Locating the Key Competitors: A New Tool for Technology Manager

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Abstract - **We propose to use the product of a competitor's *h*-index and a weighted sum of the citations of its *h*-core patents as a *Core Value* characterizing the competitor's *h*-core performance in terms of both quality and quantity. The key competitors are those of the greatest Core Values. The approach is applied to empirical data and compared with similar measures such as the products of the *h*-index and other *h*-type indices. The approach obviates the insensitivity problem to exceptionally highly cited patents and does not impose significant analytical overhead to the technology manager.**

Keywords –**h-index, h-core, c-descriptor, Core Value, key competitor**

I. INTRODUCTION

Patents assigned to the competitors are an important source of technological intelligence, and there is already a significant amount of research involving patent data in the various technology management tasks such as [5, 9, 10, 14, 25], to name some notable ones.

Before a decision is made to enter an emerging market segment or to start developing a new product, a technology manager is often challenged by the executives with questions about the current state-of-the-art technologies, whether these technologies have already been patented so that there is significant legal uncertainty and barrier, the major players that hold these patents, etc.

Usually there is little off-the-shelf information available and the technology manager is often given little time in finding the answers. A simplified yet commonly adopted approach by the technology manager can roughly be described as follows. Firstly, some keywords are applied to patent databases and a set of patents are collected. Then, the collected patents' bibliometric information is extracted and fed to some analysis tool. Finally, a number of charts or tables are produced by the tool. Quite often is the case that the technology manager then jumps to conclusions based on these coarse analytical results and considers those patent assignees holding a greater number of patents as the key players.

These quick-and-dirty answers are often not accurate and, given enough time and resource, the technology manager certainly can do a much better work. For example, the R&D spending, the number of R&D staff, etc. may provide more in-depth information, especially some key players may choose not to file patents for saving cost or to conceal their breakthrough technology, or the value of a patent is not yet manifested as it has not been involved in licensing deals or legal disputes. However, this information usually is not freely available, or costly in-depth research is required. What this paper concerns is that, if given only the free patent databases and limited time, can a technology manager do a better job in locating the key players or competitors?

Even though we limit ourselves to the bibliometric information contained in patent databases, there are various ways of applying this information in locating the key competitor. For example, if a technology is of importance to a competitor, patent applications in multiple countries are filed and therefore a sizeable patent family is formed, or continuous development and improvement is conducted and as such results in numerous continuing applications.

Here in this paper, we further limit ourselves to use the citations received by a patent as an indication to the patent's value or quality, not only because their ready availability from patent databases but also because they are relatively more objective than citations to papers.

Patent citations are more objective because that (1) citations to patents are produced not only by the applicants but also by the patent examiners who can be considered as objective third parties; and (2) self-citation is rarely an issue since there is little benefit for an applicant to cite his or her prior applications or patents unless it is necessary to do so. Therefore we can safely ignore the impact of self-citation.

Additionally, even though patents do expire and valid patents have different remaining lives, determining whether a patent is still under maintenance is actually more difficult than we imagine. The data is buried in the patent databases and usually requires laborious manual discovery for each patent. Both factors as such are not considered in this paper for simplicity's sake.

Based on the forgoing assumptions, we at the moment roughly define the key players or competitors as those patent assignees holding a greater number of patents each receiving a greater number of citations.

This definition is of course imprecise. As will be detailed subsequently, we will propose an approach that will give precise meaning to this definition, and this approach will be applied to empirical data to demonstrate its validity. In the process, we will also compare the approach with other similar measures.

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II. *h*-INDEX GEOMETRY

After we limit ourselves to use citation as an indication to a patent's value and due to the many analogous features between papers and patents [18, 19], locating the key competitors is very similar to determining the elite researchers, departments, journals, etc.

There is a wealth of tools from the scientometric and bibliometric research. Among these tools, the *h*-index [13] has attracted a lot of interests. The *h*-index actually has already become a de facto indicator in the scientific community for research performance evaluation, as evident from the large number of articles devoted to this topic (e.g., the original *h*-index paper [13] is cited more than 2,000 times) and its adoption by on-line databases such as Scopus and Web of Science.

