Computer Science Research in Artificial Intelligence

José M. Merigó, *Member*, *IAENG*, Gustavo Zurita, and Valeria Lobos-Ossandón

Abstract—**This paper presents a bibliometric overview of the research carried out between 1990 and 2014 in computer science with a focus on artificial intelligence. The work analyses all the journals available in Web of Science during this period and presents their publication and citation results. The study also considers the most cited articles in this area during the last twenty-five years. IEEE Journals obtain the most remarkable results publishing more than half of the most cited papers.**

Index Terms— **Bibliometrics, Web of Science, journals, citations.**

I. INTRODUCTION

Artificial intelligence is a research area that studies how systems can think artificially or in related ways. It represents an important part of computer science. In the Web of Science (WoS) database there is one specific research category of the 251 categories strictly dedicated to this field, "Computer Science, Artificial Intelligence". This area is becoming very popular due to the strong development of computers and technology. In order to assess the publications in this field, we can use bibliometrics which analyses the bibliographic material quantitatively [4]. In the literature, there are many articles that have developed a bibliometric analysis of a research field including management [18], economics [3,5], innovation, [8], fuzzy research [16], aggregation systems [7,23], grey systems [22] and computational intelligence [21].

Focusing on computer science, there are also some bibliometric studies. For example, Guan and Ma [12] developed a comparative analysis of the research performance, Tsai [20] studied the citation impact of computer science journals, and Feitelson and Yovel [9] analysed authors through the CiteSeer data. Some other studies have analysed computer science in specific regions including India [19], Brazil [15], Spain [14], Argentina [11] and Malaysia [2].

The aim of this paper is to analyse the artificial intelligence section of computer science. For doing so, we follow the WoS database which classifies a group of journals in this category. Thus, we study all the articles published in these journals between 1990 and 2014. Note that some journals may partially publish material in this discipline. However, our focus is on analyse the journals strictly dedicated to this area and identifying the most cited papers.

This paper is organized as follows. Section II briefly reviews the bibliometric methodology used in the paper. Section III, presents the results and Section IV summarizes the main findings and conclusions of the paper.

II. METHODS

WoS is usually regarded as the most influential database for scientific research. Usually, those journals included here are recognized of those with the highest quality. WoS contains more than 15.000 journals and 50.000.000 documents. Currently, it continues growing, especially with the newest expansion produced by the creation of the Emerging Sources Citation Index that will include journals of high quality that need a period of evaluation before receiving an impact factor although already available in the database. The scientific material is divided in 251 research categories. Computer science encompasses seven of these categories and one of them is focused on Artificial Intelligence.

In order to analyze the data, this study uses several bibliometric indicators [17]. Particularly, we use the total number of publications and citations, the h-index [13], the cites per paper, and the number of papers among the thirty most cited in the field between 1990 and 2014. Note that the h-index is a modern index that tries to integrate publications with citations. In summary, if a set of papers have an h-index of X, it means that X papers of the total set, have received X or more citations. In general, this index works quite well although it is not able to consider some exceptional situations. For example, if an author has five papers and two of them have one thousand citations and the other three zero, his h-index is two. However, if another author have five papers with five citations each, he has an h-index of five. Here, the second author gets a better result although it is clear that the first one is more influential. Due to this, some other measures have appeared in the literature including the g-index [6] and the hg-index [1].

The search process looks for the documents published in the WoS category of Computer Science, Artificial Intelligence between 1990 and 2014. Only articles, reviews, letters and notes are considered. The main reason is that the other types of documents are usually not scientific material. All the journals are ranked according to the total number of citations. However, WoS does not distinguish between the sources that give the citations. From a general perspective, this should not bring important deviations but it is worth mentioning. This issue also affects the most cited papers.

An additional column indicating the year and the volume when it first appeared in WoS is also available. Note that if the journal was available in 1990 or before, the table only shows 1990 and the volume at that time.

