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Using concatenated quantum codes for universal fault-tolerant quantum gates

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Quantum error correction and fault-tolerance are essential for large scale quantum information processing tasks. A standard method for implementing a logical fault-tolerant gate is by applying the gate transversally, that is without coupling qubits within an encoded codeblock. However, Eastin and Knill [Phys. Rev. Lett. 102, 110502 (2009)] proved that it is impossible to have a set of universal transversal gates for a given quantum error correcting code. In this work, we present sufficient conditions to obtain a set of universal fault-tolerant quantum gates by concatenating two quantum error correcting codes. Namely, the concatenation scheme does not require the preparation of special ancillary states in order to obtain universality, unlike schemes such as magic state distillation. The construction exploits the transversality of different sets of gates for the given codes, protecting for the non-transversal gates in one code by implementing these logical gates using transversal gates in the second code. The full distance of the concatenated code is sacrificed to protect against low-weight arbitrary errors, ensuring fault-tolerance.