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Generating clustered scale-free networks using Poisson based localization of edges

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We introduce a variety of network models using a Poisson-based edge localization strategy, which result in clustered scale-free topologies. We first verify the success of our localization strategy by realizing a variant of the well-known Watts-Strogatz model with an inverse approach, implying a small-world regime of rewiring from a random network through a regular one. We then apply the rewiring strategy to a pure Barabasi-Albert model and successfully achieve a small-world regime, with a limited capacity of scale-free property. To imitate the high clustering property of scale-free networks with higher accuracy, we adapted the Poisson-based wiring strategy to a growing network with the ingredients of both preferential attachment and local connectivity. To achieve the collocation of these properties, we used a routine of flattening the edges array, sorting it, and applying a mixing procedure to assemble both global connections with preferential attachment and local clusters. As a result, we achieved clustered scale-free networks with a computational fashion, diverging from the recent studies by following a simple but efficient approach.

Keywords: *Network modeling, clustering, scale-free networks, small-world networks.*

Introduction

Real networks in nature and society have some generic ingredients as being scale-free with high clustering property (R. Albert & Barabási, 2002). To investigate the main properties of real networks together with the underlying mechanisms, a large variety of studies have been performed (R. Albert & Barabási, 2002; Barabási et al., 2002; M. E. J. Newman, 2001a, 2003; M. E. J. Newman, 2006). Understanding the main mechanisms driving the network topologies led the emergence of modeling studies that the real network structures are imitated in a good approximation by the means of network parameters and distributions.

The "small-world" network model proposed by Watts and Strogatz (WS model), successfully imitated the co-occurrence of small average path length with high clustering property (Watts & Strogatz, 1998). The model was outstanding, capturing a small-world interval of rewiring process of a regular network towards randomness, whereas missing the scale-free property of having power-law degree distribution (R. Albert & Barabási, 2002). Newman and Watts proposed a variant of the WS model with the addition of new edges between randomly picked node pairs, without the removal of the edges originated from the regular lattice. This model was an upgrade for the former model, eliminating the formation of isolated clusters which were evident in the former model (M. E. J. Newman & Watts, 1999a, 1999b).

Another pioneering network model was proposed by Barabasi and Albert, capturing the "scale-free" property observed in real networks (Barabási & Albert, 1999). This property is responsible for some generic properties of real networks like robustness, fast spreading, etc. (Q. Wang, Perc, Duan, & Chen, 2009). The Barabasi-Albert (BA) model corporates the growing property of networks together with the preferential attachment to achieve the power-law degree distribution, whereas it lacks high clustering. Ravasz and Barabasi outlined that scale-free property together with high clustering can emerge with a mechanism of hierarchical organization where small groups of nodes hierarchically organize to compose large groups (Ravasz & Barabási, 2003). The shortcoming of the model was, despite providing scale-free behavior with high clustering, it builds a network as duplicates of a monotonic cluster, establishing a deterministic scheme rather than a probabilistic one.

A large variety of "clustered scale-free network" studies followed these pioneering studies, yielding various formations of network structures that combine scale-free property with small-worldness. The main motivation of the majority of these studies was promoting the triad formation (TF) process of searching initially unclustered pairs of vertices with a common neighbor and then connecting them to form triangles (Alstott, Klymko, Pyzza, & Radcliffe, 2016; Holme & Kim, 2002; Kim & Diesner, 2017; Klemm & Eguiluz, 2002a, 2002b; B. Wang, Tang, Zhang, & Xiu, 2005). Improving clustering for a network of arbitrary degree distribution preserving the evolving property is another approach that was in the core of a portion of the studies (Bansal, Khandelwal, & Meyers, 2009; Colomer-de-Simon & Boguna, 2012; Herrero, 2015; M. E. J. Newman, 2009; Serrano & Boguna, 2005; Yoon, Goltsev, Dorogovtsev, & Mendes, 2011). And another portion of the studies focused on improving clustering by constructing closer links subject to Euclidean distance between nodes (Manna & Sen, 2002; Sen & Manna, 2003; Xie, Ouyang, & Li, 2016; Xulvi-Brunet & Sokolov, 2002).

These models, with various success levels of imitating clustered scale-free networks, also have some limitations having traces on network topology, mathematical or computational complexity, unnatural behavior and so on. We can briefly list the limitations of the TF based models as employing the mixing of different strategies rather than proposing a single strategy to achieve all the goals aimed (Holme & Kim, 2002), achieving relatively small clustering without reaching an acceptable rate as in real networks (B. Wang et al., 2005), employing complex rules for achieving the desired topology such as deactivating nodes, also keeping additional parameters