The citation triad: an overview of a scientist's publication output based on Ferrers diagrams

The citation triad: An overview of a scientist's publication output based on Ferrers diagrams

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A B S T R A C T

In a recent work by Anderson, Hankin, and Killworth (2008), Ferrers diagrams and Durfee squares are used to represent the scientific output of a scientist and construct a new h-based bibliometric indicator, the tapered h-index (h_T). In the first part of this paper we examine h_T, identifying its main drawbacks and weaknesses: an arbitrary scoring system and an illusory increase in discrimination power compared to h. Subsequently, we propose a new bibliometric tool, the *citation triad* (*CT*), that better exploits the information contained in a Ferrers diagram, giving a synthetic overview of a scientist's publication output. The advantages of this new approach are discussed in detail. Argument is supported by several examples based on empirical data.

1. Introduction

In the latest years, the interest of the whole scientific community in bibliometric indicators has become higher and higher. A crucial turning point was marked by the Hirsch's h-index. h was proposed as an alternative to other bibliometric indicators. A scientist has index h if h of his or her papers have at least h citations each and the other papers have $\leq h$ citations each (Hirsch, 2005). This indicator is nothing else than a location measure that identifies the most productive core of a scientist's output and gives the number of papers in that core. The set of the h most cited papers is called "h-core" (Rousseau, 2006). For more on the advantages/disadvantages of h and the large number of proposals for new variants and improvements, we refer the reader to the vast literature and extensive reviews (Alonso, Cabrerizo, Herrera-Viedma, & Herrera, 2009; Bornmann, Mutz, & Daniel, 2008; Braun, Glänzel, & Schubert, 2006; Egghe, 2010; Franceschini & Maisano, 2010a; Glänzel, 2006; Rousseau, 2008; Van Raan, 2006). Among the h variants, one of the most appealing and refined is the tapered h-index (h_T), presented by Anderson, Hankin, and Killworth (2008). h_T takes into account all cites (not only those related to the h-core publications) and is strictly monotonic, i.e. it assigns a positive score to each new citation as it occurs. The main idea for computing this index comes from a representation of the cites of the papers in a Ferrers diagram where each row represents a partition of the citations among articles (see Fig. 1). The largest completed (filled in) square of points in the upper left hand corner of a Ferrers diagram is called the Durfee square (in honour of W.P. Durfee) (Andrews, 1998). The side of this Durfee square is nothing else than h (in the example in Fig. 1, $h = 3$), effectively assigning no credit (zero score) to all points that fall outside. The main idea of h_T is to evaluate all the citations, giving to each of them a value equal to the inverse of the increment that

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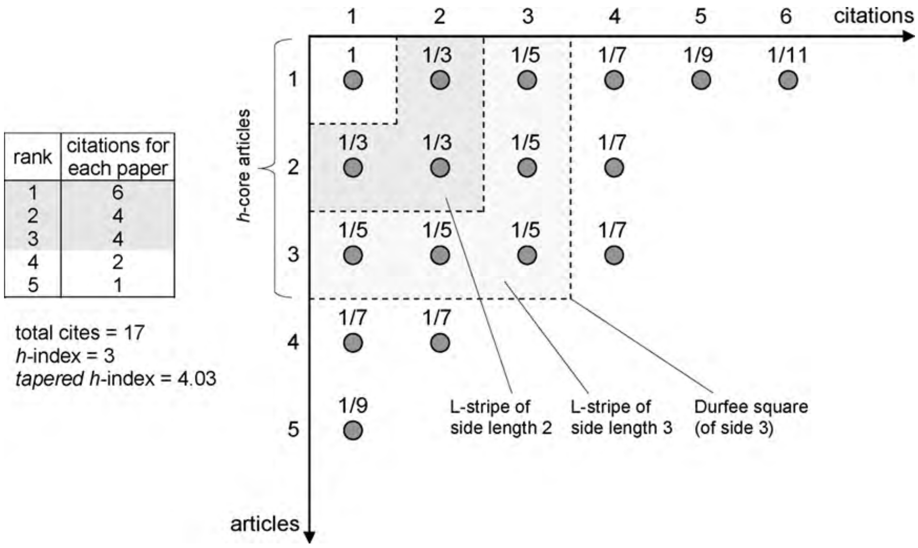

Fig. 1. Example of a Ferrers diagram of an author's citations. Adapted from Anderson et al. (2008).

would suppose to increase h one unit—i.e. $1/(2{\cdot}s-1)$, being s the side length of the square which boundary includes the citations involved. For example, in Fig. 1, we can see that to increment h from 2 to 3, 5 citations are needed (included in an L-stripe of side length 3). Thus, all the citations that are in the size 3 Durfee square will add 1/5 to the final h_T. Considering all the citations represented in Fig. 1, $h_T = 3 + 5{\cdot}1/7 + 2{\cdot}1/9 + 1{\cdot}1/11 \approx 4.03$.

We agree with Anderson et al. (2008) that the Ferrers diagram is a very powerful way for representing the scientific production of a scientist. By this diagram, scientific papers can be immediately subdivided into different categories (see Fig. 2):

1. the "series of most influential papers" forming the *h*-core (Kelly & Jennions, 2006). Among them, we can find the so called "big hit" papers, that is to say those articles with an outstandingly high number of citations, most of which to the right of the Durfee square;
2. papers with relatively few citations (below the Durfee square). Among them, we can find the so called "sleeping beauties", i.e. those papers not cited enough to be included within the *h*-core, but with the potential to do so in future, provided that they accumulate a sufficient number of citations (Van Raan, 2004).

