International Journal of General Systems

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ggen20

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To cite this article: R. Belohlavek (2022) Impact of fuzzy logic: a bibliometric view, International Journal of General Systems, 51:7, 664-674, DOI: 10.1080/03081079.2022.2063852

To link to this article: https://doi.org/10.1080/03081079.2022.2063852

Published online: 22 May 2022.

INTERNATIONAL JOURNAL OF GENERAL SYSTEMS
2022, VOL. 51, NO. 7, 664–674
https://doi.org/10.1080/03081079.2022.2063852

Impact of fuzzy logic: a bibliometric view

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ABSTRACT
We provide a bibliometric account of the impact of fuzzy logic.

ARTICLE HISTORY
Received 6 December 2021
Accepted 4 March 2022

KEYWORDS
Fuzzy logic; bibliometrics; impact

1. Aim of this paper

Since its inception in the 1960s, fuzzy logic has represented a considerably active research area. The significance of fuzzy logic basically derives from the fact that fuzzy logic addresses some fundamental issues regarding human cognition, most importantly the phenomenon of vagueness, not addressed by classical logic. In the course of its development, a large number of papers has been published contributing to both foundations and applications of fuzzy logic. In addition, many commercially successful applications have been developed. For these reasons, fuzzy logic is regarded as an area with considerable impact.

The aim of this paper is to provide a bibliometric account of fuzzy logic. For one, we focus on the most influential – in terms of the number of received citations – papers on fuzzy logic. Secondly, we provide and analyze various views of the numbers of papers on fuzzy logic that appeared in the literature since its inception. We use bibliometric data provided particularly by Scopus, but also Web of Science (WoS), and Google Scholar (GS).[1] These three sources differ in their coverage of particular areas as well as in the types of publications included. We use the data provided by these sources as of October 2021.

Being based solely on numbers of publications and citations, our assessment of the impact of fuzzy logic is clearly limited. Nevertheless, it provides evidence of possible interest to a broader scientific community. For other discussions on the significance of fuzzy logic, which are not based on bibliometrics, we refer, e.g. to Bělohlávek, Dauben, and Klir (2017), Cintula (2011), Dubois and Prade (2000), Gottwald (2001), Hájek (1998), Novák, Perfilieva, and Močkoř (1999) and Zadeh (2015).

2. Most influential papers on fuzzy logic

2.1. Zadeh's seminal 1965 paper

Zadeh's seminal paper (1965) represents an exceptional work due to its revolutionary content and significance, as well as its clarity. These qualities translate to a lasting impact of this

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paper in various fields, which we shall document. We contend that to a reasonable extent, the impact of fuzzy logic is correlated with the impact of Zadeh (1965).

The numbers of citations received by Zadeh (1965) are as follows:[2]

Scopus	Web of Science	Google Scholar
53,624	43,108	105,341

These numbers indicate an exceptional influence of Zadeh's seminal paper. Indeed, the number of citations received by this paper is about an order of magnitude larger compared to Zadeh's other highly cited works, as apparent from Table 1.[3] Worth noting is also the fact that many papers refer to Zadeh's concept of a fuzzy set but no longer cite the 1965 paper and refer instead to some classic book on fuzzy sets, which reduces the number of citations of the 1965 paper.

Another perspective, reflecting the diversity of citation sources, is provided by Table 2, which presents the numbers of citations of Zadeh's three most-cited papers by selected Scopus subject areas.[4] Most of the citations come from papers in engineering, computer science, and mathematics, but considerably high numbers come from a variety of other areas such as natural sciences, economics, medicine, and humanities.

The evolution of the number of citations in time is provided by Table 3, which presents the cumulative numbers in five-year windows. Even though the table indicates a growing influence of Zadeh's works and his seminal paper, the numbers ought to be adjusted to take into account the growing numbers of publications across all fields, which we attempt later on.

