Perspectives on the past

50 years of FSW

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Citations, h-Index, Journal Impact and Rankings: Not all Sorrow and Misery

CWTS: A Short History of Measuring Science

Ton F.J. van Raan

The Quantitative Study of Science before the Science Citation Index

The quantitative study of science is mostly referred to as *scientometrics*. Within scientometrics, the research on scientific communication, particularly with data from publications, citations, and journals is called *bibliometrics*. Comprehensive overviews of the early developments in the quantitative study of science are given by Francis Narin in his seminal report *Evaluative Bibliometrics* (Narin, 1976), and in a review by Van Raan (2004a; see also Moed et al., 1983). In the 1920s, Lotka[1] - famous for his Lotka-Volterra equations in population dynamics - published remarkable work on the productivity of chemistry researchers.[2] It is the first scientometric finding that can be expressed in a simple mathematical way: the productivity of scientists follows an inverse square law. In other words, the number of scientists producing *N* papers is proportional to *N*-2. This 'law of scientific productivity' holds that in a given period of time the majority of researchers produce only one or two papers; just a few are prolific writers producing ten papers or more. It is one of the many examples of science being characterized by skewed distributions.

Between 1925-1950 there was an increasing interest on the part of librarians to find out how papers in specific journals are cited by papers in other journals. The idea came up that analyzing these 'journal-to-journal citations' could be used to assess the usefulness of journals for university libraries. This works as follows: given a set of journals already present in a library, one may analyze which journals outside the set are frequently cited by the journals within the set. These journals can then be considered important enough to add to the library collection.

Another skewed distribution in science was found by Bradford (Science Museum, London) in the 1930s: literature on a given subject is heavily concentrated in just a small core set of journals. This *Bradford's Law of Concentration of Subject Literature* is a convenient way to estimate how many journals must be checked to obtain a specific level of coverage of the literature on the subject.

The beginning of the 1950s witnessed the appearance of the first *science maps* based on journal-to-journal citations. Daniel and Louttit constructed such a map for psychology to show the development of the field on the basis of the

1 For literature references to the early work (until 1973) discussed in Sections 1 and 2, we refer to Narin (1976) and Moed et al. (1983).
2 An even earlier scientometric work, assessing the scientific strength of nations by analyzing membership of scientific societies, was published in 1873 by De Candolle.

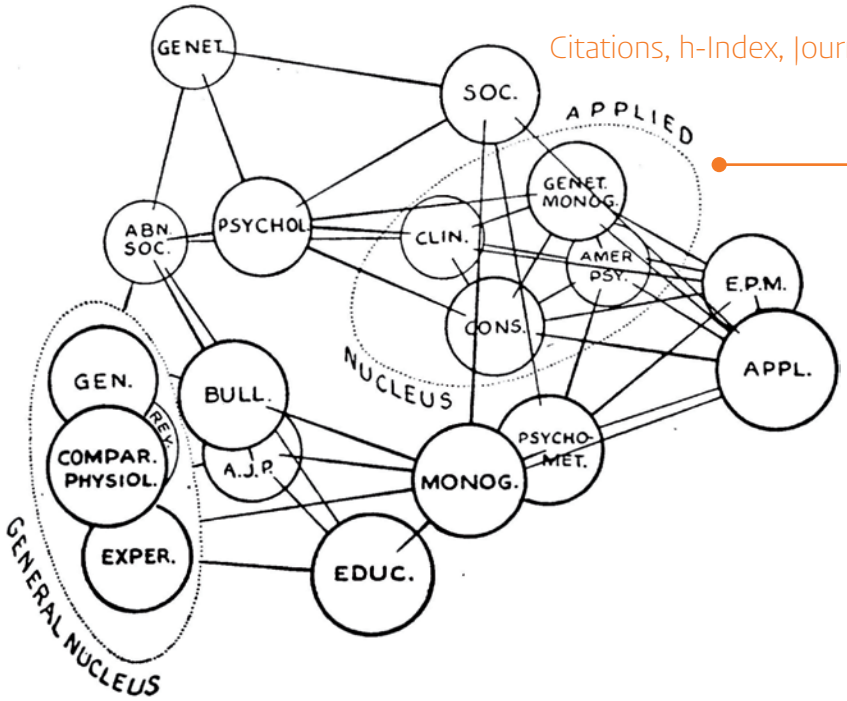

Fig. 1: Map by Daniel and Louttit based on journal-to-journal citations. Lines connect journals which are correlated above a specific threshold.

structure of the literature. After composing a journal-to-journal-citation matrix, they calculated similarity measures and applied cluster analysis. In this way they created the science map shown in Figure 1, and discovered a 'general' and an 'applied' nucleus of the psychology literature. All this had to be done manually, with a huge amount of printed journal volumes, a hell of a job without computers and automated databases.

At first, citation analysis was restricted to journals as a whole. Citation analysis of individual publications, grouped into fields, countries, universities, departments, research groups, or individual scientists, was not possible due to the lack of relevant data sources. All such studies had to wait for the invention in 1955 of the *Science Citation Index*.

