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Theory for the Emergence of Modularity in Complex Systems
MICHAEL DEEM, JEONG-MAN PARK, Rice University — Biological systems are modular, and this modularity evolves over time and in different environments. A number of observations have been made of increased modularity in biological systems under increased environmental pressure. We here develop a theory for the dynamics of modularity in these systems. We find a principle of least action for the evolved modularity at long times. In addition, we find a fluctuation dissipation relation for the rate of change of modularity at short times. We discuss a number of biological and social systems that can be understood with this framework. The modularity of the protein-protein interaction network increases when yeast are exposed to heat shock, and the modularity of the protein-protein networks in both yeast and E. coli appears to have increased over evolutionary time. Food webs in low-energy, stressful environments are more modular than those in plentiful environments, arid ecologies are more modular during droughts, and foraging of sea otters is more modular when food is limiting. The modularity of social networks changes over time: stock brokers instant messaging networks are more modular under stressful market conditions, criminal networks are more modular under increased police pressure, and world trade network modularity has decreased

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