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The DCI-index: Discounted Cumulated Impact based Research Evaluation

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Abstract

Research evaluation is increasingly popular and important among research funding bodies and science policy makers. Various indicators have been proposed to evaluate the standing of individual scientists, institutions, journals, or countries. A simple and popular one among the indicators is the *h*-index, the Hirsch index (Hirsch 2005), which is an indicator for lifetime achievement of a scholar. Several other indicators have been proposed to complement or balance the *h*-index. However, these indicators have no conception of aging. The *AR*-index (Jin & al. 2007) incorporates aging but divides the received citation counts by the raw age of the publication. Consequently, the decay of a publication is very steep and insensitive to disciplinary differences. In addition, we believe that a publication becomes outdated only when it is no more cited, not because of its age. Finally, all indicators treat citations as equally material when one might reasonably think, that a citation from a heavily cited publication

should weigh more than a citation from a non-cited or little-cited publication. We propose a new indicator, the *DCI*-index (for Discounted Cumulated Impact), which *devalues old citations* in a smooth way. It rewards an author for receiving new citations even if the publication is old. Further, it allows weighting of the citations by the citation weight of the citing publication. *DCI* can be used to calculate research performance on the basis of the *h*-core of a scholar or any other publication data set. Finally, it supports comparing research performance to the average performance in the domain and across domains as well.

Keywords: *DCI*-index, *h*-index, research evaluation, performance evaluation

Introduction

Research evaluation is an area of increasing importance as various public and private research funding bodies need to assess the quality of applicants and the impacts of their investments. Research evaluation needs preferably simple and easily available metrics. The numbers of citations publications have received have traditionally been used as an indication of quality. The citation impact of scholars (and other objects) can be measured in many ways. A simple and popular one among the possibilities is the *h*-index, the Hirsch index (Hirsch 2005), which is an indicator for lifetime achievement of a scholar. When a scientist's list of publications is ranked according to the number of citations received, the *h*-index is defined as the highest rank such that the first *h* publications received each at least *h* citations. Since its conception, the *h*-index has become popular in ranking scholars (e.g., Cronin & Meho 2006; Oppenheim 2007). Other researchers have shown that the *h*-index cannot only be used for a scholar's overall achievements, but also for other objects of evaluation: the Hirsch index has been calculated for journal citations (Braun, Glänzel & Schubert 2005; Egghe & Rousseau 2006;

Schubert & Glänzel, 2007), and topics (Banks 2006; Jin & al. 2007). Obviously, it can be used to evaluate research institutions.

Jin, Liang, Rousseau and Egghe (2007), Bornman and Daniel (2007), and Costas and Bordons (2007) summarized the advantages and disadvantages of the h -index. We only discuss the major ones here. The advantages of the h -index include its apparent simplicity, rewarding for highly visible work, possibility of aggregation (scholars, institutions, journals, ...), robustness against single peaks of high citation impact, and insensitivity to publications never cited. Its disadvantages include too much emphasis on long term observations (putting newcomers at a disadvantage); lack of ageing of citations and consequently monotonous increase; incapability to tell the difference between average scientists in a domain; and weak sensitivity to the number of citations received (i.e., one only knows that the first h publications of a scientist received the minimum of h^2 citations). In addition, the h -index suffers from typical problems of citation-based metrics: field-dependency, self-citations, problems of correct identification of a scientist, lack of reference standards, and difficulties in collecting comprehensive data (e.g., sources like the Web of Science do not cover conferences).

In order to overcome the problems of the h -index, several alternatives have been proposed. Egghe's (2006) g -index gives the highest rank such that the cumulative sum of the number of citations received is larger than or equal to the square of this rank. This indicator is sensitive to the number of citations in the h -core (the first h publications) of a scientist. Jin (2006) proposed the A -index, which measures the average number of citations in the h -core. Jin & al. (2007) propose the R -index, which gives the square root of the cumulated citations in the h -core thereby solving a problem in the A -index. Burrell (2007) proposes using the h -rate instead of the h -index to overcome the problem of monotonous growth.

However, all these indicators have the property that their values constantly grow. There is no conception of ageing in these indicators. As Jin & al. (2007) state, this allows the scholars to ‘rest on their laurels’, past achievements are carried forwards and are not affected by time. To overcome this problem, Jin & al. (2007; Jin, 2007) propose a modification of the *R*-index, called the *AR*-index, which incorporates the age of a publication as a factor: the number of citations received by a publication in the *h*-core is divided by the age of the publication. This takes both performance and its timing into account and discounts long-gone performance by its age. Notwithstanding, Hirsh (2007) argues that the *h*-index appears to be a good predictor of a scientist’s future achievement.

We see the ageing of performance as an important factor of an indicator for research evaluation. We see, however, some disadvantages in the proposed *AR*-index and alternative approaches to aging as well. First, one may wonder if the division by the raw age of a publication in the calculation of the *AR*-index is too steep, especially when it may take some years after publication before the citations begin to accumulate. Citations to a two years old publication would be worth just one half of the citation count. Secondly, even old publications may be currently valuable, if they keep on being cited. A publication becomes old, outdated, when it is no more cited, not because it was published a long time ago. Therefore one may claim that past long-gone citations should be devalued in comparison to more recent ones. Third, the *h*, *g*, *A*, and *AR*-indices treat all citations as equally valuable. One may however claim that this is not the case: citations by high quality publications are more valuable than citations from more marginal publications.

In the present article we propose a research performance evaluation metric *DCI* (for Discounted Cumulated Impact), which is based on the idea of *devaluing old citations* in a smooth and parameterizable way. It rewards an author for receiving new citations even if the

publication is old. Further, it allows weighting of the citations by the citation weight of the citing publication. *DCI* can be used to calculate research performance on the basis of the *h*-core of a scholar or any other publication data set like all publications included in the Web of Science.