To further assess the impact of Zadeh's seminal work by bibliometric means, we compare the number of citations of this seminal work to those of other highly cited papers. We start by recalling a 2014 article in *Nature*, which analyzed the 100 most-cited research papers of all time (Van Noorden, Maher, and Nuzzo 2014).[5] The vast majority of these are papers in biology, chemistry, and physics – fields in which the citation counts are generally considerably higher than in mathematics, computer science, or engineering. Yet, 11 of the top 100 papers are classified as contributions to mathematics and statistics. Zadeh's "Fuzzy sets" of 1965, ranks third among these and 46th overall.[6] Note, however, that the list does not include some influential and highly cited papers, such as Claude Shannon's seminal paper on theory of information.[7] Neither shall the list be understood as containing the most important papers because many papers considered as revolutionary, such as Albert Einstein's paper on the general theory of relativity, do not appear in it.

Table 1. Numbers of citations received by the other highly cited papers by Lotfi Zadeh.

Paper	Scopus	Web of Science	Google Scholar
The concept of linguistic variable … I	9,078	8,908	18,715
Fuzzy sets as a basis for a theory of possibility	6,560	377	12,449
Outline of a new approach …	5,875	4,493	12,102
(w Bellman) Decision-making in a fuzzy environment	5,461	n/a	10,817
The concept of linguistic variable … II	3,099	1,920	3,041
Fuzzy logic = computing with words	2,294	1,861	3,986
The concept of linguistic variable … III	2,091	2,934	3,013
Similarity relations and fuzzy orderings	1,820	1,572	3,296
Probability measures of fuzzy events	1,797	1,503	3,251
A computational approach to fuzzy quantifiers	1,355	1,161	2,383

Table 2. Numbers of citations of Zadeh (1965), Zadeh (The concept of linguistic variable and its application to approximate reasoning – I), and Zadeh (Fuzzy sets as a basis for a theory of possibility) in Scopus by selected subject areas.

Subject area	Zadeh (1965)	Zadeh (The concept of linguistic variable and its application to approximate reasoning - I)	Zadeh (Fuzzy sets as a basis for a theory of possibility)
Computer Science	30,341	6532	4380
Mathematics	20,721	4369	2970
Engineering	20,480	3479	2532
Decision Sciences	4665	982	685
Business, Mgmt., and Acct.	3446	569	391
Environmental Science	3378	314	310
Social Sciences	1364	412	286
Earth and Planetary Sciences	3229	172	193
Physics and Astronomy	2729	324	239
Energy	1872	203	143
Chem. Eng., Chemistry	1819	192	130
Materials Science	1731	199	161
Agricultural and Biological Sci.	1253	79	93
Economics, Ecmtr., and Finance	1212	172	120
Medicine	1019	98	80
Biochem., Genetics, Mol. Biol.	886	64	71
Arts and Humanities	694	84	81
Psychology	388	30	54
Neuroscience	348	52	44
Total no. Scopus citations	53,624	9078	6560

Table 3. Numbers of citations in Scopus of all works by Zadeh and of the 1965 paper.

Period	All works by Zadeh	Zadeh (1965)
1970–74	347	112
1975–79	864	262
1980–84	1465	423
1985–89	2198	659
1990–94	4140	1451
1995–99	5310	2202
2000–04	8654	3481
2005–09	18,070	7590
2010–14	27,980	13,249
2015–19	33,062	16,840
2020+	13,404	7494

Another available list of similar kind was compiled by Google.[8] The list contains the top 100 most cited works based on the Google Scholar coverage. Unlike the above list based on the Web of Science, the GS list includes books. In fact, 46 of the 100 items in the list are books. Of all the articles in this list, five do not appear in the WoS, including the above-mentioned Shannon's paper which appears 4th of all the articles in the GS list and 9th in the whole list including both articles and books. In the whole GS list, Zadeh's 1965 paper ranks 29th and appears 14th when counting articles only. If restricted to articles in mathematics, computer science, or engineering, Zadeh's paper is second after Shannon's work. Note also that the two papers classified as mathematics and statistics in the WoS list that precede Zadeh (1965) appear after Zadeh's paper in the GS list.[9]

Another perspective is offered by comparing Zadeh (1965) in terms of received citations to other highly influential papers in a similar area. For this purpose, we look into papers in computer science.[10] The top 10 most cited papers according to Scopus are shown in

Table 4. Top 10 most cited papers in the Scopus subject area computer science. The numbers of citations are according to Scopus.