The Science Citation Index Revolutionized the Study of Science

The invention of the *Science Citation Index* (SCI) by Eugene Garfield was undoubtedly a major breakthrough (Wouters, 1999), which completely revolutionized the field. The systematic collection and registration of all references in all publications in a large number of scientific journals opened the way to statistical analyses of the scientific literature on a very large scale. It marks the rise of bibliometrics as a powerful empirical field within the study of science. Garfield created a company, the *Institute for Scientific Information* (ISI), to develop the SCI and related databases. The SCI is the predecessor of the *Web of Science* (WoS). As almost all publications are connected to other publications by citations, the science communication system represented by publications is in fact a gigantic network, to which currently more than a million publications per year are added. It is therefore probably no surprise that nowadays in bibliometric research projects advanced network analysis methods from mathematics and physics are used.

Several US scientists immediately recognized the enormous potential of the SCI. In the early 1960s, the Yale University physicist and historian of science De Solla Price made a number of important bibliometric discoveries based on data from the SCI. We mention here: *Price's Law* on the distribution of publications over authors, stating that 25% of all authors are responsible for 75% of all published papers (this is in fact a more accurate revival of the Lotka study mentioned earlier); the *exponential growth* of scientific literature that started in the beginning of the 18th century; the *exponential decay* of citations received by publications as a function of time, which defines a *half-life time* of publications; and the *power law* distribution of citations. It is particularly this last finding that is an important further

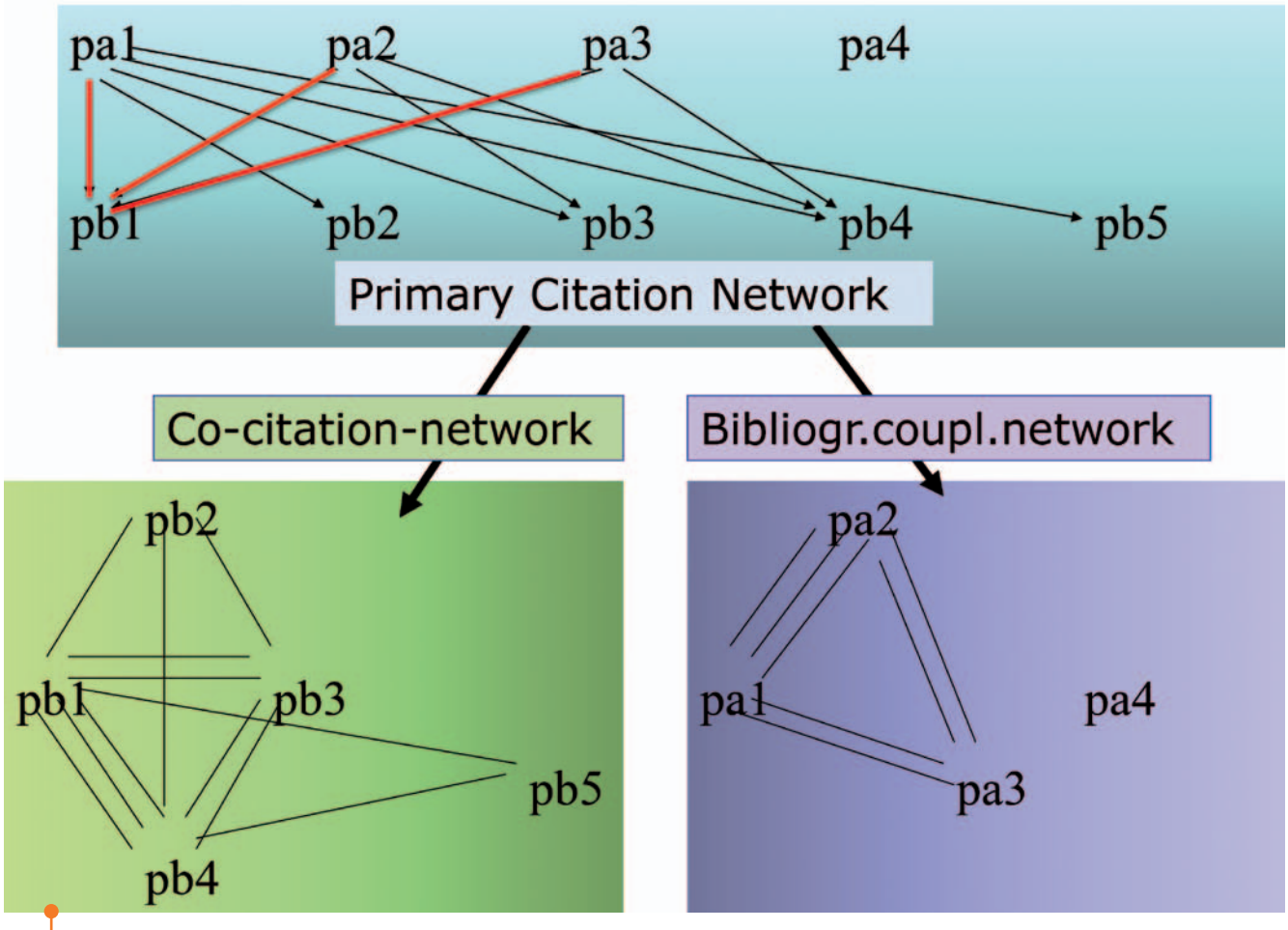

Fig.2: The primary citation network consists of 4 publications (pa1,.., pa4) in which publications pb1,...., pb5 are cited in the way indicated. By converting such networks into numerical matrices, matrix-algebraic operations can be performed on them.

example of the skewed distributions in science: most publications receive only few citations (or none), and only few publications receive many citations.