Table 1. Journals in Computer Science: Artificial Intelligence

R	Name	TC	TP	H	TC/TP	Y	V	T30
1	IEEE Trans. Pattern Analysis and Machine Intelligence	276.428	3.985	222	69,37	1990	12	9
2	IEEE Trans. Image Processing	162.993	4.894	167	33,30	1992	1	3
3	IEEE Trans. Neural Networks and Learning Systems	129.598	3.705	137	34,98	1991	2	3
4	Pattern Recognition	115.209	5.630	119	20,46	1990	23	-
5	Int. J. Computer Vision	97.525	1.639	138	59,50	1990	4	3
6	Neural Computation	88.807	2.405	129	36,93	1992	4	2
7	Expert Systems with Applications	85.240	9.165	74	9,30	1991	2	-
8	Neural Networks	75.163	2.981	113	25,21	1990	3	1
9	Machine Learning	72.098	1.199	105	60,13	1990	5	3
10	IEEE Trans. Fuzzy Systems	66.695	1.722	116	38,73	1994	2	-
11	Pattern Recognition Letters	64.250	4.860	85	13,22	1990	11	1
12	Artificial Intelligence	63.072	1.979	113	31,87	1990	41	-
13	Chemometrics and Intelligent Laboratory Systems	52.604	2.836	94	18,55	1990	7	-
14	Neurocomputing	49.704	6.436	65	7,72	1992	4	-
15	Computer Vision and Image Understanding	48.737	1.958	93	24,89	1991	53	1
16	IEEE Trans. Knowledge and Data Engineering	46.604	2.650	91	17,59	1992	4	-
17	IEEE Trans. on Evolutionary Computation	45.936	786	95	58,44	1999	3	2
18	Image and Vision Computing	39.830	2.354	78	16,92	1990	8	-
19	J. Machine Learning Research	36.363	1.220	80	29,81	2001	1	1
20	Decision Support Systems	33.782	2.493	68	13,55	1991	7	-
21	Robotics and Autonomous Systems	23.919	1.914	60	12,50	1994	13	-
22	J. Artificial Intelligence Research	19.434	777	62	25,01	1995	3	-
23	Engineering Applications of Artificial Intelligence	18.502	2.189	47	8,45	1992	5	-
24	Evolutionary Computation	18.288	502	58	36,43	1993	1	-
25	Int. J. Approximate Reasoning	17.234	1.343	53	12,83	1993	8	-
26	Artificial Intelligence in Medicine	15.890	1.189	48	13,36	1992	4	-
27	Data Mining and Knowledge Discovery	15.833	497	55	31,86	1997	1	1
28	Knowledge-Based Systems	15.608	2.044	41	7,64	1991	4	-
29	Mechatronics	15.429	1.721	43	8,97	1992	2	-
30	Autonomous Robots	15.093	806	60	18,73	1996	3	-
31	Int. J. Intelligent Systems	14.781	1.470	51	10,06	1990	5	-
32	Data & Knowledge Engineering	14.347	1.288	51	11,14	1994	12	-
33	Network-Computation in Neural Systems	14.145	603	59	23,46	1990	1	-
34	J. Intelligent Manufacturing	11.990	1.489	41	8,05	1990	1	-
35	IEEE Intelligent Systems	11.496	1.416	49	8,12	2001	16	-
36	AI Magazine	10.668	969	49	11,01	1990	11	-
37	Computational Linguistics	10.492	741	48	14,16	1995	21	-
38	J. Mathematical Imaging and Vision	10.407	888	44	11,72	1996	6	-
39	Soft Computing	9.525	1.588	35	6,00	2002	7	-
40	J. Intelligent & Robotic Systems	9.495	1.782	31	5,33	1990	3	-
41	Int. J. Uncertainty Fuzziness and Knowledge Based Systems	9.363	1.028	42	9,11	1995	3	-
42	Computer Speech and Language	8.260	612	40	13,50	1994	8	-
43	Artificial Intelligence Review	8.170	713	37	11,46	1990	4	-
44	Int. J. Pattern Recognition and Artificial Intelligence	7.757	1.439	33	5,39	1995	9	-
45	Neural Processing Letters	7.490	802	32	9,34	1994	1	-
46	Knowledge Engineering Review	7.448	459	35	16,23	1994	9	-
47	Applied Intelligence	7.074	1.011	34	7,00	1993	3	-
48	Neural Computing & Applications	7.056	1.990	28	3,55	1995	3	-
49	Artificial Life	6.442	415	36	15,52	1998	4	-
50	Applied Artificial Intelligence	6.336	912	37	6,95	1991	5	-
51	Annals of Mathematics and Artificial Intelligence	6.147	874	34	7,03	1995	13	-
52	J. Automated Reasoning	5.644	692	34	8,16	1993	10	-
53	Advanced Engineering Informatics	5.413	539	31	10,04	2002	16	-
54	Int. J. Neural Systems	5.259	562	31	9,36	1992	3	-
55	SIAM J. Imaging Sciences	5.258	398	26	13,21	2008	1	-
56	AI Edam-Artificial Intell. Engin. Design Analysis Manuf.	5.119	664	30	7,71	1993	7	-
57	Adaptive Behavior	5.051	494	36	10,22	1994	3	-
58	Autonomous Agents and Multi-Agent Systems	5.026	398	31	12,63	2000	3	-
59	Pattern Analysis and Applications	4.699	569	32	8,26	1998	1	-
60	J. Intelligent Information Systems	4.590	537	29	8,55	1998	10	-

