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Unified citation parameters for journals and individuals: Beyond the journal impact factor or the *h*-index alone

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Abstract. We seek a unified and distinctive citation description of both journals and individuals. The journal impact factor has a restrictive definition that constrains its extension to individuals, whereas the h-index for individuals can easily be applied to journals. Going beyond any single parameter, the shape of each negative slope Hirsch curve of citations vs. rank index is distinctive. This shape can be described through five minimal parameters or 'flags': the h-index itself on the curve; the average citation of each segment on either side of h; and the two axis endpoints. We obtain the five flags from real data for two journals and 10 individual faculty, showing they provide unique citation fingerprints, enabling detailed comparative assessments. A computer code is provided to calculate five flags as the output, from citation data as the input. Since papers (citations) can form nodes (links) of a network, Hirsch curves and five flags could carry over to describe local degree sequences of general networks.

Keywords. Citations; networks; structure of complex systems.

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1. Introduction

The statistics of citations, their assessment parameters and the characterisation of growing networks have been of much interest [1–40]. Both journals and individual researchers are sources of citations, but for historical reasons, they are assessed using a very different parameter for each: the journal impact factor (JIF) for journals [10–17] and the h-index for individuals [18–20]. The JIF index introduced by Garfield in 1963 is important in the development of scientometrics, and has been extensively and critically discussed [28–39]. The h-index was introduced by Hirsch in 2005 for assessing individual research output [18]. It is a special point on a Hirsch curve of decreasing citations vs. rank of the cited papers, and has been analysed [19,20]. For a unified description, we must extend the JIF to individuals; or apply the h-index to journals; or find some other set of parameters to describe both.

In this paper, we outline some of the literature on the JIF and its limitations, concluding that it is unsuitable for extending to individuals. However, the h-index for individuals can be applied to a journal, simply by treating it as a prolifically publishing individual [40]. We propose that the distinctive shape of each negative-slope Hirsch curve, for individuals and journals, can be described through an h-related minimal set, of five parameters or 'flags'. These flags are the h-index itself, dividing the curve into two segments; the first-moment of each citation segment; and the two endpoints at the axes. We evaluate and discuss the five flags (5F) that provide distinctive citational fingerprints, for real data sets of 10 faculty members and two well-known journals. These five flags or 5F enable more nuanced citational comparisons in the spirit of the Leiden manifesto [25,26], than through any single parameter alone. Finally, since citations form networks [27], a Hirsch curve in other variables could characterise local degree sequences of other networks [5–9].

The plan of the paper is as follows. Section 2 outlines the history, definition and limitations of the JIF. Section 3 introduces the h-index, H-curve and five flags and §4 uses them to assess individuals and journals. Section 5 relates H-curves to network degree sequences, and discusses hierarchical aggregations, from faculty to departments to universities. Section 6 is a summary, and mentions further work. The Appendix at the end of the paper introduces a distinctive notation, to distin-

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guish and discuss the properties of the JIF and other parameters.

2. The journal impact factor

2.1 *JIF background and definition*

Availability of journal citations was made possible by Garfield, who developed an indexing system, and in 1960 incorporated the Institute for Scientific Information, to collect, analyse and distribute data. The science citation index (SCI) listed well-cited journals in all fields [10–17] and distributed abstracts of papers in these journals by airmail. The Institute, including its Web of Science (WoS) database, was purchased by Thomson-Reuters and later became part of Clarivate Analytics, with their annual journal impact factor rankings marketed as Journal Citation Reports.

Early work [10,15] found that a small number of good journals generated most of the citations. These more important journals needed to be quickly and easily identified for inclusion in the SCI list. Parameters such as total citations (of order $\sim 10^3$), were found to capture many important journals [11–16]. Garfield says "We also recognized that smaller but important review and speciality journals might not be selected if we depended solely on total publication or citation counts" [14]. The current impact factor (of order ~ 10), used as an inclusion parameter in the SCI listing of good journals was defined [11,14] as (italics added):

"A journal's impact factor is based on two elements: the numerator, which is the number of cites in the *current* year to *any items* published in the journal in the *previous 2 years*; and the denominator, the number of substantive articles (source items) published in the same 2 years."

Here the numerator was one year's recording of citations, counting all mentions of the journal ('any items'), whether to refereed research papers/reviews ('substantive articles'), or to other material (ephemera such as editorials, letters of opinion etc. [11]). The denominator however had only substantive articles, published in the prior two years. The ratio would provide a quality indicator for SCI list inclusion with minimal effort, in the computational era of punchcards.

This 2-year impact factor was explained through an example [17]: "A = total cites in 1992. B = 1992 cites to articles published in 1990–91 (this is a subset of A). C = number of articles published in 1990–91. D = B/C 1992 journal impact factor." The generalised 5-year impact factor was similar. While the denominator had 5 years of published papers, the numerator had citations garnered only in the 6th year (to all items) and so had 'one year of citations to 5 years of papers' [17]. The original 2-year current impact factor was called the JIF and displayed up to three decimal points in rankings [11–16,41].

A notation from the Appendix is useful. Let us define $S_c(A, B; D)$ as the total citations for a publication block of A years; a citation block of B years; and a delay of D years between the starts of A and B. The number of research papers published in the A-year block is $N_p(A)$. In this notation, the JIF with a 2-year publication block $A = 2$; a $B = 1$ year subsequent citation block; and a delay $D = 2$ years between the starts, has citations $S_c(2, 1; 2)$. The JIF or 2-year impact factor is JIF≡ IF(2) $= S_c(2, 1; 2)/N_p(2)$. The five-year impact factor IF(5)= $S_c(5, 1; 5)/N_p(5)$. This notation manifests the JIF's staggered, off-diagonal character ($D \neq 0$) and its limited data record of only a single year's citations ($B = 1$), for any A. See Appendix.

We use the same symbol A for any publication duration or block. For example, an individual's 'academic age' or block of years since first publication is A years; while for journal performance monitoring, the fixed publication block is chosen as $A = 5$ years.

Provision of a JIF single ranking of thousands of journals in the order of decreasing values, inevitably turned the JIF into a single, all-field, prestige parameter. Journal websites displayed their latest JIF to three decimal places. Individual authors included journal JIF values in their publication lists, that were then used to assess faculty for hiring, promoting or funding [28–37].

2.2 *Limitations and improvements*

We discuss the shortcomings of the JIF, and possible improvements by relaxation of its definitional constraints.

(i) The JIF does not measure a field-independent quality called 'impact': It would be valuable to have a journal parameter that in every field takes on high values for leading, respected journals; and small values for journals regarded as mediocre. Such a parameter would measure the absolute journal 'impact', for any field. However, the JIF value is found to be strongly field-dependent and is manifestly, not such a field-independent metric [28,29].

Every field has a different natural time-scale for a paper to be noticed, read and cited. The JIF definition imposes a 2-year time-delay between the start of publication and the start of one year of citations. This (inverse) 'probe frequency' is clearly closer to resonance for some fields, than others.

For 3 million mathematics citations not only do 90% of all citations fall outside a 2-year window, but "50% of the citations are to items appearing in the previous decade" [28]. The well-respected *Journal of the American Medical Association* (JAMA) is in the top 10 of the rankings, with a JIF value of just under 50 cites. The well-respected *Annals of Mathematics* is ranked almost a thousand places lower, with one-tenth the JIF value. It is not clear what is conveyed to either medicos or mathematicians, by this single-list JIF ranking.

It would be useful, if field-specific separate rankings were provided, with the top-ranked journal in each field normalised to be 100. Such lists could be obtained, simply by sorting the JIF rankings by field and rescaling in the top JIF value. However, since the data are proprietary, [42] the company would itself have to offer this, as a new product.