De Solla Price also coined the idea of *cumulative advantage,* which means that publications which are already frequently cited have a higher probability of receiving even more citations. In terms of complex network theory this concept is now better known as *preferential attachment.* Quite remarkably, it was found recently that this cumulative advantage of publications starts to work as soon as a publication has acquired eight citations. Of course, this is a statistical outcome, not a guarantee.

As discussed above, the invention of the SCI opened the way for the analysis of citations at the level of individual publications. In the early 1960s Kessler at MIT developed the method of *bibliographic coupling* (BC): two publications are bibliographically coupled if they have references in common; the more common references, the stronger their relation (bibliographic coupling strength). Ten years later, Small at ISI developed the 'mirror' of bibliographic coupling, which he named *co-citation analysis* (CC). In this method, publications are defined as related if they are cited together by other papers. The more papers citing a specific pair of papers, the stronger the co-citation strength. The strength of the relations between publications provides similarity measures, and hence the possibility to cluster in such a way that both BC and CC can be used for mapping.

Figure 2 shows a diagram of both approaches based on a simple citation network. From this primary citation network two secondary networks, the co-citation and the bibliographic coupling networks, can be deduced. To give a simple explanation: in the co-citation network the strength between for instance pb1 and pb4 is 3, because there are 3 publications that cite pb1 and pb4 together (pa1, pa2, and pa3). In the bibliographic coupling network the strength between for instance pa2 and pa3 is 2, because these publications have two cited publications in common (pb1 and pb4). The usual citation analysis (i.e., counting citations of a specific paper) is illustrated by the red arrows: pb1 is cited three times. In network terms: the in-degree of pb1 as a node in the network is 3, whereas the out-degree of pa1 is 5.

The SCI also made it possible to use citation analysis for the assessment of the impact of publications: the more they are cited, the higher the impact. From the beginning it was recognized that the process of citation is complex, and certainly does not provide an ideal monitor on scientific performance. This is particularly the case at a statistically low aggregation level, e.g., just one individual publication. But the application of citation analysis to the work of *a group of researchers as a whole over a longer period of time* does yield (particularly in the natural sciences and the medical fields) a reliable indicator of scientific performance.

The sociologists Jonathan Cole and Stephen Cole were the first to use citation analysis to determine scientific impact.

They found high positive correlations between receiving citations, winning awards, membership of scientific academies, being widely known among colleagues, and working in prestigious institutes. They also concluded that it seemed as if only a small number of scientists contribute to scientific progress.

The 1970s saw a rapid expansion in research on quantitative aspects of science. Due to the increasing availability of data, the quantitative appraisal of science gained influence in national and international organizations as well. It was the beginning of the development of *science indicators* on the basis of publication and citation data. The National Science Foundation, UNESCO, OECD, and the European Commission are examples of organizations that started to systematically collect data to measure and analyze the development of science and technology. A landmark is the first publication in 1973 by the US National Science Board of what was to become the biennial series *Science Indicators Report* in 1973.

Meanwhile, the inventor of the SCI, Garfield, launched the idea of a *journal impact factor,* in which he used citation analysis as a tool for journal evaluation. Here, Garfield recognized another potential application of citation analysis: journals can be ranked by citation frequency for science policy purposes. The policy-making implications of bibliometric analyses were discussed even more explicitly in the pioneering work by Narin on evaluative bibliometrics (1976) mentioned earlier. Narin was the first *scientist-entrepreneur* who used SCI data for a commercial enterprise, in a company called Computer Horizons Inc. With a research contract from the National Science Foundation, Narin extensively described the use of publication and citation analysis in the evaluation of scientific activities. The focus was on creating performance indicators on the basis of the data of thousands of journals. An analysis on the basis of millions of individual publications was at that time still a step too far. However, besides the availability of more and more data through the SCI, computer power and memory capacity were rapidly increasing.[3] It took only a few years more to bring about the large-scale citation analysis of (sets of) individual publications.

Until that time there was not much activity in bibliometrics outside the United States. But this changed in 1975. During a four-month working visit at the National Science Foundation, Cees le Pair, physicist (PhD Leiden) and the then director of research at FOM[4], became interested in *measuring science* and got to know Derek de Solla Price and Eugene Garfield. Back in Utrecht, he started the first citation analysis studies of two fields of physics: magnetic resonance and electron microscopy. These studies showed that citation analysis made it possible to identify the most important basic

3 To give an illustration: by the end of the 1990s the size of computing power and memory storage capacity was about 10,000 times what it was in the early 1980s.

4 FOM: *Stichting Fundamenteel Onderzoek der Materie*, the physics research council, part of NWO, the Netherlands Organization for Scientific Research.

research contributions to these fields. In the field of magnetic resonance high correlations were found between the results of a citation analysis and peer assessments. However, in the case of applied and technological research - particularly in the field of electron microscopy - citation analysis did not work well.