The principle of *DCI* is as follows: for an object like publication, scholar, institution, or being evaluated, count the citations for each time interval such as a year, over a sequence of such intervals, say the past 25 years. Before summing, weigh each citation by the weight of the citing publication (based on the citations it has received). Each weighted citation is a contribution to the impact of the object. The sum for each interval denotes the impact of the object during that interval. Arrange the sum of weights for each interval as a time series – a vector of impact values. Then cumulate the vector values from the first period (the most distant past) on to the last interval of the measurement. The cumulated vector gives, for each interval, the impact accumulated up to that interval. Finally, determine the interval of evaluation (any non-first period) and apply a discounting factor on past citations, dividing by a logarithm of the number of intervals past. The rationale of using a logarithm is its smooth behavior: a difference on n intervals in citing in distant past becomes negligible while it is significant in the recent past. Devaluing by dividing by the raw interval count would effectively wipe away citations very quickly. The base of the logarithm can be set by the speed of development (or decay or historylessness) of the domain. For example, a base $b = 2$ stands for rapid decay, and a base $b = 10$ for slow decay. The resulting vector gives the discounted cumulated impact values for the object being evaluated over the intervals under scrutiny.

The paper is organized so that the following section explains the direct (non-discounted) cumulated impact, the *DCI*, the formal side of *DCI* normalization, and closes by comparing

the *DCI* to other metrics for research evaluation. The third section presents a small sample case in research evaluation and exemplifies the use of *DCI* based on citation weighting and various decay parameters. The final sections contain discussion and the conclusions.

Cumulated Impact Based Measurements

Direct Cumulated Impact

When at a given point in time examining the citations earned by an object earlier, it is may be argued that:

- citations from high impact (high quality, however measured) publications contribute more to its impact than citations from low impact (low quality) publications, and
- the longer the time that has elapsed since the citation, the less it contributes to the current impact of the object, because they are old and forgotten citations.

The first point leads to the comparison of objects through citations by their cumulated impact over intervals. In this evaluation, the impact score of each citation is somehow used as a gained impact measure for its interval and the impact is summed progressively from ranked position 1 (standing for the first interval in the past) to n , the current interval of assessment. Thus the periodical citation lists (over some determined interval) are turned to impact value lists by replacing citations by their impact scores. Assume that the impact scores 1 - 3 are used (3 denoting high impact value, 1 marginal value). Turning periodical lists from interval 1 to interval n to corresponding impact value lists gives vectors of n components each being a set of impact values for that interval. For example (ϕ , the empty set, denoting no citations):

$$C' = \langle \{3, 2, 3\}, \phi, \{1, 2, 2, 3\}, \phi, \phi, \{3\}, \{3, 2\} \dots \rangle$$

Here the object (e.g., an article) has received $3+2+3 = 8$ impact points (e.g., from three different articles) in interval 1, none in interval 2, again 8 in interval 3 (e.g., from four articles), etc. Section 3 discusses the calculation of impact scores.

As an initial step in impact computation, we turn such periodical citation lists into impact vectors of n components each of which being the sum of the corresponding set of impact values in the initial list. For example, from C' we obtain:

$$F' = \langle 8, 0, 8, 0, 0, 3, 5, \dots \rangle$$

The cumulated impact at a given interval k is computed by summing from position 1 to k . Formally, let us denote the i th component in the impact vector F by $F[i]$. Now the cumulated impact vector CI is defined recursively as the vector CI where:

$$CI[i] = \begin{cases} F[1], & \text{if } i = 1 \\ CI[i-1] + F[i], & \text{otherwise} \end{cases} \quad (1)$$

For example, from F' we obtain $CI' = \langle 8, 8, 16, 16, 16, 19, 24, \dots \rangle$. The cumulated impact at any period may be read directly, e.g., at period 4 it is 16. The cumulated impact vectors incorporate weighed citations but no decay – old and recent citations are equally valuable. CI resembles citation counts but differs in the use of weighing.

Discounted Cumulated Impact

The second point above stated that the longer the time that has elapsed from the citation, the less it contributes to the current impact of the object, just because of the elapsed time. This leads to calculation of ‘current’ impact of the object at any interval in time through its cumulated impact based on an elapsed time-based discount factor. The longer the time from

citing to the current time, the smaller share of the impact score is added to the cumulated impact.

A discounting function is needed which progressively reduces the impact score as time elapses but not too steeply (e.g., as division by the raw number of intervals in between) to allow for collective memory in assessing objects. A simple way of discounting with this requirement is to divide the impact score by the log of the number of elapsed intervals. For example ${}^2\log 2 = 1$ and ${}^2\log 128 = 7$, thus (if the intervals are years) a impact earned over a century ago still contributes a seventh of its original value. By selecting the base of the logarithm, sharper or smoother discounts can be computed to model varying collective memory. Formally, if b denotes the base of the logarithm, and t the ‘current’ interval of analysis, the discounted cumulated impact vector DCI_t is defined recursively as the vector (of length t):

$$DCI_t [i] = \begin{cases} F[1]/\max(\{1, \log_b(t-1)\}), & \text{if } i = 1 \\ DCI_t [i-1] + F[i]/\max(\{1, \log_b(t-i)\}), & \text{otherwise} \end{cases} \quad (2)$$

Here each $F[i]$ represents the summed citation weight for the interval i and its weight is discounted by $\log_b(t-i)$ when t is the ‘current’ interval of analysis. The denominator gives the value 1 (no discount and avoids boosting) when $t-i < b$. This is also realistic, since the higher the base (longer memory), the lower the discount and the more likely the impact of an object is to remain recognized.

When one moves to the interval $i+1$, the summed citation weight from past years is *added* to the weight of the year $i+1$ which has a lower discount (because it is more recent, closer to t). The added weights are always zero or positive and therefore DCI cannot sink. It levels off when no more citations are received. For example, let $b = 2$ and $t=15$, modeling a rapidly developing (historyless) area. From F' given in the preceding section we obtain $DCI_{15}' =$

<2.10, 2.10, 4.33, 4.33, 4.33, 5.28, 6.95, ...>

The DCI_t vector is static, representing the chosen interval t of analysis. Time however is dynamic and the cited objects may rise and fall over time. To analyze and visualize this we need a dynamic DCI vector which accumulates and discounts past performance at each interval of evaluation. For each interval $i, 1 \leq i \leq t$, the dynamic discounted cumulated impact $dDCI$ is:

$$dDCI[i] = DCI_i[i] \quad (3)$$

For example, let $b = 2$, modeling a rapidly developing (historyless) area. From F' given in the preceding section we obtain $dDCI' =$

<8, 8, 16, 13.05, 12, 11.5, 15.09, ...>.