R	Journal	TC	TP	IF	TC/TP	Y	V	GR
61	Computational Intelligence	4.504	596	31	7,56	1995	11	-
62	AI Communications	4.291	527	25	8,14	1994	7	-
63	J. Web Semantics	4.129	290	30	14,24	2005	3	-
64	Information Fusion	3.529	395	30	8,93	2006	7	-
65	Int. J. Information Technology & Decision Making	3.246	532	24	6,10	2004	3	-
66	J. Experimental & Theoretical Artificial Intelligence	3.196	549	25	5,82	1993	5	-
67	J. Intelligent & Fuzzy Systems	3.151	1.303	21	2,42	1995	3	-
68	IEEE Computational Intelligence Magazine	3.068	260	25	11,80	2006	1	-
69	Int. J. Software Engineering and Knowledge Engineering	2.979	963	23	3,09	1991	1	-
70	Expert Systems	2.662	771	22	3,45	1994	11	-
71	Minds and Machines	2.601	523	22	4,97	1992	2	-
72	Connection Science	2.546	308	23	8,27	1998	10	-
73	Int. J. Applied Mathematics and Computer Science	2.086	518	18	4,03	2003	13	-
74	Int. J. Computational Intelligence Systems	1.690	592	18	2,85	2008	1	-
75	Cognitive Systems Research	1.644	289	17	5,69	2005	6	-
76	Fuzzy Optimization and Decision Making	1.464	193	20	7,59	2007	6	-
77	Int. J. Artificial Intelligence Tools	1.285	557	14	2,31	2005	14	-
78	Int. J. Document Analysis and Recognition	1.220	221	17	5,52	2006	8	-
79	Intelligent Data Analysis	1.184	502	14	2,36	2005	9	-
80	Int. J. Fuzzy Systems	1.154	348	14	3,32	2007	9	-
81	ACM Trans. Intelligent Systems and Technology	1.108	259	7	4,28	2010	1	-
82	Int. J. Bio-Inspired Computation	1.040	204	15	5,10	2009	1	-
83	Computing and Informatics	1.008	663	11	1,52	2001	20	-
84	Intelligent Automation and Soft Computing	992	768	13	1,29	1998	4	-
85	ACM Trans. Autonomous and Adaptive Systems	901	190	13	4,74	2006	1	-
86	Int. J. Machine Learning and Cybernetics	888	206	13	4,31	2011	2	-
87	J. Multiple-Valued Logic and Soft Computing	887	455	12	1,95	2004	10	-
88	Int. J. Semantic Web and Information Systems	857	127	13	6,75	2006	2	-
89	J. Real-Time Image Processing	837	286	13	2,93	2006	1	-
90	Cognitive Computation	808	280	13	2,89	2009	1	-
91	IEEE Trans. Autonomous Mental Development	803	154	13	5,21	2009	1	-
92	Advances in Electrical and Computer Engineering	766	481	9	1,59	2007	7	-
93	Neural Network World	763	429	10	1,78	2005	15	-
94	Genetic Programming and Evolvable Machines	760	160	13	4,75	2007	8	-
95	IET Computer Vision	704	293	11	2,40	2007	1	-
96	Turkish J. Electrical Engineering and Computer Sciences	618	589	8	1,05	2008	16	-
97	IEEE Trans. Computational Intelligence and AI in Games	613	162	12	3,78	2009	1	-
98	J. Ambient Intelligence and Smart Environments	569	238	11	2,39	2009	1	-
99	Natural Computing	527	296	9	1,78	2010	9	-
100	Wiley Interdis. Reviews-Data Mining Knowledge Disc.	496	137	11	3,62	2011	1	-
101	J. Applied Logic	310	167	9	1,86	2009	7	-
102	Swarm Intelligence	226	67	8	3,37	2010	4	-
103	Natural Language Engineering	172	134	7	1,28	2009	15	-
104	Traitement du Signal	61	210	3	0,29	2007	24	-
105	Memetic Computing	61	74	4	0,82	2012	4	-
106	IET Biometrics	59	79	4	0,75	2012	1	-