He et al., Deep residual learning for image recognition (2016)	52,891
Krizhevsky et al., ImageNet classification with deep convolutional neural networks (2012)	52,401
Breiman, Random forests (2001)	49,175
Kennedy et al., Particle swarm optimization (1995)	43,563
Lowe, Distinctive image features from scale-invariant keypoints (2004)	40,052
Kresse et al., Efficiency of ab-initio total energy calculations for metals and semiconductors using a plane-wave basis set (1999)	38,963
Akaike, A new look at the statistical model identification (1974)	32,287
Cortes et al., Support-vector networks (1995)	30,264
Bates et al., Fitting linear mixed-effects models using lme4 (2015)	27,311
Deb et al., A fast and elitist multiobjective genetic algorithm: NSGA-II (2002)	27,182

Table 5. Selected classic papers in computer science. The numbers of citations are according to Scopus (second column) and Google Scholar (third column).

Agrawal et al., Mining association rules between sets of items in large databases (1993)	11,059	23,408
Amdahl, Validity of the single processor approach to achieving large scale computing capabilities (1967)	2474	6768
Arora et al., Proof verification and the hardness of approximation problems (1998)	427	2799
Cerf et al., A protocol for packet network intercommunication (1974)	423	1606
Chen, The entity relationship model – towards a unified view of data (1976)	4073	12,635
Chomsky, On certain formal properties of grammars (1959)	616	2177
Codd, A relational model for large shared data banks (1970)	4228	n/a
Cook, The complexity of theorem proving procedures (1971)	3362	9518
Hamming, Error detecting and error correcting codes (1950)	3040	7392
Hartmanis et al., On the computational complexity of algorithms (1965)	481	1240
Karp, Reducibility among combinatorial problems (1972)	n/a	16,431
Knuth, Semantics of context-free languages (1968)	1208	2961
McCarthy, Recursive functions of symbolic expressions and their computation by machine, part I (1960)	679	2278
Pnueli, The temporal logic of programs (1977)	3310	7258
Quinlan, Induction of decision trees (1986)	11,406	25,547
Rabin et al., Finite automata and their decision problems (1959)	n/a	2469
Rabin, Probabilistic algorithm for testing primality (1980)	439	1200
Rivest et al., A method for obtaining digital signatures and public-key cryptosystems (1978)	9914	23,723
Robinson, A machine-oriented logic based on the resolution principle (1965)	2160	6147
Rumelhart et al., Learning representations by back-propagating errors (1986)	12,255	26,021
Shannon, A mathematical theory of communication (1948)	21,777	138,679
Turing, On computable numbers, with an application to the Entscheidungs problem (1937)	3198	12,866
Turing, Computing machinery and intelligence (1950)	n/a	16,657
Valiant, A theory of the learnable (1984)	2834	7216

Table 4. In addition, Table 5 shows selected classic papers in computer science ordered alphabetically by the last name of the first author.[11] These tables confirm the extraordinary stature of Zadeh (1965) as regards citation counts.

Overall, the remarkable status of Zadeh's seminal paper in the context of the top cited and most influential papers clearly documents its exceptional nature.

2.2. *Other papers*

In this section, we present bibliometric data for other highly influential papers on fuzzy logic. In their selection, we looked at papers written by fellows of the IFSA, as well as classic

Table 6. Highly cited papers on fuzzy logic by researchers other than Lotfi Zadeh. The numbers of citations are according to Scopus.