An operational definition of the *h*-index is as follows. Firstly, the N patents assigned to a patent assignee (i.e., its patent portfolio) are sorted in descending order of their respective citation counts into an ordered list $\{P_1, P_2,\ldots, P_{N-1}, P_N\}$, and therefore $C(P_i) \geq C(P_j)$ if $1 \leq i \leq j \leq N$, where P_i is the patent ranked at the ith place and $C(P_i) \geq 0$ is the citation count of P_i. Then, the assignee has *h*-index n if $C(P_n) \geq n$ and $C(P_{n+1}) \leq n$.

Geometrically, a so-called *rank-citation curve* [27] can be obtained by plotting and connecting the points (i, $C(P_i)$), $1 \leq i \leq N$, in a smooth or stepwise manner in a two dimensional coordinate system where the horizontal axis provides the ranks of the patents and the vertical axis provides the patents' citation counts. The *h*-index n corresponds to a special point (n, n) on the rank-citation curve. A fictitious, stepwise rank-citation curve is depicted in Fig. 1.

The ordered list $\{P_1, P_2,\ldots, P_{N-1}, P_N\}$ is partitioned by the *h*-index n into the set of n patents $\{P_1,P_2,\ldots,P_{n-1},P_n\}$ and the set of $(N - n)$ patents $\{P_{n+1},P_{n+2},\ldots,P_{N-1},P_N\}$, which are referred to as the assignee's *h*-core [23] and *h*-tail [27], respectively. The *h*-tail can be further divided into the set of $(N_c - n)$ cited patents and the set of $(N - N_c)$ un-cited patents where N_c is the number of cited patents (i.e., patents having been cited at least once).

Similarly, the point (n, n) also partitions the rank-citation curve into two segments manifesting the citation distributions of the *h*-core and *h*-tail, which are referred to as the *h-core* and *h-tail segments*, respectively [16]. The areas beneath the *h*-core and *h*-tail segments corresponding to citations received by the *h*-core and *h*-tail are referred to as the *h-core area* (whose sizes is denoted as A_c) [16] and *h-tail area* (whose sizes is denoted as A_t) [27].

The popularity of the *h*-index arises mainly out of its simplicity. To characterize the research performance of a researcher, the *h*-index only involves two attributes: *quantity* (or *productivity*, a measure related to the number of papers published) and *quality* (or *impact*, a measure related to the citations received by the published papers).

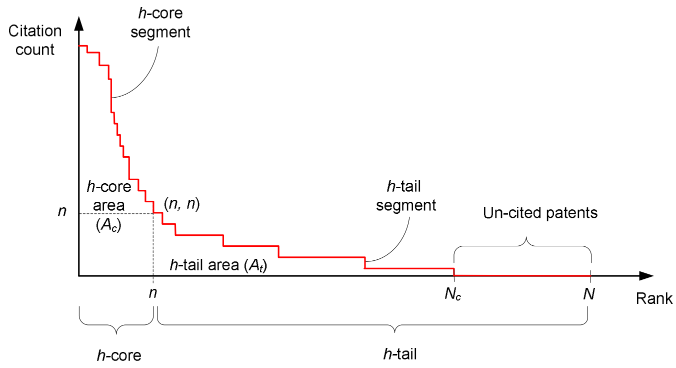

Fig. 1: A fictitious rank-citation curve.

The *h*-index combines the two in a single yet simple-to-calculate number (cf. [6, 13, 24]). Then, when we limit ourselves to the same two attributes of patent assignees, the *h*-index seems an appropriate choice for our approach.

Despite its popularity, the *h*-index has also received a lot of criticisms. By simply looking at Fig. 1, we can immediately understand the origin of some of the criticisms. A researcher's performance is actually completely reflected in its rank-citation curve [16, 17], and using a single point (n, n) to represent the entire curve definitely omits a great deal of details. For example, one of the mostly criticized characteristic of the *h*-index is its insensitivity to some exceptionally highly cited papers. This is due to the *h*-index's ignoring the area above the n^2 squire box bounded by the dashed line. As such, there are a large number of so-called *h*-type indices proposed to modify or augment the original *h*-index. For example, two of them that will be compared with our approach are the *A*-index and *R*-index [4, 15]. Some recent reviews to the various issues of the *h*-index and various *h*-type indices can be found in [2] and [8].

