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"Interdisciplinarity" and "Synergy" in the *Œuvre* of Judit Bar-Ilan

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Abstract

Both "interdisciplinarity" and "synergy" are desirable features from a policy perspective: can surplus be found in the interactions among (disciplinary) bodies of knowledge? We have recently developed measures for "interdisciplinarity" and distinguished these measurements from those of "synergy." In this study, we analyze three review papers by Judit Bar-Ilan (Scientometrics 50(1):7–32, 2001, Ann Rev Inf Sci Technol (ARIST) 38:231–288, 2004, J Informetr 2(1):1–52, 2008a) in terms of whether they rank high on interdisciplinarity and synergy values among the 130 papers of her *œuvre*. Review papers can be expected to fulfill a synergetic and perhaps also interdisciplinary function in scientific literature more than research articles, since the literature is considered from a broader perspective. Both the interdisciplinarity and synergy indicators point to Bar-Ilan (2004). The three reviews have high synergy scores. Whereas Bar-Ilan (2008a) contributed to the redefinition and shaping of the discipline of "information science," Bar-Ilan (2004) added the broader perspective of the theoretical and practical relevance of the discipline. Bar-Ilan (2001) reviews various methods for data collection at the Internet. An article of Bar-Ilan and Peritz (2002) in Library Trends scores also high on synergy.

Keywords Interdisciplinarity · Synergy · Priority programs · Reviews · Measurement

This paper is dedicated to the memory of Judit Bar-Ilan (1958–2019), an outstanding scholar and an inimitable friend and colleague.

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Introduction

Judit Bar-Ilan was a colleague and friend. She passed away on 16 July 2019; we will miss her and her valuable contributions to information science.

For the occasion of this memorial issue, we analyze her *œuvre* of 130 full papers in the Web-of-Science (WoS, Clarivate Analytics) from the perspective of recent advancements in the measurement of "interdisciplinarity" and "synergy." One of Judit's papers (Bar-Ilan 2008a, entitled "Informetrics at the beginning of the twentieth century—A review") contains an exceptional bibliography of 610 references. One can expect this review to provide more synergy than other papers. The interdisciplinarity among the cited references may also be different from normal in such a large set. A focus on Judit's *œuvre* may thus offer us an opportunity to sharpen our understanding of these measures at the level of an individual author (i.e., with a sample of specifically selected publications). We apply methods which have been explained elsewhere in more detail (Leydesdorff et al. 2019; Leydesdorff and Ivanova, under review) in order to evaluate and appreciate this *œuvre*.

A search with Judit's name in the WoS database on 7 September 2019, called up 130 papers in 38 journals. Eleven of these papers were attributed to "Barilan J" (without hyphen) and 119 to "Bar-Ilan J" (with hyphen).¹ One hundred eleven of these papers (85.4%) appeared in journals classified by Clarivate Analytics as "information science and library science." Fifty percent of the papers appeared in only four journals; these journals are listed in Table 1.

The 130 papers were cited 2725 times and contain 4746 references (Table 2). Of these references, 1943 are unique venues. Menu of these references are to reports, emails, and other communications. We use the valued matrix of 130 papers against 1943 unique cited venues as the basis for the analysis. The matrix is valued because the same journal can be cited several times in a specific reference list. The values are the numbers of bibliographic couplings (Kessler 1963) among journals cited. (Since the measurement of synergy is computationally intensive, we used in this case only the 540 reference titles which were cited more than once.)

Five of the 130 papers were classified as review articles by the provider of the Web-of-Science; three of these were first-authored by Judit. We focus on these three papers:

- 1. Bar-Ilan (2008a) with the noted bibliography of 610 cited references. This review article provides a comprehensive overview of developments in informetrics between 2000 and 2006.
- Bar-Ilan (2004) discusses literature dealing with the use of search engines in informationscience research. This paper was published in the *Annual Review of Information Science and Technology* edited by Blaise Cronin, who sought to broaden the scope of the discipline with this series (Sugimoto 2016).
- 3. Bar-Ilan (2001) discusses various methods that can be used for data collection from the Internet for informetric purposes. Despite its ambitious scope, this paper is perhaps more a research article in *Scientometrics*, but was registered as a "review" because of the use of this word in the title.² This paper provides an overview of data collection methods for informetric-research purposes.

