Which are the influential publications in the Web of Science subject categories over a long period of time? CRExplorer software used for big-data analyses in bibliometrics

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Abstract
What are the landmark papers in scientific disciplines? Which papers are indispensable for scientific progress? These are typical questions which are not only of interest for researchers (who frequently know the answers – or guess to know them), but also for the interested general public. Citation counts can be used to identify very useful papers, since they reflect the wisdom of the crowd; in this case, the scientists using published results for their research. In this study, we identified with recently developed methods for the program CRExplorer landmark publications in nearly all Web of Science subject categories (WoSSCs). These are publications which belong more frequently than other publications during the citing years to the top-‰ in their subject area. The results for three subject categories "Information Science & Library Science", "Computer Science, Information Systems", and "Computer Science, Software Engineering" are exemplarily discussed in more detail. The results for the other WoSSCs can be found online at http://crexplorer.net.

Introduction
Bibliometrics is frequently used in research evaluation. In an overview, Sivertsen (2017) notes that bibliometric indicators are considered in many national research-funding systems in the European Union to measure research performance. Not only researchers themselves, but also science administrators and the public are interested in reports about groundbreaking research from units of assessments (e.g., universities or countries; see e.g., van Noorden, Maher, & Nuzzo, 2014). According to Winnink, Tijssen, and van Raan (2018), the term groundbreaking (or breakthrough) is often used for research (discoveries) with a major impact on future scientific activities. Hollingsworth (2008) considers breakthroughs as very useful to many researchers in targeting future research questions in various scientific fields.
Although breakthroughs are of general interest in science (Orduna-Malea, Martín-Martín, & Delgado López-Cózar, 2018; Schlagberger, Bornmann, & Bauer, 2016), research evaluation focuses – as a rule – on short-time horizons: "the time horizon is 10 years or less, and the focus is on recent past performance, as it is believed to increase the policy relevance, and reduce data collection costs" (Moed, 2017, p. 6). Whereas short-term impact measurements allow statements about the research front, "long-term impact indicates to what extent they eventually succeed in scoring 'triumphs'" (Moed, Burger, Frankfort, & van Raan, 1985, p. 134). The results of Wang (2013) further show that the use of a short citation window (the standard is a minimum of three years) may lead to hasty classifications of papers as high-

impact papers which turn out to be erroneous in the long run (Baumgartner & Leydesdorff, 2014; Leydesdorff, Bornmann, Comins, & Milojević, 2016; Ponomarev, Williams, Hackett, Schnell, & Haak, 2014). The results of Wang, Veugelers, and Stephan (2017) as well as Mairesse and Pezzoni (2018) reveal that novel papers are associated with high citation rates especially in the long run. Garfield, Pudovkin, and Istomin (2002) introduced methods to produce tables with highly-cited papers.

Winnink et al. (2018) studied five algorithms for detecting breakthrough papers. The results point out that the algorithms are powerful tools for tracing breakthrough papers. van Noorden et al. (2014) used traditional citation analyses to identify the most cited publications of all time. They found that about 15,000 papers have more than 1,000 citations and thus seem to be very useful. Marx, Bornmann, Barth, and Leydesdorff (2014) developed the method Reference Publication Year Spectroscopy (RPYS) to detect the origins of research fields or topics. The method is based on counting cited references (instead of citations) to assess the impact of publications on a topic- or field-specific publication set (e.g., climate change, see Marx, Haunschild, Thor, & Bornmann, 2017).[1] The method has already been successfully applied in identifying papers with outstanding performance (Comins & Leydesdorff, 2017, 2018; Thor, Bornmann, Marx, & Mutz, 2018) and landmark patents (Comins, Carmack, & Leydesdorff, 2017).

Thor, Marx, Leydesdorff, and Bornmann (2016) introduced the CRExplorer – a program for undertaking RPYS. In a recent update of the program, Thor et al. (2018) developed an indicator for identifying publications in research fields which are influential over longer periods. In other words, publications (cited references) can be identified which belong to the 10% most-referenced publications in many citing years. In this study, we use a new variant of the indicator to identify publications which belong to the 1‰ (0.1%) most-referenced publications in all citing years between 1980 and 2017 in 205 subject categories (the indicator is named N_TOP0_1+). By focusing on the top-‰, we have identified the exceptionally useful published research in the subject categories between 1980 and 2017. In this paper, the procedure is explained how the publications have been identified. The results for three subject categories are explained in this paper in more detail; the results for all subject categories can be inspected online at http://crexplorer.net.

