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Critical Phenomena and Renormalization Group

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The interest in systems with many correlated degrees of freedom is a central aspect of Quantum Field Theory (QFT) and Statistical Mechanics. These conditions mean that the effective long-range interactions between the particles in the system become highly non-trivial, and we therefore use the Renormalization-Group method to analyze the behavior around the critical point. This process is arguably not so intuitive in QFT, since it relates to divergences that may not be directly observable. Another interesting aspect of the Renormalization Group is related to how the volume of the system transforms around the critical point. This aspect is the foundation of the Finite-Size-Scaling process, used to study numerically the behavior of systems around said point. To create a better sense of understanding, we explore the theory for Spin Models, where renormalization-group ideas and critical phenomena show up as something more natural. Starting from symmetries and important scales that define a physical system, we highlight the principles behind the nonperturbative, multiscale study of such systems, noticing that, most of the time, analytical solutions are not possible. To deal with these problems, we also introduce the Monte Carlo method, which allows us to sample configurations of the system based on a probability measure. With these tools at hand, we explore the similarities of numerical simulation (via the Metropolis algorithm) for the Ising and XY spin models compared to lattice QCD, comparing the symmetries of these systems. The calculation of observables for each system is directly related to the symmetry group that defines the interaction, making each system unique, while the process itself is universal. In this work, developed during an undergraduate research project and the first months of PhD, we show the parallels between QFT and Statistical Mechanics, by highlighting the importance of critical phenomena to Lattice QFT and applying the methods to simpler systems.

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