On the Dynamics of the $h$–index in Complex Networks with Coexisting Communities

Luciano da Fontoura Costa
Instituto de Física de São Carlos. Universidade de São Paulo,
São Carlos, SP, PO Box 369, 13560-970, phone +55 16 3373 9858,
FAX +55 16 3371 3616, Brazil, luciano@if.sc.usp.br
(Dated: 9th Sep 2006)

This article investigates the evolution of the $h$–index in a complex network including two communities (in the sense of having different features) with the same number of authors whose yearly productions follow the Zipf’s law. Models considering indiscriminate citations, as well as citations preferential to the fitness values of each community and/or the number of existing citations are proposed and numerically simulated. The $h$–indices of each type of author is estimated along a period of 20 years, while the number of authors remains constant. Interesting results are obtained including the fact that, for the model where citations are preferential to both community fitness and number of existing citations per article, the $h$–indices of the community with the largest fitness value are only moderately increased while the indices of the other community are severely and irreversibly limited to low values. Three possible strategies are discussed in order to change this situation. In addition, based on such findings, a new version of the $h$–index is proposed involving the automated identification of virtual citations which can provide complementary and unbiased quantification of the relevance of scientific works.

PACS numbers: 89.75.Hc,01.75.+m,01.00.00,01.30.-y,07.05.Mh

‘The only factor becoming scarce in a world of abundance is human attention.’ (Kevin Kelly, Wired)

I. INTRODUCTION

It all started in darkness and mystery. In the beginnings of humankind, explanation of the world and prediction of the future lied deep into the impenetrable realm of sorcerers and medicine men. Except for the extremely rare initiated, the inner ambiguous workings of divination and sorcery were jealously guarded. Similar secrecy was observed through much of the subsequent history of humankind, including the age of oracles in the classical world and alchemy all through the middle ages. ‘Knowledge’ was not for everybody, it was the power source of a few. Ultimately, the value of those practices did not stem from their effectiveness, but emanated from all types of symbology, dogmas, metaphors and ambiguities.

With time, some light was shed, and part of humankind finally realized the value of confronting explanations and predictions with reality, through experiments. That such a basic fact would take such a long time to be inferred provides a lasting indication of the inherent limitations of human nature. Be that as it may, the value of experiments finally established itself, from the renaissance up to the present day. Such an essential change was accompanied by another important fact: it became progressively clearer that once widely disseminated, new findings acted in order to catalyze still more discoveries. The popularization of printing techniques contributed substantially to implementing this new philosophy, being steadily crystalized into an ever growing number of books, and then journals and WWW files. One of the immediate consequences of the first scientific papers was the respectively unavoidable citations. Today, citations and impact factors (calculated by taking into account citations, as well as other indicators) are widely used, to the happiness of some and chagrin of others, for quantifying the quality and productivity of researchers, groups, institutions and journals.

Scientific indices \cite{1} are now regularly applied in order to decide on promotions, grants and identification of scientific trends. In this way, science became, to a large extent, driven by scientometry. However, it is important not to forget the initial purpose of scientific publishing of fostering dissemination of high quality knowledge and results for the benefit of humankind. One important point to be born in mind refers to the fact that all existing scientific indices are biased in some specific way. For instance, the total number of articles published by a researcher is not necessarily related to its productivity unless their age (or seniority) is taken into account. At the same time, the number of citations received by a work or author is also relative, because this number can depend on joint-authorship, the specific area, or even be a consequence of some error in the original work. Yet, though not perfect, scientific indices do provide some quantification of the productivity and quality of papers, researchers, institutions and even countries and continents. The common sense approach, given the unavoidable limitations of the indices, is not to dismiss them, but to try to identify their faults so that they can be further improved. And, little wonder, the best bet is to use science to improve the scientific indices.

