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Linking quantum error correction and gauge theory via quantum reference frames

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One of the defining features of gauge theories is that they describe physics redundantly, in a way that is insensitive to certain local details. This redundancy is akin to how quantum error correcting codes (QECCs) protect quantum information from local errors by redundantly encoding logical states into a larger physical space. In this talk, I will show that this analogy is not merely a coincidence but that there is a deeper underlying structural relationship. The key ingredient is quantum reference frames (QRFs), a universal tool for dealing with symmetries in quantum systems. A choice of QRF defines a split between redundant and physical information in gauge systems, thus establishing a notion of encoding in that context. This leads to an exact dictionary between group-based quantum error correcting codes and QRF setups. In stabilizer codes, this reveals a one-to-one correspondence between (maximal sets of) correctable errors and QRFs. This provides novel insights into the relation between correctability and redundancy through a reinterpretation of the Knill-Laflamme condition. The dictionary also reveals a novel error duality, based on Pontryagin duality, and somewhat akin to electromagnetic duality. Throughout the presentation, I will illustrate these findings through simple examples involving Pauli stabilizer codes. Based on: Sylvain Carrozza, Aidan Chatwin-Davies, Philipp A. Hoehn, Fabio M. Mele, A correspondence between quantum error correcting codes and quantum reference frames, arXiv: 2412.15317 [quant-ph]

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