chaos.

However, when the system is composed of a large number of entities or individuals with similar characteristics, it begins to show regularities in its behavior, so that, above its random nature, patterns of behavior can be identified that can be modeled in compact form by analytical expressions or, in more general terms, by means of algorithms. This is the behavior that sustains areas of knowledge such as psychology or sociology or new phenomena such as the "Big Data" that somehow allows to analyze and anticipate the individual or social behavior of humans and society [3], these being paradigmatic examples of the indistinguishability between reality and information.

Undoubtedly, where the establishment of formal models has been most successful has been in the field of physics, so it is in this area of knowledge where we can delve deeper into the thesis of indistinguishability between reality and information. In fact, success has been of such magnitude that we often do not distinguish the model from reality, so underlying phenomena are obviated. But the chaotic nature of our universe emerges when we try to analyze complex processes in detail, as in thermodynamic systems, fluid mechanics, celestial mechanics or quantum mechanics. And it is that behind all of them finely appears the Heisenberg uncertainty principle, as it demonstrates the quantum origin of the structure of the universe [4], reason why in essence there should not be any conceptual difference between the physical models and the rest of models that can be established in other areas of knowledge. In this essay we will use space-time as a case study, since it is the object of reality that appears in every physical model.

Space-time: An abstract structure

From a sensorial point of view, the space-time concept is something totally internalized by the human mind, since much of our activity develops within. Here, it is interesting to note that there are human activities beyond space-time, which we can define as virtual activities and that we will leave aside in the present analysis. From the physical perspective space-time is a manifest reality since we can perform precise measurements in three spatial dimensions and in a single temporal dimension. However, in physical models space-time appears, so far, as a totally abstract reality without any physical content and that in the case of space we define it as "vacuum". Thus, in Newtonian theory, massive bodies can be moved inertially within the vacuum, being able to be accelerated by external forces and interact among them by means of the force of gravity. In this model, space is nothing more than an abstract element that constitutes the reference system, but from the physical point of view it is a passive element. In short, we find a model in which an essential component is the pure information necessary to describe space-time coordinates.

Of course, the model not only works, but its creation was a major achievement in the development of physics and mathematics. But Newton himself was forced to ask questions of great depth such as the existence of an absolute reference system, which requires the provision of meter sticks and clocks distributed continuously throughout space, or creating virtual forces as is the case of the centrifugal force that led to a case study known as "Newton's cube", which triggered a strong controversy with Leibniz and that today is not satisfactorily solved. We must add that the model provides no justification for the existence of the force exerted through a distance by gravity, nor the medium in which the potential energy lies. In this way, when the distance between massive bodies increases their kinetic energy decreases, increasing the potential energy of the system, which recovers again when the two bodies re-approximate, so we have to ask where the potential energy is stored, since the kinetic energy materializes in the velocity of the mass according to the expression $\frac{1}{2}m \cdot v^2$.

An indication that the vacuum is something more than a mathematical structure arises with the development of electromagnetism, since this theory predicts the existence of electromagnetic waves that propagate through the vacuum at a speed $c = 1/\sqrt{\varepsilon_0 \cdot \mu_0}$. So it was postulated the existence of a material medium called Ether necessary to support the propagation of electromagnetic waves. However, the Michelson-Morley experiment refuted its existence by finding that the speed of light was identical in all directions regardless of the Earth's translational motion through the Ether, leading to the conclusion that the velocity of light is an invariant and independent of the observer. On the other hand, Maxwell's equations are not invariant in a Euclidean space when a coordinate change is made, being solved by the Lorentz transformations under which the Maxwell equations are covariant, which means that they remain unchanged under this transformation. All this led to the geometric formulation of special relativity (SR) [5] describing space-time according to the velocity of an inertial observer through the Minkowski space, in whose metric there are two fundamental invariants, the space-time interval $ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$ and the energy-momentum vector whose magnitude is $E^2 - (\mathbf{p}c)^2 = (mc^2)^2$. In short, SR is a model of the behavior of inertial systems, that is, systems not subjected to acceleration, which establishes that space-time is an observable dependent on the inertial velocity of the reference system. Namely, the SR considers space-time as an abstract geometric entity, offering no physical explanation of why moving clocks seem to be moving at a slower rate, moving objects appear contracted and objects in inertial motion do not interact with space-time.

