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Effect of fitness on mutual selection in network evolution

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Abstract

We propose a new mechanism leading to scale-free networks which is based on the presence of an intrinsic character of a vertex called fitness. In our model, at each vertex i a fitness x_i, drawn from a given probability distribution function $f(x)$, is assigned. During network evolution, with rate p we add a vertex j and connect to an existing vertex i of selected preferentially to a linking probability function $g(x_i, x_j)$ which depends on the fitnesses of the two vertices involved and, with rate $1 - p$ we create an edge between two already existed vertices i and j, with a probability also preferential to the connection function $g(x_i, x_j)$. For the proper choice of g, the resulting networks have power-law distributions of connectivity and small-world properties, irrespective of the fitness distribution of vertices.

Keywords: Complex Network, Scale-free Network, Fitness

1. Introduction

Complex networks are powerful tools to describe a large variety of biological, social, and technical networks. A network is a mathematical object which consists of vertices connected by edges. Despite differences in their nature, many real-world networks are characterized by similar topological properties, in contrast to those obtained by traditional random graphs. One of the most interesting phenomena is the scale-free (SF) behavior, which means a power-law distribution of connectivity, $P(k) \sim k^{-\gamma}$, where $P(k)$ is the probability that a vertex in the network is of degree k and γ is a positive real number determined by the given network. In order to understand how SF networks arise, much work has been done in the past decade. It has been shown that growth and preference seem to be the principal mechanisms for SF behavior.

The exploring the preference can be directed in two classes. The first class of research is based on the *rich-get-richer* rule, which was implemented by newcomers preferential connecting to old vertices with certain topological characteristics [1, 2, 3, 4]. In the best known Barabási-Albert (BA) Model [1], the network grows at a constant rate and new vertices attach to old

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ones with probability $\Pi(i) \sim k_i$. In this way, vertices of high degree are more likely to receive further edges from newcomers. In fact, this extreme assumption is not always available for many networks when their sizes are huge. The second class of research utilizes the *fit-get-richer* mechanism, which was carried out by newcomers preferential connecting to old vertices with high intrinsic fitnesses [5, 6, 7, 8]. This is better adapted to model certain networks where topological properties are essentially determined by "physical"information intrinsically related to the role played by each vertex in the network, such as the ability of an individual, the content of a web page, or the innovation of a scientific article.

Caldarelli et al recently introduced a varying vertex fitness model [6], where they consider an undirected graph of N vertices. At every vertex i a fitness x_i, which is a real number measuring its importance or rank, is assigned. Fitnesses are random numbers taken from a given probability distribution $f(x)$. For every couple of vertices, i and j, an edge is created with probability $g(x_i, x_j)$ (a symmetric function of its arguments) depending on the "importance"of both vertices, i.e., on x_i and x_j. Actually this is a natural generalization of the classic Erdös-Rényi graph [9]. Although it is a static model, the network recovers the power-law behavior of degree, betweenness, and clustering coefficient [6]. On the other hand, Bedogne and Rodgers proposed a growing network with intrinsic vertex fitnesses [8]. Besides employing the edge-created mechanism suggested in Ref. [6], they also considered two cases of new vertices connecting to old ones, uniform or degree-preferential. The interplay between the fitness linking mechanism and uniform attachment results in an exponential degree distribution for any fixed fitness x, while the degree-preferential attachment instead induces that the degree distribution decays as a power law [8].

Models of the first class often present us such an evolution picture: old vertices are passively attached by newcomers according to the degree- (strength-) preferential mechanism. On the contrary, models beloning to the second class pay much attention to the creation and reinforcement of internal connections. Combining above two aspects, we argue that the connection between two vertices is the result of their mutual affinity and attachment, not only for interactions among new vertices and old ones, but also for that among old vertices, called "mutual selection"in the literature [10]. Motivated by this, we suggest an evolving network model ruled by the fitness-dependent selection dynamics. The generated network has a good right-skewed distribution of degrees. Meanwhile, the scaling behavior of the clustering coefficient and the shortest path length of the resulting network exhibit the small-world property. In case that the values of vertex degrees are not available, we believe that the present model is relatively suitable.

2. Model

The present model starts from an initial m_0 isolated seeds and each vertex i is endowed with a fitness $x_i \geq 0$, drawn from a given probability distribution $f(x)$. At each time step, we perform either of the following two operations. (i) With rate $p \in (0, 1)$ we add a new vertex j of fitness $x_j \in f(x)$ to the network. The new vertex connects to an existing vertex i of fitness x_i selected preferentially to a linking probability function $g(x_i, x_j)$ which is symmetric and dependent on the associativity of the both vertices. (ii) With rate $1 - p$ we create an edge between two vertices, i and j, already presented in the network with the probability also preferential to their integration $g(x_i, x_j)$. After t time steps, this scheme generates a network of $m_0 + pt$ vertices and t links. Notice that either process is chosen in the network growth, only one edge is added to the system at each time step (duplicate and self-connected edges are forbidden), however, this is not essential.