



“Betweenness” and “Diversity” in Journal Citation Networks as Measures of Interdisciplinarity

**— A Tribute to Eugene Garfield —
Scientometrics, memorial issue**

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“Interdisciplinarity”?

1. Political and scholarly discourse

- Politicians ask for more “interdisciplinarity” and “transdisciplinarity”;
- Quality control problems when one moves beyond “multi-disciplinarity”
 - Van Noorden (2015): Interdisciplinary research has long-term impact (> 10 years)
 - Nichols (2014): 89% of the portfolio of the Directorate for SBE of the the NSF is IDR.

2. How to delineate disciplines → potential drift in the definitions

- Indicators are sensitive for changes in the delineations
- WoS Subject Categories (pragmatic) vs. algorithmic decompositions
- Changing boundaries

3. Different indicators:

- Diversity: composed of (i) variety, (ii) disparity and (iii) balance
- Betweenness Centrality: a family of indicators.

4. New developments

- in the journal landscape such as *PLoS ONE* (2006); multi-disciplinary?
- Paper level (“direct citation”) vs. journal level

Advances since: Leydesdorff, L., & Rafols, I. (2011). Indicators of the interdisciplinarity of journals: Diversity, centrality, and citations. *Journal of Informetrics*, 5(1), 87-100.

1. The *problem of **delineation*** can be “solved” in terms of the statistics using VOSviewer:
 - Leydesdorff, L., Bornmann, L., & Wagner, C. S. (2017). Generating Clustered Journal Maps: An Automated System for **Hierarchical Classification**. *Scientometrics*, 110(3), 1601-1614.
2. **Valued betweenness** centrality (Brandes, *visone*); 64-bit computing power;
3. **“True diversity”**:
 - Zhang, L., Rousseau, R., & Glänzel, W. (2016). **Diversity of references as an indicator for interdisciplinarity of journals**: Taking similarity between subject fields into account. *Journal of the Association for Information Science and Technology*, 67(5), 1257-1265.
4. Network measures (based on relations; e.g., geodesics) *versus* measures in the vector space (based on correlations) → different distances

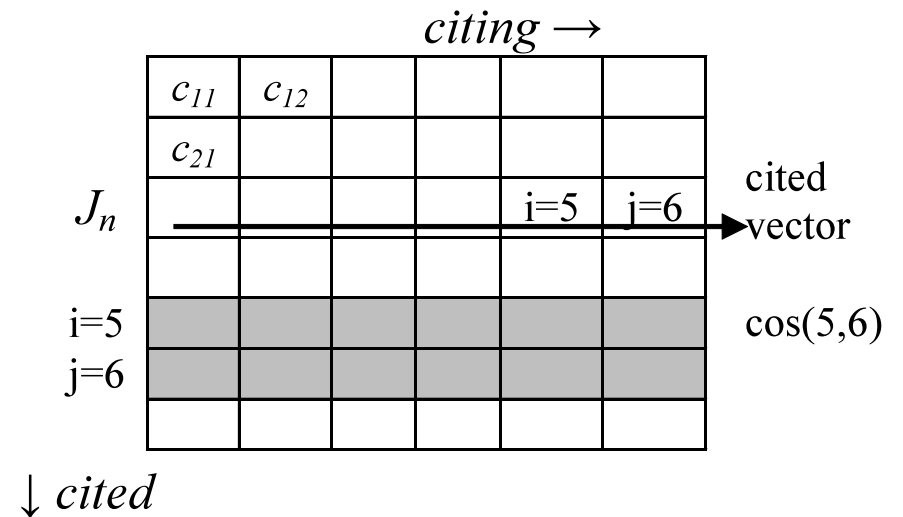
Betweenness Centrality: $BC_k = \sum_i \sum_j \frac{g_{ijk}}{g_{ij}}, i \neq j \neq k$

- Family of measures developed since Freeman's introduction in 1971:
 - Freeman, L. C., Borgatti, S. P., & White, D. R. (1991). Centrality in valued graphs: A measure of betweenness based on network flow. *Social Networks*, 13(2), 141-154.
 - Brandes, U. (2008). On variants of shortest-path betweenness centrality and their generic computation. *Social Networks*, 30(2), 136-145.
→ **implementation in visone**
 - Liu, J. S., & Lu, L. Y. (2012). An integrated approach for main path analysis: Development of the Hirsch index as an example. *Journal of the American Society for Information Science and Technology*, 63(3), 528-542.
- BC can be computed on an **asymmetrical (1-mode) matrix**.
- Graph-analytical: based on **geodesics**

Rao-Stirling Diversity:

$$\Delta = \sum_{i \neq j} p_i p_j d_{ij}$$

- **Variety times disparity: “ecological entropy” or “quadratic entropy”;**
- **Balance** can be added (for example, Gini or Shannon entropy; between 0 and 1)
- **d is a distance measure:**
 - Euclidean distances
 - $(1 - \text{Jaccard})$; $(1 - \text{cosine})$
 - The cosine is defined in the vector space.
- **True Diversity:** ${}^2D^3 = 1/(1 - \Delta)$ varies from 1 to infinity when Δ varies from zero to one.



