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Evolving model of weighted networks inspired by scientific collaboration networks

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Abstract

Inspired by scientific collaboration networks (SCN), especially our empirical analysis of econophysicists network, an evolutionary model for weighted networks is proposed. Besides a new vertex added in at every time step, old vertices can also attempt to build up new links, or to reconnect the existing links. The number of connections repeated between two nodes is converted into the weight of the link. This provides a natural way for the evolution of link weight. The path-dependent preferential attachment mechanism with local information is also introduced. It increases the clustering coefficient of the network significantly. The model shows the scale-free phenomena in degree and vertex weight distribution. It also gives well qualitatively consistent behavior with the empirical results.

Keywords: Weighted networks; Scientific collaboration network; Evolving model

1. Introduction

Network analysis is now widely used in many fields [1,2]. In binary network, the edge only represents the presence or absence of interaction. While in weighted network, the weight on the edge provides a natural way to take into account the interaction strength. It gives us more information about the interaction. Recently more and more works on weighted networks appear in both empirical and modeling analysis.

The first important problem about the analysis of weighted networks is how to assign the weight to edges. Sometimes, the real-world phenomena investigated provide a typically natural measurement of the link weight, such as the number of flights or seats between any two cities in airport networks [3–5], the reaction rate in metabolic networks [6] and so on. In the scientific collaboration networks (SCN), the number of connections is a natural quantity which is related very closely to the link weight. Therefore, the happening number of the event is converted as the weight of the edge by different expressions in the study of SCN [4,7–10]. Actually, weighted

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network is one mode (scientist or paper only) projection of a bipartite network (scientists and papers), link weights show the number of collaboration acts between the corresponding vertices [11].

In the work of modeling weighted networks, how link weight evolves with the growth of network is also important. Some models introduced prior weights onto edges with the evolution of networks. In Ref. [12], each link $j \leftrightarrow i$ from the newly added node j is assigned a weight as $w_{ji} = k_i / \sum_{\{i'\}} k_{i'}$, where $\{i'\}$ represents a sum over the m existing nodes to which the new node j is connected. Zheng et al. proposed an improved model [13], in which the link weight depends not only on total degree of the existing nodes, but also on some intrinsic quality ("fitness") of the nodes. In Ref. [14], the link weight depends on randomly modified intervals between the time at which linked vertices are connected to the system. In Ref. [15], the weight w_{ij} of a link l_{ij} connecting a pair of nodes (i and j) is defined as $w_{ij} = (w_i + w_j)/2$, and w_i is defined as i node's assigned number (from 1 to N) divided by N. In other evolving models [16,17], the weight w is assigned to the link when it is created and it is drawn from a certain distribution. As pointed out in Ref. [18], most models here are not really evolutionary models in the sense of weight. The link weight keeps the same value after it was assigned onto its edge.

Recently, some evolving models are set up in which the link weights are coupled directly with the network evolution. In Ref. [18], Barrat et al. proposed a weight-driven model, where the new edges starting from the new vertex added in at every time step are preferentially attached to old vertices determined by their vertex weight. After this attachment, an increase of weight δ is distributed among all the edges connecting to the chosen old vertices. The model yields a nontrivial time evolution of vertices' properties and scale-free behavior for the link weight, vertex weight, and degree distributions. In Ref. [19], Bianconi presented a model with co-evolution of link weight and vertex weight. In his weighted fitness network model, the fitness of node and link are introduced. Dorogovtsev [11] presented a "Minimal models" of weighted networks. The model evolves according to the link weight. One edge is picked up firstly with a probability proportional to its weight, then two vertices are connected onto this edge and the edge weight is increased by a fixed amount Δ. In Ref. [20], the network evolves with connectivity-driven topology and the weight is assigned from a special distribution $\rho_k(x)$. Wang et al. proposed a traffic-driven evolution model of weighted technological networks [21]. By introducing a general vertex weight coupling mechanism under which the traffic and topology mutually interact, the model gave power-law distributions of degree, weight, and vertex weight, as confirmed in many real networks.

Based on the models mentioned above coupled weight and network evolution, we think that a natural evolutionary processes of the weight is needed for weighted networks. Our empirical investigation on SCN gives us some hints on modeling weighted networks. As we mentioned before, link weight in collaboration networks is usually related closely to the number of connections. Using weight converted from the connection number is a convenient way to construct weighted networks. In our model, we keep the relationship between weight and the number of connections. Only the quantities directly rooted in networks are used. So the picture of the evolution looks like the number of connections evolves according to weight, and then the new connection number comes into the weight, which drives the evolution of the network again.

Another important improvement of our model is the introduction of local-path-related preferential attachment, i.e., the δ term in our model. This mechanism works for the network evolution in the real world but is neglected by many other models and it is helpful to increase the clustering coefficient of the networks. One major difference between empirical results and the results of most other models is about the clustering coefficient. Usually, BA model [22] or similar models [18], gave a quite low clustering coefficient, while in reality, real phenomena show highly clustered behavior. Some evolutionary models gave high clustering coefficient with additional mechanisms [23–25]. In Ref. [23], if an edge between v and w is added, then add one more edge from v to a randomly chosen neighbor of w. In Ref. [24], one randomly chosen person introduces two random acquaintances to each another who have not met before. Another idea is to introduce an extra Euclidean distance, and vertices prefer to interact with nearby vertices. Different from the above mechanisms, the δ term in our model is based directly on the topological structure of network. The local-path-related preferential attachment requires only the information about the local structure but it improves the situation about clustering coefficient obviously.

The paper is presented as following. The description of the general model is given in Section 2. The asymptotic distributions of vertex weights for the weight-driven case is given analytically. In Section 3, results of numerical simulations are given. They are well consistent with the analytical results. In Section 4, in order to