Abbreviations: R = Ranking according to TC; TC = Total citations; TP = Total papers; TC/TP = Average citations per paper; Y= Year; V = Volume; IF = Impact factor; IF5 = 5-year impact factor; T50 = Number of papers among the 50 most cited of the category; T200 = Number of papers among the 200 most cited in all fields of computer science since 1990; T200 < 1990 = Number of papers among the 200 most cited in all fields of computer science before 1990; GR = Global ranking considering all the computer science journals.

III. RESULTS

Currently, there are 106 journals in WoS in the category of Computer Science, Artificial Intelligence. However, note that this number is constantly changing, especially now with the introduction of the Emerging Sources Citation Index. Table 1 presents the journals ranked according to their number of citations obtained between 1990 and 2014.

The IEEE Transactions Journals obtain the most remarkable results [10]. Particularly, the IEEE Transactions on Pattern Analysis and Machine Intelligence, the IEEE Transaction on Image Processing and the IEEE Transactions on Neural Networks and Learning Systems, obtain the first three positions. Note that some other journals obtain better results according to other indicators including the International Journal of Computer Vision, Machine Learning and the IEEE Transactions on Evolutionary Computation.

Next, let us look into the most cited papers in this field over the last twenty-five years. Table 2 presents the thirty most cited papers in Computer Science, Artificial Intelligence.