¹ These results agree with the information on Judit's Publon site at https://publons.com/researcher/28689 68/judit-bar-ilan.

² Clarivate's criterion for classifying papers as reviews is as follows: "In the *JCR* system any article containing more than 100 references is coded as a review. Articles in 'review' sections of research or clinical journals are also coded as reviews, as are articles whose titles contain the word 'review' or 'overview'" (at http://thomsonreuters.com/products_services/science/free/essays/impact_factor/ (retrieved 8 April 2012). A less precise definition can currently be found at https://clarivate.com/webofsciencegroup/essays/impact t-factor/ (retrieved on 13 October 2019).

Table 1Journals with the largestnumber of publications by JuditBar-Ilan

Ν	%
27	20.8
18	13.8
14	10.8
6	4.6
65	50.0
	N 27 18 14 6 65

Of these eighteen papers, twelve were published in the *Journal of the American Society for Information Science and Technology* and six in the *Journal of the Association for Information Science and Technology.* The name (but not the abbreviation) of the journal was changed in 2014

Table 2 Three review articles of which Judit Bar-Ilan was first author

Paper	Cited	%	N of refs.	%
Bar-Ilan J, 2008, J INFORMETR, V2, P1 "Informetrics at the beginning of the 21st century—A review"	179	6.6	610	12.9
Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231 "The use of Web search engines in information science research"	58	2.1	191	4.0
Bar-Ilan J, 2001, SCIENTOMETRICS, V50, P7 "Data collection methods on the Web for informetric purposes—A review"	79	2.9	73	1.5
Sum	316	11.6	874	18.4
127 other papers in the set Total	2409 2725	88.4	3872 4746	81.6

The measurement of "interdisciplinarity" and "synergy"

When policy-makers prioritize "interdisciplinarity" they most likely mean a form of "synergy," that is, the creation of additional options generated by interactions among disciplinary bodies of knowledge. In recent papers (e.g., Leydesdorff et al. 2019), we have further developed measures for "interdisciplinarity" and distinguished the measurement of "interdisciplinarity" from that of "synergy" (Leydesdorff and Ivanova, under review). The two concepts complement each other and sometimes overlap in practice, but their theoretical background and operationalization are different.

Synergy is a *result* of interactions among subsets, whereas interdisciplinarity can also be considered as a means to generate synergy. From this perspective, interdisciplinarity can be considered as a *process* characteristic of an R&D process, whereas synergy is a *product* characteristic. In university-industry-government relations, for example, the objective is the generation of synergy, and interdisciplinarity may be a means to this end. Other factors, such as teams with researchers from different institutions or countries, or researchers representing various academic generations, can also contribute to interdisciplinarity and synergy.

Interdisciplinarity

Interdisciplinarity can be measured in a variety of ways. On the basis of a literature review, Stirling (2007) and cf. Rao (1982) proposed combining three existing measures of diversity—"variety," "balance," and "disparity"—into a single measure, as follows (e.g., Rafols and Meyer 2010; Rao 1982; Stirling 2007):

$$\Delta = \sum_{i,j} (p_i p_j)^{\alpha} d_{ij}^{\beta} \tag{1}$$

For the least complex case of $\alpha = \beta = 1$, this measure $[\Delta = \sum_{i,j} p_i p_j d_{ij}]$ is also called Rao-Stirling (RS) diversity. In Eq. 1 the Simpson index $[\sum_{i,j} (p_i p_j)]$ first combines variety and balance, whereas the factor d_{ij} represents disparity. The combination of the first two factors into the Simpson index is also called "dual concept" diversity.

RS is also known as the "integration score" developed by Porter et al. (2006, 2007; cf. Porter and Chubin 1985). More recently, Zhang et al. (2016) have proposed replaceing RS with "true" diversity. This measure ${}^{2}D^{3}$ is monotonously increasing and decreasing with RS as follows:

$${}^{2}D^{3} = 1/(1-\Delta)$$
 (2)

The advantage of "true" diversity is that one diversity can be expressed as a percentage of another, thus providing a measure for above- and below-expected values in the evaluation. Note that "true" diversity is not bounded between zero and one. We use ${}^{2}D^{3}$ as one of the measures of interdisciplinarity in this study.