It is a positive sign of our age that relatively great effort, reflected in a growing number of related publications (e.g. \cite{1,2,3,4,5,6,7,8,9,10,11,12,13}), that science has indeed been systematically used for studying and enhancing scientific indices. One of the most in-
esting recent developments was Hirsh’s proposal of the $h$–index \( h \). Having sorted the articles of a researcher in decreasing order of citations, the $h$ value can be immediately obtained as the position $h$ along the sequence of articles just before the number of citations become smaller than $h$. Several are the advantages of such an index \( h \), with respect to other more traditional indicators, including the fact that the $h$–index does not take into account the citation tail (i.e. works with few citations) and is more robust than the total number of citations per author in the form of sporadic joint publications with famous researchers \( f \). However, the $h$–index has also been acknowledged by Hirsh to be potentially biased by factors such as the number of authors and the specific scientific area \( a \). Several additional specific shortcomings of the $h$–index have been identified and efforts have been made at their respective correction (e.g. \( h \), \( h \), \( h \), \( h \)). Yet, the $h$–index is indeed an interesting alternative which deserves continuing attention aimed at possible further refinements. Growing attention has also been focused on the dynamical aspects of the evolution of the $h$–index (e.g. \( h \)) as well as the joint consideration of the evolution of author and articles networks (e.g. \( h \)). Another interesting trend is the comparison of the $h$–index with more standard scientometrics indicators including peer judgements (e.g. \( h \), \( h \)). The total number of publications of an author can be roughly estimated from the $h$–index as $C_T = ah^2$, where $a$ is a constant empirically found to lie between 3 and 5. In other words, though not precise, this relationship explains a good deal about the source of the greater stability of this measurement when compared to the traditional total number of citations $C_T$. At the same time, the above relationship is not perfect, otherwise the $h$–index would be but a transformed version of the total number of citations. Another interesting measurement proposed by Hirsch \( h \) is the $m$–index, defined by the linear model $h \propto mn$, where $n$ is the number of subsequent ages (usually years). Therefore, $m$ corresponds to the approximate (mean or instant) rate of increase of the $h$–index with time. An $m$–index of 3 obtained for a researcher, for instance, suggests that his $h$–index tends to increase 30 times after 10 years.

Several related investigations, including Hirsh’s original work \( h \), assume that the articles tend to receive a fixed number of citations $c$ along time. While it would be possible to consider a time window for citations, it is also interesting to take into account preferential citation rules such as in complex networks research (e.g. \( h \), \( h \), \( h \), \( h \)). According to this model, nodes which have many connections (e.g. citations) tend to attract more connections, giving rise to the ‘rich get richer’ paradigm. Another important aspect which has been relatively overlooked is the presence of communities in the scientific world (e.g. \( h \), \( h \)). Several are the possible origins for such communities, including the area of research, language of publication, age, style, among many others.

The present work reports an investigation on the simulated dynamics of the $h$–index considering variable number $c$ of citations received per article, defined by preferential attachment. As such, this work represents one of the first approaches integrating $h$–index and complex networks. However, we believe its main contributions to lie elsewhere, mainly in the consideration of the two communities \( A \), henceforth abbreviated as A and B, with distinct fitness values and under the realistic dynamics of preferential attachment, as well as the assumption that the number of papers published by each author follows the Zipf’s law (e.g. \( h \)). These two communities produce articles with respective fixed fitness indices $f_A$ and $f_B$. In order to reflect some inherent difference between the two communities – e.g. as a consequence of the researcher age, writing style, language or specific area (more likely combinations of these) – we impose that $f_A = 2f_B$, i.e. the articles in community A are inherently twice as much more citable than those produced by the other community. Note that any of the above criterion can be used to separate the citation networks into 2 or more subgraphs, e.g. by establishing respective thresholds \( h \). It is also important to emphasize at the outset that the presence of these two (or more) communities is assumed rather than taken for granted. The same can be said about the possible origin of the fitness difference. It is hoped that the present work can provide subsidies for the eventual identification of such distinct communities from the perspective of the observation of the $h$–indices of the respective authors.

The considered simulated dynamics extends over 20 years. Because of computational restrictions, the number of authors is limited to 78 which, under the Zipf’s law, implies a total of 302 papers per year. Each article is assumed to yield the fixed number of $w$ citations to other works, self-citations included. For simplicity’s sake, the number of papers published per year by each author, as well as the number of authors, are also considered fixed, which is not a great drawback given the relatively short period of the simulation (i.e. 20 years). Despite its unavoidable simplifications, the suggested model provides a number of remarkable results and trends, including bleak perspectives for the community with smaller fitness (B), which are identified and discussed. A brief discussion is also provided concerning possible strategies to be adopted by community B in order to improve its overall $h$–indices. Based on the simulation results, the proposal for yet another enhanced version of the $h$–index, based on the identification of virtual citations in terms of the number of shared main features of each work (e.g. revealed by statistics or artificial intelligence), is outlined.

