

The Ontology of General Relativity

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June 31, 2019

Sfetcu, Nicolae, "The Ontology of General Relativity", SetThings (January 31, 2019), DOI: 10.13140/RG.2.2.11641.93281, URL = <https://www.telework.ro/en/the-ontology-of-general-relativity/>

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Excerptfrom:

Sfetcu, Nicolae, "*The singularities as ontologicalimits of the general relativity*", SetThings (June 1, 2018), MultiMedia Publishing (ed.), DOI: 10.13140/RG.2.2.14521.06241/1, ISBN: 978-606-033-136-0, URL = <https://www.telework.ro/en/e-books/the-singularities-as-ontological-limits-of-the-general-relativity/>

In classical vision, space and time are containers; matter is the content. The distinctive property of matter is that it carries energy and impulse, preserved over time, resulting in energy and impulse being fundamental ontologically. (Norton 2012)

GR generated various early philosophical interpretations. His adherents have highlighted the "relativization of inertia" and the concept of simultaneity, Kantians and Neo-Kantians have underlined the approach of certain synthetic "intellectual forms" (especially the principle of general covariance, and logical empirics have emphasized the philosophical methodological significance of the theory.

Reichenbach approached the GR through the "relativity of geometry" thesis, trying to build a "constructive axiomatization" (Rendall 2005) of relativity based on "elementary matters of fact" (*Elementartatbestande*) for the observable behavior of light rays, rods and clocks.

The mathematician Hermann Weyl attempted a reconstruction of Einstein's theory based on the epistemology of a "pure infinitesimal geometry", an extended geometry with additional terms that formally identified with the potential of the electromagnetic field. (Weyl and Weyl 1993, 115–16)

Thomas Ryckman asserts that the unified geometric field theory program appears to be inseparably framed into a form of scientific realism, called "structural realism," with a possible tendency inspired by Platonism. (Ryckman 2018) In its contemporary form, structural realism has both an epistemic form and an "ontic" form, the latter claiming in essence that current physical theories justify the fact that the structural features of the physical world are ontologically fundamental (Ladyman and Ross 2007), subscribing to the idea that the only ontological continuity in terms of changes in fundamental physical theory is the continuity of the structure. Ontic structural realism is a metaphysical framework that provides an adequate

understanding of the characteristics of fundamental physical theories. According to him, there are structures in the field of fundamental physics in the sense of networks of concrete physical relations, without these relations to depend on fundamental physical objects that possess an intrinsic identity, ie an identity consisting of intrinsic properties or primitive thisness. This position can consider significantly the fundamental characteristics of the GR of invariance of diffeomorphism and background independence (Esfeld and Lam 2008).

Some philosophers see an opposition between traditionally metaphysics committed to an ontological priority of objects over relations, and ontic structural realism that is dedicated to an ontological priority of relations over objects. Supporters of ontic structural realism think that the error leading to this conclusion lies in the supposition of existence of an ontological distinction between objects, on the one hand, and properties, including relations, on the other (Esfeld and Lam 2011). They consider that there is no ontological distinction between objects and properties, including relations, and thus no relation of ontological dependence between objects and properties, including relation, so there is no problem of ontological priority. The distinction is only conceptual, (Lam and Esfeld 2012) but it would be a mistake to deduce from this way of representation that there are spacetime points in the world as entities distinct ontologically from the properties of the metric field. It would result that the assumption of an ontological distinction between objects and properties, including relations, must be abandoned. There is no ontological distinction between objects and their ways of being, but only a conceptual one.

Anti-metaphysical logical empiricists such as Carnap and neo-Kantians such as Cassirer (who consider the theory as a crucial test for Erkenntniskritik, the preferred term for Marburg's transcendental idealist epistemology) played an important role in the debates on GR ontology and development of modern concept of categorization in formal semantics (D. Howard 1996).

