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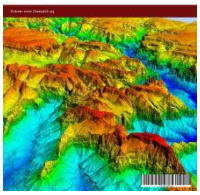
Emerging Science Journal

Vol. 3, No. 1, February, 2019



Deep Learning Research: Scientometric Assessment of Global Publications Output during 2004 -17

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Abstract

The paper provides a quantitative and qualitative description of deep learning research using bibliometric indicators covering global research publications published during 14-year period 2004-17. Global deep learning research registered 106.76% high growth per annum, and averaged 7.99 citations per paper. Top 10 countries world- over dominate the research field with their 99.74% global publications share and more than 100% global citations share. China ranks the top with the highest (29.25%) global publications share, followed by USA (26.46%), U.K. (6.40%), etc. during the period. Canada tops in relative citation index (5.30). International collaboration has been a major driver of research in the subject with 14.96% to 53.76% of national-level share of top 10 countries output appeared as international collaborative publications. Computer Science is one of the most popular areas of research in deep learning research (76.85% share). The study identifies top 50 most productive organizations and 50 most productive authors and top 20 most productive journals reporting deep learning research and 118 highly cited papers with 100+ citations per paper.

Keywords:

Deep Learning;
Machine Learning;
Artificial Intelligence;
Global Publications;
Scientometrics;
Bibliometrics.

Article History:

Received:	21	November	2018
Accepted:	20	January	2019

1- Introduction

Deep learning is an advanced way of achieving artificial intelligence using neural network algorithms. Deep learning (also known as deep structured learning or hierarchical learning) is a specialized form of machine learning research. Basically, it is designed on the way human brain processes information and learns. In deep learning, neural networks perform pattern recognition and classification tasks from images, texts, and sound. Neural networks (also known as artificial neural networks) are trained to first learn how to perform artificial intelligence tasks by exposing them to a labeled data set and to defined neural network architecture. Neural networks consist of hidden layers and that these layers model complex relationship among data, where the current hidden layer takes the output from the previous layer as an input. The term 'deep' in 'deep learning' usually refers to the number of hidden layers in the neural network. Deep networks can have as many as 150 layers. Learning can be both supervised and unsupervised and it is applied to train and fine-tune neural networks using class target labeled data set of inputs and expected outputs. Its availability means supervised system, if it is not labeled it is an unsupervised system. Neural networks come in several different architecture types such as deep neural networks, deep belief networks, and recurrent neural networks [1-3].

Deep learning has been applied to fields including computer vision, speech recognition, natural language processing, audio recognition, social network filtering, machine translation, bio-informatics, drug design and board game programs. Deep learning methods have dramatically improved the state-of-the-art in speech recognition, visual object recognition, object detection and many other domains such as drug discovery and genomics and have produced results comparable to and in some cases superior to human experts [4-6]. Deep convolutional nets have brought about breakthroughs in

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DOI: http://dx.doi.org/10.28991/esj-2019-01165

processing images, video, speech and audio, whereas recurrent nets have shone light on sequential data such as text and speech [7].

Deep learning research lies in the intersections of research areas including as neural networks, artificial intelligence, graphical modeling, optimization, pattern recognition, and signal processing. Although deep learning models are vaguely inspired by information processing and communication patterns in biological nervous systems yet differences between neural networks and the structural and functional properties of biological brains (especially human brain), make them incompatible with neuroscience evidences [8-10].

1-1- Literature Review

Till recently, only one study each on machine learning research and deep learning research has been found to be available in this area. Mao, Li, Zhao and Zeng [11] analyzed the global research output (3599 papers) to ascertain research status in the subject, current trends and hotspots within the domain of deep learning using bibliometric indicators during 1968-2018. Research was categorized into three layers: application research, algorithm research and modeling research into computer vision technology. Rincon-Patino, Ramirez-Gonzalez and Corrales [12] presented a bibliometric analysis of machine learning during 2007-2017, using SciMAT tool and Scopus database. This analysis shows strategic diagrams of evolution and a set of thematic networks. However, in addition, a number of other studies do exist in the bibliometric analysis of computer science research in general [13] and in its sub-fields, such as artificial intelligence [14], cloud computing [15-16], pervasive and ubiquitous computing [17], quantum computing [18] and mobile computing [19-20] etc.

