A Classification of Author Co-citations

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Abstract

The term author co-citation is defined and classified according to four distinct forms: the *pure first-author co-citation*, the *pure author co-citation*, the *general author co-citation* and the special *co-author co-citation*. Each form can be used to obtain one count in an author co-citation study, based on a binary counting rule, which either recognizes the co-citedness of two authors in a given reference list (1) or does not (0). Previous studies using author co-citations, with the exception of Persson's all-author study, have relied solely on *first-autho*r co-citation counts as evidence of an author's *oeuvre* or body of work contributed to a research field. In this paper, we argue that an author's contribution to a selected field of study should not be limited, but should be based on his/her complete list of publications, regardless of author ranking. Examples are given for each author co-citation form defined in our classification scheme.

1. Introduction

Citation studies are mainly undertaken for faculty and institutional evaluation purposes (Moed et al., 1985), to study the structure and development of a scientific field (Small, 1999; Small & Griffith, 1974), or to study citer motivation (Brooks, 1985). Such studies may focus on different actors, including authors, journals, institutes, countries, scientific journals, or combinations thereof. In this article we focus on the 'co-citedness' of *authors* and the structure of a research field based on the research interests of its researchers.

Author Co-Citation Analysis (ACA) is a widely recognized research technique, which has received a significant amount of attention in past years (McCain, 1990b; Persson, 2001; White, 1986; 1990, and White & Griffith, 1981a,b; 1982). White and Griffith (1981a,b) introduced ACA in their study of authors from the field of judgment and decision research. Since the publication of this article, the standard references for researchers interested in applying the technique have been White's (1986) article on co-cited author retrieval and McCain's (1990a) technical overview. ACA has been used, e.g., to trace changes in a field over time (McCain, 1984), to test for the possibility of convergence among research traditions (Borgman & Rice, 1992), to test the "branching" model of scientific growth (Perry & Rice, 1998), and to understand how scholars seek and use information in the creation of new knowledge (Sandstrom, 1998).

Despite its widespread application, one of the interesting problems associated with ACA is that the term used to substantiate this bibliometric technique – *author co-citation* – has not been fully defined or classified according to various forms. Although there are different ways to *collect* and *observe* an *author co-citation*, the research literature mainly uses one definition, namely one that refers to "*oeuvres*" or "body of writings by the same author (or first author in collaborations)" (White & Griffith, 1982, p. 257). Expressed otherwise it is

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stated that "two authors are co-cited when at least one document in each other's *oeuvre* occurs in the same reference list" (McCain, 1990b, p. 195). The term *author co-citation* therefore needs further clarification. Consequently, we propose a new classification scheme: one that defines the various forms of author co-citedness and describes the techniques that might be used in Dialog™ to retrieve or collect co-citation data for an ACA. This description is inspired and guided in part by Christensen and Ingwersen's (1996) article, which concentrates more on the use of RANK, MAP and TARGET provided by Dialog™. In the following paragraphs a list of author co-citation forms is presented and for each form we provide a fictitious example.

2. Author Co-citation Forms: A Classification

Our proposed classification scheme is based on what 'being co-cited' can further tell us about a field's structure and the relationships among authors who contribute to this structure. Citing two papers with no authorship overlap, as shown in Example a, *might* contain a new clue about the intellectual relationship between the authors. Citing a co-authored paper, as shown in Example b, tells us *nothing new* about the relation (scientific interest) between joint authors.

Example a

> *Smith, K. (1990). A splendid result. The Alpha Journal.*
> *Thomas, T. (1991). The use of this-and-that: Part I. The Beta Journal.*

Example b

> *Smith, K. & Thomas, T. (1992). The k-procedure. The Gamma Journal.*
> *Thomas, T. & Smith, K. (1992). More details about the k-procedure. The Gamma Journal.*

The first form, Example a, is considered to be the purest (and most interesting) form. Example b by comparison is 'less pure' because there is already a given relationship or "intellectual similarity" between the authors, which does not result from 'being co-cited' (namely co-authorship).

