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Bibliometrics in Computer Science: An Institution Ranking

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Abstract. Computer Science degrees are very popular currently among institutions worldwide. The proliferation of these programs in different universities has led to the creation of rankings for classifying programs according to their prestige and quality. However, these rankings do not specify the quality of research. This study develops a bibliometric overview of all the journals that are currently indexed in the Web of Science (WoS) database in any of the seven categories connected to Computer Science research. These categories include Artificial Intelligence, Cybernetics, Hardware and Architecture, Information Systems, Interdisciplinary Applications, Software Engineering and Theory and Methods. This study aims to identify the leading institutions over the last 25 years (1991–2015) in each area selected according to a wide range of bibliometric indicators. The results indicate that American universities are the most influential in Computer Science research. This study concludes that Computer Science traverses many institutions.

Keywords: Computer Science; Bibliometrics; Institutions; Web of Science; Citations, Ranking.

1. Introduction

During recent years, research on the productivity of institutions has proliferated. The ranks elaborated influence an institution's reputation [23] and affect its ability to raise funds ([22], [2]). These rankings are based on a multitude of factors, such as peer-review surveys, research, teaching, the size of the institution, the grants, etc. [24]. However, these rankings are criticized because they lack accuracy and only measure results, which implies that many indicators are left behind when ranking institutions [8]. This is why one must also take into account the article count method and the quality-weighted method. It counts citations as one of the main quality indicators of publications, although there are other indicators, such as the h-index and impact index, that can rank institutions [15].

Some of the bibliometric studies that perform ranks usually include incomparable methods ([20], [30]), as some of them are based on article counts instead of publication quality. Others use citations but ignore article counts.

Bibliometric studies have been carried out in a large number of fields. Among them, we can highlight the analysis of journals ([6], [29], [28]), countries ([3], [21], [33]), research topics [32] and institutions ([18], [19], [25], [14], [4], [39]). In Computer Science, there are many bibliometric studies concerning a wide range of issues, including journals ([9], [10], [37]), countries ([13], [38]) and institutions [36].

In a recent paper, the authors focused on analyzing the 100 most productive institutions in India, comparing the results obtained by these institutions with major world institutions. This analysis was based on research output data indexed in Scopus between 1989 and 2013.

However, no research has applied a bibliometric overview to all journals currently indexed in the WoS database in any of the seven categories connected to Computer Science research. Additionally, there are no existing tools for ranking universities according to their production of Computer Science research. As a consequence, no ranking includes other institutions such as companies and research centers. Attempting to fill this research gap, the bibliometric analysis in this paper is particularly useful since it identifies the main institutions that have published in the Computer Science field and enables the evaluation of output performed over the years by these institutions.

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This paper aims to develop an analysis that identifies the most productive and influential organizations in Computer Science research. The specific objectives of this study are (1) to create a ranking of Computer Science organizations according to bibliometric indicators; (2) to create rankings of Computer Science organizations for each category of Computer Science; (3) to identify the most productive and influence institutions in Computer Science research; and (4) to identify the number of research institutions that are universities, companies and research centers.

The rest of the study is organized as follows. First, we present the methodology used in this article. Next, the results and discussion analyse the results of the paper. Finally, conclusions summarize the main findings, limitations and suggestions for future research.

2. Methods

There are different approaches to classifying the bibliographic material, with bibliometrics being one of the most used approaches. Bibliometrics is a research field that quantitatively studies bibliographic material by analyzing a research area and identifying its leading trends [26].

The source used for the selection of the panel of journals for this study was the WoS, which is considered the most influential database in the world since it collects high-quality articles recognized by the scientific community (This is without prejudice to other databases such as Scopus or Google Scholar.). The WoS includes information from more than 15,000 periodicals and 50,000,000 articles, which are ranked in 251 categories and 151 research areas [27].

By searching for keywords, WoS shows bibliometric indicators for the selected papers. This work searches for publication names in a period of time of 25 years (1991-2015). This time period is selected because it is representative of the latest developments in the field. Data collection was performed during the first half of 2016.

The WoS categorizes Computer Science into seven categories: Artificial Intelligence (106 journals), Cybernetics (21 journals), Hardware and Architecture (34 journals), Information Systems (106 journals), Interdisciplinary Applications (90 journals), Software Engineering (65 journals), and Theory and Methods (58 journals). In each case, the analysis considers a Global Ranking where all the institutions are ranked together. This allows comparisons between subfields when needed.

For each Computer Science category in the WoS, we search for the 30 organizations with the highest number of articles. Next, some bibliometric indicators are selected for each organization. Several indicators are considered, including the total number

of papers, the total number of citations, the ratio of total citations/total paper, the h- index [16] and the number of papers that an institution has among the most cited ones for a specific field. The most cited papers are found in the WoS by ordering the results of a search from the most cited papers to the least cited [29].

