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Statstics and asymptotics of subdivergence-free Feynman integrals in ϕ^4 theory

Recent algorithmic improvements have made it possible to numerically compute the value of subdivergence-free (=primitive=skeleton) Feynman integrals in ϕ^4 theory up to 18 loops. By now, all such integrals up to 13 loops and several hundred thousand of higher loop order have been computed numerically. This data enables a statistical analysis of the typical behavior of Feynman integrals at large loop order. We find that the average value per integral grows exponentially, as expected from instanton analysis. The distribution has a largely continuous inner part but a few extreme outlier diagrams which make uniform random sampling inefficient. The number of diagrams grows factorially with the loop order, but the value of the integral can be estimated from simple features of the diagram, such as counts of cuts and cycles, to a few percent accuracy. We used this for importance sampling on the set of diagrams and obtained approximately 1000-fold decrease in runtime compared with uniform sampling.
Thirdly, a long standing conjecture is that subdivergence-free diagrams should be the asymptotically dominant contribution to the (full) beta function in minimal subtraction at large loop order. This effect is not clearly visible even at 18 loops. The relevant counts of graphs, and their exact asymptotics, can be computed from zero-dimensional QFT. There, one finds strikingly similar behavior to the 4-dimensional numerical data which suggests that the leading asymptotic growth rate of subdivergence-free integrals can probably only be observed upwards of 25 loops.
Based on JHEP 11 (2023) 160, JHEP11 (2024) 038 (with Kimia Shaban), and arXiv 2412.08617 (with Johannes Thürigen). Underlying data sets and Mathematica implementations are available from paulbalduf.com/research

Secondary track

T12 - Data Handling and Computing

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