The article starts by defining the model and follows by presenting the results obtained considering two values of $w$ and uniform/preferential attachment. Considerations are made regarding possible means to change the situation of community B as well as for the proposal of a new version of the $h$–index. The work concludes by summarizing the main findings and suggesting perspectives for future works.
II. THE MODELS

The number of articles published by each author, henceforth $y(i)$, is assumed to follow the Zipf’s distribution \[ p(y) = cy^\beta, \] where $p(y)$ is the distribution probability of $y$ and $\beta$ and $c$ are real parameters. We define the specific form of this relation (i.e., its parameters) by establishing the two extremity points $(y, p(y))$ and $(1, m)$ and $(s, 1)$ of the respective distribution. In other words, we assume that $m$ authors publish only one paper per year and only one author publishes $s$ papers per year. Therefore, we have that

\[ c = m, \] \[ \beta = -\log(m)/\log(s) \]

It is henceforth assumed that $m = 15$ and $s = 30$. In addition, we have to sample from this distribution. Without great loss of generality, we chose $y = (1, 2, 3, 5, 10, 15, 30)$ and consequently obtain $p(y) = (15, 9, 6, 4, 2, 2, 1)$. In other words, 15 authors publish one article per year, 9 authors publish 2 articles per year, and so on. This leads to $NA = 39$ authors and a total of 151 yearly articles. Such a configuration is assumed for the two considered communities A and B, implying a grand total of 78 authors and 302 papers per year.

In order to represent the citations network, we adopt a directed network (i.e., a digraph) defined as $\Gamma = (V, Q)$, where $V$ is the set of $N$ vertices (or nodes) representing the articles and $Q$ is the set of $E$ edges (or links) connecting the nodes (i.e., the citations). Note that both $V$ and $Q$ vary along the 20 considered years. A citation from an article $j$ to another article $i$ is represented as $(j, i)$ and stored into the adjacency matrix $K$ as $K(i, j) = 1$ (a null entry is imposed otherwise). The number of citations received by each article $i$ is immediately given in terms of the respective indegree of the respective node, i.e.

\[ k(i) = \sum_{r=1}^{N} K(i, r) \]

Although presenting identical structure as far as the number of authors and respective number of articles published per year are concerned, the fitness of the articles produced by community A can be considere to be twice as large as those published by community B, i.e. $f_A = 2f_B$. We henceforth assume that $f_B = 1$. These values are used in order to bias the establishment of the links during the simulations as explained below.

The growth of the citation network is performed in yearly terms. Four dynamics are considered for comparison purposes: (i) UNI – uniform; (ii) PREFF – preferential to community fitness; (iii) PREFC – preferential to existing article citations; and (iv) DBPREF – preferential to community fitness and existing citations, each of which is described in the following. Though all models considered in this article do not include a citation time window, this is not a great shortcoming given the relatively short period of the simulation (i.e., 20 years).

In the UNI model, each of the 301 articles added each year are assumed to cite exactly $w$ articles randomly chosen among those published from the previous to the current year. We consider two situations, defined by $w = 5$ and 20. The PREFF model is similar to the UNI scheme, but now the new citations take into account the communities fitness. As a consequence, articles from community A become twice as much likely to be cited than those from community B. The PREFC model is also preferential, but here each of the $w$ citations per article is performed preferentially to the number of existing citations of each article published from the beginning to the current year. This model is therefore similar to the Barabási-Albert model (e.g., [14, 15, 16, 17]), except that the indegrees (i.e., number of citations) are not updated during the year, but only at its end. Finally, the DBPREF model is doubly preferential, to both existing citations and communities. More specifically, a list is kept where the identification of each article is entered a total number of times corresponding to the value of its incoming citations multiplied by the community fitness (i.e., $f_A = 2$ for community A and $f_B = 1$ for community B). New citations are then chosen by random uniform selection among the elements in the above list. Each of the configurations was run 50 times in order to provide statistical representativeness, while the $h$-index and total number of citations per author $N_T$ were calculated for each author at each year.

