REINFORCEMENT LEARNING RESEARCH: A SCIENTOMETRIC ASSESSMENT OF GLOBAL PUBLICATIONS OUTPUT DURING 2009-18

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The paper provides quantitative and qualitative description of reinforcement learning research based on global publications output (5345 publications) in the field as indexed in Scopus database during 2009-18. Reinforcement learning research registered 11.5% growth per annum and averaged 17.11 citations per paper in 10 years. Top 10 most productive countries account for 97.17% global publication share. The paper characterizes performance of reinforcement learning research on measures such as relative citation index, citations per paper, highly cited papers, top 20 global organizations and top 20 global authors in the field. The study identifies hot areas of research in the subject. The study concludes that the USA, China, the UK, Japan, and Germany are the mainstream nations in reinforcement learning research whereas rest of the world countries are peripheral to research in the subject. The challenge is how to bring other world leading economies like India, Russia and France to the mainstream research in the subject.

Keywords: Reinforcement learning, Machine learning, Global publications, Scientometrics, Bibliometrics

INTRODUCTION

Reinforcement learning is a type of machine learning that enables intelligent systems, like robots, to respond and perform actions mostly in a constantly changing dynamic environment[1-2]. Reinforcement learning is all about the science of decision making in an interactive environment. A reinforcement learning algorithm learns to decide what to do or what action to take in order to perform a specific task in a specific situation to achieve a specific goal using a system of reward and punishment. The algorithm is both a learner and a decision maker [3]. As a decision maker, the goal of algorithm, is to discover the best sequence of decisions that maximizes total cumulative rewards to an action, through a process of feedback and trial and error, define it as an action model that can solve a task faster, and eventually generalize it as a policy on how the agent will behave in a given situation. Reinforcement learning is therefore a general framework needed

for learning and solving sequential decision making tasks [4]. Deep reinforcement learning, on the other hand, is about the best set of algorithms needed for pattern representation. The combination of these two models is ideal for finding solutions to solving challenging real world problems [5].

The origin of reinforcement learning dates back to 1980s. In a short span of nearly three decades, this modern field of computational technology has witnessed tremendous achievements in robotics, logistics, gaming, network traffic signal control systems, auto driven cars, auto web system configuration and in such other real-life applications[6]. Reinforcement learning has given rise to the growth of several startups and SMEs in business and industry. Key research areas in the subject are expanding in scope[7]. As seen from Scopus database research studies in the field are growing in volume year-on-year. Leading universities mainly in the USA and few other developed nations have started to offer educational courses at master's level in the subject. Given its multidimensional growth in research, education, and industry, it is worthwhile to know the current trends and developments in reinforcement learning research. Given this context, this study therefore seeks to analyze global research output in the the field of reinforcement learning with the aim to ascertain its current status of research using bibliometric measures.

LITERATURE REVIEW

On evaluation of published literature on bibliometric assessment of machine learning research and its branches, it is noted that no study has so far been attempted on bibliometric assessment on reinforcement learning both at both national and global level. However, quite a few quantitative studies are available in the bibliometric literature covering of machine learning and deep learning research. Rincon-Patino, Ramirez-Gonzalez and Corrales[8] analyzed and explored global machine learning research during 2007-17, using WoS database. The article identified most notable authors, institutions, keywords, countries, categories, and journals. Gupta and Dhawan[9] examined Indian literature on machine learning research in India, consisting of 3960 papers, using Scopus database during 2006-17, considering aspects such as growth rate, publication output and global share, international collaborative papers share of foreign participating countries, scattering of country research across source journals, and distribution of research by subject areas, contribution and citation impact of top organizations and authors, identification of leading journals and analysis of highly cited papers. Mao, Li, Zhao and Zeng[10] studied deep learning research output (3599 papers), using Web of Science database during 1968-2018. They identified key countries, organizations, authors and their collaborative profiles, trends and hotspots in the domain of deep learning including modeling research and algorithm research. Gupta and Dhawan[11] described the status of global deep learning research using bibliometric indicators during 2004-17.