This present study is aimed at undertaking a scientometric assessment of the global deep learning research as indexed in Scopus international database covering 2004-17. The main objectives are to study: (i) study growth and distribution of global literature and its citation impact; (ii) examine research output of top 10 most productive countries, including their citation impact and international collaborative papers share; (iii) distribution of research by broad subject areas and dynamics of growth and decline across sub-areas over time; (iv) publication and citation profile of top most productive research organizations and authors; (v) main modes of communication, and (vi) bibliographic characteristics of highly cited papers.

2- Methodology

The study retrieved and downloaded 14-year global publications data and of top 10 countries on deep learning research. The data was sourced from Scopus database (http://www.scopus.com). The field tags “Keyword” and The “Title of Paper” (as shown in search string below) were searched using keywords and restricted the hit to the period 2004-17 in “date range” field tag. This formed the main search string and it was restricted to individual countries by name in “country tag”, for obtaining publication data on top 10 countries in deep learning research. The search string was further refined, using tools as provided in Scopus database, and accordingly sourced data/information on the distribution of global publications output by subject, collaborating countries, author-wise, organization-wise and journal-wise, etc. For citation data, citations to publications were collected from date of publication till 5 July 2018.

(KEY ("deep learning") OR TITLE ("deep learning")) AND PUBYEAR > 2003 AND PUBYEAR < 2018

3- Data Analysis and Results

Global publications output on deep learning research in 14 years cumulated to 10027 publications during 2004-17. Its annual publication output registered annual average growth of 106.76%, its annual output went up from 3 in 2004 to 6040 publications in 2017. The 7-year global publication output in the subject registered 4788.56% absolute growth, up from 201 during 2004-10 to 9826 publications during 2011-17. The global research output (10027) on deep learning research during 14-years received 80148 citations, averaging 7.99 citations per publication (CPP) during 2004-17. The 7-year citation impact of research in the subject declined from 31.11 CPP during 2004-10 to 7.99 CPP during 2011-17 (Table 1, Figure 1).

Table 1. Annual global publications output on deep learning, 2004-17

Publication Period	World		
	TP	TC	CPP
2004	3	13	4.33
2005	19	311	16.37
2006	21	239	11.38
2007	18	174	9.67
2008	34	757	22.26

2009	41	1475	35.98
2010	65	3284	50.52
2011	76	3628	47.74
2012	115	3077	26.76
2013	190	10009	52.68
2014	382	11527	30.18
2015	886	19097	21.55
2016	2137	16748	7.84
2017	6040	9809	1.62
2004-10	201	6253	31.11
2011-17	9826	73895	7.52
2004-17	10027	80148	7.99

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Of the total global publications output (10027), 67.07% (6725) appeared as conference papers, 26.98% (2705) as articles. 2.22% (223) as articles in press, 1.39% (139) as reviews, 1.34% (134) as book chapter, and others such as editorials, notes, short surveys, book, letters, erratum and conference reviews accounted for 0.04% to 0.38%) during the period.