III. SIMULATION RESULTS AND DISCUSSION

Figure 1(a) shows the evolution of the $h$-indices for the seven considered types of authors (i.e., those publishing $y = (1, 2, 3, 5, 10, 15, 30)$ articles per year have similar dynamics and are averaged together) in community A or B under the UNI dynamics while assuming $w = 5$. The analogue results obtained for the PREFF dynamics for communities A and B are given in Figures 1(c) and (e), respectively. Figures 1(b,d,f) give the respective results obtained for $w = 20$. It is clear from Figure 1 that the $h$-indices of all types of authors tend to increase monotonically with time, though at different rates. Actually, as revealed after some elementary reasoning, all citations will tend to increase linearly with the years. This is a direct consequence of the adopted indiscriminate citation scheme: in principle, any author will receive a fixed average number of citations per year (equal to $w$). Therefore, the $h$-indices will be roughly proportional to the square root of the years. In addition, the $h$-indices of each type of author will directly reflect its yearly production.

Because of the linear rate of increase of the citations per type of author, this model has little interest, except
for providing a comparison standard for the other models considering citations preferential to the number of citations. In particular, note that in the case of identical community fitness values (shown in (a) for \( w = 5 \) and (d) for \( w = 20 \)), the evolution of the \( h \)-indices would not be too different from those obtained for different fitness values (shown in (b,c) for \( w = 5 \) and (e,f) for \( w = 20 \)). For instance, the most productive author in community A would reach an \( h \)-index of 13 after 20 years in case the two communities were identical and an \( h \)-index of 18 after that same period in case its community had twice as much fitness as community B. In other words, the different fitness values have relatively little effect on the relative evolution of the \( h \)-indices.

Figure 2(a) shows the evolution of the \( h \)-indices for the seven considered types of authors in communities A or B under the \( \text{PREFC} \) dynamics while assuming \( w = 5 \). The analogue results obtained for the \( \text{DBPREF} \) dynamics for the A and B are given in Figures 2(c) and (e), respectively. Figures 2(b,d,f) give the respective results obtained for \( w = 20 \). Recall that all these simulations consider citations preferential to the current total among citations of each article (‘rich get richer’). All curves are characterized by a non-linear portion along the first years, followed by nearly linear evolution. Also, as in the indiscriminate case, the \( h \)-indices of the 7 types of authors tend to reflect their yearly production. As could be expected, the standard deviations for all cases tend to increase with the author type productivity.

Let us first discuss the situation arising for \( w = 5 \). Note that a pronouncedly sharper increase of the \( h \)-indices is verified along the first 4 or 5 years for the most productive author types for this value of \( w \). When no distinction is made between the fitness values of the two communities (i.e. model \( \text{PREF} \)) – see Figure 2(a), the \( h \)-indices of the 7 types of authors tend to evolve steadily until reaching, at year 20, the configuration shown in line 1 of Table I. Now, in the case of different fitness values for the two communities (model \( \text{DBPREF} \)), the evolution of the \( h \)-indices is much steeper for community A (Fig. 2(h)) than for community B (Fig. 2(i)). The \( h \)-indices harvested after 20 years by the 7 types of authors in communities A and B in this case would be like those given in lines 2 and 3 of Table I respectively. The ratio between the \( h \)-indices of communities A and B with different fitness values and the \( h \)-index values in the case of equal fitness are given in lines 4 and 5, respectively, in Table I.

Strikingly, while the different fitness of community A contributes to moderate increase ratios varying from 1.174 to 1.402, the effect is catastrophic for community B, with respective ratios varying from 0.56 to 0.43. The reason for such a dynamics is that, with the progress of the years, the articles in community A become ever more cited and competitive, deviating most of the citations that would be otherwise established within community B. This is a situation where, though the rich do not get so much richer, the poor becomes irreversibly poorer as the preferential effect will continue until virtually no citation take place yearly inside community B. An even more acute situation would have been observed in the likely case that the fitness of community A increased with its overall growing \( h \)-indices. As is visible in Figure 2(e), this same effect will slightly contribute to level the \( h \)-index values among the individuals in community B.

