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Covariance, Equivalence and Locality: Reconsidering The Methodological Lesson from General Relativity

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Einstein's general theory of relativity is often presented as a significant turning point indicating a methodological shift in theoretical physics towards mathematically-based patterns of reasoning, and theories populated by abstract mathematical structures constructed using non-empirical guiding principles. This approach, which was advocated inter alia by Einstein himself from the mid 1920s, stands in contrast to his early presentation of the theory using principles of general covariance and a principle of equivalence, which he described as empirical observations extended and promoted to fundamental principles. Einstein's appeal to these principles, however, was immediately criticized, and never reached a mature form as a coherent construction of the theory. In this paper we follow the lead of the earlier Einstein, presenting a reconstruction of the basic structure of the theory, stressing how one can go a long way towards the general theory via inductive and empirical principles, and moreover without invoking geometrical considerations. The key theoretical device which we deploy in order to underwrite our demonstrations is what we call the 'Methodological Equivalence Principle', that together with general covariance, is understood and employed as a straightforward extrapolation of empirical considerations. We show that understanding general covariance and the equivalence principle as methodological principles of theory construction can resolve issues concerning their physical content and applicability in general relativity, while at the same time keeping them as clearly formulated theoretical principles.

In the above derivation the violation of general covariance prescribes the introduction of an additional field, to be interpreted as the metric field. We further show that this derivation can be regarded as a template for later employment of invariance arguments. Thus, applications of the gauge principle similarly do not set-off merely from an invariance requirement but rather from the particular way in which the requirement is violated in an existing successful theory.

Finally, we turn to discuss the place of locality in the argument. Locality is commonly understood as a fundamental physical principle, or at least as a theoretical virtue. Yang and Mills, for example, motivated local gauge invariance by arguing that global invariance is inconsistent with the idea of a local field theory. We argue that this kind of argument misses the point. According to our construction, relativistic gravity and gauge theories share a notion of locality which is not imposed, but is rather an identified characterization of the evidence for the interaction-free theory. The applicability of inertial frames for the description of non-gravitational forces is perceived, in accordance with existing evidence, as a local matter, and therefore explained as such. The applicability of a preferred isospin convention is similarly explained as a local matter, determined by the local values of a conjectured bosonic field (that depends contingently by itself on its interaction with fermionic matter fields). Our reconstruction of relativistic gravitation from principles therefore suggests that the case of general relativity shows that the weight of empirical considerations (as opposed to mathematical ones) is sometimes greater than is usually appreciated.

Author: HETZRONI, Guy (The Open University of Israel)

Co-author: Prof. READ, James (University of Oxford)

Presenter: HETZRONI, Guy (The Open University of Israel)

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