The papers contained in the *h*-core are usually considered as the most visible ones or as having the greatest impact (cf. [4, 8]) from a researcher. The idea has been extended to various levels of aggregation. For example, the eminence of scientific journals is determined by the relatively most important papers of these journals referred to as the *elite set*, and *h*-index is suggested as one of the ways in determining the elite set [26]. The *h*-index is also applied to research topics and the topics with greater *h*-indices are considered as "hot" (i.e., more eminent) topics in contrast to the "older" (i.e., less eminent) topics with smaller *h*-indices [3].

Due to the *h*-index's lack of information and the representative role played by the *h*-core, in this paper we propose to use the *h*-core's performance (i.e., its quality and quantity), instead of the *h*-index, to determine the key competitors or patent assignees.

III. CHARACTERIZING THE *h*-CORE

The question then is how we characterize the performance reflected in a patent assignee's *h*-core. Before proceeding, we like to point out that using the *h*-

index to determine a set of relatively more visible papers or patents is by no means the only approach. There are various other approaches in selecting the so-called *highly cited papers* (HCPs) as a measure to a researcher's scientific performance (cf. [22, 1]). We can also expect that some of the *h*-type indices can be potential candidates as well such as the *g*-index [7]. One therefore may question why the *h*-index (and therefore *h*-core) is any superior.

We choose the *h*-index as it has a unique merit. In a prior study [16, 17], it is pointed out that the *h*-index usually reflects the smallest distance from the rank-citation curve to the origin, and therefore that the rank-citation curve of an assignee with smaller *h*-index is located closer to the origin and may run completely beneath the rank-citation curve of another assignee with greater *h*-index, implying that the former is outperformed by the latter. Even though the above statement is often true, especially when the difference between two assignees' *h*-indices is large enough, there are exceptions.

Fig. 2 provides the rank-citation curves for three fictitious assignees S_i, S_j, and S_k having *h*-indices n_i, n_j, and n_k, respectively, with $n_i<n_j<n_k$. As illustrated, S_i has the smallest *h*-index n_i and its rank-citation curve runs completely beneath those of S_j and S_k. Since every patent in S_i's *h*-core receives fewer citations than those ranked at the same places in the S_j and S_k's *h*-cores, together with $n_i<n_j<n_k$, we can infer that S_i's *h*-core performance is inferior to S_j and S_k, both in terms of quantity and quality. On the other hand, even though $n_j<n_k$, S_j's rank-citation curve does not run completely beneath that of S_k as their *h*-core segments cross each other. Under this scenario we can no longer confidently reach the conclusion that S_j is outperformed by S_k. Some additional information is required.

As mentioned in the previous section, a number of *h*-type indices are proposed to supplement the *h*-index. However, most of them involves the area size of the *h*-core area (A_c) such as the *A*-index ($=A_c/n$) and *R*-index ($=A_c^{1/2}$), yet the area size is notorious in hiding details.

Believing that the shape of the *h*-core segment, not the size of the *h*-core area, more accurately reflects an assignee's *h*-core performance, we have proposed in a previous study [16] a shape descriptor called *c-descriptor* (short for *core descriptor*) for supplementing the *h*-index:

$$c\text{-descriptor} = \sum_{i=1}^{n} C(P_i)\left(\frac{C(P_i)}{A_c}\right) = \frac{\sum_{i=1}^{n} C(P_i)^2}{\sum_{i=1}^{n} C(P_i)}. \quad (1)$$

According to (1), the *c*-descriptor is a weighted sum of the citation counts $C(P_i)$, $1 \le i \le n$, of the *h*-core patents $\{P_1,P_2,\ldots,P_{n-1},P_n\}$ where the weight is the citation count divided by the total citation count. The *c*-descriptor is therefore a measure of the quality or impact of the *h*-core patents. Geometrically, the *c*-descriptor is a weighted sum of the heights of each point along the *h*-core segment. Since $C(P_1)\geq c$-descriptor$\geq C(P_n)$, the *c*-descriptor can be considered as a characteristic height of the *h*-core segment.