The situation for \( w = 20 \) is largely similar to that discussed above for \( w = 5 \), with the following differences. First, a short plateau of \( h \)-index values appear along the first years, especially for the most productive authors in the cases of equal fitness (Figure 2(c)) and for community A with different fitness (Figure 2(f)). The relative increase of the \( h \)-indices observed with respect to the equal fitness case (i.e. the ratios between the lines 7 and 8 with line 6, respectively) are given in lines 9 and 10. Now, while minimal increase ranging from 1.052 to 1.162 is obtained for community A in the case of different fitness values, the ratio for community B varies from 0.50 to 0.43. In addition, the exhaustion of the citations inside community B is now clearly visible in the saturation of the \( h \)-indices in Figure 2(f).

### Table I: The \( h \)-indices of the 7 types of authors after 20 years and respective ratios. See text for explanation. Each of the author types \( i \) is identified as \( \text{AT} \).

| line | AT1  | AT2  | AT3  | AT4  | AT5  | AT6  | AT7  |
|------|------|------|------|------|------|------|------|
| 1    | 4.6  | 7.0  | 8.7  | 11.5 | 16.4 | 19.2 | 26.1 |
| 2    | 5.4  | 8.2  | 10.5 | 14.2 | 21.5 | 25.9 | 36.6 |
| 3    | 2.6  | 3.5  | 4.3  | 5.3  | 6.6  | 7.4  | 9.7  |
| 4    | 1.174| 1.171| 1.207| 1.235| 1.311| 1.349| 1.402|
| 5    | 0.56 | 0.50 | 0.49 | 0.46 | 0.40 | 0.39 | 0.37 |
| 6    | 5.8  | 9.1  | 11.7 | 16.6 | 25.6 | 32.6 | 50.7 |
| 7    | 6.1  | 9.9  | 13.3 | 18.1 | 29.5 | 38.2 | 58.9 |
| 8    | 2.9  | 4.2  | 5.2  | 6.9  | 11.0 | 14.7 | 21.8 |
| 9    | 1.052| 1.088| 1.137| 1.090| 1.152| 1.172| 1.162|
| 10   | 0.50 | 0.46 | 0.44 | 0.42 | 0.43 | 0.45 | 0.43 |

### IV. STRATEGIES FOR IMPROVING INDIVIDUAL \( h \)-INDICES

Given the largely unfair dynamics identified for the authors in community B, it becomes interesting to consider by which means this situation could be, at least partially, improved. Of course, in case the fitness difference were a direct consequence of the quality of the publications in community B, the immediate answer would be that the authors in that community should try to improve their standards or be doomed indeed. However, in case the differences of fitness have a more arbitrary and biased origin, it becomes justifiable to consider means to correct
FIG. 1: The $h$–indices for the seven considered types of authors obtained for any of the two communities with the $UNI$ model (a) and the indices obtained for communities A (c) and B (e) while considering the $PREFF$ (b) model for $w = 5$. The analogue results obtained for $w = 20$ are given in (b) and (d,f).
the situation. The following three possibilities, which are by no means exhaustive, could be considered:

A bit more attention from the richer: Authors in community A tries to cite those in B more frequently. The main advantage of this solution is that the authors in community A would just loose a little bit, while those in B would gain a lot with respect to the even fitness situation. After all, citations should be based only on the inherent quality and contribution of each work.

Collaborative strategy: Authors in B participate as co-authors with community A. Although such a practice would tend to enhance the h−index values in community B, such an increase would be limited by the high resilience of the h-index with respect to such initiatives.

A bit more attention among the poorer: In this case, the authors in community B would pay greater attention to the work of their colleagues, trying to reduce the different fitness effect on the preferential citations. Again, this should reflect the inherent quality and contributions of each work.

V. TOWARDS MORE COMPREHENSIVE CITATION INDICES

Although creative proposals such as the h−index and enhanced variations do provide interesting advantages for measuring the significance of scientific publishing, they can still be biased by several factors including the presence of communities with varying citation fitness which, as shown in the previous section, can lead to critical situations. It would be interesting, in the light of the obtained results, to consider some possible modifications and enhancements to the h−index, as addressed in the following.