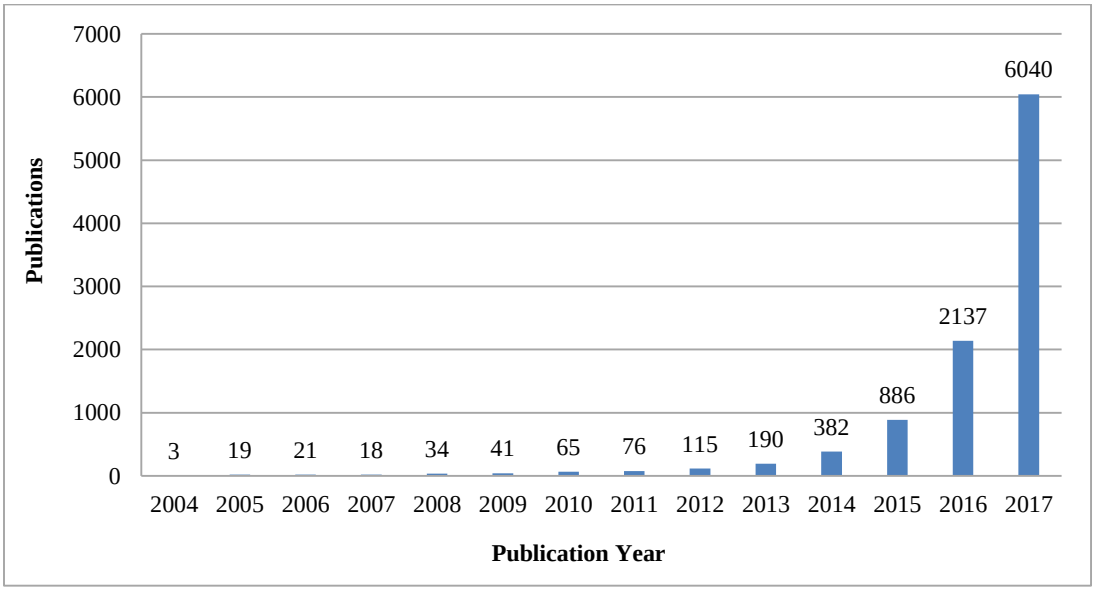

Figure 1. Publications Trend in Deep Learning Research 2004-2017

3-1- Most Productive Countries in Deep Learning

102 countries contributed 10027 global papers in 14 years during 2004-17 to deep learning research and their distribution by participating countries was skewed. Of the 102 participating countries, 46 contributed 1-10 papers each, 27 countries 11-50 papers each, 10 countries 51-100 papers each, 16 countries 101-500 papers, 1 country each contributed 501-1000 papers and 2 countries each 2001-2933 papers.

The top 10 most productive countries together contributed 8898 papers (accounting for 99.74% global publications share) and 121193 citations (accounting for more than 100% global citations share) in deep learning research during 2004-17.

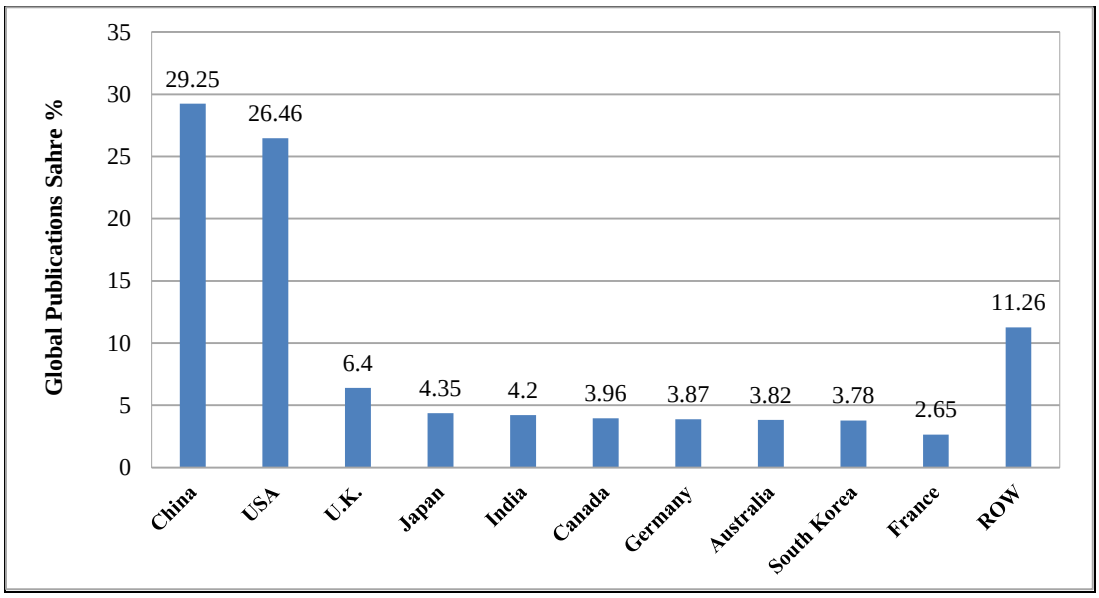

Figure 2. Deep Learning Research: Most Productive Countries in the World 2004-17

Their global publications share (GPS) increased from 78.61% to 94.12% during 2004-10 to 2011-17. The global publication share of top 10 countries, individually, varied from 2.65% to 29.25% during 2004-17. China contributed largest share (29.25%), followed closely by USA (26.46%), U.K. (6.40%), and other 7 countries (from 2.65% to 4.35%) etc. Only 2 countries registered relative citation index above their average of 1.78: Canada (5.30) and USA (3.23) during 2004-17 (Table 2, Figure 2).

