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Effect of the age of papers on the preferential attachment in citation networks

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ABSTRACT

In this paper, we investigated the influences of the age of papers on the preferential attachment on the basis of three actual citation networks. We found that the time dependence of the attachment rate $\Pi(k, t)$ follows a uniform exponentially decreasing function, $T(t) \sim \exp(-\lambda t)$, in different citation networks. Younger papers are more likely to be cited by new ones than older papers. On the basis of the aging influences, we modified the expression for the preferential attachment, to $\Pi(k, t) \propto k * \exp(-\lambda t)$. Our results show that the modified preferential attachment works well for citation networks.

1. Introduction

In most real-world networks, aging of the nodes usually takes place, e.g., older papers tend to be cited less, or in social networks, people of the same age are more likely to be linked [1]. This aging effect has been addressed in a few theoretical models for studying the preferential attachment in evolving complex networks [1–6]. In these models, the attachment rate $\Pi(k, t)$ with which a new node gets attached to the older ones is dependent on the degree k as well as the age t of the existing node and can be expressed as [5]

$$\Pi(k, t) = K(k)T(t). \tag{1}$$

A citation network is a good example of an evolving complex network; the nodes are papers and a link will be generated when a new paper cites an old one. Price was the first to study the preferential attachment in a citation network; he called it the cumulative advantage in his work [7]. He suggested that a paper's attachment rate $\Pi(k, t)$ should increase monotonically with its in-degree k, which is the cumulation of the paper's past citations. Redner [8] and Jeong et al. [9] found a linear dependence of $\Pi(k, t)$ on k on the basis of the actual citation networks. But the k considered in these works are not the papers' total in-degrees, because the time span used to generate k is shorter than that used to generate the papers' in-degrees. We also found a good linear relationship between $\Pi(k, t)$ and the past citations obtained in the last year. But there is only a rough linearity if we consider the preferential attachment on the basis of papers' total in-degrees [10].

Brookes proposed that the citations to papers decrease with increasing age of the papers [11]. In other words, papers' age plays an important role in papers' citation behavior. This aging effect has been paid more attention in citation networks in recent years. Some works had been done to investigate the influences of papers' age on their attachment property [1,5,6]. However, these studies are mainly given theoretically, and fewer experimental works have been done on the basis of the actual citation networks.

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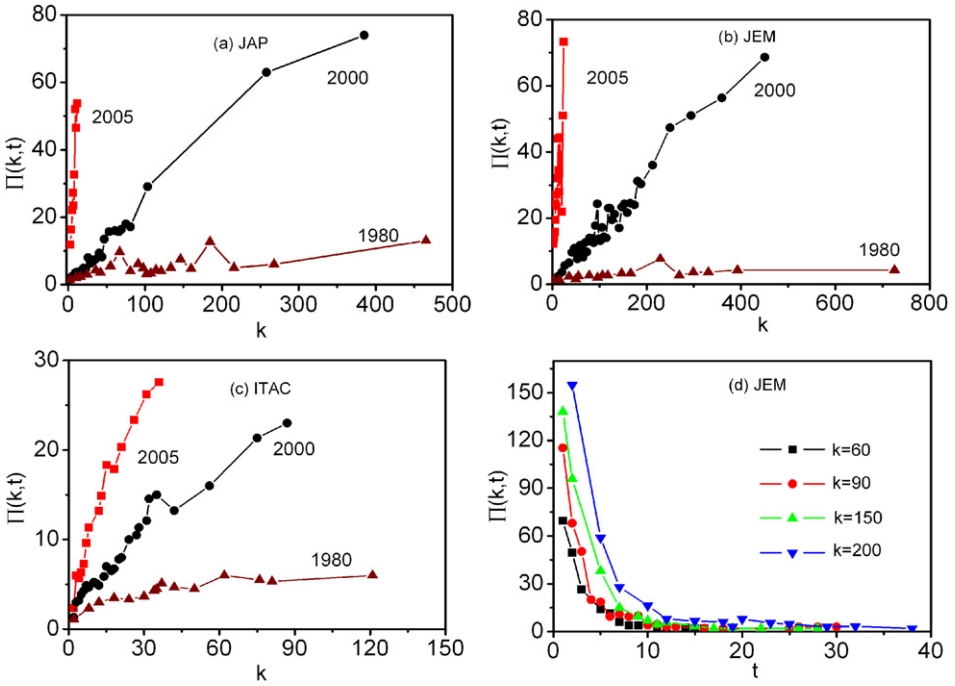

Fig. 1. The attachment rate $\Pi(k, t)$ as a function of papers' in-degree k for JAP (a), JEM (b) and ITAC (c). (d) is an example of $\Pi(k, t)$ as a function of papers' age t for JEM.

In this paper, we studied the preferential attachment in three actual citation networks with the emphasis on characterizing the influences of papers' age on their attachment property. We found a good linear dependence of attachment rate $\Pi(k, t)$ on papers' in-degree k for papers with the same age. But the attachment rate decreases with increasing papers' age. Younger papers are more likely to obtain larger citations. We proposed a method for characterizing the dependence of $\Pi(k, t)$ on papers' age t and found a universal exponentially decaying form. On the basis of these results, we modified the expression for $\Pi(k, t)$ and found a good linear attachment in the three citation networks.

2. Experiments and results

Three journals from different fields of Applied Physics, Immunology Medicine and Automation and Control Systems are chosen to construct the citation networks on the basis of the Web version of the *Science Citation Index* (SCI) produced by ISI:

(1) *Journal of Applied Physics* (JAP), 1931–2005, 2045 papers;
(2) *Journal of Experimental Medicine* (JEM), 1900–2005, 4631 papers;
(3) *IEEE Transactions on Automatic Control* (ITAC), 1963–2005, 1093 papers.

The well-separated citation data for these three journals provide a good platform for opening out the intrinsic character of preferential attachment. In order to investigate the attachment property, we first studied the relationship between $\Pi(k, t)$ and the papers' in-degree k for papers with the same age t. Taking one year as the basic unit and the year 2006 as the reference year, the citations that older papers obtained in year 2006 are calculated as $\Pi(k, t)$ and the citations that papers obtained from their publication to year 2005 as their in-degree k. A paper's age t is the time interval from the paper's publication to the reference year 2006. Here, papers published in different years (2005, 2000 and 1980) in the three journals were chosen as the benchmark for studying the preferential attachment. We find a good linear dependence of $\Pi(k, t)$ on papers' in-degree k when studying the preferential attachment in one given year, as shown in Fig. 1(a), (b) and (c). These results suggest that the preferential attachment works well in a citation network. But the value of the attachment rate $\Pi(k, t)$ changes a lot for papers with different ages and the same in-degree in the same citation network. Papers that are published lately have larger attachment rate, which suggests the preferential property of younger papers. A clearer experimental result is shown in Fig. 1(d), for the example of JEM, where papers with the same in-degree ($k = 60, 90, 150, 200$) were chosen for studying the relationship between $\Pi(k, t)$ and papers' age t. It is interesting that $\Pi(k, t)$ decreases continually with increasing papers' age, which clearly suggests a strong influences of papers' age on the preferential attachment in citation networks. Therefore, it is necessary to consider the papers' in-degree k as well as papers' age t for studying $\Pi(k, t)$ in citation networks.

We propose a method for characterizing the dependence of $\Pi(k, t)$ on papers' age t by studying the citations that papers obtained in a fixed year as a function of papers' age t. Suppose a paper A published in year t_A cites paper B which was published in year t_B. The age of paper B is $t_i = t_A - t_B$ and the number of citations where paper B was cited by paper A is