First, we have to go back to the reasons why citations exist after all, which include mainly: (a) establish the context of the research; (b) provide additional information about the adopted concepts and methods; and (c) compare methodologies or results. However, all such cases can be conveniently unified into the following criterion:

- Citations should included in order to complement the work in question. As such, all citations should be directly related to the main aspects developed in each new article.

Now, it happens that the relationship between any two articles can be automatically inferred, to some degree of accuracy, by using artificial intelligence methods combined with the ever increasing online access to high-quality scientific databases and repositories. One of the simplest approaches involves counting how many keywords are shared by any pair of articles. In order to define the direction of the citations (actually its causality), the new article would be naturally linked to older entries in the databases. The number of implied citations would naturally vary with the comparison methodology and adopted thresholds, but would nevertheless provide a less arbitrary and complete means for getting more comprehensive and less biased citations from which the respective h−index could be calculated. Actually, after some further reflection it becomes clear that such a citation system allows a series of additional advantages, including:

1. Inherently linked to bibliographical research: One of the preliminary steps in every article is to perform a reasonably complete research on existing related works, the so-called bibliographical search. It would be interesting to use the same system(s) for both bibliographical search and automatic citations, ensuring consistency.

2. More substantive evaluation: Provided good journals (e.g. with reasonable impact factor) are considered for the databases, the quality of the cited works would be at least partially assured. Indeed, a given article could be more likely to be read and evaluated by referees of a good journal than by an eventually hassled author seeking for contextual references. After all, citations are known sometimes to include copies from references in related previous articles (e.g. [1]).

3. Avoidance of personal biases: Because the virtual citations would be established from databases while considering objective keywords, no space is left for any eventual personal biases.

4. Quantification of the quality of the work: With the advance of more sophisticated intelligent computer systems, it will become possible to have the automatic citation system to try to quantify several important qualities of an article, including originality, clarity, grammar, and even fraud detection.

It can not be said that automatic citation can be easily accomplished so that it will be fully precise from the beginning, but certainly it can provide a second, complementary, indication to be taken into account jointly with more traditional scientometric indices. At the same time, the continuing advances of multivariate statistics and artificial intelligence will contribute to achieving ever more intelligent and versatile automatic citation and indexing systems.

VI. CONCLUDING REMARKS AND FUTURE WORKS

In order any artificial process can be improved, it is imperative to quantify its performance in the most objective and unbiased way as possible. Scientific citations – properly normalized by area, number of authors and always under the auspices of common sense – are no exception to this rule. Since the first printed scientific and technical works, authors and readers have been involved in an
FIG. 2: The $h$–indices for the seven considered types of authors obtained for any of the two communities with the \textit{PREFC} model (a) and the indices obtained for communities A (c) and B (e) while considering the \textit{DBPREF} (b) model for $w = 5$. The analogue results obtained for $w = 20$ are shown in (b) and (d,f).
ever evolving complex system of citations aimed at contextualizing and complementing each piece of reported research. Though indicators such as the total number of published articles per author, the total number of citations, or the citations per article, amongst many others, have been systematically used for promotions, grants and identification of scientific trends, there is still no perfect index. Recently introduced by Hirsch [9], the $h$–index presents a series of interesting advantages over more traditional indicators, as well as some specific shortcomings which have been progressively addressed.

At the same time as scientometrics progresses healthly and inexorably, it is important to stick to the original aims of scientific publication, namely the dissemination of new findings in order to foster even further development. In order to complement and enhance reported works, it is essential to provide significant and unbiased citations which can properly contextualize and complement each piece of work. Primarily, each citation is an acknowledgement of a previous work, contributing to its significance and recognition of the respective author. However, because scientometrics increasingly determines the course of science, it is critically important to always revise and improve the respective indices.

The present work has addressed the dynamical evolution of the $h$–index considering a limited period of time (20 years) in a citation network involving two communities whose number of authors follow a particular configuration of Zipf’s law. Other distinguishing features of the reported models include the consideration of citations preferential to an inherent value of fitness assigned to each community as well as to the existing number of citations. Although the number of papers published by year by each author remains constant, two different number of citations emanating from each article (i.e. $w = 5$ and 20) were considered separately.