Consequently the first principle of our classification scheme is to give preference to author co-citations that do not involve the type of co-authorship shown in Example b. A second classifying principle might be that if the order of the authors in a co-authorship pair is significant with respect to the claims or novelties brought forward by each collaborator, then preference may be given to the co-citation of first-authored articles over the co-citation of secondary-authored articles. This approach, however, is not studied in detail in this contribution. Note that it is clearly not always the case that ranking of authors in the byline reflects importance (the authors of this article are ordered alphabetically).

And finally, we consider co-citation counting as a form of binary counting (0-1 counting): one reference list produces at most one count for the total co-citation score of two authors (A,B). Once we have introduced the details of this full binary classification, we will suggest some further generalizations, including some non-binary methods.

2.1 Pure First-Author Co-citations

The term *pure first-author co-citation* refers to the situation where at least one publication with A as first or sole author and one publication with B as first or sole author co-occur in the reference list of an article. Articles, however, with A and B as co-authors are not taken into account. In practice, this means that when we examine a reference list for a particular pair of

authors, all articles with these two authors as co-authors are not included in the calculation of their pure first-author co-citation frequency.
Let us consider examples a and c. Example a yields one Smith-Thomas *pure first-author co-citation*. Equally, the next example c yields exactly one *pure first-author co-citation* for the Smith-Thomas pair even though there are two cited papers with Thomas as first author in the reference list (due to the binary method of counting).

Example c

Smith, K. (1990). A splendid result. The Alpha Journal.
Thomas, T. (1991). The use of this-and-that: Part I. The Beta Journal.
Thomas, T. & Zhang, W. (1992). The use of this-and-that: Part II. The Beta Journal.

Examples b and d however, do not yield a pure first-author co-citation for the pair Smith-Thomas. With example b there is a 0 co-citation count because of the co-authorship link between the pair of authors and with example d the pure first author form also yields a 0 count for the authors in question because both are ranked secondary.

Example d

Janssens, J. & Smith, K. (1996). The breakthrough. New World: Delta Publishers.
Peters, P., Zhang, W. & Thomas, T. (1999). The breakthrough revisited. The Alpha Journal.

2.2. Pure Co-citations

The term *pure co-citation* refers to a situation where at least one publication with A as a co-author (regardless of rank order) and one publication with B as a co-author (regardless of order) co-occur in the reference list of an article. However, articles with A and B as co-authors are, once again, not taken into account.

Every pure first-author co-citation is also a pure co-citation. Example d gives one pure co-citation for the Smith-Thomas pair. Examples b and e below, however, do not yield a pure co-citation for this pair.

Example e

Smith, K. & Thomas, T. (1992). The k-procedure. The Gamma Journal.
Thomas, T. & Smith, K. (1992). More details about the k-procedure. The Gamma Journal.
Rao, S. & Thomas, T. (1994). Problems with the k-procedure. The Gamma Journal.

Finally, example f yields one pure co-citation for Smith-Thomas, in that the first two articles are not taken into account, but the last two are.

Example f

Smith, K. & Thomas, T. (1992). The k-procedure. The Gamma Journal.
Thomas, T. & Smith, K. (1992). More details about the k-procedure. The Gamma Journal.
Rao, S. & Thomas, T. (1994). Problems with the k-procedure. The Gamma Journal.
Janssens, J. & Smith, K. (1996). The breakthrough. New World:Delta Publishers.

2.3 General Co-citations

The term *general co-citation* refers to a situation where at least one publication with A as a co-author, and one (additional) publication with B as a co-author co-occur in the same reference list. All pure co-citations, and consequently also all pure first-author co-citations are

general co-citations; but the *general co-citation* is distinct because this time articles co-authored by A and B are taken into account as well. This definition implies that examples b and e shown above are Smith-Thomas general co-citations. Example g, however, is not a Smith-Thomas general co-citation.

Example g

Smith, K. & Thomas, T. (1992). The k-procedure. The Gamma Journal.
Zhang, W. (1999). A local k-procedure. The Phi Journal.
Rao, S. & Janssens, J. (1998). A note on the m-procedure. The Iota Journal.

2.4 Co-Author Co-Citations Scores

The term *co-author co-citation* scores is used to suggest that in addition to the first three co-citation forms, a publication with A and B as co-authors can be used to count a special form of co-citation, which recognizes the intellectual link between the authors due to their collaborative work together. So in all the previous examples, including example g, we have at least one form of Smith-Thomas co-author co-citation.