Atanassov, Intuitionistic fuzzy sets (1986)	9349
Bezdek et al., FCM: The fuzzy c-means clustering algorithm (1984)	3873
Cai, Kwan, Fuzzy classifications using fuzzy inference networks (1998)	10,291
Chang, Applications of the extent analysis method on fuzzy AHP (1996)	2837
2837 Chang, Fuzzy topological spaces (1968)	1366
De Luca, Termini, A definition of a nonprobabilistic entropy in the setting of fuzzy sets theory (1972)	2638
Dubois, Prade, Operations on fuzzy numbers (1978)	1902
Dubois, Prade, Rough fuzzy sets and fuzzy rough sets (1990)	1954
Dunn, A fuzzy relative of the ISODATA process and its use in detecting compact well-separated clusters (1973)	4191
Esteva, Godo, Monoidal t-norm based logic: towards a logic for left-continuous t-norms (2001)	782
Goguen, L-fuzzy sets (1967)	1778
Grabisch, The application of fuzzy integrals in multicriteria decision making (1996)	744
Herrera, Martínez, A 2-tuple fuzzy linguistic representation model for computing with words (2000)	2047
Jang, ANFIS: Adaptive-network-based fuzzy inference system (1993)	11,782
Keller et al., A fuzzy k-nearest neighbor algorithm (1985)	1683
Kosko, Fuzzy cognitive maps (1986)	2283
Lee, Fuzzy logic in control systems: fuzzy logic controller. I (1990)	3815
Lin, Lee, Neural-network-based fuzzy logic control and decision system (1991)	1092
Mamdani, Assilian, Experiment in linguistic synthesis with a fuzzy logic controller (1975)	3483
Mamdani, Application of fuzzy algorithms for control of simple dynamic plant (1974)	3034
Mendel, John, Type-2 fuzzy sets made simple (2002)	1965
Puri, Ralescu, Fuzzy random variables (1986)	1460
Ruspini, A new approach to clustering (1969)	1141
Sanchez, Resolution of composite fuzzy relation equations (1976)	754
Sugeno, Kang, Structure identification of fuzzy model (1988)	1971
Szmidt, Kacprzyk, Distances between intuitionistic fuzzy sets (2000)	1120
Takagi, Sugeno, Fuzzy identification of systems and its applications to modeling and control (1985)	15,452
Tanaka, Sugeno, Stability analysis and design of fuzzy control systems (1992)	2077
van Laarhoven, Pedrycz, A fuzzy extension of Saaty's priority theory (1983)	2082
Wang, Mendel, Generating fuzzy rules by learning from examples (1992)	2141
Xie et al., A validity measure for fuzzy clustering (1991)	2563
Yager, On ordered weighted averaging aggregation operators in multicriteria decision making (1988)	5462
Yager, A procedure for ordering fuzzy subsets of the unit interval (1981)	1008
Zimmermann, Fuzzy programming and linear programming with several objective functions (1978)	2,482

fuzzy logic papers.[12] The selected papers represent a variety of areas in fuzzy logic research and are listed in Table 6. In view of the numbers of citations to influential computer science papers, these data reveal that highly cited papers written on fuzzy logic still appear as highly cited when assessed in the context of all of computer science.

3. Number of papers on fuzzy logic

3.1. Absolute numbers of papers on fuzzy logic

To assess the impact of fuzzy logic by bibliometric means further, we now explore the quantity of papers written on fuzzy logic. The impact of the inception of fuzzy logic, as expressed by the number of publications written on fuzzy logic, on all areas and the impact on engineering, computer science, and mathematics, in particular, is demonstrated in Table 7. The

Table 7. Numbers of papers in Scopus and Scopus's subject areas Engineering, Computer Science, and Mathematics, containing "fuzzy" in the title, abstract, or keywords.

