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Network topological conditions for stochastic oscillations

A better understanding of stochastic biological networks is essential to understand signaling pathways in natural organisms, propose new molecular therapies, and to design new synthetic circuits with desired functions. Therefore it is of tremendous value to systematically define the landscapes of stochastic dynamical behavior as a function of biological network architectures and parameter space. First, we investigate network topological conditions for stochastically amplified and coherent oscillation, by exhaustively and systematically considering all possible topologies of three-nodes biochemical networks with coupled positive and negative feedbacks and mass-action kinetics. For each network topology, we derive power spectra based on the linear noise approximation of the master equation for the corresponding stochastic biochemical reaction system and characterize stochastic oscillatory behavior as a function of network architecture and parameter space. We find that (a) any network with at least one negative feedback is capable of generating stochastically amplified and coherent oscillations whereas their deterministic counterparts are unable to produce oscillations with any values of kinetic rate constants; (b) networks with coupled positive and negative feedbacks are much more amplified and robust than networks with only coupled negative feedbacks; (c) timescale difference among the kinetic rate constants is generally required for highly amplified and coherent stochastic oscillation.