In order to explain the behavior of accelerated systems, Einstein first defined the equivalence principle (EP), which states that physics in a free fall system in a gravitational field is equivalent to physics in an inertial system without gravity. From this, in free fall the gravitational field will be compensated by the acceleration of the system and there will be no sign of gravity or acceleration and therefore no means of detecting them. Consequently, physics in a non-accelerated system with gravity $\mathbf{g}$ is equivalent to physics in a system without gravity but with acceleration $\mathbf{a} = -\mathbf{g}$. Einstein extended the principle of equivalence not only to the gravitational mass and the inertial mass but to all physics, which leads to the curvature of space-time by the effect of gravity and that becomes evident in the gravitational redshift of photons and their geodesic trajectory.

Later, Einstein completed the general relativity (GR) model [5] as a geometric theory of gravity, based on Riemannian geometry and tensor calculus and formally expressed by the field equation $G_{\mu\nu} = \kappa T_{\mu\nu}$. Where, $G_{\mu\nu}$ is the space-time curvature tensor which is a function of the metric tensor $g_{\mu\nu}$ through the Ricci tensor and the derivatives of the metric tensor (Christoffel), $T_{\mu\nu}$ is the energy-momentum tensor, that is, the description of the energy-momentum distribution existing in space-time, where κ is a constant $\kappa = -8\pi G_N/c^4$ and G_N is the Newton's gravitational constant. It must be considered that the metric tensor and the energy-momentum tensor depend on the reference system, but the field equation verifies the general principle of covariance, so that it is verified that:

- The measure of the space-time interval $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$ is an invariant.
- In a local inertial reference system the field equation is reduced to that determined by SR.

It is also verified that the divergence of the curvature tensor is zero, and as a consequence the divergence of the energy-momentum tensor will be zero, so that the amount of energy-momentum of the system is kept constant.

The solution of the field equation determines the dynamics of the system in such a way that the distribution of energy-momentum establishes the geometry of space-time $g_{\mu\nu}$ by which mass-radiation travels along space-time geodesics. To be more specific, according to GR, what happens when two orbiting massive bodies is that they both deform the surrounding space and follow a geodesic trajectory of minimal space-time length, so that they do not actually directly exert a force of gravity between them, but it is a feedback interaction between the masses and space-time that determines the trajectory of the bodies, so there is no force at a distance between them.

The field equation is a symmetric tensor structure of rank 2 (4 space-time dimensions). This means that the tensors have 16 components that form a symmetric structure of 4x4, which requires solving 10 nonlinear differential equations, 4 of which are redundant as a consequence of the divergence of the tensor of curvature being zero, so that for its resolution requires additional conditions. In practice, all this involves a problem of enormous complexity and as it has been justified [1] it will not admit analytical solutions in the majority of the cases. However, there are solutions for simplified cases such as the Minkowsky metric corresponding to an energy-momentum free space, described by SR, or the case of the field created by a homogeneous spherical mass known as the Schwarzschild metric. From the point of view of cosmology, a case of great importance is the cosmological model FLRW (Friedmann-Lamaître-Robertson-Walker) corresponding to the solution of the field equation for a universe in which the cosmological principle is verified (CP), that is, in an isotropic and homogeneous universe.

The CP implies that the curvature of space-time must be constant at all points, being able to take values k = + 1.0, -1. According to the FLRW model, the time space metric turns out to be:

$$ds^2 = c^2dt^2 - dl^2 = c^2dt^2 - R^2(t)[dr^2/(1-kr^2) + r^2(d\theta^2 + sen^2\theta d\phi^2)]$$

So that, to have a more intuitive view, it is interesting to embed the spatial part of the expression into a 4-dimensional Euclidean space, which for k = 1 and through the transformation $r = sen\,\psi$, we get:

$$dl^2 = R^2(t)[d\psi^2 + sen^2\psi(d\theta^2 + sen^2\theta d\phi^2)],$$

that corresponds to a sphere of 4 dimensions of radius R, that is, to a closed universe. In a three-dimensional space, the spatial part would correspond to the surface of a sphere of radius R that would vary over time, giving a rather intuitive idea of the structure of space-time. Similarly, we can make this embedding for the case of a curvature $k = -1$ by means of the transformation $r = senh\,\psi$, resulting in a 4-dimensional hyperboloid, corresponding to an open universe. For $k = 0$ the expression of the space part corresponds directly with an ordinary Euclidean space and consequently a flat universe.

The solution of the field equation, assuming the FLRM metric and considering the energy-momentum tensor produced by an ideal fluid, results in the so-called Friedmann equations, which determine the evolution of the scaling factor $a(t) = R(t)/R_0$ for each of the possible universe types determined by the curvature k. The result of these equations agrees with the observations of Hubble and predicts a decelerated expanding universe, that in the case of a closed universe and for a threshold of the density of radiation-matter the process of expansion would reach a maximum point, reverting the process until arriving to a collapse of the universe $(a = 0)$, called "big crunch". It is as if at the origin of the universe there had been an explosion that propelled the matter-energy and that gradually is decelerating by the effect of gravity. Thus, if the density of matter-energy were low, the expansion process might have no end, or, conversely, if the density were high, the effect of gravity would ultimately prevail over the kinetic energy produced by the explosion.