Table 2. Global research output, publication share, international collaborative publications and citation impact of top 10 countries in deep learning during 2004-17

S. No	Name of the Country	Number of Papers			% Share of Global Papers			TC	CPP	RCI	ICP	%ICP
		2004-10	2011-17	2004-17	2004-10	2011-17	2004-17	2004-17				
1	China	10	2923	2933	4.98	31.48	29.25	18067	6.16	0.77	842	28.71
2	USA	65	2588	2653	32.34	27.87	26.46	68484	25.81	3.23	891	33.58
3	U.K.	34	608	642	16.92	6.55	6.40	5967	9.29	1.16	335	52.18
4	Japan	0	436	436	0.00	4.70	4.35	1062	2.44	0.30	78	17.89
5	India	0	421	421	0.00	4.53	4.20	879	2.09	0.26	63	14.96
6	Canada	12	385	397	5.97	4.15	3.96	16821	42.37	5.30	198	49.87
7	Germany	2	386	388	1.00	4.16	3.87	2434	6.27	0.79	178	45.88
8	Australia	32	351	383	15.92	3.78	3.82	3238	8.45	1.06	183	47.78
9	South Korea	0	379	379	0.00	4.08	3.78	1620	4.27	0.53	67	17.68
10	France	3	263	266	1.49	2.83	2.65	2621	9.85	1.23	143	53.76
	Total of 10 countries	158	8740	8898	78.61	94.12	88.74	121193	13.62	1.70	2978	33.47
	World Total	201	9286	10027				80148	7.99			
	Share of 10 Countries in World Total	78.61	94.12	88.74								

* TC=Total Citations; CPP=Citations Per Paper; ICP=International Collaborative Papers; RCI=Relative Citation Index

3-2-International Collaboration

The national-level share of top 10 countries towards international collaborative papers (ICP) in deep learning research varied from 14.96% to 53.76% (an average of 33.47%) during 2004-17. France, U.K. and Canada (53.76%, 52.18% and 49.87%) are top three counties for their highest ICP share, followed by Australia and Germany (47.78% and 45.88%) and 5 other countries, namely USA, China, Japan, South Korea and India contributed 14.96% to 33.58% national-level share in 14 years during 2004-17.

3-3- Subject-Wise Distribution of Papers

The global publication output on deep learning research published during 2004-17 was classified under six broad subjects (as defined by Scopus). Computer science accounted for the largest publications share (76.86%), followed by engineering (32.64%), mathematics (22.19%) and other 3 subjects (from 6.58% to 7.27%) during 2004-17.

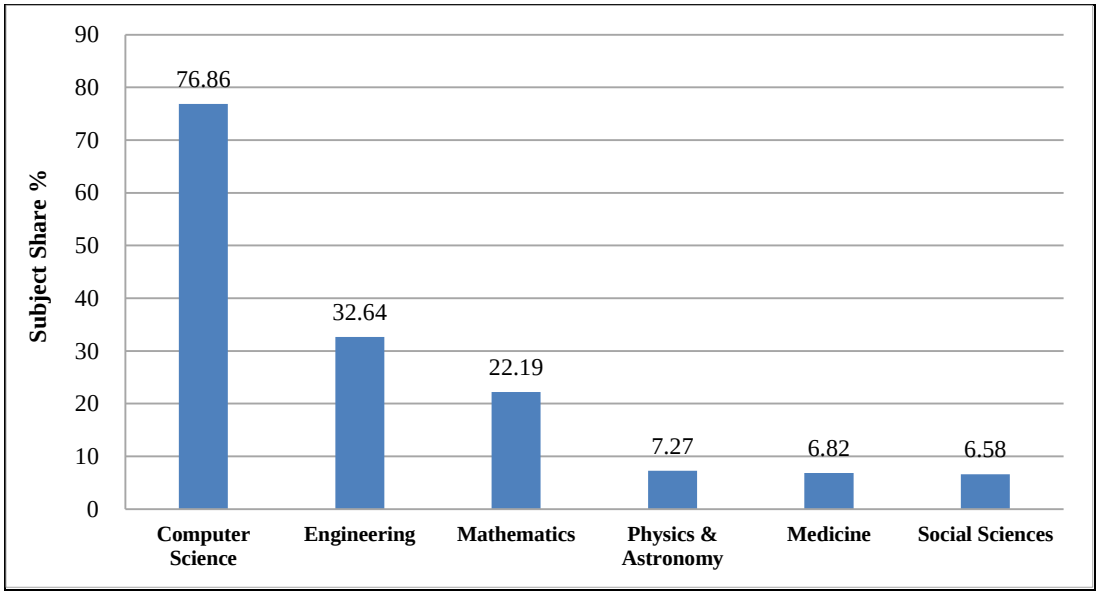

Figure 3. Deep Learning Research by Subject 2004-17

The activity index showed increase in publication activity across all six subjects (from 43.83 to 94.0) over seven years. The average value of activity index is 100. Social Sciences registered the highest citation impact of 10.35 per paper and Physics & Astronomy registered the least citation impact (4.17 per paper) during 2004-17 (Table 3, Figure 3).