Note that this classification scheme yields a hierarchy, beginning with: 1) *pure first-author co-citations*, 2) *pure co-citations*, 3) *general co-citations*, and 4) the "special" *co-author co-citation score*. Figure 1 is used to illustrate this hierarchy.

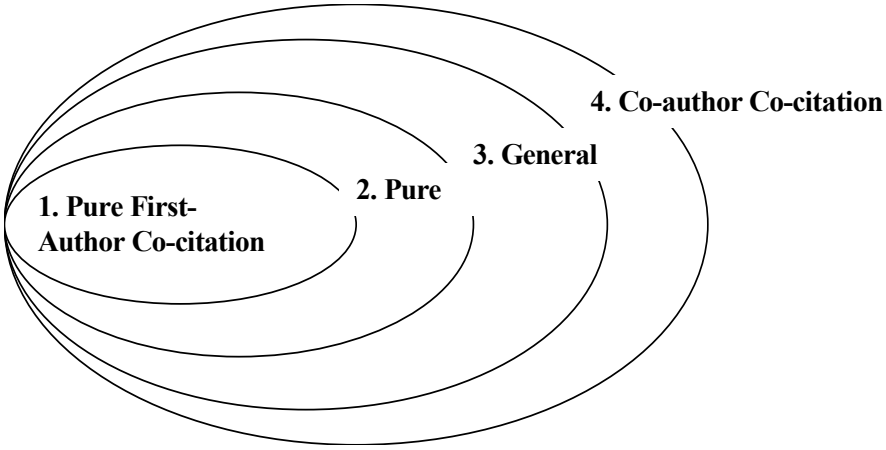

Figure 1. Classification hierarchy of author co-citation forms

2.5 Weighted Counting

In addition to the 'normal' (binary) form of counting, one may also use *weighted counting* to take into consideration the number of co-citations in the same document. For instance example c would, under a weighted counting scheme, yield two co-citation counts for the Smith-Thomas pair.

First-author co-citations, under another *weighted counting* scheme may also be weighted more heavily than secondary author co-citations. For example, in the reference list shown in example h the first two references might yield Smith and Thomas a co-citation count of 2 and the last two references, with Smith and Thomas listed as secondary authors might be given

only a standard co-citation count of 1. Note that this is just an example. Many other weighting schemes are feasible.

Example h

Smith, K. (1990). A splendid result. The Alpha Journal.
Thomas, T. & Zhang, W. (1992). The use of this-and-that: Part II. The Beta Journal.
Rao, S. & Thomas, T. (1994). Problems with the k-procedure. The Gamma Journal.
Janssens, J. & Smith, K. (1996). The breakthrough. New World: Delta Publishers.

2.6 Same-author co-citations

Finally the A-A co-citation, or *same-author co-citation*, deserves special mention, particularly in cases where A is not a co-author with B or with any other authors in question for an ACA. Example c, for instance, yields one Thomas-Thomas co-citation.

The s*ame-author co-citation* is relevant to the current diagonal problem in ACA, which focuses technically on what type of data should be added to the diagonal cells: missing, scaled or statistically complete data (Ahlgren, Jarneving, & Rousseau, 2003). In ACA the key to observing intellectual similarities between author pairs rests on the collection of inter-author co-citation counts. For this reason, a researcher may omit retrieving same-author co-citation counts (because authors are already intellectually similar to themselves) and leave the cells along the diagonal empty. On the other hand, data based on the number of times an author has been co-cited with him/herself (excluding self citations) yields a more mathematically complete co-citation matrix, which is statistically easier to study (Ahlgren, Jarneving, & Rousseau, 2003). A new retrieval method dedicated to this form of co-cited author count might therefore be of use in solving the diagonal problem.

2.7 Importance of these different forms

Clearly, every article that results from the collaborative work of different authors, and that is cited at least once in the dataset under investigation is captured when collecting co-authorship co-citations. Hence the resulting co-citation network will include an underlying co-authorship network. General co-citations also take co-authorship into account, but pure co-citations are intended not to include co-authorships. In this sense a pure co-citation network might be totally different from the underlying co-authorship network. It has the potential of leading to a complementary view on the field under investigation.