Period	All publications	Engineering	Computer Science	Mathematics
$<$ 1965	26	1	0	0
1965–69	48	15	8	11
1970–74	221	120	61	42
1975–79	627	320	208	237
1980–84	1630	809	592	583
1985–89	3015	1380	1261	1114
1990–94	9166	5044	4907	3423
1995–99	19,502	10,699	11,650	7173
2000–04	29,909	16,455	16,404	10,042
2005–09	63,448	31,383	38,502	18,692
2010–14	88,461	41,529	46,646	22,477
2015–19	96,925	46,703	54,704	30,456
$>$ 2019	45,146	21,837	24,119	13,694
total	358,126	176,295	199,061	107,944

Table 8. Numbers of papers in Scopus whose title, abstract, or keywords contain "fuzzy" by subject areas.

Computer Science	199,062	Business, Mgmt. and Acct.	13,704
Engineering	176,295	Earth and Planetary Sciences	12,691
Mathematics	107,944	Chem. Eng., Chemistry	12,147
Physics and Astronomy	22,581	Medicine	9382
Energy	20,693	Agricultural and Biological Sci.	7155
Decision Sciences	19,604	Biochem., Genetics, Mol. Biol.	6258
Materials Science	16,958	Economics, Economtr. and Finance	3789
Environmental Science	16,073	Neuroscience	2879
Social Sciences	15,036	Arts and Humanities	2445

table shows the numbers of papers indexed by Scopus, whose title, abstract, or keywords contain the term "fuzzy." The clusters by five-year periods in Table 7 indicate that the influence of fuzzy logic is steadily growing. In addition, the classification of papers in Scopus containing the term "fuzzy" in title, abstract, or keywords according to subject areas is provided in Table 8. This table makes it apparent that the impact of fuzzy logic spreads over a variety of areas, although – naturally – to varying extents.

3.2. *Inflation in publishing and inflation-adjusted numbers*

Over the years, the extent of academic publishing has grown considerably. The resulting inflation in publishing is caused by several factors. Rather than exploring these factors, we are interested in estimating the inflation rate in order to adjust the numbers of publications presented in the previous section and hence make it possible to compare the numbers over different time periods.[13]

To start with, Table 9 contains the numbers of all publications and the publications in the three observed subjects areas, namely Engineering, Computers Science, and Mathematics, clustered by five-year periods, from 1965–69 to 2015–19. The numbers are also depicted in Figure 1. The table also shows the increase in percentages in the number of publications from 1965–69 to 2015–19. Thus, for instance, as regards publications across all areas, the number of publications in 2015–2019 is higher by 1,278% compared to those

Table 9. Numbers of publications indexed in Scopus by publication date.

Period	All publications	Engineering	Computer Science	Mathematics
$<$ 1965	3,389,274	144,932	26,623	71,778
1965–69	1,060,537	104,459	11,168	35,298
1970–74	1,516,631	162,036	19,995	59,545
1975–79	2,009,058	214,012	34,410	77,964
1980–84	2,871,765	596,538	66,242	104,098
1985–89	3,484,158	708,246	127,954	153,467
1990–94	4,204,898	728,665	242,750	239,092
1995–99	5,276,817	932,190	382,261	338,399
2000–04	6,560,925	1,278,980	545,339	454,049
2005–09	9,403,605	1,942,467	1,111,598	668,995
2010–14	12,459,312	2,457,061	1,542,927	842,349
2015–19	14,613,328	3,038,744	2,029,761	1,121,480
$>$ 2019	6,012,642	1,171,991	789,572	449,876
total	72,862,950	13,480,321	6,930,600	4,616,390
increase				
65–69 to 15–19	+1278%	+2821%	+18,345%	+3103%
inflation/yr				
65–69 to 15–19	5.3%	7.0%	11.0%	7.2%