Table 3. Subject-wise break-up of global publications on deep learning during 2004-17

S. No.	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		2004-10	2011-17	2004-17	2004-10	2011-17	2004-17	2004-17	2004-17
1	Computer Science	97	7610	7707	62.79	106.62	55953	7.26	76.86
2	Engineering	31	3242	3273	47.25	106.96	24675	7.54	32.64
3	Mathematics	14	2211	2225	31.39	107.30	19260	8.66	22.19
4	Physics & Astronomy	2	727	729	13.69	107.68	3038	4.17	7.27
5	Medicine	5	679	684	36.47	107.19	4286	6.27	6.82
6	Social Sciences	122	538	660	19.96	88.02	6828	10.35	6.58
	World Output	201	9286	10027					
There is overlapping of literature covered under various subjects									

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

3-4- Contribution and Citation Impact of Top 50 Global Organizations

1545 organizations contributed 10027 global papers in 14 years to deep learning research during 2004-17, with their distribution by participating organizations was highly skewed. Of the 1545 organizations, 765 contributed 1-5 papers each, 368 organizations 6-10 papers each, 261 organizations 11-20 papers each, 110 organizations 21-50 papers each, 36 organizations 51-100 papers each and 5 organizations 108-356 papers each. The top 50 most productive organizations contributed 3507 papers (34.98% global publications share) and 65534 citations (81.77% global citations share) in deep learning research during 2004-17. Individually the contribution of top 50 organizations varied from 43 to 197 publications in 14 years.

Table 4. Scientometric profile of top 15 most productive global organizations and 15 top organizations in relative citation index on deep learning during 2004-17

S.No	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Tsinghua University, China	197	1590	8.07	21	70	35.53	1.01
2	Ministry of Education, China	145	719	4.96	14	28	19.31	0.62
3	Institute of Automation, CAS, China	108	875	8.10	14	32	29.63	1.01
4	Microsoft Research, USA	108	2855	26.44	25	65	60.19	3.31
5	Harbin Institute of Technology, China	100	1345	13.45	16	27	27.00	1.68
6	Northwestern Polytechnic University, China	94	642	6.83	11	32	34.04	0.85
7	National University of Singapore	90	726	8.07	15	65	72.22	1.01
8	Nanyang Technological University, Singapore	88	1816	20.64	19	55	62.50	2.58
9	Stanford University, USA	86	3810	44.30	22	18	20.93	5.54
10	Beijing University of Posts & Telecommunications, China	86	279	3.24	8	15	17.44	0.41
11	Chinese University of Hong Kong	85	3228	37.98	23	52	61.18	4.75
12	Shanghai Jiao Tong University, China	85	467	5.49	11	31	36.47	0.69
13	Carnegie Mellon University, USA	84	527	6.27	10	26	30.95	0.79
14	Peking University, China	79	612	7.75	11	23	29.11	0.97
15	Zhejiang University, China	78	470	6.03	11	15	19.23	0.75
16	University of Toronto, Canada	67	10618	158.48	22	34	50.75	19.83
17	University of California, Berkeley, USA	63	1074	17.05	14	21	33.33	2.13
18	Google LLC, USA	62	6143	99.08	19	26	41.94	12.40
19	IBM Thomas J Walton Research Centre	60	1199	19.98	15	22	36.67	2.50
20	Technical University of Munich, Germany,	56	755	13.48	13	35	62.50	1.69
21	University of Oxford, U.K.	52	1483	28.52	14	31	59.62	3.57
22	University of Montreal, Canada	46	10162	220.91	19	23	50.00	27.65
23	University of Illinois at Urbana-Champaign	45	1180	26.22	14	14	31.11	3.28
24	University of Cambridge, U.K.	44	673	15.30	14	22	50.00	1.91
25	University of North Carolina at Chapel Hill	43	939	21.84	16	25	58.14	2.73
26	University of Washington, Seattle, USA	43	656	15.26	9	6	13.95	1.91

On further analysis, it was observed that:

- Only 17 organizations registered productivity rate above the group average of 701.14 papers per organization: Tsinghua University, China (197 publications), Ministry of Education, China (145 publications), Institute of Automation, CAS, China (108 publications), Microsoft Research, USA(108 publications), Harbin Institute of Technology, China (100 publications), etc. (Table 4);
- Only eleven organizations registered citation impact and relative citation index above the group average of 18.69 per paper and 2.34: University of Montreal, Canada (220.91 and 27.65), University of Toronto, Canada (158.48 and 19.83), Google LLC, USA (99.08 and 12.40), Stanford University, USA (44.30 and 5.54), etc., etc. (Table 4);
- Twenty two organizations registered international collaborative publications above the group average of 36.73%: National University of Singapore (72.22%), Hong Kong Polytechnic University (64.29%), Nanyang Technological University, Singapore and Technical University of Munich, Germany (62.50% each), etc.