3. First-author co-citations as used in most ACA studies

In a *first-author co-citation*, as used in most ACA studies, at least one publication written by A as the first or sole author and one publication written by B as the first or sole author co-occurs in the reference list of an article. This co-occurrence of the surnames in one article gives only one first-author co-citation (a binary procedure) for the pair (A,B) and the data collection technique, which uses the authors' names as input forms the basis of what is known as a "traditional ACA".

Consequently, a series of first-author co-citation counts cannot contribute to a pure or general ACA and an alternative retrieval method is needed so that all author co-citations may be counted regardless of an author's rank. The first author co-citation form is most useful for illustrating “overall trends or dimensions in scholars’ approach toward research” and providing a “general historical view of the intellectual structure of a research area” (McCain,

1990b, p. 213). Nevertheless, if an ACA is designed to determine the historical development or thematic structure of a field, our view is that it does not make sense conceptually to omit certain authors (i.e., secondary authors), particularly if they have been participants all along in the development of that structure. Some authors who make significant contributions to a research field collaborate frequently with other members from this field and this fact cannot be ignored. For instance, Persson (2001) recently compared the structure of a first-author co-citation map to that of an all-author co-citation map of the field of information studies, and found that it is a "risky business to rank the most influential researchers by first author citations only" (p.342). What this means is that the new authors who were added to the structure probably should have been there in the first place and were not included because they simply had been ranked for non-essential (e.g., alphabetical) reasons. In those cases, first authorship does not necessarily reflect level of contribution. An ACA must therefore be open to the inclusion of all authors, regardless of their co-authorship rank, and must be open to different retrieval and counting methods other than the traditional first-author binary count that is currently used.

4. How to determine a co-citation matrix with existing Dialog™ software capability?

Assume we want to determine the number of times authors A and B are co-cited in the ISI-database(s) (e.g., *Science Citation Index, Social Sciences Citation Index, Arts & Humanities Citation Index, Web of Knowledge*). First we have to determine which kind of co-citation counts we want to consider: traditional first-author co-citations, or pure first-author ones, or pure and/or general co-citations? Since the traditional first-author case is well known we will not examine it, but focus instead on the other co-citation forms of counting.

In addition to choosing the kind of co-citation (according to our classification scheme), we may also want to introduce other constraints. Perhaps, we are only interested in publications dealing with a certain topic, or articles published in journals covered by ISI, or articles published during a certain time span, or articles cited during a fixed citation window. All these constraints are likely to complicate the retrieval process considerably.

The first step in an ACA exercise would be to compile a complete publication list for A, and for B. Complete here means taking into account the restrictions noted above, for instance, all publications in ISI journals published during the period 1995-2000, or perhaps 'all publications ever written.' This leads to the construction of lists similar to those shown in Table 1. In this table, A, B, X, Y, etc. symbolize authors, while xxxxxx represents other types of bibliographical data (i.e., title, journal name, volume number, page number, etc.)

Table 1. Complete publication lists of authors A and B

A	B
A X Y, xxxxx	*B, xxxxx*
X A Z H, xxxxx	*B Z, xxxxx*
T Y H A, xxxxx	*T A S B, xxxxx*
T A S B, xxxxx	*U B, xxxxx*

With the lists composed, we can then search for each publication as a Cited Reference (CR), using complete bibliographic data, in Dialog™ format, assuming that there are no errors (e.g. mistyped volume) or omissions (e.g. volume is not mentioned) in the database.

This leads to a set S1 consisting of all articles citing document *AXY,xxxx*, and further sets S2, S3 and S4 consisting of all articles citing documents *XAZH,xxxxxxx*, *TYHA,xxxxx* and *TASB,xxxxx*. Under author B, S5 consists of all articles citing document *B,xxxx* and so on (for all A and all B publications).

To illustrate the procedure further, we present a second table, Table 2, with a 'real' example of a short (incomplete) publication list of two authors: P. S. ASPINWALL and D. R. MORRISON. Both authors are theoretical physicists and the bibliographic data for their lists has been extracted from Dialog™ MathSci.