<http://www.leydesdorff.net/software/diversity/net2rao.exe>

Between-group and within-group Diversity

Cassi, L., Mescheba, W., & De Turckheim, E. (2014). How to evaluate the degree of interdisciplinarity of an institution? *Scientometrics*, 101(3), 1871-1895. Further elaboration in Cassi *et al.*, 2017; cf. Chiu & Chao, 2014.

- In our opinion, Rao-Stirling diversity is a summation (Σ) like Shannon entropy and therefore **fully decomposable**.
 - Differences among aggregated subsets (“within group”) can be tested for significance using ANOVA with Bonferroni correction;
 - Off-diagonal parts of the matrix can be summed as between-group diversity.
- The matrix of diversity scores can be used for further analysis
 - Knowledge integration networks and knowledge diffusion networks.
 - Perhaps: “knowledge differentiation”?
 - See also <http://www.leydesdorff.net/software/diversity/net2rao.exe>

Data and descriptive statistics

<http://www.leydesdorff.net/jcr15>

	<i>JCR 2015</i>
N of journals (nodes)	11,359
Links	2,848,736 (11,049 loops)
Total citations	43,010,234
Density	0.022
Average (total) degree	501.582
Cluster coefficient	0.220
Avg. distance	2.495
Maximum distance	6

	<i>Field-designation</i>	<i>N</i>
1	Social Sciences	3,274
2	Computer Science	2,003
3	Medicine	1,965
4	Environmental Sci	1,595
5	Biomedical	784
6	Chemistry	652
7	Bio-agricultural	583
8	Physics	440
9	Ophthalmology	57
10	Data analysis ("Big data")	6
		11,359

Results BC

n = 11,359

<i>Journal</i>	<i>BC (Pajek)</i>	<i>Journal</i>	<i>Valued % BC</i>
PLOS ONE	16.56	PLOS ONE	17.30
P Natl Acad Sci Usa	5.11	P Natl Acad Sci Usa	4.97
Soc Sci Med	3.40	Soc Sci Med	3.30
Sci Rep-Uk	2.85	Psychol Bull	2.06
Nature	2.26	Sci Rep-Uk	1.71
Science	2.12	Am J Public Health	1.69
Am J Public Health	1.75	Nature	1.61
Psychol Bull	1.50	Science	1.47
Energ Policy	1.19	Energ Policy	0.96
Ecol Econ	0.95	Ecol Econ	0.87
Scientometrics	0.85	Annu Rev Psychol	0.84
Nat Commun	0.78	Psychol Rev	0.61
Sustainability-Basel	0.78	Manage Sci	0.60
Manage Sci	0.71	Phys Rev E	0.59
Phys Rev E	0.66	Scientometrics	0.57
Biomed Res Int	0.59	Global Environ Chang	0.48

<i>Journal</i>	<i>Diversity ²D³ Cited</i>	<i>Journal</i>	<i>Diversity ²D³ Citing</i>
Am Behav Sci	17.56	J Chin Inst Eng	20.13
Daedalus-Us	16.67	Sci Iran	16.22
Ann Am Acad Polit Ss	16.06	Arab J Sci Eng	15.89
P leee	15.2	Teh Vjesn	15.83
Field Method	14.58	J Cent South Univ	15.4
Qual Quant	14.25	Adv Mech Eng	14.85
Am J Econ Sociol	13.73	J Mar Sci Tech-Taiw	14.56
Am J Sociol	13.57	J Test Eval	14.35
Brit J Sociol	13.39	Measurement	14.29
Technol Rev	13.11	Sustainability-Basel	14.1
Annu Rev Sociol	12.92	Dyna-Bilbao	14.03
Philos T R Soc A	12.84	J Zhejiang Univ-Sc A	13.99
Crit Inquiry	12.49	Math Probl Eng	13.78
Am Hist Rev	12.37	J Eng Res-Kuwait	13.32
Am Sociol Rev	12.18	Sadhana-Acad P Eng S	12.92
P Roy Soc A-Math Phy	11.99	Sains Malays	12.81

Correlations

Table 4: Pearson and Spearman' rank correlations of BC and $^2D^3$ among 11,359 journals (in the lower and upper triangle, respectively); all correlations are significant at the level $<.01$.