(ii) The JIF, intended for journals, is used for authors: The use of the JIF to characterise individual papers in the journal has been supported by some [43–45], but strongly criticised by others [28–37,46]. Anecdotes illustrate JIF misuse [28], especially affecting young people [36,37]. The San Francisco declaration on research assessment (DORA) suggests [38] that journal metrics should not be used as a surrogate quality measure for individuals, for hiring, promotion or funding. A paper's importance is best indicated by the citations to the paper itself, rather than to the journal that contains it [37].

(iii) The JIF is quoted to three-decimal precision, that could be somewhat misleading: Although the denominator (rightly) refers to research items only, the JIF numerator counts all mentions to 'any items' in the citation year. For multifield journals, the percentage of ephemera that are neither research articles nor research reviews, can be [39] from 4% to 8%. A journal position in the JIF ranking list of thousands, can be shifted downwards by a decrease in its third decimal place. The implied research-metric precision of 0.1% may not be entirely justified [41].

(iv) The JIF distribution is broad, skewed and sparse: The JIF sequential ranking list was purchased as a finished product, that was described as not reproducible and the data that support it not publicly available [29–34]. However, transparency was enhanced in 2016 by Larivière *et al* [39] who showed through sequential screenshots, how to independently extract information from the subscription databases Web of Science (WoS), or Scopus. For any journal, the distribution of different cite values that make up its one-year citation mentions, could now be obtained directly by the public. Journal websites displayed this JIF distribution, along with their three-decimal JIF values. The distribution was broad and skewed, with more than 65% of cites smaller than the JIF value itself [28,39]: a high-JIF journal could have many lower-citation papers [46].

We consider actual data from WoS for the journals J1 = *Biology Letters* and J2 = *Science*. The J1 distribution of cites in 2014 had a JIF of around 3 and was quite sparse [39]. Figure 1 shows for J1, the citation distribution with

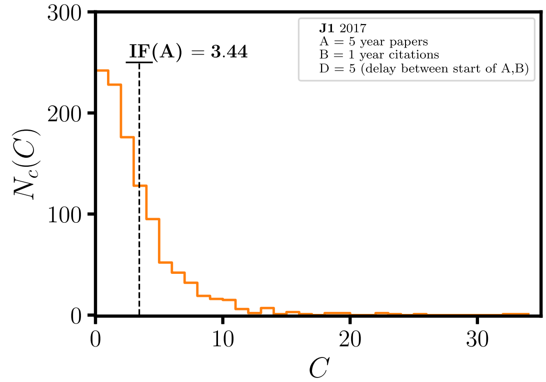

Figure 1. Citation distribution for a journal with restrictions of the impact factor IF(5): Plot is shown for journal J1, of only citations garnered in a 1-year period 2017, to papers published in the previous 5-year period (2012–16). The durations and delay A, B, D years in the legend are explained in the text and Appendix.

5-year impact factor IF(5) constraints: all-item citations garnered only during 2017, to papers published in prior 5 years (2012–2016), with IF(5) = 3.447. The data are also quite sparse, from the very definition of the JIF (see Appendix).

Instead of the restricted JIF citations $S_c(2, 1; 2)$, more data could be captured if we (i) expand the citation block from $B = 1$ year to $B = A$ citation years and (ii) relax the off-diagonal condition of $D \neq 0$, to allow $D = 0$ diagonal data collection, with citation/publication blocks now coincident. The resultant citations $S_c(A, A; 0)$ determine the A-year citation distribution $N_c(C)$, that carries much more data than the IF(A). The total number of papers is $N_p = \sum_{C=2,3...,\infty} N_c(C)$; the total number of citations $N_{c,\text{tot}} = \sum_{C=2,3,...,\infty} C N_c(C)$; and the mean cites per paper is $\bar{C}(A) = N_{c,\text{tot}}/N_p(A)$. Note that we retain only papers cited more than once, or $C \geq 2$. This tends to filter out most ephemera [47].

Consider J1= *Biology Letters* that has $N_p(5) = 849$ papers published in the 5-year block (2012–2016). Figure 2a distribution $N_c(C) \sim S_c(5, 5; 0)$ displays research-paper citations over the same period (2012–2016). The distribution is manifestly richer than the figure 1 distribution for IF(5) that records citations only for the single year 2017. The 5-year citation average $\bar{C}(5) = 10.1$ cites/paper is higher than IF(5)= 3.4. Similarly, figure 2b for J2 = *Science*, shows that for $N_p = 3566$ papers during the same 5-year publication block, the distribution $N_c(C)$ has average $\bar{C} = 76.1$ cites. Citation distributions $N_c(C)$ displayed on websites would be a fairer depiction of journal profiles than the JIF alone.

The h-index defined by Hirsch for individuals [18] is provided automatically by databases even for journals [40]. The distribution of figure 2 for $C < h$ is above zero, while for $C \geq h$, there are many zero regions separating high-citation spikes: the h index seems to be a natural divider.

The average citations over the two segments are nac and hac numbers of figure 2,

$$nac = \sum_{h \geq C \geq 2} N_c(C)\, C/n; \tag{1}$$

$$hac = \sum_{\infty > C \geq h} N_c(C)\, C/h. \tag{2}$$

We next consider 5F for 10 faculty members F1, F2, . . ., F10 from different countries, fields and ages. Figure 3 shows the citation distribution for two of these faculty members F5 and F8, of academic ages $A = 17$ and 31 years, respectively. The average cites are $\bar{C}(A) =$ 14.8 and 27.1 cites/paper and $h = 20$ and 33. The h-index and partial averages nac, hac are denoted by lighter-dash vertical lines in figures 2 and 3.

The qualitative similarity of figures 2 and 3 suggest that it is natural to describe journals and individuals by a unified set of citation parameters. It is only for historical reasons that they were described differently [11,18].

3. The H-curve of citation vs. rank

The Hirsch 'curve' is a histogram of citations $c(s)$ to specific, identified papers, arranged in descending order, in serially numbered slots $s = 1, 2, \ldots, N_p$. This H-curve is the basic concept and the citation distribution or citation frequency $N_c(C)$ can be derived from it. A narrow horizontal band at citation $C = c(s)$ (of bin width ΔC) captures $N_c(C)\Delta C$ points. Thus $N_c(C)$ is the number of papers with citation values between C and $C + \Delta C$, without retaining identification of the papers. Treating degenerate citations of distinct papers through Kronecker deltas, the number of papers with citation C is

$$N_c(C) = \sum_{s=1,2\ldots N_p} \delta_{c(s),C} \tag{3}$$

with total papers

$$N_p = \sum_{C=2,3,\ldots,\infty} N_c(C) = \sum_{s=1,2,\ldots,N_p} 1. \tag{4}$$

A useful input for the individual is the academic age A, or years from first publication, with the temporal label A incremented yearly:

$$A = \text{current year} - \text{first publication year} + 1. \tag{5}$$

For journals, A should not be the widely varying actual ages from founding, since old papers are rarely cited beyond their half-life (see Appendix). To normalise comparisons between journals, and make editorial monitoring uniform, we take a common, fixed-width window of $A = 5$ years, sliding it forward annually.

The parameters to describe the H-curve can be the two curve endpoints at the citation and rank axes; an h-index point in between; plus the qth moments of the two (finite) curve segments on either side of h. The number of such parameters is $3+2q$. The simplest set is with the $q = 1$ moments, or the mean citation over each segment, for a total of $3 + 2 = 5$ flags, for both individuals and journals.