Table 2. Most cited papers in Computer Science: Artificial Intelligence

R	J	TC	Title	Author/s	Year
1	IJCV	10356	Distinctive image features from scale-invariant keypoints	Lowe, DG	2004
2	ML	7192	Random forests	Breiman, L	2001
3	ML	6494	Support - Vector Networks	Cortes, C; Vapnik V	1995
4	TRECO	6035	A fast and elitist multiobjective genetic algorithm: NSGA-II	Deb, K; Pratap, A; Agarwal, S; et al.	2002
5	ML	5354	Bagging predictors	Breiman, L	1996
6	TPA	4430	A method for registration of 3-D shapes	Besl, PJ; Mckay, ND	1992
7	DMKD	4262	A tutorial on Support Vector Machines for pattern recognition	Burges, CJC	1998
8	TPA	4251	Scale-Space and Edge-Detection using anisotropic diffusion	Perona, P; Malik J	1990
9	TIP	4032	Image quality assessment: From error visibility to structural similarity	Wang, Z; Bovik, AC; Sheikh, HR; et al.	2004
10	TPA	3890	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection	Belhumeur, PN; Hespanha, JP; Kriegman, DJ; et al.	1997
11	NC	3487	An information maximization approach to blind separation and blind deconvolution	Bell, AJ; Sejnowski, TJ	1995
12	TPA	3306	Normalized cuts and image segmentation	Shi, JB; Malik, J	2000
13	TIP	3239	Active contours without edges	Chan, TF; Vese, LA	2001
14	TPA	2972	Mean shift: A robust approach toward feature space analysis	Comaniciu, D; Meer, P	2002
15	CVIU	2841	Active shape models - Their training and application	Cootes, TF; Taylor CJ; Cooper DH; et al.	1995
16	IJCV	2818	Robust real-time face detection	Viola, P; Jones, MJ	2004
17	TPA	2700	A model of saliency-based visual attention for rapid scene analysis	Itti, L; Koch, C; Niebur, E; et al.	1998
18	TRECO	2585	The particle swarm - Explosion, stability, and convergence in a multidimensional complex space	Clerc, M; Kennedy, J	2002
19	JMLR	2581	Latent Dirichlet allocation	Blei, DM; Ng, AY; Jordan, MI; et al.	2003
20	NC	2534	Nonlinear component analysis as a kernel eigenvalue problem	Scholkopf, B; Smola, A; Muller, KR; et al.	1998
21	TNN	2407	Training feedforward networks with the marquardt algorithm	Hagan, MT; Menhaj, MB	1994
22	PRL	2396	An introduction to ROC analysis	Fawcett, T	2006
23	TPA	2336	A flexible new technique for camera calibration	Zhang, ZY	2000
24	TIP	2312	Secure spread spectrum watermarking for multimedia	Cox, IJ; Kilian, J; Leighton, FT; et al.	1997
25	TPA	2296	Multiresolution gray-scale and rotation invariant texture classification with local binary patterns	Ojala, T; Pietikainen, M; Maenpaa, T; et al.	2002
26	IJCV	2292	Color indexing	Swain, MJ; Ballard, DH	1991
27	TPA	2265	On combining classifiers	Kittler, J; Hatef, M; Duin, RPW; et al.	1998
28	NN	2208	Independent component analysis: algorithms and applications	Hyvarinen, A; Oja, E	2000
29	TNN	2199	Fast and robust fixed-point algorithms for independent component analysis	Hyvarinen, A	1999
30	TNN	2120	A comparison of methods for multiclass support vector machines	Hsu, CW; Lin, CJ	2002

Abbreviations: R = Rank; TC = Total citations; IJCV = Int. J. Computer Vision; ML = Machine Learning; TRECO = IEEE Trans. Evolutionary Computation; IEEE Trans. Pattern Analysis and Machine Intelligence; DMKD = Data Mining and Knowledge Discovery; TIP = IEEE Trans. Image Processing; NC = Neural Computation; CVIU = Computer Vision and Image Understanding; JMLR = J. Machine Learning Research; TNN = IEEE Trans. Neural Networks; PRL = Pattern Recognition Letters.

The most cited article of the last twenty-five years is published in the International Journal of Computer Vision by Lowe and has received more than 10.000 citations. The IEEE Transactions on Pattern Analysis and Machine Intelligence has nine papers in the Top 30. All the papers in the list have received more than 2.000 citations.

IV. Conclusion

This study has presented an overview of the leading trends in the field of artificial intelligence in computer science. The results are based on WoS and clearly show the relevance of the IEEE journals as the leaders of the field. However, there are many other important journals in this area. Depending on the bibliometric indicator considered, some journals may obtain better results than others. This work has ranked the journals according to the total number of citations but it also presents other indicators in order to give a more general perspective of the characteristics of each journal. The current trend is that more journals are entering WoS, especially motivated by the strong growth of researchers worldwide that needs a higher supply of journals.

The paper has also considered the most cited papers in this area between 1990 and 2014. The IEEE Transactions on Pattern Analysis and Machine Intelligence is the most influential journal with nine papers in the Top 30 and is the most cited journal in the ranking.

In future research, we will look into other issues including leading authors, institutions and countries. Moreover, we will also consider other computer science categories including information systems, interdisciplinary applications and cybernetics.