Table 2. Example publication lists for authors P. S. ASPINWALL and D. R. MORRISON

A: P. S. ASPINWALL	B: D. R. MORRISON
1. **Aspinwall, P. S**. Enhanced gauge symmetries and $K3$ surfaces. Phys. Lett. B 357 (1995), no. 3, 329--334.	5. **Morrison, D. R**.; Vafa, C. Compactifications of F-theory on Calabi-Yau threefolds. I. Nuclear Phys. B 473 (1996), no. 1-2, 74--92.
2. **Aspinwall, P. S**.; Greene, B. R. On the geometric interpretation of $N=2$ superconformal theories. Nuclear Phys. B 437 (1995), no. 1, 205--227.	6. **Morrison, D. R**.; Vafa, C. Compactifications of F-theory on Calabi-Yau threefolds. II. Nuclear Phys. B 476 (1996), no. 3, 437--469.
3. **Aspinwall, P. S**.; **Morrison, D. R**. U-duality and integral structures. Phys. Lett. B 355 (1995), no. 1-2, 141--149.	7. **Aspinwall, P. S**.; **Morrison, D. R**. U-duality and integral structures. Phys. Lett. B 355 (1995), no. 1-2, 141--149.
4. **Aspinwall, P. S**. Point-like instantons and the ${\rm Spin}(32)/Z\sb 2$ heterotic string. Nuclear Phys. B 496 (1997), no. 1-2, 149--176.	8. **Distler, J.; Greene, B. R**.; **Morrison, D. R**. Resolving singularities in $(0,2)$ models. Nuclear Phys. B 481 (1996), no. 1-2, 289--312.

To begin the co-citation procedure, we use the EXPAND command provided by Dialog™ to search for the cited reference form (CR) of each listed paper (e.g., #4 = e CR=ASPINWALL PS, 1997, V496, P149, NUCL PHYS B). We then use the CR data to form the set T_A = S1 ∪ S2 ∪ S3 ∪ S4, consisting of all articles that cite at least one of the A-publications (ASPINWALL). Similarly, we form the set T_B = S5 ∪ S6 ∪ S7 ∪ S8 consisting of all articles that cite at least one of the B-publications (MORRISON). The search procedure in Dialog™ for both ASPINWALL and MORRISON yielded the following results:

$$\#(T_{A\ (ASPINWALL)}) = 149$$
$$\#(T_{B\ (MORRISON)}) = 196$$

Next, we form $U = T_A \cap T_B$, consisting of all articles that co-cite (at least) one A-publication (ASPINWALL) and (at least) one B-publication (MORRISON). This lead to:

$$\#(U) = \#(T_{A\ (ASPINWALL)} \cap T_{B\ (MORRISON)}) = 43$$

Generally, if the same article appears in the first list of A-publications, and occurs also in the second list of B-publications, then two of the S-sets are identical. In this case, we know from Table 2 that ASPINWALL and MORRISON share one co-authored article in their respective publication sets: S3 is equal to S7; therefore, it is a part of the intersection (the U-set). This example illustrates the procedure for co-author co-citation scores.

4. How to find pure first-author, pure or general co-citations?

Suppose we are not interested in counting co-author co-citations and want only the number of *pure first-author*, *pure co-citations* or *general co-citations*? To find all *pure first-author co-citations*, we remove all articles from the two lists of publications (the A-list and the B-list) where A and B are identified as co-authors. We also remove all articles where ASPINWALL or MORRISON is not the first author. This leads to the articles shown in Table 3. This gives T-sets consisting of all articles that cite at least one first-authored article, for instance, by A. This cited A article, moreover, is certainly not co-authored by B. An article in the corresponding U-set is thus one that co-cites at least one A first-authored article, and one B first-authored article, and which does not include any co-authored publications by A and B.

Table 3. Restricted publication lists for authors P. S. ASPINWALL and D. R. MORRISON, used for the calculation of *pure first-author co-citations* (numbering is kept the same as in Table 2).

A: P. S. ASPINWALL	B: D. R. MORRISON
1. **Aspinwall, P. S**. Enhanced gauge … 357	5. **Morrison, D. R**.; Vafa, C. Compactifications I …
2. **Aspinwall, P. S**.; Greene, B. R. On the … 437	6. **Morrison, D. R**.; Vafa, C. Compactifications II …
4. **Aspinwall, P. S**. Point-like instantons … 496	

In this case $T_A = S1 \cup S2 \cup S4$, while $T_B = S5 \cup S6$. We found the following results:

$$\#(T_{A\ (ASPINWALL)}) = 132$$
$$\#(T_{B\ (MORRISON)}) = 170$$

$$\#(U) = \#(T_{A\ (ASPINWALL)} \cap T_{B\ (MORRISON)}) = 20$$

This means that there are 20 pure first-author co-citations for the pair of authors in this small set of publications.