OBJECTIVES OF THE STUDY

The study is aimed at making a qualitative and qualitative assessment of global reinforcement research output, based on publications covered in Scopus database during 2009-18. In particular, the study focuses on ascertaining the status of

research in the subject on various parameters such as : (i) the annual and cumulative global output over 10 years, annual growth rate, (ii) the citation impact of research output, (iii) the global publication profile of top 10 most productive participating countries, (iv) the distribution of publication output by broad sub-fields, (v)) the productivity and citation impact of top 20 most productive organizations and authors, (iv) the main media of research communications, and (vii) the characteristic features of top highly cited papers.

METHODOLOGY

For the present study, the authors sourced publications data on the topic of reinforcement learning from Scopus database (http://www.scopus.com) covering 10-year period 2009-18. The study formulated a search string by suffixing "Reinforcement learning"' to "Title-Abs-Key" tag and restricting the search output to publication period '2009-18' using "date range tag". The search yielded 14707 records. The global search output was restricted to "articles" (resulting to 5353 records), and subsequently to "articles in journals". This search was further refined by country of publication to identify top 10 most productive countries in the subject. To analyze research by subject, collaborating countries, author-wise, organization-wise and journal-wise, etc. the global publications output was distributed accordingly. The authors used for the purpose analytical provisions as provided in the Scopus database such as "subject area tag", "country tag", "source title tag", "journal title name" and "affiliation tag". The citations to publications were counted from date of their publication till 11 July 2019.

Title-Abs-Key ("Reinforcement learning") and Pubyear>2008 and Pubyear<2019 and (Limit-to (Document Type"ar")) and (Limit-to (SRC Type "j"))

ANALYSIS AND RESULTS

The global research output in field of reinforcement learning accumulated a total of 5345 research articles in a 10-year period during 2009-18. The research in the subject registered 11.15% annual average growth, published an average of 534.5 papers per year, and received an average of 17.11 citations per paper (Table 1, Fig 1). The subject received a significant jump in its five-year cumulative research output, by 56.85%, up from 2081 in 2009-13 to 3264 publications in 2014-18.

Table 1: Reinforcement Learning Research: Annual Publications output in the World and Citations 2009-18

Publication Period	World		
	TP	TC	CPP
2009	381	13402	35.18
2010	379	10336	27.27
2011	401	11481	28.63
2012	419	9559	22.81
2013	501	9642	19.25
2014	558	9110	16.33
2015	534	10705	20.05
2016	528	8227	15.58
2017	717	5816	8.11
2018	927	3199	3.45
2009-13	2081	54420	26.15
2014-18	3264	37057	11.35
Total	5345	91477	17.11

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

Leading Countries in Reinforcement Learning

Reinforcement learning research is undertaken across as many as 85 countries. The distribution of research by country of publication is highly skewed. For instance, 30 countries published 1-10 papers each, 14 countries 11-20 papers each, 9 countries 21-50 papers each, 7 countries 50-100 papers each, 9 countries 101-200 papers each, 4 countries 201-500 papers each and 3 countries above 500 papers each. However, bulk of research output (97.17%) in the field still comes from just 10 most productive countries. The USA leads the world ranking with 29.09% global publications share, followed closely by China (21.25%), U.K, Germany, Japan and Canada (from 5.86% and 10.51%), France, Iran, Netherlands and Spain (from 3.37% to 4.06%) during 2009-18 (Table 2). Five of top 10 leading countries scored relative citation index above global average: U.K. (1.98), USA (1.62), Germany (1.39), Netherlands (1.24) and Canada (1.08). Further, these top 10 countries published 23.10% to 70.31% share of their country output in the subject as international collaborative papers.

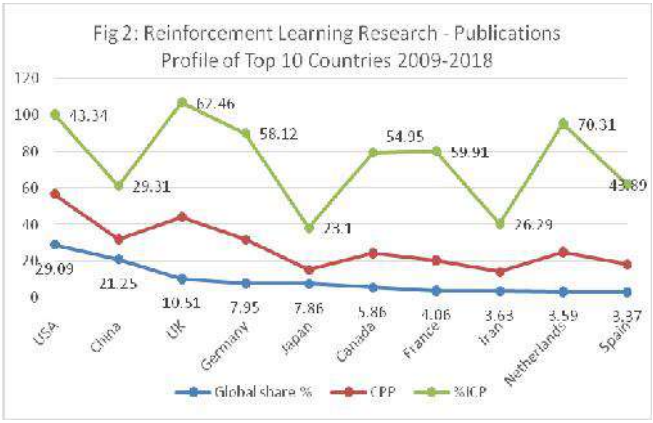
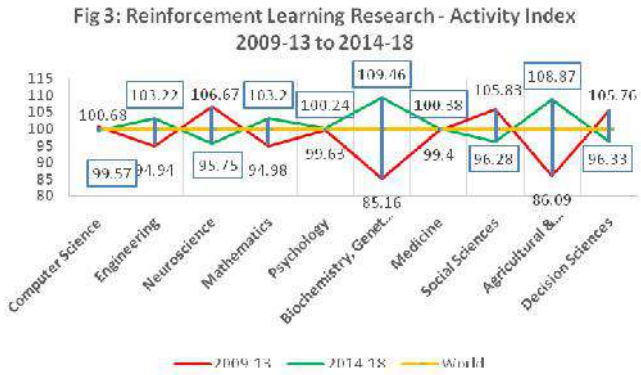