	<i>BC</i>	<i>Valued BC</i>	<i>$^2D^3$ cited</i>	<i>$^2D^3$ citing</i>
<i>BC</i>		.964	.396	.190
<i>Valued BC</i>	.993		.472	.231
<i>$^2D^3$ cited</i>	.050	.041		.442
<i>$^2D^3$ citing</i>	.042	.033	.406	

Results BC

n = 3,264
(Social Sciences)

<i>Journal</i>	<i>BC (Pajek)</i>	<i>Journal</i>	<i>Valued BC (visone)</i>
Soc Sci Med	7.38	Soc Sci Med	6.64
Am J Public Health	2.62	Psychol Bull	2.18
Psychol Bull	2.34	Am J Public Health	2.06
Front Psychol	2.25	Front Psychol	1.75
Comput Hum Behav	2.04	Comput Hum Behav	1.61
J Bus Ethics	1.61	J Pers Soc Psychol	1.26
J Pers Soc Psychol	1.31	J Bus Ethics	1.20
World Dev	1.24	World Dev	1.04
Pers Individ Differ	1.22	Pers Individ Differ	1.04
Soc Indic Res	1.08	Soc Indic Res	0.89
Appl Econ	1.04	J Adv Nurs	0.79
Am Psychol	0.94	Am Sociol Rev	0.78
J Adv Nurs	0.92	Am Psychol	0.70
J Pragmatics	0.91	Appl Econ	0.70
Am Sociol Rev	0.90	Geoforum	0.66
Am Econ Rev	0.80	Am J Sociol	0.65
Geoforum	0.80	J Pragmatics	0.63
J Bus Res	0.79	J Appl Psychol	0.62
Am J Sociol	0.78	Am Econ Rev	0.61
J Appl Psychol	0.73	J Bus Res	0.58
Scientometrics	0.73	J Econ Behav Organ	0.51
Psychol Sci	0.68	Annu Rev Sociol	0.50
J Econ Behav Organ	0.68	Ecol Econ	0.49
Curr Anthropol	0.65	Cognition	0.49
Comput Educ	0.64	Child Dev	0.49

<i>Journal</i>	<i>²D³ cited</i>	<i>Journal</i>	<i>²D³ citing</i>
Soc Res	18.11	Disasters	9.15
Qual Res Psychol	17.92	Convergencia	8.64
Am Behav Sci	17.39	Continuum-J Media Cu	8.13
Daedalus-US	16.44	Evaluation Rev	7.79
Ann Am Acad Polit Ss	15.94	Indian J Gend Stud	7.71
Field Method	14.97	Food Cult Soc	7.3
Qual Inq	14.91	Educ Sci-Theor Pract	7.2
Nation	13.81	Hum Organ	7.1
Soc Sci Inform	13.8	Etikk Praksis	7.09
Am J Econ Sociol	13.56	Inform Cult	7.03
Am J Sociol	13.38	China Rev	7.01
Brit J Sociol	13.31	Curr Sociol	6.85
Theor Soc	12.95	Inform Res	6.84
Qual Res	12.9	Educ Assess Eval Acc	6.83
Signs	12.81	Crit Asian Stud	6.76
Annu Rev Sociol	12.75	Hist Soc Res	6.65
J Socio-Econ	12.75	Environ Plann C	6.62
Crit Inquiry	12.38	Eur J Womens Stud	6.61
J R Stat Soc A Stat	12.38	Educ Xx1	6.53
Am Hist Rev	12.36	Eval Program Plann	6.49
Sociol Methodol	12.09	Econ Soc	6.47
Am Sociol Rev	12.05	Fem Psychol	6.47
Qual Quant	11.84	Health Soc Care Comm	6.44
Curr Sociol	11.81	Cult Stud	6.39
New Left Rev	11.79	Child Soc	6.39

Results BC

n = 86
(LIS)

<i>Journal</i>	<i>BC (Pajek)</i>	<i>Journal</i>	<i>Valued BC (visone)</i>
Scientometrics	6.82	Scientometrics	10.12
J Doc	5.79	Libr Inform Sci Res	7.38
Libr Inform Sci Res	4.36	J Acad Libr	7.06
J Acad Libr	3.82	J Libr Inf Sci	7.04
Electron Libr	3.71	J Doc	6.22
Online Inform Rev	3.71	Inform Res	5.25
Int J Inform Manage	3.42	Mis Quart	5.05
Inform Res	3.41	Electron Libr	4.89
Mis Quart	3.35	Online Inform Rev	4.06
Inform Manage-Amster	2.92	Gov Inform Q	3.70
Gov Inform Q	2.57	Inform Manage-Amster	3.22
J Assoc Inf Sci Tech	2.25	J Assoc Inf Sci Tech	3.21
J Inf Sci	2.19	Int J Inform Manage	2.90
Libr Trends	1.91	Libr Trends	2.57
J Manage Inform Syst	1.72	J Inf Sci	2.25
J Libr Inf Sci	1.69	Inform Soc	2.12
Inform Soc	1.62	Inform Process Manag	1.68
Coll Res Libr	1.57	J Manage Inform Syst	1.60
Inform Dev	1.40	Inform Dev	1.54
J Informetr	1.40	Inform Technol Peopl	1.47
Inform Process Manag	1.37	Coll Res Libr	1.31
Inform Technol Peopl	1.23	J Knowl Manag	1.12
J Assoc Inf Syst	1.05	J Med Libr Assoc	0.91
Eur J Inform Syst	1.02	Telecommun Policy	0.86