The problem is that this interpretation does not correspond at all with observations, which indicate that the expansion of the universe is not slowed down and even the recent measures indicate that it is in an accelerated process [6], reason why the model of explosion is not correct. In addition, this model requires the preexistence of space, something that contradicts the fact that there are objects that are separating at a faster rate than light, which indicates that matter-energy is intimately embedded to an expanding spatial structure. Thus, in the simplified model in which spatial component is embedded in a spherical surface, the relative velocity of the points of the spherical surface by increasing the radius of the sphere is a virtual velocity. This indicates that the redshift of photons is not the result of the Doppler effect, but is a consequence of the expansion of the space in which the photon itself is embedded. This in turn raises a question regarding the energy conservation principle in the comoving frame, as a consequence of the loss of energy of the photon.

The CP can clarify the vision of what happens at cosmological distances. Since at this scale the universe is homogeneous and isotropic, which agrees with the observations, no point is distinguishable from another, so that the gravitational forces produced on a point by the rest of the universe will be zero, producing no gravitational deceleration effect. The gravitational effect will only be observable locally, since at this scale the mass-energy distribution is not homogeneous producing the curvature of space-time and establishing the dynamics between space-time and mass-energy. Gravitational effects must materialize through gravitational waves, that is to say, through gravitons that must be energy-carrying particles (bosons), so they will be subject to the same interactions with space-time as photons. Consequently, at great distances the gravitons will suffer a decrease of energy that must be transferred to space-time. Consequently, photons and gravitons, as energy-carrying particles, must in fact be the engines of expansion of the universe, creating space-time. This indicates that the universe could be an expanding structure until the available energy in the form of bosons is exhausted. In this sense, Friedmann's equations assume an energy-momentum tensor determined by an ideal fluid, in which the possible interactions between space-time and energy-carrying particles, such as photons and gravitons, are not considered. This would justify their disagreement with the observations.

As a consequence of the inflationary result of Friedmann's equations, Einstein introduced a modification in the field equation, in order to make space-time flat and static, resulting in the expression $G_{\mu\nu} - \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$, where Λ is the cosmological constant. The introduction of the cosmological constant has been a controversial subject, since it involves the introduction into the field equation of an arbitrary parameter and also does not explain satisfactorily the vanishing of the gravitational effect at great distances. But observations concerning a possible accelerated expansion of the universe have revitalized the existence of that term in the field equation, now being interpreted as the dark energy or vacuum energy [7]. However, reasoning about the interaction of space-time with electromagnetic and gravitational radiation should guide the problem in the direction of defining a moment-energy tensor that contemplates the energy-momentum exchange between ordinary particles and space-time, so that one can delve into the complex structure of the vacuum, beyond the abstract space-time concept.

Returning to the central theme of the present analysis, which is the determination of the nature of space-time, we conclude that it must be a physical entity similar to the physical world of particles, since they are entities that interact with each other. But GR is only a model of mass-energy dynamics in space-time, this being a geometric element without physical identity. Thus the model provides no hint of fundamental aspects such as the causality of the universe, the relative observation of space-time, the mechanisms behind inertial movement or accelerated motion. Consequently, GR consolidates space-time as an abstract geometric entity with no other physical content than the determination of space-time dynamics of the physical entities contained within it. Thus, space-time would be no more than a description of the relationship between physical entities of mass-energy and therefore nothing physical. But this leads to a contradiction, since we should then fill in all space-time not occupied by mass-energy with other physical entities, in order to explain the physical interaction between mass-energy and vacuum. From the point of view of GR, the nature of space-time is similar to the classical view in which distances sticks and clocks must be available, providing no physical justification for this. Although there is a fundamental difference, since in the case of GR the space-time marks are dynamic and dependent on the observer.

But the establishment of space-time as a physical entity seems to contradict the hypothesis that reality and information are indistinguishable entities. However, it should be pointed out that the idea that space-time is a physical reality does not change at all the emergent model described by GR. Thus, space-time will only be an emergent reality of a more complex underlying model, which means that we can assimilate it with an observable and irreducible geometric entity that has very little to do with the underlying reality that supports it. Put simply, this underlying reality would constitute a structure that will determine the space-time relationship between the observable particles at the emerging reality level, so the observed space-time will be no more than a perceptual "illusion". A pertinent question is how it is possible that what we define as "vacuum" can be a complex physical structure. The answer may lie in the fact that the means for their observation are always indirect through physical entities with mass-momentum properties. Nevertheless, there are some observations of the complexity of the vacuum that go beyond the mere observation of space-time such as the Casimir effect [8] or the vacuum polarization [9].