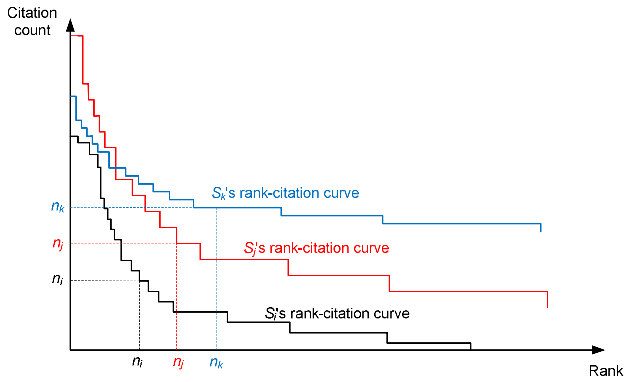

Fig. 2: The rank-citation curves for three fictitious assignees.

We can also see from (1) that the *c*-descriptor significantly favors the patents having greater numbers of citations and therefore the assignees whose *h*-core segments are more skewed to the left. To see this, a fictitious example is as follows. Assuming that S_i, S_j, and S_k all have 3 patents and their citation counts are {6,3,3}, {5,4,3}, and {4,4,4}, respectively, their identical *h*-index (3), *h*-core area size A_c (12), *A*-index (4), and *R*-index ($12^{1/2}$) cannot differentiate them, yet their respective *c*-descriptors, 54/12, 50/12, 48/12, indicate not only their difference but also S_i's more skewed citation distribution {6,3,3}.

One may challenge the adequacy of assigning significantly more weight to patents of greater number of citations. This is because empirical studies [11, 12, 20] indicated that highly cited patents are scarce and the great majority of patents are either lowly cited or un-cited. Since we are trying to determine the key or more eminent assignees, the patents capable of attracting more citations should be better recognized and rewarded.

After introducing the *c*-descriptors, we define a patent assignee's *Core Value* as a characterization of the patent assignee's *h*-core performance as follows:

$$Core\,Value = n \cdot c\text{-descriptor} = n \cdot \frac{\sum_{i=1}^{n} C(P_i)^2}{\sum_{i=1}^{n} C(P_i)}. \quad (2)$$

We can see from (2) that this Core Value captures the *h*-core performance by combining both the quantity side (i.e., *h*-index *n*) and the quality side (i.e., *c*-descriptor) of the *h*-core.

To see this, another fictitious example involving three assignees S_i, S_j, and S_k having the same A_c but with different *h*-indices is provided, whose citations distributions, *h*-indices, *A*-indices, *R*-indices, *c*-descriptors, and Core Values are summarized in Table I. For comparison's sake, two similar measures, the products of *h*-index with *A*-index (actually this is exactly A_c) and products of *h*-index and *R*-index, are also included in Table I.

In this example, these assignees' *R*-indices and $n{\cdot}A$-indices cannot differentiate them due to their identical A_c. Also due to their identical A_c, these assignees' rankings by *h*-index and by $n{\cdot}R$-index ($=n{\cdot}A_c^{1/2}$) are identical and these rankings reflect more of the quantity side of these assignees' h-core performance. On the other hand, these assignees' rankings by A-index ($=A_c/n$) and by c-descriptor are identical and these rankings reflect more of the quality side of these assignees' h-core performance. The more quantity-side rankings are in reverse order to the more quality-side rankings. In contrast to the more quantity-side and quality-side rankings, these assignees' Core Values indicate that S_j actually has the best h-core performance.

TABLE I: Relevant data for the three fictitious assignees.

	Citation Distribution.	h-Index (n)	A-index	R-index	c-Desc.	$n{\cdot}A$-index	$n{\cdot}R$-index	Core Value
S_i	{10, 6}	2	16/2	4	136/16	16	8	278/16
S_j	{8,5,3}	3	16/3	4	98/16	16	12	294/16
S_k	{4,4,4,4}	4	16/4	4	64/16	16	16	256/16

This example illustrates the Core Value's striking a balance between the quality and quantity of the h-core performance. From the quality side (e.g., reflected by the c-descriptor), S_j is not as influential as S_i and, from the quantity side (e.g., reflected by the h-index), S_j is not as productive as S_k. Yet, S_j's inferiority to S_i and S_k is limited so that after combing both quality and quantity together, S_j is considered as having the best h-core performance among the three assignees. However, if S_i has citation distribution {12, 4}, S_j's inferiority to S_i in terms of quality would be so great that S_i becomes the one having the best h-core performance.