A comparison of several single parameters for journals [35] gives a very relevant conclusion: "The notion of scientific impact is a multidimensional construct, that cannot be adequately measured by any single indicator." Our proposed multidimensional indicators are the five flags $\boldsymbol{\phi}_5 \equiv (h, r, u, nac, hac)$ obtained from the shape of the H-curve and defined as follows:

(i) The first flag is the h-index itself as defined in [18], "A scientist has index h if h of his or her N_p papers have at least h citations each and the other $N_p - h$ papers have $\leq h$ citations each." This h definition has

$$c(h) \geq h. \tag{6}$$

The N_p papers are divided by h into h-type and n-type populations, of sizes $\sum_{s=1}^{h} 1 = h$ and $\sum_{s=h+1}^{N_p} 1 = n$. So

$$N_p = h + n. \tag{7}$$

(ii) The second flag is a ratio or r-index related to the H-curve endpoint at the x-axis, where $s = s_{\max} = N_p$, the number of papers [47]. The r-index is the fraction $0 < r < 1$ of papers that are h-type,

$$r \equiv h/N_p. \tag{8}$$

The percentage of the papers that are h-type, is $100r$. The normally cited or n-type papers are the remaining fraction:

$$n/N_p = 1 - r. \tag{9}$$

(iii) The third flag or u-number is the endpoint of the Hirsch curve at the y-axis, or the uppermost or maximum citation, $c(1) = C_{\max}$, divided by the h-index,

$$u \equiv C_{\max}/h. \tag{10}$$

(iv) The fourth flag is the average citation of the n papers that are less cited, with the lowest [47] as $c(N_p) \geq 2$. Using an acronym for a variable name,

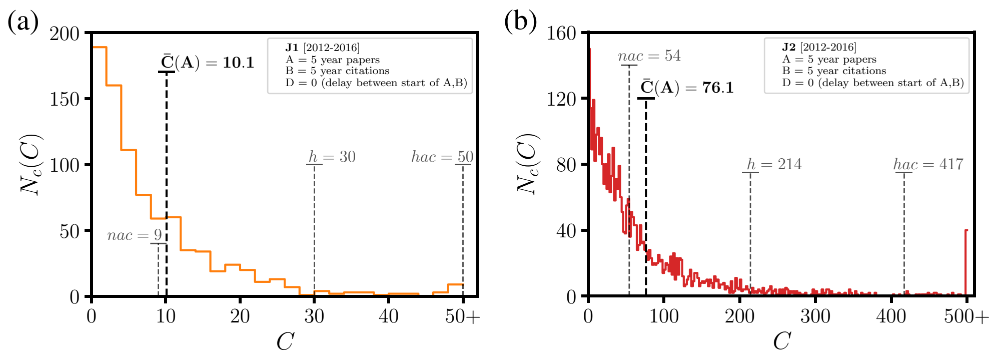

Figure 2. Citation distributions for journals: Plots of citation distribution $N_c(C)$ vs. C, for (**a**) journal J1 and (**b**) journal J2, of all citations garnered in the 5-year period (2012–16) to papers published in the same 5-year period. Data beyond the x-axis limit are combined into a final spike of relevant height. Heavier dashed vertical lines show the cites/paper $\bar{C}(A)$ over A years of the distribution. Lighter dashed vertical lines show the Hirsch index h for journals, and the (rounded) partial averages hac, nac over segments below and above h.

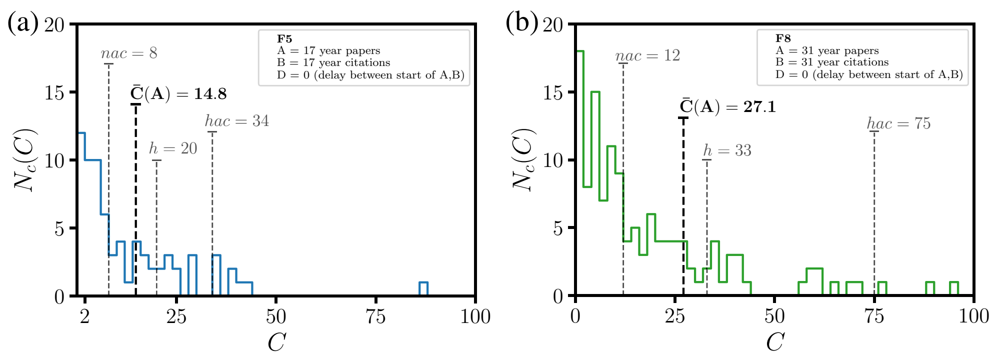

Figure 3. Citation distributions for individuals: Plots of citation distribution $N_c(C)$ vs. C, of all citations garnered by faculty F5, F8 in the 5-year period (2012–16), to papers published in the same 5-year period. The durations and delay A, B, D years are explained in the text and Appendix. Dark dashed vertical lines show the cites/paper $\bar{C}(A)$ over A years of the distribution. Light dashed vertical lines show the Hirsch index h and the (rounded) partial averages nac, hac over segments below and above the h-index.

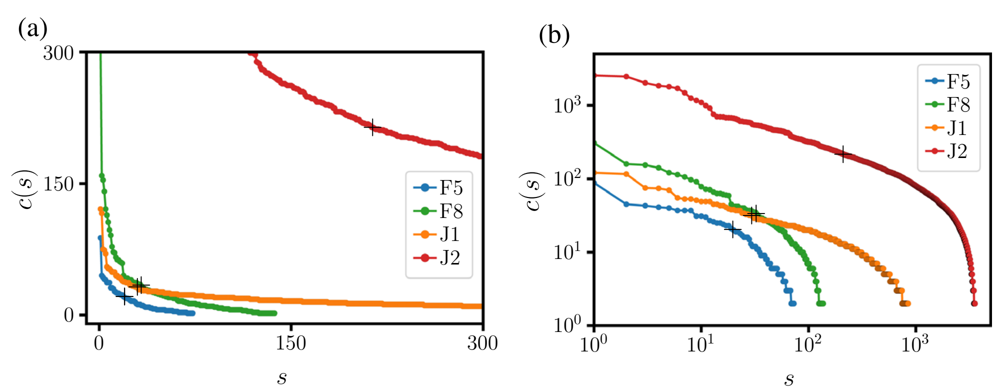

Figure 4. Hirsch curve for two individuals and two journals: The citation $c(s)$ vs. rank index s are shown for two faculty members F5 and F8 and two journals J1 and J2. A cross marks the Hirsch point $(h, c(h))$. A diagonal line of slope +1 would intersect the H-curve close to or at, the H-point. (**a**) Linear–linear Hirsch curves and (**b**) log–log Hirsch curves, or citation profiles.

the **n**-population **a**verage **c**itation is called the **nac**-number. The numerator is only over the n normally cited papers:

$$nac \equiv \sum_{s=h+1,\ldots,N_p} c(s)/n. \tag{11}$$

(v) The fifth flag is the average citation of the h papers that are cited more, going between $c(1) = C_{\max}$ and $c(h)$. Again, using an acronym, the **h**-population **a**verage **c**itation is called the **hac**-number. The numerator is only over the h higher-cited papers:

$$hac \equiv \sum_{s=1,2..h} c(s)/h. \tag{12}$$

The flags are related to certain averages proposed independently [19,48], although these were not motivated by the H-curve shape.

Five flags compactly carry other citational information and eight further citation parameters can be derived from them. These include the average citations per paper, the total number of papers and of citations, the publication rate per year and the incremental citation rate per year per paper, the maximum number of citations and the number of citations coming from h-type papers and from n-type papers.