The fact that h captures only a part of the citation data is usually considered as a drawback. Both (1) the vast majority of the citations that accompany the most highly cited papers (to the right of the Durfee square) and (2) the low-cited articles (below the Durfee square) count for nothing in the sense that h is not affected by them. Conversely, h_T – by means of an original but questionable scoring system – positively scores all of an author's citations (i.e. it is strictly monotonic). It is worth remarking that other h variants, such as g, R or hg, take account of the total citations of the most cited papers, but they tend to neglect the low-cited articles (Alonso, Cabrerizo, Herrera-Viedma, & Herrera, 2010; Egghe, 2006; Hua, Wan, & Wu, 2010; Jin, Liang, Rousseau, & Egghe, 2007; Prathap, 2010).

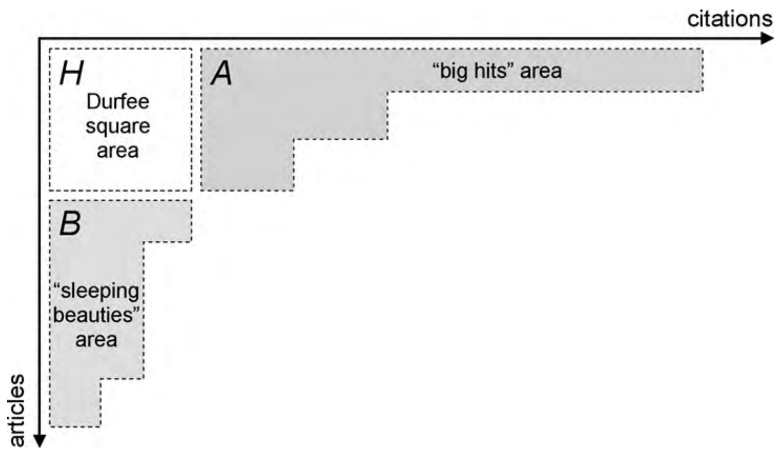

Fig. 2. Functional partitioning of a Ferrers diagram. Three areas are highlighted: the Durfee square area (H), the "big hits" area (A) and the "sleeping beauties" area (B).

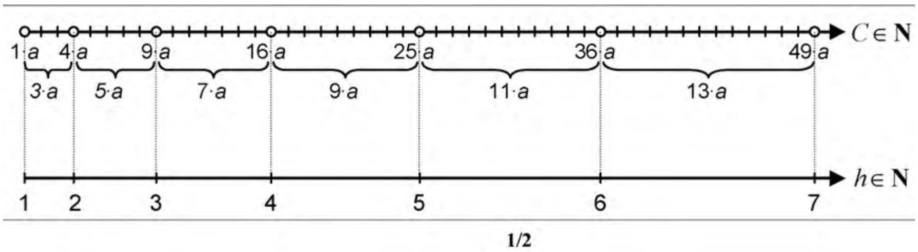

Fig. 3. *h* values represented on the *C* axis. Since $h \approx (C/a)^{1/2}$ (from Eq. (1)), the average distance (in terms of citations) between two consecutive *h*-classes is not constant.

In the first part of this paper we examine h_T identifying and discussing its major drawbacks and weaknesses.

The second part of the paper introduces a new tool – the *citation triad* (*CT*) – for synthesising the Ferrers diagram and depicting the scientific production of a scientist in a more exhaustive way.

The third part describes in detail *CT*. Finally, advantages and limitations of the new tool are discussed in Section 4.

2. Reflection and criticism on h_T

According to several authors, one of the main drawbacks of *h* is not to be strictly monotonic. As seen before, *h* does not necessarily increases when one paper receives a new citation, because it neglects the citations beyond the Durfee square. Conversely, being based on a weighted sum with scores determined as shown in Fig. 1, h_T is strictly monotonic. Precisely, scores associated to citations far from the Durfee square (i.e. citations of "big hits" or low-cited papers) gradually decrease. According to Anderson et al. (2008), another alleged benefit of h_T is to be more efficient than *h* but, at the same time, directly comparable to it. In our opinion, h_T is constructed on the basis of an original and appealing criterion, but the fact remains that there are some arbitrary operations that undermine the real efficiency of this indicator. In the following sections the major drawbacks of h_T are individually described:

- the arbitrariness of the scoring system at the basis of its construction;
- the weakness of the presumed functional connection between h_T and *h*;
- the illusory and misleading increase in discrimination power (with respect to *h*);
- the fact that h_T contains no information on the "shape" of the corresponding Ferrers diagram.

2.1. Arbitrary assignment of scores to citations

The criterion for assigning scores to citations starts from the fact that, for high values of *h*, it becomes more and more difficult to increase it (Burrell, 2007; Egghe, 2006). Precisely, Hirsch empirically showed that, on the average, the total number of citations (*C*) is approximately proportional to h^2 (Hirsch, 2005):

$$C \approx a \cdot h^2 \tag{1}$$

Thus, *h* value is roughly proportional to $C^{1/2}$. The same result is confirmed by the study of Egghe and Rousseau (2006): they prove that *h* is proportional to $C^{1/\alpha}$, where α equals the exponent in the law of Lotka, which most classical value is 2. According to Eq. (1), Fig. 3 illustrates the values of *h* depending on the value of *C*.