Leydesdorff et al. (2019) proposed measuring "variety" and "balance" independently that is, unlike the Simpson Index—on the basis of Nijssen et al.'s (1998) conclusion that the Gini index is a measure of balance, but not of variety. This allows us to write:

$$\text{DIV}_{c} = [n_{c}/N] \cdot [1 - \text{Gini}] \cdot \left[\sum_{\substack{i=n_{c} \\ i=n_{c} \\ j=1, \\ i \neq j}}^{j=n_{c}} d_{ij} / [n_{c} * (n_{c} - 1)]\right]$$
(3)

The three components (between zero and one) are indicated in Eq. 3 with brackets. The right-most factor in this equation is similar to the disparity measure used in RS diversity (in Eq. 1), albeit normalized differently. The other two factors represent relative variety as (n_c/N) and balance measured as (1-Gini). Rousseau (2019) further improved DIV into a "true" diversity measure DIV* as follows:

$$\mathrm{DIV}^* = (N * \mathrm{DIV}) \tag{4}$$

It follows that:

$$\text{DIV}^* = n_c \cdot [1 - \text{Gini}] \cdot \left[\sum_{\substack{i=n_c \\ i=n_c \\ j=1, \\ i \neq j}}^{j=n_c} d_{ij} / [n_c * (n_c - 1)] \right]$$
(5)

DIV* is a "true" measure of diversity defined in terms of variety, balance, and disparity.

Synergy

Whereas the measurement of diversity is rooted in ecology and economics, the measurement of synergy, in terms of additional options made available when subsets are combined, finds its origin in Shannon's (1948) information theory and in systems theory. In information theory the sum of the possible, but not yet realized states of a system (the redundancy) and the realized ones (the uncertainty) is by definition equal to the system's maximum information capacity. Synergy among subroutines or subsystems means that a system contains in total more states than the sum of its parts. When a system grows, for example, the number of both realized and possible states may increase, but without a necessary coupling between the two growth rates (Brooks and Wiley 1986). When the redundancy increases more than the relative uncertainty, synergy is generated as negative entropy.

This is not the place to explain the indicator in detail; this is elaborated in another paper (Leydesdorff and Ivanova, under review). Here, we apply the measure pragmatically to Judith Bar-Ilan's *œuvre* as a test case. Does the application of this indicator to this data provide new insights? Which nodes and links (in terms of bibliographic couplings at the journal level) contribute to synergy in the system? Is synergy concentrated in specific parts of the network?

Synergy can be measured as mutual information among *three* or more subsystems. While mutual information between two random variables ($T_{xy} = H_x + H_y - H_{xy}$) is always and necessarily larger than or equal to zero (Theil, 1972; Leydesdorff et al. 2017), a third dimension can spuriously correlate with the other two, and thus reduce or add to the uncertainty as a contextual factor. For example, the answers of two parents to questions from their child can sometimes be almost identical. Analogously, mutual information among *three* or more subsystems can be positive, negative, or zero (e.g., McGill 1954; McGill and Quastler 1955; Yeung 2008).

The number of possible combinations among three sets is $n^*(n-1)^*(n-2)/(2^*3)$. For n=130, this results in $(130^*129^*128)/(2^*3)=357,760$ possible triads. Secondly, each *link* can be part of $n^*(n-1)/2$ triads; for n=130, this amounts to $(130^*129/2=)$ 8385 possible links in triads; some triads generate redundancy, others entropy. Thirdly, each *node* can be involved in n-1=129 links, of which some are parts of triads which generate redundancy. Not amazingly given the focus in our data collection, all nodes and links in this data generate more synergy (redundancy; $T_{123} \le 0$) than uncertainty (information; $T_{123} \ge 0$).

By summing the negative and positive values of T_{123} for each paper's participation in a triad of papers, we can attribute their respective participations in the generation of redundancy and entropy, respectively. Links are similarly partaking in triads with positive and negative signs for the bibliographic coupling. The core set of links and nodes which contribute to the synergy can also be mapped.

Results

In the following three tables, we limit the discussion first to the top-15 papers in each dimension, but the values were computed over all references in each case. We have added betweenness centrality to the comparison since this indicator has also been considered as a measure of interdisciplinarity (e.g., Leydesdorff 2007; cf. Abbasi et al. 2012). The three reviews are boldfaced in each table if ranked among the top-15 values of the respective lists.