IV. EMPIRICAL RESULTS

As an illustrative case, the proposed approach is applied to the 100 assignees having the greatest numbers of U.S. patents granted in the year 2009 [21], and these assignees' U.S. patents issued between 1976 and 2009 are collected. This may not be the ideal set of data as we didn't take into consideration these assignees' areas of expertise and different technology fields usually have different patent filing patterns and citation densities. However, for illustration purpose, this data set should suit our investigation by their diverse h-indices ranging from 161 (IBM with total 58,185 patents) to 3 (LG DISPLAY CO., LTD. with total 872 patents).

In Fig. 3 the 100 assignees are decreasingly sorted according to their h-indices[1] and arranged along the x-axis. Their respective c-descriptors, A-indices, and R-indices, due to their different orders of magnitude, are plotted against log-scaled y-axis.

[1] For assignees of identical h-index, they are further decreasingly sorted by their h-core area sizes (A_c).

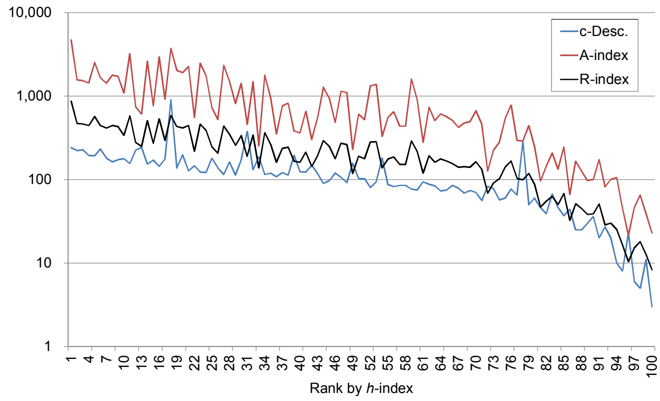

Fig. 3: The c-descriptors, A-indices, and R-indices for the 100 assignees (log-scale y-axis).

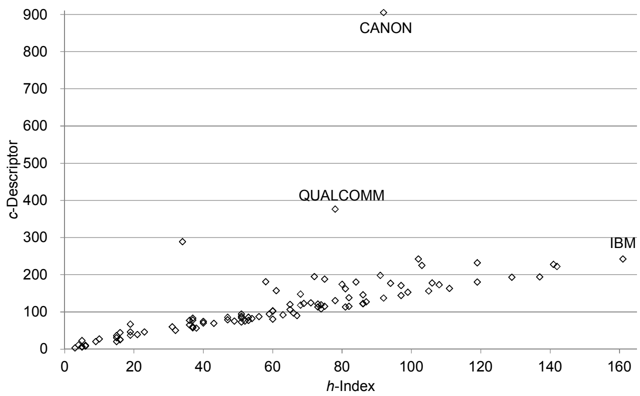

Fig. 4: The Core Values, $n{\cdot}A$-indices, and $n{\cdot}R$-indices for the 100 assignees (log-scale y-axis).

As illustrated, the three curves manifest a general downward trend consistent with the decreasing h-indices, suggesting that the rankings by c-descriptor, A-index, R-index, and h-index are correlated. This is indeed the case as the Spearman's rhos between the ranking by h-index and the rankings by c-descriptor, A-index, and R-index are as high as 0.910, 0.838, and 0.919, respectively[2].

However the unpredictable fluctuations along the curves indicate that the c-descriptor, A-index, and R-index have captured additional information that is missed by the h-index. We can also see the high resemblance between the curves of the A- and R-indices as they are all derived from A_c, and their Spearman's rho is indeed as high as 0.979. Interestingly, some significant spikes along the c-descriptor's curve are often in a reversed direction from those along the curves of the A- and R-indices. The Spearman's rhos between the ranking by c-descriptor and the rankings by A- and R-indices are indeed relatively smaller at 0.680 and 0.776. The spikes along the c-descriptor curve reflect high skewedness and the presence of exceptionally highly cited patents. The reversed directions imply that these exceptionally highly cited patents, which are ignored by A_c and therefore the A-, R-indices, are captured by the c-descriptor.

In Fig. 4 each of the 100 assignees is represented by a point in a two-dimensional coordinate system whose x-

[2] All Spearman's rhos are significant at 0.01 level (two-tailed).

coordinate is its h-index and y-coordinate its c-descriptor. Fig. 4 is therefore a visualization of the 100 assignees' h-core performance where the quantity and quality sides of their h-core performance are manifested.