Considering a particular class (*h*), the distance from the higher consecutive class ($h+1$) – in terms of number of citations – can be calculated as:

$$C(h+1) - C(h) \approx a \cdot (h+1)^2 - a \cdot h^2 = a \cdot (2h+1) \tag{2}$$

Eq. (2) shows that the average distance between two consecutive (*h*) classes increases proportionally with the *h* value. For example, if $h=5$ this distance is about $a \cdot 11$, and if $h=10$ it is about $a \cdot 21$ citations (Franceschini & Maisano, submitted for publication).

With regard to the h_T scoring system, each citation is scored individually and "in a manner that generates identical *h* scores when relevant Durfee squares are complete" (Anderson et al., 2008). When all citations are included within the Durfee square, then $a=1$ and $h_T = h$. Nevertheless, the scheme for which citations in the same L-stripe (see Fig. 1) have the same score – i.e. $1/(2 \cdot s - 1)$, being *s* the side length of the L-stripe – is rather arbitrary. It can be shown that there are other possible scoring systems satisfying the equality $h_T = h$, when all citations are included in the Durfee square. For example, scores in the same L-stripes can be divided inequitably, giving more importance to citations of "big hits". Starting from the h_T original scoring system (Fig. 4a), one half of the weight of each citation below the main diagonal is transferred to the citations symmetrical with respect to it (see the resulting scores in Fig. 4b). This is just one of the infinitive scoring systems that leaves intact the equality $h_T = h$, when all citations are included in the Durfee square. Using this new scoring system, we would obtain a new variant of the original h_T: say h'_T. For example, considering the same scientific output in Fig. 1, $h'_T \approx 4.14$ against $h_T \approx 4.03$.

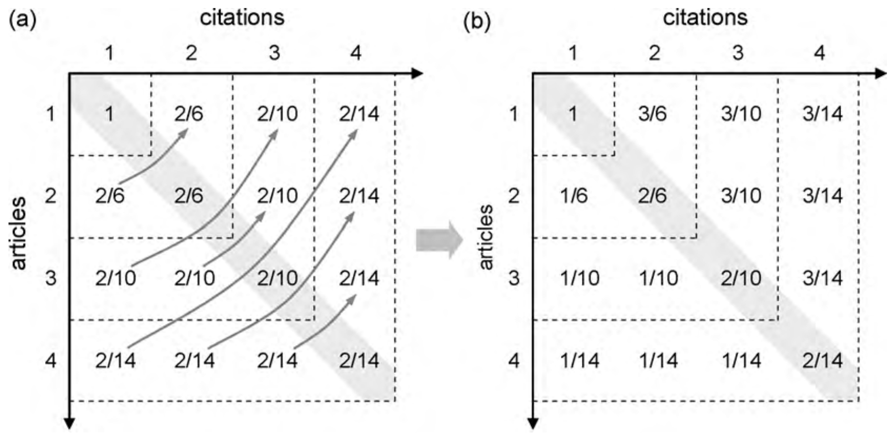

Fig. 4. Example of a scoring system different from that one proposed by Anderson et al. (2008). In the case (b), scores of citations above the main diagonal are 3 times higher than those of the citations below it. Despite this, the sum of the scores in the same L-stripe is still equal to one. (a) h_T original scoring system; (b) alternative scoring system (h'_T).

But which is the most appropriate scoring system among the possible ones? In our opinion, they are equally arbitrary and there is no indisputable proof to claim that one is superior to the others. In general, the very assignment of different scores to citations is arbitrary and generates arbitrary results.

In conclusion, it can be said that the h_T scoring system derives from one of the possible interpretations of h.

2.2. *Functional connection between h_T and h*

In our opinion, the sole fact that h_T and h coincide when there are no citations beyond the Durfee square is not a proof of the fact that the two indicators are logically connected. Precisely, extending the scoring system to citations beyond the Durfee generates a number (h_T) with no direct meaning in terms of citations/papers. For instance, assuming that the scientific production of a scientist is $h_T = 6.81$, we cannot say how much it is different from another scientist's with $h = 6$. Also, differently from h, h_T tells us nothing about the minimum number of citations of the most cited papers. For example, $h_T = 4$ can be obtained through just two "big hit" papers with 111 citations each, or through four papers with four citations each.

Furthermore, the empirical correlation between h_T and h (or other bibliometric indicators) is not, in general, a proof of their logical connection.

2.3. *Illusory discriminatory power*

h is a $\mathbb{N}$ number and is defined over an ordinal scale with only equivalence and ordering properties (Franceschini & Maisano, 2010a; Franceschini, Maisano, Perotti, & Proto, in press; Roberts, 1979; Stevens, 1946). So, only ordering comparisons (greater and less) can be made, in addition to equivalence. For the purpose of example, if two scholars (A and B) have the same h, they are considered as equivalent, while, if $h_{(A)} > h_{(B)}$, then A is considered better than B.

h_T, being the result of a weighted sum with fractional weights is a $\mathbb{R}^+$ number. In our view, the increase in granularity of h_T with respect to h should not be confused with an increase in discriminatory power. To clarify this concept, let consider two examples.