Methods

Datasets used

We used the Web of Science (WoS, Clarivate Analytics) custom data of the Max Planck Society's in-house database derived from the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), and Arts and Humanities Citation Index (AHCI) produced by Clarivate Analytics (Philadelphia, USA). All records for the papers of the document type "article" published between 1980 and 2017 were exported separately for each WoS subject category (WoSSC). The WoSSCs were ordered by their number of publications from CQ ("Biochemistry & Molecular Biology") with 1,455,479 articles to 9a ("Green & Sustainable Science & Technology") with 3,169 articles (see Leydesdorff, 2006). We required a ratio of linked vs. cited references of at least 0.30 for a WoSSC to be included. The reason is that only WoSSCs with sufficient references covered by the WoS should be considered in the analyses. In total, 205 WoSSCs were considered.

[1] Within a set of publications, the number of references ("cited references") and the number of citations (obtained by the publications) is identical – provided that all cited references can be matched with the publications in the set.

Indicator used

We are interested in those cited references which have been cited disproportionally more frequently in the citing years than other cited references in the dataset. To this end, for each cited reference we count the number of citing years where the cited reference was cited extraordinarily frequently.

For each citing year, all *n* cited references have been sorted in descending order based on their citation counts in the citing year. We then identified the citation count *c* of the cited reference at rank (1+*n*/1000), i.e., the cited reference that follows the first (top) 0.1% cited references. For example, for *n*=10.000 cited references we determined the number of citations of the cited reference at rank #11. All cited references with a citation count greater than *c* are then considered as "top-cited reference" in the citing year if their citation count is additionally above the average of the expected citation count (see Thor et al., 2018, for details on the sequence computation). The metric N_TOP0_1+ is the number of citing years where the cited reference is a "top-cited reference".

The total number of papers and the citation rates in the WoSSCs considered here are very different. Consequently, the number of citing years for belonging to the top cited publications is different in the sets (as the results online at http://crexplorer.net demonstrate). This should be considered in the interpretation of the results. It should be taken into consideration additionally that the citing papers are frequently assigned to more than a single WoSSC. Thus, the same highly cited publications (presented online) can occur in different WoSSCs.

CRExplorer script

The following CRExplorer script was used to perform the RPYS and filter for exceptionally highly referenced publications for each of the WoSSCs:

```
set(n_pct_range: 2, median_range: 2)
importFile(file: "xx_wos.txt", type: "WOS",
RPY: [1900, 2015, false], PY: [1980, 2017, false], maxCR: 0)
info()
cluster(threshold: 0.75, volume: true, page: true, DOI: false)
merge()
exportFile(file: "xx_wos.rpys_CR.csv", type: "CSV_CR",
     sort: ["N_TOP0_1_Plus DESC", "N_CR DESC"],
filter: { it.N_TOP0_1_Plus >= 10 } )
```

