Analyzing the dynamics and structure of biochemical reaction networks via network decomposition

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The complexity of biochemical reaction networks, characterized by their intricate structures and dynamic behaviors, presents considerable challenges in their analysis. To address these challenges, we apply network decomposition techniques to study the structural and dynamical properties of biochemical networks. In this approach, we decompose the network into independent subnetworks, where the stoichiometric matrices of the subnetworks can be directly summed to match the stoichiometric matrix of the entire network. This technique facilitates the computation of positive steady states, aiding in the description of long-term network behavior. We also observe a widespread property across many networks involving incidence-independent decomposition, where the incidence matrices of subnetworks can be directly summed to match the incidence matrix of the entire network. A key discovery is the phenomenon we term Finest Decomposition Coarsening (FDC), in which the finest independent decomposition (FID) is a coarsening of the finest incidence-independent decomposition (FIID). We characterize this property and find conditions under which these two types of decomposition coincide. Furthermore, we establish connections between these decompositions and the connected components of the network, known as linkage classes. This study provides a deeper understanding of the algebraic structure underlying biochemical reaction networks, advancing our ability to model and analyze their behavior.