EMERGENT COMPLEXITY FROM MICROBIAL NETWORKS

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Complex systems composed of interacting agents often exhibit large, structured fluctuations, and microbial ecosystems are no exception. In particular, microbial communities—such as those in the human gut—show strong correlations in species abundance that are not easily explained by simple ecological models. To address this, we infer effective interaction networks directly from time-averaged abundance data using a combination of Bayesian inference and maximum entropy principles. This approach yields sparse yet structured networks that capture empirical correlation patterns while remaining consistent with known large-scale statistical regularities (macroecological laws). The resulting networks exhibit emergent motifs—small-scale interaction patterns—reminiscent of those seen in other complex systems, such as ecological or technological networks, where they are known to support stability and diversity. Finally, we explore how changes in network structure correlate with physiological states (e.g., healthy vs. dysbiotic microbiomes), showing how these tools can uncover hidden organization in biological systems. Overall, this work highlights how statistical physics and network theory can shed light on the structure and dynamics of complex biological collectives.

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