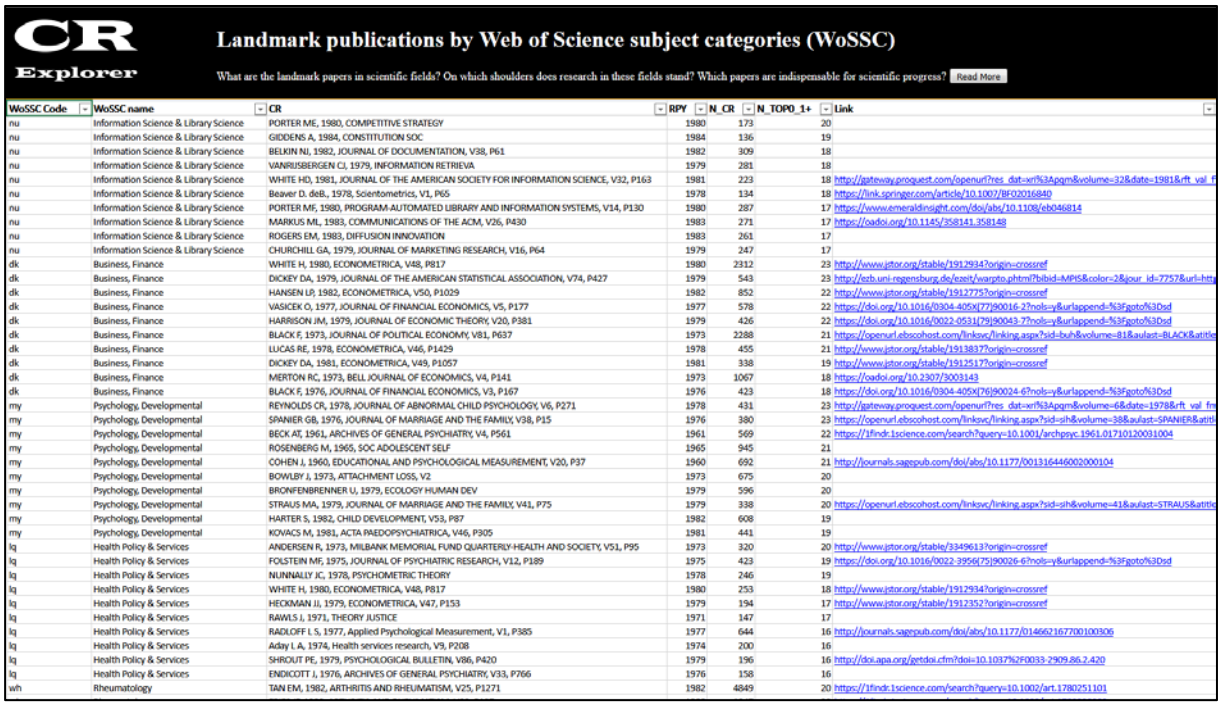
Listing 1: CRExplorer script to perform RPYS and filter for cited references with an indicator value of at least 10 for N_TOP0_1+

Two neighboring years are included in the calculation of the advanced indicators via the set options. Thus, not only the focal years are considered in the calculation, but also neighboring years to increase the case numbers for the analyses. The file name "xx_wos.txt" has to be adjusted for each WoSSC in the importFile function. The PY option ensures that only papers published between 1980 and 2017 are included. The RPY option guarantees that only cited references published between 1900 and 2015 are included. We expect no exceptionally highly referenced papers before 1900. We also expect that cited references published after 2015 did not have enough time to become exceptionally highly referenced during many citing years. The clustering and merging of variants of the same cited reference in the dataset is done with the Levenshtein threshold of 0.75 including volume and page; but not the DOI in the cited references' information (Thor et al., 2016). The file name "xx_wos.rpys_CR.csv" in the exportFile function has to be adjusted for each WoSSC. In addition, this function filters for

cited references with an indicator value of at least 10 (number of citing years where the cited reference is a "top-cited reference") and sorts the results according to the indicator value and the number of cited references before writing the cited references into the csv file. The value of 10 is adjusted to a lower one if cited references in some WoSSCs do not achieve large enough indicator values. For the WoSSCs with many papers and many cited references variants, we needed 382 GB of main memory (RAM).

Results

The identified landmark papers for nearly all WoSSC can be inspected online at http://crexplorer.net (see Figure 1).



CR Explorer

Landmark publications by Web of Science subject categories (WoSSC)

What are the landmark papers in scientific fields? On which shoulders does research in these fields stand? Which papers are indispensable for scientific progress? Read More

