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The simplicity of confinement

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Motivated by recent literature on the possible existence of a second higher-temperature phase transition in Quantum Chromodynamics (QCD), I revisit the proposal that colour confinement is related to the dynamics of magnetic monopoles using methods derived from Topological Data Analysis, which provide a mathematically rigorous characterisation of topological properties of quantities defined on a lattice. After introducing homology, I shall discuss how this concept can be used to quantitatively analyse the behaviour of monopoles across the deconfinement phase transition. The proposed approach is first demonstrated for Compact U(1) Lattice Gauge Theory, which is known to have a zero-temperature deconfinement phase transition driven by the restoration of the symmetry associated with the conservation of the magnetic charge. For this system, I perform a finite-size scaling analysis of observables capturing the homology of magnetic current loops, showing that the approach reproduces the expected value of the deconfinement critical coupling. Then, I extend this method to SU(3) gauge theory, in which Abelian magnetic monopoles are identified after projection in the Maximal Abelian Gauge. Specifically, I define an observable called "simplicity", which measures the number of topologically non-trivial loops per connected component in a current network. A finite-size scaling of the ensemble-averaged simplicity of Abelian magnetic currents provides the expected value of the critical coupling with an accuracy that is generally higher than that obtained with conventional thermodynamic approaches at comparable statistics, suggesting the relevance of the topological properties of monopole currents for confinement. Finally, preliminary results from a study of simplicity in QCD will be briefly discussed.

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