Cassirer concluded that GR presents "the most determinate application and carrying through within empirical science of the standpoint of critical idealism." (Cassirer 1921)

Einstein, together with Schlick and Reichenbach, developed a new form of empiricism, appropriate to the argumentation of GR against neo-Kantian critique. (Schlick 1921)(Reichenbach 1928)

Mach's idea that mass and inertial motion of the body results from the influence of all other surrounding masses (eliminating the concept of absolute space) strongly influenced Einstein in the epistemological attempt to generalize the principle of relativity, combining a valid principle of invariance of the forms of natural laws (general covariance) with a false "general relativity principle" of accelerated movements.(Ryckman 2018)

Einstein was not a scientific realist, but he believed that there was a theoretical content beyond the empirical content, that the theoretical science gave us a window on nature, even if in principle there would not be a single correct explanation at the level of deep ontology.(D. A. Howard 2017)

In this context, there has been a permanent discussion of the nature and role of the conventions in science continued until the end and after Einstein's life, (Schilpp and Schilpp 1959) whether the choice of geometry is empirical, conventional, or *a priori*. Duhem(Duhem, Vuillemin, and Broglie 1991) believes that in physics, assumptions are not tested in isolation, but only as part of theory as a whole (theoretical holism and the underestimation of choice of theory through empirical evidence). In a 1918 letter to Max Planck, Einstein approached the question of underdetermination (translation by Don A Howard):

"The supreme task of the physicist is ... the search for those most general, elementary laws from which the world picture is to be obtained through pure deduction. No logical path leads to these elementary laws; it is instead just the intuition that rests on an empathic understanding of experience. In this state of methodological uncertainty, one

can think that arbitrarily many, in themselves equally justified systems of theoretical principles were possible; and this opinion is, *in principle*, certainly correct. But the development of physics has shown that of all the conceivable theoretical constructions a single one has, at any given time, proved itself unconditionally superior to all others. No one who has really gone deeply into the subject will deny that, in practice, the world of perceptions determines the theoretical system unambiguously, even though no logical path leads from the perceptions to the basic principles of the theory."(Einstein 1918, 31)

Einstein argued why the theoretical choice is empirically determined in a letter addressed to Schlick, where he used Schlick's argument on the elements of a theoretical ontology:

"It appears to me that the word "real" is taken in different senses, according to whether impressions or events, that is to say, states of affairs in the physical sense, are spoken of.

If two different peoples pursue physics independently of one another, they will create systems that certainly agree as regards the impressions ("elements" in Mach's sense). The mental constructions that the two devises for connecting these "elements" can be vastly different. And the two constructions need not agree as regards the "events"; for these surely belong to the conceptual constructions. Certainly, on the "elements," but not the "events," are real in the sense of being "given unavoidably in experience.

"But if we designate as "real" that which we arrange in the space-time-schema, as you have done in the theory of knowledge, then without doubt the "events," above all, are real.... *I would like to recommend a clean conceptual distinction here.*"(D. A. Howard 2017)

Einstein's point of view, according to which physical reality consists exclusively of what can be built based on spacetime coincidences, spacetime points, for example, being considered as intersections of the world lines, is now known as the "point-coincidence argument." (D. A. Howard 2017) Coincidences thus have a privileged ontic role because they are invariant and thus univocally determined.

Einstein's new perspective on spacetime ontology has led Schlick to assert that Mach has only erroneously considered elements of sensation to be real, spacetime events individualized invariantly as spacetime coincidences also having the right to be considered real due to the univocal way of their determination. (D. A. Howard 2017) Einstein agreed, provided that it is possible to distinguish between the two types of reality, the elements and the spacetime events,

that “two different peoples” pursued physics independently will agree on the elements but would disagree at the level of the spacetime event ontology.

