Foundations of General-Relativistic Gauge Field Theory

Report of Contributions

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Gravity is gauge? A unification perspective

The question of the extent to which gravity is a gauge theory can prove to be surprisingly complicated, considering constraint classes, internal and external symmetries, spacetime tangent structure, and connection versus metric variables. Furthermore, unifying gravity with the rest of the interactions provides even more conundrum, but also an arena for theory development. The premise for classical gravity unification in field theory is reviewed, with emphasis in form of a recently proposed Khronon Lorentz gauge theory of gravity, and with motivations in Cartan geometry, topological field theory, and pre(geo)metric ideas. Unification in particle physics has a well-motivated list of requirements, and rigorous limitations, e.g. by the Coleman-Mandula theorem among others. There are a multitude of ways to bypass this, but it will be argued that it seems also an inherently spacetime-geometric obstruction. Special attention will be brought to how to distinguish gravity and internal gauge theory, and how to approach a gravity-unified phase for theory development.

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From generalized principal connections to generalized Yang-Mills theories

In the framework of the fiber bundle approach to covariant Lagrangian field theories we investigate the notions of generalized principal bundle and generalized principal connection as introduced by Castrillón López and Rodríguez Abella (2023), aiming at the development of an instance of generalized mathematical gauge theories. We provide a characterization of Lie group fiber bundle connections and generalized principal connections in order to obtain the local coordinate representation of all such structures. In particular, studying the curvature of generalized principal connections, we specialize the Bianchi identities obtaining a generalized version of the classical homogeneous field equations. As an application, we prove also that vector bundles are an example of generalized principal bundles, that a generalized principal connection on a vector bundle is an affine connection and that the generalized homogeneous field equations can be rephrased, in this case, in terms of basic soldering forms and torsion tensors. Finally, resorting to gauge theories and variational calculus on fiber bundles, we propose a first approach to (an instance of) generalized Yang-Mills theories. We accordingly prove that the corresponding variational field equations (i.e. Euler-Lagrange equations) generalize the classical Yang-Mills equations. While generalized Yang-Mills theories need more developments to give a full answer, we expect that the Einstein equations can be formulated ultimately as an example of generalized Yang-Mills equations. This is a joint work with Lorenzo Fatibene.

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A Journey through Higher-Derivative Models in Contemporary Field Theory

With a initial motivation of treating point charge divergences in electrodynamics, higher-derivative (HD) models have come a long way in quantum in field theory passing through important challenges concerning their unitarity evolution and existence of propagating ghost fields. In modern physics, the relevance of HD models relies not only on abstract mathematical curiosities, but actually brings new possibilities for approaching open problems. In fact, since the 1950 well-known Pais-Uhlenbeck groundbreaking paper, models containing derivatives of order higher than two have abounded in the literature. In this talk, we briefly review and contextualize important HD models including Bopp-Podolsky, Lee-Wick, Pais-Uhlenbeck and HD Klein-Gordon generalizations while discussing their roles within recent new physics proposals. We present a consistently parametrized family of higher-order generalizations for the Klein-Gordon equation with their corresponding HD actions, illustrate the BRST quantization of the Pais-Uhlenbeck oscillator and discuss the null-plane dynamics and constraint structure of the Bopp-Podolsky model. We show that through the introduction of higher-derivatives, it is possible to generate massive modes for the fields whitout breaking gauge invariance. Different alternative interpretations are formulated concerning connections to the Pauli-Vilars regularization scheme, existence of new massive physical fields or disposal of consistent building blocks for constructions of larger relevant effective theories. We end with some remarks on the consistent reduction of order for higher-derivative models as recently presented in the literature.

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Gauge-Invariant Renormalisation Group Flows

In this talk I give a brief introduction to the functional renormalisation group, a non-perturbative framework widely used to study gauge field theories. While this approach has been successfully applied to Yang–Mills theory and quantum gravity, standard implementations generally modify gauge invariance. This modification obscures the physical interpretation of results. I present a novel formalism of renormalisation group flows that systematically resolves the modification of gauge redundancies. I apply this to quantum gravity and highlight the consequences of recovering a gauge invariant renormalisation group flow.

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Classical gauge theories and gravity

It belongs to folklore that electromagnetic, electroweak, and strong interactions are understood as gauge theories. In contrast, the situation regarding gravitational interaction is often considered more complex. Since the 1960s, this complexity has led to extensive research on the question: Can gravity be understood as a gauge theory?
In this talk, we explore a framework for describing classical gauge theories developed by Andrzej Trautman in the 1970s. This framework utilizes the theory of Ehresmann connections on principal G-bundles. Within the framework, gravity can be understood as a classical gauge theory, where the metric tensor field is treated as a classical Higgs field. One significant advantage of this framework is that it enables the description of gravity and gauge theories of internal symmetries using the same mathematical formalism. This unification leads to a deeper understanding of the crucial geometrical differences between these two distinct classes of classical gauge theories, which have non-trivial physical implications.

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The autoparallel equations with non-metricity as Finsler geodesics

Autoparallel curves in metric-affine geometries are generally non-variational and do not generally coincide with the Euler-Lagrange equations of any Lagrangian. For symmetric connections with vectorial nonmetricity, we show that the autoparallel equations can be realized as geodesics of a suitably chosen Finsler metric, reducing the problem of variationality to Finsler metrizability. By formulating this as a first-order partial differential equation, we obtain necessary and sufficient conditions and classify all (α, β)-metrics whose geodesics coincide with these autoparallels. For generalized (α, β)-metrics, necessary conditions are obtained.

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Conserved Charges in Asymptotically Locally AdS Spacetimes via the Katz Method

The Katz boundary term provides a well-defined variational principle under Dirichlet boundary conditions and, when combined with a subtraction of the action evaluated on a background, yields finite Noether charges and a finite on-shell action. This boundary term is constructed from the dynamical metric and the difference between the Christoffel symbols associated with the dynamical manifold and a reference background. So far, this method has been tested only for specific classes of solutions. In this work, using the Fefferman–Graham gauge, we show that the finiteness of conserved charges can be proven for families of asymptotically locally Anti–de Sitter spacetimes in general relativity. The finiteness of the charges can be established in arbitrary dimensions; however, the prescription for defining the background in this framework distinguishes between even and odd spacetime dimensions.

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Holographic thermal propagator from modularity

We revisit the low-temperature thermal propagator of a holographic conformal field theory in four spacetime dimensions by exploiting its connection to the Nekrasov–Shatashvili (NS) limit of the Ω-deformed $\mathcal{N} = 2$ supersymmetric $SU(2)$ Yang–Mills theory with $N_f = 4$ hypermultiplets. In the regime of vanishing energy, the low-temperature expansion corresponds to a large adjoint vacuum expectation value expansion. In this limit, we show that a second expansion in instanton numbers organizes into quasi-modular forms, which can be resummed into closed-form expressions in terms of Eisenstein series. The resulting thermal propagator series in positive powers of small temperatures exhibits clear signs of being asymptotic. Our method—combining modular properties, q-recursion techniques, and the NS prepotential—provides a systematic and computationally efficient framework for analyzing retarded Green's functions of holographic black branes in the low-temperature limit.

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