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Introduction

Why devote an *ARIST* chapter to scholarly communication and bibliometrics, and why now? Bibliometrics already is a frequently covered *ARIST* topic, with chapters such as that by White and McCain (1989) on bibliometrics generally, White and McCain (1997) on visualization of literatures, Wilson and Hood (in press) on informetric laws, and Tabah (in press) on literature dynamics. Similarly, scholarly communication has been addressed in other *ARIST* chapters such as Bishop and Star (1996) on social informatics and digital libraries, Schamber (1994) on relevance and information behavior, and many earlier chapters on information needs and uses. More than a decade ago, the first author addressed the intersection of scholarly communication and bibliometrics with a journal special issue and an edited book (Borgman, 1990; Borgman & Paisley, 1989), and she recently examined interim developments (Borgman, 2000a, c). This review covers the decade (1990-2000) since the comprehensive 1990 volume, citing earlier works only when necessary to explain the foundation for recent developments.

Given the amount of attention these topics have received, what's new and exciting enough to warrant a full chapter in 2001? What is new is that electronic scholarly communication is reaching critical mass, and we are witnessing qualitative and quantitative changes in the ways that scholars communicate with each other for informal conversations, for collaborating locally and over distances, for publishing and disseminating their work, and for constructing links between their work and that of others. Most readers of this chapter will be scholars and students who conduct research, write papers, submit their work to journals, conferences, and book publishers, search for new information resources, and read the work of other scholars. We expect that most readers conduct substantial portions of their scholarly activities online. Many will have their own web sites where they post their work, and many will circulate their work to colleagues in electronic form, whether through direct distribution or through online pre-print servers. The cycle of scholarly activities is blending into a continuous, looping flow, as people discuss, write, share, and seek information through networked information systems.

In technological terms, scholarly communication is being transformed through the use of personal and portable computers, electronic mail, word processing software, electronic publishing, digital libraries, the Internet, the World-Wide Web, mobile phones, wireless networks, and other information technologies. But how much has human behavior really changed? How much has the infrastructure for scholarly communication changed? Are we witnessing a revolution in scholarly communication, or an evolution? Or a co-evolution of technology and behavior? (Bishop & Star, 1996; Borgman, 2000b; Kling & McKim, 1999). And how do we determine what kinds of change are occurring?

Bibliometrics offers a powerful set of methods and measures for studying the structure and process of scholarly communication. Citation analysis, the best known of bibliometric approaches, has become more sophisticated, and the advent of networked information technologies has led to quantitative and qualitative advances in other bibliometric methods. More content is available online in digital libraries, and more of it is in full text (and in other media including still and moving images, sound, and numeric data). More connections exist between documents, both in the form of citations and in the form of active hyperlinks that allow an information seeker to move between related documents (Cronin, Snyder, Rosenbaum, Martinson, & Callahan, 1998; Harnad & Carr, 2000; Lynch, 1998). Bibliometrics is being applied in new ways, to ask new questions. Co-citation measures designed to identify relationships between print publications are being applied to frame the intellectual space of the World-Wide Web (Larson, 1996). Similarly, impact factors, which were developed to assess the influence of a journal, an author, a laboratory, a university, or a country, are being applied to assess the influence of web sites (Almind & Ingwersen, 1997; Ingwersen, 1998; Smith, 1999). In addition to bibliometrics, scientometrics, and informetrics, we now have "cybermetrics" (the title of an electronic journal) and "webometrics" (Almind & Ingwersen, 1997). Citations are complemented by "sitations" (McKiernan, 1996; Rousseau, 1997).

Bibliometrics is now an accepted method in the sociology of science (J. R. Cole, 2000; Cronin & Atkins, 2000; Merton, 2000), especially by scholars whose inquiries are well-served by quantitative

methods and structural approaches. Others prefer more qualitative methods and more interpretive or constructivist approaches to the study of scholarly communication (Diamond, 2000). Bibliometrics has gained popularity due to its complementarity to econometrics, social network analysis, and other quantitative approaches to modeling behavior. Concerns such as the nature of "trust" have moved from sociology to electronic commerce, and may be modeled through bibliometrics (Davenport & Cronin, 2000). Documents are no longer viewed simply as stable artifacts of communication. Rather, documents can be malleable, mutable, and mobile (Bishop & Star, 1996), and can have a "social life" (Brown & Duguid, 1995, 2000). New genres of documents are emerging to take advantage of the special capabilities of electronic forms. Electronic publishing, while expanding rapidly, still consists of a wide range of unstable forms and genres (Kling & McKim, 1999; Schauder, 1994). As electronic publishing evolves, and perhaps stabilizes, we can employ bibliometrics to observe patterns and trends as they emerge. Bibliometrics can be applied to a broader array of behaviors and to a broader array of content than in the past, and thus more sophisticated methods and measures are required (Paisley, 1990). Indeed, a generation of scholars schooled in bibliometrics is developing innovative new methods to explore new research questions, and scholars schooled in other areas are contributing new methods and new questions. In sum, this is an ideal time to devote an *ARIST* chapter to scholarly communication and bibliometrics, and to draw yet more researchers' attention to fertile territory that is ripe for exploration.

Scope

The communicative activity of scholarly authors

Our use of the term "scholarly communication" in the title of this chapter is intended to signal that our primary interest is in the communicative activity of scholars. In other words, we are deliberately limiting ourselves to consideration (a) of a particular group of people, and (b) of a particular kind of goal-oriented activity. We also propose to take "scholars," in this context, strictly to refer to people directly engaged in the creation of original scholarly works — in other words, authors. Clearly, there are several other groups of people who may be characterized not only by their common engagement in scholarship but also by their shared propensity for communicative activity — groups such as peer reviewers, editors, indexers, information-seekers, and readers. It may further be argued that the fundamental activity common to all these groups is the making of *relevance judgments* — i.e., the making of assessments of, or decisions about, the extent to which particular documents are relevant, in particular situations, to the judge. Even once the limitation to authors is made, we may still distinguish between the various kinds of communication behavior exhibited by authors in their various capacities (a) as *writers* (i.e., choosers of occasions for writing; of genres to write in; of subjects, themes, and arguments to write about; and of sentences and words to write); (b) as *linkers* (choosers of documents to cite, acknowledge, or otherwise point, link, or refer to); (c) as *submitters* (choosers of journals or other sources to submit papers to); (d) as *collaborators* (choosers of co-authors to work with, or institutions to affiliate with); and so on.

Bibliometric methods

Our second primary area of interest in this chapter is the bibliometric methods that may be used in the study of scholarly communication. One general method by which communicative activity may be explained, interpreted, or otherwise understood, is to consider the objects, agents, events, products, and contexts of such activity as entities to be counted, measured, or quantified. Numerical data may be collected about samples drawn from general populations of such entities; these data may be analyzed using statistical techniques; and conclusions drawn about the nature of the populations, and about the existence of certain causal processes. Of course, quantitative methods such as these are applied in many different disciplines, and in many cases the development and application of domain-specific quantitative

methods has become a field of study in its own right: allied to psychology, for instance, we have psychometrics; economics has econometrics; biology, biometrics; sociology, sociometrics; and so on. Analogously, the field whose concern is with the measurement specifically of properties of *documents*, and of document-related processes, is known as bibliometrics[1] (from the Greek *biblion*, "book").

In bibliometrics, as in the other fields mentioned, the derived measures or metrics are typically counts of the frequencies with which events of specified types are observed to occur, which (once expressed as ratios of the total number of observed events) may be considered as probabilities of occurrence. The probability distributions that are thus formed are known as the bibliometric distributions, and these form the basis of certain bibliometric "laws;" examples are the well-known Bradford, Lotka, and Zipf distributions, of journals, authors, and words, respectively. Many of these distributions may be distinguished from other common empirical distributions (such as the uniform and normal distributions) by an asymmetric skew and a long tail. Distributions of a similar nature have been observed in other fields (sociometrics, for instance) where the objects of interest are not documents, but other products of human activity. Much historical and current research is concerned with (a) collecting data from ever larger and more representative samples in order more accurately to determine the parameters of the distributions from which the samples are drawn; (b) identification of commonalities among observed distributions (and, potentially, reduction to one or more general formulae of which individual distributions are special cases); and (c) hypothesizing as to the cause of such regularity, given the voluntary nature of the human actions that are being observed.[2] Egghe and Rousseau (1990) provide a textbook of informetric methods; Diodato (1994) offers a dictionary of bibliometric terminology, and readers looking for authoritative definitions and discussion of the bibliometric distributions are directed to these sources.

A typology of research studies

The focus of this chapter, then, is the knowledge of scholarly communicative behavior that bibliometric methods can provide. One of our primary purposes is to review the findings of those studies that use bibliometric methods in order to describe, explain, predict, and evaluate the communication behavior of scholars. Yet we may make a distinction between, on the one hand, *studies that use* bibliometric methods, and on the other, *studies of the use of* bibliometric methods. In effect, we have two (intricately interrelated) central topics: (a) the nature of scholars' communicative behavior (as explored bibliometrically); and (b) the theoretical basis for, design of, and evaluation of, bibliometric methods (as applied in efforts to improve our understanding of scholarly communication behavior). Somewhat arbitrarily, we might label studies that lean toward either side of this distinction as "behavioral" and "methodological" studies, respectively, although in practice studies vary in the relative extents to which they represent advances either in our understanding of behavior or our understanding of method.

The distinctions we have already made are summarized, along with a few others, in Table 1, which offers a 7-facet scheme for the classification of studies of the kind reviewed in this chapter. Facet A expresses the distinction between writing, linking, submission, and collaboration, as communicative activities to be examined; Facet B embodies the dichotomy of behavioral and methodological studies. As indicated in the Table, other significant variables are (Facet D) the level of *aggregation* at which behavior is being observed (person, group, domain, nation), and (Facet E) the extent to which *comparison* is made (across people, groups, domains, nations, or methods). We have organized the present chapter along the broad lines of Facet A, reviewing both behavioral and methodological studies under each heading of "Linking," "Writing," "Submission," and "Collaboration." By dint, no doubt, of the special complexities

[1] Other related terms are "informetrics," "scientometrics," and "librametrics." All these may be distinguished by subtle shades of meaning; the interested reader is referred to Sengupta (1992) and Tague-Sutcliffe (1992) for clarifications.

[2] As indicated above, Wilson and Hood (in press) have recently covered this ground in their *ARIST* chapter on the informetric laws, and we do not intend to go further here.

and challenges it presents, however, the largest quantity of work continues to be done in the analysis of linking activity, and we have divided the section on "Linking" into sub-sections accordingly.

[TABLE 1 ABOUT HERE]

Linking or citing?

The terms "link" and "linking" are commonly associated, in the scholarly, professional, and popular literatures alike, with hypertext in general, and the World-Wide Web in particular. Historically, bibliometricians interested in the explicit expressions of connections between documents have preferred to talk about "citations" and "citing." These latter terms, and the area of study known as "citation analysis," have come to be used in a somewhat narrower sense, in which (a) the documents being linked are typically scholarly papers published in academic journals; (b) the principal mode of distribution of the documents is in hard-copy format; (c) the links take the form of bibliographic references collected in lists at the end of citing documents; and (d) the links are identified by the authors of the citing documents. It is only relatively recently, with the emergence of Web-accessible databases of full-text scholarly papers whose citations are instantly navigable by readers, that researchers have begun in earnest to apply the well-established methods of citation analysis to the electronic environment. Given the prior and pervasive usage of "links" and "linking," we prefer to retain the distinction between citation analysis (in the narrower sense described above) and *link analysis* defined in a broader sense — to encompass all quantitative techniques in which inter-document connections are classified and counted with a view to the description, explanation, prediction, and evaluation of document-related phenomena. Our intention is to highlight the potential of using bibliometric techniques, not just in their traditional domains of application (i.e., networks of printed journal papers), but in the new digital environments that have developed over the last decade.

The methods of link analysis, then, are those employed in studies in which data are collected primarily in the form of counts of *links* — pointers to, references to, or citations of "target," "cited," or "later"[3] documents made in the text of "origin," "source," "citing" or "earlier" documents. There are two general purposes for which link analyses may be conducted: contextualization and evaluation. In the following sections, we consider what we will from now on call *relational link analysis* and *evaluative link analysis* in turn[4]. A simple distinction may also be drawn between (a) relational and evaluative studies, in which quantitative link analysis is employed as a method for describing, evaluating, explaining, or predicting some aspect of human behavior other than the act of linking, and (b) studies in which the act of citing is itself the phenomenon to be understood (and which may not, strictly speaking, involve link analysis as defined above) (Snyder, Cronin, & Davenport, 1995). In a third section, we discuss studies of this latter type in which the *theoretical and methodological foundations* of link analysis are examined.

Relational link analysis

Relational link analysis is a means to set links in context. In relational studies, link counts are used as indicators of the level of connectedness, the strength of relationship, or the direction of flow, *between* documents, people, journals, groups, organizations, domains, or nations. Relational citation analysis is used to answer research questions of the type, Who is *related to* whom? On the basis of scores derived from link counts, we may produce maps, graphs or networks of individuals positioned in a way that demonstrates their relatedness to one another. Such maps may then be used (a) to inform descriptions

[3] The distinction between "later" and "earlier" documents is one that may only be made in the context of networks of printed papers, each of which exists in only one permanent version.

[4] The more obvious label — contextual link analysis — is unfortunately one that could lead to confusion with the particular technique of "citation context analysis" discussed in our section on theoretical and methodological citation studies.

and explanations of the historical and contemporary structure and direction of communication in particular organizations, domains, or geographical areas, and to assist in the making of inductive predictions of future trends, and (b) in information retrieval (IR) systems, to assist information seekers in identifying probably relevant documents (i.e., those 'nearest' or most closely related to an initial query).

The first of these applications — visualization of literatures — was recently the subject of a comprehensive review in *ARIST* (White & McCain, 1997), and we do not intend to retread that ground here. Similarly, we have decided to reserve an overview of the second application — IR — for a separate occasion, since the design and evaluation of IR systems is typically considered as a field of inquiry distinct from that of scholarly communication. Note should perhaps be made, however, of a few studies (White & McCain, 1998; Chen & Carr, 1999; Ding, Chowdhury, & Foo, 1999; Small, 1999; White, 2000), published after White and McCain's review, that may serve as recent exemplars of work in co-citation analysis.

Evaluative link analysis

The more controversial of the purposes of link analysis is that of evaluation. In *evaluative link analysis*, link counts are used as indicators or measurements of the level of quality, importance, influence, or performance, of individual documents, people, journals, groups, domains (subject areas, fields, or disciplines), or nations. Evaluative link analysis is used to answer research questions of the type, Whose research or influence is *better*, or has greater impact, than whose? Ranked lists can be produced on the basis of scores derived from link counts, thus allowing direct comparison of the performance of one individual (or group) with that of another. Such rankings may then be used to inform decisions made, and policies formulated, about the distribution of resources and rewards such as funding, prizes, tenure, or purchase agreements.

The classic overview of this subfield was provided by Narin (1976); Van Raan (1988) and Kostoff (1997) each have compiled useful handbooks; Garfield and Welljams-Dorof (1992a) make a succinct presentation of the ISI-sponsored viewpoint; several reviews have appeared more recently in the journal *Scientometrics* (Kostoff, 1996; Narin & Hamilton, 1996; Van Raan, 1997); and Van Raan (2000) summarizes the latest developments. An historical account of the development of evaluative bibliometrics in the USA is given by Narin, Hamilton, and Olivastro, (2000). In the period under consideration in the present review (1990-2000), hundreds of published papers have reported evaluative citation analyses. It is not our intention to provide a comprehensive review of this work, as interest in most of these studies is limited to those working in the particular scholarly or professional communities whose artifacts are evaluated. For the sake of example, we make reference to a few evaluations that have been published in the core journals of library and information science (LIS); otherwise, our primary concern is with developments in method and measurement. In the next subsection, we describe a few of the more common measures. In the subsections following, we consider evaluations of documents, people, journals, groups, and nations, in turn.

Measures of evaluation

The fundamental measure used in most evaluative studies is *citedness* — the number of times an individual *x* is cited, or the frequency of occurrence of citations whose target is *x*. A value for *citedness rate* (a.k.a. *normalized citedness* or *mean citedness*) may be calculated by dividing total citedness either by the number of years over which citation activity is observed, or by the number of years over which citation activity was possible (e.g., since a cited document's date of publication, or a cited author's date of entry to the field).

Since the late-1990s, and specifically with the application of citation-analytic techniques in second-generation Web search engines such as Google[5], interest in measures of greater sophistication

[5] http://www.google.com/

than raw citedness has resurfaced. In their original paper on the workings of Google, Brin and Page (1998) describe their PageRank formula for ranking individual Web pages on the basis not only of (a) the number of "citations" each page receives (i.e., the number of Web pages linking to the "cited" page), but also of (b) the PageRank of "citing" pages, and (c) the total number of "citations" (outgoing links) made in each "citing" page. In effect, the pages with the highest PageRanks are the ones that are most highly cited by those other pages that have high in-degree (many incoming links) but low out-degree (few outgoing links). Given an adjacency matrix in which the structure of the Web is represented by binary values indicating the presence or absence of a link between each pair of documents, the set of PageRanks corresponds to the principal eigenvector of the matrix when normalized by link-totals. Brin and Page claim (p. 110) that, using an algorithm for calculating eigenvectors that is a standard procedure in linear algebra, "a PageRank for 26 million Web pages can be computed in a few hours on a medium-size workstation."

