4 About the Substantival Nature of Spacetime

Anguel S. Stefanov

Abstract The relationist-substantivalist debate about the nature of spacetime has not still come to an end. The aim of this paper is to present and analyze four arguments in support of the substantival nature of spacetime. The first one is an argument based on chirality. The second and the third one take into account the cosmological constant and the gravitational waves respectively, as displaying non-relational qualities of spacetime. And the fourth argument involves an arguable interpretation of the basic equation in the theory of general relativity, pretending to be the only consistent one. It is my claim that this fourth argument provides a general ontological framework for the validity of the first three arguments.

1 Introduction

Since the Newton-Leibniz debate about the substantival or relational nature of space and time the problem is still going to be a bone of contention among philosophers.

> There are two venerable traditions in the philosophy of space and time. One is 'substantivalism', which maintains that space and time (relativistically, spacetime) are objects that exist *in addition to* ordinary material objects such as tables and chairs. The opposing tradition, 'relationism', rejects the existence of space and time (spacetime) and maintains that all that exists is material objects. According to traditional relationism at each time there are spatial distances between material objects and there are temporal distances between events involving these material objects. [2, p. 125, my italics]

My paper will neither be based on historical facts about the debate, nor on the cogent arguments offered by Frank Arntzenius [2] in favour of sub-

A. S. Stefanov, M. Giovanelli (Eds), *General Relativity 1916 - 2016. Selected peer-reviewed papers presented at the Fourth International Conference on the Nature and Ontology of Spacetime, dedicated to the 100th anniversary of the publication of General Relativity, 30 May - 2 June 2016, Golden Sands, Varna, Bulgaria* (Minkowski Institute Press, Montreal 2017). ISBN 978-1-927763-46-9 (softcover), ISBN 978-1-927763-47-6 (ebook).

stantivalism. Its aim is the explication and the analysis of four relatively independent arguments supporting the substantival nature of spacetime. I say that these arguments are relatively independent not because they share some common theoretical parts, but because the fourth of them (the argument from a consistent interpretation of the basic equation in general relativity) may be considered to provide a general ontological framework for the first three.

2 Argument based on chirality

Incongruent counterparts are mirror objects, which, though being quite similar like the left and the right human hands still cannot be superimposed on each other through ordinary translations and rotations within a fixed orientable space. A left glove cannot fit a right hand, and vice versa. For the first time the possibility for the existence of such objects was taken as an argument for the existence of the absolute Newtonian space in the last pre-critical work of Kant from 1768 [6]. But if the argument is correct, and the absolute Newtonian space exists, then the three-dimensional physical space is substantival, and not relational.

If only one human hand existed in the world, Kant contended, it would be either a left, or a right hand. Relationists disagree, insisting that a single hand could neither be qualified as a left, nor as a right one, since there is no other object to be involved in relation to the solitary hand, so that its handedness to be ascertained. Let us imagine to this effect the existence of a suitable "referent object" alongside the lonely hand, and let the referent object be a handless human body. Then we may see to which of the two wrists of the body the hand will match. Suppose it matches the right wrist. Thus the right-handedness of the hand would be ascertained. But without the referent body no right-handedness of the solitary hand exists. Its righthandedness comes as a result of a relation to the handless body and is not a property of the hand itself, if it were the only existing thing in the universe.

There is a clear objection to this criticism. Let us revisit Kant's story with the solitary hand. It was accepted that it was the only existing thing in the universe, till the handless human body has come into being. The objection states that the hand was a right one even before the appearance of the referent object. Indeed, the appearance of the handless body does not affect the nature of the hand that was created before the body. The appearance of the latter does not affect the spatial characteristics of the region where the hand was situated, as well. But if so, then it certainly follows that the solitary hand was right for all of the time of its existence, and the referent body serves only for its right-handedness to be observed, and in no way to be created.