3-5- Contribution and Citation Impact of Top 50 Global Authors

2010 authors across the world participated in deep learning research, of which 1765 authors published 1-5 papers each, 189 authors 6-10 papers each, 49 authors 11-20 papers each and 7 authors 21-39 papers each. The research productivity of top 50 authors in deep learning research varied from 11 to 39 publications. Together they contributed 7.87% (789) global publication share and 45.66% (36597) citation share of total research output in 14 years during 2004-17.

On further analysis, it was observed that:

- Thirteen (13) of top 50 authors registered publications output above the group average of 15.78: X. Wang (39 papers), L. Deng (32 papers), Y. Bengio, G. Carneiro and D. Shen (30 papers each), etc. (Table 5);
- Thirteen authors (13) registered citation impact per paper and relative citation index above the group average of 46.38 and 5.81: Y. Bengio (334.20 and 41.83), A.Y. Ng (225.33 and 28.20). H. Lee (148.58 and 18.60), etc. (Table 6);
- Twenty two authors (22) contributed international collaborative publications above the group average share of 42.84% of all authors: C.H. Lee (90.91%), S. Yan (88.89%), D. Tao (84.62%), N.D. Lane and H. Larochelle (81.82% each), K. Cho (72.73%), H. Chen and J. Feng (71.43% each), etc.

Table 5. Scientometric profile of top 15 most productive authors in deep learning research during 2004-17

S.No	Name of the	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	M.Billinghurst	University of Canterbury, N.Z	204	4357	21.36	31	141	69.12	2.67
2	D.Schmalstieg	Graz University of Technology, Austria	138	3829	27.75	35	49	35.51	3.47
3	N.Navab	Siemens Corporate Research, Princeton, USA	136	1948	14.32	24	71	52.21	1.79
4	G.Klinker	Technical University of Munchen, Germany	92	1073	11.66	18	21	22.83	1.46
5	B.H.Thomas	University of Southern Australia	86	821	9.55	16	16	18.60	1.19
6	H.Saito	Keio University, Japan	85	386	4.54	11	13	15.29	0.57
7	W.Woo	GIST U-VR Lab., South Korea	83	412	4.96	11	25	30.12	0.62
8	H.Kato	Hiroshima City University, Japan	77	1791	23.26	19	38	49.35	2.91
9	A.Y.C. Nee	National University of Singapore	75	1169	15.59	17	6	8.00	1.95
10	S.K. Ong	National University of Singapore	75	1182	15.76	17	5	6.67	1.97
11	Y. Liu	Beijing Institute of Technology, China	73	205	2.81	7	3	4.11	0.35
12	S.Feiner	Columbia University, USA	63	3855	61.19	24	14	22.22	7.66
13	G. Reitmayr	University of Cambridge, U.K.	62	1747	28.18	19	26	41.94	3.53
14	T. Hollerer	University of California, Santa Barbara, USA	61	1915	31.39	21	10	16.39	3.93
15	K.K. Yokawa	Osaka University, Japan	61	555	9.10	13	24	39.34	1.14

Table 6. Scientometric profile of top 15 authors in deep learning research in citation per paper and relative citation index during 2004-17