- Table 3 provides descriptive statistics about "times cited" at the retrieval date (7 September 2019) and the numbers of references;
- Table 4 shows the top-15 values of ²D³ and DIV* as two "true" diversity measures of interdisciplinarity;
- Table 5 shows the top-15 values for synergy in an analogous manner.

The three reviews are boldfaced in each table if ranked among the top-15 values of the respective lists. Table 6 summarizes the findings by providing the rank-order position of the three review articles in the set of 130 papers on each respective dimension.

Descriptive statistics

Table 3 provides descriptive statistics of times cited and numbers of references in decreasing order for the 15 most-highly ranked papers in the respective dimensions. Bar-Ilan's (2008a) review in the *Journal of Informetrics* is ranked first in terms of the number of references, but only second in terms of the times cited. Bar-Ilan (2008b), entitled "Which h-index?—A comparison of WoS, Scopus and Google Scholar" and published in *Scientometrics*, has hitherto been cited more often.

On the citing side, Bar-Ilan (2008a) is in the first position, followed by the 2004-review published in *ARIST* containing 191 references. This paper, entitled "The use of Web search engines in information science research," is perhaps less frequently cited because the source journal is not so widely available as the central journals of the field, such as *Scientometrics, JASIST*, and the *Journal of Informetrics*. The third review (Bar-Ilan, 2001), entitled "Data collection methods on the Web for informetric purposes – A review," follows at the ninth place with only 73 references. As noted, this paper was probably registered as a "review" because of the use of this word in the title.

Figure 1 shows the main path among eleven papers of the set using Single Path Link Count for the extraction and the analysis (Lucio-Arias and Leydesdorff 2008, p. 1951). The resulting figure confirms that the 2004 review in *ARIST* is not on the main path, probably because of the different objectives of this venue and its lower numbers of citations than the other two reviews. Four groupings on the main path—indicated with different colors— are distinguished similarly by both VOSviewer and the Louvain algorithm (Blondel et al. 2008). The two other reviews are positioned at the begin of the green and yellow colored sections on this path, respectively.

Interdisciplinarity

Table 4 shows the top 15 papers ranked on both ${}^{2}D^{3}$ and DIV* as two "true" measures of interdisciplinary diversity. None of the three review papers, however, is indicated as

Table 3 Fifteen papers with highest scores on "times cited" at	nd "numbers of cited	references," respectively	
	Times cited		NC
Bar-Ilan J, 2008, SCIENTOMETRICS, V74, P257	323	Bar-Ilan J, 2008, J INFORMETR, V2, P1	61(
Bar-Ilan J, 2008, J INFORMETR, V2, P1	179	Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231	19
Aguillo IF, 2010, SCIENTOMETRICS, V85, P243	109	Perez O, 2019, MOD LAW REV, V82, P240	36
Haustein S, 2014, SCIENTOMETRICS, V101, P1145	103	Perez O, 2018, J INF TECHNOL POLITI, V15, P278	8
Bar-Ilan J, 2010, SCIENTOMETRICS, V82, P495	93	Bronstein J, 2018, ASLIB J INFORM MANAG, V70, P551	8

	Times cited		N of refs.
Bar-Ilan J, 2008, SCIENTOMETRICS, V74, P257	323	Bar-Ilan J, 2008, J INFORMETR, V2, PI	610
Bar-Ilan J, 2008, J INFORMETR, V2, P1	179	Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231	191
Aguillo IF, 2010, SCIENTOMETRICS, V85, P243	109	Perez O, 2019, MOD LAW REV, V82, P240	98
Haustein S, 2014, SCIENTOMETRICS, V101, P1145	103	Perez O, 2018, J INF TECHNOL POLITI, V15, P278	88
Bar-Ilan J, 2010, SCIENTOMETRICS, V82, P495	93	Bronstein J, 2018, ASLIB J INFORM MANAG, V70, P551	83
Shema H, 2014, J ASSOC INF SCI TECH, V65, P1018	88	Amichai-Hamburger Y, 2016, COMPUT HUM BEHAV, V55,	83
Shema H, 2012, PLOS ONE, V7, P	80	Bar-Ilan J, 2002, LIBR TRENDS, V50, P371	78
Bar-Ilan J, 2001, SCIENTOMETRICS, V50, P7	79	Halevi G, 2017, J INFORMETR, V11, P823	75
BARILAN J, 1993, J ALGORITHM, V15, P385	77	Bar-Ilan J, 2001, SCIENTOMETRICS, V50, P7	73
Bar-Ilan J, 2004, SCIENTOMETRICS, V59, P391	66	Aharony N, 2018, J LIBR INF SCI, V50, P3	71
Bar-Ilan J, 2005, INFORM PROCESS MANAG, V41, P973	65	Bronstein J, 2016, ASLIB J INFORM MANAG, V68, P793	71
Bar-Ilan J, 2007, J INFORMETR, V1, P26	63	Zhitomirsky-Geffet M, 2016, ASLIB J INFORM MANAG,	64
Bar-Ilan J, 2005, J INF SCI, V31, P297	60	Shema H, 2015, J ASSOC INF SCI TECH, V66, P1136	61
Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231	58	Bar-Ilan J, 2008, SCIENTOMETRICS, V74, P257	61
Bar-Ilan J, 2006, COMPUT NETW, V50, P1448	53	Barsky E, 2012, J AM SOC INF SCI TEC, V63, P1987	59