In addition to the above indicators, two more indicators have been added that refer to quality indicators for universities, such as the Shanghai Academic Ranking of World Universities (ARWU) and Quacquarelli Symonds (QS). Although both the ARWU and QS have several critiques, including the difficulty of defining and measuring quality and their lack of objectivity and precision [23], they are useful for providing a reference on the global position of a university.

We have utilized several indicators in this paper, since there is no general agreement on the optimal method for measuring research. In fact, the current literature addresses many indicators that have appeared during the recent years ([1], [3], [29]).

3. Results and discussion

This section presents the main bibliometric results found in the WoS for all Computer Science journals from 1991 to 2015. First, the paper analyzes the global results obtained in the Computer Science field. It then analyzes the individual results of each category that constitute the Computer Science field.

3.1. Global Results

Figure 1 shows the typology of the different research organizations that have published in the Computer Science field. For a better understanding, we have classified these institutions into three categories: universities, companies and research centers. The difference between the last two categories is that research centers have the purpose of generating knowledge, while companies aim to commercialize goods and services.
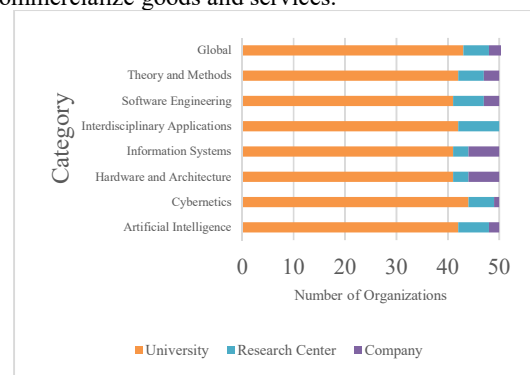

Figure 1. Types of research organizations in Computer Science field

As shown, universities are the institutions with a greater presence in each area that forms the Computer Science field. In fact, universities represent more than 80% of the most prolific institutions in each of the 7 areas that constitute the field. Therefore, it can be asserted that universities have a strong research presence in the Computer Science field. However, research centers and companies have a more residual presence, although these institutions also promote Computer Science research. This is due to the various idiosyncrasies of universities. Each year they welcome new students that contribute fresh perspectives to research. With respect to research centers and companies, it can be seen how their weight in the TOP 50 is quite similar, except in the Interdisciplinary Applications field, where there are no company contributions.

Table 1 shows the global results.

Table 1. Global Ranking

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	MIT	USA	5.978	260.295	43,54	218	183	490	970	3	1
2	University of California Berkeley	USA	4.733	233.234	49,28	192	155	352	748	4	27
3	Stanford University	USA	5.248	214.233	40,82	195	124	437	887	2	7
4	IBM	USA	8.485	204.312	24,08	188	115	400	870	-	-
5	CNRS	France	12.156	175.522	14,44	135	57	217	670	-	-
6	US Department of Energy	USA	5.682	167.285	29,44	156	92	270	570	-	-
7	AT&T	USA	4.115	166.699	40,51	161	81	296	600	-	-
8	Carnegie Mellon University	USA	5.332	166.183	31,17	176	102	329	680	62	66
9	University of Illinois Urbana Champaign	USA	4.800	156.450	32,59	150	77	249	594	28	63
10	INRIA	France	5.752	113.775	19,78	135	60	200	486	-	-
11	University of Maryland College Park	USA	4.362	111.363	25,53	130	59	194	447	43	121
12	University of California Los Angeles	USA	2.993	107.298	35,85	126	58	173	382	12	37
13	University of Southern California	USA	3.517	95.674	27,20	131	49	199	459	51	130
14	Microsoft	USA	3.685	94.740	25,71	121	57	153	328	-	-
15	University of Michigan	USA	3.565	91.540	25,68	116	38	136	357	22	23
16	University of Minnesota Twin Cities	USA	3.037	91.317	30,07	122	50	160	367	30	-
17	University of Texas Austin	USA	3.501	88.669	25,33	120	46	159	352	39	79
18	University of California San Diego	USA	2.940	87.420	29,73	114	47	135	313	14	59
19	Georgia Institute of Technology	USA	3.938	87.026	22,10	108	41	127	338	99	106
20	Technion Israel Institute of Technology	Israel	3.689	85.306	23,12	117	40	146	321	78	189
21	Harvard University	USA	2.829	82.604	29,20	124	39	170	359	1	4
22	University of North Carolina	USA	4.734	78.343	16,55	107	29	124	320	-	-
23	University of Toronto	Canada	3.127	76.714	24,53	112	44	131	332	24	20
24	Purdue University	USA	4.439	76.452	17,22	106	25	116	302	60	101
25	National University of Singapore	Singapore	4.675	71.509	15,30	98	19	94	288	101-150	22
26	University of Washington	USA	2.789	69.510	24,92	112	40	129	316	-	-
27	Tel Aviv University	Israel	2.963	68.843	23,23	109	24	118	297	151-200	195
28	University of Washington	USA	2.692	68.420	25,42	112	40	128	312	15	65
29	Chinese Academy of Sciences	PRC	7.108	68.360	9,62	86	11	72	247	-	-
30	Nanyang Technological University	Singapore	4.604	68.100	14,79	95	17	85	276	-	-

Source: Own elaboration.