S.No	Name of the	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Y. Bengio	University of Montreal, Canada	30	10026	334.20	17	13	43.33	41.83
2	A.Y.Ng	Stanford University, USA	12	2704	225.33	11	1	8.33	28.20
3	H. Lee	University of Michigan, USA	12	1783	148.58	9	0	0.00	18.60
4	H.Larochelle	University of Toronto, Canada	11	1606	146.00	7	9	81.82	18.27
5	X. Tang	Shenzhen Institute of Advanced Tech, China	20	2038	101.90	13	12	60.00	12.75
6	K. Yu	Tsinghua University, China	12	1132	94.33	8	4	33.33	11.81
7	S. Ji	Old Dominion University, USA	14	1129	80.64	9	4	28.57	10.09
8	X.Wang	Chinese University of Hong Kong	39	2622	67.23	17	23	58.97	8.41
9	D. Yu	Microsoft Research, USA	20	1212	60.60	13	4	20.00	7.58
10	L. Deng	Microsoft Research, USA	32	1922	60.06	19	12	37.50	7.52
11	P. Luo	Chinese University of Hong Kong	16	913	57.06	9	11	68.75	7.14
12	X.He	Microsoft Research, USA	13	736	56.62	9	2	15.38	7.09
13	W. Ouyang	Chinese University of Hong Kong	13	699	53.77	7	4	30.77	6.73
14	B.Van Ginneken	Redbound University Medical Centre, Nethererland	11	455	41.36	7	5	45.45	5.18
15	H.Greenspan	Tel Aviv University, Israel	11	352	32.00	6	2	18.18	4.01

3-6- Medium of Research Communication

Of the global output in deep learning research, 54.31% (5446) appeared in conference proceedings, 31.28% (3136) in journals, 13.13% (1317) in book series, 1.01% (101) as books, 0.23% (23) as trade publications and 0.04% (4) as undefined. Of the total of 876 journals which published deep learning research, 773 published 1-5 papers each, 59 journals 6-10 papers each, 24 journals 11-20 papers each, 18 journals 21-50 papers each and 2 journals 51-91 papers each. The top 20 most productive journals published 21 to 91 papers each, accounted for 23.05% publications share (723 papers) of total papers reported in journal medium in 14 years during 2004-17. The top most productive journals include: *Neurocomputing (91* papers), followed by IEEE Access (53 papers), *Multimedia Tools & Applications* (48 papers), *IEEE Transaction on Image Processing* (43 papers), *Pattern Recognition* (42 papers), *etc*. during 2004-17 (Table 7).

Table 7. Top 20 most productive journals in deep learning research during 2004-17

S.No	Name of the Journal	Number of Papers		
		2004-10	2011-17	2004-17
1	Neurocomputing	1	90	91
2	IEEE Access	1	52	53
3	Multimedia Tools & Applications	0	48	48
4	IEEE Transaction on Image Processing	1	42	43
5	Pattern Recognition	1	41	42
6	Pattern Recognition Letters	1	39	40
7	IEEE Transaction on Pattern Analysis & Machine Intelligence	5	34	39
8	IEEE Transaction on Multimedia	0	38	38
9	IEEE Transaction on Medical Imaging	8	29	37
10	Sensors Switzerland	1	36	37
11	IEEE Geoscience & Remote Sensing	0	35	35
12	Zidonghua Xuebao Acta Automatica Senica	0	31	31
13	Scientific Reports	0	30	30
14	IEEE Transaction on Neural Networks & Learning Systems	2	23	25
15	Journal of Machine Learning Research	5	20	25
16	Neural Computing & Applications	0	23	23
17	Expert System & Applications	0	22	22
18	IEEE Transaction on Geoscience & Remote Sensing	2	20	22
19	IEEE Transaction on Circuit & Systems for Video Technology	0	21	21
20	Neural Networks	0	21	21
	Total of 20 journals	28	695	723
	Total global journal output	94	3042	3136
	Share of top 20 journals in global journal output	29.79	22.85	23.05

3-7- Highly Cited Papers

For this study, all such papers that received 100 or 100 plus citations per paper within 14 years since their publication during 2004-17 have been acknowledged as highly cited papers in deep learning field. A total of 118 papers were identified as highly cited papers, which accounted for 1.18% share of the total world output (10027 papers) in the subject during the period. The distribution of highly cited papers across discrete citations frequencies is highly skewed.

- Of the 118 highly cited papers, 77 were in citation range 101-200 citations per paper, 17 in the range 201-300 citations per paper, 11 in the range 301-500 citations per paper, 8 in the range 501-900 citations per paper, 3 in the range 1480-1721 citations per paper and 2 papers 2908-4165 citations since its publication during 2007-16.
- These 118 highly cited papers cumulated a total of 35374 citations, with an average of 299.78 citations per paper.
- Of the 118 highly cited papers, 44 were contributed by such individual organizations who pursued research in their standalone capacity (non-collaborative) and 74 by such other collaborating organizations who pursued research as a group of two or more organizations per paper (35 national collaborative and 39 as international collaborative organizations).