	$^{2}D^{3}$		DIV*
Bar-Ilan J, 2009, SCIENTOMETRICS, V79, P7	3.11	Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231	25.8
Aharony N, 2019, J LIBR INF SCI, V51, P843	3.09	Bronstein J, 2016, ASLIB J INFORM MANAG, V68, P793	21.6
Zhitomirsky-Geffet M, 2018, J ASSOC INF SCI TECH,	2.93	Zhitomirsky-Geffet M, 2016, ASLIB J INFORM MANAG,	20.7
Bar-Ilan J, 2007, J INFORMETR, V1, P26	2.91	Bar-Ilan J, 2009, SCIENTOMETRICS, V79, P7	20.5
Zhitomirsky-Geffet M, 2017, J ASSOC INF SCI TECH,	2.86	Halevi G, 2017, J INFORMETR, V11, P823	20.5
Halevi G, 2017, PUBLISH RES Q, V33, P56	2.80	Zimmerman E, 2009, ONLINE INFORM REV, V33, P22	20.5
Shema H, 2014, J ASSOC INF SCI TECH, V65, P1018	2.79	Haustein S, 2014, SCIENTOMETRICS, V101, P1145	20.3
Halevi G, 2016, PUBLISH RES Q, V32, P187	2.78	Zhitomirsky-Geffet M, 2017, J ASSOC INF SCI TECH,	19.4
Bar-Ilan J, 2011, ONLINE INFORM REV, V35, P854	2.76	Bar-Ilan J, 2007, J COMPUT-MEDIAT COMM, V12, P910	19.4
Bar-Ilan J, 2015, SCIENTOMETRICS, V102, P2247	2.74	Bar-Ilan J, 2001, SCIENTOMETRICS, V50, P7	18.9
Bar-Ilan J, 2005, INFORM PROCESS MANAG, V41, P973	2.67	Bar-Ilan J, 2007, J AM SOC INF SCI TEC, V58, P1254	18.6
Bar-Ilan J, 2010, SCIENTOMETRICS, V82, P495	2.67	Bar-Ilan J, 2008, J INFORMETR, V2, P1	18.5
Moed HF, 2016, J INFORMETR, V10, P533	2.67	Bar-Ilan J, 2006, COMPUT NETW, V50, P1448	18.2
Fenner T, 2018, PLOS ONE, V13, P	2.67	Fink-Shamit N, 2008, INFORM RES, V13, P	18.1
Zhitomirsky-Geffet M, 2016, ASLIB J INFORM MANAG,	2.64	Gazit T, 2018, INFORM RES, V23, P	17.9

Table 4 Fifteen papers with highest scores on ${}^{2}D^{3}$ and DIV *, respectively