Kleinberg (1999) introduces a related idea that is currently implemented in IBM's experimental search engine, Clever (Chakrabarti et al., 1999). Kleinberg describes an iterative algorithm, similarly based on the derivation of principal eigenvectors from adjacency matrices, that assigns weights of *two* kinds to individual Web pages on the following reciprocal basis: if a given page "cites" many pages with high *authority*-weights, its *hub*-weight should be high; if a given page is "cited" by many pages with high *hub*-weights, its *authority*-weight should be high. The result is the identification of good hubs — pages that provide collections of links to many good authorities — as well as good authorities — pages that are pointed to by many good hubs and that are thus good candidates for the "best" (most probably relevant) sources of information about the topic of a given query.

The success of systems such as Google and Clever is reflected in the extent to which research in Web-based IR is currently dominated by attempts to implement link-analytic techniques at ever-increasing levels of sophistication. It should be recognized (in a manner that Brin and Page, for example, do not) that bibliometricians working on conventional citation analysis have, in their efforts to replace reliance on crude citation counts, produced similar formulations at earlier dates (see, for example, Pinski and Narin (1976)) — and, moreover, that these echo the measures of relative "standing" of individuals in social networks first examined in the 1950s and 60s (Kleinberg, 1999). Doreian (1994) describes an iterative algorithm for calculating values for a measure of standing of documents in citation networks that predates current concerns with Web IR; but it remains the case that work of this kind has had little influence on the methods used in "traditional" citation-based evaluations of scholars and their products.

Evaluation of documents

One simple kind of evaluative study is that which analyzes the counts of citations received by individual documents. In the first in a series of papers published in *Current Contents* in which he identifies and ranks the "most-cited papers of all time," Garfield (1990) lists those articles that attracted most citations from citing papers indexed by *Science Citation Index* in the period 1945-88. About 175 million citations were analyzed; 33 million cited items were distinguished and ranked in order of the total number of citations received in the 44-year period; and the "citation classics" appearing at the top of this ranking were listed. The paper ranked at number one, published in the *Journal of Biological Chemistry* in 1951 and describing a method of protein determination, had received the remarkable number of 187,652 citations, for a mean of 4,938 citations per year since publication. This method of evaluating documents may also be used to identify "hot" (newly published and already highly cited) papers, and thus the "hot" research areas that provide their subject matter, by limiting both publication and citation "windows" to short, most-recent periods.

In the LIS domain, Brooks (2000) reports on a citation analysis of the 28 papers that have won the annual "Best *JASIS* Paper Award" for "the outstanding paper published in the *Journal of the American Society for Information Science*" in each year between 1969 and 1996. Counts of citations received by these papers were compared with counts for a sample of other (non-award-winning) *JASIS* papers, and the award-winners were found to be cited at a significantly higher rate, supplying some evidence of a

correlation between citation counts and peers' judgments of quality (echoing earlier correlative studies such as those reported in Bayer and Folger (1966) and Cole and Cole (1967)). It remains unclear, however, to what extent award-winners have been cited on their own merits, without the citing author's knowledge of their "best paper" status.

Evaluation of people

ISI regularly publishes lists, not just of most-cited papers, but of most-cited authors. Such lists have been used since the 1960s to forecast, with a fair degree of success, future Nobel prize winners (see, for example, Garfield and Welljams-Dorof (1992b)).

In the LIS domain, two articles published in *Library Quarterly* (Budd & Seavey, 1996; Budd, 2000) have extended a series of papers reporting evaluations of the scholarly productivity of U.S. faculty. Taking ISI's *Social Sciences Citation Index* as their source of data, the investigators produced lists both of individuals and of LIS programs, ranked both by productivity (number of publications authored) and citedness (number of citations received) in specified time periods (1981-92 and 1993-98, respectively). Normalized rankings of programs were produced by dividing the total score for each program by the number of faculty in that program; a composite ranking of programs was also derived by assigning scores corresponding to positions achieved in the separate productivity and citedness rankings; and this composite ranking was directly compared with that produced by the magazine *US News & World Report*, which is based not on publication nor citation counts, but on a survey of the opinions of faculty. No attempt was made, however, to combine productivity and citedness scores in a single measure of the performance of individuals in a manner such as that suggested by Sen, Pandalai, and Karanjai (1998).

In two smaller-scale studies, Bradley, Willett, and Wood (1992) and Cronin and Overfelt (1994a) have conducted citation analyses of faculty at the Department of Information Studies of the University of Sheffield and the School of Library and Information Science of Indiana University, respectively. The designers of studies such as these typically find themselves grappling with four questions, inter alia, that bear on methodological issues:

1. How should credit be allocated in the case of multi-authored works?
2. How should citedness scores be normalized to take into account the varying time-in-field of individual faculty?
3. Should author self-citations be included in citation counts, or should only "residual" (non-self-citing) citations be considered?
4. How may productivity (number of publications authored) and citedness scores be combined in order to produce a single measure of the performance of individuals?

With respect to the first of these issues, Harsanyi (1993) provides a comprehensive review both of numerous different aspects of the problem and of potential solutions. Following MacRoberts and MacRoberts (1987), Cronin and Overfelt (1994a) identify three different approaches: (a) "straight" counting, by which only the first author of an article receives credit for it; (b) "whole" counting, in which every author of an article receives credit for it; and (c) "adjusted" counting, in which each co-author receives a fractional count. The straight counting approach seems to re-introduce the "first-author problem" for which the print and CD-ROM versions of ISI's citation indexes used to be criticized; in these versions of the indexes, cited items were listed under first authors only. Burrell and Rousseau (1995) further elucidate the implications of fractional counting; Egghe, Rousseau, and Van Hooydonk (2000) describe three more complex methods of accrediting publications to authors that were not considered by Cronin and Overfelt.

Cronin and Overfelt found that rankings of faculty at Indiana were subject to significant change when decisions on the first two of these issues are varied. Referring to a general trend toward collaboration and co-authorship, they surmise that, since junior faculty are more likely than their senior colleagues to be co-authors, "straight" counting underrepresents their impact. They conclude that adjusted counting is an "attractive" means of correcting for this distortion, and that normalized counting based on time-in-field is also more "equitable." Nevertheless, there seems to be little consensus in the literature as

to how each of the four issues listed above should be dealt with; no standardized framework for the citation-based evaluation of individuals yet exists.

In a series of "influmetric" studies (see, for example, Cronin (1991), Cronin, McKenzie, and Stiffler (1992), Cronin, McKenzie, and Rubio (1993), and Cronin and Overfelt (1994a)) culminating in a monographic treatment (Cronin, 1995), Cronin and his co-workers have developed the notion that the published *acknowledgements* made by scholarly authors of the contributions of others may be similarly, perhaps even more directly, regarded as indicators of the extent of influence or impact of the acknowledged on the acknowledger. Cronin was able to employ bibliometric methods in analyzing counts of instances of acknowledgement in order to develop a typology of acknowledgements, to identify highly acknowledged authors in various disciplines, to characterize the frequency distributions of acknowledgements, and to describe acknowledgers' behavior. Future attempts to use acknowledgement statistics as an evaluative tool may be hamstrung, however, by the labor-intensive nature of the manual data-gathering that is involved.

Evaluation of journals

Counts of citations received by the articles published in specific journals can be used to rank journal titles. Harter (1998), for instance, uses citation counts to compare the impact of eight well-established electronic journals with that of competing titles which appear only in print form. Since 1976, ISI has published in its annual *Journal Citation Reports* lists of journals, classified by subject area, and ranked according to their "impact factor" (IF) (Garfield, 1973). ISI calculates values for a journal's IF by dividing (a) the number of citations received in the current year by papers published in the journal in the previous two years, by (b) the number of papers published in the journal in the previous two years. In effect, the IF is a measure of the number of citations received in a given year by the "average" paper in a given journal. Many other citation-based methods of ranking journals have been suggested in the literature. Nisonger (1999) reviews these in the context of a comprehensive overview of evaluations of *JASIS* in published analyses of LIS journals.

Van Leeuwen, Moed, and Reedijk (1999) summarize some of the criticisms that have been leveled at ISI's IF: (a) the accuracy of IF values may vary, often as a result of citations being counted in the numerator of the IF formula even though they are to theoretically "uncitable" works (e.g., letters and editorials) that are not counted in the denominator (see also Moed and Van Leeuwen (1995)); (b) a journal's IF may be correlated (positively or negatively) with the proportion of its content that consists of reviews, letters, or notes; (c) other parameters of the distribution of citations received by a journal (e.g., the percentage of articles that are *uncited* in a given year) may provide very different indications of a journal's impact than the mean of that distribution; (d) the two-year citation "window" used in IF calculations may lead to systematic bias against journals in fields (specifically, many in the social sciences and humanities) where the maximum citedness of the average article is obtained more than two years after publication. Rousseau and Van Hooydonk (1996) supply evidence to suggest that a journal's IF may be correlated at an even more basic level simply with the number of papers that the journal publishes; Roy (1983) was one of the first to suggest the possible correlation of impact with number of papers.

Journal IFs are sometimes used, not simply as measures of the competitiveness of the journals themselves, but as convenient surrogates for citation counts for individual papers, especially in the evaluation of the output of individual authors for promotion or tenure decisions. If a given author has published an article in *JASIS*, for instance, it is easier to measure the worth of that particular article by finding *JASIS*'s current IF, than by conducting a search for all citations made to that article. (If the article is a very recently published one, of course, there will in any case be no citations to count.) But the use of journal IFs in this manner has been subject to regular criticism for reasons additional to those commonly invoked in general critiques of citation analysis. Seglen (1992) demonstrates clearly that the typical distribution of citation counts for the articles published in a given journal is not a Gaussian one, with counts distributed "normally" around a mean represented by the journal's IF, but a highly skewed one,

with a few articles receiving much higher numbers of citations that the IF will indicate. Seglen concludes that the IF is thus not representative of individual articles, and should not be treated as such. Seglen (1994) reports on a study in which two groups of authors were compared — one group characterized by citation scores roughly twice the size of the other's, but both publishing in similar sets of journals. Analysis of the citation counts received by papers published in individual journals showed that the ratio between the highly cited and the less-cited groups' citation scores did not vary significantly from journal to journal. Seglen drew the conclusion that the likelihood of being cited does not increase with publication in a journal with a high IF; there is no "citation bonus" to be garnered from publishing in a high-impact journal. It remains to be explained, of course, how some journals have higher IFs than others: Seglen (1997) suggests that much of the variation stems from the nature of the research area that any given journal covers, and from the length or secondary status of articles typically published in a journal (long papers and review articles tend to receive more citations), as well as from the "quality" of the typical submission.

Álvarez and Pulgarín (1998) describe a statistical method based on quantum measurement, a technique derived from item response theory and Rasch probability, that may be used to normalize for the "field effects" highlighted by Seglen and many others. Álvarez and Pulgarín evaluate each single citation in library and information science, for instance, as being "equivalent" (in terms of its "diffusive" power) to 190 citations in biochemistry and molecular biology. Other attempts, more or less arbitrary, to normalize for field effects in the calculation of IFs are described by Sen (1999), Van Leeuwen, Moed, and Reedijk (1999), and Vinkler (2000).

Evaluation of groups and organizations

The performance of individual scholars may be aggregated at the level of groups of various sizes. Research groups, departments, and entire universities and corporations may thus be evaluated in much the same way as that employed (e.g., by Bradley et al. (1992) and Cronin & Overfelt (1994a) — see above) to assess the performance of individuals (Van Raan, 1999; Russell and Rousseau, in press). According to Garfield and Welljams-Dorof (1992a: p. 324), the value of using citation-based institutional rankings as science-and-technology (S&T) indicators is "obvious:" "... university administrators and corporate managers can compare their peers and competitors. Government and private funding sources can monitor the return on their S&T investment. And policymakers can identify relative strengths and weaknesses in strategically important S&T sectors."

Noyons, Moed, and Luwel (1999) describe their comparative evaluation of a Belgian research institute in micro-electronics, in which indicators of its own performance and that of its peer institutions were derived both from counts of citations received by publications written by members of those institutions, and from structural maps created using co-citation and co-word techniques. Vinkler (2000) summarizes the applicability of a range of metrics, varying in degree of sophistication, for evaluating the performance of research teams, differentiating "gross" indicators (e.g., raw counts of citations received) from "specific" indicators (e.g., number of citations per paper or per researcher), "distribution" indicators (e.g., proportion of total citations received by all research teams being compared), and "relative" indicators such as Vinkler's Relative Citation Rate (RCR) — the number of citations received, divided by the sum of the IFs of the journals where the cited papers were published. This last metric is an example of a measure that compares counts of observed citations with estimates of some "expected" citation score, and is similar to the categorical journal impact used by ISI in their "macro" journal studies (see Garfield (1975) for an early example of such a study). Van Hooydonk (1998) examines several alternative formulae of this nature, and Ingwersen, Larsen, and Wormell (2000) conduct a comparison of observed with expected (IF-based) scores in their evaluation of nine Danish research centers.

Evaluation of nations

Moed, DeBruin, and Van Leeuwen (1995) review bibliometric methods of assessing the research performance of entire nations. In his overview of "what citations tell us about Canadian research," Garfield (1993) demonstrates the range of indicators of national productivity that may be derived from citation data. The tables and figures published in this article indicate both recent trends in Canadian science (based on raw citation counts — total numbers of citations to Canadian papers in regularly spaced five-year windows — and on impact factors — average numbers of citations per paper published in these periods) and Canada's relative standing in the world (based on comparisons of these data with those for other nations). (Switzerland heads a listing of the twenty "highest-impact" nations for 1981-1990.) May (1997) and Rousseau and Rousseau (1998) refine methods of ranking countries by the supposed impact of their research output; Egghe et al. (2000) consider some of the technical problems that arise over the attribution of publications written by cross-national collaborators.

The relatively low positions of Germany and France in May's rankings came as a surprise to many. In a provocatively titled piece, Van Leeuwen, Moed, Tijssen, Visser, and Van Raan (2000) respond to May's analysis by discussing "First evidence of serious language-bias in the use of citation analysis for the evaluation of national science systems." Van Leeuwen et al. report their finding that the national impact factors of France and Germany (i.e., the average citedness of articles published by French and German authors in the most recent five-year period) would reach much higher levels if all cited articles written in languages other than English were eliminated from the analysis. This is because the impact factor of the average paper written in English — when calculated from *SCI* data — is higher than that of the average non-English paper. The implication is that this phenomenon, in turn, is a result of the combination of two factors: (a) the general tendency for authors to cite papers written in their own language (see, for example, Yitzhaki (1998)); and (b) the predominance of English-language journals among those that are published, and thus among those whose citing articles are indexed by *SCI*. Van Leeuwen et al. use their finding to criticize *SCI*'s indexing policy, but the "bias" seems to be less a fault of ISI's and more a reflection of the real-life practice of authors, publishers, readers, and citers. What seems to be needed is a more-sophisticated method of normalizing impact-factor scores in order to "correct" for the outcomes of own-language citing behavior.

Theoretical foundations of link analysis

Many studies take the act of linking itself to be the phenomenon to be described, evaluated, explained, or predicted. Studies of this type may conveniently be categorized as theoretical. The purpose of these is justification; i.e., establishing the validity and reliability (or invalidity and unreliability) of conducting link analyses of the kinds described above. Theoretical linking studies seek to answer research questions of the type, *Why* do people link? The idea is that, if we can improve our understanding of the nature and role of links and the act of linking, we can correspondingly improve our understanding of whatever it is that link counts can be used to measure. Any justification of the use of quantitative link analysis in studies of the former type is typically couched — on those occasions where such justification is provided — in terms that derive from evidence supplied by theoretical studies, and in particular by answers to the question "*Why* does author *a* decide to link document *x* to document *y*?" Cronin (1984) provides the classic overview of theories of citation.

In some theoretical studies, the contents, contexts or other characteristics of individual links are examined in order to determine their function, purpose, role, or meaning (such work is often called *citation content analysis* or *citation context analysis* (Small, 1982)); in others, the creators of links (viz., linkers) are observed or questioned in order to determine their motivations, intentions, or goals in linking (these are commonly known as *citer motivation* or *citer behavior* studies). The stated aim of such studies is typically the isolation of those factors, influences, reasons, criteria, or sometimes even "determinants" that lead (or that are perceived to lead) linkers to behave, judge, decide, act, and thus link, in the ways that they do. Liu (1993) provides an overview of citation studies of this kind.