We may read here that after an initial rise in the impact for the first three periods, the lack of received citations causes a fall in the discounted impact in intervals 4 – 6. New citations in interval 7 give a boost again.

The lack of ability of an object to recently attract high quality citations shows on the dynamic DCI vectors by descending curves while the plain DCI curves present a plateau. The dynamic ones are more explicit in that they explicate for each interval the object's impact at that point. The impact may then rise or fall depending on the future citations.

Aggregated and Normalized Dynamic Impact

Basic citation data involves citations received by individual publications as the objects. This is however rarely interesting. In research evaluation, the objects of evaluation rather are persons, institutions, countries, and sometimes journals. Therefore article citation data need to be *aggregated* into objects of proper level. Often one needs to compare objects based on their

impact. This can be based on the (dynamic) *DCI* graphs. However, in order to compare objects belonging to different domains and thus having different citation data sets, a *normalized DCI* performance would be helpful. We base normalization on *average DCI* across some objects. Below we define functions needed for aggregation, averaging and normalization.

A higher level object's (say, person's) impact is based on aggregating the impact of lower level objects (say, articles). This may be computed as the *sum of impact vectors* representing the lower level objects. The average impact of some objects (say, persons) may be computed as the *average of impact vectors* representing these objects. Finally, the normalized impact may be computed as the *relative-to-the-average impact vector* representing an object. Here the object's impact vector is divided by the average impact vector of the comparable object set. The following definitions are for the vector sum, vector average and normalized vector functions.

Vector sum. Let $\mathbf{V} = \langle v_1, v_2, \dots, v_k \rangle$ and $\mathbf{W} = \langle w_1, w_2, \dots, w_k \rangle$ be two vectors. Their sum is the vector $\mathbf{V} + \mathbf{W} = \langle v_1 + w_1, v_2 + w_2, \dots, v_k + w_k \rangle$. For a set of vectors $\mathbf{V} = \{V_1, V_2, \dots, V_n\}$, each of k components, the sum vector is generalised as

$$\text{sum-vect}(\mathbf{V}) = \sum_{V \in \mathbf{V}} V = V_1 + V_2 + \dots + V_n.$$

(4)

Vector average. Let $\mathbf{V} = \langle v_1, v_2, \dots, v_k \rangle$ be a vector. The multiplication (division) of a vector $\mathbf{V} = \langle v_1, v_2, \dots, v_k \rangle$ by a constant r is the vector $r * \mathbf{V} = \langle r * v_1, r * v_2, \dots, r * v_k \rangle$. The average vector based on vectors $\mathbf{V} = \{V_1, V_2, \dots, V_n\}$, is given by the function *avg-vect*(\mathbf{V}):

$$\text{avg-vect}(\mathbf{V}) = (1/|\mathbf{V}|) * \text{sum-vect}(\mathbf{V}) \tag{5}$$

Normalized vector. Let \mathbf{V} be a set of vectors $\mathbf{V} = \{V_1, V_2, \dots, V_n\}$, each of k components, and $W \in \mathbf{V}$. Let M be a vector of k components, each with value -1, i.e., $M = \langle -1, -1, \dots, -1 \rangle$.

$$\text{norm-vect}(W, \mathbf{V}) = (W/\text{avg-vect}(\mathbf{V})) + M \quad (6)$$

The first term of the sum normalizes the vector W by the average of the set \mathbf{V} . The second term, in effect, subtracts one from each component thus rendering average impact as zero, and total neglect as -1.

Now the actual *CI* and *(d)DCI* vectors for a particular object may also be compared to the mean vector of similar objects in a domain. For example, the impact of an article compared to the mean impact of all articles in the same domain, or the impact of a scholar compared to the mean impact of all scholars in the same domain (and perhaps country).

Comparison to Traditional Citation-based Evaluation Measures

In comparison to other recent citation performance measures, the salient features of *(d)DCI* are:

- *Accumulation of citations:* The *(d)DCI* takes all citations of the selected publication base into account. The publication base may be selected in many ways, e.g., be the object's total production or restricted in a chosen way like type of publication, or the *h*-core. The *h*-index, *g*-index, *A*-index, and *R*-index are dependent on the *h*-core and do not take all citations in it into account.
- *Aging or decay:* The past proposals for indicators have the property that their values constantly grow. Long-gone performance is rewarded and a lack of recent contributions is not recognized in any way. The *AR*-index (Jin & al. 2007) is an exception, which incorporates the age of the cited publication as a factor: the number of citations received

by a publication in the h -core is divided by the age of the publication. The $(d)DCI$ is different: the decay is not based on the age of the cited publications but on the age of the citations. That is, even old but constantly cited publications are rewarded whereas a publication that is no more cited is decaying in the evaluation.

- *The weighing of citations:* The past proposals for indicators are insensitive to the quality of the citing publications whereas $(d)DCI$ explicitly takes their quality into account. In third section we show, how the citations can be weighed by the number of citations the citing publication has received.
- *Treatment of newcomers:* The $(d)DCI$ treats newcomers reasonably because the rise and fall of objects may be read from the $(d)DCI$ graphs and the decay of citations may be adjusted by adjusting the discounting factor. By employing rapid decay past achievements fade away and recent ones stand out.
- *Capability to tell the difference to the average scientists in a domain:* Using $(d)DCI$ makes it easy to calculate the average performance of a set of objects over time. Thereafter it is simple to find out the relative-to-average performance of each object being evaluated.

The $(d)DCI$ obviously is more complex than the measures of the type of h -index. One needs to weigh the citations and set the decay parameter. The dynamic DCI requires calculating the DCI for each year in the time span of the assessment. Comparison to the average requires the average be known and the ratio-to-the-average calculation. However, these calculations are unavoidable for achieving the benefits of $(d)DCI$. In addition, $(d)DCI$ suffers from the typical problems of citation-based metrics: field-dependency, self-citations, lack of reference

standards, and difficulties in collecting comprehensive data (e.g., sources like the Web of Science do not cover conferences). In this respect (*d*)*DCI* is no better, no worse.