(i) The average cites/paper $\bar{C}(A)$ garnered over A years is a weighted sum of the hac, nac 'components':

$$\bar{C} \equiv N_{c,\mathrm{tot}}/N_p = [r\ hac + (1-r)\ nac]. \tag{13}$$

(ii) The total number of papers $N_p \equiv \sum_{s=1,2,\ldots,N_p} 1$, as well as the total number of citations $N_{c,\mathrm{tot}} \equiv \sum_{s=1,\ldots,N_p} c(s)$ can be derived from the five flags:

$$N_p = h/r, \tag{14}$$

$$N_{c,\mathrm{tot}} = (h/r)\ [r\ hac + (1-r)\ nac]. \tag{15}$$

(iii) The average publications per year, or publication rate R_p is

$$R_p \equiv N_p/A = (h/rA). \tag{16}$$

The average incremental citations per paper per year $R_c = \bar{C}(A)/A$ is

$$R_c \equiv N_{c,\mathrm{tot}}/AN_p = (1/\ A)\ [r\ hac + (1-r)\ nac]. \tag{17}$$

(iv) The maximum citation is

$$C_{\max} = u \times h. \tag{18}$$

(v) The number of citations from h-type and n-type papers are the areas under H-curves above and below the divider $s = h$, or in terms of 5F, are respectively

$$N_{c,n} = n \times nac, \quad N_{c,h} = h \times hac. \tag{19}$$

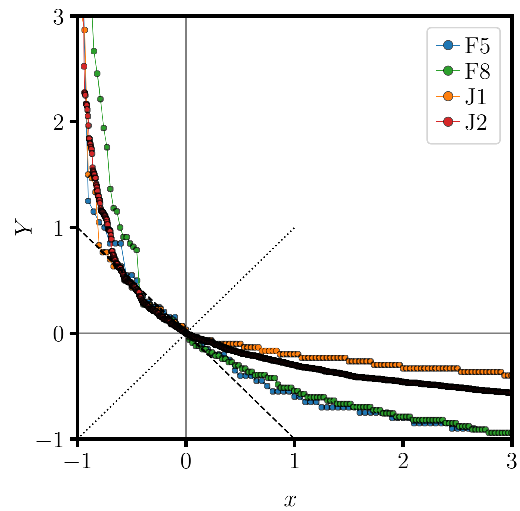

Figure 5. Shape of H-curve with the H-point as the origin: Linear–linear plot in scaled and shifted variables, of citations $Y \equiv [c(s)-c(h)]/c(h)$ vs. rank $x \equiv [s-h]/h$ for two faculty members F5, F8 and two journals J1, J2. The H-point is (0, 0). The dashed line is the linear approximation [18] of $Y = -x$, of slope -1. Dotted line through the origin has slope $+1$.

Figure 4 shows that H-curves for two faculties F5 and F8 and two journals J1 and J2 have a small number of papers $s \leq h$ cited a large number of times; and a large number of papers $s \geq h+1$ cited a smaller number of times. Note that (a) the overall shapes are qualitatively similar, justifying a unified 5F analysis for both individuals and journals and (b) the segment curvatures and endpoints are however quantitatively distinct (even for close by h values). The 5F fingerprints of table 2 are distinctive, for each of the 10 individuals or two journals [49].

For a steady publication rate R_p, new papers will enter to the right of the endpoint $s = N_p$ in figure 4a. If the citation rate is constant and equal for every paper, older papers would have more accumulation time and have more citations. The $c(s)$ would be a straight line of negative slope.

Figure 5 is the data of figure 4a, but now plotted with shifted and scaled variables

$$x \equiv (s-h)/h; \ \ Y \equiv [c(s)-c(h]/c(h). \tag{20}$$

The curve origin $(x, Y) = (0, 0)$ is the H point. A constant citation rate or linear approximation [18] is shown in figure 5 as $Y = -x$ of slope -1. The deviations from linearity of the actual H-curves suggests that citation increments depend on existing citations, in autocatalytic

Table 1. Five flags from toy-model data for four applicants.

App	A	h	r	u	nac	hac	Y/N	N_p	R_p	R_c	$N_{c,\mathrm{tot}}$	$\bar{C}$	$C_{\max}$
Y1	5	4	0.8	1.5	3	4.75	No	5	1	0.9	22	4.4	6
Y2	5	4	0.8	25	3	51	Yes	5	1	8.3	207	41.4	100
Y3	8	20	0.5	2	2	30.5	No	40	5	2.0	650	16.3	40
Y4	8	20	0.5	2	20	30.5	Yes	40	5	3.2	1010	25.3	40

Table 2. Five flags from actual data for 10 faculties and two journals.

F/J	A	h	r	u	nac	hac	N_p	R_p	R_c	$N_{c,\mathrm{tot}}$	$\bar{C}$	$C_{\max}$
F1	3	8	0.62	32.0	5.8	73.1	13	4.3	15.7	614	47.2	256
F2	26	18	0.29	11.9	6.3	36.6	63	2.4	0.6	940	14.9	214
F3	12	18	0.56	8.6	8.4	37.4	32	2.7	2.1	792	24.8	155
F4	27	19	0.25	5.6	6.9	41.1	76	2.8	0.6	1174	15.4	106
F5	17	20	0.27	4.4	7.7	33.7	73	4.3	0.9	1083	14.8	88
F6	9	22	0.46	6.4	10.2	53.4	48	5.3	3.3	1439	30.0	141
F7	45	23	0.33	53.7	10.1	159.7	70	1.6	1.3	4147	59.2	1234
F8	31	33	0.24	9.3	12.0	74.6	137	4.4	0.9	3710	27.1	308
F9	28	33	0.28	5.8	11.4	67.1	119	4.3	1.0	3193	26.8	191
F10	24	33	0.31	11.6	13.5	85.8	107	4.5	1.5	3831	35.8	382
$J1$	5	30	0.04	4.0	8.7	49.6	849	169.8	2.0	8578	10.1	121
$J2$	5	214	0.06	11.9	54.4	416.6	3566	713.2	15.2	2,71,549	76.1	2553

growth of cumulative advantage or preferential attachment [1–9].

4. Five flags for assessments

We consider 5F for assessing applicants, faculty and journals and examine 5F dependence on the size of the citation network.

4.1 *5F and assessing applicants*

There are limitations in using the h-index alone [19,28,35] as a sole assessment parameter screening faculty applicants. Since $h < N_p$, there are structural reasons for h to be small for those who have published less, whether because of their field, or their youth. The full $\boldsymbol{\phi}_5$ gives a fairer and more complete description, as illustrated by toy-model data, with 5F calculable 'by hand'.

Consider applications by two young faculty candidates Y1, Y2, in a subfield that has a low publication rate of one paper/year, and so over academic age $A = 5$ years the papers published are $N_p = 5$ for both. Suppose their citations are

$$\mathrm{Y1} = [6, 5, 4, 4], 3; \quad \mathrm{Y2} = [100, 50, 50, 4], 3,$$

where the square brackets contain the $c(s) \geq 4$ relatively higher citations. The pair Y1, Y2 would be classified as equivalent, based only on their common $h = 4$. This does not match with our intuitive perception that Y2 has a stronger citation record.

A second (youngish) pair Y3,Y4 of age $A = 8$ is in a high publication-rate subfield with five papers per year, and so $N_p = 40$ for both. Their higher-cited papers in square brackets below are the same, with the citations for 20 papers stepping down by 1 each time, from 40 to 21. However, while Y3 has another 20 papers, each cited 2 times, Y4 has another 20 papers each cited 20 times,

$$\mathrm{Y3} = [40, 39, \ldots, 21], 2, \ldots, 2;$$
$$\mathrm{Y4} = [40, 39, \ldots, 21], 20, \ldots, 20.$$

The pair Y3,Y4 will be classified as equivalent, based only on their common $h = 20$. This again does not match our intuitive perception that Y4 has a somewhat better citation record.

Thus, h is unchanged, unless there is a citation increase in the last of the h-type papers. However, the averages in the five flags together, compensate for such limitations of the h-index used alone [35].

Table 1 shows the five flag parameters [h, r, u, nac and hac] of these four applications considered by a screening committee, for two faculty positions. The 5F are on the left with six useful derived parameters on the right. A blind use of N_p alone, or h alone, would yield a short list of the older, same-sub-field candidates Y3,Y4, resulting in an unbalanced department.

The 5F not only help in applicant shortlisting, but also reveal the different contributions of h-type and n-type papers. The candidate Y4 has a higher nac-number than Y3 (solid performance by normal papers), with hac-numbers the same. The candidate Y2 has a higher hac-number (strong record of highly cited papers) than Y1, while the nac-numbers are the same. The overall average $\bar{C}$ is a combination, that naturally suggests the same choice Y2, Y4, but carries less information. The high u values of short-listed applicants will prompt a reading of their star publications. Thus, the usual scientific evaluations, supplemented by 5F assessments, can enable academically sound choices of a balanced department, through a logical, legally justifiable procedure.