WoSSC Code	WoSSC name	CR	RPY	N_CR	N_TOPO_1+	Link
nu	Information Science & Library Science	PORTER ME, 1980, COMPETITIVE STRATEGY	1980	173	20	
nu	Information Science & Library Science	GIDDENS A, 1984, CONSTITUTION SOC	1984	136	19	
nu	Information Science & Library Science	BELKIN NJ, 1982, JOURNAL OF DOCUMENTATION, V38, P61	1982	309	18	
nu	Information Science & Library Science	VANRIJSBERGEN CJ, 1979, INFORMATION RETRIEVA	1979	281	18	
nu	Information Science & Library Science	WHITE HD, 1981, JOURNAL OF THE AMERICAN SOCIETY FOR INFORMATION SCIENCE, V32, P163	1981	223	18	http://gateway.proquest.com/openurl?res_dat=xri%3Apqm&volume=32&date=1981&rft_val_f
nu	Information Science & Library Science	Beaver D. deB., 1978, Scientometrics, V1, P65	1978	134	18	https://link.springer.com/article/10.1007/BF02016840
nu	Information Science & Library Science	PORTER MF, 1980, PROGRAM-AUTOMATED LIBRARY AND INFORMATION SYSTEMS, V14, P130	1980	287	17	https://www.emeraldinsight.com/doi/abs/10.1108/eb046814
nu	Information Science & Library Science	MARKUS ML, 1983, COMMUNICATIONS OF THE ACM, V26, P430	1983	271	17	https://oadoi.org/10.1145/358141.358148
nu	Information Science & Library Science	ROGERS EM, 1983, DIFFUSION INNOVATION	1983	261	17	
nu	Information Science & Library Science	CHURCHILL GA, 1979, JOURNAL OF MARKETING RESEARCH, V16, P64	1979	247	17	
dk	Business, Finance	WHITE H, 1980, ECONOMETRICA, V48, P817	1980	2312	23	http://www.jstor.org/stable/1912934?origin=crossref
dk	Business, Finance	DICKEY DA, 1979, JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION, V74, P427	1979	543	23	http://eeb.uni-regensburg.de/ezeit/warpto.phtml?bibid=MPIS&color=2&jour_id=7757&url=htt
dk	Business, Finance	HANSEN LP, 1982, ECONOMETRICA, V50, P1029	1982	852	22	http://www.jstor.org/stable/1912775?origin=crossref
dk	Business, Finance	VASICEK O, 1977, JOURNAL OF FINANCIAL ECONOMICS, V5, P177	1977	578	22	https://doi.org/10.1016/0304-405X(77)90016-2?nols=y&urlappend=%3Fgoto%3Dsd
dk	Business, Finance	HARRISON JM, 1979, JOURNAL OF ECONOMIC THEORY, V20, P381	1979	426	22	https://doi.org/10.1016/0022-0531(79)90043-7?nols=y&urlappend=%3Fgoto%3Dsd
dk	Business, Finance	BLACK F, 1973, JOURNAL OF POLITICAL ECONOMY, V81, P637	1973	2288	21	https://openurl.ebscohost.com/linksvc/linking.aspx?sid=buh&volume=81&aulast=BLACK&atitle
dk	Business, Finance	LUCAS RE, 1978, ECONOMETRICA, V46, P1429	1978	455	21	http://www.jstor.org/stable/1913837?origin=crossref
dk	Business, Finance	DICKEY DA, 1981, ECONOMETRICA, V49, P1057	1981	338	19	http://www.jstor.org/stable/1912517?origin=crossref
dk	Business, Finance	MERTON RC, 1973, BELL JOURNAL OF ECONOMICS, V4, P141	1973	1067	18	https://oadoi.org/10.2307/3003143
dk	Business, Finance	BLACK F, 1976, JOURNAL OF FINANCIAL ECONOMICS, V3, P167	1976	423	18	https://doi.org/10.1016/0304-405X(76)90024-6?nols=y&urlappend=%3Fgoto%3Dsd
my	Psychology, Developmental	REYNOLDS CR, 1978, JOURNAL OF ABNORMAL CHILD PSYCHOLOGY, V6, P271	1978	431	23	http://gateway.proquest.com/openurl?res_dat=xri%3Apqm&volume=6&date=1978&rft_val_fm
my	Psychology, Developmental	SPANIER GB, 1976, JOURNAL OF MARRIAGE AND THE FAMILY, V38, P15	1976	380	23	https://openurl.ebscohost.com/linksvc/linking.aspx?sid=sih&volume=38&aulast=SPANIER&atitl
my	Psychology, Developmental	BECK AT, 1961, ARCHIVES OF GENERAL PSYCHIATRY, V4, P561	1961	569	22	https://1ffindr.1science.com/search?query=10.1001/archpsyc.1961.01710120031004
my	Psychology, Developmental	ROSENBERG M, 1965, SOC ADOLESCENT SELF	1965	945	21	
my	Psychology, Developmental	COHEN J, 1960, EDUCATIONAL AND PSYCHOLOGICAL MEASUREMENT, V20, P37	1960	692	21	http://journals.sagepub.com/doi/abs/10.1177/001316446002000104
my	Psychology, Developmental	BOWLBY J, 1973, ATTACHMENT LOSS, V2	1973	675	20	
my	Psychology, Developmental	BRONFENBRENNER U, 1979, ECOLOGY HUMAN DEV	1979	596	20	
my	Psychology, Developmental	STRAUS MA, 1979, JOURNAL OF MARRIAGE AND THE FAMILY, V41, P75	1979	338	20	https://openurl.ebscohost.com/linksvc/linking.aspx?sid=sih&volume=41&aulast=STRAUS&atitle
my	Psychology, Developmental	HARTER S, 1982, CHILD DEVELOPMENT, V53, P87	1982	608	19	
my	Psychology, Developmental	KOVACS M, 1981, ACTA PAEDOPSYCHIATRICA, V46, P305	1981	441	19	
lq	Health Policy & Services	ANDERSEN R, 1973, MILBANK MEMORIAL FUND QUARTERLY-HEALTH AND SOCIETY, V51, P95	1973	320	20	http://www.jstor.org/stable/3349613?origin=crossref
lq	Health Policy & Services	FOLSTEIN MF, 1975, JOURNAL OF PSYCHIATRIC RESEARCH, V12, P189	1975	423	19	https://doi.org/10.1016/0022-3956(75)90026-6?nols=y&urlappend=%3Fgoto%3Dsd
lq	Health Policy & Services	NUNNALLY JC, 1978, PSYCHOMETRIC THEORY	1978	246	19	
lq	Health Policy & Services	WHITE H, 1980, ECONOMETRICA, V48, P817	1980	253	18	http://www.jstor.org/stable/1912934?origin=crossref
lq	Health Policy & Services	HECKMAN JJ, 1979, ECONOMETRICA, V47, P153	1979	194	17	http://www.jstor.org/stable/1912352?origin=crossref
lq	Health Policy & Services	RAWLS J, 1971, THEORY JUSTICE	1971	147	17	
lq	Health Policy & Services	RADLOFF L S, 1977, Applied Psychological Measurement, V1, P385	1977	644	16	http://journals.sagepub.com/doi/abs/10.1177/014662167700100306
lq	Health Policy & Services	Aday L A, 1974, Health services research, V9, P208	1974	200	16	
lq	Health Policy & Services	SHROUT PE, 1979, PSYCHOLOGICAL BULLETIN, V86, P420	1979	196	16	http://doi.apa.org/getdoi.cfm?doi=10.1037%2F0033-2909.86.2.420
lq	Health Policy & Services	ENDICOTT J, 1976, ARCHIVES OF GENERAL PSYCHIATRY, V33, P766	1976	158	16	
wh	Rheumatology	TAN EM, 1982, ARTHRITIS AND RHEUMATISM, V25, P1271	1982	4849	20	https://1ffindr.1science.com/search?query=10.1002/art.1780251101