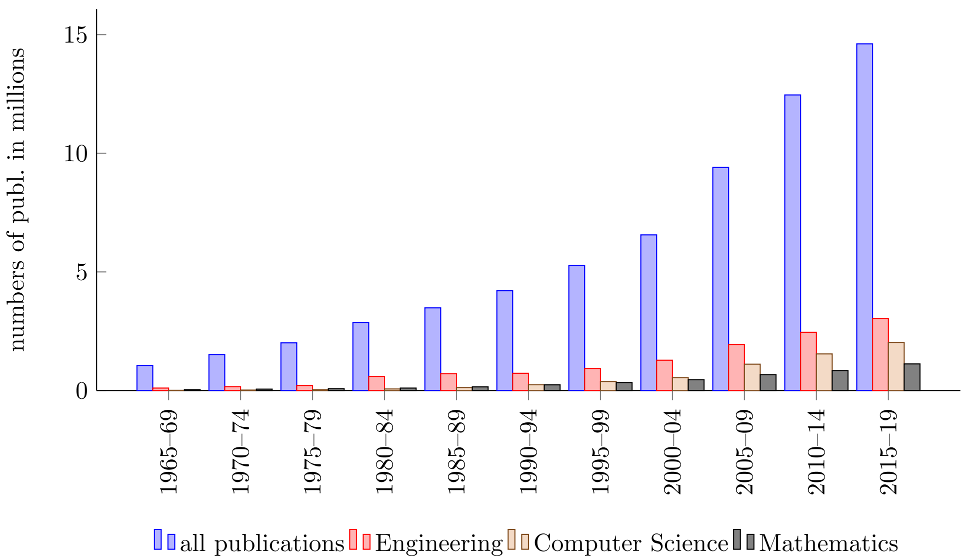

Figure 1. Numbers of publications indexed in Scopus by publication date (histograms for Table 9).

in 1965–69, since

$$1,278 \approx 100 \cdot (14,613,328/1,060,537 - 1)).$$

In addition, the table shows the average inflation rate per year from 1965–69 to 2015–19. For instance, as regards all publications again, we obtain a 5.4% inflation rate as

$$\sqrt[50]{\frac{14,613,328}{1,060,537}} \approx 1.054.$$

From the table, one easily obtains cumulative inflation rates. For instance, the cumulative inflation rate from 1965–69 to 1975–79 is 89% as $\frac{2,009,058}{1,060,537} \approx 1.89$.

Table 10. Inflation-adjusted numbers of papers in Scopus and Scopus's subject areas Engineering, Computer Science, and Mathematics, containing "fuzzy" in the title, abstract, or keywords.

Period	All publications	Engineering	Computer Science	Mathematics
1965–69	48	15	8	11
1970–74	155	77	34	25
1975–79	332	156	68	107
1980–84	601	141	100	198
1985–89	916	204	110	256
1990–94	2315	722	226	506
1995–99	3916	1199	340	748
2000–04	4832	1344	336	781
2005–09	7153	1687	387	986
2010–14	7503	1766	338	942
2015–19	7033	1605	301	959

Table 11. Share in % of papers whose title, abstract, or keywords contain "fuzzy" in papers indexed in Scopus in the cluster of all papers, and the subject areas Engineering, Computer Science, and Mathematics.

Period	All publications	Engineering	Computer Science	Mathematics
1965–69	0.005	0.014	0.072	0.031
1970–74	0.015	0.074	0.305	0.071
1975–79	0.031	0.150	0.604	0.304
1980–84	0.057	0.136	0.894	0.560
1985–89	0.087	0.195	0.986	0.726
1990–94	0.218	0.692	2.021	1.432
1995–99	0.370	1.148	3.048	2.120
2000–04	0.456	1.283	3.001	2.212
2005–09	0.675	1.616	3.464	2.794
2010–14	0.710	1.690	3.023	2.668
2015–19	0.663	1.800	2.695	2.716

Using the cumulative inflation rates for the four categories of publications, i.e. all publications, and the publications in Engineering, Computer Science, and Mathematics, one may adjust the numbers in Table 7, and hence observe whether the numbers of publications increase when the overall inflation in publishing is taken into account. The adjusted numbers are displayed in Table 10. The period 1965–69 is taken as the base period in the table. For instance, we obtain 332 for 1975–79 because the adjustment by inflation rate 89% of the absolute number 627 of publications in 1975–79 yields $332 \approx 627/1.89$. Table 10 presents an interesting pattern not apparent from the absolute numbers in Table 7. Namely, the adjusted numbers of publications reveal a rapidly growing trend in the extent of publishing papers on fuzzy logic since the late 1960s up until the period 2005–09, when the extent of publications on fuzzy logic stabilized at a level at which remains until the present. Roughly the same patterns can be observed in the subject areas Engineering, Computer Science, and Mathematics, with Computer Science stabilizing somewhat earlier. A similar tendency is apparent from Table 11, which summarizes the percentage share of papers on fuzzy logic among all papers and among the papers in the three observed subject areas.

