The Status of D-Theory

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Abstract: D-theory is an alternative formulation of field theory in which continuous classical fields arise from the dimensional reduction of discrete quantum variables that undergo dimensional reduction.

Quantum spin models in 2+1 dimensions reduce to asymptotically free 2-d field theories. For example, 2-d $CP(N-1)$ models arise from the dimensional reduction of $(2+1)$-d $SU(N)$ quantum spin ladders, and the vacuum angle $\theta = n\pi$ is determined by the number n of transversely coupled spin chains. Efficient cluster algorithms have been used to simulate $CP(N-1)$ models both at non-zero vacuum angle and at non-zero chemical potential.

The gauge analogs of quantum spins are quantum links — parallel transporter matrices whose matrix elements are operators in a Lie algebra. The Lie algebras for the $SU(N)$, $SO(N)$, and $Sp(N)$ quantum link models are $SU(2N)$, $SO(2N)$, and $Sp(2N)$, respectively, while the Lie algebra for the exceptional $G(2)$ quantum link model is $SO(14)$. The $(4+1)$-d $SU(N)$ quantum link model exists in a massless non-Abelian Coulomb phase from which 4-d gluons arise as collective excitations of quantum links.

In the D-theory framework, QCD arises from a $(4+1)$-d $SU(3)$ quantum link model with domain wall quarks. The continuum and chiral limits are reached naturally, i.e. without fine-tuning, by increasing the size β of the extra dimension in lattice units. Remarkably, due to asymptotic freedom, β still vanishes in physical units which hence implies dimensional reduction.

Quantum spins and quantum links are interesting candidates for truly fundamental degrees of freedom (alternative to strings and branes) that Nature may have chosen to regularize the physical world. Meeting the challenges of constructing the full standard model or even gravity from discrete quantum variables has the potential to shed new light on fundamental puzzles such as the hierarchy problem or the strong CP problem.