2.3.1. *Example 1*

In Fig. 5, there are two scientists (A and B), with almost identical scientific productions. The only difference is that the most cited work of scientist B is one citation short with respect to scientist A's, while B has one more publication with a single citation. It can be seen that $C_{(A)} = C_{(B)} = 9$ and $h_{(A)} = h_{(B)} = 2$ (side 2 Durfee square). Considering h_T, we notice that $h_{T(A)} < h_{T(B)}$ but, using the alternative scoring system in Fig. 4b, the classification is subverted ($h'_{T(A)} > h'_{T(B)}$).

2.3.2. *Example 2*

In Fig. 6, the Ferrers diagrams of two other fictitious scientists (E and F) are represented. It is easily seen that F is obtained from E, by mirroring the corresponding Ferrers diagram over the main diagonal. In the theory of partitions, E and F are said "conjugate" partitions (Andrews, 1998; Egghe, in press). It is trivial to demonstrate that $h_{T(E)} = h_{T(F)}$. Now, the question is: what is the rationale for considering two so different scientific productions as exactly equivalent (according to h_T)? In fact, apart from sharing the same Durfee square, the scientific production of E mainly consists of "sleeping beauties", while the F's mainly consists of "big hits". Of course, changing the scoring system (for example, using the one proposed in Fig. 4b), the equivalence will no longer be respected.

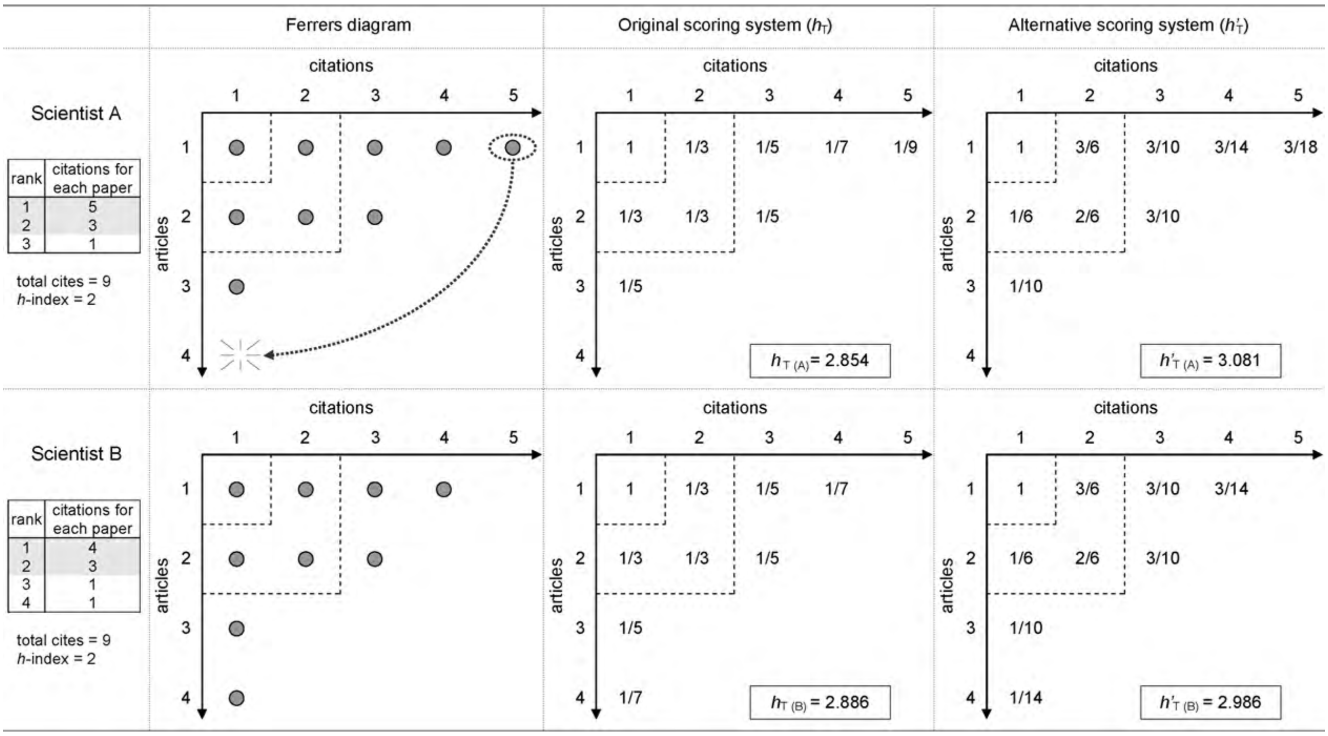

Fig. 5. Ferrers diagrams related to two fictitious scientists (A and B). It can be noticed that the classification by h_T is opposite to the one by h'_T.

The two examples above show that, on the one hand, h_T's granularity is larger than h's and apparently makes it possible to distinguish between hardly comparable situations like those exemplified in the Example 2, on the other hand, h_T may give arbitrary classifications (see Example 1). In other words, the increase in granularity is an effect of the (arbitrary) citation scoring system, but it does not necessarily correspond to a higher discriminatory power of h_T with respect to h. Also, we think that this illusion can increase the risk of passing hasty judgements.