This objection supports the substantival nature of space, since it is an argument that space has something to do with the concrete handedness (chirality) of the hand. But what answer could be suggested to the question why a lone hand is either right or left *per se*. A general idea for such an answer was proposed for the first time in the same work of Kant [6, p. 20, original italics]:

> [M]y aim in this treatise is to investigate whether there is not to be found in the intuitive judgments of extension, such as are contained in geometry, an evident proof *that absolute space has a reality of its own, independent of the existence of matter, and indeed as the first ground of the possibility of the compositeness of matter.*

That absolute space, as a reality of its own, can be looked upon "*as the first ground of the possibility of the compositeness of matter*" is an original idea that has an explanatory potential. It implies the assumption that some inherent features of space (for instance the specific metric and topology of a space) could affect (at least) the in/congruency of geometrical objects. Thus incongruent geometrical figures drawn on a plane, to continue the story by flat images of left and right human hands, can become congruent counterparts, if placed on a Möbius strip, representing a non-orientable two-dimensional space. Kant was not in a position to develop further his original idea on the background of the classical physical and mathematical knowledge of his time. Nevertheless, he was not surprised that incongruent counterparts might display a functional asymmetry concerning some of their exhibited properties, like those of left and right human hands and ears [6, p. 30].

Having in mind the parity violation in the micro-world, Kant's argument could be extrapolated to the effect that if there were only one weak interaction breaking the CP-symmetry (the charge conjugation – parity symmetry) in the universe, it would do so. The difference now is that such a quantum process takes place in spacetime. But what is the role of time here? Its role is to restore the symmetry at a deeper level. A quantum physical system is invariant only with respect to the triple CPT transformation, including the operation of time reversal.

If spacetime had a relational nature, the last two statements could hardly be taken to be meaningful, because in a purely relational context they would have no reasonable explanation. Moreover, if spacetime had a relational nature, it would have no impact on the symmetry of physical interactions. Spatial distances and time intervals would be kept the same under rigid and symmetrical transformations, because spacetime is accepted to emerge *out of the relations* among material objects and force fields. But if it is true that symmetries are sometimes broken in isolation, or in couples, it comes out that spacetime affects the compositeness of matter (instead of being dependent on the latter), and thus has a substantival nature.

3 Argument concerning the cosmological constant

When A. Einstein firstly wrote his equation of the general theory of relativity, he introduced an additional term, known as the cosmological constant, so that the equation could describe a static Universe. When astronomic observations showed that this was not the case, he removed this term. However, 43 years after Einstein was gone, observations showed not only that the Universe is expanding, but that its expansion is accelerating. Contemporary cosmologists re-introduced Einstein's cosmological constant. They have done this for the sake of a consistent explanation for the observed acceleration of the expansion of the Universe. But even if this acceleration would not be confirmed by interpreting new astrophysical observational data, the universal expansion is an established fact, and it is certainly in need of an explanation.

> As well as matter, the universe may contain what is called "vacuum energy", energy that is present even in apparently empty space... vacuum energy causes the expansion to accelerate, as in inflation. In fact, vacuum energy acts just like the cosmological constant... that Einstein added to his original equations in 1917, when he realized that they didn't admit a solution representing a static universe. [5, pp. 96-97]

The energy ruling the expansion of the Universe, known by its popular name today as dark energy, is a fundamental quality that cosmologists refer to the "empty" spacetime itself. Dark energy opposes the effect of the universal gravitation that is empirically expressed by the well-known attractive force among material bodies. This force is inversely proportional to the square of the distances among material bodies, so that the gravitational interaction becomes weaker in an expanding space shifting material configurations aside from each other. However, if dark energy expressed by the cosmological constant is a quality of spacetime itself, its anti-gravitational effect ought to be one and the same independently of the fact how much the universal space has been expanded. Thus one may certainly expect that there must be a stage in the evolution of the Universe, when the effect of the dark energy would become stronger than the gravitational attraction. From this stage on the universal expansion would exhibit acceleration. And this is exactly what astronomers found to be the case in 1998.

> But then, as ordinary matter spread out and its gravitational pull diminished, the repulsive push of the cosmological constant (whose strength does not change as matter spreads out) would have gradually gained the upper hand, and *the era of decelerated spatial expansion would have given way to a new era of accelerated expansion.* [4, p. 300, his italics]

If the nature of spacetime were relational, then spacetime could hardly possess such an *intrinsic* dynamic quality as dark energy. Energy is a fundamental property of material systems, and they have an existence of their own. So, we must concede that spacetime, possessing energy of its own, has also an existence of its own; or in other words, it has a substantival nature.

4 Argument concerning gravitational waves

Since the birth of Einstein's general theory of relativity in 1916, it has been suggested that gravitational waves could exist. They are ripples in the curvature of spacetime that propagate as waves at the speed of light. One hundred years after Einstein hypothesized their existence, on February 11, 2016, the LIGO Scientific Collaboration and Virgo Collaboration teams (covering the international participation of scientists from several universities and research institutions) announced that they had made the first observation of gravitational waves. They originated from a pair of merging black holes being at a distance of 1.3 billion light years from the Earth, somewhere beyond the Large Magellanic Cloud in the southern hemisphere sky.