Table 2: Publication Profile of Top 10 Countries in Reinforcement Learning Research during 2009-18

Sl. No.	Name of the Country	Number of Papers			Share of Papers			TC	CPP	ICP	%ICP	RCI
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18	2010-18				
1	USA	607	948	1555	29.17	29.04	29.09	43052	27.69	674	43.34	1.62
2	China	344	792	1136	16.53	24.26	21.25	12110	10.66	333	29.31	0.62
3	UK	198	364	562	9.51	11.15	10.51	19019	33.84	351	62.46	1.98
4	Germany	168	257	425	8.07	7.87	7.95	10093	23.75	247	58.12	1.39
5	Japan	214	206	420	10.28	6.31	7.86	3087	7.35	97	23.1	0.43
6	Canada	117	196	313	5.62	6.0	5.86	5776	18.45	172	54.95	1.08
7	France	93	124	217	4.47	3.8	4.06	3528	16.26	130	59.91	0.95
8	Iran	72	122	194	3.46	3.74	3.63	2044	10.54	51	26.29	0.62
9	Netherlands	72	120	192	3.46	3.68	3.59	4085	21.28	135	70.31	1.24
10	Spain	76	104	180	3.65	3.19	3.37	2650	14.72	79	43.89	0.86
	World Total	2081	3264	5345	94.22	99.04	97.17	91477	17.11	2269	42.45	1.00

Subject-Wise Distribution of Research Output

Computer Science is the top most subject area for research pursuit in reinforcement learning"; it accounts for 54.13% publications share, followed distantly by engineering (36.24%), neuroscience (21.76%), mathematics (17.10%), psychology (8.34%), during the period (Table 3). All of these 10 sub-fields of reinforcement learning research (as identified in Scopus database classification) witnessed fluctuations in their research activity index during the period between 2009-13 and 2014-18. The average world activity index in each of this subject area is 100. The activity index in most sub-fields changed from above to below world average in 2014-18 compared to their corresponding status in 2009-13. Neuroscience registered the highest citation impact per paper of 24.81, followed by psychology (21.06), medicine (20.99), etc. (Table 3).



Distribution of Publications by Type of Reinforcement Learning

Deep reinforcement learning accounts for the highest share of publications (954, 17.85%) in the global output on reinforcement learning research, followed by inverse reinforcement learning (331, 6.19%) and apprenticeship learning (40, 0.75%) during 2009-18. During the period

Table 3: Subject-Wise Breakup of Global Publications in Reinforcement Learning Research 2009-18

Sl. No.	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18		
1	Computer Science	1134	1759	2893	100.68	99.57	39313	13.59	54.13
2	Engineering	716	1221	1937	94.94	103.22	25354	13.09	36.24
3	Neuroscience	483	680	1163	106.67	95.75	28856	24.81	21.76
4	Mathematics	338	576	914	94.98	103.20	12656	13.85	17.10
5	Psychology	173	273	446	99.63	100.24	9393	21.06	8.34
6	Biochemistry, Genetics & Molecular Biology	124	250	374	85.16	109.46	6231	16.66	7.00
7	Medicine	125	198	323	99.40	100.38	6780	20.99	6.04
8	Social Sciences	89	127	216	105.83	96.28	3534	16.36	4.04
9	Agricultural & Biological Sciences	60	119	179	86.09	108.87	3116	17.41	3.35
10	Decision Sciences	70	100	170	105.76	96.33	2549	14.99	3.18
	World Output	2081	3264	5345			91477	17.11	
* There is overlapping of literature covered under various subjects									
TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper									

from 2009-13 to 2014-18 deep reinforcement learning witnessed highest rise in its share in the global output (from 0.0% to 29.23%), followed by inverse reinforcement learning (from 4.61% to 7.20%), and apprenticeWITHship learning witnessed decrease from 0.91% to 0.75% from 2009-13 to 2014-18.