2.4. Other drawbacks of h_T

h_T has other drawbacks that are partly mentioned by Anderson et al. (2008). In particular:

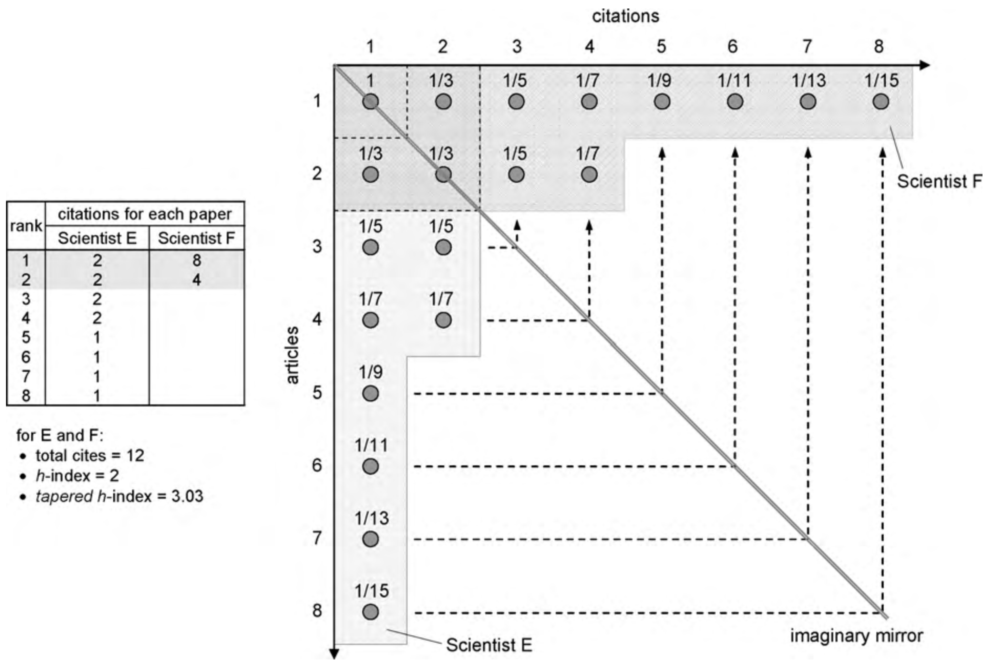

Fig. 6. Example of two fictitious scientists (E and F) with conjugate Ferrers diagrams and, as a consequence, equivalent h_T values (Andrews, 1998). $h_{T(E)} = h_{T(F)} = 3.03$.

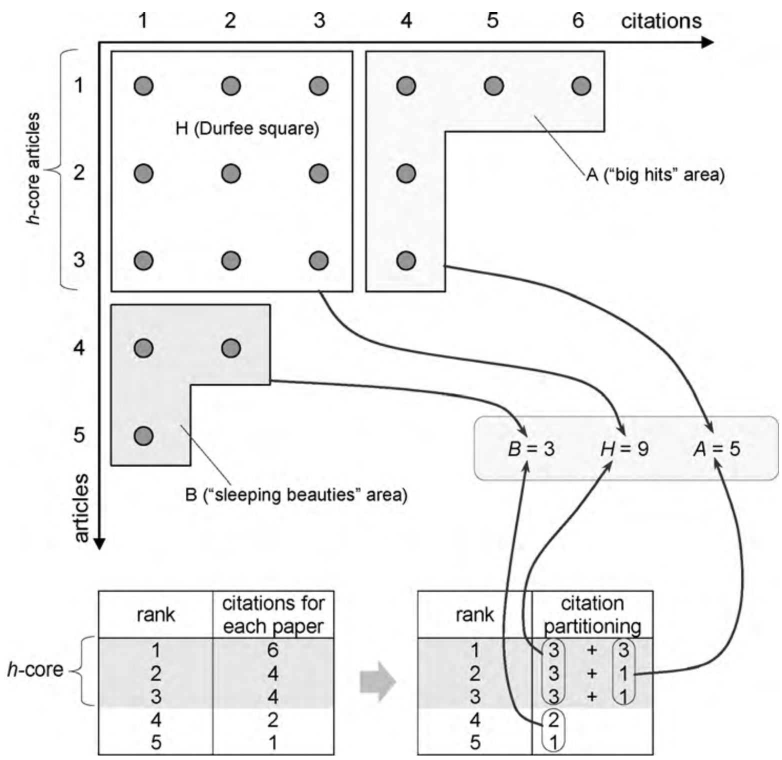

Fig. 7. Calculation of the citation triad – *CT* = (*H*, *A* and *B*) – for the same Ferrers diagram in Fig. 1.

- The calculation of h_T, is much more complex than the *h*'s and requires accurate data from bibliographic databases even for the less cited papers of one author. For this reason, the manual calculation of h_T is very impractical.
- Since h_T takes into account "extra" citations beyond the Durfee square, it is trivial to demonstrate that $h_T \geq h$. However, h_T does not contain any information on the shape of the corresponding Ferrers diagram in terms of predominance of "big hits" or "sleeping beauties". For instance, the two Ferrers diagrams in Fig. 6 have the same h_T even if most of the citations contribution of E is due to "sleeping beauties", while for F is due to "big hits".

3. A new bibliometric tool for synthesising Ferrers diagrams

Despite our criticism of h_T, we give merit to Anderson et al. (2008) for having introduced Ferrers diagrams to represent the scientific output of a scientist. This diagram can be also used to subdivide the total number of citations (*C*) into three main contributions (see Fig. 2):

(*H*) citations in the Durfee square. *H* coincides with h^2, that is the number of citations for the *h*-core publications;
(*A*) citations to the right of the Durfee square ("big hit" papers);
(*B*) citations below the Durfee square ("sleeping beauties").