At first, the results of bibliometric research were published mainly in sociological or general journals, even top journals such as *Science*. An important sign of the emancipation of the field of bibliometrics, however, was the creation of its first journal, *Scientometrics,* by the Hungarian chemist Tibor Braun in 1978. Scientometrics is still one of the core journals of the field. Braun also created a flourishing bibliometric research group at the Academy of Sciences in Budapest.

The Take-Off Run to CWTS

How did the field of scientometrics reach Leiden University? In 1979 the Leiden University Executive Board introduced a new institutional policy. The money allocation model used to divide the block financing from the Ministry among the faculties should no longer be largely dependent on student numbers, but should also have a *research-quality dependent* factor. The crux was to find a reliable method to assess research quality. At the time, I myself was involved in the development of this model, and as a physicist, and knowing Cees le Pair, I proposed using citation analysis in the assessment of research performance. In 1980 the first experiments were performed: a citation analysis of all chemistry departments, followed by a second citation analysis of the entire Faculty of Sciences and the Faculty of Medicine, combined with interviews with experts. The report of this study (Moed et al., 1983), followed by a series of highly cited papers based on the report, catapulted the Leiden group to instant fame within the field of scientometrics. Never before had a bibliometric study been performed on so many (140) departments within a research-intensive university. But certainly, shortly before and around the same time there had also been other important bibliometric studies, of which the work on radio astronomy by Irvine and Martin can be considered ground-breaking.

From 1983 onwards the brand-new Leiden group could count on continuous support of the Executive Board, the Ministry of Education, Culture and Sciences, and the publishing company *Elsevier*, mostly via contract-research projects. Elsevier was particularly interested in creating new performance indicators of scientific journals. We also enjoyed a rapidly increasing international interest followed by more and more contract research assignments. However, we were not alone in the world. In the early 1980s there was a rapid rise in the number of co-citation analyses; an increasing emphasis on important themes such as advanced statistical analyses of scientometric parameters; application of bibliometric methods in the social sciences; comparison of peer opinions and bibliometric indicators; and development of indicators of interdisciplinary research (see, e.g., Van Raan, 2004a).

A new development was *co-word analysis*. Mathematically this is similar to co-citation analysis, but instead of citing earlier publications it is based on the use of specific concepts. To put it simply, next to the list of references in publications, we can also characterize publications by a list of concepts used in them. After a slow start, co-word analysis went sky-high and became one of the primary methods to create science maps. But it took a long time, almost two decades, before sufficient computer power was available. Our Leiden group played an important role in this development.

In 1986 the Leiden group became part of the Faculty of Social and Behavioural Sciences (hereafter *FSW*) as a research group within the Leiden Institute of Social Policy Research (LISBON) which was established by the then Professor of Sociology Mark van de Vall. Already from the very beginning our bibliometric work benefited from contacts within FSW. One of the main pillars of the CWTS work, science mapping, originated from collaboration with the department of Data Theory (Jan de Leeuw, Jacqueline Meulman, Willem Heiser). We collaborated with the department of Sociology on research proposals in which bibliometrics was presented as an important instrument in research on the sociology of science (Kees Bertels, Kees Schuyt). The FSW contract research department DSWO (Peter van Hoesel) was also a great help to our group, particularly by providing advice on how to manage a rapidly growing research group that for about 90% made its 'living' from contracts.

The first international conference on bibliometrics and the theoretical aspects of information retrieval (the predecessor of the ISSI[5] conference) was organized in 1987 by Leo Egghe in Hasselt (Belgium). The Leiden group was prominently present at this conference. In 1988 we published the first *Handbook of Quantitative Studies of Science and Technology* (Van Raan, 1988), and CWTS organized the first international conference on Science and Technology Indicators in Leiden. The field of bibliometric research became more and more dynamic - and even heated. As can be expected, opponents of the use of citation analysis started to agitate the field, for instance by pointing to the many different motives authors may have to cite or not to cite, thus questioning the validity of using citations as a performance measure. Although such debates can be quite irritating, they are part of a healthy development of the field. At the same time, more and more large-scale empirical work was done. For instance, the Budapest researchers published an extensive study on the publication output and field-specific citation impact of scientific work in about a hundred countries. In 1989 the Leiden group acquired its formal name: *Centre for Science and Technology Studies* (CWTS), and in the same year we started with patent analysis in order to create bridges between science and technology on the basis of citations to the scientific literature in patents.

By this time CWTS was housed in the new premises of the FSW, the Pieter de la Court Building. After several

5 ISSI: International Society for Scientometrics and Informetrics, http://www.issi-society.info/.

organizational restructuring operations CWTS became an autonomous research department. Important work in the second half of the 1980s focused on, for instance, research performance in the humanities and social sciences, and the use of quasi-correspondence and multidimensional scaling analysis for science mapping. The 1980s can be characterized as the period of the birth and rapid growth of CWTS. Particularly in the second half of the decade we were able to create one of the most active and influential bibliometrics research institutes worldwide.

What was the secret behind this success? Next to the competence and ambitions of our staff, I think two elements were crucial. First, the optimal mix of basic and applied research, using contract-research data to continuously investigate new paths: application as a source of innovation. Second, our heavy investments in computers and ICT personnel. Bibliometrics is an immensely data-intensive field that cannot do without massive computing power. In addition, the fact that the head of CWTS was a physicist may also have been instrumental in being taken seriously in a sometimes quite arrogant and averse academic environment. Next to these content-related elements, the Leiden University Board has always been well-disposed towards CWTS in terms of organizational and policy support. After a successful take-off, our task was to consolidate and further reinforce the unique position of CWTS.