Defenses of evaluative link analysis

Historically, the archetypal contribution of a given theoretical linking study has been a link typology; i.e., a scheme of categories, classes or types of links. Garfield's oft-reproduced list of 15 "major reasons" for citing, first presented in 1965 (Garfield, 1965), is a well-known scheme, but is rather more *prescriptive* of "when to cite" (this phrase is the title of Garfield's paper in *Library Quarterly* of 1996 (Garfield, 1996)) than *descriptive* of the actual motivations of citers in practice. The general prescription is that authors should use the opportunity to cite as a means of "acknowledging intellectual debts;" i.e., to give credit to those whose earlier work is, in one *relevant* way or another, *related* to that of the citer, and thus deserving of credit through citation. In this sense, Garfield's list is one of *criteria* by which the degree of relevance of the relationship between citing and cited work may be determined. The citer acting on the basis of Garfield's criteria would be selflessly serving the goals of scholarship.

That citers do, in practice and in general, act in this way is the primary component of a presumptive argument typically made (or implied) by the proponents of evaluative citation analysis, which runs as follows:

1. that the motivation or goal of the citer is to identify all and only *citation-worthy* works — works that "ought" to be cited in the citing work;
2. that the general result of citers' activities is such that (a) all works that ought to be cited in the citing work indeed are cited, and (b) all works that are cited indeed ought to be cited in the citing work; and
3. that the quality of a given citable work consists in its citation worthiness, and thus may be measured by citation counts.

Such an argument is typical of presentations of so-called "normative" theories of citing (the idea being that citers are, in effect, conditioned to follow the norms of science in general and the norms of citation practice in their chosen fields in particular), and is often associated with the writings of Merton (1973), Garfield (1979), and Price (1986).

Critiques of evaluative link analysis

Defenders of evaluative citation analysis typically point to evidence of the correlation of citation counts with other measures of the quality of documents or their authors, such as publication productivity, peer ratings, and awards of grants and prizes (for two older but continuously well-cited examples of such defenses, see Bayer and Folger (1966) and Cole and Cole (1967)). Yet the plausibility of each part of the normative argument has regularly been denied, and much empirical evidence supporting its falsification has been marshaled by its detractors. Cole (2000) provides an historical synopsis of early resistance to the use of citations for evaluative purposes. Edge (1979) wrote an influential critical review; MacRoberts and MacRoberts began publishing a series of critiques in the mid-1980s (see, for example, MacRoberts and MacRoberts (1987) and MacRoberts and MacRoberts (1996)); Peritz (1992) offered a succinct summary of "problems of theory and method;" and recently Seglen has assumed the MacRoberts' mantle as perhaps the most prolific contributor to the critical viewpoint (see, for example, Seglen (1998)).

Fault is regularly found with certain technical aspects of the means by which ISI's citation indexes are compiled (see Seglen (1998) for a summary of such reliability issues), and citation analysis is sometimes seen to be invalidated by its specific reliance on these indexes. In their study of the citing literature of sociology, for instance, Cronin, Snyder, and Atkins (1997) found evidence to suggest that there are two distinct populations of highly cited scholars in sociology — one consisting of authors cited in the journal literature, another of authors cited in the monographic literature. Given the citation indexes' limited coverage of monographic citing material, the latter population may regularly go unrecognized.

Moreover, and more fundamentally, at least two of the basic assumptions made by the normative theorists may be tested by empirical means. First, it is suggested that the motivations and goals of citers are more numerous and complex than the normative argument supposes, and many may be characterized

as personal, self-serving, or political (rather than as professional, scholarship-serving, or rational). Second, it is argued that, even by the normative theorists' own standards, not all works that "ought" to be cited are, and not all works that are cited "ought" to be. The validity of using citation counts in evaluative citation analysis rests on the truth of a hypothesis that does more than suggest simply that the probability of citation of an earlier document by a later one varies *partly* with the level of quality of the earlier document and partly with other variables; it proposes that the quality of the earlier document is *the most significant* factor affecting its citation count. Detractors of citation analysis point to evidence that the combined effect of other variables is sufficiently powerful and complex to rule out *any* such positive correlation between citation count and cited-document quality. Seglen (1998: p. 226) concludes that "... citation rates are determined by so many technical factors that it is doubtful whether pure scientific quality has any detectable effect at all ..." In practice, it is common both for low-quality work to be cited, and for high-quality work to go uncited. Even if it is conceded, as Seglen suggests we should, that citers are motivated less by considerations of quality and more by the mere fact that, in the course of any research project, certain documents (whatever their quality) are *used* (i.e., read) and certain others are not, we might still observe that it is also common both for material that is used to go uncited, and for material that is not used to be cited (White & Wang, 1997).

One of the primary aims of empirical studies of citation context/content and citer motivation has been to supply evidence to support or disprove one or more hypotheses of the following kind — that it is more likely that a given (earlier) document will be cited by another (later) one if either (a) the earlier document, or (b) the pair of documents, is characterized by a certain property.

Some of the properties that have been suggested as candidate factors influencing citation are identified in the following sections, accompanied by references to studies that have isolated such factors as being of particular significance. In the first section, we consider attributes of cited ("earlier") documents; in the second, we focus on attributes of document pairs.

Attributes of cited documents

1. *Quality of content*: the content of the earlier document is of a high quality (Shadish, Tolliver, Gray, & Sen Gupta, 1995).
2. *Sex of author*: the earlier document is written by a male author (Baldi, 1998).
3. *Number of authors*: the earlier document is written by a large number of co-authors (Rousseau, 1992b).
4. *Source*: the earlier document is a journal article (Baldi, 1998).
5. *Citedness*: the earlier document has been cited many times before. This is the so-called "Matthew" or "halo" effect identified by Merton (1968a), who quotes from the Gospel according to St. Matthew: "For unto every one that hath shall be given, and he shall have abundance; but from him that hath not shall be taken away from that which he hath."
6. *Subject*: the earlier document is a recent one on a "hot" topic. As Seglen (1998: p. 225) points out, the very choice, made by a researcher, of a topic on which to write "will determine, *a priori*, the probability of becoming highly cited."
7. *Approach*: the earlier document is a review of previous work or otherwise of a "secondary" nature.
8. *Field*: the earlier document is in a field of basic (rather than applied) research.
9. *Assimilation*: the earlier document does not cover material that is now so well-understood that it has been "obliterated by incorporation" (Merton, 1968b).

Attributes of citing/cited pairs

1. *Relatedness of content*: the content of the earlier document is relevantly related to that of the later document (White & Wang, 1997). In their study of the semantic relationships between citing and cited documents in a sample of document pairs drawn from three LIS journals, Harter, Nisonger, and Weng (1993) found the subject similarity to be "typically very small."

2. *Field*: the field in which both documents are written is one characterized by high citation rates (i.e., has a high "citation potential"), whether due to: (a) (in a field in which citation practice is highly institutionalized) a high mean number of citations per citing document; (b) (in a highly productive field) a high mean number of citing documents written per citer; (c) (in a rapidly growing field) a high number of citers relative to the number of citable documents (Vinkler, 1996).
3. *Persuasiveness*: the earlier document is perceived by the author of the later document (a) to be supportive or justificatory of the ideas or arguments put forward in the later document, (b) to be written by an author whose name will lend authority to the later document, (c) to meet the expectations of the later document's audience (Case & Higgins, 2000).
4. *Availability*: the earlier document is available for examination by the author of the later one.
5. *Author self-citation*: the earlier document is written by the same author as the later one (see the next section below).
6. *Journal self-citation*: the earlier document is published in the journal to which the later document is to be submitted.
7. *Social citation*: the earlier document is written by a friend, colleague, co-author, mentor, or student of the author of the later one, or by an editor or a referee of the journal to which the later document is to be submitted.
8. *Language self-citation*: the earlier document is written in the same language as the later one (Yitzhaki, 1998).
9. *Nationality self-citation*: the earlier document is written by an author of the same nationality as that of the author of the later one (Herman, 1991).
10. *Time difference*: the earlier document is published not long before the later one.

Author self-citation

Author self-citation may be said to occur when at least one of the authors of a cited document is the same person as one of the authors of the citing document. The *author self-citation rate* of an individual may be calculated by dividing the number of self-citations by the total number of all citations made by the individual. In effect, this rate indicates the probability that any given citation, drawn randomly from the population originally sampled, will be a self-citation.

The very ubiquity of the phenomenon of self-citation is commonly thought to pose problems for those who would attest to the reliability of citation analysis for evaluative purposes. The assumption typically made is that authors guilty of "excessive" self-citing are doing so gratuitously, in order "to prove how clever they are" (Baird & Oppenheim, 1994: p. 7) or in an unashamed attempt specifically to raise their own citation counts. Yet it should be clear that there are many noble reasons for self-citing. "In some research papers, discussion of relevant information will include the author's previous work, and it is no less improper to exclude it out of modesty than to include a poor reference out of egotism." (Bonzi & Snyder, 1991: p. 245). Very often, adherence to one primary norm of citing — that which suggests that citations should be made to previous work on which the present work builds — would seem to *require* the author to self-cite. In fact, as a researcher publishes more and more, quite possibly in a specialized research area that she is making more and more her own, the more difficult it may become *not* to self-cite. In the case of multi-authored papers, a decision not to self-cite may even be seen as a disservice to co-authors. It might be argued, on these bases, that evaluative studies that deliberately ignore self-citations are unfairly penalizing scholars who tend to publish in new or unfashionable fields in which few others are working, as well as those who have built careers through systematic exploration of a particular topic with which their name is associated (but see White (2001) for a rather different perspective).

There will continue to be an interest, then, in comparisons of the self-citation practices (a) of individual authors, and (b) of whole disciplines. The research questions are: (a) do high author self-citation rates betray egotists whose infected citation counts are thus rendered inadmissible in evaluations of their performance or influence?; and (b) do author self-citation rates vary between disciplines, and (if so) what are the reasons for such variation? Partial answers to the latter part of the second question may

be found in comparative examinations of authors' motivations to cite and to self-cite: are the factors that combine to increase the probability of a self-citation different from those that are positively correlated with citation events in general?

In their study of the citations made in a sample of journal papers in library and information science (LIS), Dimitroff and Arlitsch (1995) found that any given article was more likely to contain at least one self-citation if it was a full-length research paper, if it addressed theoretical topics, if it was authored by faculty rather than practitioners, or if it had a large number of co-authors. Bonzi and Snyder (1991) conducted a survey of authors' self-assessments of the functions of citations they had made; reasons that were more likely to be given for self-citations than for citations of other kinds were that "[The cited work is] Earlier work on which current work builds," and that "[The purpose of the citation is to] Establish [the cited work's] writer's authority in the field." In a follow-up study, Snyder and Bonzi (1998) analyzed citations made in six different disciplines, and found significant differences in the proportions of the total number of citations in each discipline that were self-citations: 15% in the physical sciences, 6% in the social sciences, and 3% in the humanities. Snyder and Bonzi suggest that the discrepancy may be partly due to "the more incremental nature of research in the physical sciences."

Quality, popularity, citation-worthiness, and credit-worthiness

The third plank of the normative argument — that the quality of a work consists in its citation-worthiness, and thus may be measured by citation counts — also deserves attention. Evaluative citation analysis is sometimes impugned on the basis that "quality" — the characteristic that citation counts are used to measure — is not an attribute that may be evaluated objectively at all, but one whose values depend on the subjective opinions of individuals. Where, then, is the warrant (it is asked) for any attempt to reify such a property, whether through citation counts or indeed through any objective measure? We might choose to head off such an attack by carefully distinguishing between (a) individuals' judgments of quality (which are subjective), and (b) the evidence or records that such judgments have been made (which is normally objective, reliable, and easily gathered). It might be that, as evaluators, we are satisfied with our ability merely to determine the degree of inter-subjective consensus about the level of quality of documents. We might be happy, in other words, to measure (and to distribute resources on the basis of) what is, in effect, *popularity*.

A more intransigent problem arises, however, once we distinguish between (a) *citation-worthiness*, defined as a property perceived to inhere in the relationships between documents, and (b) *credit-worthiness* (cf. "quality"), defined as a property perceived to inhere in individual documents. In one sense, the distinction is unimportant: judgments as to the level of either kind of worthiness are subjective evaluations, made by individual people; and evidence of the occurrence of judgments of either kind is objective. In another respect, the distinction is crucial: citations do not provide evidence of the making of judgments of credit-worthiness (i.e., judgments of quality); yet evaluative citation analysis proceeds as if they do.

The point (it might be argued) is that not all credit-worthy works happen to be *relevantly related* to other works. A given work may be perceived to be highly credit-worthy and thus of high quality — perhaps by virtue of its author exhibiting high levels of creativity or innovation in its subject matter or execution — and yet bear no relevant relation to any potentially citing work. Thus, no matter how credit-worthy such a work may be, its credit-worthiness will not be recognized in the form of citation events; no evidence of its credit-worthiness will be supplied by citation counts.

Trends in link analysis

In the search for explanations of linking practice, several trends may be identified that, in combination, distinguish work done in the period under consideration (1990-2000) from earlier studies. We distinguish below between, first, technological trends, and second, theoretical and methodological trends.

Technological trends

One important group of related trends may be observed to stem directly from a shared recognition that technological developments have redefined the scope both of the arenas in which scholars' communication may take place, and of the contexts in which bibliometric techniques may usefully be applied. Prominent among these developments is the emergence of hypertext technology in general, and the rapid rise to its currently dominant state of the World-Wide Web in particular.

Hypertext and citation analysis

Hypertext databases (of which the Web may be considered a vast, distributed example) and citation networks have the same formal structure. Each may be represented, at the same level of abstraction, as a directed graph, consisting of (a) a set of nodes (i.e., "pages" or documents), and (b) a set of ordered pairs of those nodes, each of which may be considered as a directed, inter-nodal link (i.e., a hyperlink or citation). This graph-theoretic formalization of structure has been documented and developed for various purposes on various occasions in the separate literatures of hypertext (see, e.g., Botafogo, Rivlin, and Shneiderman (1992) and Furner, Ellis, and Willett (1996)) and citation analysis (see, e.g., Pinski and Narin (1976) and Doreian (1988)). Seldom have the connections between these literatures been made explicit; but see Kleinberg, Kumar, Raghavan, Rajagopalan, and Tomkins (1999) for a recent exception.

The analogies that might profitably be drawn between hypertext and citation networks are not limited to observations about structure. For example, we might expect that researchers would be interested enough to ask in general — just as students of scholarly citation processes have asked with regard to the specific document-types that are the preserve of the academic and scientific world — what motivations lead authors of hypertexts, or of electronic documents specifically created for the Web, to link nodes together in the manner that they do? On what criteria do linkers base their decisions to link or not to link? What are the factors that influence linkers' prioritization of such criteria? Kim (2000), reporting on a study of the hyperlinking motivations of 15 authors of scholarly papers published in electronic form, concludes that linking behavior (much like traditional citing behavior?) is inherently multidimensional: each individual link may be made for a variety of scholarly and non-scholarly ("social" and/or "technological") reasons. Cronin, Snyder, Rosenbaum, Martinson, and Callahan (1998) describe their derivation of a typology of "genres of invocation" — ways in which scholars are invoked (cited, acknowledged, linked to, pointed to, referred to, or simply "mentioned" in the manner studied by Beniger (1990)) on the Web — and suggest various means by which and purposes for which counts of invocations might be analyzed bibliometrically.

Digital libraries and open archives

We are currently witnessing the construction of large-scale, full-text, distributed digital libraries of scholarly works (journal articles, technical reports, etc.) in which inter-document citations are rendered in active (actionable) form, so that readers may navigate among works, following citations at will, and enjoying the facility immediately to retrieve and view related material, just as Web surfers have long been able to take advantage of the hyperlinks created specifically for this purpose by the authors of Web pages. In 1999, a consortium of commercial publishers began to collaborate on the implementation of CrossRef[6], a technology that uses Digital Object Identifiers (DOIs) to identify the papers cited in the journals published by consortium members, and thus to enable the automatic creation of active hyperlinks between electronic versions of citing and cited papers (Atkins et al., 2000). Caplan and Arms (1999) reviewed the

[6] http://www.crossref.org/

then current state-of-the-art of reference linking for journal articles; Atkins (1999) summarized the approach of ISI to reference linking in the *Web of Science* version of its citation indexes.

Effective use of commercial databases of hyperlinked journal articles is hampered by the "financial firewalls" that readers come up against when attempting to navigate beyond the corpus to which they or their institution subscribes. Access to research archives maintained by academic rather than commercial institutions is typically more open. Such digital libraries are the results of the first steps taken toward realizing the dream of "the ideal online resource for scholars and scientists: all research papers in all fields, systematically interconnected, effortlessly accessible and rationally navigable from any researcher's desk worldwide" (Harnad & Carr, 2000).