Deep reinforcement learning registered the highest citation impact per paper (9.69) compared to inverse reinforcement learning (8.80) and apprenticeship learning (5.05) (Table 4).

Table 4: Distribution of Publications by Type of Reinforcement Learning during 2009-18

Sl. No.	Type of Learning	Total Papers			Share of Papers			TC	CPP	% Share
		2009-13	2014-18	2009-18	2009-13	2014-18	2009-18	2009-18		
1	Deep Reinforcement Learning	0	954	954	0.00	29.23	17.85	9241	9.69	17.85
2	Inverse Reinforcement Learning	96	235	331	4.61	7.20	6.19	2914	8.80	6.19
3	Apprenticeship Learning	19	21	40	0.91	0.64	0.75	202	5.05	0.75
		2081	3264	5345						

Significant Keywords

Reinforcement, learning algorithms, learning, reward, decision making are the most sought after keywords used for searching reinforcement learning research output from the Scopus database. This is seen from search results of top 28 keywords listed according to decreasing order of the frequency of their occurrence in database (Table 5).

Table 5: Significant Keywords in Global Reinforcement Learning Literature during 2009-18

Sl. No.	Keyword	Period			Sl. No.	Keyword	Period		
		2009-13	2014-18	2009-18			2009-13	2014-18	2009-18
1	Reinforcement Learning	1500	2573	4073	15	Q-learning	151	199	350
2	Reinforcement	721	686	1407	16	Multi Agent Systems	115	197	312
3	Learning Algorithms	416	597	1013	17	Learning Systems	41	263	304
4	Learning	421	509	930	18	Neural Networks	110	186	296
5	Reward	279	442	721	19	Dopamine	129	145	274
6	Decision Making	243	475	718	20	Machine Learning	61	198	259
7	Reinforcement (Psychology)	235	346	581	21	Robots	79	167	246
8	Physiology	101	461	562	22	Prediction	104	139	243
9	Algorithms	240	311	551	23	Markov Decision Processes	94	147	241
10	Optimization	202	225	427	24	Dynamic Programming	67	171	238
11	Task Performance	199	215	414	25	Brain	98	138	236
12	Artificial Intelligence	152	240	392	26	Iterative Methods	36	185	221
13	Computer Simulation	213	162	375	27	Controllers	76	143	219
14	Markov Processes	133	226	359	28	Models, Neurological	95	118	213

Top 20 Most Productive Global Organizations

Five Hundred Eighty Eight (588) organizations participated in reinforcement learning research during 2009-18. Of these organizations, 290 published 1-5 papers each, 175 organizations 6-10 papers each, 74 organizations 11-20 papers each, 65 organizations 21-

50 papers each, 12 organizations 51-100 papers each and 2 organization 101-127 papers each during 2009-18. The productivity of top 20 most productive organizations varied from 45 to 127 publications per organization; together they contributed 22.62% (1209) global publications share and 38.95% (35626) global citations share during 2009-18. Their scientometric profile is presented in Table 6.

- Four organizations registered their publication productivity above the group average (17.87) of all organizations: Carnegie Mellon University, USA (49 papers), University of Piraeus, Greece (27 papers), University of Pittsburg, USA (24 papers) and University of Split, Croatia (19 papers) during 2009-18;
- Six organizations registered their citation impact per paper and relative citation index above the group average (11.41 and 1.65) of all organizations: National Cheng Kung University, Taiwan (23.29 and 3.37), University of Pittsburg, USA (16.04 and 2.32), Carnegie Mellon University, USA (15.63 and 2.27), Worcester Polytechnic Institute, USA (15.08 and 2.19), University of Memphis, USA (12.88 and 1.87) and University of Piraeus, Greece (12.67 and 1.84) during 2009-18

Table 6: Scientometric Profile of 20 Most Productive Global Organizations in Reinforcement Learning Research during 2009-18