Figure 1. Online presentation of the landmark papers

In the following we focus exemplarily on three WoSSCs and explain the results in more detail. We selected WoSSCs which we are able to interpret based on our own field-specific expertises. Table 1 shows the results for the WoSSC "Information Science & Library Science". Five cited publications are listed exemplarily with the most citing years in which the publication belongs to the top-‰. Two publications in the table are basic works on information retrieval (Belkin, Oddy, & Brooks, 1982; Van Rijsbergen, 1979). Three of the five publications in the table are not primarily contributions to the library and information science (LIS) field: Michael Porter's (1980) book is one of his contributions to the field of business economics. In later work, Porter (1990) became specifically known for cluster analysis in the follow-up book entitled "The Competitive Advantage of Nations." Anthony Giddens' (1984) book entitled "The Constitution of Society" is the *locus classicus* of Giddens' "structuration theory" in sociology. Both this book and Porter (1980) are well known and intensively used in communications among non-specialists. Both books are theoretical, but oriented towards application (without providing a methodology). White and Griffith (1981) introduced author-co-citation analysis (ACA) in LIS and Science &

Technology Studies. ACA became thereafter a widely used technique. It is primarily a statistical method, but it can also be used in qualitative analysis.

Table 1. Most exceptionally referenced cited references in the WoSSC "Information Science & Library Science".

RPY	CR	N_CR	N_TOP0_1+
1980	Porter, M. E.: *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. Free Press	173	20
1984	Giddens, A.: *The Constitution* of *Society*. Outline of the Theory of Structuration. Polity Press	136	19
1982	*Belkin, N. J.*, Oddy, R. N. and Brooks, H.: ASK for Information Retrieval: Part I. Background and Theory. *Journal of Documentation, 38*(2), *61*-71	309	18
1979	Van Rijsbergen, C.J.: *Information Retrieval*. Unpublished PhD thesis, Department of Computing Science, University of Glasgow	281	18
1981	White, H. D., & Griffith, B. C.: Author Cocitation - a Literature Measure of Intellectual Structure. *Journal of the American Society for Information Science, 32*(3), 163-171	223	18

Notes. RPY=Reference publication year; CR=Cited reference; N_CR=Number of cited references; N_TOP0_1+=Number of citing years in which the publication belongs to the top-‰.