The most well-established repository of research papers in electronic form, increasing in size by 25,000 papers a year, is the arXiv.org e-Print Archive[7], formerly known as the LANL e-Print Archive (Ginsparg, 1994), and maintained at the Los Alamos National Laboratory (Los Alamos, New Mexico) as a digital library for physics, mathematics, computer science, and related disciplines. The provision of free, open, discipline-based access to e-prints — electronic pre-print and re-prints — is the response of many scholarly communities to the tactics of the commercial journal publishers who are perceived to profit unreasonably from scholarly work (Harnad, 1990; 1999). The usefulness of arXiv.org, and other e-print archives like it (CogPrints[8], for example, in the cognitive sciences, and BioMed Central[9] in the biomedical sciences), will be further enhanced by the implementation of techniques for automatically detecting the occurrence of citations within texts, and creating active hyperlinks on that basis (Hitchcock et al., 2000). Such techniques have been developed in a series of exploratory projects conducted in a variety of contexts, including the Open Journal project (Hitchcock et al., 1998), the Open Citation project[10] (a.k.a. OpCit) (Harnad & Carr, 2000), NEC's ResearchIndex[11] (formerly CiteSeer) (Lawrence et al., 1999), and Ex Libris' SFX[12] framework for dynamic, context-sensitive linking (Van de Sompel & Hochstenbach, 1999a; 1999b). Interoperability among the various emerging "standards" for automated citation-detection and link-creation is one of the primary goals of the Sante Fe Convention (Van de Sompel & Lagoze, 2000), developed by the Open Archives Initiative[13]; the citation-detection process itself may be made easier through widespread adoption of a standard format specification such as the Scholarly Link Specification Framework (a.k.a. SLinkS)[14]. Doyle (2000) reviews some of the proposed solutions to the link-standardization problem.

The nature and extent of the benefits that will be enjoyed by information seekers using open, hyperlinked e-print archives are already becoming clear. The facilities to conduct keyword searches of full, digitized texts, and to navigate directly from one citing paper to another cited paper, will be supplemented by the provision of citation-based retrieval functionality, by which the searcher may identify documents whose relationship to a query is not necessarily one of adjacency or similarity of content, but of level of co-citation or bibliographic coupling. Documents in retrieval sets may further be ranked by citedness, by their qualities as "hubs" or "authorities" (Kleinberg, 1999), or by other, more *reader-centered* measures of popularity such as hit-rate or frequency of download. Such is the promise of "a universal citation database as a catalyst for reform in scholarly communication" (Cameron, 1997): new methods of retrieval are, in effect, new methods of communication.

A full discussion of the implications of link-based retrieval for the design of future IR systems is beyond the scope of the present review. But it is also clear that new measures of scholarly communication will soon be possible. For example, we will be able to determine both (a) the extent to which the mere

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[7] http://www.arXiv.org/
[8] http://cogprints.soton.ac.uk/
[9] http://www.biomedcentral.com/
[10] http://opcit.eprints.org/
[11] http://www.researchindex.org/
[12] http://www.sfxit.com/
[13] http://www.openarchives.org/
[14] http://www.openly.com/SLinkS/

availability of certain material either in general electronic form or in some specific proprietary format is an influence on the decisions of authors to cite or not to cite that material, and (b) the extent of correlation between the level of citedness of a document and the extent to which it is used. This is because we will be able to measure not only the mere existence of citations but also the frequency with which the hyperlinks representing those citations are activated, the time spent viewing cited works, and the frequency with which cited works are downloaded for future use. Ultimately, we will be able to compare these measurements with properties of citing texts, cited texts, and citing-cited pairs, in an effort to determine which of these properties have the most influence on decisions to view (retrieve), to use (read), and to save (for future use). Evaluative bibliometric analysis, just like bibliometric IR, will become reader-centered rather than writer-centered. Cronin (in press) reviews the kinds of opportunity provided to bibliometricians by the new, Web-based contexts, contents, and technologies.

At the time of writing, very little of the current digital library development work in open linking, cross-referencing, etc., involves the use of bibliometric (i.e., quantitative) methods. Studies in which some kind of link or citation analysis is applied with a view to improving our understanding of the ways in which open link structures are created or used are currently few and far between; nevertheless, reports of the ways in which these structures are being built are of definite relevance in the present context, in the sense that they are indicative of the kind of arena in which we might expect bibliometric methods to be applied in the future. The "usage-based analysis" of the Computing Research Repository[15] (a.k.a. CoRR, part of arXiv.org) reported by Carr, Hitchcock, Hall, and Harnad (2000) represents one small step in this direction.

Bibliometric analyses of the World-Wide Web

Counts of documents accessible via the Web, and related estimates of the Web's rate of growth, have been undertaken by various means since its inauguration (see, for example, Gray (1996)). The varying extent to which the entire population of Web documents is indexed by individual search engines, and the degree of overlap between those services' coverages, have subsequently become of particular interest to both developers and users (see, for example, Lawrence and Giles (1998)). The results of a study conducted by Albert, Jeong, and Barabasi (1999) suggest that the distance between any two Web documents is almost always less than 20 links. In other words, the Web is indeed huge, but it is also so highly connected that it may be viewed as a "small world," in the sense established by Milgram (1967), recently revisited in a high-profile paper by Watts and Strogatz (1998), and embedded in the popular imagination in the notions of "six degrees of separation" and "(Kevin) Bacon numbers" (Gladwell, 1999). A more detailed model of Web structure is provided by the "bow-tie" model (Broder et al., 2000), constructed through analysis of over 200 million pages and 1.5 billion links identified by AltaVista's Web crawler, which suggests that the Web consists of four main components, each of roughly the same size: a "strongly connected component" (SCC) at its heart; a set of pages (the "in" component) that link to the SCC, but that are not linked to by it; a set of pages (the "out" component) that are linked to by the SCC, but that do not link to it; and a set of pages ("tendrils") that neither link to, nor are linked to by, the SCC.

Larson (1996) was one of the earliest to consider the Web from an explicitly bibliometric point of view, in this case using the techniques of co-citation analysis and multidimensional scaling, in order to construct a two-dimensional map depicting the relationships among Web pages in the field of earth sciences. Larson's work may thus be considered part of the literature of relational citation analysis as defined earlier. Almind and Ingwersen (1997) introduced the term "webometrics" in reference to "research of all network-based communication using informetric or other quantitative measures," and described a webometric case study of Web pages originating in Denmark, Sweden, and Norway. Almind and Ingwersen compared counts of Web pages with counts of research papers indexed in ISI's citation indexes, and found that Norway's relative "visibility" on the Web was better than might be predicted from the traditional citation data. Almind and Ingwersen were more concerned to identify the

[15] http://www.arxiv.org/archive/cs/intro.html

characteristics of the "typical" Web document (its size, the frequency of outgoing links, etc.) than they were to evaluate documents on the basis of counts of incoming links, and their study should be seen as a contribution to the literature on writers' productivity.

In a subsequent paper, Ingwersen (1998) developed the notion of the Web impact factor (Web-IF) as an indicator of the "relative attractiveness" of individual Web pages, institutional Web sites, and national Web presences. Values for the Web-IF of a given Web site or country are calculated by dividing the number of *pages pointing to* that site or country by the number of *pages in* that site or country. In Ingwersen's comparison of the four Nordic countries with the UK, France, and Japan, Norway was found to have the highest Web-IF. Smith (1999) clarifies some methodological issues regarding the calculation and interpretation of Web-IF values; Snyder and Rosenbaum (1999) caution against using commercial search engines for data-gathering in such bibliometric analyses of Web links, since their coverage is highly variable and their search functionality limited, poorly documented, and changeable. The inability of conventional search engines to access the so-called "dark," "deep," "gray," or "hidden" Web (Lyman & Varian, 1998) — that formed by pages created in real-time, in on-the-fly responses to searchers' queries — is also a source of hindrance to bibliometricians seeking to model the Web's structural properties.

The first issue of *Cybermetrics*, an electronic journal devoted to scientometrics, informetrics, and bibliometrics, was published in 1997. In its first issue, Rousseau (1997) used McKiernan's term "sitation" (McKiernan, 1996) to refer to any of a given Web site's incoming links; the neologism in the journal's title seems already to have enjoyed wider usage, whereas McKiernan's term has as yet failed to catch on. Rousseau's exploratory data — counts of sitations received by Web pages in the field of bibliometrics — indicated the possibility that a Lotka-like "power law" function (see Rousseau and Rousseau (1993) for an introductory presentation) may be used to model the empirical distribution of such counts. This conjecture has subsequently been confirmed by three analyses of massive Web document-sets (325 thousand, 40 million, and 200 million documents, respectively) (Barabasi & Albert, 1999; Kumar, Raghavan, Rajagopaian, & Tomkins, 1999; Broder et al. 2000). All three suggest that the distribution of in-degrees (where the in-degree of a document is the number of its incoming links) may be modeled by a power law function, such that the probability that a document has in-degree i is proportional to $1/i^x$, for some $x > 1$. Broder et al. perceive a fractal-like quality to such distributions, in that they occur at macroscopic levels (on the entire Web), microscopic levels (within single Web sites), and at all levels in between. Egghe (2000) provides a review of the challenges that the Web sets for bibliometric analyses.

Theoretical and methodological trends

A second, no less significant, group of related trends may be identified in the development of theoretical and methodological approaches to understanding linking behavior. A selection of such intellectual trends are summarized in the following subsections.

The definitions of concepts

Links are commonly conceptualized as representations of the relationships between documents. A conceptualization of this kind may be characterized as being *artifact-oriented*, in that it is the citing/cited document-pair (rather than the citing author) which is the dominant component of the definition, and studies that conceptualize links in these terms are typically more concerned with properties of documents rather than properties of people. Conversely, links may primarily be viewed either as the results of human actions, or as actions or events in themselves. The current trend is toward a *person-oriented* conceptualization which allows the researcher to focus on the motivations, goals, and purposes of the citer, and on those aspects of the situation in which the citer finds herself — beyond observable properties of the citing/cited document-pair — that may potentially have an influence on the citer's judgment and decision-making. Cronin (2000), drawing on Wouters (1999), offers a sophisticated semiotic analysis of

citations (viewed as signs) and citation behavior (viewed as symbolic practice) in which artifact-centered and person-centered orientations may potentially be reconciled.

The goals of inquiry

The inquirer into linking behavior may have a goal of any of several kinds. That goal may be simply to *describe* and classify the behavior observed; it may be further to *explain* the behavior, either by identifying a *causal* mechanism (which may or may not allow for prediction of future behavior) or by interpreting the *meaning* that the agent assigns to their activity and to the context in which the activity takes place; alternatively, the goal may be to *evaluate* or even prescribe behavior on the basis of judgments as to its relative worth or utility. In the 1990-2000 period, there seems to be evidence of a continuing trend toward explanatory studies, and away both from purely descriptive accounts of linking behavior and from prescriptions of best practice. Research questions are more commonly posed in the form, "*Why* does person *x* cite document *d* at time *t*?," rather than, "*What* (or *when*) does (or should) person *x* cite?" Data relating to questions of the latter type continue, of course, to be used frequently in evaluative and relational linking studies, whose goals are not to understand citing behavior *per se*, but to provide more-general accounts of various scholarly communication processes.

In attempts to understand the motivations of linkers and thence to supply a theory of linking, at least two general explanatory approaches or orientations may be identified. One of these emphasizes the *purposes* of individual citations — i.e., the uses to which they are put by the citer, or the functions that the citer intends for them to fulfill. The other focuses on the *criteria* that are used by citers in making decisions about the citation worthiness of individual citations. That we can make such a distinction is not to deny that among the criteria of the kind identified in studies taking the second approach are likely to be properties of cited documents (or of cited/citing pairs) that differentiate among candidates for particular purposes, and thus that it may on occasion be difficult (and unnecessary) to distinguish between purpose and criterion. Nevertheless, it is usually possible to contrast studies of the first kind — that are concerned more with citation *function*, with finding answers to questions of the form "Why does author *x* cite document *d* at time *t*?" in analyses of the *roles* that individual citations are understood to play for the citer, and with explaining the "when" of citing — with studies of the second kind — that are concerned more with citation *quality*, with finding answers in analyses of the *reasons* that citers have for choosing certain citations rather than others, and with explaining the "what" of citing. The observed trend is for researchers increasingly to seek understanding of criteria, quality, and reasons rather than of purposes, function, and roles.

Citation behavior as relevance behavior

At the most general level, much current intellectual development in citation studies is related to a tendency for research designers simply to take more seriously the notions that citer behavior, like relevance judges' behavior in general (Schamber, Eisenberg, & Nilan, 1990), is (a) *individual and subjective* — in that different people, even when placed in otherwise similar situations and taking into account similar factors, will make different decisions; (b) *complex and multidimensional* — in that single decisions are often based on multiple factors, and multiple kinds of factors, simultaneously; and (c) *dynamic and situational* — in that, on different occasions or when placed in different situations, people take account of different factors and make different decisions.

Studies of relevance judges' behavior — i.e., studies of those decisions and actions of information seekers that are based on their judgments as to whether or not particular documents are relevant to them in particular situations — are core to the sub-field of library and information science (LIS) that is devoted to understanding information-related behavior. Furthermore, the perception that there is an important analogy to be drawn between linking behavior and the making of relevance judgments has been expressed with increasing frequency. Harter (1992: pp. 612-613) puts it as follows: "An author who includes particular citations in his list of references is announcing to readers the historical

relevance of these citations to the research; at some point in the research or writing process the author found each reference relevant. Relevance is the idea that connects IR to bibliometrics, and understanding it in one context should aid our understanding of it in the other." Studies of linking behavior may thus be explicitly positioned not simply as contributions to the general literature of information-related behavior, but specifically as close relatives of impressive recent work that has led to an improved understanding of the criteria used by information seekers when judging relevance. An implicit recognition is that the use of relevance judgments as grounds for subsequent decision-making and action is not solely the preserve of information seekers; authors (not just as linkers, but also as writers, submitters, and collaborators), indexers, editors, and reviewers, are all continuously engaged in action-guiding evaluations of the relevance of concepts, documents, and people.

Beyond content/context analysis

We might imagine a primitive study of relevance behavior that involved the *researchers* assigning *information seekers'* relevance judgments to the *researchers'* pre-defined categories of reasons for making such judgments. Perhaps such categories would include "Topicality," "Currency," "Authority," and so on. What grounds would we have for making the assumption that the researchers' post-hoc, hypothetical categorization accurately reflected the process of reasoning in which information seekers in fact engaged? Yet, this is precisely one assumption made by most contributors to the "cottage industry" of citation typology that was most active between 1965 and 1985. In work of this kind, categories are derived from analysis of either the content or the context of existing citations.

Interpretivism in link analysis

Since the mid-1980s, however, researchers have tended to take more care — both when identifying categories, and when making assignments of individual citing actions to categories — to seek justification for doing so in the evidence gathered from direct questioning of the agents themselves. This development might be labeled the "*interpretivist*" trend in studies of citing behavior.

Reports of notable studies in which researchers have sought to elicit citers' opinions about their own citing activity have appeared in three recent articles. Shadish, Tolliver, Gray, and Sen Gupta (1995) report on two related surveys of authors' perceptions of documents they have cited. In the first of these, they randomly sampled one citation from each of all 283 full-length articles published in 1985 in three top journals in psychology. The author of each article was asked (and 192 (68%) assented) to specify, on a five-point Likert scale, the degree to which they agreed with each of 28 statements describing the cited document. Further, each author was asked to indicate the one attribute (of the 28) that was the "most important" in their decision to cite, and to answer nine "Yes" / "No" questions about "things that might have increased the likelihood that respondents would know about the reference" (such as whether or not they had ever "spoken directly or by phone" with the cited author). In their factor analysis of responses to the Likert items, Shadish et al. extracted a number of groups of moderately correlated factors; they then carried out a multiple regression analysis to test the relationship between degree of citedness and citing authors' perceptions of cited works — i.e., to determine which of the groups of factors was the best predictor of citation scores. Their results were that a highly cited work is more likely than a less-cited work to be the following:

1. perceived as an "exemplar" — i.e., as a classic reference in a field, as a "concept marker," as a representative of a particular genre, as one of the earliest works in a field, as authored by a recognized authority, as generative of much novel work, or as especially resistant to falsification;
2. old;
3. perceived as "high quality;" and
4. perceived as a source of a method or a design feature.

Most significantly of all, however, a highly cited work is *less* likely than a less-cited work to be perceived as "creative." Shadish et al. (p. 485) posit the existence of high quality but poorly cited articles "that are creative in a way that does not fit into existing conceptual frameworks or into accepted social norms for scholarship in an area."

Shadish et al. were led from their findings to conclude that, although citation counts are correlated with perceptions of quality, quality is not the only factor that has an impact on citation counts, and other such factors are themselves not correlated with quality. Evidence is provided by the observations, firstly, that some work that is perceived as high quality (e.g., documents perceived to be "creative in a way that no one is ready to use") is not highly cited, and secondly, that some work that is highly cited (e.g., documents perceived to have "exemplar" status) is not perceived as high quality. As a result, it can never be possible, through examination of citation counts alone, to determine the level of quality of an individual document; and if citation counts continue to be used in university promotion decisions, the authors of "creative" works (for example) will find themselves to be at an immediate disadvantage.

