Symmetries and stochastic gene regulation

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Abstract:
Randomness is an unavoidable feature of the intracellular environment due to chemical reactants being present in low copy number. That phenomenon, predicted by Delbr\"uck long ago, has been detected in both prokaryotic and eukaryotic cells after the development of the fluorescence techniques. On the other hand, developing organisms, {\em e.g.} {\em D. melanogaster}, exhibit strikingly precise spatio-temporal patterns of protein/mRNA concentrations. Those two characteristics of living organisms are in apparent contradiction: the precise patterns of protein concentrations are the result of multiple mutually interacting random chemical reactions. The main question is to establish biochemical mechanisms for coupling random reactions so that canalization, or fluctuations reduction instead of amplification, takes place. Here we explore a model for coupling two stochastic processes where the noise of the combined process can be smaller than that of the isolated ones. Such a canalization occurs if, and only if, there is negative covariance between the random variables of the model. Our results are obtained in the framework of a master equation for a negatively self-regulated -- or externally regulated – binary gene and show that the precise control due to negative self regulation is because it may generate negative covariance. Our results suggest that negative covariance, in the coupling of random chemical reactions, is a theoretical mechanism underlying the precision of developmental processes.