These triple indicators – (*H*, *A* and *B*) denominated as *citation triad* (*CT*) – provide an exhaustive snapshot of a scientist's citation contributions. An example of calculation is shown in Fig. 7.

CT's information content is certainly superior than the one given by a single indicator, such as *h*, *C* or h_T. Our proposal is to associate these three indicators to each scientist's publication output. The meaning of *CT* is immediate since each element represents a number of citations: those included in the Durfee square (*H*), in the "big hits" area (*A*) and in the "sleeping beauties" area (*B*). In this sense, the new tool gives an instant overview of a scientist's publication output.Alternatively, *CT* could be expressed by the side length of the three (equivalent) squares of area *H*, *A* and *B*. Like *h* with respect to *H*, $\sqrt{A}$ and $\sqrt{B}$ are the sides of two equivalent squares, containing the citation contributions *A* and *B* respectively (see Fig. 8). The advantage of this notation $CT^{(II)} = (h, \sqrt{A}, \sqrt{B})$ is a quicker comparison in terms of *h* (Bornmann, Mutz, & Daniel, in press; Zhang, 2009).

For the purpose of example, *CT* related to the Ferrers diagram in Fig. 1 can be expressed using the two alternative notations reported in Fig. 8: $CT^{(I)} = (9, 5, 3)$ or $CT^{(II)} \approx (3, 2.2, 1.7)$. While those related to the two Ferrers graphs in Fig. 5 (respectively associated to scientists A and B) can be expressed as $CT_A^{(I)} = (4, 3, 1)$ and $CT_B^{(I)} = (4, 2, 2)$, or $CT_A^{(II)} \approx (2, 1.7, 1)$ and $CT_B^{(II)} \approx (2, 1.4, 1.4)$.

For a more extensive example, let consider the list of scientists of Table 1. For each scientist, the following indicators are evaluated: *P* (total papers with at least one cite), *H*, *A*, *B*, *C* and h_T.

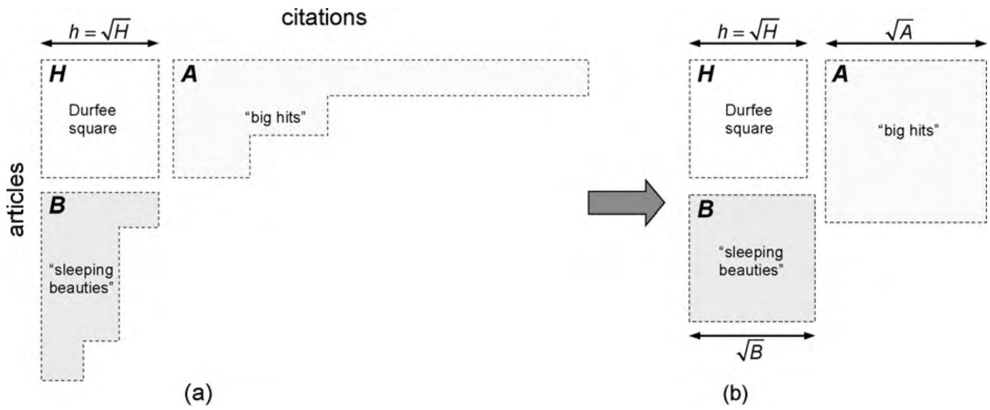

Fig. 8. Graphical representation of the two possible notations for the citation triad. The first one – $CT^{(I)}$ – is based on citations, whereas the second one – $CT^{(II)}$ – is based on h. (a) notation based on citations: $CT^{(I)} = (h^2, A, B)$; (b) notation based on h: $CT^{(II)} = (h, \sqrt{A}, \sqrt{B})$.

Table 1
List of 21 scientists in the same scientific field. For each scientist the following bibliometric indicators are reported: P (total papers with at least one cite), H (citations in the Durfee square), A (citations to the right of the Durfee square: "big hits" area), B (citations below the Durfee square: "sleeping beauties" area), C (total citations), and h_T (tapered h-index).

Scientist	P (with at least one cite)	Citation triad			$C=H+A+B$	h_T
		H (h^2)	A	B		
1	68	169 (13^2)	162	303	634	22.9
2	44	121 (11^2)	291	146	558	19.5
3	47	81 (9^2)	89	132	302	15.4
4	42	81 (9^2)	81	120	282	15.3
5	26	81 (9^2)	82	76	239	14.1
6	28	64 (8^2)	36	59	159	11.6
7	15	49 (7^2)	49	43	141	10.9
8	16	49 (7^2)	53	22	124	10.1
9	16	36 (6^2)	75	22	133	10.2
10	41	25 (5^2)	18	107	150	10.1
11	19	25 (5^2)	38	32	95	8.1
12	18	16 (4^2)	22	30	68	7.5
13	6	9 (3^2)	8	4	21	4.4
14	6	4 (2^2)	25	7	36	4.6
15	2	4 (2^2)	9	0	13	3.1
16	2	4 (2^2)	1	0	5	2.2
17	2	4 (2^2)	0	0	4	2.0
18	3	1 (1^2)	0	2	3	1.5
19	2	1 (1^2)	0	1	2	1.3
20	0	0	0	0	0	0.0
21	0	0	0	0	0	0.0