Responding to calls for comparisons across disciplines, Case and Higgins (2000) set out to replicate Shadish et al.'s study, in a different discipline (communication studies) and using a slightly modified research design. Case and Higgins' analysis indicated that the two best predictors of citation counts were the citer's perception of the cited work as a "Classic" (i.e., in Shadish et al.'s terms, an exemplar), and the citer's having a "Social Reason" for citing (e.g., to demonstrate their familiarity with the important literature in the field, to cite a document published in a prestigious journal in the field, to appeal to the readers or reviewers of the journal in which the citing document is to be published, or to "establish the legitimacy" of the topic of the citing document). Case and Higgins take care to remind the reader (p. 642) that, as always, "results from one discipline may not be easily generalized to other disciplines;" but they tentatively conclude that one interpretation of their data might be to support the constructivist argument, that citations are "largely used to persuade." Certainly, Case and Higgins' identification of the importance of "Social Reasons" for citers in the field of communication studies is striking.

In a landmark study, White and Wang (1997) conducted interviews in 1995 with 12 faculty and graduate students working in the field of agricultural economics. Interviewees were questioned about their decisions to cite (or not to cite) documents that were either those in fact cited by the interviewees in the final reports of the research projects on which they had been working, or those identified as potentially relevant references by searches carried out in 1992. (White and Wang's citation study was part of a larger, long-term study of researchers' use of documents in general.) In their content analysis of the interviews, White and Wang identified a total of 314 individual decisions to cite or not to cite, and categorized each on the basis of (a) the citing author's judgment as to the *contribution* the cited document made to the citing paper; and (b) the *criteria* used by the citing author in choosing to cite the cited document. White and Wang were also able to identify (c) a set of "metalevel" concerns, i.e., beliefs held by the citer about the role and function of citation practice, and about the criteria by which such practice may be evaluated, that sometimes have an impact on individual citing decisions. White and Wang noted that their scheme of categories of the ways in which cited documents contribute to citing documents (by providing, for example, definitions of concepts, justifications of arguments, data, methods, or analogies) bears close similarity to other schemes (such as that devised by Peritz (1983)) derived rationally rather than empirically; they also found that most of the criteria identified as being used in citation decisions were equivalent to those observed in their earlier study of the "document use decisions" (i.e., decisions to use or not to use documents retrieved in searches of bibliographic databases) made by interviewees in the early stages of their projects.

White and Wang concluded (p. 147) that "citing behavior is complex, multidimensional behavior" and summarized their findings roughly as follows. Firstly, the "topicality" and "content" of the cited document were the most commonly used criteria on which citation decisions were based, although numerous other criteria were used on multiple occasions. Secondly, the choice of criteria in a particular instance seemed to depend on the "frame of reference" or purpose prioritized by the citer at that instance

(e.g., execution of the research project or of the immediate task, augmentation of the field, satisfaction of external judges, etc.). Thirdly, some "metalevel" beliefs influence citation decisions independently of considerations of the ways in which individual documents can be used: these include beliefs about the value (even the morality) of self-citing, of copy-citing (copying citations found in other citers' papers), of citing secondary sources, of citing articles from peripheral journals, and of citing to meet external judges' expectations. White and Wang suggest that it might be possible, on this basis, to identify particular styles or codes of citing, and that certain styles may be characteristic not just of individual citers but of disciplines.

Structuralism in link analysis

A concurrent development might be called the "*structuralist*" trend. This consists in the increasing interest in deriving explanatory models from sophisticated statistical analyses of the objective properties of both cited and citing documents, and of cited–citing document pairs. In studies designed from this perspective, citations (and non-citations alike) are considered as discrete events, each involving a pair (or dyad) of documents, one "potentially citing" (the origin, source, or "later," document) and one "potentially cited" (the target, destination, or "earlier," document). The decision taken by the author of a later document *x* to "cite" a particular earlier document *y* may be viewed as the result of an assessment that, in a given situation, the degree of relevance of the relationship between *x* and *y* exceeds a certain threshold, and consequently that this relationship should be explicitly represented in the form of a citation. From a graph-theoretic viewpoint, the universe of "potentially citing" and "potentially cited" documents may be regarded as a directed graph (Harary, Norman, & Cartwright, 1965), each of whose nodes represents a document, and each of whose links represents the occurrence of a positive citation event — i.e., an assessment made by the author of a later document *x* that the relationship between *x* and an earlier document *y* is sufficiently relevant for it to be expressed in the form of a citation.

Each pair of documents may be characterized by multiple attributes of the origin, of the target, and of the relationship between origin and target. These attributes may be treated as the *independent* variables, whose level of correlation with the *dependent* variable (whether or not that pair of documents is the object of a citation event) is to be assessed. We may ask, for example, how much of an effect the nationality of the author of document *y* has on the probability that it will ever be cited (i.e., the probability that it will ever participate in a citation event); we may also distinguish this question from one that asks about the effect that the nationality of the author of document *y* has on the probability that it will be cited specifically *in document* x. Our conjecture might be not only that English-speaking authors are more likely to be cited, but also that this likelihood increases even further if the authors of the citing papers are themselves English-speaking. (For examples of studies of nationality and language self-citation, see Herman (1991) and Yitzhaki (1998), respectively.)

What are the kinds of attributes that we might hypothesize as having an effect on the likelihood that an author will link a given pair of documents in a citation event? Many different variables have been identified in the literature as candidate factors; some of these were specified in the lists in the previous section on "Critiques of evaluative link analysis." Many studies have been carried out with the aim of determining the relative impact of these variables. An impressive recent addition is described by Baldi (1998), who sampled 100 documents from the 384 painstakingly identified by Hargens (1993) as the totality of literature published between 1965 and 1980 in the field of celestial masers, a subfield of astrophysics. Baldi constructed an adjacency matrix containing $(n^2-n)/2 = 4950$ binary values (where $n = 100$), each value of 0 or 1 representing an observation of the absence or presence, respectively, of a citation in later document *i* to earlier document *j*. Baldi went on to treat each of these observations as an event that could itself be described not only by the binary absence/presence property, but also by numerous properties of the later and earlier documents and of the relationship between them. Baldi's aim was to determine the impact of each of these latter properties (the independent variables), and of each of certain combinations of such properties, on the absence/presence property (the dependent variable). The properties that he found to have the most significant effect were the following (in order of strength):

1. sex of authors of cited document;
2. format of cited document;
3. shared sub-topic;
4. number of authors of cited document;
5. quality of cited document (Baldi measures "quality" by the frequency with which the cited document is cited in the third and fourth years after its publication, excluding self-citations and the citation from the citing paper itself under consideration).

In other words, in the field of celestial masers, any given document *j* is more likely to be cited by any given document *i* if its authors are male, if it is not a book chapter, if it is about the same sub-topic as the citing document, if it has many authors, or if it has already been cited many times.

Baldi also found that, with the crucial exception of the sex of the cited author, none of the properties commonly highlighted by proponents of "constructivist" theories of citing had a significant impact. He concluded (p. 843), "... at least in the research area examined, one's position in the stratification structure of science is likely to be the result of the worth and usefulness of one's scientific contributions rather than the reverse, as social constructivists would have us believe." The implication of the first few words of Baldi's conclusion is clear: further comparison of citing practices within different disciplines is necessary if we are to determine how far results such as these may be generalized. Baldi hypothesizes that properties of cited authors may have rather less impact in the natural sciences than they do in the social sciences, since the former are "more codified" and are characterized by "greater consensus over what constitutes quality work."

In an earlier study with similar aims and methods, Peters and van Raan (1994) identified the following factors as predictive of citation counts:

1. the identity of the cited author;
2. the size of the cited paper's bibliography (i.e., the number of citations made in the cited paper);
3. the language of the cited paper (English papers being cited three times more frequently than those written in French or German);
4. the impact (or "prestige") of the cited journal; and
5. the Price Index (Price, 1970) of the cited paper (i.e., the proportion of citations made in the cited paper that are to works published in the last five years).

Yet Peters and van Raan also concluded that all such predicting factors explained only 58% of the variance in citation counts. The implication is that other factors, perhaps less easy to operationalize and measure and hence not included in their study, must have considerable effect.

At a general level, the interpretivist and structuralist trends are oppositional, in that the former is characterized by an emphasis on the primacy of the citer's personal actions (influenced but not determined by context), whereas the latter consists in the renewal of interest in identifying probabilistic regularities and patterns that (as some might be tempted to say) "govern" human behavior. This should not be taken to imply, however, that a reconciliation is logically impossible, or even that evidence of both trends cannot be found simultaneously in single studies (see, e.g., White and Wang (1997)).

The ethics of citers

Another trend consists in an increasing level of interest in understanding what White and Wang (1997) call "metalevel concerns" — i.e., the beliefs, attitudes, and opinions about the function and value of citing in general that are held by citers themselves. The set of such beliefs held by an individual citer — her opinions as to when and what, in general, she should cite — could almost be construed as her philosophy or ethic of citing. A distinction might then be made between "normative" ethics, held by citers who cite in the ways that they think they "should" do so, and "egotistical" ethics, held by those who cite in the ways that they believe will most benefit their own personal goals. Prior to the time-frame of the present article, Gilbert (1977) established the view of citing as an act of persuasion, by which the citer is concerned to convince the reader of the validity of the citer's own arguments; it is now commonplace for

studies of citer motivation to distinguish a normative theory of citing from some version of a theory that attributes an egotistical attitude to the "average" citer. Baldi (1998), for instance, refers to the "social constructivist" view; Case and Higgins (2000) to a "persuasional" strategy. The citing ethic of an individual may simultaneously involve both normative and egotistical values, and it will always be difficult to categorize individual acts of citation as having been guided by one or the other. It is clear, nevertheless, that contemporary researchers are rather more willing than their forebears to account for such acts in egotistical terms.

General theories of citing

Echoing Cronin (1984), calls for a "theory of citing" have long been a regular feature of the bibliometric literature. In a discussion paper published in *Scientometrics* along with invited responses from such as Cronin (1998), Egghe (1998), and Kostoff (1998), Leydesdorff (1998) re-articulates the plea ("Citation analysis calls for a theory of what is being analyzed; citation analysts consequently tend to be in need of theoretical legitimation" (p. 5)), and supplies a major contribution to the debate about the possibility and nature of a theory of this kind. Leydesdorff distinguishes between at least two things to be explained in any theory of citing: the citation per se, and citation analysis as an area of study. He sketches the histories both of citation practice (identifying shifts over time in the function and role of citations), and of citation analysis, positioning the latter in the framework provided by the interdisciplinary field of science and technology studies. He paints a rich portrait of the inherent complexity of citation practice, arguing that citation networks are dual-layered (the result of interaction between first-order, social networks of authors and second-author networks of "communications" or texts). He uses this distinction to demonstrate that any individual cited-citing pair may be viewed as an author-author, text-text, author-text, or text-author relation, as well as either at a disaggregated (micro-) level or at various (macro-) levels of aggregation, and suggests a two-facet taxonomy of the functions of citations on this basis. He further concludes that social and cognitive perspectives on citation practice are equally necessary; that there thus exists a multiplicity of theories of citation; and that it remains "uncertain" whether a meta-theory reconciling the insights, for example, of qualitative and quantitative studies is attainable.

We may nevertheless identify an increasing tendency for researchers to take seriously certain notions that are made explicit in interpretivist accounts of citing behavior: that citers' own interpretations of the meanings and roles of citation-related phenomena both influence and are influenced by the social structure of the scholarly community; that the citation researcher is as much a part of this community as the scholars whose behavior she is studying; and that the very occurrence of citation-analytic activity affects the phenomena that it is supposedly measuring (Woolgar, 1991; Luukkonen, 1997). It is time, perhaps, for a *critical* theory of citing, that seeks not only to account for the mutual influence of social structures and citers' motivations, but that also leads the way for the researcher-citer to make a positive contribution to the development of a more equitable system of scholarly reward.

Writing, submission, and collaboration

Our focus in this chapter is on authors and on what can be learned about their scholarly communication behavior via bibliometric theory and method. Scholarly authors make relevance decisions throughout the cycle of their communication activities. The section above on "Linking" focuses on decisions to cite (i.e., to choose to create certain links between documents). Here the section on "Writing" focuses on decisions to write (i.e., to choose to create certain documents), the "Submission" section addresses decisions to submit documents to journals, and the "Collaboration" section focuses on decisions to work with other authors. All of these decisions (or the evidentiary records of decisions) may be viewed as events, and any study that involves the counting of such events may be viewed as a bibliometric study. Writing, submission, and collaboration are areas with great potential for bibliometric study, though we found less empirical research in these topics than expected. We summarize what we found, and suggest promising questions and methods for future research.

Writing

Writing is of interest because "a scholar makes his or her statement in the text, not in the reference list" (Paisley, 1990: p. 285). Authors' choices of words in the text and titles of their publications can be studied to address questions such as the content of their publications, trends within fields, and the transfer of ideas from one field to another. Authors' word choices also can be used for evaluative purposes, especially in combination with linking studies. Methods for bibliometric studies of writing (sometimes called *stylometrics*) are similar to those of content analysis, a well-established area of research in communication and in psychology[16]. Both approaches count words in the text and titles. However, bibliometrics is concerned with *characteristics* of the text itself, while content analysis is concerned with the *meaning* of the text. Thus the two approaches are distinguished more by their purposes than by their methods (Paisley, 1990). Typical examples of content analysis include Evans and Davies (2000), who examined how males and females are portrayed in elementary school reading textbooks, and Lisovskaya and Karpov (1999), who analyzed how ideologies represented in Russian textbooks varied between communist and post-communist periods.

Research productivity is an area long studied by bibliometricians. The statistical distribution of research productivity has been postulated to follow Lotka's law, namely that a small number of authors account for a large portion of the work produced (Gupta, Kumar, Syed, & Singh, 1996; Gupta & Karisiddippa, 1999; Rousseau, 1992a, 1993; Wagner-Dobler & Berg, 1995). These and similar studies find that the empirical distribution fits Lotka's law to varying degrees. Various adjustments to the law are proposed for a better fit and issues of sampling and measurement are raised in these studies.

Paisley (1990) proposed that the demographics of authorship was a potentially fruitful area for bibliometric research, and indeed we find some work in this area since. Meadows (1998) analyzes a wide range of demographic studies of authorship. Of particular interest are studies of differences in productivity and in type of publication by discipline. Disciplines vary by such factors as the number of authors per article (typically greater in the sciences than in social sciences and humanities) and the number of articles published (more per author in the sciences and medicine that in social sciences, medicine, and technology). Bonzi (1992) found similar distributions by disciplines in one large research university. Bates (1998) analyzed productivity by type of publication within one discipline (library and information science) in the four most productive universities in that field. She found that individual publication patterns tend to follow the discipline orientation of authors within this multi-disciplinary field. For example, humanities-oriented LIS authors tend to write books, while science and technology-oriented authors tend to write journal articles. Her data indicate that the ranking of authors and universities within discipline vary considerably depending upon what forms of publications are included in the dataset. Studies that use journal citation data (which are the easiest to obtain) as a surrogate for all forms of publication yield much different results from those that include books or those that include book reviews in authorship counts. Although the studies reviewed by Meadows (1998) suggest that when counts are adjusted by weighting the effort involved in different types of publication (e.g., books, articles, patents), outputs are similar across fields. Scholars' choices of the form in which they write appear to influence their recognition (as reflected in citation counts) considerably.

Other demographic variables applied to writing productivity include sex (Gupta, Kumar, & Aggarwal, 1999), university (Budd, 1995, 1999), "career age" (Bonzi, 1992), and chronological age (Diamond, 2000). Comparisons based on these demographic variables tend to anomalous. For example, writing output may increase with age, as scholars gain more funding and more collaborators. Conversely, productivity in writing output may decline with age. The latter result is usually attributed to an increase in administrative and other gate-keeping duties (reviewing, tenure and promotion committees, service in

[16] A search of the Psycinfo database on the exact subject heading "content analysis," limited to publications of 1990 or later, in English, yielded more than 1200 records. Additional records were found in the ERIC and LISA databases, with some overlap in the three sets.

scholarly societies and academic governance, etc.) rather than to a decline in capacity (Diamond, 2000; Meadows, 1998). We also found a large number of evaluative studies of the productivity of individual departments and fields, often in combination with citation analyses; most tend to be narrow in focus and primarily of local interest.

Writing style is another area of potential interest for bibliometric study. Diamond and Levy (1994), responding to arguments that the field of economics "rewards obscurity and penalizes clarity" (Diamond, 2000), analyzed texts with a grammar-checking program and compared the results to citations received. Their only significant finding was that passive voice was negatively related to citations received. Fortunately, they also found that the use of passive voice was decreasing over time.

