Ranking scientists

To the Editor — The ranking of scientists is largely based on J. E. Hirsch's index[1] to measure "an individual's scientific research output". If a researcher's papers are ranked in descending order by the number of times cited, c_r, where $r = 1, 2, \ldots N$, then the Hirsch index, h, is the maximum r such that $c_r \geq r$. This measure boasts one clear advantage over the total number of citations, C, as a measure of scientific productivity: it doesn't require knowledge of a scientist's complete citation record. Unfortunately, although it reasonably ignores the tail of the citation record, its major drawback is that it neglects a researcher's most cited works[2,3] — giving it a reputation as an imprecise, but nonetheless useful metric of scientific productivity[4].

The problem arises when one tries to evaluate a scientist's achievements based exclusively on this number. Indeed, in almost any physics department, you can find at least one prolific researcher with an h index greater than those of the most successful scientists of both bygone and recent years. By studying a representative sample of researchers from physics and complex systems extracted from the Thomson Reuters Web of Science (Core Collection) database (http://apps.webofknowledge.com) we found that h systematically favours long lists of modestly cited publications.

Our sample contains 208 scientists with various citation records, at different stages of their academic careers. We include many highly cited researchers, enabling us to measure correlations in a wide range of citation data. Typically, citation datasets are highly heterogeneous (in particular, it is difficult to separate science administrators from active researchers), so a larger sample would not improve the statistics. Each dot in Fig. 1 shows how the ratio of h to its maximum possible value $\sqrt{C}$ for one scientist relates to $\sqrt{C}$. The colour of a dot indicates the mean number of citations $\langle c \rangle = C/N$ per paper for the researcher, where N is their total number of papers.

One can see that the bright dots tend to occur at the bottom of the plot, indicating that for a given C, on average, h decreases with increasing $\langle c \rangle$. We observe this trend everywhere except in the region of low C, in which h strongly fluctuates. We indicate the scientists' names for some points in the figure, and it is easy to see that the region of small values of $h/\sqrt{C}$ — corresponding to the worst possible h — is completely occupied by outstanding researchers[5].

To quantify this negative gradient we apply the method of least squares to this dataset, which provides the approximation $0.584 + 0.00023\sqrt{C} - 0.020\sqrt{\langle c \rangle}$ for $h/\sqrt{C}$. We find that the standard deviation is relatively small, 0.057, compared with the standard deviation, 0.091, from the average value $\langle h/\sqrt{C} \rangle = 0.452$ for our sample, so we can rely on this fit. The negative sign of the third term in the expression above confirms that for two researchers receiving the same total number of citations, the one with a higher number of publications has, on average, a higher h index. Consequently the Hirsch index is not merely imperfect, but it unfairly favours poorly performing scientists and punishes stronger researchers with a large mean number of citations per paper.

The widespread acceptance of h as a measure of scientific productivity can be largely attributed to human nature. To compute your h index, you need only compare two numbers: the number of citations a paper receives and its rank. There is something particularly attractive in the point where these two numbers meet each other. Ironically, the fact that it is possible to manipulate and increase your h index by self-citing only adds to its charm. The more you publish, the easier it is to increase h in this way.

So, if h does not provide a fair ranking, is it possible to rank scientists based on a simple metric? Numerous efforts to introduce a more reasonable measure by trying to include more detail sacrifice the charming simplicity of the Hirsch index[2,6,7]. Instead, we propose a new measure that focuses on a researcher's most cited paper as an indicator of his or her major achievement — and good luck — but also accounts for h.

We introduce the o index, which is based on two numbers that any researcher can remember: the h index and the number of citations to his or her most cited paper, m. The o index is the geometric mean of m and