4.2 *5F and the assessing faculty*

We discuss the 5F from real citation data of 10 faculty members, from four countries, including India and in the fields of physics (mostly), but also biology and chemistry; both theorists and experimentalists; of various levels of juniority/seniority; and of two genders, with data from Google Scholar in November 2018. Table 2 shows the five flags h, r, u, nac, hac on the left; they are clearly distinctive for each individual. Three faculties have degenerate $h = 33$, but very different 5F and derived quantities. Parameters (except for r) are given only up to one decimal place, avoiding spurious precision. Six derived quantities $N_p, R_p, R_c, N_{c,\text{tot}}, \bar{C}, C_{\max}$, are on the right.

The table shows the following:

(i) In the spirit of the 80:20 rule [50], a majority of citations come from the (h-type) minority of papers, e.g. for F8 a percentage $100\ N_{c,h}/N_{c,\text{tot}} = 66\%$ of the total citations come from $100r = 24\%$ of the papers.

(ii) The values and ranges of 5F values are as follows. The h values go from 8 to 33. Senior-level faculty, of age-range $A = 17$ to 45 years have smallish ratio-indexes $r = 0.24$ to 0.33; whereas younger faculty of age $A = 3, 9, 12$ years tend to have larger $r = 0.62, 0.46, 0.56$. The number of faculty publications range from $N_p = 13$ to 137, while the publication rate $R_p = N_p/A$ ranges from 1.6 to 5.3 papers per year. The average citations per paper, per year $R_c = N_{c,\text{tot}}/N_p A \sim 1$ suggests accumulation is typically slow. (The anomalous young F1 has unusually small A, N_p). The total citations of each faculty member $N_{c,\text{tot}} = N_p \times \bar{C} = R_p \times R_c \times A^2$ range from $\simeq 614$ to $\simeq 4147$ cites.

The highest citation in units of h, or $u \equiv C_{\max}/h$, goes from 4.4 to 53.7. The maximum citations are derived as $C_{\max} = u \times h$ and range from 88 to 1234.

(iii) Faculties like F5, F8 can be compared for a more senior position, in a nuanced manner, through 5F and derived quantities. They have $h = 20$ and 33 and age $A = 17$ and 31 years; almost the same publication rate $R_P = 4.3$ and 4.4; ratio index $r = 0.27, 0.24$; and the same citations per paper, per year $R_c = 0.9$. The difference in the total number of publications $N_p = 73$ and 137 can be attributed to the 13 year age difference. But the h-population parameters of F8 are ($hac \simeq 75, C_{\max} = 308, N_{c,\text{tot}} = 3710$), that exceed 5F values of ($hac \simeq 34, C_{max} = 88, N_{c,\text{tot}} = 1083$), well beyond the age effects. The 5F points to candidate F8, but of course are supplements to other factors, of academic quality and administrative ability.

(iv) The five flags $\boldsymbol{\phi}_5$ give a fairer chance to young people and faculty in low-publication fields. Using the h-index alone, they would be structurally disadvantaged. However, youngish faculty members F1, F6, F3 with ages $A = 3, 9, 12$, have values of $u \simeq 32, 6, 9$, of $nac \simeq 6, 10, 8$ cites/paper, and of $hac \simeq 73, 53, 37$ cites/paper, that can exceed those for some senior or more prolific faculty. Thus, 5F could be talent-spotting flags, for young people [51].

4.3 *5F and assessing journals*

We show five flags in table 2 collected from actual WoS data around December 2018 for journals J1 and J2. The journal J1 = *Biology Letters* is a well-regarded single-field journal that is small in size. The journal J2 = *Science* is a well-regarded, much larger and multidisciplinary journal. The 5F and derived quantities of table 2 are very different: here we try to understand the reasons.

Garfield has noted that journal size matters, for citations [52]. Thus, if over five years J1 has $N_p = 849$ while J2 has $N_p = 3566$ papers, the size difference alone would make the J2 total citations larger by at least a factor of 4.

The nac-numbers for J1 and J2 are 9 and 54, respectively, a factor of ~ 6. The hac-numbers for J1 and J2 are ~ 50 and ~ 417 respectively, for a relative factor of 8.3. These are slightly higher than the size factor of 4.

However, the maximum citations for J1, J2 are $C_{\max} = h \times u = 121$ and 2553 cites, a factor of 21. The n-type papers that are $\sim 95\%$ of the total, garner citations $N_{c,n} = n \times nac$ that for J1, J2 are $\simeq 7400$ and $\simeq 171000$ cites respectively, a factor of 23. The 5-year

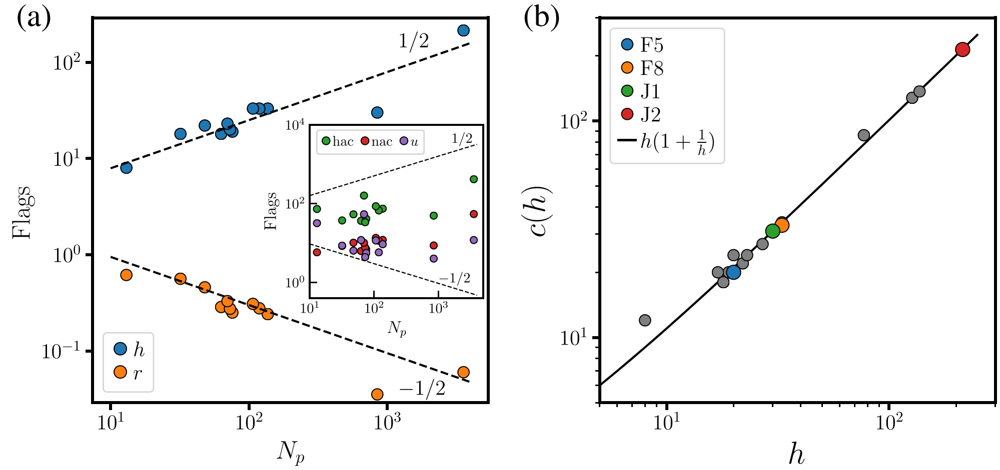

Figure 6. Log–log plots of 5F-related variables vs. size: (**a**) The plots are the 5F parameters vs. number of papers. For 12 datas ets of F1,…,F10 and two journals J1 and J2, log–log plots show that h and r go as powers of N_p. (Inset) Plots of the remaining flags u, nac, hac show uncorrelated scatter vs. N_p. (**b**) Plot of $c(h)$ vs. h for the 12 data sets, plus 6 extra sets (grey coloured circles) used in a later work [64]. For large $h(N_p)$, the H-point $(h, c(h))$ tends to (h, h).

total citations $N_{c,\mathrm{tot}} = (h\bar{C}/r)$ is $\simeq 8600$ cites for J1, vs. $\simeq 272000$ cites for J2, a factor of 32. The small fraction $\sim 5\%$ of h-type papers generate citations $N_{c,h} = (h \times hac)$ that for J1, J2 are $\simeq$ 1500 and $\simeq$ 89000 cites respectively, a factor of 59.

The factors well beyond the size effect could come from the nature of J2, that might have a multifield multiplier from its (at least) four fields, for combined enhancements of $4 \times 4 = 16$. It would be interesting to focus on the size factor alone, by comparing J1=*Biology Letters* with larger single-field journals and J2=*Science* with other multifield journals.

4.4 *5F and size dependence*

As N_p increases, and as citations are garnered nonlinearly, the H-curve shape and therefore 5F values will change. We consider here the N_p dependence of the five flags and related parameters.

