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The basics and applications of the tempered Lefschetz thimble method for the numerical sign problem

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The numerical sign problem is one of the major obstacles to the first-principles calculations for important physical systems, such as finite-density QCD, strongly-correlated electron systems and frustrated spin systems, as well as for the real-time dynamics of quantum systems. The tempered Lefschetz thimble method (TLTM) [1] was proposed as a versatile algorithm towards solving the numerical sign problem. There, the integration region is deformed into the complex space according to the antiholomorphic gradient flow equation, and the system is tempered using the flow time as a tempering parameter so as to solve both the sign and ergodicity problems simultaneously.
In this talk, I first summarize Monte Carlo approaches to the sign problem, including the methods based on the complex Langevin equation and those on the Lefschetz thimbles. I then focus on the TLTM and explain the basics of the algorithm. I demonstrate the effectiveness and versatility of the algorithm by showing its successful applications to various models, such as the (0+1)-dimensional massive Thirring model [1], the Hubbard model away from half filling [2,3], and the Stephanov model (a chiral random matrix model) [4]. I also explain some of the recent improvements in the algorithm [3,4].

[1] M. Fukuma and N. Umeda, "Parallel tempering algorithm for integration over Lefschetz thimbles,"PTEP 2017, no.7, 073B01 (2017) [arXiv:1703.00861 [hep-lat]].
[2] M. Fukuma, N. Matsumoto and N. Umeda, "Applying the tempered Lefschetz thimble method to the Hubbard model away from half filling," Phys. Rev. D 100, no.11, 114510 (2019) [arXiv:1906.04243 [cond-mat.str-el]].
[3] M. Fukuma, N. Matsumoto and N. Umeda, "Implementation of the HMC algorithm on the tempered Lefschetz thimble method," [arXiv:1912.13303 [hep-lat]].
[4] M. Fukuma and N. Matsumoto, "Worldvolume approach to the tempered Lefschetz thimble method,"PTEP 2021, no.2, 023B08 (2021) [arXiv:2012.08468 [hep-lat]].

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