<i>journal</i>	<i>²D³ cited</i>	<i>Journal</i>	<i>²D³ citing</i>
Inform Soc	4.28	Libr Inform Sci Res	3.78
J Comput-Mediat Comm	3.89	Online Inform Rev	3.76
Online Inform Rev	3.39	J Assoc Inf Sci Tech	3.72
Int J Inform Manage	3.32	Aslib J Inform Manag	3.69
Aslib Proc	3.26	Electron Libr	3.67
Inform Dev	3.15	Inform Res	3.51
Inform Manage-Amster	3.11	J Inf Sci	3.48
J Inf Sci	3.10	Can J Inform Lib Sci	3.46
Serials Rev	2.93	Investig Bibliotecol	3.30
J Med Libr Assoc	2.90	Inform Cult	3.23
Ethics Inf Technol	2.66	Libr Hi Tech	3.10
J Scholarly Publ	2.57	J Doc	3.07
J Inf Technol	2.47	Program-Electron Lib	3.02
Learn Publ	2.46	Inform Soc-Estud	2.99
Libr Hi Tech	2.44	J Libr Inf Sci	2.98
Libr Inform Sci Res	2.41	Afr J Libr Arch Info	2.92
J Doc	2.40	Libri	2.91
Libr Trends	2.38	Libr Trends	2.89
Program-Electron Lib	2.36	Libr Resour Tech Ser	2.89
Inform Technol Libr	2.36	Inform Process Manag	2.84
J Am Soc Inf Sci Tec	2.33	Libr Quart	2.83
Inform Res	2.33	Learn Publ	2.71
Aust Acad Res Libr	2.33	Malays J Libr Inf Sc	2.70
J Strategic Inf Syst	2.32	Inform Soc	2.60
Inform Technol Peopl	2.31	Ref User Serv Q	2.60

Decomposition of Diversity

$$\Delta \neq \Delta_0 + \sum_1^G P_G \Delta_G$$

Table 10: Decomposition of the diversity in the LIS set.

<i>Specialism</i>	<i>²D³ cited</i>	<i>Δ cited</i>	<i>²D³ citing</i>	<i>Δ citing</i>	<i>N of journals</i>
1. library science	54.02	12.36	59.11	13.19	32
2. information systems	31.95	7.14	22.51	2.86	19
3. bibliometrics	19.37	3.69	26.95	6.08	14
4. information and organization	14.15	2.3	13.75	2.41	10
5. information management	9.66	1.19	8.84	1.39	7
Within-group	129.15	26.68	131.16	25.93	82
Total	175.35	39.06	179.36	37.21	86

Table 11: Between-group diversity in the LIS set.

	<i>Δ cited</i>	<i>Δ citing</i>
0. between-group	20.82	21.61
	53.3%	58.1%
1. library science	8.33	8.21
2. information systems	5.58	2.56
3. bibliometrics	2.51	3.49
4. information and organization	1.06	1.08
5. information management	0.77	0.25
Total	39.06	37.21

Conclusions

Betweenness

1. BC can be considered as an indicator of **multi-disciplinarity**;
2. Valued BC improves on binary BC because citation networks are valued.

Diversity

1. Diversity in the citing dimension (“**knowledge integration**”) indicates **trans- or non-disciplinarity**;
 2. Diversity in the cited dimension (“**knowledge differentiation**”; bibliographic coupling) trades off between structure (selection) and action (variation);
 - this is probably the best indicator of “**interdisciplinarity**”;
- Diversity can be decomposed into within- and between-group diversity
see <http://www.leydesdorff.net/software/diversity>

Scientometrics

	N	Rao-Stirling		${}^2D^3$		Σ cited	Σ citing	Σ Self-citation
		Cited	Citing	Cited	Citing			
Complete Set	11,359	0.35	0.43	3.39	6.84	5766	9158	1963
Social science	3,274	0.28	0.19	2.27	1.63	4570	6840	1963
LIS	86	0.16	0.25	1.45	1.98	3494	3676	1963

Table 10: *Scientometrics* at three levels of aggregation.