Impact Dynamics in Information Science

In order to illustrate the proposed indicators we have collected data from the Web of Science (WoS) for five scholars in Information Science, two of whom score high among scholars in Information Science and three being internationally recognized while less famous. We keep them anonymous since our purpose in this paper is not to perform an empirical analysis, per se, but instead to illustrate the properties and possibilities of the (dynamic) *DCI* measure. In the following we first describe the data, and then discuss the weighing of citations based on the citation weights of the citing documents. The final three subsections illustrate the *DCI* index at a fixed time point but with rapid vs. moderate citation decay, the dynamic *DCI* across two decades for the whole data set and one subset (the less famous), and relative-to-average normalized *dDCI* for the entire population and its subset.

The Evaluation Case and Data

We collected WoS citation data for five anonymous scholars in Information Science. The data included the following:

- Cited documents, their authors, journals, publication years, and times cited
- Identified self-citations (which were excluded from analyses)
- Citing document IDs and the count of citations they had received
- Citing journal, citing author(s), and citing document reference count
- Citing year

The data represented nearly 4500 citation events over a time span of nearly 20 years (1988-2006).

Using this data, we aim to illustrate impact-based research evaluation. In particular, we look at the following evaluation issues:

- The variation of the *DCI* performance of the five scholars across 20 years under slow, rapid and extreme decay conditions.
- The variation of the dynamic *DCI* performance of the five scholars and a subgroup of three across 20 years under a rapid decay condition.
- The normalized, relative to the average dynamic *DCI* performance of the five scholars and a subgroup of three across 20 years under a rapid decay condition.

Decay and Weighing of Citations

In research evaluation, devaluing citations on grounds such as due to multiple authorships (of cited documents) or self-citations, has been proposed before, e.g., for the calculation of the *h*-index (Burrell 2007). While these ideas are noteworthy, *DCI* evaluation has a quite different devaluation principle, the age of the citation at the time of evaluation. Here the decay of a citation depends on the discounting factor, which is calculated from the time difference between the interval of citation and that of the evaluation. The discounting factor is $\max(\{1, \log_b(t - i)\})$ in Formula (2), where t represents the interval of evaluation and i the publication interval of the citing document. Note this is not dependent on the publication year of the cited publication. Extremely rapid decay may be represented by setting $b = 1.1$ and slow decay by $b = 10$.

We do not apply second order decay of citations, however. To illustrate, assume a publication *A* published one hundred years ago and cited by a publication *B* published 50 years ago, and the latter cited one hundred times exactly 25 years ago. The weight of *B* is based on the one hundred citations – in a way defined below – and not decayed by the fact that they were given 25 years ago. The weight of *B* in citing *A* decays on the basis that it was published 50 years ago, however.

In *DCI* evaluation, an additional idea is that the impact of a citation on the cited object also depends on the original weight of the citing publication. Citations may be weighed in several ways, e.g., by the impact factor (*IF*) of the citing publication forum, by the weight of the authors (e.g. their maximum or average *h*-index), or the citation count of the citing publication, among others. The strength of the impact factor is that it exists at the time of publication of the citing article – but with the down side that the forum's *IF* may weakly correlate with the citing article's later impact. A weight based on the authors' *h*-index is available at the time of publication or may be obtained later – but also this one may be weakly correlate with the citing article's impact. The citation count of the citing publication is zero at the time of publication but will later reflect the publication's current impact and its strength in leading readers toward the cited publication (e.g., in citation chaining). Moreover, it is independent of the citing journal's continued existence.

In the present paper we employ the citation count of the citing publication for weighing, believing that a heavily cited publication represents high quality and thus its references earn more recognition than references in a little or non-cited publication. We do not use the raw number of received citations, however, as its citing weight but normalize this as follows: let *c-count* be the citation count of the citing publication and $cit, 1 = cit = 1000$, the base of the

logarithm used to normalize citation counts. The citing weight of the citing publication is *c-weight*, when:

$$c\text{-weight} = \max(\{1, \log_{cit} c\text{-count}\})$$

The weight has a minimum of one and exceeds this by the *cit*-based logarithm of the citation count. These weights are cumulated in the Formulas (1) and (2). When the base of the logarithm is small, say $cit = 2$, one hundred citations gives a weight of close to 7, whereas by setting $cit = 1000$, practically all citing weights are equal to one ($\log_{1000} 1000 = 1$). In the examples below we shall employ mostly a small base $cit = 2$ to reward the evaluated publications for high-quality citations.

The DCI Graphs

Figures 1 – 3 indicate the *DCI* performance of the five scholars. Figure 1 represents slow decay ($b=10$) of citations and Figure 2 a rapid one ($b=2$). In both cases $cit=2$ allowing for fairly strong citation weighing. The curves are much of the same shape but in Figure 2 the curves begin to turn convex. The *DCI* scores vary greatly between the figures. Figure 3 gives the *DCI* performance of the scholars under extreme decay and flat weighing of citations. Here only the very recent citations matter and the curves are thus quite convex.

Together these analyses indicate that large differences in citation performance stand out no matter how fast past performance is made to decay. On the other hand, the speed of decay greatly affects the cumulated *DCI* for the final interval of analysis. It also affects the shape of the accumulating *DCI* curve. Rapid decay tends to produce convex curves (Figure 3). In this case, Person B slightly outperforms Person D.