References

[1] S. Alonso, F.J. Cabrerizo, E. Herrera-Viedma, F. Herrera, H-index: A review focused on its variants, computation and standarization for different scientific fields. *Journal of Informetrics*, 3:273-289, 2009.

[2] A. Bakri, P. Willet, Computer science research in Malaysia: A bibliometric analysis. *Aslib Proceedings*, 63:321-335, 2011.

[3] C. Bonilla, J.M. Merigó, C. Torres-Abad, Economics in Latin America: A bibliometric analysis. *Scientometrics*, 105:1239-1252, 2015.

[4] R.N. Broadus, Toward a definition of "Bibliometrics". *Scientometrics*, 12:373-379, 1987.

[5] T. Coupé, Revealed performances: Worldwide rankings of economists and economics departments, 1990–2000. *Journal of the European Economic Association*, 1:1309-1345, 2003.

[6] L. Egghe, Theory and practice of the g-index. *Scientometrics*, 69:131-152, 2006.

[7] A. Emrouznejad, M. Marra, Ordered weighted averaging operators 1988–2014. A citation based literature survey. *International Journal of Intelligent Systems*, 29:994-1014, 2014.

[8] J. Fagerberg, M. Fosaas, K. Sapprasert, Innovation: Exploring the knowledge base. *Research Policy*, 41:1132-1153, 2012.

[9] D.G. Feitelson, U. Yovel, Predictive ranking of computer scientists using CiteSeer data. *Journal of Documentation*, 60:44-61, 2004.

[10] F. Franceschini, D. Maisano, Sub-field normalization of the IEEE scientific journals based on their connection with Technical Societies. *Journal of Informetrics*, 8:508-533, 2014.

[11] D. Godoy, A. Zunino, C. Mateos, Publication practices in the Argentinian computer science community: a bibliometric perspective. *Scientometrics*, 102:1795-1814, 2015.

[12] J.C. Guan and N. Ma, A comparative study of research performance in computer science. *Scientometrics*, 61:339-359, 2004.

[13] J.E. Hirsch, An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America*, 102:16569-16572, 2005.

[14] A. Ibáñez, P. Larrañaga, C. Bielza, Cluster methods for assessing research performance: exploring Spanish computer science. *Scientometrics*, 97:571-600, 2013.

[15] H. Lima, T.H.P. Silva, M.M. Moro, R.L.T. Santos, W. Meira Jr, A.H.F. Laender, Assessing the profile of top Brazilian computer science researchers. *Scientometrics*, 103:879-896, 2015.

[16] J.M. Merigó, A.M. Gil-Lafuente, R.R. Yager, An overview of fuzzy research with bibliometric indicators. *Applied Soft Computing*, 27: 420-433, 2015.

[17] J.M. Merigó, A. Mas-Tur, N. Roig-Tierno, D. Ribeiro-Soriano, A bibliometric overview of the Journal of Business Research between 1973 and 2014. *Journal of Business Research*, 68: 2645-2653, 2015.

[18] P.M. Podsakoff, S.B. MacKenzie, N.P. Podsakoff, D.G. Bachrach, Scholarly influence in the field of management: A bibliometric analysis of the determinants of university and author impact in the management literature in the past quarter century. *Journal of Management*, 34:641-720, 2008.

[19] V.K. Singh, A. Uddin, D. Pinto, Computer science research: the top 100 institutions in India and in the world. *Scientometrics*, 104: 529-553, 2015.

[20] C.F. Tsai, Citation impact analysis of top ranked computer science journals and their rankings. *Journal of Informetrics*, 8:318-328, 2014

[21] N.J. Van Eck, L. Waltman, Bibliometric mapping of the computational intelligence field, *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 15:625-645, 2007.

[22] M.S. Yin, Fifteen years of grey system theory research: A historical review and bibliometric analysis, *Expert Systems with Applications*, 40:2767-2775, 2013.

[23] D. Yu, A scientometrics review on aggregation operator research. *Scientometrics*, 105:115-133, 2015.