Sl. No.	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	University College London), U.K.	127	5129	40.39	38	115	90.55	2.36
2	Princeton University, Princeton, USA	77	3482	45.22	29	61	79.22	2.64
3	New York University, New York, USA	75	4157	55.43	35	65	86.67	3.24
4	Ministry of Education China, China	68	497	7.31	11	68	100.00	0.43
5	Brown University, Providence, USA	67	3103	46.31	30	57	85.07	2.71
6	The French National Center for Scientific Research, Paris, France	66	1086	16.45	18	66	100.00	0.96
7	Institute of Automation, Chinese Academy of Sciences, Beijing, China	65	2713	41.74	29	65	100.00	2.44
8	Northeastern University, Shenyang, China	61	787	12.90	15	36	59.02	0.75
9	South China University of Technology, Guangzhou, China	57	444	7.79	12	38	66.67	0.46
10	National University of Defense Technology, Changsha, China	55	885	16.09	17	27	49.09	0.94
11	Harvard University, Boston, USA	54	1387	25.69	20	33	61.11	1.50
12	Massachusetts Institute of Technology, USA	51	1456	28.55	19	46	90.20	1.67
13	Soochow University, Suzhou, China	50	113	2.26	6	42	84.00	0.13
14	ETH Zurich, Zurich, Switzerland	50	1354	27.08	20	45	90.00	1.58
15	University of Cambridge, U.K.	50	1935	38.70	24	37	74.00	2.26
16	University of Amsterdam, Netherlands	48	1057	22.02	17	43	89.58	1.29
17	Stanford University, California, USA	48	992	20.67	18	39	81.25	1.21
18	Wellcome Trust Centre for Neuroimaging, London, U.K.	48	2809	58.52	26	48	100.00	3.42
19	University of Texas at Austin, USA	47	1662	35.36	21	38	80.85	2.07
20	Tsinghua University	45	578	12.84	13	37	82.22	0.75
	Total of 20 organizations	1209	35626	29.47	10.85	1006	83.21	1.72
	Total of the world	5345	91477	17.11				
		22.62	38.95					

Top 20 Most Productive Authors

916 authors participated in reinforcement learning research during 2009-18, of which 554 authors published 1-5 papers each, 287 authors 6-10 papers each, 59 authors 11-20 papers each, 15 authors 21-50 papers each and 1 authors 52 papers. The research productivity of top 20 most productive authors varied from 19 to 52 publications per author. Together they contributed 10.42% (557) global publications share and 25.18% (23031) global citations share during 2009-18. Their detailed Scientometric profile is presented in Table 7.

- Eight authors registered their publications output above the group average of 27.85: M.J. Frank (52 papers), Q. Liu (43 papers), F.L. Lewis (42 papers), T. Yu. (33 papers), S.J. Gershman and D. Liu (31 papers each), N.D. Daw (30 papers) and P. Dayan (30 papers) during 2009-18.
- Nine authors registered their citation impact per paper and relative citation index above the group average (41.35 and 2.42) of all authors:: R.J. Dolan (80.73 and 4.72), P. Dayan (74.07 and 4.33), Q. Wei (72.18 and 4.22), F.L. Lewis (70.38 and 4.11), D. Liu (70.10 and 4.10), N.D. Daw (62.73 and 3.67), H. Modares Ferdowsi (60.30 and 3.52), J. Peters (48.92 and 2.86) and S.J. Gershman(48.84 and 2.85) during 2009-18.

Table 7: Scientometric Profile of Top 20 Most Productive Authors in Reinforcement Learning Research during 2009-18