	Synergy in bits
- Bar-Ilan J, 2004, ANNU REV INFORM SCI, V38, P231	-3513
Bar-Ilan J, 2008, J INFORMETR, V2, P1	- 2968
Bar-Ilan J, 2002, LIBR TRENDS, V50, P371	-2679
Bar-Ilan J, 2001, SCIENTOMETRICS, V50, P7	- 2582
Bar-Ilan J, 2002, J INF SCI, V28, P455	- 1888
Bar-Ilan J, 2002, J AM SOC INF SCI TEC, V53, P308	- 1553
Bar-Ilan J, 2004, SCIENTOMETRICS, V59, P29	-1500
Bar-Ilan J, 2008, SCIENTOMETRICS, V74, P257	- 1498
Bar-Ilan J, 2005, INFORM PROCESS MANAG, V41, P973	- 1495
Bar-Ilan J, 2006, COMPUT NETW, V50, P1448	-1441
Bar-Ilan J, 2004, J AM SOC INF SCI TEC, V55, P980	-1412
Bar-Ilan J, 2008, SCIENTOMETRICS, V75, P591	-1401
Ravid G, 2006, LECT NOTES COMPUT SC, V4032, P26	-1381
Bar-Ilan J, 2009, J AM SOC INF SCI TEC, V60, P1730	-1360
Ravid G, 2007, J INF SCI, V33, P567	-1352

 Table 5
 Fifteen papers with highest scores on "synergy" (with other papers in the sample)

	Bar-Ilan (2001)	Bar-Ilan (2004)	Bar-Ilan (2008a)
Times cited	8	14	2
N of references	11	2	1
$^{2}D^{3}$	38	68	113
DIV*	14	2	28
Synergy	4	1	2
Betweenness centrality	16	11	6
DIV* Synergy Betweenness centrality	14 4 16	2 1 11	28 2 6

Table 6 Rankings of the three review articles under study in the full set of 130 papers



Fig. 1 Eleven papers on the main path among the "local citations" within the set of 130 papers authored by Judit Bar-Ilan. Citation weights on the basis of SPLC (Search path link count)

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highly "interdisciplinary" using ${}^{2}D^{3}$ as the measure. Bar-Ilan (2004) is indicated as the most "interdisciplinary" using the DIV* measure. When measuring "interdisciplinary" using ${}^{2}D^{3}$, however, Bar-Ilan (2008a) ranks only in 113th position and is thus not visible in this list. Using this indicator for "interdisciplinarity," neither Bar-Ilan (2008a) nor Bar-Ilan (2001) are indicated as interdisciplinary using cited references as the domain.

Synergy

Participation in triads that generate redundancy can be measured for both nodes and links of the network corresponding to the matrix under study. The units of analysis (nodes) and their relations (links) are both positioned in a configuration, and can thus be mapped in a visualization (Fig. 2 below).

Synergy contributions of individual papers (N = 130)

All 130 documents participate in triads generating synergy. However, the synergy varies from 3513 bits for Bar-Ilan (2004) to 16 Bits for Arkin et al. (1991). "The low synergy of this latter paper is generated by a Letter to the Editor of the *Communications of the ACM* entitled "Women in Computing" signed by 51 authors in alphabetic order. One cannot expect such a letter to function intellectually, since the objective is social.

The fifteen papers with highest values on this indicator are listed in the left column of Table 5. The three reviews are listed on the first, second, and fourth place of this list. The in-between (third) position is for a paper coauthored by Judit with Bluma Peritz and entitled "Informetric theories and methods for exploring the Internet: An analytical survey of recent research literature" in *Library Trends*. In our opinion, this paper could also be considered as a review given the scope of the title and the 78 references; that is, more



Fig. 2 Synergy map among the 130 documents under study

Table 7 Correlations among130 papers authored by Judit		$^{2}D^{3}$	DIV*	Synergy	Times cited	N of Refs
Bar-Ilan on several indicators for interdisciplinarity and synergy	$^{2}D^{3}$	1.000	.622**	473**	.405**	.287**
interenserprinarity and synergy		_	.000	.000	.000	.001
		130	130	130	130	130
	DIV*	.623**	1.000	671**	.427**	.818**
		.000	-	.000	.000	.000
		130	130	130	130	130
	Synergy	317**	549**	1.000	336**	639**
		.000	.000	-	.000	.000
		130	130	130	130	130
	Times cited	.170	.232**	361**	1.000	.357**
		.053	.006	.000	-	.000
		130	130	130	130	130
	N of refs.	.008	.399**	604**	.357**	1.000
		.928	.000	.000	.000	-
		130	130	130	130	130

Pearson correlations are provided in the lower triangle and Spearman rank-order correlation in the upper triangle

**Correlation is statistically significant at the 0.01 level (2-tailed)

*Correlation is statistically significant at the 0.05 level (2-tailed)

references than the 73 in the 2001 article in *Scientometrics*. However, the article has less been cited (17 times at the time of the download).