Four types of models were considered in simulations involving 50 realizations of each configuration. Linear increase of citations was observed for the two models involving indiscriminate citations and citations preferential to the community fitness only. The two more realistic situations assuming the citations to be preferential to the current number of citations of each paper, especially the model where the citations were also preferential to the community fitness values, yielded particularly interesting results. When compared to the evolution of the $h$–indices of the two communities evolving with citations preferential only to the number of citations, the model involving citations also preferential to the communities fitness values showed that the authors in community $A$ experienced moderate increase in the $h$–indices while the indices of the authors in community $B$ suffered severe reduction. It should be recalled that the presence of coexisting communities is but a hypothesis, to be eventually confirmed through additional experimental work.

Having identified such trends in multiple-community systems of citations, we briefly discussed three strategies which could be adopted in order to compensate for the different fitness values. In addition, an improved approach has been outlined which can provide complementary characterization of the significance and productivity of the production of authors or groups. More specifically, it has been suggested that statistical and artificial intelligence methods be used in order to identify virtual citations from each new work to other previous works stores in databases while taking into account the overlap of key features (e.g. key words, main contributions, etc.) between the new and previous works. A number of further advantages have been identified for this approach.

Future extensions of the present work include the consideration of larger number of authors, coexistence of more than two communities, as well as the investigation of possible border effects implied by the relatively small size of the adopted networks. It would also be interesting to perform simulations taking into account longer periods of time, citation time windows (e.g. no citations to articles older than a given threshold), and the progressive addition and retirement of authors.

Scientometrics corresponds to a peculiarly interesting circular application of science to improve itself through the proposal of ever more accurate and unbiased indices and measurements. While the advances of computing have implied an inexorably increasing number of articles and new results, it is suggested that they also hold the key – in the form of artificial intelligence – to proper quantification of scientific productivity and quality. After all, as hinted in the quotation at the beginning of this work, if human attention is becoming so scarce, perhaps automated digital attention can at least provide some complementation.

Luciano da F. Costa is grateful to CNPq (308231/03-1) and FAPESP (05/00587-5) for financial support.

[1] E. Garfield, Science **178** (1972).
[2] P. Ball, Nature **436** (2005).
[3] P. A. Batista, M. G. Campitely, O. Kinouch, and A. S. Martinez (2007), arXiv:physics/0509048.
[4] L. Bornmann and H.-D. Daniel, Scientometrics **5** (2005).
[5] A. Sidiropoulos, D. Katsaros, and Y. Manolopoulos (2005), arXiv:cs:DL/0607066.
[6] L. Egghe (2006), to appear.
[7] L. Egghe, ISSI Newsletter **2** (2006).
[8] K. Boerner, J. T. Maru, and R. L. Goldstone, Proc. Natl. Acad. Sci. **101** (2004).
[9] J. E. Hirsch, Proc. Nat. Acad. Sci. **102** (2005), arXiv:physics/0508025.
[10] S. B. Popov, Proc. Nat. Acad. Sci. (2005),
[11] C. W. Miller (2006), cond-mat/0608183.
[12] B. Cronin and L. Meho, J. Am. Soc. Inform. Sci. Techn. 57 (2006).
[13] A. F. J. van Raan (2005), physics/0511206.
[14] R. Albert and A. L. Barabási, Rev. Mod. Phys. 74, 47 (2002).
[15] S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, and D.-U. Hwang, Physics Reports 424, 175 (2006), cond-mat/0303516.
[16] M. E. J. Newman, SIAM Review 45, 167 (2003), cond-mat/0303516.
[17] L. da F. Costa, F. A. Rodrigues, G. Travieso, and P. R. V. Boas (2006), cond-mat/0505185.
[18] M. E. J. Newman (2004), cond-mat/0410004.

[19] Though an author may have harvested as many as 1000 citations from a single jointly written article, this entry alone will imply an $h$-index equal to 1.

[20] It should be observed that the term community is used in this work in order to identify two subsets of nodes which share some features (i.e. fitness), rather than in the sense of being more interconnected one another than with the remainder of the network.

[21] For instance, if age is to be considered as a parameter, community $A$ could be obtained by selecting those nodes (and respective edges) corresponding to authors older than $T$ years, with the remainder nodes defining community $B$. 