We found a few other studies that fall on the boundaries of writing and other areas of interest. For example, although information seeking and use is outside the scope of the present chapter, some interesting work falls on the boundaries of information-seeking, writing, and citing. These are studies that ask questions about the relationship between the resources available to scholars to be cited and what those scholars choose to cite in their own writing (Harter, 1998; Harter & Kim, 1998; Jacobs, Woodfield, & Morris, 2000). Similarly, while decisions of what to cite fall within the linking category for the purposes of the present article, White (2001) analyses citations made by authors as a characteristic of writing style. In an exploratory study of "citation identity" (the set of authors than an author cites), he selected four pairs of authors who work in similar areas. He found that citation identities are highly individualized, with authors having much different thresholds of what they consider acceptable numbers of citations per article and acceptable variety of citations over time. Some build all of their work on the same core set of cited authors, while others paint a broad sweep across topics and disciplines.

Several studies have employed bibliometrics to produce biographical sketches of authors. These studies fall somewhere between evaluative bibliometrics and studies of writing. White (2000) applies a wide range of citation and co-citation methods to characterize the writing and influence of Eugene Garfield, for example. Kalyane and Kademani (1997) produced a "scientometric portrait" of Barbara McClintock, who won the Nobel laureate in physiology.

Other research on scholarly productivity lies on the boundary with evaluative bibliometrics. Wouters (2000) comments that scholars' early objections to the development of citation indexes were founded on concerns that private knowledge about productivity and recognition would become public knowledge. Diamond (2000), an economist, argues that measures of writing and productivity can be used to allocate scarce resources within the academy. In analyzing the academic labor market, he reports on studies (published prior to the time frame of the present chapter) which consistently found that the number of citations received is correlated with salary. Thus authors have an economic incentive to write more, and especially to gain citations for their work (Cronin, 1996). As Diamond notes, citations vary more than salaries do, which suggests that intrinsic rewards may be driving writing behavior more than extrinsic ones.

The typical genres of scholarly publishing are partly artifacts of print publication. In a print world, journal articles are aggregated into journal issues and thence into volumes; conference papers are aggregated into proceedings volumes; and monographs are published as a whole (although they can be serialized, as was common in past centuries). In an electronic world, articles and papers are easily distributed individually because they need not be collected into convenient and economical packages for mailing, and monographs can be serialized online. Scholars may tend to write in smaller units when the technology and publication venues make it convenient to do so (Borgman, 2000b). Even in a print world, authors tend to decompose their prior written documents and use parts of them in later publications (Bishop, 1999; Covi, 1999; Rayward, 1994). Electronic publication allows individual chapters, sections, tables, and illustrations to be distributed. Similarly, electronic documents can be tightly coupled through hyperlinks, with a specific part of one paper linked to a specific part of another. Electronic publishing also offers the ability to update previous works, raising issues about when a revised document should be considered a variant on the previous version and when it should be considered a new document (Buckland, 1997). We have not encountered studies that employ bibliometrics to examine units of writing

and how they may change from print to electronic forms, and we suggest that this may be a fruitful area of research.

Submission

Sometime before, during, or after writing a document for publication, authors make a conscious decision about where to submit it. Authors are making relevance judgements when selecting a journal, conference, book publisher, e-print server, or other publication venue. Bibliometric methods are of limited value for capturing the motivations for submission, because the methods are inherently unobtrusive. However, bibliometrics can be used to analyze the record of where authors chose to submit their work, to corroborate other evidence about submission decisions, and to test hypotheses about submission patterns.

Scholarly documents represent ideas that authors own, or at least ideas for which they claim some rights (Van Raan, 2000). They wish to position their work so that it will reach its intended audience and will bring them recognition, whether in the form of citations, acknowledgements, scientific prizes, or tangible property rights (such as patents). In selecting the "best" venue to submit the work, authors may draw explicitly on bibliometric evaluations such as journal impact factors (discussed earlier under "Linking"), or subjective opinions by colleagues on the most highly regarded journals, conferences, or publishers. Authors with sophisticated knowledge of how the literature in their field is controlled bibliographically can draw upon bibliometric indicators, directories that indicate where journals are indexed, and on a variety of other tools to position their work (Borgman, 1993, 2000b). Robinson (1991) proposes a bibliometric method specifically for determining which journal is most appropriate for a given article, providing examples for the field of economics.

A few studies are starting to examine authors' choices between print and electronic journals (Harter, 1998; Kling & McKim, 1999; Schauder, 1994; Younger, 1998). Harnad (1995), Odlyzko (1995), Okerson (1995), and others predicted that electronic publishing would soon replace the bulk of print publishing for scholarly journals. The number of electronic journals has grown substantially since their predictions, although many of the new entrants are electronic versions of established print journals (Kling & McKim, 1999). Data on comparative submission rates is difficult to obtain, due both to its proprietary nature and to the wide range of definitions of "electronic journal." Harter's (1998) data for 1995 on two of the most highly cited electronic-only journals showed that they published very small numbers of articles (4 each for the *Online Journal of Current Clinical Trials* and *Psycoloquy*) compared to print journals in their fields (median number of articles 107 and 30, respectively), confirming anecdotal reports that electronic-only journals are not attracting large numbers of submissions. Online databases of "e-prints" and "pre-prints" such as the arXiv.org e-Print Archive[17] attract large numbers of submissions in fields such as high-energy physics, mathematics, and computer science (Ginsparg, 1994; Younger, 1998). However, e-print servers are not the equivalent of journals; they are a repository and distribution mechanism for published and unpublished documents. Authors can submit articles that have been accepted by journals, adding the publication data at the time of submission to the e-print server or later when the article is published.[18] It is not yet clear whether electronic journals will supplant print journals, as originally predicted, or whether hybrid print and electronic forms will predominate. At present, it appears that electronic forms are favored for access and distribution, but print forms are favored as the permanent archival record of scholarship. Bibliometric studies of submission patterns to electronic-only, print-only, and hybrid journals will shed light on this important question.

The distribution of submissions is highly skewed, with a few top journals attracting large numbers of articles and many other journals attracting relatively few (S. Cole, 2000). Cole asks whether this is evidence of the economic efficiency of the journal system, such that journals with high rejection rates necessarily publish the best papers, and thus attract other good papers and citations. He reviews the

[17] See footnote 7.
[18] http://www.arxiv.org/help.faq

many arguments for and against this proposition (most of which have to do with social, rather than bibliometric, variables), concluding that the system is not efficient. Rather, much of the distribution has to do with self-selection by authors, who know which of their own work is best and which papers to submit to what journals. Odlyzko (1998), who argues that electronic journal publishing is the most efficient and cost-effective solution to the spiraling costs of scholarly publication, also acknowledges the "perverse incentives" of authors to publish in prestigious journals regardless of journal prices.

Bibliometrics is not likely to shed much light on the motivations of authors for choosing where to submit their work, but it can provide evidence of what those choices are. Pierce (1999), for example, uses bibliometrics to explore the behavior of "boundary crossing" authors. She identifies three forms of boundary crossing behavior: borrowing theory or method from other fields, collaborating with co-authors from other fields, and placing one's work in the journals of other disciplines. The latter is potentially the most effective form of crossing disciplinary boundaries, and can be studied bibliometrically. She identified 199 articles in four core journals of political science and sociology where the first authors were affiliated with other disciplines. Citation analyses revealed that these articles received more citations from the disciplines in which they were published than from their home disciplines, and more citations from other disciplines than from either the home discipline or the discipline of publication; thus she judged the boundary crossing to be successful. Pierce (1999) concludes that scholars are more able to place their work across disciplines than has been assumed in other studies of journal submission patterns.

Most bibliometric studies of the distribution of authorship fall in the category of literature dynamics or visualizing literature, which were addressed in recent *ARIST* chapters by Tabah (in press) and White and McCain (1997). Wormell (1998) mapped the distribution of authorship by country of top LIS journals as a means of determining who is submitting to what journals. She also examined relationships between the geographic distribution of authors, citations, and subscriptions to determine the geographic scope of influence of these journals.

Collaboration

Collaboration is a significant factor in scholarly productivity. Just as the format of publication (e.g., papers, articles, books) and number of publications vary by discipline, so do collaborations and co-authorships (Bordons & Gomez, 2000; Meadows, 1998). Solo research is the norm in some disciplines, particularly in the humanities, but also in mathematics, while collaborative research is typical of most scientific disciplines. Although co-authorship is often used as a convenient surrogate for collaboration (especially in bibliometric studies), it is but one aspect of collaboration. Bordons and Gomez (2000), in their extensive review of recent bibliometric research on collaboration, summarize multiple aspects of this complex relationship and the associated methodological risks. For example, scholars may work together on a project but publish their results separately, and thus not appear as co-authors despite their collaboration. Conversely, individuals such as heads of laboratories may be listed as co-authors by social convention, but may not have participated directly in the research reported. In other cases, scholars may have multiple concurrent affiliations or may be visitors in someone's lab. Depending upon how affiliations are listed on a paper, intra-institutional collaboration may appear to be multi-institutional or multi-national, and vice versa. Bibliometric studies of collaboration usually require data on the names of individuals and their affiliations. The ISI citation databases are essentially the sole source for such information, which limits the scope of this type of research.

Bibliometric studies of collaboration generally conclude that the amount of collaboration between scholars (usually as evidenced by number of co-authors) is growing, and that the degree of collaboration continues to vary greatly by field (Arunachalam, 2000; Bordons & Gomez, 2000; Meadows, 1998; Pao, 1992; Russell, 2000). Reasons for the growth in collaboration are many. One is the increasing specialization within disciplines, such that multiple partners are often needed to tackle complex research problems. Another is economics, given the need to amortize expensive laboratory equipment, computers, data, and other resources across multiple researchers and projects. Yet another is sources of funding that encourage larger projects (Bordons & Gomez, 2000). Higher rates of collaboration are usually associated

with higher productivity, although counts will vary based on the method of allocating authorship (one credit for each publication vs. partial credit based on number of authors, etc.).

Collaboration is a form of boundary crossing between disciplines (Pierce, 1999; Qin, Lancaster, & Allen, 1997), although determining disciplinary affiliations of authors is a complex exercise that influences the outcomes of such studies. Persson, Melin, and Kretschmer (Kretschmer, 1993, 1997; Persson & Melin, 1996; Persson, Melin, Danell, & Kaludis, 1997; Persson & Beckman, 1995) are among the authors who have explored co-authorship and collaboration across international boundaries and identified evidence of invisible colleges.

Studies of collaboration often are a form of evaluative citation analysis, as discussed earlier under linking. They can be used to assess the level of partnerships between countries and between laboratories, for example. Similarly, many studies of collaboration fall in the category of mapping literatures that is outside the scope of this review.

Conclusions

The circumstances of scholarly communication have changed radically in the decade covered by this review. A large and growing portion of scholars' communicative activities are conducted via computers and networks: interpersonal interaction with colleagues, searching for information, writing, submitting works for publication, reviewing, collaborating with colleagues, and the conduct of research itself. More of the content of scholarly publications is available online, whether published electronically, published concurrently in print and electronic forms, or published in print and later collected into digital libraries. Once online, documents can be linked electronically. Citations, acknowledgements, datasets, and other indicators of relationships between documents become active links whose paths can be followed through networks. Both the content and the links can be treated as indicators of scholarly communication, thus providing rich new data sources for bibliometric study. As scholarly communication evolves and as methods for studying it improve, opportunities become available for new theory, method, and topics of inquiry.

Our goal in this review was to identify the research areas, methods, and theories that have been explored at the intersection of scholarly communication and bibliometrics during the decade since the last major review and to identify which of these opportunities have yet to be pursued. We found even more activity in these areas than we could review, so narrowed our focus to the study of scholars as authors. We required that studies be concerned with what could be learned about scholarly communication via bibliometrics, including both studies that *use* bibliometrics and those that study the *use of* bibliometrics. Thus we excluded behavioral studies of other scholarly activities such as information searching and peer reviewing, as well as the large body of research that employs bibliometrics to map literatures but does not have an explicitly behavioral component. Even with these constraints, and without claiming to be comprehensive, we have reviewed studies reported in more than 200 publications. We found that some aspects of scholarly communication and bibliometrics have been addressed extensively, while others are only beginning to be explored.

The area that continues to receive the most attention, not surprisingly, is evaluative bibliometrics. Bibliometrics offers a wide range of methods and measures for evaluating scholarly productivity and for comparing the recognition of individuals, groups, fields, universities, nations, and other aggregates. Evaluative studies are based on assumptions, whether implicit or explicit, about how and why the authors of one work cite other works. We are finding that while the methods and measures for evaluative bibliometrics are becoming more sophisticated, the defenses and critiques of citation-related behavior also are becoming more sophisticated. Many of the implicit assumptions about scholars' choices of what to cite are being called into question. Similarly, the validity of some widely accepted measures is being questioned. At the same time, new theories and new methods are available for examining those assumptions and pursuing better ways of accounting for scholarly behavior.

Among the most promising developments are new theories of citation-related behavior and new bibliometric concepts, for example viewing citation choices as judgments of relevance or of trust. Also of

interest are studies of social networks in electronic environments and the explicit application of bibliometric methods to the study of the World-Wide Web.

We found less activity than expected in bibliometric research on scholars' activities in writing, in submitting for publication, and in collaboration. Given that scholars actually make their claims in their text rather than in their citations, and we now have direct access to their text, this area seems ripe for bibliometric study. Some bibliometric research has been done on scholarly productivity across disciplines, boundary-crossing activities, choices in submitting to print and electronic journals, and other judgments in where scholars choose to place their work. We also found studies that challenged the use of co-authorship as a surrogate for collaboration, exploring other means of assessing scholars' behavior in working together.

Overall trends in scholarly communication and bibliometrics reflect larger trends in social science and technology research. Part of what we are seeing is a tension between structural and interpretive approaches and between quantitative and qualitative methods. Our review identified developments in theory and method on all of these fronts. We are seeing interesting new measures and models, and significant new interpretations of scholarly behavior. We view these developments as complementary, for each challenges the other. Models must be explained, and theories must be validated. Some of the territory reviewed has been deeply mined, while research in other areas has barely scratched the surface. A plethora of opportunities and challenges remain for those wishing to investigate this rich territory.

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References

Albert, R., Jeong, H., & Barabasi, A.-L. (1999). Diameter of the World Wide Web. *Nature*, 401, 130-131.

Almind, T. C., & Ingwersen, P. (1997). Informetric analyses on the World Wide Web: Methodological approaches to "Webometrics". *Journal of Documentation*, 53, 404-426.

Álvarez, P., & Pulgarín, A. (1998). Equating research production in different scientific fields. *Information Processing & Management*, 34, 465-470.

Arunachalam, S. (2000). International collaboration in science: The case of India and China. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 215-231). Medford, NJ: Information Today.

Atkins, H. (1999). The ISI Web of Science: Links and electronic journals: How links work today in the Web of Science, and the challenges posed by electronic journals. *D-Lib Magazine* [On-line], 5(9). Available: http://www.dlib.org/dlib/september99/atkins/09atkins.html

Atkins, H., Lyons, C., Ratner, H., Risher, C., Shillum, C., Sidman, D., & Stevens, A. (2000). Reference linking with DOIs: A case study. *D-Lib Magazine* [On-line], 6(2). Available: http://www.dlib.org/dlib/february00/02risher.html

Baird, L. M., & Oppenheim, C. (1994). Do citations matter? *Journal of Information Science*, 20, 2-15.

Baldi, S. (1998). Normative versus social constructivist processes in the allocation of citations: A network-analytic model. *American Sociological Review,* 63, 829-846.

Barabasi, A.-L., & Albert, R. (1999). Emergence of scaling in random networks. *Science,* 286, 509-512.

Bates, M. J. (1998). The role of publication type in the evaluation of LIS programs. *Library & Information Science Research,* 20, 187-198.

Bayer, A. E., & Folger, J. (1966). Some correlates of a citation measure of productivity in science. *Sociology of Education,* 39, 381-390.

Beniger, J. R. (1990). Identifying the important theorists of communication: Use of latent measures to test manifest assumptions in scholarly communication. In C. L. Borgman (Ed.), *Scholarly communication and bibliometrics* (pp. 254-280). Newbury Park, CA: Sage.

Bishop, A. P. (1999). Document structure and digital libraries: How researchers mobilize information in journal articles. *Information Processing & Management,* 35, 255-279.

Bishop, A. P., & Star, S. L. (1996). Social informatics of digital library use and infrastructure. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 31* (pp. 301-401). Medford, NJ: Information Today.

Bonzi, S. (1992). Trends in research productivity among senior faculty. *Information Processing & Management,* 28, 111-120.

Bonzi, S., & Snyder, H. W. (1991). Motivations for citation: A comparison of self citation and citation to others. *Scientometrics,* 21, 245-254.

Bordons, M., & Gomez, I. (2000). Collaboration networks in science. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 197-213). Medford, NJ: Information Today.

Borgman, C. L. (1989). Bibliometrics and scholarly communication: Editor's introduction. *Communication Research,* 16, 583-599.