- Amongst highly cited papers, research participation by a country was the largest from USA (with 65 papers), followed by China (26 papers), Canada (17 papers), Hong Kong (9 papers), U.K. (8 papers), Netherlands (6 papers), Singapore (5 papers), Australia, Germany and Switzerland (4 papers each), France (3 papers), South Korea (2 papers),Brazil, Denmark, Czech Republic, India, Israel, Portugal, Qatar, Russia Federation, Spain, Sweden and Taiwan(1 paper each).
- The 118 highly cited papers involved the participation of 490 authors from 252 organizations.
- The research organizations accounting for the largest number of highly cited papers include:

  University of Stanford, USA and University of Toronto, Canada (11 papers each), Chinese University of Hong Kong and University of Montreal, Canada (8 papers each), Microsoft Research, USA and Google LLC, USA (6 papers each), University of Illinois at Urbana-Champaign, USA (5 papers), Nanyang Technological University, Singapore, University of California, Berkeley, USA and IBM Thomas J Watson Research Centre, USA (4 papers each), Harbin Institute of Technology, China (3 papers), Tsinghua University, China, Northwestern Polytechnic University, China, Technical University of Munich, Germany, University of Oxford, U.K., Institute of Computing Research, CAS, China, University of Washington, Seattle, USA and University of North Carolina at Chapel Hill, USA (2 papers each), etc.
- The authors accounting for the largest number of highly cited papers include: X. Wang and A.Y.Ng (8 papers each), Y.Bengio (7 papers), X. Tang and H. Lee(6 papers), L. Deng (5 papers), D. Yu (4 papers), P. Luo (3 papers), D. Shen, J.Lu , S. Ji , X. He, W. Quyang and B.VanGinneken (2 papers each)
- Of the 118 highly cited papers, 55 were published as conference papers, 54 as articles, 6 as review papers, 2 as books and 1 as editorials.
- These 118 highly cited papers were published across 36 national and international journals. Seven (7) papers appeared in *IEEE Transactions on Medical Imaging*, 6 papers in *Advances in Neural Information Processing Systems*, 5 papers each in *Journal of Machine Learning Research* and *IEEE Transactions on Pattern Analysis & Machine Intelligence*, 2 papers each in 10 journals and 1 paper each in 25 other journals.

4- Summary & Conclusion

4-1- Summary

The present study provides a quantitative and qualitative description of deep learning research during 2004-17, using global publications data sourced from the Scopus database. Deep learning research across the world accumulated a total of 10027 publications, and registered a high 106.76% annual growth and averaged citation impact of 7.99 citations per paper during the period. Among 102 participating countries, the top 10 dominate the world of deep learning research with China contributing the largest global share (29.25%), followed by USA (26.46%), U.K. (6.40%), etc. These top 10 countries together accounted for 99.74% global publication share and more than 100% global citation share. Deep learning highly cited papers (118) averaged a high citation impact of 299.78 citations per paper. Two of the top 10 most productive countries scored relative citation index above the group average of 1.78: Canada (5.30) and USA (3.23) during 2004-17.

Computer science is one of the most popular areas of study in quantum computing research, accounting for the highest subject share (44.89%), followed by physics & astronomy (39.55%), and others. Among 1545 organizations and 2010 authors, the top 50 most productive organizations in deep learning contributed 34.98% and 7.87% of global publication share and 81.77% and 45.66% of global citation share during 2004-17. Among the top 50 organizations 46% (23) are from China, 24% (12) from USA, 6.0% (3 each) from Canada and U.K., 4.0% (2 each) from Australia, Hong Kong and Singapore, and 2% (1 each) from France, Germany and South Korea. Their citation impact averaged between 3.24 and 220.91 CPP on a 14-year window. 31.28% of global publications share in the subject appeared in journal literature (in 876 journals), with top 20 journals accounting for 23.05% share of total output covered by journal medium.

4-1- Conclusion

Deep learning is gaining much popularity due to its supremacy in terms of accuracy when trained with huge amount of data. Deep learning outshines several other artificial intelligence techniques when there is lack of domain expertise in feature engineering, or when it comes to complex problems such as image classification, natural language processing, and speech recognition. Despite its faster annual average growth of 106.76%, domain expertise expertise in deep learning techniques is dominated mainly by China and USA, whereas other top ranking countries are still secondary players. Google, Microsoft, Facebook and Apple are some of the top major players spending millions of dollars in driving and developing deep learning applications, such as autonomous cars, image recognition, speech recognition, street view detection, language translation and spam detection.

5- Conflict of Interest

The authors declare no conflict of interest.

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