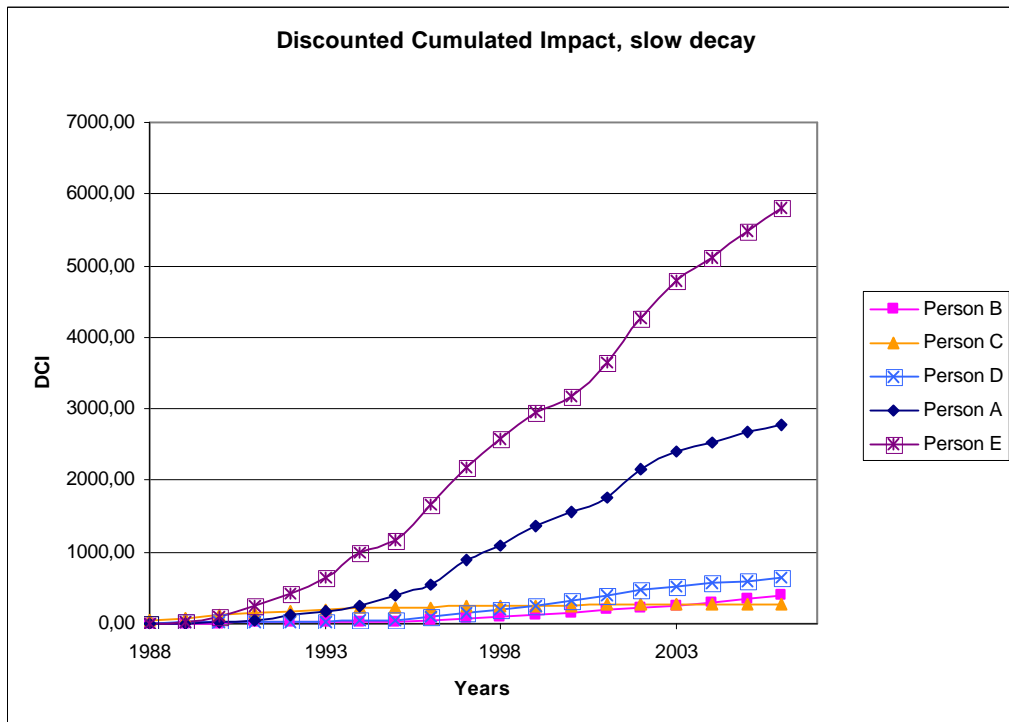


Figure 1. DCI for population A-E ($cit=2$; $b=10$)

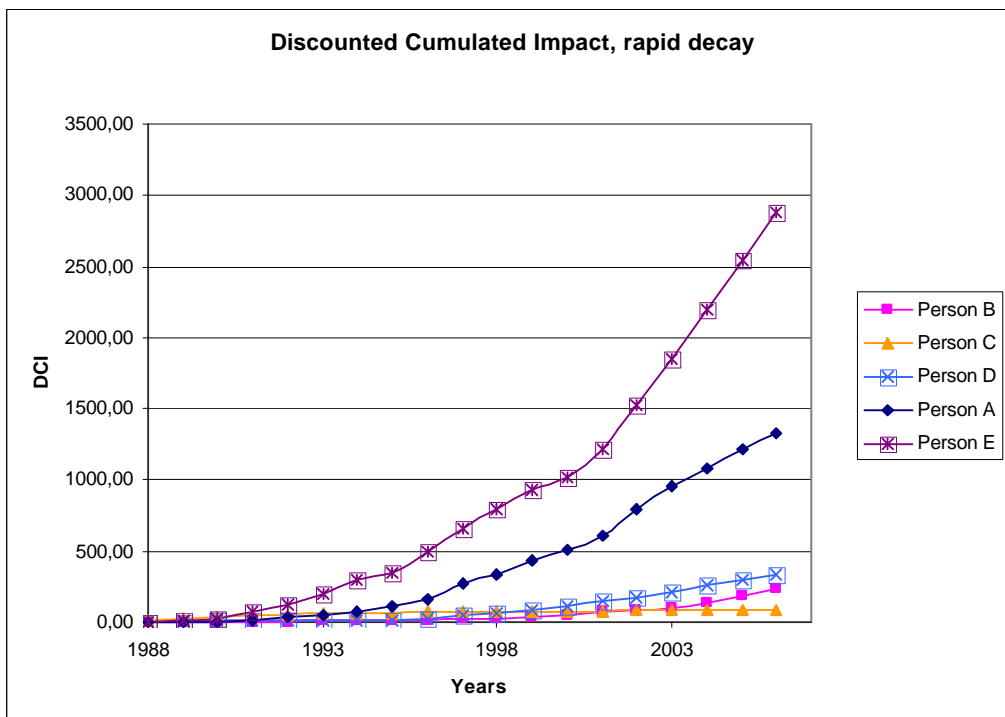


Figure 2. DCI for population A-E ($cit=2$; $b=2$)

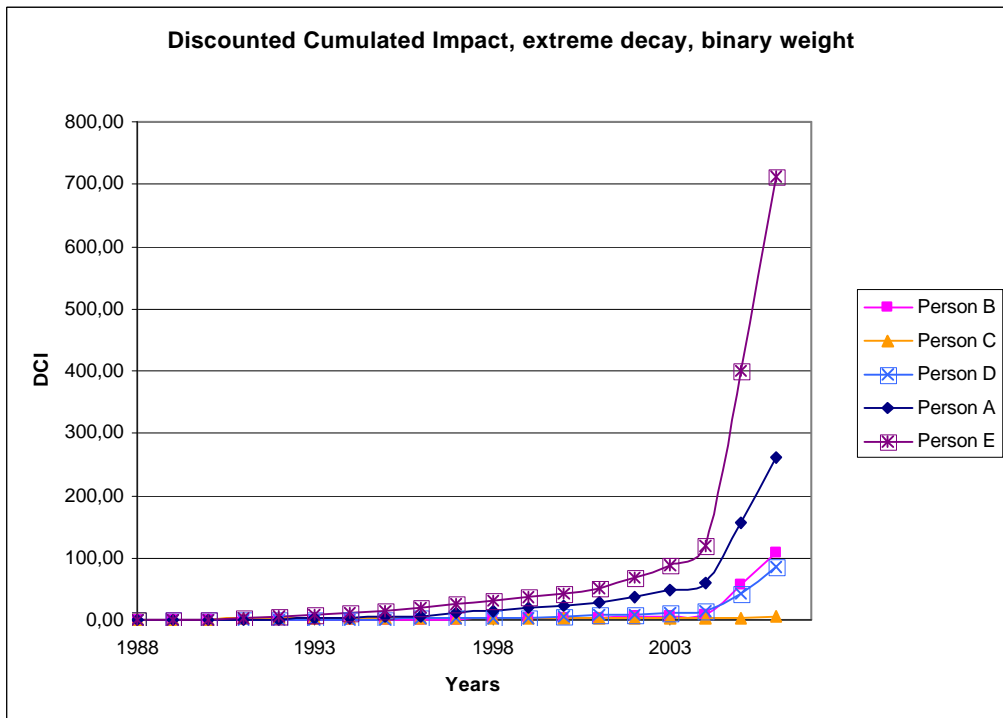


Figure 3. *DCI* for population A-E ($cit=100$; $b=1.1$)

The Dynamic DCI Graphs

Figures 4 – 5 exemplify the dynamic *DCI* curves. In Figure 4, including all five scholars, the two top persons shadow the rest as before, but both show a declining trend in the final years of analysis. The trends for the three others are not that clear.