The two-dimensional representation shown in Fig. 4 would be a valuable tool as a large number of competitors' h-core performance can be simultaneously depicted, thereby achieving a overall view to these competitors' relative performance. With this overall view, a technology manager can immediately determine his or her organization's position among a group of competitors. The technology manager can also determine where the performance difference relative to these competitors lies and the degree of such difference. The technology manager can also quickly determine those competitors having, say, top 10% h-core performance in terms of quality and quantity.

TABLE II: The Core Values, h-indices, A_c's, and the respective ranks of the 100 assignees.

Assignee	Rank by Core Value	Core Value	Rank by h-Index	h-Index	A_c
CANON	1	83,260	18	92	22,371
IBM	2	38,962	1	161	35,636
TEXAS INSTRUMENTS	3	32,148	3	141	29,274
AT&T CORP.	4	31,524	2	142	27,957
QUALCOMM	5	29,328	31	78	13,874
XEROX	6	27,608	6	119	22,526
MICRON	7	26,578	4	137	25,135
MOTOROLA	8	24,897	5	129	22,597
SEMICON. ENERGY LAB.	9	24,684	13	102	19,148
MEDTRONIC	10	23,175	12	103	17,861

In determining the key competitors, we can sort the competitors in accordance with their Core Values, and choose, for example, the top 10 or the top 10% competitors having the greatest Core Values as the key competitor. For the 100 assignees, the top 10 assignees' Core Values, h-indices, A_c's and their respective ranks are summarized in Table II.

Together with Table II and Fig. 4, we can see that CANON and QUALCOMM probably are not considered the key competitors by conventional measures such as the h-index. Yet they are able to emerge as key competitors with their rather small h-indices (92 and 78) and, as such, their h-core segments must be significantly skewed so as to achieve significantly large c-descriptors, thereby compensating their inferior h-indices. By examining their raw data, this is indeed true. For example, the highest ranking patents of CANON and QUALCOMM are cited 1,950 and 1,139 times, respectively, whereas the highest ranking patent of IBM (having the greatest h-index) is cited only 488 times.

V. SUMMARY AND DISCUSSION

In this paper we have proposed a new index called *Core Value* to characterize a patent assignee's h-core performance in terms of both quantity and quality calculated as the product of the assignee's h-index and c-descriptor. From (1) and (2), the c-descriptor and Core Value can be easily obtained as by-products when a technology manager iterates through an assignee's decreasingly sorted portfolio to determine the assignee's h-index. We have also used empirical data to illustrate the difference of the c-descriptor and Core Value against some conventional h-type indices and similar characterizations based on the h-type indices.

We have demonstrated the use of the Core Value in the paper using empirical data. However, due to the page limitation of the paper, rigorous analysis of the property of the Core Value is not covered, and the validity of the Core Value and the ranking it achieves should also be verified against some firm-level innovation or R&D metrics. These could be desirable topics for future study.

We have also noticed that the conventional definition of the h-core is not accurate. The h-core is considered conventionally as containing the papers or patents ranked ahead of or at the same place as the h-index. An alternative way of determining the h-core is to include the papers or patents whose received citations are more than or equal to the h-index. For example, an assignee has 5 patents with citations 5, 3, 3, 3, and 1, respectively, and therefore has h-index 3. The conventional h-core contains the first 3 patents whereas the alternative h-core contains the first 4 patents. We think the alternative h-core is more reasonable since there is no point ignoring one of the three patents that also receives 3 citations as the other two. Therefore, another topic for the future would be to adapt the c-descriptor and the Core Value based on the alternative definition of the h-core.

The approach proposed by this paper is rather simplified by considering only the number of patents and their citations, and a technology manager should utilize this approach with its limitations in mind. For example, as mentioned in section I, patents do expire and valid patents have different remaining lives but both factors are not considered in this paper. A more elaborate approach would be to remove the expired patents from the portfolio and apply some discounting scheme based on a patent's remaining life. Additionally, competitors usually have several lines of products and patents in different technological areas should be treated separately, not altogether. Also, different phases of a technology's life cycle may also involve different patterns of patent filing activities and citation densities. All these factors should be carefully weighted so as not to make misleading conclusions.

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