Right after the apparition of GR, a reduction of physics to geometry was discussed: "physics is a four-dimensional pseudo-geometry [i.e., a geometry distinguishing spatial and temporal dimensions] whose metric determination $g_{\mu\nu}$ is bound, according to the fundamental equations ... of my first [1915] contribution, to the electromagnetic quantities, that is, to matter. ((Hilbert 1917, 63), translation by Thomas A. Ryckman)

In GR, the density of non-gravitational energy and impulse for an event is represented by the stress-energy tensor of matter (T), being the structure that encodes total energy and momentum densities due to all non-gravitational forms. Einstein defined an analogous quantity, the stress-energy tensor for the gravitational field (t). T is a true tensor, but t is a pseudotensor, which means that T can be represented independently of a particular coordinate system, unlike t . Thus, no change in the coordinate system cannot cause T to disappear, unlike t that can be made null for a particular event. (Norton 2012) The total energy and impulse of the system are no longer well defined.

In GR, "the gravitational field energy cannot be located". We can speak only about the gravitational energy and the momentum of an extended system, not about the density of the energy and the gravitational momentum at a certain event. (Misner et al. 2017, §20.3-20.4)

Also, GR no longer offers a precise notion of gravitational force, this being "geometrized". The restoration of the Minkowski spacetime in the flat asymptomatic regions of space allows us to use the resources of special relativity to reintroduce the notion of gravitational force, identified with the geometric disturbances of the metric structure of the exact planeness required by a Minkowski spacetime. (Norton 2012)

The material metric (metric structure) of spacetime in GR is reducible to the behavior of material entities (clocks, ray, light, geodesic, etc.) from spacetime. (Grünbaum 2012)

Respectively, spacetime measurement always depends on measuring instruments chosen as measurement standards, and metric relations involve the chosen standards. It follows that the metric relations between the material content of spacetime are not explained by the spacetime metric, but they are constitutive of it. At the same time, in the metric of the physical field, the metric relations of a spacetime are determined by an irreducible physical field, the second order metric tensor field, which, although separated from the material entities of spacetime, explains the metric relations between those entities. (Weingard 1976)

From this point of view, the epistemological status of our belief that there is a tensor metric field is the same as our beliefs about other theoretical entities, such as neutrinos. As we postulate the existence of neutrino to explain the energy deficit observed in beta decay, we will postulate the metric field, according to the physical metrical field, to explain the different phenomena observed, such as why the free particles in a gravitational field have the trajectories they have. And in this process, the metric tensors field helps explain the metric relations observed between material entities. Robert Weingard asserts that there is an ontological disagreement between the two metrics, the first being the relations between material entities in spacetime, while the latter is a self-contained physical field, distinct and indivisible to the material content of spacetime. Robert Weingard argues that the physical field metric provides a more appropriate ratio of the ontological state of metrics in GR spacetime. According to this thesis, an empty spacetime with a well-defined metric is perfectly understandable. This idea was contradicted by Grünbaum:

”If there are no extrageochronometric physical entities to specify (individuate) the *homogeneous* elements of space-time . . . then whence do these elements of otherwise

equivalent punctual constitution derive their individual identities? Must the world points not be individuated before the space-time manifold can even be meaningfully said to have a metric? I see no answer to this question as to the principle of individuation here within the framework of the ontology of the Leibnizian identity of indiscernibles. Nor do I know of any other ontology which provides an intelligible answer to this *particular* problem of individuating avowedly *homogeneous* individuals.” (Grünbaum 1970)

Since 2000, a new approach to the nature of space-time structures has emerged, particularly in Oliver Pooley's (Pooley 2012) and Harvey Brown works. (Brown 2015) The dynamic approach asserts that the spacetime structure of our world is due to the dynamic (fundamental) laws of their nature and symmetry, the spacetime structure being derived. A given geometry for spacetime constrains formally the accepted theories to those with a straight symmetry. An assumption of many substantialists was that this constraint was not only formal but ontological: geometry (hence the manifestation itself) is more fundamental than laws, or that geometry provides a "real" explanation of the form of laws. (Earman 1992, 125). But symmetry could be reversed so that symmetry is determined ontologically by the laws of theory, resulting that geometry itself is an expression of matter dynamics. (Huggett and Hoefer 2018)

Gustavo E. Romero states that GR is a "space and time theory". (Misner et al. 2017) Spacetime is the emergence of the ontological composition of all events, (Romero 2013) being able to be represented by a concept with a four-dimensional representation of a metric field.

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