Sl. No.	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	%ICP	RCI
1	M.J. Frank	Brown University, Providence, USA	52	1895	36.44	28	27	51.92	2.13
2	Q. Liu	Soochow University, Suzhou, China	43	63	1.47	5	2	4.65	0.09
3	F.L. Lewis	University of Texas at Arlington, USA	42	2956	70.38	26	37	88.10	4.11
4	T. Yu.	South China University of Technology, Guangzhou, China	33	326	9.88	10	14	42.42	0.58
5	S.J. Gershman	Harvard University, Cambridge, USA	31	1514	48.84	18	10	32.26	2.85
6	D. Liu	University of Science and Technology Beijing, China	31	2173	70.10	24	6	19.35	4.10
7	N.D. Daw	Princeton University NJ, USA	30	1882	62.73	21	14	46.67	3.67
8	P. Dayan	University College London, London, U.K.	30	2222	74.07	21	28	93.33	4.33
9	R.J. Dolan	University College London, London, U.K.	26	2099	80.73	19	31	119.23	4.72
10	J. Peters	The Technical University of Darmstadt, Germany	25	1223	48.92	12	21	84.00	2.86
11	C.B. Holroyd	University of Victoria, Canada	24	791	32.96	12	9	37.50	1.93
12	K.S. Hwang	National Sun Yat-sen University, Kaohsiung, Taiwan	24	172	7.17	7	6	25.00	0.42
13	Q. Wei	Chinese Academy of Sciences, Beijing, China	22	1588	72.18	16	7	31.82	4.22
14	H. Zhang.	Northeastern University, Shenyang, China	22	405	18.41	10	3	13.64	1.08
15	K. Doya	Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan	21	291	13.86	8	4	19.05	0.81
16	A. Heinz.	Charité – Universitätsmedizin Berlin, Germany	21	727	34.62	13	32	152.38	2.02
17	X. Xu	National University of Defense Technology, China	21	559	26.62	12	10	47.62	1.56
18	H. He	University of Rhode Island, USA	20	823	41.15	13	15	75.00	2.41
19	H. Modares	Ferdowsi University of Mashhad, Iran	20	1206	60.30	16	31	155.00	3.52
20	S. Mabu	Waseda University, Kitakyushu, Japan	19	116	6.11	6	2	10.53	0.36
	Total OF 20 authors		557	23031	41.35	14.85	309	55.48	2.42
	Total of World		5345	91477	17.11				
	Share of 20 Authors in World Total Output		10.42	25.18					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index

Medium of Research Communication

Reinforcement learning research comprising 5345 articles was published across a total of 894 journals. The distribution of articles across source journals is skewed. For instance, 186 journals published 1-5 papers each, 97 published 6-10 papers each, 67 published 11-20 papers each, 36 published 21-50 papers each and 8 published 51-99 papers each during 2009-18. The top 15 most productive journals accounted for 16.82% share of total research output in reinforcement learning during 2009-18. The source journals in the leading positions include *Neurocomputing* (with 99 papers) was, followed by *Journal of Neuroscience* (94 papers), *IEEE Transactions on Neural Networks and Learning Systems* (78 papers), *PLOS One* (72 papers), etc. during 2009-18 (Table 8).

Table 8: Top 15 Most Productive Journals in Reinforcement Learning Research during 2009-18

Sl. No.	Name of the Journal	Number of Papers		
		2009-13	2014-18	2009-18
1	Neurocomputing	35	64	99
2	Journal of Neuroscience	38	56	94
3	IEEE Transactions on Neural Networks and Learning Systems	11	67	78
4	PLOS One	29	43	72
5	Neural Networks	46	23	69
6	Expert Systems with Applications	33	27	60
7	Journal Of Machine Learning Research	22	33	55
8	IEEE Access	0	53	53
9	Neuroimage	25	28	53
10	Frontiers In Psychology	17	30	47
11	Journal of Advanced Computational Intelligence and Intelligent Informatics	20	27	47
12	Proceedings of The National Academy Of Sciences Of The USA	23	23	46
13	Plos Computational Biology	14	29	43
14	IFAC Papersonline	0	42	42
15	IEEEJ Transactions on Electronics Information and Systems	23	18	41
	Total of 15 Journals	336	563	899
	Total of World	2081	3264	5345
	Share of 15 journals in World journal output	16.15	17.25	16.82

Highly-Cited Papers

The share of highly cited papers in reinforcement learning research is found to be small and insignificant (2.53% share, 135 papers). Highly cited papers include only such research papers that received 100 or more citations since publication during 2009-18. The highly cited papers (135) received a total of 29029 citations

with an average of 215.03 citations per paper. The distribution of highly cited papers by citation count is skewed. One hundred two (102) papers accumulated citations in the range 101-200 per paper, 23 papers were in citation range 201-400, 6 papers in citation range 401-600, 2 papers in citation range 701-800 and 2 papers were in citation range 1655-2454.

1. Of the 135 highly cited papers, 59 were non-collaborative papers, each contributed by standalone single organization, and 76 were collaborative papers, each contributed by two or more organizations (33 national collaborative and 43 international collaborative papers).