We also present inflation-adjusted numbers of citations of Zadeh's papers presented in absolute numbers in Table 3. Even though adjustment of citation counts by inflation rates of publication numbers may be disputed, it certainly is reasonable as a rough approximation. The adjusted numbers are presented in Table 12. The base period is now 1970–74. The

Table 12. Inflation-adjusted numbers of citations in Scopus of all works by Zadeh and of the 1965 paper.

Period	All works by Zadeh	Zadeh (1965)
1970–74	347	112
1975–79	654	198
1980–84	775	224
1985–89	981	294
1990–94	1528	535
1995–99	1562	648
2000–04	2046	823
2005–09	2982	1252
2010–14	3484	1650
2015–19	3510	1788

table suggests that Zadeh's works are being increasingly cited since the early dates of fuzzy logic, with the pace slowing down in the past decade or a decade and a half.

4. Discussion

In the first part of our paper, we analyzed the impact of Zadeh's seminal paper "Fuzzy sets" (1965), Zadeh's other highly influential papers, as well as the impact of selected influential papers on fuzzy logic written by other authors. It turns out that "Fuzzy sets" (1965) is one of the most cited papers in the fields of computer science, engineering, and mathematics. Moreover, as pointed out by studies exploring top cited papers, the paper is among the most cited papers of all times across all fields. These data clearly document the remarkable status of Zadeh's 1965 paper. A number of other influential fuzzy logic papers, even though considerably less cited than Zadeh's seminal paper, also received extraordinary numbers of citations and rank among the most cited papers in computer science, engineering, and mathematics. Worth noting is also the variety of fields in which Zadeh's work is being cited.

In the second part, we observed the numbers of papers written on fuzzy logic in all domains, as well as in the three most significant Scopus subject areas, namely Engineering, Computer Science, and Mathematics. The numbers of papers as well as their dispersion over a variety of research areas, including science, humanities, and medicine, clearly document a broad impact of fuzzy logic on research in a variety of domains. To eliminate the influence of increasing extent of academic publishing, we adjusted the numbers of publications on fuzzy logic by inflation rates obtained from the number of publications in the observed categories in the respective time spans. The adjusted numbers reveal an interesting pattern suggesting that the relative extent of papers written on fuzzy logic had been increasing since the inception of fuzzy logic and that it is stabilizing for over the recent decade and a half.

According to the presented analysis, fuzzy logic represents a significant and extensive research direction. While its impact is most noticeable in engineering, computer science, and mathematics, work on fuzzy logic is considerable across virtually all research areas. Based on the observed numbers, we contend that the relative extent of fuzzy logic research has ceased to grow and has been relatively stable for over a decade. It remains to be seen how the present trend will evolve.

Our basic analysis may be extended in a number of ways to provide a more detailed picture of fuzzy logic research. A particularly interesting quantity to be explored seems to be the extent of research in the foundations vs applications of fuzzy logic, which may help us understand where fuzzy logic as a discipline is heading.

