The Higher Dimensional Unification Program in Physics

By: Koray Karaca

In this paper, I aim to call attention to the higher dimensional unification program (HDUP) in physics that culminated in a class of higher dimensional space-time theories—aka Kaluza-Klein (KK) theories—aiming to unify gravity with gaugefields in a higher dimensional Riemannian space-time. Despite the immenseness of the physics literature on the topic on higher dimensional unification, unfortunately except a limited number of sources, such as Weingard 1988, Vizgin 1994, Cao 1997 and van Dongen 2002, the literature of history and philosophy of science is very sparse with regard to the issue of higher dimensional unification. In the present work, I adopt a methodology that is both philosophical and historical. My historical analysis traces the emergence and development of HDUP as a research program. It also complements my philosophical analysis by showing how the methodology of theory construction in HDUP has evolved and changed over the years. I divide the history of HDUP into two distinct, but related, periods. What I call the classical period concerns the five-dimensional KK theory constructed by the joint efforts of Theodor Kaluza (1921)and Oskar Klein(1926)in the twenties to unify gravity with electromagnetism in a five-dimensional Riemannian space-time. And, what I call the modern period of HDUP spans the late seventies to the early eighties and concerns modern KK theories—namely, higher dimensional supergravity and superstring theories—which are still considered by the majority of the physics community to be the best hope for a complete unified theory of all physical interactions including gravity.

My philosophical analysis aims to reveal different conceptions of unity that have operated in the history of HDUP. In the first part of my analysis, I examine the conception of unity underlying the five-dimensional KK theory. I argue that the unity achieved in this theory is structural in the sense that electromagnetic and gravitational fields, which were previously represented under different mathematical representations respectively in Maxwell's theory of electromagnetism (EMT) and Einstein's theory of general relativity (GTR), were united under the same mathematical representation. However, I argue, the structural unity in the representation of fields did not produce any ontological unity regarding the fields as well as the relation between them. Nevertheless, I argue, even though the unity in the five-dimensional KK theory failed to yield a common understanding of gravitational and electromagnetic fields, in modern parlance, it can be said to have offered an understanding of U(1) gauge symmetry of EMT as a geometrical symmetry of space-time around the coordinate associated with the fifth dimension.

I also compare and contrast the structural unity achieved in the five-dimensional KK theory to the unity in Einstein's special theory of relativity (STR). I also characterize the unity in STR as structural in the sense of being achieved at the level of the mathematical representation of electric and magnetic fields. However, I argue, the structural unity operates differently in these two historical cases. In the case of STR, the mathematical representation of the electromagnetic field is irreducible; i.e., it cannot be reduced further to the separate representations of electric and magnetic fields. However, in the case of the five-dimensional KK theory, the combined mathematical representation of gravity and electromagnetic fields in the five-dimensional space-time is further reducible to the distinct irreducible representations offered by GTR and EMT in the four-dimensional space-time. Based upon this result, I conclude that the structural unity in the five-dimensional KK theory is weaker than the structural unity in Einstein's STR.

My analysis of the modern period of HDUP is guided by my analysis of the historical link between the classical and the modern periods of HDUP. First, I explore how the five-dimensional KK theory re-entered the practice of current physics in the seventies after having stayed dormant for almost half a century. To this end, I discuss the historical reasons behind physicists' changing attitudes towards the issue of higher dimensional unification in general, and towards KK theory in particular. I argue that the revival of KK theory in the seventies was largely fueled by the confluence of two factors: First, the desire to incorporate gravity into the gauge-theory program—which had unified fundamental force fields except gravity—led the relevant physics community to adopt a new conception of unity that aimed to unify nuclear force fields with gravity. Second, in the sixties it was realized by the joint efforts of physicists such as DeWitt 1964, Kerner 1968 and Trautman 1970 that with the addition of more spatial dimensions the mathematical formalism of the five-dimensional KK theory—which was originally used to unify gravity and electromagnetic fields—could be extended as to include also the mathematical representations of nuclear force fields—namely, weak and strong force fields. This in turn led the physics community to extend and use the mathematical formalism of the five-dimensional KK theory to implement their new conception of unity.

Lastly, I examine the way the unity was achieved in higher dimensional supergravity and superstring theories. Here again in this case, I argue that the unity obtained is a kind of structural unity, i.e., unity in the mathematical representation of all fundamental force fields, rather than anontological unity. I also examine the theoretical structures of higher dimensional supergravity and superstring theories. I identify two key features that are common to these theories as follows: The unification of the representations of fields by means of enlarging the dimensionality of space, and the treatment of different internal symmetries associated with nuclear interactions as gauge symmetries. I also note that while the former feature is reminiscent of the way structural unity was obtained in the five-dimensional KK theory, the latter feature follows from the basic tenet of gauge-theory program. Based on this result, I reach the conclusion that the synthesis of higher dimensional unification with gauge symmetry formalism is constitutive to the theoretical structures of higher dimensional supergravity and superstring theories.