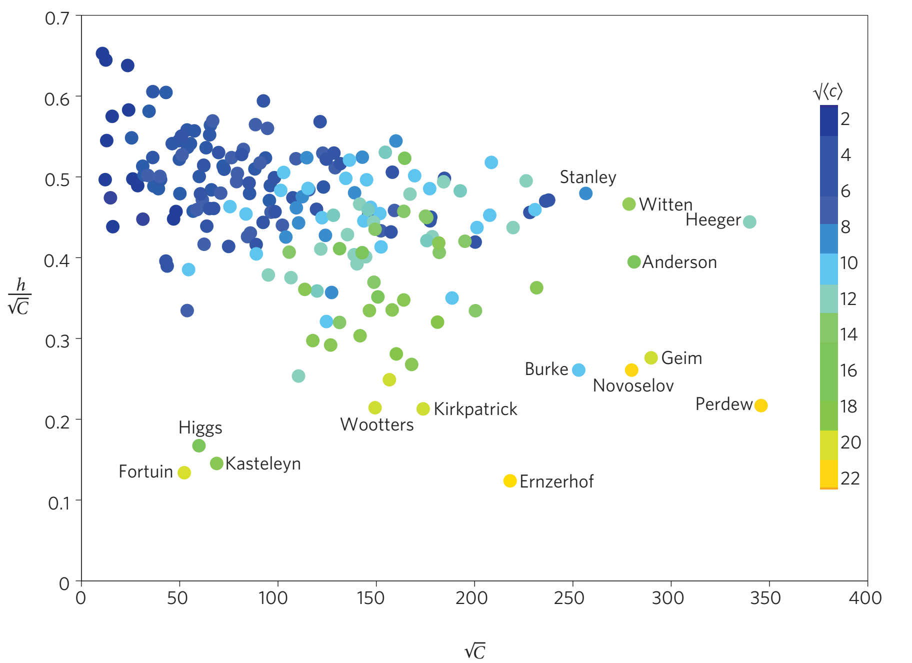

Figure 1 | Plot of $h/\sqrt{C}$ versus $\sqrt{C}$ for a sample of researchers from physics and complex systems, extracted from the Web of Science database. Here C is the total number of citations to the researcher's papers and h is his or her Hirsch index. $\sqrt{C}$ is the maximum possible value of h. The colour of a dot shows the mean number of citations $\langle c \rangle$ per paper for the researcher. The bright dots tend to occur at the bottom of the plot, indicating that for a given C, on average, h decreases with increasing $\langle c \rangle$. Note that the region of small $h/\sqrt{C}$ is completely occupied by outstanding researchers.

h, given by $o = \sqrt{(mh)}$. Here *m* accounts for the researcher's greatest result, and *h* for his or her diligence. The geometric mean is the simplest combination that can be written without knowing the statistics of citations for an individual researcher.

The *h* and *o* indices generate markedly different rankings. Figure 2 shows how many successful researchers, hidden in the *h*-based ranking, become visible if we examine *o*. Interestingly, the highest *o* index for a physicist (John Perdew, with $o = 1,680$) is not far below the maximum *o* for a scientist (Bert Vogelstein, a medical researcher with $o = 2,071$).

Let us roughly estimate *o*, ignoring fluctuations, to find how it depends on the number of publications. We know that $h \sim \sqrt{C}$ (refs 1,5). The number of citations to the most cited paper falls somewhere between two numbers: $C/N \leq m \leq C$, so, without knowing the statistics of citations for a researcher, we roughly estimate it as $m \sim C/\sqrt{N}$. As a result, we obtain $o \sim C^{3/4}N^{-1/4} \sim C^{1/2}\langle c\rangle^{1/4}$. This shows that *o*, on average, grows with the mean number of citations per paper — as is reasonable for proper ranking. For our sample of scientists we find a coefficient of 0.88 with a relatively small standard deviation of 0.25, suggesting that this simple estimate works well.

It is more difficult to manipulate *o* than it is *h* — but it is still possible. For many, this may be reason enough to adopt it. For others, *o* may appeal in that it clearly distinguishes successful researchers and provides a natural, easily implementable ranking criterion for scientists.

The merit of a researcher is determined by his or her strongest results, not by the number of publications. We find that the widely used *h*-based ranking of scientists consistently contradicts this principle. This is all the more surprising given that one can so easily avoid this contradiction and rank scientists reasonably and fairly. ❐

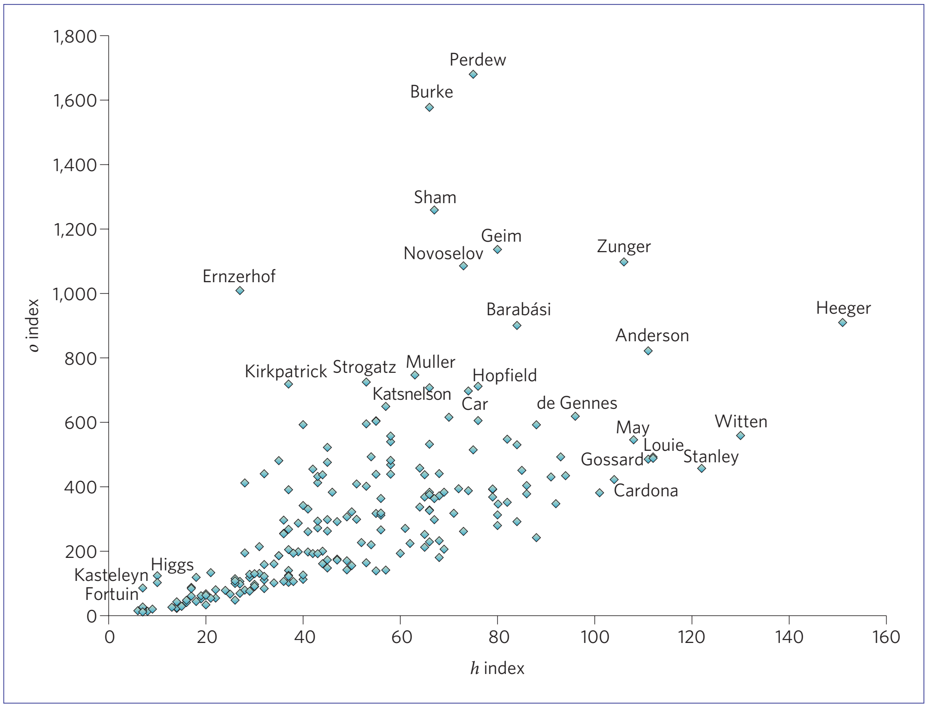

Figure 2 | Plot of *o* versus *h* for the same sample of scientists as in Fig. 1. Here $o = \sqrt{(mh)}$, where *m* is the number of citations to a researcher's most cited work. We highlight the scientists' names for the points standing out from the crowd in this plot. Note, for example, that Andre Geim and Konstantin Novoselov are hidden in the *h*-based ranking, but appear among the top physicists according to the *o* index.

References

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