Borgman, C. L. (Ed.). (1990). *Scholarly communication and bibliometrics.* Newbury Park, CA: Sage.

Borgman, C. L. (1993). Round in circles: The scholar as author and end-user in the electronic environment. In H. Woodward & S. Pilling (Eds.), *The international serials industry* (pp. 45-59). London: Gower.

Borgman, C. L. (2000a). Digital libraries and the continuum of scholarly communication. *Journal of Documentation,* 56, 412-430.

Borgman, C. L. (2000b). *From Gutenberg to the global information infrastructure: Access to information in the networked world.* Cambridge, MA: MIT Press.

Borgman, C. L. (2000c). Scholarly communication and bibliometrics revisited. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 143-162). Medford, NJ: Information Today.

Borgman, C. L., & Paisley, W. (1989). Bibliometric methods for the study of scholarly communication: Preface. *Communication Research,* 16, 581-582.

Botafogo, R. A., Rivlin, E., & Shneiderman, B. (1992). Structural analysis of hypertexts: Identifying hierarchies and useful metrics. *ACM Transactions on Information Systems,* 10, 142-180.

Bradley, S. J., Willett, P., & Wood, F. E. (1992). A publication and citation analysis of the Department of Information Studies, University of Sheffield, 1980-1990. *Journal of Information Science,* 18, 225-232.

Brin, S., & Page, L. (1998). Anatomy of a large-scale hypertextual Web search engine. *Computer Networks and ISDN Systems,* 30, 107-117.

Broder, A., Kumar, R., Maghoul, F., Raghavan, P., Rajagopalan, S., Stata, R., Tomkins, A., & Wiener, J. (2000). Graph structure in the Web. In D. Bulterman (Ed.), *Proceedings of the 9th International World Wide Web Conference: The web: The next generation* (Amsterdam, May 15-19, 2000). Amsterdam: Elsevier. Available: http://www9.org/w9cdrom/160/160.html

Brooks, T. A. (2000). How good are the best papers of JASIS? *Journal of the American Society for Information Science,* 51, 485-486.

Brown, J. S., & Duguid, P. (1995). The social life of documents. *First Monday* [On-line], 1(1). Available: http://www.firstmonday.dk/issues/issue1/documents/index.html

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston, MA: Harvard Business School Press.

Buckland, M. (1997). What is a "document"? *Journal of the American Society for Information Science,* 48, 804-809.

Budd, J. M. (1995). Faculty publishing productivity: An institutional analysis and comparison with library and other measures. *College & Research Libraries,* 56, 547-554.

Budd, J. M. (1999). Increases in faculty publishing activity: An analysis of ARL and ACRL institutions. *College & Research Libraries,* 60, 308-315.

Budd, J. M. (2000). Scholarly productivity of U.S. LIS faculty: An update. *Library Quarterly,* 70, 230-245.

Budd, J. M., & Seavey, C. A. (1996). Productivity of U.S. library and information science faculty: The Hayes study revisited. *Library Quarterly,* 66, 1-20.

Burrell, Q., & Rousseau, R. (1995). Fractional counts for authorship attribution: A numerical study. *Journal of the American Society for Information Science,* 46, 97-102.

Cameron, R. D. (1997). A universal citation database as a catalyst for reform in scholarly communication. *First Monday* [On-line], 2(4). Available: http://www.firstmonday.org/issues/issue2_4/cameron/index.html

Caplan, P., & Arms, W. Y. (1999). Reference linking for journal articles. *D-Lib Magazine* [On-line], 5(7/8). Available: http://www.dlib.org/dlib/july99/caplan/07caplan.html

Carr, L., Hitchcock, S., Hall, W., & Harnad, S. (2000). A usage based analysis of CoRR. *ACM Journal of Computer Documentation,* 24, 54-59.

Case, D. O., & Higgins, G. M. (2000). How can we investigate citation behavior?: A study of reasons for citing literature in communication. *Journal of the American Society for Information Science,* 51, 635-645.

Chakrabarti, S., Dom, B. E., Kumar, S. R., Raghavan, P., Rajagopalan, S., Tomkins, A., Gibson, D., & Kleinberg, J. M. (1999). Mining the Web's link structure. *Computer,* 32, 60-67.

Chen, C., & Carr, L. (1999). Trailblazing the literature of hypertext: Author co-citation analysis (1989-1998). In K. Tochtermann, J. Westbomke, U. K. Wiil, & J. J. Leggett (Eds.), *Hypertext '99: Returning to our diverse roots: The 10th ACM Conference on Hypertext and Hypermedia* (Darmstadt, Germany, February 21-25, 1999) (pp. 51-60). New York, NY: ACM Press.

Cole, J. R. (2000). A short history of the use of citations as a measure of the impact of scientific and scholarly work. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 281-300). Medford, NJ: Information Today.

Cole, S. (2000). The role of journals in the growth of scientific knowledge. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 143-162). Medford, NJ: Information Today.

Cole, S., & Cole, J. R. (1967). Scientific output and recognition: A study in the operation of the reward system in science. *American Sociological Review,* 32, 377-390.

Covi, L. M. (1999). Material mastery: Situating digital library use in university research practices. *Information Processing & Management,* 35, 293-316.

Cronin, B. (1984). *The citation process: The role and significance of citations in scientific communication*. London: Taylor Graham.

Cronin, B. (1991). Let the credits roll: The role of mentors and trusted assessors in disciplinary formation. *Journal of Documentation,* 47, 227-239.

Cronin, B. (1995). *The scholar's courtesy: The role of acknowledgement in the primary communication process*. London: Taylor Graham.

Cronin, B. (1996). Rates of return to citation. *Journal of Documentation,* 52, 188-197.

Cronin, B. (1998). Metatheorizing citation. *Scientometrics,* 43, 45-55.

Cronin, B. (2000). Semiotics and evaluative bibliometrics. *Journal of Documentation,* 56, 440-453.

Cronin, B. (in press). Bibliometrics and beyond: Some thoughts on Web-based citation analysis. *Journal of Information Science*.

Cronin, B., & Atkins, H. B. (2000). The scholar's spoor. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 1-7). Medford, NJ: Information Today.

Cronin, B., McKenzie, G., & Rubio, L. (1993). The norms of acknowledgement in four humanities and social science disciplines. *Journal of Documentation,* 49, 29-43.

Cronin, B., McKenzie, G., & Stiffler, M. (1992). Patterns of acknowledgement. *Journal of Documentation,* 48, 107-122.

Cronin, B., & Overfelt, K. (1994a). Citation-based auditing of academic performance. *Journal of the American Society for Information Science,* 45, 61-72.

Cronin, B., & Overfelt, K. (1994b). The scholar's courtesy: A survey of acknowledgement behavior. *Journal of Documentation,* 50, 165-196.

Cronin, B., Snyder, H., & Atkins, H. (1997). Comparative citation rankings of authors in monographic and journal literature: A study of sociology. *Journal of Documentation,* 53, 263-273.

Cronin, B., Snyder, H. W., Rosenbaum, H., Martinson, A., & Callahan, E. (1998). Invoked on the Web. *Journal of the American Society for Information Science,* 49, 1319-1328.

Davenport, E., & Cronin, B. (2000). The citation network as a prototype for representing trust in virtual environments. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 517-534). Medford, NJ: Information Today.

Diamond, A. M., Jr. (2000). The complementarity of scientometrics and economics. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: a festschrift in honor of Eugene Garfield* (pp. 321-336). Medford, NJ: Information Today.

Diamond, A. M., Jr., & Levy, D. M. (1994). The metrics of style: Adam Smith teaches efficient rhetoric. *Economic Inquiry,* 32, 138-145.

Dimitroff, A., & Arlitsch, K. (1995). Self-citations in the library and information science literature. *Journal of Documentation,* 51, 44-56.

Ding, Y., Chowdhury, G., & Foo, S. (1999). Mapping the intellectual structure of information retrieval studies: An author co-citation analysis, 1987-1997. *Journal of Information Science,* 25, 67-78.

Diodato, V. (1994). *Dictionary of bibliometrics*. New York, NY: Haworth Press.

Doreian, P. (1988). Measuring the relative standing of disciplinary journals. *Information Processing & Management,* 24, 45-56.

Doreian, P. (1994). A measure of standing for citation networks within a wider environment. *Information Processing & Management,* 30, 21-31.

Doyle, M. (2000). Pragmatic citing and linking in electronic scholarly publishing. *Learned Publishing,* 13, 5-14.

Edge, D. O. (1979). Quantitative measures of communication in science: A critical review. *History of Science,* 17, 102-134.

Egghe, L. (1998). Mathematical theories of citation. *Scientometrics,* 43, 57-62.

Egghe, L. (2000). New informetric aspects of the Internet: Some reflections: Many problems. *Journal of Information Science,* 26, 329-335.

Egghe, L., & Rousseau, R. (1990). *Introduction to informetrics: Quantitative methods in library, documentation and information science*. Amsterdam: Elsevier.

Egghe, L., Rousseau, R., & van Hooydonk, G. (2000). Methods for accrediting publications to authors or countries: Consequences for evaluation studies. *Journal of the American Society for Information Science,* 51, 145-157.

Evans, L., & Davies, K. (2000). No sissy boys here: A content analysis of the representation of masculinity in elementary school reading textbooks. *Sex Roles,* 42, 255-270.

Furner, J., Ellis, D., & Willett, P. (1996). The representation and comparison of hypertext structures using graphs. In M. Agosti & A. F. Smeaton (Eds.), *Information retrieval and hypertext* (pp. 75-96). Boston, MA: Kluwer.

Garfield, E. (1965). Can citation indexing be automated? In M. E. Stevens, V. E. Giuliano, & L. B. Heilprin (Eds.), *Statistical association methods for mechanized documentation: Symposium proceedings* (pp. 189-192). Washington, DC: National Bureau of Standards.

Garfield, E. (1973, August 15). The new ISI Journal Citation Reports should significantly affect the future course of scientific publication. *Current Contents,* 33, 5-6.

Garfield, E. (1975, May 19). Journal citation studies, 20: Agriculture journals and the agricultural literature. *Current Contents,* 20, 5-11.

Garfield, E. (1979). *Citation indexing: Its theory and application in science, technology, and humanities*. New York, NY: John Wiley.

Garfield, E. (1990, February 12). The most-cited papers of all time, SCI 1945-1988, part 1A: The SCI top 100: Will the Lowry method ever be obliterated? *Current Contents,* 7, 3-14.

Garfield, E. (1993). What citations tell us about Canadian research. *Canadian Journal of Information and Library Science,* 18, 14-35.

Garfield, E. (1996). When to cite. *Library Quarterly,* 66, 449-458.

Garfield, E., & Welljams-Dorof, A. (1992a). Citation data: Their use as quantitative indicators for science and technology evaluation and policy-making. *Science and Public Policy,* 19, 321-327.

Garfield, E., & Welljams-Dorof, A. (1992b). Of Nobel class: A citation perspective on high impact research authors. *Theoretical Medicine,* 13, 117-135.

Gilbert, G. N. (1977). Referencing as persuasion. *Social Studies of Science,* 7, 113-122.

Ginsparg, P. (1994). First steps towards electronic research communication. *Computers in Physics,* 8, 390-396.

Gladwell, M. (1999, January 11). Six degrees of Lois Weisberg. *New Yorker,* 74(41), 52-63.

Gray, M. (1996, June 20). Internet statistics: Web growth, Internet growth [On-line]. Cambridge, MA: Massachusetts Institute of Technology. Available: http://www.mit.edu/people/mkgray/net/

Gupta, B. M., & Karisiddippa, C. R. (1999). Collaboration and author productivity: A study with a new variable in Lotka's law. *Scientometrics,* 44, 129-134.

Gupta, B. M., Kumar, S., & Aggarwal, B. S. (1999). A comparison of productivity of male and female scientists of CSIR. *Scientometrics,* 45, 269-289.

Gupta, B. M., Kumar, S., Syed, S., & Singh, K. V. (1996). Distribution of productivity among authors in potato research, 1900-1980. *Library Science with a Slant to Documentation and Information Studies,* 33, 127-134.

Harary, F., Norman, R. Z., & Cartwright, D. (1965). *Structural models: An introduction to the theory of directed graphs*. New York, NY: John Wiley.

Hargens, L. L. (1993). *Reference networks and scientific development: A comparative study* (NSF proposal, grant no. SBR-9223317). Columbus, OH: Department of Sociology, Ohio State University.

Harnad, S. (1990). Scholarly skywriting and the prepublication continuum of scientific inquiry. *Psychological Science,* 1, 342-343.

Harnad, S. (1995). The post-Gutenberg galaxy: How to get there from here. *The Information Society*, 11, 285-291.

Harnad, S. (1999). Free at last: The future of peer-reviewed journals. *D-Lib Magazine* [On-line], 5(12). Available: http://www.dlib.org/dlib/december99/12harnad.html

Harnad, S., & Carr, L. (2000). Integrating, navigating, and analysing open Eprint archives through open citation linking (the OpCit project). *Current Science,* 79, 629-638.

Harsanyi, M. A. (1993). Multiple authors, multiple problems: Bibliometrics and the study of scholarly collaboration: A literature review. *Library & Information Science Research,* 15, 325-354.

Harter, S. P. (1992). Psychological relevance and information science. *Journal of the American Society for Information Science,* 43, 602-615.

Harter, S. P. (1998). Scholarly communication and electronic journals: An impact study. *Journal of the American Society for Information Science,* 49, 507-516.

Harter, S. P., & Kim, H. J. (1996). Accessing electronic journals and other e-publications: An empirical study. *College & Research Libraries,* 57, 440-456.

Harter, S. P., Nisonger, T. E., & Weng, A. (1993). Semantic relationships between cited and citing articles in library and information science journals. *Journal of the American Society for Information Science,* 44, 543-552.

Herman, I. L. (1991). Receptivity to foreign literature: A comparison of UK and US citing behavior in librarianship and information science. *Library & Information Science Research,* 13, 37-47.

Hitchcock, S., Carr, L., Hall, W., Harris, S., Probets, S., Evans, D., & Brailsford, D. (1998). Linking electronic journals: Lessons from the Open Journal project. *D-Lib Magazine* [On-line], 4(12). Available: http://www.dlib.org/dlib/december98/12hitchcock.html

Hitchcock, S., Carr, L., Jiao, Z., Bergmark, D., Hall, W., Lagoze, C., & Harnad, S. (2000). Developing services for open eprint archives: Globalisation, integration and the impact of links. In R. K. Furuta (Ed.), *DL'00: Proceedings of the 5th ACM Conference on Digital Libraries* (San Antonio, TX, June 2-7, 2000) (pp. 143-151). New York, NY: ACM Press.

Ingwersen, P. (1998). The calculation of Web impact factors. *Journal of Documentation,* 54, 236-243.

Ingwersen, P., Larsen, B., & Wormell, I. (2000). Applying diachronic citation analysis to research program evaluations. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 373-387). Medford, NJ: Information Today.

Jacobs, N., Woodfield, J., & Morris, A. (2000). Using local citation data to relate the use of journal articles by academic researchers to the coverage of full-text document access systems. *Journal of Documentation,* 56, 563-581.

Kalyane, V. L., & Kademani, B. S. (1997). Scientometric portrait of Barbara McClintock: The Nobel laureate in physiology. *Kelpro Bulletin,* 1, 3-14.

Kim, H. J. (2000). Motivations for hyperlinking in scholarly electronic articles: A qualitative study. *Journal of the American Society for Information Science,* 51, 887-899.

Kleinberg, J. M. (1999). Authoritative sources in a hyperlinked environment. *Journal of the ACM,* 46, 604-632.

Kleinberg, J. M., Kumar, R., Raghavan, P., Rajagopalan, S., & Tomkins, A. S. (1999). The Web as a graph: Measurements, models, and methods. In T. Asano, H. Imai, D. T. Lee, S. Nakano, & T. Tokuyama (Eds.), *Computing and Combinatorics: 5th Annual International Conference, COCOON'99: Tokyo, Japan, July 1999: Proceedings*. Berlin: Springer. Available: http://link.springer.de/link/service/series/0558/papers/1627/16270001.pdf

Kling, R., & McKim, G. (1999). Scholarly communication and the continuum of electronic publishing. *Journal of the American Society for Information Science,* 50, 890-906.

Kostoff, R. N. (1996). Performance measures for government-sponsored research: Overview and background. *Scientometrics,* 36, 281-292.

Kostoff, R. N. (1997). *The handbook of research impact assessment* (7th ed.). Springfield, VA: National Technical Information Service.

Kostoff, R. N. (1998). The use and misuse of citation analysis in research evaluation. *Scientometrics,* 43, 27-43.

Kretschmer, H. (1993). Measurement of social stratification: A contribution to the disput on the Ortega hypothesis. *Scientometrics,* 26, 97-113.

Kretschmer, H. (1997). Patterns of behavior in co-authorship networks of invisible colleges. *Scientometrics,* 40, 579-591.

