Catalytic Cooling and the Catalytic Entropy Conjecture

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Algorithmic cooling provides a way to extract a finite fraction of cold (pure) qubits from an asymptotically large number of identical and uncorrelated warm (mixed) qubits. The process is unitary (hence reversible) and the optimal fraction of cold qubits is determined by the von Neumann entropy of the initial qubits. We introduce a new theoretical cooling scheme called *catalytic cooling* that does not require an asymptotic limit, but achieves the same (optimal) efficiency as algorithmic cooling. It relies on having access to a suitable additional system which remains invariant in the process and hence acts as a catalyst, as well as having access to a decohering environment. Building upon this, we introduce the *catalytic entropy conjecture*, which provides a novel operational characterization of the von Neumann entropy with potentially far-reaching consequences. In particular, its correctness would imply that catalytic cooling is possible without access to a decohering environment. That is, cooling with the same efficiency as algorithmic cooling in the asymptotic regime could also be done in the single-shot setting by only having access to a suitable catalyst. Finally, we present strong evidence for the correctness of the conjecture.