Extradimensional space-time

The objective of the unification of gravity with the rest of the forces in a quantum context seems to require a space-time with a number of dimensions greater than the one observed in classic scale. Intuitively it is possible to put clear examples that suggest this need, as it is the case that the electrons of the atoms do not radiate, suggesting the existence of a species of quantum cavity at atomic scale, which would require the existence of additional spatial dimensions at such scale. However, what has driven the definition of extradimensional spaces of greater order has been the objective of unification of gravity with the rest of the forces.

The first physical model, in which an extradimensional space of 5 dimensions, 4 spatial and 1 temporal appears, is that of Kulula-Klein, whose objective was the unification of gravity and electromagnetism. But the unification of all forces within the framework of field theory and quantum physics has led to the definition of string theory [10]. Without going into details of its development, there are 5 versions within a context defined as superstring theory, named type I, IIA, IIB, heterotic SO (32) and heterotic E8xE8, from which emerges one-dimensional vibrational states, in a space of 10 dimensions, 1 temporal and 9 spatial, of which 3 are observable at the classical level and 6 are compacted, which means that they close on themselves on a reduced scale. The idea is that these states called strings can justify all particles and interactions between them. Currently, M-theory conjectures that the five types of string theory are limiting cases of a single theory defined in a space of 11 dimensions, 1 temporal and 10 spatial, in which new mathematical objects called branes appear.

String theory is controversial because there is currently no experimental result to justify it, presenting technological difficulties for its corroboration far beyond the current capabilities. However, it provides arguments in relation to the hypothesis that reality and information are somewhat indistinguishable:

- It is a strictly mathematical model in which the number of dimensions is determined by criteria of mathematical consistency.
- Space-time is an abstract entity in which mathematical objects interact.

Consequently, string theory and M-theory implicitly support the hypothesis that reality and information are indistinguishable, at least in the sense that the description of reality must correspond to a model of consistent axiomatic information processing.

The fact that the mathematical objects resulting from string theory have a complex structure in space-time returns to the same situation as described above with relativistic space-time, since it assumes that these objects have a finite dimension in an abstract space-time, with the difference that now the scale is much smaller. This means that strings and branes, which from the physical point of view would be objects of reality, have a complex structure in space-time, so their justification would require new elementary objects corresponding to an underlying functional layer.

Thus, string theory or M-theory would be no more than the description of an underlying functional layer that would irreducibly support the emergent functional layer of particle physics in a space-time of compacted dimensions, in which extra dimensions have vanished. But it is also clear that string theory or M-theory must be supported by an underlying reality that can justify strings or branes as well as extradimensional space-time, since these are complex structures. This stratification of irreducible functional layers must be such that their complexity is increasing as we go deeper into it, since, according to information theory, it is not possible to create a complex description from a simpler one.

Finally, the temporal dimension is an issue that has not been analyzed in this essay, it should be noted that in string theory and in M-theory there is only one temporal dimension, analogously to the other existing models of reality. Although this may seem natural, the fact that we can pose multidimensional space-time structures in which the time dimension is always restricted to a single one, it is an issue that must be analyzed.

Conclusions

From the analysis of the models of classical physics, relativistic physics, string theory and M-theory can be deduced that space time is nothing more than an emerging reality of a more complex underlying physical structure that is equivalent to an abstract model of information process and therefore indistinguishable from such model. Thus, in the case of classical physics and relativistic physics, space-time emerges from a reality that is observed by its interaction with mass-energy, but which hides its internal nature, and which really only materializes as something abstract in the mathematical models and consequently in the systems of perception. Consequently, it can be said that it corresponds to a virtual reality and therefore to a purely informative structure.

When it comes to go deeper into the underlying structure, as is the case of string theory or theory M, this situation is repeated again, so that it could be said that space-time is only a consequence of Information that remains hidden in a system structured in irreducible functional layers, whose complexity grows as we go deeper into it. In short, space-time is a clear example of how reality and information are indistinguishable concepts. Thus, observed space-time can be considered a physical reality at different levels, but also an abstract information structure.

The indistinguishability between reality and information allows postulating a principle, which could be defined as reality principle, in such a way that any consistent axiomatic information process structure can be an element of reality. Conversely, every element of reality will correspond to a consistent axiomatic information process structure, something that is systematically assumed.

The fact that space-time models have a single time dimension is an aspect that should be analyzed in depth.

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