Life at the Forefront

The 1990s was a decade of numerous CWTS achievements. From the perspective of institutional academic status the appointment of Ton van Raan in 1991 to Professor of Quantitative Studies of Science, probably the first chair in this field worldwide, was crucial. It put CWTS at the level of a well-established university department, and enabled us to organize PhD work largely autonomously.[6] The chair was established by the Leiden University Foundation (LUF), and was later changed into an ordinary professorship. Next to the FSW it was particularly the Faculties of Medicine and Science that strongly supported the establishment of the chair. Immediately after the appointment an annual series of lectures for MSc students was established. This series of lectures has evolved to what is now the CWTS international *Graduate Course on Measuring Science*.

The 1990s witnessed a strong increase in contract research commissioned by organizations and institutions worldwide, but especially in the European Union (ministries, national research councils, charities, universities). CWTS's involvement with research evaluation practices led directly to the improvement of bibliometric indicators and maps. Number and impact of our publications increased steadily. Highly cited work, basic as well as applied, was published. From the harvest of new ideas and initiatives in the first half of the 1990s we mention the idea of the fractal

6 CWTS was never a 'normal' institute combining teaching and research: we always had to survive for about 90% of our budget on contract research. Nevertheless, CWTS has realized 12 PhD examinations over the years.

Excursion to the Delta Works during Eugene Garfield's visit to Leiden in 1991. From right to left: Eugene Garfield; Junjia Liu (Chinese guest worker at CWTS); Cees Le Pair, the chief engineer of the Storm Surge Barrier; Magriet Jansz (colleague of Cees le Pair); youngest son and wife of the author.

structure of co-citation clusters (our first paper in *Nature)*; combining co-citation and word analysis; classifications of interdisciplinary research; new approaches in co-word analysis, leading to improved science mapping; the correlation between peer review judgements and outcomes of citation analysis; the measurement of international scientific collaboration; determinants of citation scores; technology mapping based on patent analysis, and the study of the interface of science and technology by analysis of author-inventor relations.[7]

In the meantime, elsewhere in the world new developments also took place. In 1992 Garfield decided to sell his Institute of Scientific Information. After a few years of different owners, ISI became part of the information giant *Thomson Reuters*. Things began to change gradually, with research becoming more and more determined by business interests. As Tibor Braun once noted: this was the end of the romantic period for the bibliometric world.

A new development was the foundation of the *Netherlands Observatory for Science and Technology* (NOWT), established in 1994 as a joint venture of CWTS and MERIT, Maastricht University. Its purpose was to compile the biannual Science and Technology Indicators (WTI) Report for the Ministry of Education, Culture and Sciences. At CWTS Robert Tijssen was the NOWT supervisor. CWTS produced the WTI reports until 2010.

7 CWTS collaborators also received some prestigious awards. In 1995 Van Raan received the Derek de Solla award together with American sociologist Robert Merton. In 1999 this award was presented to Henk Moed (CWTS) and Wolfgang Glänzel (PhD Leiden and now University of Leuven).

In the second half of the 1990s further new work was published on the cognitive resemblance of citing and cited papers; the inappropriateness of journal impact factors for research evaluation[8]; time-dependent co-word analysis; and, unavoidably, quarrels with theorists, particularly constructivists and philosophers. In the period 1994-2000 CWTS was involved in the VSNU national research assessment procedures.[9] For several disciplines, for instance biology, chemistry, physics, and psychology, we performed extensive bibliometric analyses of all research groups. The presentation of our results often evoked (and still does) strong emotional reactions. To mention a few: "I am far better than you measured!"; "I am ahead of my time and you cannot capture this in your silly citations"; "Your work is horrifying: for me science is like love, you cannot express its importance quantitatively"; "Your work is dangerous, it is part of the machinery of Orwell's Brave New World"; "Counting citations to assess the value of scientific work is disgusting".

Sometimes there is truth is these emotions, often they are unreasonable. Anyway, we went on and continued to develop even better indicators of research performance. Let me show how we actually apply citation analysis. Figure 3 is a schematic presentation of the CWTS basic bibliometric indicators. These indicators are briefly explained in Text box 1. Table 1 contains a recent real-life example of an application of these indicators. Prominent in these figures is our *crown indicator* cd/cf, which measures the extent to which a research group, department, institute, etc. performs significantly above international level. For a comprehensive description of our bibliometric method we refer to Van Raan (2004a). To the outsider some of the indicators shown in Figure 3 may look like 'just counting numbers', but reliably establishing even the two basic indicators (number of publications and number of citations) is far from trivial. Verification is crucial in order to remove errors, to detect incompleteness, and to assure the correct assignment of publications to research groups and completeness of publications sets. We have developed standardized procedures for the execution of such analyses, as conscientiously as possible.

