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lips: complex phase space goes singular and p-adic

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High-multiplicity loop-level amplitude computations involve significant algebraic complexity, which is usually sidestepped by employing numerical routines. Yet, when available, final analytical expressions can display improved numerical stability and reduced evaluation times. It has been shown that significant insights into the analytic structure of the results can be obtained by tailored numerical evaluations. I present new developments on the object-oriented python package lips (Lorentz invariant phase space) for the generation and manipulation of complex massless kinematics. Phase-space points can be defined at the spinor level over complex numbers ($\mathbb{C}$), finite fields ($\mathbb{F}_p$), and p-adic numbers ($\mathbb{Q}_p$). Facilities are also available for the evaluation of arbitrary spinor-helicity expressions in any of these fields. Through the algebraic-geometry submodule, which relies on Singular through the python interface syngular, one can define and manipulate ideals in spinor variables (either covariant components or invariant brackets). These allow to identify irreducible varieties, where amplitudes have well-defined zeros and poles, and to fine-tune numerical phase-space points to be on or close to such varieties. Explicit precision tracking in the p-adic implementation allows one to perform numerical computations in singular configurations while keeping track of the numerical uncertainty as an $\mathcal{O}(p^k)$ term. As an example application, I will show how to infer valid partial-fraction decompositions from p-adic evaluations.

Significance

1) Finite fields have become a staple of modern amplitude computations, but have their limitations. p-adic numbers, while retaining many features of finite fields, address two of these limitations: they enable non-trivial scale separations and the evaluation of transcendental functions.
2) Likewise, partial-fraction decompositions play an important role in managing the complexity of the analytical expressions. However, these decompositions are generally obtained only after analytical expressions have already been obtained. The proposed approach allows determining the validity of a decomposition purely from numerical evaluations.

References

The theoretical/mathematical background can be found at:
arXiv:1904.04067, arXiv:2203.04269, arXiv:2203.17170 (Appendix C mainly)

Experiment context, if any

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