The log–log plot of figure 6a (main) indeed shows that the h-index goes [18] as $\sim {N_p}^{1/2}$, with exponent 0.5 close to those ~ 0.4 from institutional data [21,22]. The ratio-index goes as $r \equiv h/N_p \sim 1/N_p^{1/2}$. This explains why r is smaller for journals than for individuals, in table 2.

The u, nac, hac do not depend solely on the number of papers N_p. Two PhDs with the same academic age, publication rate and number of papers $N_p(A)$ can nonetheless be cited at different rates, yielding very different 5F. Consistent with this, figure 6a (inset) indeed shows an uncorrelated scatter and not a strong correlation for increasing N_p.

The H-point of figure 4 is $(h, c(h))$ in general, with $c(h) \geq h$. A diagnostic $\rho(s) \equiv 1 - [s/c(s)]$ decreases with increasing rank index and falling citations and is positive $\rho(h) \geq 0$, for $c(h) \geq h$. There is a sign change at an overshoot point $s = h + 1$, when $\rho(h + 1) < 0$, that is one way to identify the h-index value. This yields the conditions $c(h + 1) < (h + 1)$, $c(h) \geq h$. For slots at and above the h-index $s = h, h + 1, h + 2, \ldots$, the conditions are satisfied by a solution $c(s) = h + 1, h, h - 1$, that has the smallest citation decrements of unity and a linear slope of -1. The diagnostic at h is then $\rho(h) \simeq 1/[h + 1]$, for an estimate $c(h) \simeq h + 1$. For large systems, the H-point $(h, c(h)) \rightarrow (h, h)$, as approximated earlier [18]. Figure 6b shows that a log–log plot of $c(h)$ vs. h for 18 data sets reasonably matches the estimate, that is used in a later work.

5. Network hierarchies

Citations form networks: nodes are particular papers and directed links are citations pointing from the citing paper to the cited. Hence, citational concepts like H-curves and 5F parameters may be carried over to growing general networks [5–9]. The H-curve of a group of nodes would more generally be, a histogram in the number of inward links, decreasing with rank index and related to a network degree sequence.

The basic or level 0 network has all papers, citing and being cited. Growth of citation network occurs at level 0, both by the addition of paper nodes and by the addition of citation links [1–9]. A striking video illustrates the growth of level 0 network through fresh citing links, that point to a well-known paper node [27].

Multilayer hierarchies [6] can be generated through successive levels of aggregation. Level 0 network has paper nodes identified by the author, institution and journal reference. Grouping nodes by journal (for any authors) generates a level 1 network of journals. Grouping nodes by the author (for any journal) generates a level 1 network for individuals. Further successive groupings of N_F individual faculty at level 1, form a department at level 2; the N_D departments constitute a university [23] at level 3 (with 5F supplementing university rankings [53]) and N_U universities together indicate a national research effort at level 4.

The Hirsch curves can be carried over to other network realisations [5–9]. For networks, the number of inward links $\{k_i\} = (k_1, k_2, \ldots, k_{N_p})$ to a set of nodes $\{i\} = (1, 2, \ldots, N_p)$ is called the 'inward degree sequence'. If the number of links is in increasing value [7–9], or $k_1 < k_2 < \cdots < k_{N_p}$, then the decreasing H-curve is an inversely ordered inward degree sequence, identified as $c(1) = k_{N_p}, c(2) = k_{N_p-1}, \ldots, c(N_p) = k_1$. The shape of the H-curve reflects the shape of the degree sequence. The overall citation distribution $N_c(C)$ is thus related to $P(k)$, the degree, or connectivity distribution [6,7].

Characteristic H-curves can describe other networks such as biochemical reactions in organisms [8,54] or airline routings to cities [6,55]. For example, a level 0 flight network has all nodes of cities served by all airlines, linked by all directed flight links. A level 1 network node is a city hub, comprising member airlines in serial slots $s = 1, 2, \ldots, N_p$, each with a number of inward weekly flights $c(s)$. Going down the ordered list, the h-th most common airline has h or more weekly arrivals, and the fraction of airlines is $r = h/N_p$. The least common airline counted has at least two inward flights weekly, while the most common has inward flights $c(1) = C_{\max} > h$. The Hirsch curve and its 5F summary $\boldsymbol{\phi}_5 = (h, r, u, nac, hac)$ quantitatively describe the airline flight profile of the city hub. Aggregating sequentially will yield H-curves at each level of states, regions and the level 4 national [55] airline network. Similarly, a level 0 reaction network has all nodes of proteins produced by all metabolic reactions as directed links. Aggregation would be to sequential levels of microscopic organisms of the life domains and so on [54].

Illustratively, figure 7a shows for faculty toy-model data, the direct connection between H-curves and networks. Suppose we group $s = 1, 2, \ldots, N_p$ nodes/papers authored by Y1 along a line of slots. A histogram

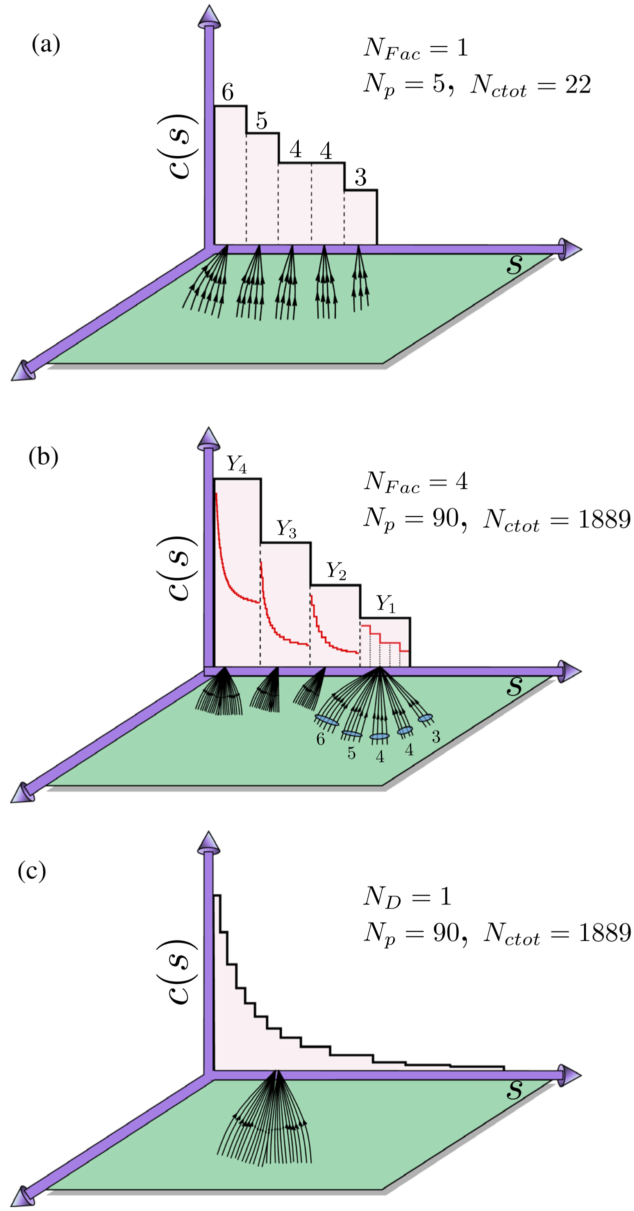

Figure 7. Schematic of relations between Hirsch histogram and network links. (**a**) The z-axis H-histogram for faculty member Y1 with $N_p = 5$ papers, showing $N_{c,\text{tot}} = 22$ citations in decreasing order of column height $\{c(s)\} = 6, 5, 4, 4, 3$. The corresponding inward stubs or half-links of the faculty node are in the $x - y$ plane. (**b**) The grouping of faculty members Y1, Y2, Y3, Y4, with only the Y1 stubs, in detail. (**c**) The H-curve from the merged and sorted data, in the decreasing order of column height, for the four-member department, with $N_p = 90$, $N_{c,\text{tot}} = 1889$. In all the cases, the citations are still to specified papers (level 0); they are merely credited to different aggregates, as symbolised in the figure by joining the endpoints of citation lines.

of the number of inward links/citations $c(s)$ to these $N_p = 5$ papers, arranged in decreasing value, is recognised as the H-curve for Y1, with $N_{c,\text{tot}} = 22$. The citations are shown in the horizontal plane, as directed stubs [9] to each paper, cited by any other papers.