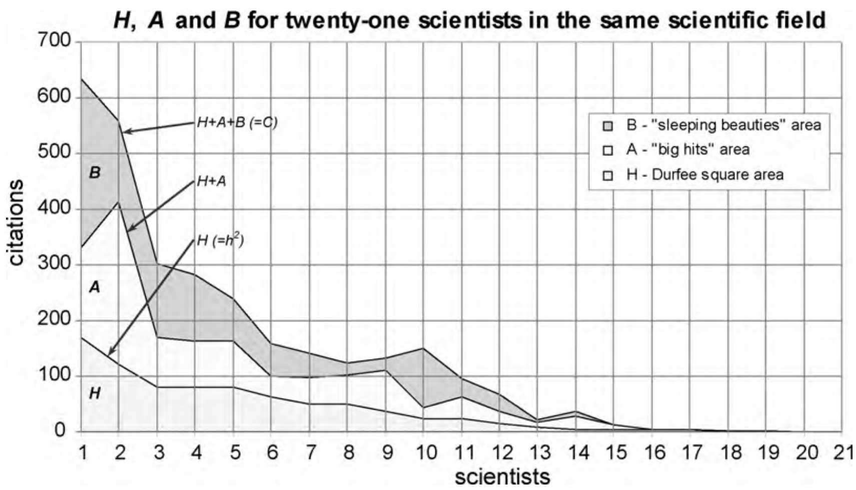

Fig. 9. Chart representing the citation triad for the scientists in Table 1. Scientists are reported on the horizontal axis, while citation contributions (H, A and B) on the vertical axis. Conventionally, scientists are ranked in lexicographic order $H \rightarrow C$ (sort according to H and, in case of equality, according to $C=H+A+B$).

An effective graphical way to represent *CT* is shown in Fig. 9. This chart represents the H, $H+A$ and $H+A+B$ curves of the 21 scientists of interest. Scientists can be quickly compared on the basis of H (lower curve), A (distance between the H and $H+A$ curves), B (distance between the $H+A$ and $H+A+B=C$ curves). This chart gives an exhaustive picture of the scientific production of a scientist and makes it possible to identify doubtful situations, in which there can be conflicting classifications depending on the indicator in use. For example, let consider scientists 9 and 10: $h_{(9)} > h_{(10)}$ but $B_{(9)}$ is much smaller than $B_{(10)}$, so that $C_{(9)} < C_{(10)}$. Also, $B_{(10)}$ is much larger than $B_{(9)}$, because of the large number of "sleeping beauties" of scientist 10.

Using h_T alone, most of the information contained in the scientists' Ferrers diagrams tends to be lost and there is a risk of generating questionable classifications. When possible, it is often recommended using a set of indicators, so as to take many aspects into account and provide an exhaustive picture of the matter of interest (Costas & Bordons, 2007; Franceschini, Galetto, & Maisano, 2007; Van Leeuwen, Visser, Moed, Nederhof, & Van Raan, 2003).

4. Discussion and final remarks

CT makes it possible to synthesise and to compare the Ferrers diagrams of several scientists. Here follows a list of the major benefits, especially in comparison with h_T:

- The information content is higher, since different kinds of citation contributions are distinguished. For example, scientists with large H (or h) values are probably more productive and diffused in the scientific community than others. A relatively high A, with respect to H, means that most of the citations are concentrated on few "big hit" paper. On the contrary, a relatively high B means that the "sleeping beauties" tend to prevail and perhaps they will "come to life" at some point in future.
- Differently from h_T, the calculation of *CT* does not require any arbitrary assignment of scores.
- The three indicators of the triad have an immediate meaning. H corresponds to the square of the h-index, so it has a direct meaning in terms of number of papers and citations, A and B are the citations respectively to the right ("big hits" area) and below the Durfee square ("sleeping beauties" area). In contrast, h_T can be confused with a "magic number" with no clear meaning, which can be used to make arbitrary discriminations.

Also, we are aware of the limitations of *CT*:

- The calculation is elementary, but is not immediate like that of h (see Fig. 7).
- Since Ferrers diagrams do not take account of papers with no cites, *CT* is insensitive to them.
- The use of *CT* does not directly generate an univocal classification of the scientists, because it is based on three different indicators. However, precise strategies can be adopted to construct a classification. For example, in the graph in Fig. 9, the lexicographic order $H \rightarrow C$ is used. In any case, we should never forget that the presence of conflicting classifications (according to different bibliometric indicators) is a signal of possible incomparability or need for a closer examination (Franceschini et al., 2007).
- Being based on citations, the indicators of the triad are subject to the criticism made to h, C and other bibliometric indicators. For example, these indicators can be distorted by self-citations or multi-authorship, they are not useful for cross-disciplinary comparisons, unfavourable to young scientists with few articles, etc. (Franceschini & Maisano, 2010b; Franceschini et al., in press).

References

Alonso, S., Cabrerizo, F., Herrera-Viedma, E., & Herrera, F. (2009). *h*-Index: A review focused in its variants, computation and standardization for different scientific fields. *Journal of Informetrics*, *3*(4), 273–289. doi:10.1016/j.joi.2009.04.001

Alonso, S., Cabrerizo, F., Herrera-Viedma, E., & Herrera, F. (2010). *hg*-index: a new index to characterize the scientific output of researchers based on the *h*- and *g*-indices. *Scientometrics*, *82*(2), 391–400.

Anderson, T. R., Hankin, R. K. S., & Killworth, P. D. (2008). Beyond the Durfee square: Enhancing the *h*-index to score total publication output. *Scientometrics*, *76*(3), 577–588.