8 'Journal impact factors' concern the average number of citations per paper in the journal over a two-year period after publication. There is no distinction between types of papers, such as 'normal papers' and reviews. Therefore, journal impact factors should not be used as surrogates for the actual citation impact of individual publications. An advanced methodology such as developed by CWTS is capable of measuring actual citation impact.

9 VSNU: *Vereniging van Samenwerkende Nederlandse Universiteiten*, Association of Universities in the Netherlands.

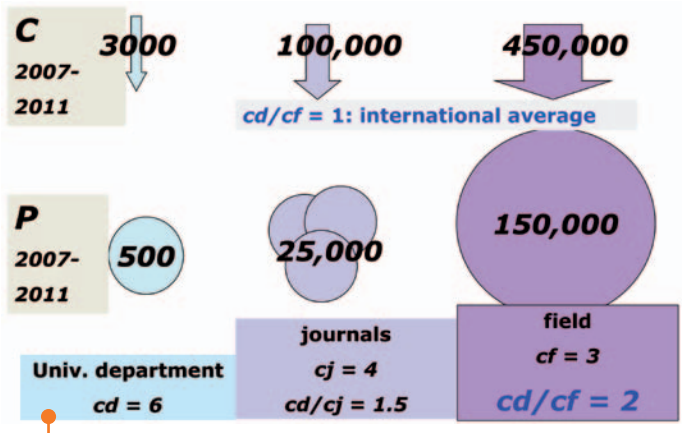

Fig. 3: Basic principles of bibliometric indicators..

Text Box 1: A short explanation of Fig. 3.

A university department has 500 publications in the period 2008-2012 (***P***=500). Within the same period these publications are cited 3,000 times (***C***=3,000). The average citation impact of the department then is ***cd*** = 6. For normalization purposes this impact is compared with similar measures for (1) all journals used by the department: the journal impact ***cj*** (measured over the same 5-year period and taking article type into account), and (2) all journals in all fields in which the department is active: the field average ***cf*** (again measured over the same 5-year period and taking article type into account). In the example given, ***cj*** = 4 and ***cf***=3.

From these figures the following observations can be made: the department performs better than both the journal and the field average (***cd/cj*** = 1.5; ***cd/cf*** = 2.0), and the journals chosen by the department for publications are the better ones in the fields (***cj/cf*** = 1.3). We call ***cd/cf*** our *crown indicator* because this indicator directly measures the extent to which a research group, department, institute, etc. performs significantly above the international level.

The above example is a simple representation of the normalization procedure. In reality this is somewhat more complicated (Waltman et al., 2011). Given the skewness of the distribution of citations over publications, we increasingly apply indicators related to the entire citation distribution. See for instance the methodology section of the latest version of the Leiden Ranking http://www.leidenranking.com/.

LUMC	*P*	*C*	*cd*	*%Pnc*	*cd/cf*	*cj/cf*	*%Scit*
2000 - 2003	4,146	45,643	8.76	16%	1.38	1.28	20%
2001 - 2004	4,247	49,057	9.17	14%	1.41	1.28	21%
2002 - 2005	4,422	50,595	9.03	13%	1.37	1.28	21%
2003 - 2006	4,738	54,777	9.10	13%	1.37	1.29	21%
2004 - 2007	4,967	64,551	10.35	12%	1.44	1.30	20%
2005 - 2008	5,360	70,540	10.43	11%	1.51	1.31	21%
2006 - 2009	5,522	76,001	10.89	12%	1.54	1.36	21%
2007 - 2010	5,871	85,733	11.47	11%	1.64	1.43	21%

Table 1: The main bibliometric indicators for the Leiden University Medical Centre (LUMC). In reality a more advanced normalization procedure was used and all indicators were corrected for self-citations. Indicator *%Pnc* is the percentage of publications not cited in the given period, and *%Scit* is the percentage of self-citations in the total number of citations. Clearly LUMC performs well above the international level.

CWTS in a Changing World

At the beginning of the new century several significant events took place. In 2001 the bibliometric *data delivery policy* of Thomson Reuters changed: compelling financial and usage conditions as well as usage control were imposed by a strict license agreement. In the same year CWTS had its first evaluation by an international peer committee. No reason to complain: the overall judgment was *excellent*. This qualification reinforced our position within the Faculty in terms of reputation, but unfortunately had no (positive) financial consequences at all.

A year later, *CWTSbv* was established as a small spin-off company of CWTS. It was felt that commissioned work (in which new R&D is hardly involved) could be better conducted in a company context. CWTS staff was (and still is) involved in the CWTSbv projects on a time-writing basis. In spite of the strongly increasing burden of this commercial contract research, CWTS managed to go on publishing internationally novel, attractive, and highly cited work on a broad range of basic and applied research themes: fractal differentiation of science; the great influence of language on the citation impact of particularly German and French research groups; industrially relevant science

and the dependence of technology on science; the rapidly upcoming scientific performance of China; identification of scientific excellence; Sleeping Beauties[10] (Van Raan, 2004b); and, after the publication of the first Shanghai Ranking, an inventory of conceptual and methodological problems in the construction of university rankings (Van Raan, 2005). Within a short period three books were produced, one on the scientific performance of German medical research (Tijssen et al., 2002), a handbook (Moed et al., 2004), and a book on citation analysis (Moed, 2005).