The aggregation procedure is of grouping, merging and sorting. Each faculty has ${N_p}^{(F)}$ papers and ordered citational H-curves $c^{(F)}(s)$, with $F = 1, 2, \ldots, {N_{Fac}}^{(D)}$. Grouping as in figure 7b brings identified faculty nodes Y4, Y3, Y2, Y1 together on a line, forming a four-member department, ${N_{Fac}}^{(D)} = 4$. Merging combines faculty citational data sets $\{\{c^{(F)}(s)\}\}$ into a single (unsorted), aggregated departmental data set. The combined papers and citations of the member faculty are attributed to the department, with ${N_p}^{(D)} = \sum_{F=1}^{{N_{Fac}}^{(D)}} {N_p}^{(F)} = 90$ papers and $N_{c,\text{tot}}^{(D)} = \sum_{F=1}^{{N_{Fac}}^{(D)}} N_{c,\text{tot}}^{(F)} = 1889$ citations. Sorting as in figure 7c, is arranging the merged data in the order of decreasing citations, yielding the H-curve of a single department $N_D = 1$. The departmental 5F vector is $\boldsymbol{\phi}_5 = (h = 28, r = 0.31, u = 3.6, nac = 13.4, hac = 37.7)$, with a derived overall average of $\bar{C} = 21$ cites per paper. Network growth occurs at level 0 and feeds up to the higher-level aggregates. A possible renormalisation group treatment of sequential aggregation might generate (scale-dependent) node strengths and link weights [6].

Balls-and-boxes models have been used to illustrate the statistical concepts. The modelling of [1,2] of the number $N_c(C)$ of papers with citations C to any paper, uses identical balls. However for $c(s)$ citations garnered by uniquely identified papers, a more convenient analogy is buckets (papers) each with a unique label (paper reference) and cups of water poured in (citations). Every 'month', the number of cups added to a bucket, is proportional to the existing water depth (cumulative advantage). Fresh, empty buckets (new publications) if any, are inserted at the end of the line. Every 'year', there is a Hirsch sorting, to arrange buckets in sequential decreasing order of depth $c(s)$ cups, vs. slots $s = 1, 2 \ldots$. The first slot $s = 1$ has the bucket filled to maximum depth $c(1) = C_{\max}$. Going down the ranking, the h-index is determined by the overshoot slot $s = h + 1$, where the water depth first becomes less than the slot number, $c(h + 1) < h + 1$. The hac partial average is over the $s = 1, 2, \ldots, h$ deeper-filled buckets; and the nac partial-average is over normally filled buckets $s = h+1, \ldots, N_p$, down to the smallest depth counted, of $c(N_p) \geq 2$ cups.

Another analogy is with sandpile-like models of self-organised criticality [56,57]. The sand-grain columns are now positioned along a 1D line, with a directionality of decreasing column height. Grains randomly added to columns are now of incremental number proportional to the existing column height. Grains are also added to the empty slots on the right. Previous sandpile models have toppling rules to nearest-neighbours from collapsing of grain columns, exceeding a certain height [56,57]. Here, by contrast, the sorting rules are over the entire system, ordering entire grain column units to descending heights, at certain periodic times.

6. Summary and further work

In summary, we have shown that the shape of the H-curve of citations vs. rank can provide a unified description of citation profiles for individuals, institutions and journals.The shape can be minimally described by three points on the curve and two segment averages. The 5F parameters provide a multidimensional space [25,26], required to more fairly assess smaller journals and young researchers. Sequentially aggregated citations and papers lead to level hierarchies of H-curves, for faculty, departments and universities. The five flags at any level can describe the inward degree sequences at nodes of hierarchical, multilayer networks [6].

In further work, faculty, departments and editors can annually obtain their five flags for themselves [58], or use a code provided [59], with inputs from e.g. Google Scholar, a freely [42] usable database that also includes social science data [60]. Longitudinal studies of annually updated 5F vs. time would trace how young researchers mature, after their first publication [51]. It would be interesting to compare the 5F citations of Nobel prize scientists with those of general faculty [61]. A comparison of several single-field journals would explore the size-dependence of 5F in the single-field universality class.

We can also attempt the inverse problem of obtaining the entire theoretical Hirsch curves from just five flag inputs. This requires an understanding of why some papers are cited more than others. We have explored the possibility of two types of citation motivations [28,62] (reward, rhetorical), possibly related to a microversion of two types of science (normal, revolutionary) [63]. This will be presented elsewhere [64].

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Appendix A. Properties of the IF

We introduce a notation to describe citations to published papers. Citations to papers involve pairs of publication year/citation year and a suitables notation is needed to uniquely identify various citation parameters.

Consider $n_p(y)$ papers published in the year y, in a publication block $y(A)$ of duration A years. The total papers are $N_p(A) = \sum_{y(A)} n_p(y)$. We define $P_c(C; y, Y)$ as the number of citations C garnered in the year Y, in a citation block $Y(B)$ of duration B years. The difference between the start of the publication block of A years and the start of the citation block of B years is the delay $D \equiv \text{Start } (B) - \text{Start } (A)$ years, i.e., zero for $B = A$ block coincidence.

A useful notation to describe different citation variables is the sum over all allowed C, y, Y that defines the total citations $S_c(A, B; D)$:

$$S_c(A, B; D) \equiv \sum_C N_c(C; A, B, D), \quad (A.1)$$

where

$$N_c(C; A, B, D) \equiv \sum_{y(A)} \sum_{Y(B)} P_c(C; y, Y). \quad (A.2)$$

We make four observations.

Observation 1: *The A-year IF is not an A-year average*

In the familiar case of a citation average, the publication/citation year blocks are equal, coincident and not sequential. Thus, $A = B$ and $D = 0$. The total number of citations is $N_{c,\text{tot}} = \sum_C N_c(C; A, A, 0) = S_c(A, A, 0)$, where $N_c(C; A, A, 0) \equiv \sum_{y(A)} \sum_{Y(A)} P_c(C; y, Y))$. The average citation per paper $\bar{C}$ over A years is

$$\bar{C}(A) = S_c(A, A; 0)/N_p(A). \quad (A.1)$$

Here $N_c(C; 5, 5, 0)$ is the 5-year citation frequency, written simply as $N_c(C)$ and shown in figures 2 and 3. On the other hand, the A-year current impact factor IF(A) has publication/citation year blocks that are unequal and not coincident, but sequential, so $A \neq B$ and $D \neq 0$. The single citation year $B = 1$ commences right after A, and so $D = A$. Thus

$$\text{IF}(A) = S_c(A, 1; A)/N(A). \quad (A.2)$$

Clearly, $\text{IF}(A) \neq \bar{C}(A)$. Here, the number of papers $N_p(A)$ (cited more than once [47]) is replaced by the number of items $N(A)$ (with any citations).

Observation 2: *IF(A) has far fewer citations than A-year average*

The JIF with one citation year, has restricted (and hence fewer) publication–citation year pairs. A toy-model for the 2018 citation year is illustrative. Publications in $y = 2016$ have citations $P_c(C; 16, 16)$, $P_c(C; 16, 17)$, $P_c(C; 16, 18)$. Publications in $y = 2017$ have citations $P_c(C; 17, 17)$, $P_c(C; 17, 18)$. Now suppose the number of citations are $P_c = 2000$ in the year of publication, 1500 in the second year, 500 in the third year and zero thereafter. For the JIF in the year 2018, the two allowed publication–citation pairs are $(y, Y) = (16, 18), (17, 18)$ and so total citations are $[(500) + (1500)] = 2000$, for a smaller $\text{IF}(2) \equiv \text{JIF} = 2000/[100 + 100] = 10$. For the average citation with the same two publication years, the pairs are $(y, Y) = (16, 16), (16, 17), (17, 17)$ and so total citations are the larger $[(2000 + 1500) + (2000)] = 5500$ cites, yielding $\bar{C} = 5500/[100 + 100] = 27.5$ cites > JIF = 10 cites.

