Detailed balance and nonequilibrium fluctuation theorems

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Fluctuation theorems are a group of exact relations comparing the probabilities of time reversed realizations of out of equilibrium processes. Although their simple structure and general applicability have generated great interest and a vigorous research effort, an intuitive understanding of why such results hold has proven elusive. Should we have expected them?

We point out that in many cases the out of equilibrium process of interest can be viewed as a carefully designed limit of a rare fluctuations in a suitably defined equilibrium system. Fluctuation theorems then emerge naturally from a combination of the principle of detailed balance and the aforementioned limit. This perspective suggests that fluctuation theorems can be viewed a consequence of Onsager's regression hypothesis in the limit of large (and extremely rare) fluctuations, just as the classical fluctuation-dissipation theorem is a consequence of the regression hypothesis for small fluctuations. We use a stochastic jump process with a finite number of states as an instructive example to elucidate these considerations.