> The discovery is a great triumph for three physicists — Kip Thorne of the California Institute of Technology, Rainer Weiss of the Massachusetts Institute of Technology and Ronald Drever, formerly of Caltech and now retired in Scotland — who bet their careers on the dream of measuring the most ineffable of Einstein's notions. [7]

I will not comment here how precisely the experiment was carried out, although the history of its planning and realization deserves a special attention. As far as I am aware, its positive result has been accepted by the scientific community. Besides, the LIGO – VIRGO Scientific Collaboration teams announced on June 15, 2016, that a second detection of gravitational waves from coalescing black holes was observed.

What is important here for my purpose is the following. If the gravitational waves could not be detected for some principal reason, then this would be no good news for the proponents of the substantival view of spacetime. But what after their existence was confirmed?

The observation of gravitational waves represents a clear argument in support of substantivalism. Relationism could hardly account for the existence of such waves. Indeed, from a relationalist point of view, only material objects really exist, while space and time are specific relations among them. However, relations are relational *properties* of objects, and as such properties they have no existence of their own. But if so, relational properties cannot possess non-relational properties on their part, and in particular, spacetime cannot initiate gravitational waves, as being a genuine disturbance of spacetime, even if they transmit no energy. On the contrary, only if spacetime exists as an entity of its own and exhibits local curvatures responsible for the gravitational interaction, then collisions of massive cosmic objects like galaxies and black holes can certainly account for the appearance of gravitational waves.

5 Argument from a consistent interpretation of the basic equation in general relativity

I have in mind the so called by A. Einstein field equation, or his well-known tensor equation of the general theory of relativity (the one hundred anniversary of the publication of which we are celebrating this year):

$$R_{\alpha\beta} - \frac{1}{2}\, g_{\alpha\beta} R = \kappa T_{\alpha\beta}.$$

As is well known, the left side of this equation is usually called now Einstein's tensor, and it refers to the geometry of spacetime, but more ontologically speaking, to the entire set of spatial-temporal events. The tensor at the right side is the tensor of matter, known also as the energy-momentum tensor, and is taken to structurally represent the state and distribution of the different kinds of matter. However, Einstein himself had a problem concerning the construal of his field equation [3, p. 370]:

> But, it is similar to a building, one wing of which is made of fine marble (left part of the equation), but the other wing of which is built of low grade wood (right side of equation). The phenomenological representation of matter is, in fact, only a crude substitute for a representation which would correspond to all known properties of matter.

At that, there is another interpretative problem concerning the motion of matter according to the general theory of relativity:

> The theory incorporates the effect of gravity by saying that the distribution of matter and energy in the universe warps and distorts spacetime, so that it is not flat. Objects in this spacetime try to move in straight lines, but because spacetime is curved, their paths appear bent. They move as if affected by a gravitational field. [5, p. 35]

So, we are faced with a *curious situation*: material bodies warp spacetime, while at the same time spacetime curvatures determine the movement of material bodies.

The just outlined problems point to the need of a consistent interpretation of Einstein's basic equation of general relativity.

As it seems, there are two interpretative possibilities. The first one is to construe the equation as a standard equality of two different kinds of tensors, representing *independent kinds of entities* – Einstein's tensor and the matter tensor (referring to spacetime and the composition of matter, respectively). At that, the tensor of matter is of a primary significance, since it is said that material bodies do cause the curvature of spacetime. In this case, however, the curious situation at hand could not be consistently elucidated. That is to say, this interpretation provides no arguable answer to the questions "Why, and how material objects warp spacetime?"

The remaining alternative is to construe the equation as *expressing an identity*, and not merely a correlation of equality between its left and right sides. Thus both these sides ought to be taken as theoretical constructs that refer to one and the same entity. It is certainly represented by the "fine marble (left part of the equation)", or in other words, this initial entity is spacetime.