Observation 3: *Different parameters give different rankings*

In the early scientometric literature, an adjective made a difference: Current IF means one year of citations and cumulative IF means summing up several years of citations. A multiple-citation-year parameter is [11] the 5-year 'cumulated' impact factor with $B = 5$ years of citations, e.g. 1999–2004, from one $A = 1$ publication year of say 1999, with the same start year and so $D = 0$. It is given by $\sim S_c(1, 5; 0)/N(1)$ and was applied to JAMA for different single years of publication.

Another parameter is the 15-year 'cumulative' impact factor [12,13] for citations over $B = 15$ years, e.g. 1981–1995, to $A = 2$ years of publications, e.g. 1981–1982, with the same start year and so $D = 0$. It is $\sim S_c(2, 15; 0)/N(2)$ and is applied to generate rankings for 100 journals [12,13] and compare: with the JIF rankings for JCR reference year 1983.

With ΔR the difference between the two rankings for a given journal, the average ranking-change magnitude $\langle|\Delta R|\rangle$ can be found, over subsets of the ranks. For the top 10 journals, the average $\langle|\Delta R|\rangle = 2$, is small, consistent with a claimed insensitivity [12,13]. However, for all the 100 journals, the average ranking shift shows substantial shuffle, $\langle|\Delta R|\rangle \simeq 34$. The specific JIF rankings depend on the chosen JIF parameter: other choices could give other journal rankings.

Observation 4: *The IF(A) definition makes rankings A-insensitive*

For different durations A, how different are the rankings obtained from the A-year current impact factor of $\mathrm{IF}(A) = S_c(A, 1; A)/N(A)$? Surprisingly, the large-A ranking can be close to the usual $A = 2$ ranking from the JIF. Suppose that the numerator rises as more years are included, but then flattens to a constant, for A larger than the half-life ('old papers are less cited'). Suppose further, that the denominator varies as the number of years A in the block, or $N(A) = AN(1)$ ('journal size is the same, every year'). In such a case, $\mathrm{IF}(A) \simeq (2/A)\mathrm{IF}(2)$ and the journal rankings (not values) can be A-insensitive, from the definition. The ranking commonality does not imply that the JIF ranking has any property of uniqueness, or of optimisation [35].

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[42] Novel citational correlations may be discovered by analysing proprietary databases that are properly subscribed to and with the database use duly acknowledged in the paper. However, authors may still not be allowed to make their detailed research analysis available to colleagues, in a journal data depository. See Data Availability section of L Bornmann, *Quant. Sci. Stud*. **1**, 1553 (2020)
[43] S Saha, S Saint and D A Christakis, *J. Med. Libr. Assoc.* **91**, 42 (2003)
[44] A I Pudovkin, *Front. Res. Metr. Anal.*, https://doi.org/10.3389/frma.2018.00002
[45] L Waltman and V A Traag, https://arxiv.org/ftp/arxiv/papers/1703/1703.02334.pdf
[46] Garfield notes [11] "Thus the impact factor is used to estimate the influence of individual papers, which is rather dubious considering the known skewness observed for most journals"

[47] Database searches for individuals, yield items $N_{\rm items}$ but not all are (original or review) research articles. Items displayed could include arXiv preprints, conference abstracts, seminar notices, etc. Eliminating them 'by hand'could be tedious. However, empirical examination shows that such 'ephemera' either have zero cites (N_0 items), or are cited only once (N_1 items). Subtracting these yields a pruned number of papers $N_p \equiv N_{\rm items} - (N_0 + N_1)$ that tend to have ephemera automatically filtered out. The resultant $N_p(A)$ items cited more than once or $c(s = N_p) \geq 2$ are taken as the number of research papers. New research publications would eventually get cited, meet this criterion and be included. Similarly, for journals, a database search for 'all item' mentions, would include non-research items like editorials, letters of opinion, news items etc. Again, we retain only those items cited more than once, to filter out ephemera. For ten faculty members, the average fractions discarded are $\langle N_0/N_{\rm items}\rangle = 0.28$, and $\langle N_1/N_{\rm items}\rangle = 0.08$. For the two journals, J1 has $N_0/N_{\rm items} = 0.18$, $N_1/N_{\rm items} = 0.11$; while J2 has $N_0/N_{\rm items} = 0.02$, $N_1/N_{\rm items} = 0.03$

[48] B-H Jin, L-M Liang, R Rosseau and L Egghe, *Chin. Sci. Bull.* **52**, 855 (2007). Their parameters are related to the 5F as 'A-index' = hac; 'R-index' = $\sqrt{h \times hac}$

[49] Each 5F data set could be depicted by a symbol with three Cartesian axes of $(x, y, z) = (nac, hac, h)$. The other two 5F parameters could enter through variations in symbol size (diameter $\sim \ln u$) and symbol colour ($0<r<1$ fixes position in colour bar). In a simpler 2D plot of hac vs. nac, the more well-cited individuals or journals will be points near the upper right corner

[50] R Koch, *The 80:20 principle* (Little Brown, 2013)

[51] R Sinatra, D Wang, P Deville and A-L Barabasi, *Science* **354**, 6312 (2016)

[52] Garfield recognised that [10] the "citation frequency of a journal is thus a function not only of the scientific significance of the material it publishes (as reflected by citation), but also of the amount of material it publishes"

[53] https://www.topuniversities.com/university-rankings/world-university-rankings/2022

[54] H Jeong, B Tombor, R Albert, Z N Oltvai and A L Barabasi, *Nature* **407**, 651 (2000)

[55] G Bagler, *Physica A* **387**, 2972 (2008)

[56] P Bak, C Tang and K Wiesenfeld, *Phys. Rev. Lett.* **59**, 381 (1987)

[57] D Dhar and R Ramaswamy, *Phys. Rev. Lett.* **63**, 1659 (1989)

[58] The five flags defined in §3 can be obtained as follows from Google Scholar that provides citations in decreasing values. Note down your academic age A, the years after your first paper. Find your citations $c(s)$ to your $s = 1, 2, \ldots$ papers, with the highest $c(1) = C_{\max}$. Note down the largest s for which $c(s) \geq s$: this is your h-index. The largest serial number s of papers cited more than once $c(s = N_p) \geq 2$ fixes $N_p(A)$. Three of the F5 are then known, $h, r = h/N_p, u = C_{\max}/h$. The average citation of the first h papers over $s = 1, \ldots, h$ is the hac-number. The average citation of the remainder $n = N_p - h$ papers over $s = h + 1, \ldots, N_p$ is the nac-number. These are the five flag components $\phi_5 = (h, r, u, nac, hac)$

[59] We also have developed and provide, a computer code that yields the 5F as output directly from citation data in any order, as input. This is useful when adding new papers to previous-year data files. See URL https://citation-profiler.tifrh.res.in. The source code is also available at URL https://github.com/pankajpopli/cit-prof

[60] A-W Harzing and S Alakangas, *Scientometrics* **106**, 787 (2016). See also the Harzing blog for useful packages to obtain citational information from Google Scholar. URL: https://harzing.com/

[61] J Li, S Fortunato and D Wang, *Nat. Rev. Phys.* **1**, 302 (2019)

[62] S E Cozzens, *Scientometrics* **15**, 437 (1989)

[63] T S Kuhn, *The structure of scientific revolutions* (University of Chicago Press, 1962)

[64] P Popli and S R Shenoy, unpublished (2022)