Meanwhile, the internet had changed scientific communication. In addition to the publication and citation data provided by the WoS database, a vast number of further publication data included in institutional and personal websites became available. Thus, next to citation analysis the use of data provided via the internet, *webometrics*, was (and still is) considered to offer interesting additional opportunities to complement citation-based analysis in evaluation and mapping approaches (references to early webometrics work can be found in Moed et al., 2004).

We already mentioned another important event in the scientometric world: the emergence of *university rankings*, with the Shanghai Ranking[11] as the first in 2003, soon followed by the introduction of the Times Higher Education ranking.[12] In 2007 CWTS started its own Leiden Ranking.[13] Despite the many problems inherent in the ranking of universities, this new phenomenon evoked a rapidly increasing public and political interest in the performance of universities. It greatly stimulated the application of research assessment, particularly with bibliometric methods. Another important event was Elsevier's start with the development of *Scopus* in 2004, the first competitor of Thomson Reuters's WoS. After a run-up of a few years Scopus was launched commercially as the new citation index, marking the end of a very long period of a strict monopoly of the WoS.

In 2005 the physicist Jorge Hirsch (University of California at San Diego) introduced the *h* index[14] (Hirsch, 2005). This new indicator attracted enormous attention. A simple method for individual scientists to find their *h* index is to rank their publications, for instance in the WoS, according to the number of times the publications are cited (starting with the highest cited). Somewhere in this ranking there will be a publication with a number of citations that is the same as its ranking number. A torrent of publications describing numerous variants of the *h* index followed, but hardly any attempt was made to compare the *h* index carefully with existing efficacious indicators - except by the CWTS (Van

10 A Sleeping Beauty in science is a publication that goes unnoticed (i.e., is not cited, "sleeps") for a long time and then, suddenly, attracts a lot of attention ("is awakened by a prince"), as measured by citations.
11 Version 2013 of the Academic World Universities Ranking (Shanghai Ranking): http://www.ShanghaiRanking.com/.
12 Version 2013 of the Times Higher Education Ranking: http://www.timeshighereducation.co.uk/world-university-rankings/2013/reputation-ranking.
13 Version 2013 of the Leiden Ranking: http://www.leidenranking.com/
14 A scientist has an *h* index of *h* if *h* of his/her publications each have at least *h* citations, and the remaining publications each have fewer than $h + 1$ citations.

Raan, 2006). Because the *h* index does not take into account the often large differences in citation density between, and even within, fields of science, this indicator is in many situations not appropriate for the assessment of research performance. Furthermore, it was recently proved that the *h* index is mathematically inconsistent (Waltman & van Eck, 2012). A few years ago Google Scholar launched a citation index including publications from different sources than only journals (Harzing, 2010); therefore, the *h* index obtained via Google Scholar will be different from those obtained via WoS or Scopus.

The second half of the first decade of the new century can be characterized as a period of strong increase in commercialization, competition, new data sources, new approaches, the influence of Open Access. All these have proved challenges for CWTS. Therefore, the year 2008 was remarkable for our institute, because the Minister of Education, Culture and Sciences decided to grant CWTS a substantial amount of *ear-marked financing* in order to improve its innovative power. Fortunately, but in the nick of time, it had become clear that with the extremely heavy burden of working on 90% financing from contract research, CWTS could not adequately maintain - let alone reinforce - its international position. The then Dean of our Faculty, Theo Toonen, played a crucial role in the minister's decision. The new money also enabled us to establish a second chair at CWTS: Cornelis van Bochove was appointed Professor of Science Policy. Also in 2008, a new evaluation by an international peer committee took place. Next to several important recommendations, the overall judgment was again excellent. Finally, in 2008 we also moved to the beautifully renovated Willem Einthoven building.

CWTS continued to produce highly cited work: bibliometric analyses of research performance in the social sciences and humanities; finding the properties of the statistics and particularly scaling of bibliometric indicators; citation analysis of publications not covered by the WoS; assessing the influence of Open Access on citation impact; a new indicator of journal citation impact, the *source normalized impact per paper* (SNIP) (Moed, 2010); new indicator-normalization procedures - which evoked a fierce dispute in the international literature (Waltman et al., 2011); and a new mapping technology (Van Eck & Waltman, 2010).

In 2010 Robert Tijssen was appointed Professor of Science and Innovation Studies, the third chair at CWTS. In the same year Ton van Raan retired as Director of CWTS while keeping his position as research professor. Paul Wouters was appointed Professor of Scientometrics and became the new director. He energetically took over the responsibility for CWTS, whose program now includes new research themes such as evaluation practices, scientific careers, and the social impact of science. The last theme is particularly closely related to new approaches to finding data on the outcomes of scientific results, 'altmetrics' (Priem et al., 2012). Further important work in recent years includes research on the