Since the synergy values are in bits of information, one is allowed to state that Bar-Ilan (2004) contributes (3513/2968=) 1.18 times more to the synergy than Bar-Ilan (2008a, b), and analogously 1.36 times more than the 2001-review in *Scientometrics*.

Table 6 summarizes the above results from another perspective. The three review papers are listed in terms of their ranking among the set of 130 papers. Using ${}^{2}D^{3}$, Bar-Ilan (2008a), for example, is ranked only at low positions. It would thus be indicated as extremely *disciplinary*. The score of 28/130 for DIV* seems more realistic to us than the 113th position using ${}^{2}D^{3}$. As noted, Bar-Ilan (2008a) is ranked in the first position (among 130 papers) with the synergy score.

Bar-Ilan (2004) ranks highly on both "interdisciplinarity" (second position) and "synergy" (first position), and also on the number of references. This score accords with the objective of *ARIST* and of Blaise Cronin as the editor at the time to broaden the scope of contributions by making them both theoretically informed and relevant for the long-term development of the field of library and information sciences (Sugimoto 2016).

Table 7 shows the Pearson correlations (in the lower triangle) and Spearman's rankorder correlations (in the upper triangle) among these various indicators. The (negative) synergy values correlate negatively with the interdisciplinarity indicators. However, all these indicators are statistically significantly correlated with the synergy indicator (p <. 01).
 Table 8 Ten links with highest scores on "synergy"

Node A	Node B	Synergy contribution in bits
Halevi G, 2015, PUBLISH RES Q, V31, P102	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Bar-Ilan J, 2013, J AM SOC INF SCI TEC, V64, P2400	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Bar-Ilan J, 2011, ONLINE INFORM REV, V35, P502	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Thijs B, 2010, RES EVALUAT, V19, P80	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Bar-Ilan J, 2010, ONLINE INFORM REV, V34, P354	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Bar-Ilan J, 2009, ONLINE INFORM REV, V33, P620	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.86
Bronstein J, 2018, ASLIB J INFORM MANAG, V70, P551	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.81
Halevi G, 2016, PUBLISH RES Q, V32, P22	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.81
Bergman O, 2013, J AM SOC INF SCI TEC, V64, P1995	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.81
Bar-Ilan J, 2012, SCIENTOMETRICS, V92, P261	Bar-Ilan J, 2008, J INFORMETR, V2, P1	-72.81

Synergy contributions of the links

Table 8 shows the 15 most synergetic relations among papers in the document set. The dominant position of Bar-Ilan (2008a) is obvious.

Figure 1 combines the synergy values of the nodes and links into a synergy network. Bar-Ilan (2004 and 2008b) are spanning the largest cluster (in red). Bar-Ilan (2001) is embedded in the green cluster. The modularity is low (Q=0.035 using Blondel et al. 2008).

Conclusions

We compared 130 full papers (co-)authored by Judit Bar-Ilan in terms of measures for "interdisciplinarity" and "synergy." The three review papers in this set occupy a special position and enable us to study differences in the "interdisciplinarity" and "synergy" among the papers in the sample.

Among the interdisciplinarity indicators, DIV* improves on measuring with ${}^{2}D^{3}$ although the two measures are significantly correlated (both *r* and ρ are 0.62; *p* < .01). None of the three review papers were indicated as interdisciplinary using ${}^{2}D^{3}$. Bar-Ilan (2004), however, was indicated as "interdisciplinary" using DIV*, followed by Bar-Ilan (2001). Bar-Ilan (2008a) is ranked in at the 113th position using ${}^{2}D^{3}$. Thus, this paper would be ranked as very disciplinary. In our opinion, this measurement of interdisciplinarity using ${}^{2}D^{3}$ is erroneous: the author tried to write an overview of all developments in the informetrics area (including a diverse spectrum of topics such as indicators, webometrics,

and patent analysis) for the purpose of defining the discipline in relation to its relevant sources..

The synergy indicator especially points to Bar-Ilan (2004, 2008a). Whereas Bar-Ilan (2008a) contributed to the redefinition and shaping of the discipline, Bar-Ilan (2004) added the broader perspective of the theoretical and practical relevance of the discipline, leading to both interdisciplinarity and synergy in this sample.

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