Motiforge: Flexible Motif-Constrained Network Generation for Structured Neural Architectures

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Benchmarking spiking neural networks is a central challenge in neuromorphic computing, where performance is often evaluated on networks with randomly generated connectivity, which provide a well-controlled and widely adopted baseline [1]. However, biological neuronal circuits exhibit highly structured connectivity, including structural features such as network motifs—frequently recurring patterns of connections between small groups of neurons [2]. This mismatch raises the question of how network dynamics and, consequently, performance evaluation are shaped by structural features that are typically not represented in random connectivity models.

To complement existing approaches, we introduce Motiforge, a novel algorithmic framework for generating networks with controlled higher-order motif distributions. Unlike existing approaches, which are limited to undirected connectivity patterns, directed, second-order connectivity patterns, or to very sparse networks [3, 4, 5], Motiforge enables the systematic construction of directed networks with arbitrary three-node motif distributions at moderate connection densities. The method is based on Markov Chain Monte Carlo sampling within an exponential random graph model and exploits the local nature of three-node motif constraints. Furthermore, the framework supports motif control both within and across multiple node populations, enabling the creation of structured, heterogeneous networks.

Using Motiforge, we construct networks that replicate empirically observed motif statistics and compare their structural and dynamical properties to those of traditionally used random networks, such as the fixed in-degree Brunel network. Our results show that motif-constrained networks exhibit emergent features, such as long-tailed degree and firing rates distributions, that more closely resemble biological data [6, 7]. These differences highlight the significant role of higher-order connectivity in shaping network behavior and suggest that commonly used random benchmarks may not fully reflect the structural conditions relevant for biologically inspired and neuromorphic computation.

Overall, Motiforge offers a practical tool for exploring networks with biologically inspired connectivity patterns, offering new avenues for understanding and evaluating (spiking) neural networks in both research and neuromorphic applications.

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