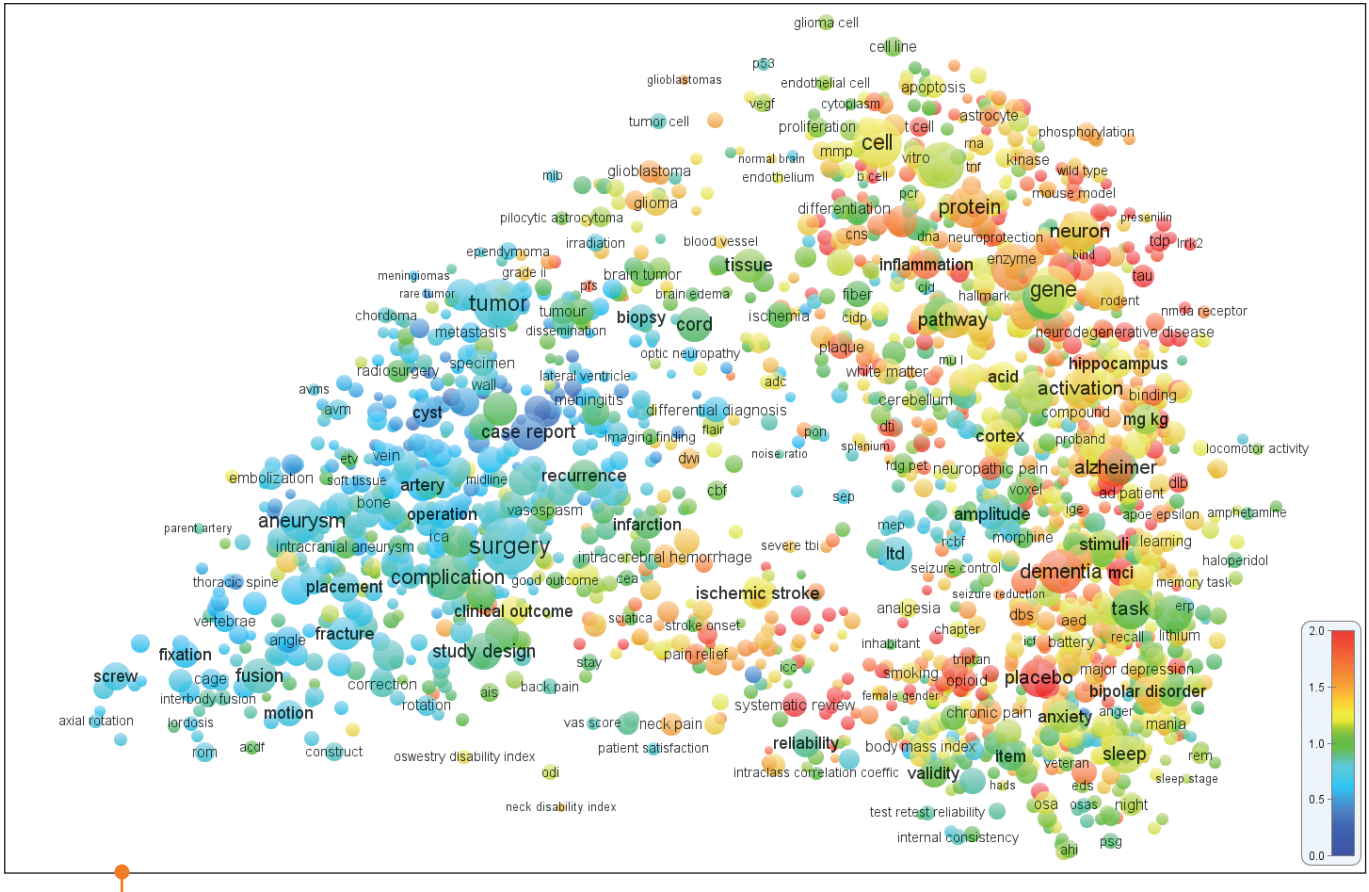

Figure 4: Science map of neurology. Colors indicate local citation density. This map is based on all publications classified as article or review and published between 2006 and 2010. For each publication citations have been counted until the end of 2011. A detailed discussion of this map can be found in Van Eck et al., (2013).

CWTS *University-Industry Research Cooperation Scoreboard*; on the effect of language in rankings (Van Raan et al., 2011); and on the large differences in citation density within medical research fields (Van Eck et al., 2013) (see Figure 4 for an example).

In recent years commercial database producers have started to launch their own bibliometric products: Elsevier's Scopus with SciVal, and Thomson Reuters with InCites. This does not make life easier for CWTS. But we have a dedicated and broadly oriented staff and a wide expertise in the application of bibliometric methods. By further improving our indicator and mapping products, particularly automated research performance assessment and mapping tools, by creating the best possible ranking method (Waltman et al., 2012), and by our research on the qualitative aspects of scientometrics and the impact of science on society and on technology, CWTS will succeed in continuing its forefront position.

Ton F.J. van Raan studied mathematics, physics and astronomy at Utrecht University. PhD Physics, Utrecht (1973). Post-doctoral fellow in physics at the University of Bielefeld (Germany), visiting scientist in the US, UK, and France. From 1977 senior research fellow physics in Leiden, in 1985 'field switch' from physics to science and technology (S&T) studies. Since 1991 Professor of Quantitative Studies of Science. Founder and until 2010 Director of the Centre for Science and Technology Studies (CWTS), Leiden. As author and co-author he published around thirty articles in physics and two hundred in science and technology studies. Ton van Raan also set up a small company, Science Consult, for advice on research evaluation and science policy issues. On the occasion of his retirement as CWTS director he was made a Knight in the Order of the Dutch Lion by Queen Beatrix of the Netherlands.

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