

# Dimensional Reduction, Fluctuation-Response Relationship, and Multi-timescale Consistency in Evolution, Development, and Learning

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Life systems are complex and hierarchical, with diverse components at different scales, yet they sustain themselves, grow and evolve over time. Here we note that for a hierarchical biological system to be robust, it must achieve consistency between micro-scale (e.g. molecular) and macro-scale (e.g. cellular) phenomena, which allows for a universal theory of adaptive changes in biological systems. The talk will present a demonstration of how adaptive changes in high-dimensional phenotypes (biological states) are constrained to low-dimensional manifold, leading to a macroscopic law for cellular states, as confirmed by adaptation experiments of bacteria. The theory is then extended to evolution and development, leading to the proportionality between phenotypic variations due to environmental adaptation and genetic changes. Finally, we extend this argument to the learning in neural systems, including learning-fluctuation relationship.

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