Andrews, G. E. (1998). *The theory of partitions*. Cambridge, UK: Cambridge University Press.

Bornmann, L., Mutz, R., & Daniel, H. D. (2008). Are there better indices for evaluation purposes than the *h* index? A comparison of nine different variants of the *h* index using data from biomedicine. *Journal of the American Society for Information Science and Technology*, *59*(5), 830–837.

Bornmann, L., Mutz, R., & Daniel, H. D. (in press). The *h* index research output measurement: Two approaches to enhance its accuracy. *Journal of Informetrics*.

Braun, T., Glänzel, W., & Schubert, A. (2006). A Hirsch-type index for journals. *The Scientist*, *69*(1), 169–173.

Burrell, Q. L. (2007). Hirsch index or Hirsch rate? Some thoughts arising from Liang's data. *Scientometrics*, *73*(1), 19–28.

Costas, R., & Bordons, M. (2007). The *h*-index: Advantages, limitations and its relation with other bibliometric indicators at the micro level. *Journal of Informetrics*, *1*(3), 193–203.

Egghe, L. (2006). Theory and practise of the *g*-index. *Scientometrics*, *69*(1), 131–152.

Egghe, L. (2010). The Hirsch-index and related impact measures. *Annual Review of Information Science and Technology*, *44*, 65–114.

Egghe, L. (in press). Conjugate partitions in informetrics: Lorenz curves, *h*-type indices, Ferrers graphs and Durfee squares in a discrete and continuous setting. *Journal of Informetrics*.

Egghe, L., & Rousseau, R. (2006). An informetric model for the Hirsch-index. *Scientometrics*, *69*(1), 121–129.

Franceschini, F., Galetto, M., & Maisano, D. (2007). *Management by measurement: Designing key indicators and performance measurement systems*. Berlin: Springer Verlag.

Franceschini, F., & Maisano, D. (2010a). Analysis of the Hirsch index's operational properties. *European Journal of Operational Research*, *203*(2), 494–504. doi:10.1016/j.ejor.2009.08.001

Franceschini, F., & Maisano, D. (2010b). The Hirsch spectrum: A novel tool for analysing scientific journals. *Journal of Informetrics*, *4*(1), 64–73. doi:10.1016/j.joi.2009.08.003

Franceschini, F., Maisano, D., Perotti, A., & Proto, A. (in press). Analysis of the *ch*-index, an indicator to evaluate the diffusion of scientific research output by citers. *Scientometrics*.

Franceschini, F., & Maisano, D. (submitted for publication). Criticism on the *hg*-index. *Scientometrics*.

Glänzel, W. (2006). On the opportunities and limitations of the *h*-index. *Science Focus*, *1*(1), 10–11.

Hirsch, J.E. (2005). An index to quantify an individual's scientific research output, in *Proceedings of the National Academy of Sciences of the United States of America*, vol. 102, pp. 16569–16572.

Hua, P. H., Wan, J. K., & Wu, J. H. (2010). A perfect Hirsch-type index? Experiences using the tapered *h*-index (h_T). *Chinese Journal of Scientific and Technical Periodicals, 21*(1), 33–37 (in Chinese). An English translation is provided at E-LIS, ID-code 17847, http://eprints.rclis.org/17847/.

Jin, B. H., Liang, L. M., Rousseau, R., & Egghe, L. (2007). The R- and AR-indices: Complementing the *h*-index. *Chinese Science Bulletin*, *52*(6), 855–963.

Kelly, C. D., & Jennions, M. D. (2006). The *h* index and career assessment by numbers. *Trends in Ecology & Evolution*, *21*(4), 167–170.

Prathap, G. (2010). Going much beyond the Durfee square: Enhancing the h_T index. *Scientometrics*, doi:10.1007/s11192-009r-r0067-1

Roberts, F. S. (1979). *Measurement theory: With applications to decisionmaking, utility, and the social sciences*. *Encyclopedia of Mathematics and its Applications* Reading, MA: Addison-Wesley.

Rousseau, R. (2006). New developments related to the Hirsch index. *Science Focus, 1*(4), 23–25 (in Chinese). An English translation is provided at E-LIS, ID-code 6376, http://eprints.rclis.org/6376/.

Rousseau, R. (2008). Reflections on recent developments of the *h*-index and *h*-type indices. *COLLNET Journal of Scientometrics and Information Management*, *2*(1), 1–8.

Stevens, S. S. (1946). On the theory of scales of measurement. *Science*, *103*(2684), 677–680. doi:10.1126/science.103.2684.677

Van Leeuwen, T. N., Visser, M. S., Moed, H. F., Nederhof, T. J., & Van Raan, A. F. J. (2003). The Holy Grail of science policy: Exploring and combining bibliometric tools in search of scientific excellence. *Scientometrics*, *57*(2), 257–280.

Van Raan, A. J. F. (2004). Sleeping beauties in science. *Scientometrics*, *59*(3), 467–472.

Van Raan, A. F. J. (2006). Comparison of the Hirsch-index with standard bibliometric indicators and with peer judgment for 147 chemistry research groups. *Scientometrics*, *67*(3), 491–502.

Zhang, C. T. (2009). The *e*-index, complementing the *h*-index for excess citations. *PLoS One*, *4*(5), 1–4. doi:10.1371/journal.pone.0005429