Operator basis construction and projection for effective field theories with AutoEFT

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Effective Field Theories

Effective field theories (EFTs) are an important tool in particle physics. They can be used both for describing the low-energy behavior of Standard-Model processes, as well as for model-independent searches for BSM physics.

The effects of BSM physics on low-energy processes can be described by constructing an Effective Field Theory from the Standard Model (SMEFT). The Standard Model Lagrangian is extended with additional higher-dimensional terms. The full SMEFT Lagrangian up to order N is

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d=5}^{N} \frac{1}{\Lambda^{d-4}} \, \mathcal{C}_i^{(d)} \mathcal{O}_i^{(d)}. \tag{1}$$

All EFT operators $\mathcal{O}_i^{(d)}$ are suppressed with inverse powers of Λ. Operators with a higher dimension d are more suppressed and thus contribute less to low-energy processes, so it is possible to cut off this infinite sum at some order N. The coupling constants $\mathcal{C}_i^{(d)}$, called Wilson coefficients, are the coupling constants for the new interaction terms.

A linear combination of EFT operators will itself be a valid EFT operator, so the operators form a vector space. The terms of the EFT Lagrangian must be a basis of this vector space. All operators must be linearly independent to ensure that the Wilson coefficients can be determined from observables.

AutoEFT

AutoEFT [1] is a Python program that allows one to construct operator bases for EFTs from the field content and the symmetries of the underlying low-energy theory. It can work with SMEFT, but is not limited to it; the allowed fields include scalars, spinors and gauge bosons, and the allowed symmetries are U(1) and SU(N). A group-theoretical approach is used to determine the invariants of the Lorentz and gauge groups and to eliminate the redundancies between them. AutoEFT can construct bases of independent parameters (onshell bases) as well as bases of independent Green's functions, which are required for renormalization and RGE evolution.

Operator projection

As with any vector space there no preferred basis and any complete set of linearly independent operators will work. This can lead to situations where different groups that work in the same EFT use different operator bases in their calculations. To compare results, a change of basis is required.

Usually this is done by simply taking the inner products of the basis vectors from each basis. However, due to the complicated relations between different operators, it is not easy to define an inner product on the space of EFT operators. My current research topic is to develop an algorithm that can calculate this inner product. This would enable researchers to represent arbitrary EFT operators in terms of basis operators of a basis of their choice. It would also be possible to perform an arbitrary change-of-basis, so different groups can work in a basis of their own preference and still easily compare results.

References

[1] R. V. Harlander und M. C. Schaaf. "AutoEFT: Automated operator construction for effective field theories". In: *Comput. Phys. Commun.* 300 (2024), S. 109198. DOI: 10.1016/j.cpc.2024.109198. arXiv: 2309.15783 [hep-ph].