For the coupling of all *pure author co-citations*, all A and B co-authored papers are removed again from the A and B publication lists. However, if A or B are ranked as secondary authors in joint papers with 'other' authors (C, D, E etc), these articles are included, leading to Table 4. (Note: ASPINWALL is always first-named author in Dialog™ MathSci; therefore we could not include an example where he was secondary author.) This gives T-sets consisting of all articles that cite at least one first or co-authored article, for instance, by A. This cited A article however, is not co-authored by B (by the removal of co-authored articles). An article in the corresponding U-set is thus one that co-cites at least one A-authored article, and one B-authored article, but does not include any articles co-authored by A and B.

Table 4. Restricted publication lists for authors P. S. ASPINWALL and D. R. MORRISON, used for the calculation of *pure author co-citations* (numbers are kept the same as in Table 2).

A: P. S. ASPINWALL	B: D. R. MORRISON
1. **Aspinwall, P. S**. Enhanced gauge symmetries …	5. **Morrison, D. R**.; Vafa, C. Compactifications …
2. **Aspinwall, P. S**.; Greene, B. R. On the …	6. **Morrison, D. R**.; Vafa, C. Compactifications. II….
4. **Aspinwall, P. S**. Point-like …	8. **Distler, J.; Greene, B. R**.; **Morrison, D. R**. Resolving singularities …

A *pure author co-citation* data collection procedure, carried out in Dialog™ SciSearch, yielded a total of 22 pure author co-citation counts (based on Table 4).

$$\#(U) = \#(T_{A\,(ASPINWALL)} \cap T_{B\,(MORRISON)}) = 22$$

Finally, obtaining *general co-citations* is the most elaborate procedure. First, one obtains the T sets T_A and T_B as in the pure co-citation case. Then, one determines S sets for all co-authored publications: S_{AB1}, S_{AB2}, S_{AB3}, …etc. These are the sets of articles citing co-authored article ABj, j = 1,2,3… etc. (note that in the case of ASPINWALL and MORRISON there is only one co-authored article S_{AB1} common to the two authors' publication lists). In addition, we form the union of all these S sets, and denote this new set by T_{AB}. Thus, T_{AB} consists of all articles that cite, among other ones, at least one A-B co-authored article.

The next step, is to form the sets $U_1 = T_A \cap T_B$, $U_2 = T_A \cap T_{AB}$ and $U_3 = T_B \cap T_{AB}$. The set U_1 is the U-set obtained for the pure co-citation case. The set U_2 consists of all articles that co-cite at least one article co-authored by A (but certainly not by B) and an article co-authored by A and B. Similarly, U_3 consists of all articles that co-cite at least one article co-authored by B (but certainly not by A) and an article co-authored by A and B. For the final result, a search is carried out for $U = U_1 \cup U_2 \cup U_3$ and number of elements in this U-set is equal to the number of A-B general co-citations. For the ASPINWALL-MORRISON example we found:

$$\#(U) = \#([T_{A\,(ASPINWALL)} \cap T_{B\,(MORRISON)}] \cup [T_{A\,(ASPINWALL)} \cap T_{AB\,(ASPINWALL\text{-}MORRISON)}] \cup (T_{B\,(MORRISON)} \cap T_{AB\,(ASPINWALL\text{-}MORRISON)}]) = 31$$

Note that, as expected, the totals obtained in the four cases form an ascending sequence (cf. Fig.1): $20 < 22 < 31 < 43$.

5. Conclusion

The term author co-citation has been defined more precisely than was previously done, and further classified according to four distinct forms: the *pure first-author co-citation*, the *pure author co-citation*, the *general author co-citation* and the special *co-author co-citation*. We have argued that an author's contribution to a selected field of study should not be limited to first authorship, but should be based on his/her complete list of publications, regardless of author ranking. Examples were given for each author co-citation form defined in our classification scheme.

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