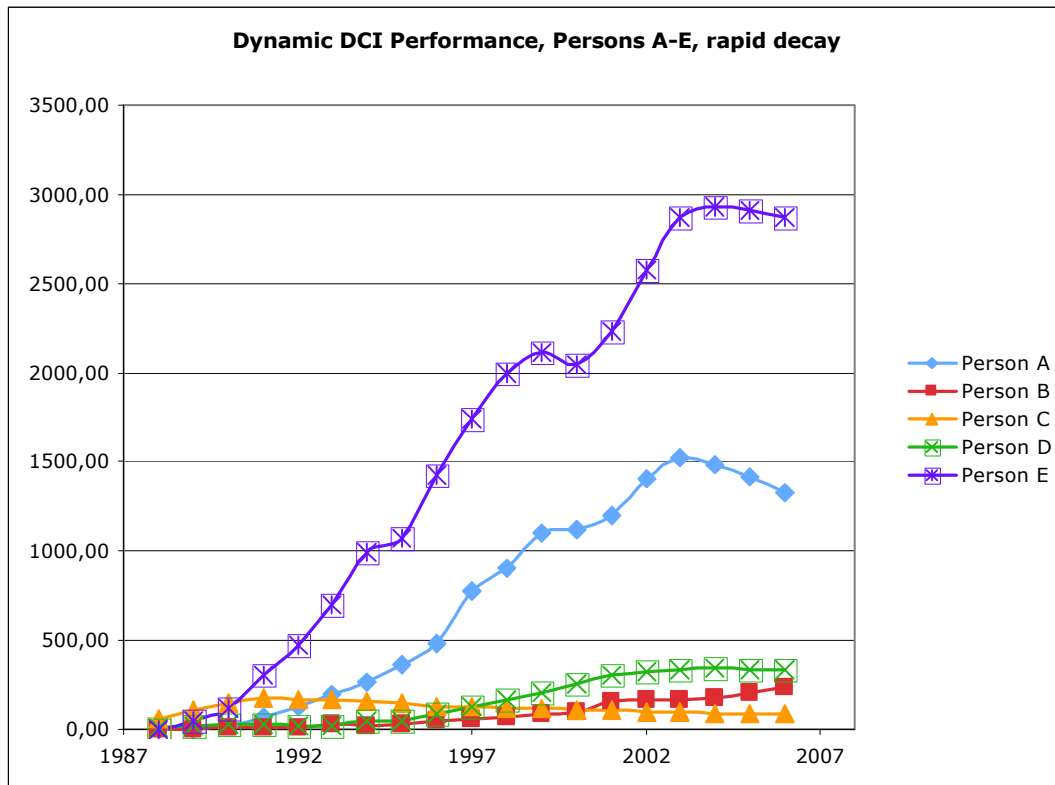


Figure 4. Dynamic DCI for population A-E ($cit=2$; $b=2$)

Figure 5 focuses on the three less performing scholars. One may think of this figure as representing a narrow specialty field of a broader field, or a regional (local) set of scholars within a discipline. Now the trends between the scholars are obvious. Scholar C has been a star in the past but is sinking towards oblivion, perhaps due to ceasing to produce new publications and the field moving fast forward. The two others are gaining much in recognition, with Scholar D being faster but reaching a plateau. These scholars both seem to be at an active, productive stage.

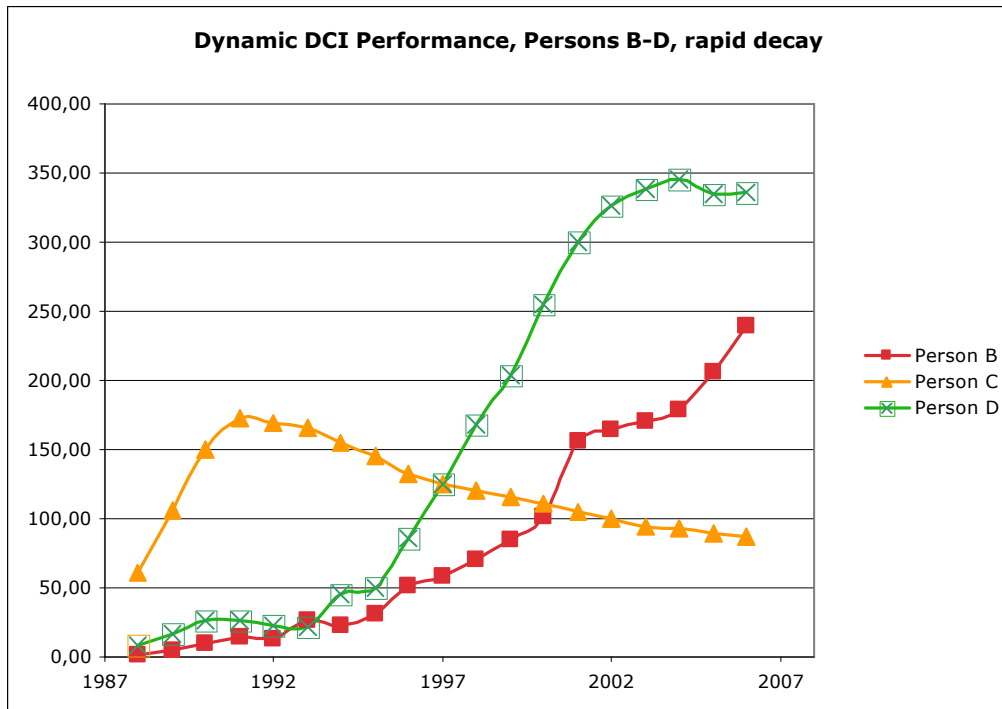


Figure 5. Dynamic *DCI* for subgroup B-D (*cit=2; b=2*)

Figures 4 – 5 suggest that the dynamic *DCI* graphs are able to trace the rise and decline of the performance of whatever objects put under scrutiny.