Kumar, R., Raghavan, P., Rajagopalan, S., & Tomkins, A. (1999). Trawling the web for emerging cyber-communities. In A. Mendelzon (Ed.), *Proceedings of the Eighth International World Wide Web*

Conference (Toronto, Canada, May 11-14, 1999). Amsterdam: Elsevier. Available: http://www8.org/w8-papers/4a-search-mining/trawling/trawling.html

Larson, R. R. (1996). Bibliometrics of the World Wide Web: An exploratory analysis of the intellectual structure of cyberspace. In S. Hardin (Ed.), *ASIS '96: Global complexity: Information, chaos, and control: Proceedings of the 59th ASIS Annual Meeting* (Baltimore, MD, October 21-24, 1996) (pp. 71-78). Medford, NJ: Information Today.

Lawrence, S., & Giles, C. L. (1998). Searching the World Wide Web. *Science,* 280, 98-100.

Lawrence, S., Giles, C. L., & Bollacker, K. (1999). Digital libraries and autonomous citation indexing. *Computer,* 32, 67-71.

Leydesdorff, L. (1998). Theories of citation? *Scientometrics,* 43, 5-25.

Lisovskaya, E., & Karpov, V. (1999). New ideologies in postcommunist Russian textbooks. *Comparative Education Review,* 43, 522-543.

Liu, M. (1993). The complexities of citation practice: A review of citation studies. *Journal of Documentation,* 49, 370-408.

Luukkonen, T. (1997). Why has Latour's theory of citations been ignored by the bibliometric community?: Discussion of sociological interpretations of citation analysis. *Scientometrics,* 38, 27-37.

Lyman, P., & Varian, H. R. (2000). How much information? Internet [On-line]. Berkeley, CA: School of Information Management and Systems, University of California, Berkeley. Available: http://www.sims.berkeley.edu/how-much-info/internet.html

Lynch, C. A. (1998). Identifiers and their role in information applications. *Bulletin of the American Society for Information Science,* 24, 17-20.

MacRoberts, M. H., & MacRoberts, B. R. (1987). Problems of citation analysis: A critical review. *Journal of the American Society for Information Science,* 40, 342-349.

MacRoberts, M. H., & MacRoberts, B. R. (1996). Problems of citation analysis. *Scientometrics,* 36, 435-444.

May, R. M. (1997). The scientific wealth of nations. *Science,* 275, 793-796.

McKiernan, G. (1996). CitedSites(sm): Citation indexing of Web resources [On-line]. Ames, IA: Iowa State University. Available: http://www.public.iastate.edu/~CYBERSTACKS/Cited.htm

Meadows, A. J. (1998). *Communicating research*. San Diego, CA: Academic Press.

Merton, R. K. (1968a). The Matthew effect in science. *Science,* 159, 56-63.

Merton, R. K. (1968b). *Social theory and social structure*. New York: Free Press.

Merton, R. K. (1973). *The sociology of science: Theoretical and empirical investigations*. Chicago, IL: University of Chicago Press.

Merton, R. K. (2000). On the Garfield input to the sociology of science: A retrospective collage. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 435-448). Medford, NJ: Information Today.

Milgram, S. (1967). The small world problem. *Psychology Today,* 2, 60-67.

Moed, H. F., de Bruin, R. E., & van Leeuwen, T. N. (1995). New bibliometric tools for the assessment of national research performance: Database description, overview of indicators and first applications. *Scientometrics,* 33, 381-422.

Moed, H. F., & Van Leeuwen, T. N. (1995). Improving the accuracy of the Institute for Scientific Information's journal impact factors. *Journal of the American Society for Information Science,* 46, 461-467.

Moed, H. F., van Leeuwen, T. N., & Reedijk, J. (1999). Towards appropriate indicators of journal impact. *Scientometrics,* 46, 575-589.

Narin, F. (1976). *Evaluative bibliometrics: The use of publication and citation analysis in the evaluation of scientific activity*. Cherry Hill, NJ: Computer Horizons.

Narin, F., & Hamilton, K. S. (1996). Bibliometric performance measures. *Scientometrics,* 36, 293-310.

Narin, F., Hamilton, K. S., & Olivastro, D. (2000). The development of scientific indicators in the United States. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 337-360). Medford, NJ: Information Today.

Nisonger, T. E. (1999). JASIS and library and information science journal rankings: A review and analysis of the last half-century. *Journal of the American Society for Information Science,* 50, 1004-1019.

Noyons, E. C. M., Moed, H. F., & Luwel, M. (1999). Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. *Journal of the American Society for Information Science,* 50, 115-131.

Odlyzko, A. M. (1995). Tragic loss or good riddance?: The impending demise of traditional scholarly journals. *International Journal of Human-Computer Studies,* 42, 71-122.

Odlyzko, A. M. (1998). The economics of electronic journals. In R. Ekman & R. E. Quandt (Eds.), *Technology and scholarly communication* (pp. 380-393). Berkeley, CA: University of California Press.

Okerson, A. S., & O'Donnell, J. J. (Eds.). (1995). *Scholarly journals at the crossroads: A subversive proposal for electronic publishing*. Washington, DC: Association of Research Libraries.

Paisley, W. (1990). The future of bibliometrics. In C. L. Borgman (Ed.), *Scholarly communication and bibliometrics* (pp. 281-299). Newbury Park, CA: Sage.

Pao, M. L. (1992). Global and local collaborators: A study of scientific collaboration. *Information Processing & Management,* 28, 99-109.

Peritz, B. C. (1983). A classification of citation roles for the social sciences and related fields. *Scientometrics,* 5, 303-312.

Peritz, B. C. (1992). On the objectives of citation analysis: Problems of theory and method. *Journal of the American Society for Information Science,* 43, 448-451.

Persson, O., & Beckmann, M. (1995). Locating the network of interacting authors in scientific specialties. *Scientometrics,* 33, 351-366.

Persson, O., & Melin, G. (1996). Equalization, growth and integration of science. *Scientometrics,* 37, 153-157.

Persson, O., Melin, G., Danell, R., & Kaloudis, A. (1997). Research collaboration at Nordic universities. *Scientometrics,* 39, 209-223.

Peters, H. F. P., & van Raan, A. F. J. (1994). On determinants of citation scores: A case study in chemical engineering. *Journal of the American Society for Information Science,* 45, 39-49.

Pierce, S. J. (1999). Boundary crossing in research literatures as a means of interdisciplinary information transfer. *Journal of the American Society for Information Science,* 50, 271-279.

Pinski, G., & Narin, F. (1976). Citation influence for journal aggregates of scientific publcations: Theory, with application to the literature of physics. *Information Processing & Management,* 12, 297-312.

Price, D. J. de S. (1970). Citation measures of hard science, soft science, technology and nonscience. In C. E. Nelson & D. K. Pollock (Eds.), *Communication among scientists and engineers* (pp. 3-22). Lexington, MA: Heath.

Price, D. J. de S. (1986). *Little science, big science: and beyond*. New York, NY: Columbia University Press.

Qin, J., Lancaster, F. W., & Allen, B. (1997). Types and levels of collaboration in interdisciplinary research in the sciences. *Journal of the American Society for Information Science,* 48, 893-916.

Rayward, W. B. (1994). Some schemes for restructuring and mobilising information in documents: A historical perspective. *Information Processing & Management,* 30, 163-175.

Robinson, M. D. (1991). Applied bibliometrics: Using citation analysis in the journal submission process. *Journal of the American Society for Information Science,* 42, 308-310.

Rousseau, R. (1992a). Breakdown of the robustness property of Lotka's Law: The case of adjusted counts for multiauthorship attribution. *Journal of the American Society for Information Science,* 43, 645-647.

Rousseau, R. (1992b). Why am I not cited or why are multi-authored papers more cited than others? [Letter]. *Journal of Documentation,* 48, 79-80.

Rousseau, R. (1993). A table for estimating the exponent in Lotka's Law. *Journal of Documentation,* 49, 409-412.

Rousseau, R. (1997). Sitations: An exploratory study. *Cybermetrics: International Journal of Scientometrics, Informetrics and Bibliometrics* [On-line], 1(1). Available: http://www.cindoc.csic.es/cybermetrics/articles/v1i1p1.html

Rousseau, R., & Rousseau, S. (1993). Informetric distributions: A tutorial review. *Canadian Journal of Information and Library Science,* 18, 51-63.

Rousseau, R., & van Hooydonk, G. (1996). Journal production and journal impact factors. *Journal of the American Society for Information Science,* 47, 775-780.

Rousseau, S., & Rousseau, R. (1998). The scientific wealth of European nations: Taking effectiveness into account. *Scientometrics,* 42, 75-87.

Roy, R., Roy, N. R., & Johnson, G. G. (1983). Approximating total citation counts from 1st author counts and from total papers. *Scientometrics,* 5, 117-124.

Russell, J. M. (2000). Publication indicators in Latin America revisited. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 233-250). Medford, NJ: Information Today.

Russell, J. M., & Rousseau, R. (in press). Bibliometrics and institutional evaluation. In K. Rosner (Ed.), *The encyclopedia of life support systems*. Oxford, England: UNESCO-EOLSS.

Schamber, L. (1994). Relevance and information behavior. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 29* (pp. 3-48). Medford, NJ: Learned Information.

Schamber, L., Eisenberg, M. B., & Nilan, M. S. (1990). A re-examination of relevance: Toward a dynamic, situational definition. *Information Processing & Management,* 26, 755-776.

Schauder, D. (1994). Electronic publishing of professional articles: Attitudes of academics and implications for the scholarly communication industry. *Journal of the American Society for Information Science,* 45, 73-100.

Seglen, P. O. (1992). The skewness of science. *Journal of the American Society for Information Science,* 43, 628-638.

Seglen, P. O. (1994). Causal relationship between article citedness and journal impact. *Journal of the American Society for Information Science,* 45, 1-11.

Seglen, P. O. (1998). Citation rates and journal impact factors are not suitable for evaluation of research. *Acta Orthopaedica Scandinavica,* 69, 224-229.

Sen, B. K. (1999). Symbols and formulas for a few bibliometric concepts. *Journal of Documentation,* 55, 325-334.

Sen, B. K., Pandalai, T. A., & Karanjai, A. (1998). Ranking of scientists: A new approach. *Journal of Documentation,* 54, 622-628.

Sengupta, I. N. (1992). Bibliometrics, informetrics, scientometrics and librametrics: An overview. *Libri,* 42, 75-98.

Shadish, W. R., Tolliver, D., Gray, M., & Sen Gupta, S. K. (1995). Author judgments about works they cite: Three studies from psychology journals. *Social Studies of Science,* 25, 477-498.

Small, H. (1982). Citation context analysis. In B. Dervin & M. Voigt (Eds.), *Progress in communication sciences: Volume 3* (pp. 287-310). Norwood, NJ: Ablex.

Small, H. (1999). Visualizing science by citation mapping. *Journal of the American Society for Information Science,* 50, 799-813.

Smith, A. G. (1999). A tale of two web spaces: Comparing sites using web impact factors. *Journal of Documentation,* 55, 577-592.

Snyder, H. W., & Bonzi, S. (1998). Patterns of self-citation across disciplines (1980-1989). *Journal of Information Science,* 24, 431-435.

Snyder, H. W., Cronin, B., & Davenport, E. (1995). What's the use of citation?: Citation analysis as a literature topic in selected disciplines of the social sciences. *Journal of Information Science,* 21, 75-85.

Snyder, H. W., & Rosenbaum, H. (1999). Can search engines be used as tools for web-link analysis?: A critical review. *Journal of Documentation,* 55, 375-384.

Tabah, A. (in press). Literature dynamics: Studies on growth, diffusion, and epidemics. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 34*. Medford, NJ: Information Today.

Tague-Sutcliffe, J. (1992). An introduction to informetrics. *Information Processing & Management,* 28, 1-3.

van de Sompel, H., & Hochstenbach, P. (1999a). Reference linking in a hybrid library environment, part 1: Frameworks for linking. *D-Lib Magazine* [On-line], 5(4). Available: http://www.dlib.org/dlib/april99/van_de_sompel/04van_de_sompel-pt1.html

van de Sompel, H., & Hochstenbach, P. (1999b). Reference linking in a hybrid library environment, part 2: SFX, a generic linking solution. *D-Lib Magazine* [On-line], 5(4). Available: http://www.dlib.org/dlib/april99/van_de_sompel/04van_de_sompel-pt2.html

van de Sompel, H., & Lagoze, C. (2000). The Sante Fe Convention of the Open Archives Initiative. *D-Lib Magazine* [On-line], 6(2). Available: http://www.dlib.org/dlib/february00/vandesompel-oai/02vandesompel-oai.html

van Hooydonk, G. (1998). Standardizing relative impacts: Estimating the quality of research from citation counts. *Journal of the American Society for Information Science,* 49, 932-941.

van Leeuwen, T. N., Moed, H. F., & Reedijk, J. (1999). Critical comments on Institute for Scientific Information impact factors: A sample of inorganic molecular chemistry journals. *Journal of Information Science,* 25, 489-498.

van Leeuwen, T. N., Moed, H. F., Tijssen, R. J. W., Visser, M. S., & van Raan, A. F. J. (2000). First evidence of serious language-bias in the use of citation analysis for the evaluation of national science systems. *Research Evaluation,* 9, 155-156.

van Raan, A. F. J. (1988). *Handbook of quantitative studies of science and technology*. Amsterdam: Elsevier.

van Raan, A. F. J. (1997). Scientometrics: State of the art. *Scientometrics,* 38, 205-218.

van Raan, A. F. J. (1999). Advanced bibliometric methods for the evaluation of universities. *Scientometrics*, 45, 417-423.

van Raan, A. F. J. (2000). The Pandora's box of citation analysis: Measuring scientific excellence: The last evil? In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 301-319). Medford, NJ: Information Today.

Vinkler, P. (1996). Relationships between the rate of scientific development and citations: The chances for a citedness model. *Scientometrics*, 35, 375-386.

Vinkler, P. (2000). Evaluation of the publication activity of research teams by means of scientometric indicators. *Current Science*, 79, 602-612.

Wagner-Dobler, R., & Berg, J. (1995). The dependence of Lotka's Law on the selection of time periods in the development of scientific areas and authors. *Journal of Documentation*, 51, 28-43.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of “small-world” networks. *Nature*, 393, 440-442.

White, H. D. (2000). Toward ego-centered citation analysis. In B. Cronin & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 475-496). Medford, NJ: Information Today.

White, H. D. (2001). Authors as citers over time. *Journal of the American Society for Information Science*, 52, 87-108.

White, H. D., & McCain, K. W. (1989). Bibliometrics. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 24* (pp. 119-186). Amsterdam: Elsevier.

White, H. D., & McCain, K. W. (1997). Visualization of literatures. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 32* (pp. 99-168). Medford, NJ: Information Today.

White, H. D., & McCain, K. W. (1998). Visualizing a discipline: An author co-citation analysis of information science, 1972-1995. *Journal of the American Society for Information Science*, 49, 327-355.

White, M. D., & Wang, P. (1997). A qualitative study of citing behavior: Contributions, criteria, and metalevel documentation concerns. *Library Quarterly*, 67, 122-154.

Wilson, C. S., & Hood, W. W. (in press). Informetric laws. In M. E. Williams (Ed.), *Annual review of information science and technology: Vol. 34*. Medford, NJ: Information Today.

Woolgar, S. (1991). Beyond the citation debate: Towards a sociology of measurement technologies and their use in science policy. *Science and Public Policy*, 18, 319-326.

Wormell, I. (1998). Informetric analysis of the international impact of scientific journals: How “international” are the international journals? *Journal of Documentation*, 54, 584-605.

Wouters, P. (1999). *The citation culture.* Unpublished Ph.D. thesis, University of Amsterdam, Amsterdam.

Wouters, P. (2000). Garfield as alchemist. In B. Cronin, & H. B. Atkins (Eds.), *The web of knowledge: A festschrift in honor of Eugene Garfield* (pp. 65-71). Medford, NJ: Information Today.

Yitzhaki, M. (1998). The "language preference" in sociology: Measures of "language self-citation", "relative own-language preference indicator", and "mutual use of languages". *Scientometrics,* 41, 243-254.

Table 1: 7-facet scheme for the classification of bibliometric studies of scholarly communication

A. BEHAVIOR	A1. Writing
	A2. Linking
	A3. Submission
	A4. Collaboration
B. ORIENTATION	B1. Behavioral
	B2. Methodological
C. GOAL	C1. Description
	C2. Explanation
	C3. Prediction
	C4. Evaluation
D. LEVEL OF AGGREGATION	D1. Person
	D2. Group
	D3. Domain
	D4. Nation
E. SCOPE	E1. Non-comparative
	E2. Comparative
F. EXTENT OF TRIANGULATION	F1. Single-method
	F2. Multi-method
G. FORMAT	G1. Research paper: empirical
	G2. Research paper: theoretical
	G3. Literature review
	G4. Reference work