2. Among highly cited papers, the USA participated in the largest number of papers (74 papers), followed by U.K. (25 papers), Germany (18 papers), China (15 papers), Canada (11 papers), Netherlands (8 papers), Switzerland (6 papers), France, Iran, Japan and Spain (4 papers each), Ireland (3 papers), Austria, India, Israel, Qatar and Singapore (2 papers each), Brazil, Denmark, Finland, Portugal and Taiwan (1 papers each).

3. The 135 highly cited papers belonged to 396 authors from 277 global organizations.

4. The participating organizations in the top and leading positions include: University College London, London, U.K. (14 papers), Brown University, Providence, USA (13 papers), Institute of Automation Chinese Academy of Sciences, Beijing, China (10 papers), Princeton University, Princeton, USA, New York University, New York, USA and Wellcome Trust Centre for Neuroimaging, London, U.K. (9 papers), University of Cambridge, Cambridge, U.K. (7 papers), etc.

5. The participating authors in the top and leading positions include: F.L. Lewis (11 papers), M.J. Frank and D. Liu (10 papers each), Q. Wei (9 papers), R.J. Dolan (8 papers), H. Modares (6papers), P. Dayan (5 papers), J. Peters (4 papers), etc.

6. The 135 highly cited papers appeared across 65 journals. Of these, 10 papers were published in Journal of Neuroscience, 8 papers each in *Automatica*and *IEEE Transactions on Neural Networks & Learning Systems,* 7 papers each in *Neuron* and *Proceedings of the National Academy of Sciences of United States of America,* 5 papers each in *Nature* and *Nature Neurosciences,* 4 papers in *Journal of Machine Learning Research,* 3 papers each in *IEEE Transactions on Cybernetics, Neural Networks* and *Neurocomputing*, 2 papers each in *Autonomous Agents &Multisystems, Cerebral Cortex, Cognition, European Journal of Neuroscience, Frontiers in Human Neurosciences, IEEE Journal in Selected Areas of Communication, IEEE Transaction on Industrial Electronics, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Transactions on Vehicular Technology, Journal of Cognitive Neuroscience, Neuroimage, Psychological Review, Psychological Science* and *Science* and 1 paper each in 40 other journals.

SUMMARY AND CONCLUSION

The paper analyzes global research output in the field of reinforcement learning (a branch of machine learning research) to ascertain the current status of research in the subject using bibliometric measures. The authors sourced publications data for the study from Scopus database. During the period under review and study, 2009-18, it was noted that reinforcement learning research accumulated 5345 articles, registered 11.15% growth, published an average of 534.5 papers per year, and received an average of 17.11 citations per paper (CPP) on a 10-year window. In all 916 authors from 599 organizations from across 85 countries contributed to global research in the subject. The distribution of reinforcement learning research by source country is highly skewed, just 10 out of 85 contributing countries accounted for 97.17% global publication share. The quality of research was also measured on highly cited papers. The study found that just 2.53% (135 papers) global publications share in the subject appeared as highly cited papers. The citations to these papers ranged from 100 to 2454 per paper, with an average of 215.03 citations per paper. The highly cited papers were contributed by 43% (396) of global authors from 53% (277) ofglobal organizations which contributed to the research during the period.

The USA is the world leader in publications output, and the UK tops the world ranking in relative citation index. Computer science is the most sought after subject area in reinforcement learning research. Reinforcement, learning algorithms, learning, reward, decision making are the top most productive keywords in searching reinforcement learning research publications. M.J. Frank, USA is the most productive author and Carnegie Mellon University, USA the most productive organization in reinforcement learning research. R.J. Dolan, U.K. is the most cited author and National Cheng Kung University, Taiwan, the most cited organization. *Neurocomputing* leads other source journals in terms of their research publications productivity. The USA is also the leading most country in publishing most number of highly cited papers.

In overall, it is seen that the USA, China, the UK, Japan, and Germany are the mainstream nations in reinforcement learning research whereas rest of the world countries are peripheral to research in the subject. Their combined productivity accounts for 76% global publications share, nearly 3/4th of the total world output in the subject. These are also the home countries to most productive organizations in the world and the most productive authors. The challenge is how to bring other world leading economies like India, Russia and France to the mainstream research in the subject.

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