Still there is one more reason in favour of the identity interpretation, and it is of a logical character. As is well known, the covariant derivative of the tensor at the right part of the equation – the tensor of matter, or the energy-momentum tensor – must be zero. Applying covariant derivation includes the Christoffel symbols of the second kind (which are the affine connections of the four dimensional Riemannian spacetime). The Christoffel symbols, however, are functions of the metric tensor and its ordinary derivatives. Thus it comes out that in order to see whether the tensor at the right side of the equation is really a tensor of matter, one has to know beforehand the metric of the spacetime. This vicious circle could be overcome only by the identity interpretation, since within it spacetime and matter (or better say spacetime without and with material bodies) belong to one and the same initial, or fundamental essence.

What is this fundamental essence?

It has been shown that according to a consistent reconstruction of the general theory of relativity the concept of spacetime as a world of physical events has a logical priority to the tensor of matter [1, p. 250]. At the same time the identity interpretation takes the referents of the tensor structures at both sides of Einstein's basic equation to be, or fall into one and the same, ontological essence. The latter then must be identified somehow with space-time, but not only with the geometry of spacetime. It would not be correct the geometry of spacetime and matter to be separated as two independent entities. On the contrary, they must be construed as two cognitively separable parts of a unique ontological essence. This could certainly be neither "empty" spacetime, i.e. spacetime without matter, nor "pure" matter without spacetime (that could even hardly be conceived of). It could be provisionally named "prime-matter", or "primal matter", and so to remind us of the ancient Greek idea of a prim(aev)al essence giving birth to the variety of all visible and tangible natural objects, or of something like Anaximander's apeiron. When Einstein's tensor equals zero, then prime-matter is reduced to "empty" Riemannian spacetime; and when it is different from zero, then prime-matter presents itself as spacetime filled with material structures. Prime-matter is the fundamental essence that is looked for, since it unites spacetime as an entity described by a mathematical language with the material structures emerging within it.

The identity interpretation provides an ontological framework for the three previous arguments for the substantival character of spacetime. Space-time, interpreted as prime-matter, is the genetic background for the emergence and the compositeness of matter. And it also possesses an immutable feature of matter – energy of its own. This is not strange at all, since according to the suggested interpretation spacetime – accepted as prime-matter –

is the fundamental element in the theory, while all the properties and interactions of material objects are taken to be specific states of prime-matter. Gravitational waves as ripples in the fabric of spacetime are properties of this same prime-matter.

The final conclusion in the end is that the identity interpretation of the Einstein's equation of general relativity certainly excludes the possibility for the relational nature of spacetime. It could be thought in no way as some set of relations among material objects whatsoever, because, just on the contrary, it is spacetime in its quality of prime-matter, which gives birth to material structures, and not vice-versa.

Space-time has a substantival nature even not in the traditional sense of this qualification. It was stated at the beginning in Arntzenius' words that traditional substantivalism "maintains that space and time (relativistically, spacetime) are objects that exist *in addition to* ordinary material objects such as tables and chairs." As we have seen, however, it could be said that spacetime does not merely exist in addition to material objects; it is the very base for their existence.

References

[1] Anastassov, Anastas. 1973. "On the Logical Structure of Physical Theories and Particularly of the Relativity Theory (Space, Time, Matter)" (in Bulgarian) In (A. Polikarov et al eds.), *Contemporary Physics. Directions of Development, Methodological Problems.* Sofia: "Nauka i Izkustvo", 241-262.

[2] Arntzenius, Frank. 2012. *Space, Time and Stuff.* Oxford, New York: Oxford University Press.

[3] Einstein, Albert. 1936. "Physics and Reality." *J. F. I.*, March, 349-382. (Translation by Jean Piccard.) Hosted by Prof. M. Kostic at: www.costic.niu.edu

[4] Greene, Brian. 2004. *The Fabric of the Cosmos. Space, Time, and the Texture of Reality.* New York: Alfred A. Knopf.

[5] Hawking, Stephen. 2001. *The Universe in a Nutshell.* London, New York, Toronto, Sydney, Auckland: Bantam Press.

[6] Kant, Immanuel. 1991. "On the First Ground of the Distinction of Regions in Space." In *The Philosophy of Right and Left. Incongruent Counterparts and the Nature of Space*, edited by James Van Cleve and Robert E. Frederick, 27-33. Dordrecht / Boston / London: Kluwer Academic Publishers.

[7] Overbye, Dennis. 2016. "Gravitational Waves Detected, Confirming Einstein's Theory", http://www.nytimes.com/2016/02/12/science/ligo-gravitational-waves-black-holes-einstein.html?_r=0