Table 2 shows the results for the WoSSC "Computer Science, Information Systems". The three papers "A Method for obtaining digital Signatures and public-key Cryptosystems" (Rivest, Shamir, & Adleman, 1978), "A public-key Cryptosystem and a Signature Scheme based on discrete Logarithms" (ElGamal, 1985), and "New Directions in Cryptography" (Diffie & Hellman, 2006) describe fundamental algorithms for data encryption and digital signatures. These algorithms are important for secure (i.e., encrypted) data transmission over the Internet. The idea of an asymmetric cryptosystem based on public and private keys (that can be exchanged securely) is used in current software such as PGP. Rivest et al. (1978) also received the ACM Turing award (the "Nobel prize for computer science") for their work. The book by Garey and Johnson (1979) "Computers and Intractability: a Guide to the Theory of NP-Completeness" gives an introduction to computational complexity, a fundamental concept in theoretical computer science. The book is well-known for its extensive list of NP-complete problems, i.e., problems where an efficient solution (i.e., in polynomial time) does not yet exist. Especially in the era of big data, efficient software algorithms (besides large clusters of hardware components) are a cornerstone of many web applications. "The Theory of error-correcting Codes" (MacWilliams & Sloane, 1977) is an influencing book on information theory and coding theory. It describes approaches for the reliable transmission of data over unreliable communication channels, e.g., when multiple mobile phones interfere with each other on the same WiFi network.

Table 2. Most exceptionally referenced cited references in the WoSSC "Computer Science, Information Systems".

RPY	CR	N_CR	N_TOP0_1+
1978	Rivest, R. L., Shamir, A., & Adleman, L. (1978). A Method for obtaining digital Signatures and public-key Cryptosystems. *J Commun. ACM, 21*(2), 120-126	862	21
1979	Garey, M. R. & Johnson, D. S. (1979). *Computers and Intractability: A Guide to the Theory of NP-completeness.* W. H. Freeman	1137	19
1977	MacWilliams, F. J., & Sloane, N. J. A. (1977). *The Theory of error Correcting Codes.* North-Holland Publishing Company	689	19
1985	ElGamal, T. (1985). *A public key Cryptosystem and a Signature Scheme Based on discrete Logarithms.* Paper presented at the Workshop on the Theory and Application of Cryptographic Techniques, Berlin, Heidelberg	503	19
1976	Diffie, W., & Hellman, M. (2006). New Directions in Cryptography *J IEEE Trans. Inf. Theor, 22*(6), 644-654	878	18

Notes. RPY=Reference publication year; CR=Cited reference; N_CR=Number of cited references; N_TOP0_1+=Number of citing years in which the publication belongs to the top-‰.

The results for the WoSSC "Computer Science, Software Engineering" are reported in Table 3. The first two cited references are the in area of theoretical computer science. The book by Garey and Johnson (1979) has already been described since it also appears in the top list of "Computer Science, Information Systems". The paper "Maintaining Knowledge about temporal Intervals" (Allen, 1983) introduces a calculus for temporal reasoning. This is important for software or robots using artificial intelligence where the concept of time (i.e., when things happen) is important. The two papers "Recursively generated B-spline Surfaces on arbitrary topological Meshes" (Catmull & Clark, 1978) and "Theory of Edge Detection" (Marr, Hildreth, & Brenner, 1980) are in the area of computer graphics. The technique of B-spline surfaces is used in computer graphics to create smooth surfaces. This is, for example, important in 3D video games to generate realistically looking objects. Edge detection is a core task in processing digital images to detect and extract features (e.g., objects) in digital images. This is particularly important in computed tomography technique (CT) to detect objects of interest, e.g., arteries. Weiser (1984) introduced the concept of "Program slicing", a method for automatically decomposing programs into so-called slices. The decomposition can be used for efficient finding of errors (debugging) but also for software maintenance and optimization. Though the concept has been significantly extended over the years, it is still a fundamental concept in professional software engineering.

Table 3. Most exceptionally referenced cited references in the WoSSC "Computer Science, Software Engineering".