Performance Related to the Average

Figures 6 – 7 assume the whole data set on five scholars, and the subset of three, as representing domains where the relative performance of scholars (objects) is of interest. The larger data set may be seen as representing some entire discipline, and the smaller one as national scholars, or candidates to a position, within that discipline. The Y-axis gives the relative to the average performance of scholars in each figure, when $Y=0$ represents the average. One may see in Figure 6 that Person C performed clearly best in the early years while A and E dominate the later ones. In the ‘national race’ of Figure 7, Person C is clearly top-scoring initially, but dropping to below average by the beginning of the new millennium.

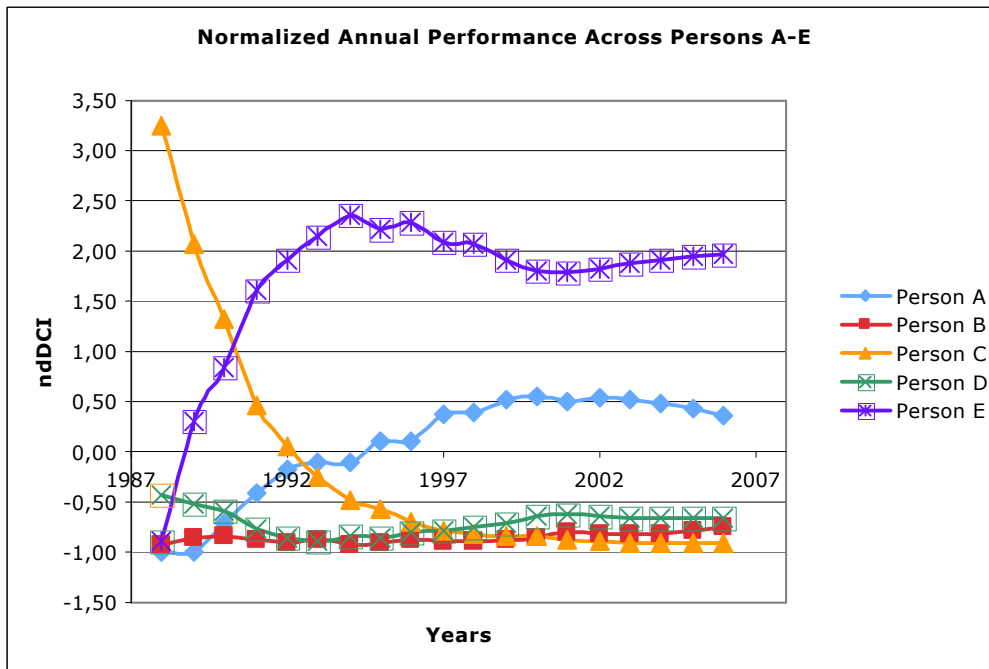


Figure 6. Performance relative to the average of the population: dynamic *DCI* for A-E (*cit*=2; *b*=2)

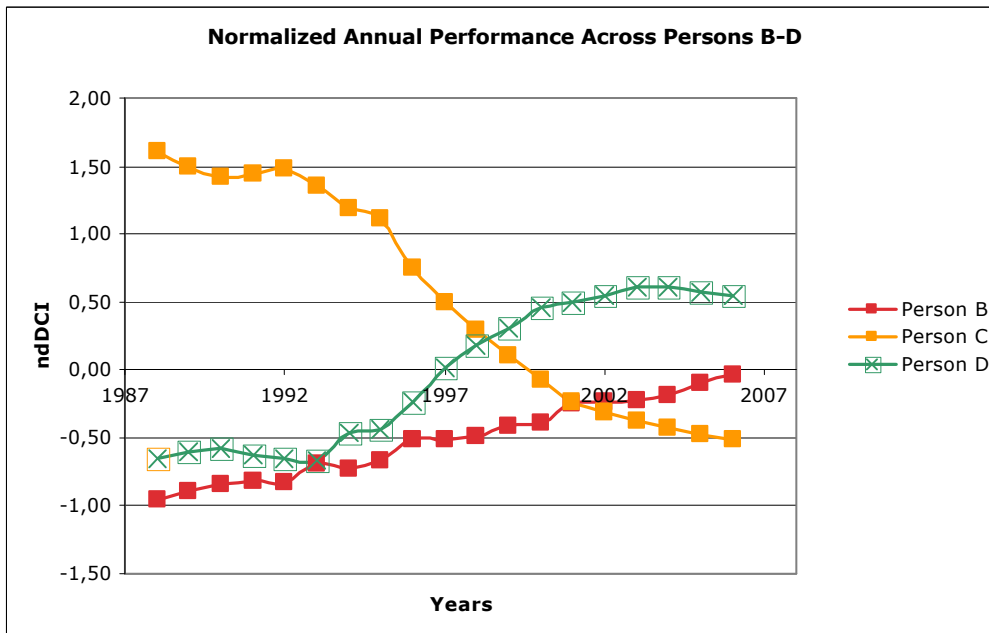


Figure 7. Normalized performance relative to the average of the subgroup: dynamic *DCI* for B-D (*cit*=2; *b*=4)

Suppose that the two top scholars and the three other represent different disciplines with greatly differing head counts and citation counts, say Medicine and Information Science. One may calculate the normalized dynamic *DCI* for both populations separately and perform cross-discipline comparisons where the standing of each object to be compared is relative to its own background discipline – Figure 8. Interestingly, Person D’s normalized standing after the year 2000 is the highest of all.