Notes

1. Scopus is a bibliographic database owned by Elsevier. Web of Science is an online scientific citation indexing service maintained by Clarivate Analytics. Google Scholar is a freely accessible web search engine indexing scholarly literature of various formats in numerous areas.
2. As mentioned above, our bibliometric dates are as of October 2021. Google Scholar presents the number of citations to a reprint of Zadeh (1965) in Klir and Yuan (1996).
3. Apparently, the number of 377 citations of "Fuzzy sets as a basis …" reported by WoS is due to a flaw.
4. Scopus subject areas overlap in that a given journal may belong to multiple subject areas. The sum of citations over all subject areas may therefore be larger than the total number of citations of a particular paper. The abbreviated subject areas here, respectively, stand for "Business, Management, and Accounting"; "Chemical Engineering"; "Agricultural and Biological Sciences"; "Economics, Econometrics, and Finance"; and "Biochemistry, Genetics, and Molecular Biology."
5. The results are available at http://www.nature.com/news/the-top-100-papers-1.16224. The citation counts were made using the Web of Science.
6. The first two are Kaplan, E. L., and P. Meier. 1958. "Nonparametric Estimation From Incomplete Observations." *Journal of the American Statistical Association* 53 (282): 457–481, which ranked 11th overall, and Cox, D. R. 1972. "Regression Models and Life-tables." *Journal of the Royal Statistical Society* 34 (2): 187–220, which ranked 24th.
7. Shannon, C. E. 1948. "A Mathematical Theory of Communication." *Bell System Technical Journal* 27 (3): 379–423.
8. https://www.nature.com/news/polopoly_fs/7.21245!/file/GoogleScholartop100.xlsx.
9. Kaplan and Meier's paper ranks 46th; Cox's paper ranks 61st.
10. This seems to be a proper area for our purpose, given the areas offered by the bibliometric databases and the nature of contributions by research in fuzzy logic. Note also that compared to engineering and mathematics as possible other areas, the most influential papers in computer science enjoy more citation counts according to the databases.
11. Several lists of classic papers in computer science and its areas are found on Wikipedia. The papers in Table 5 represent my personal selection.
12. The fellow award of the IFSA (International Fuzzy Systems Association) is a title conferred to people who made outstanding contributions to fuzzy logic.
13. Perhaps the most important factor is a growing number of researchers in academia, and a growing demand for publications by governmental policies, grant agencies, and academic institutions.

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributor

Radim Belohlavek received PhD degree in computer science from the Technical University of Ostrava, Czech Republic, in 1998, PhD degree in mathematics from Palacky University, Olomouc, Czech Republic, in 2001, and DSc degree in informatics and cybernetics from the Academy of Sciences of the Czech Republic in 2008. He is professor of computer science at Palacky University. Dr Belohlavek's academic interests are in discrete mathematics, logic, uncertainty and information, and data analysis. He published books with Kluwer, Springer, MIT Press, and Oxford University Press, and over 200 papers in conference proceedings and journals.

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References

Bělohlávek, R., J. W. Dauben, and G. J. Klir. 2017. *Fuzzy Logic and Mathematics: A Historical Perspective*. New York: Oxford University Press.
Cintula, P, eds. 2011. *Handbook of Mathematical Fuzzy Logic*. Vol. 2. London: College Publications.
Dubois, D., and H. Prade, eds. 2000. *Fundamentals of Fuzzy Sets*. Boston: Kluwer.
Gottwald, S. 2001. *A Treatise on Many-Valued Logics*. Baldock, Hertfordshire: Research Studies Press.
Hájek, P. 1998. *Metamathematics of Fuzzy Logic*. Dordrecht: Kluwer.
Klir, G. J., and B. Yuan. 1996. *Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected Papers by Lotfi A Zadeh*. Singapore, World Scientific.
Novák, V., I. Perfilieva, and J. Močkoř. 1999. *Mathematical Principles of Fuzzy Logic*. Boston: Kluwer.
Van Noorden, R., B. Maher, and R. Nuzzo. 2014. “The Top 100 Papers: *Nature* Explores the Most-cited Research of All Time.” *Nature* 514: 550–553.
Zadeh, L. A. 1965. “Fuzzy Sets.” *Information and Control* 8 (3): 338–353.
Zadeh, L. A. 2015. “Fuzzy Logic–a Personal Perspective.” *Fuzzy Sets and Systems* 281 (6): 4–20.