RPY	CR	N_CR	N_TOP0_1+
1979	Garey, M. R. & Johnson, D. S. (1979). *Computers and Intractability: A Guide to the Theory of NP-completeness.* W. H. Freeman	867	19
1983	Allen, J. F. (1983). Maintaining knowledge about temporal Intervals. *J Commun. ACM, 26*(11), 832-843	231	19
1978	Catmull, E., & Clark, J. (1978). Recursively generated B-spline Surfaces on arbitrary topological Meshes. *Computer-Aided Design, 10*(6), 350-355	364	18
1980	Marr, D., Hildreth, E., & Brenner, S. (1980). Theory of Edge Detection. *207*(1167), 187-217	206	18
1984	Weiser, M. (1984). Program slicing. *IEEE Transactions on Software Engineering, SE-10*(4), 439-449	351	17

Notes. RPY=Reference publication year; CR=Cited reference; N_CR=Number of cited references; N_TOP0_1+=Number of citing years in which the publication belongs to the top-‰.

Discussion

What are the landmark papers in scientific fields? Which papers would be indispensable for scientific progress? These are typical questions which are not only of interest for researchers (who frequently know the answers – or are supposed to know them), but also for the general public (e.g., science journalists). Citation counts are often used to identify very useful papers, since they reflect the wisdom of the crowd; in this case, the many scientists citing the published results in their own papers. The problem with today's research evaluation processes is, however, that they focus on rather recent years (the last few years) to assess the recent developments. This focus might be able to identify research at the research front which is short-term oriented, but neglect research which appears successful in the long run. Extreme representatives of delayed recognition are so-called "sleeping beauties" which are not or scarcely cited during many years, but are heavily cited after a decade or so. These papers become useful only many years after the research has been finished.

In this study, we identified landmark publications in 205 WoSSCs with recently developed methods for the program CRExplorer. These are publications which belong more frequently than other publications to the top-‰ in their subject category across the citing years. In this paper, the results for the three WoSSCs "Information Science & Library Science", "Computer Science, Information Systems", and "Computer Science, Software Engineering" have been discussed in more detail. The results for nearly all WoSSCs can be found online (see http://crexplorer.net). It was only possible with a very powerful computer to generate the results for very large WoSSCs in our dataset. Since most users of the CRExplorer do not have these computers for undertaking cited references analyses, we deem it useful for researchers in various fields, science administrators, science journalists, and other people from the general public to have access to these landmark papers' lists.

The identification of very useful research based on citations (or cited references) is based on the premise that citations measure usefulness. Recent research suggests that citations reflect

"usefulness" which supports the use of citations in science studies and evaluation practices (Wang, 2014). However, citations are not able to reflect all influences which were useful for extraordinary research (the later landmark papers). It is especially relevant for extraordinary research to be influenced by many channels to receive this specific status (MacRoberts & MacRoberts, 2017). Another problem is the incompleteness of many reference lists: "No one who has read J. D. Watson's (1968) personal account of the discovery of the structure of DNA can ever accept that the six references listed at the end of the famous Watson and Crick 1953 paper in *Nature* reflect the influence on their discovery … It is also clear from all accounts that, by 1952, it was the informal level of communication that was important. It was what the scientists were doing on the moving edge of research/speculation that was important to Watson and Crick, and they made every effort to get that information. Clearly, the Watson and Crick paper, similar to all scientific papers, is a 'misrepresentation' of what scientists actually do" (MacRoberts & MacRoberts, 2017, p. 475).

Our generated lists should only be used as hints to possible landmark publications. Users of the lists should be experts in the fields (or should consult experts) who can compare the results with their own reception of landmark papers. For example, in the "Information Science & Library Science" field, the results seem counter-intuitive (against the backdrop of our expert knowledge). One would not expect Porter (1980) and Giddens (1984) to head the ranks. However, one should consider in the interpretation of the results presented in this paper and online at http://crexplorer.net that only up to ten classic papers are presented and many others follow which are (somewhat) lower ranked. The user of our lists should be aware of the fact that the quality of specific publications is not necessarily reflected in high citation counts (Marx & Bornmann, 2010).

Acknowledgments

The bibliometric data used in this paper are from the Max Planck Society's in-house database. The database is developed and maintained in cooperation with the Max Planck Digital Library (MPDL, Munich). It is derived from the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI) prepared by Clarivate Analytics, formerly the IP & Science business of Thomson Reuters (Philadelphia, Pennsylvania, USA).

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