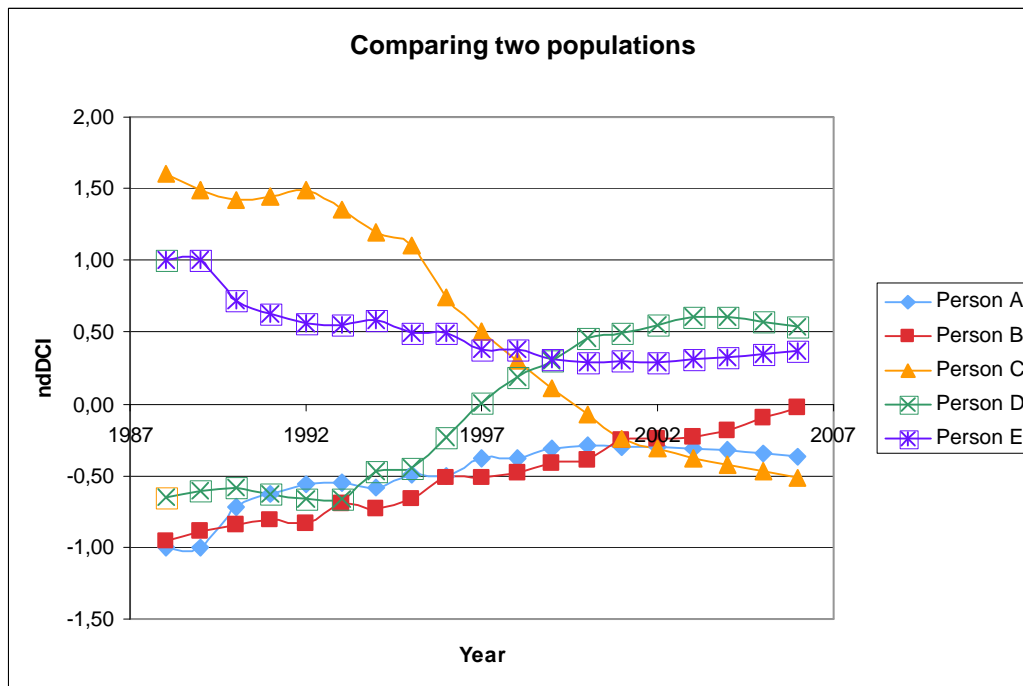


Figure 8. Comparison of scholars of two populations by the relative-to-the-average normalized performance in each population: normalized dynamic *DCI* for A&E vs. B-D ($cit=2; b=2$)

4. Discussion

We have defined the research performance evaluation metric *DCI* (for Discounted Cumulated Impact) and exemplified its use on a small but real data set. The metric is based on the idea of *devaluing old citations* in a smooth and parameterizable way. The total cumulated impact

across a time frame, and the relative differences, are greatly affected by adjusting the decay parameter b (Figures 1-3). The metric rewards an author for receiving new citations even if the publication is old. The dynamic *DCI* metric shows the rise and fall of the citation performance of objects (Figures 4-5). Further, it allows weighing of the citations by the citation weight of the citing publication (Figures 2-3). Finally, the normalized dynamic *DCI* supports the analysis of the performance of objects relative to the average of the population they belong to (Figures 6-8). This supports national vs. international evaluation and cross-disciplinary evaluation. The *DCI* metric can be used to calculate research performance on the basis of the h -core of a scholar or any other publication data set like all publications included in the Web of Science.

As defined, the *DCI* index of a cited paper (and consequently, of aggregated objects like authors) increases on the basis of (a) the number of papers citing the paper and (b) the citation weight of the citing paper. This allows for a rise in the index also only as a function of the citing papers becoming more cited, without the cited paper gaining new original citations. When the citation is made, the impact of the citing paper is zero and if no more original citations are received "then one's impact is only a function of one's friend becoming more and more famous". This is the whole idea of citations having different weights: if a paper is heavily cited, also its cited sources are more noteworthy. We proposed weighing based on an adjustable logarithm of the received citations. Thus no single popular citing publication dominates the *DCI* index while some (adjustable) weight is granted to citations. However, if the evaluator wishes to exclude citation weighing, the *DCI* supports flat weights as well. An alternative to the citation weight based on the citations of the citing paper would be the impact factor of the citing journal. It is known at the time of publication and changes moderately.

Obviously, one may compute the *DCI* index for individual papers and authors (as done in the present paper). In addition, it may compute the index for any definable aggregation of papers, i.e. objects such as institutions, countries, journals, topics, etc. By carefully collecting the original citation data, one may compute the *DCI* of the objects in their own or neighboring domains; and internationally or by region.

We believe that the (dynamic) *DCI* index augments the analyst's toolbox in Informetrics in an important way: it incorporates aging of citing in a parametrizable way and thus emphasizes the analysis of sustained currency of publications or aggregated objects. It also allows the analyst to weigh citations instead of treating them as binary. It does not replace the *h*-index (Hirsch, 2005) or its extensions, *A*-index (Jin, 2006), the *R*-index (Jin & al., 2007), or the *AR*-index Jin & al. (2007). Rather, it enriches the view one obtains of citation performance. Because the dynamic *DCI* is able to show both the rise and fall of an object's citation performance over time it would enrich the analysis of creativity Cronin and Meho (2007) performed. For 12 Information Science scholars they tracked their high-impact works and the citation the latter cumulated over time. The *DCI* index would show how these works have kept their currency.

The computation of the *DCI* or the *(d)DCI* is not excessively demanding. Having the sample data set of 4500 citation events, used in the example, at hand, the calculations of the index values for a new set of parameter values take only a couple of seconds in Excel on a standard PC. As the present paper is a methodological one, the data are only used to illustrate the *(d)DCI*. We claim no empirical results as such. The *DCI* index also needs empirical validation across fields in future work.

5. Conclusions

We propose the Discounted Cumulated Impact metric, *DCI*, for research performance evaluation. The *DCI* incorporates aging – in contrast to the *h*-index – but in a parametrizable and smooth way - in contrast to raw publication age based division of the *AR*-index. In addition, in impact computation, the *DCI* index *devalues citations* based on the age of the citing documents. It rewards an author for receiving new citations even if the publication is old. Finally, the *DCI* index can weigh citations from heavily cited publications more than citations from less cited publications, if desired, or use traditional flat citation counts. This is controlled by an adjustable parameter and opens a new possibility in impact evaluation. The *dynamic DCI* is able to show the ascents and descents in citation performance of an object across years. Finally, the *dynamic DCI* readings of objects may be normalized by the averages of the (disciplinary or regional) populations they belong to. This facilitates cross-population comparisons of research performance.

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