Abbreviations: (1) Total Papers (TP), which indicates the numbers of papers associated for each organization; (2) Total Citations (TC), that means the sum of citations obtained by the selected institution; (3) Total Citations/Total Papers (TC/TP) it is a ratio for the average number of citations for each published article; (4) h-index, which indicates X number of articles that have at least X number of citations [16]; (5) ≥250, that indicates the papers that have at least 250 citations; (6) ≥100, which specifies the number of papers that have at least 100 citations; (7) ≥50, that identifies the number of papers that have at least 50 citations.

Table 1 presents the 30 most productive institutions in Computer Science research. The ranking is listed in a descending order according to the number of citations. The top 5 institutions in the ranking constitute approximately 32% of all citations received by the TOP 30. Of these 5 institutions, there are three universities, one company and one research center, which shows the relevance of companies and research centers in Computer Science research. In this respect, these 5 institutions are very influential because they account for 22% of all publications made by the TOP 30.

The most productive institution is the Center National de la Recherche Scientifique CNRS, an institution that has 43% more publications than the institution that occupies the second place, which is the American International Business Machines (IBM). The University of California Berkeley has the best ratio of total citations to total papers presented. Massachusetts Institute of Technology (MIT) is the institution with the highest h-index and

the highest number of publications that received more than 250, 100 and 50 appointments, respectively. All these institutions are part of the TOP 5 of institutions, ordered by the number of citations received.

In general, the institutions that constitute the TOP 30 worldwide by number of citations belong to business areas such as telecommunications and software development. The research that these institutions perform are usually improvements to the goods that they commercialize. In addition, these institutions have a wide presence in the ARWU and QS ranks, which implies that highly cited organizations are not necessary the most prestigious. Finally, the ranking presented shows a high dispersion between different institutions, indicating that Computer Science research transverses many organizations.

Next, we discuss the individual results for each category of the Computer Science field.

3.2. Artificial Intelligence

According to the definition of the WoS, "Computer Science, Artificial Intelligence" covers resources that focus on research and techniques to create machines that attempt to efficiently reason, problem-solve, use knowledge representation, and perform analysis of contradictory or ambiguous information. This category includes resources on artificial intelligence technologies such as expert systems, fuzzy systems, natural language processing, speech recognition, pattern recognition, computer vision, decision-support systems, knowledge bases, and neural networks.

Artificial intelligence research has experienced a rapid growth over recent decades [31], both in terms of the number of papers and the number of citations, with an increasing number of articles.

Table 2 shows the most influential institutions in this category.

Table 2. Artificial Intelligence

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	MIT	USA	1.104	81.953	74,23	128	63	154	253	3	1
2	University of California Berkeley	USA	604	70.459	116,65	84	39	71	143	4	27
3	Carnegie Mellon University	USA	1.320	64.474	48,84	118	51	131	235	62	66
4	CNRS	France	2.627	50.524	19,23	87	19	75	204	-	-
5	Microsoft	USA	841	45.753	54,40	86	30	72	141	-	-
6	INRIA	France	1.127	44.455	39,45	94	35	92	183	-	-
7	University of Illinois Urbana Champaign	USA	786	39.794	50,63	86	30	76	154	28	63
8	Stanford University	USA	833	38.857	46,65	93	25	86	148	2	7
9	University of California San Diego	USA	525	33.848	64,47	68	24	45	86	14	59
10	Nanyang Technological University National	Singapore	1.451	33.191	22,87	77	13	50	148	-	-
11	Nanyang Technological University	Singapore	1.451	33.191	22,87	77	13	50	148	151-200	39
12	University of Maryland College Park	USA	1.130	32.086	28,39	75	20	60	127	43	121
13	University of Southern California	USA	848	32.000	37,74	87	17	78	172	51	130
14	IBM	USA	819	29.925	36,54	76	21	60	117	-	-
15	Chinese Academy of Sciences	PRC	2.080	28.194	13,55	72	6	43	118	-	-
16	Technion Israel Institute of Technology	Israel	600	25.792	42,99	66	16	46	83	78	189
17	Hong Kong Polytechnic University	PRC	1.082	25.598	23,66	70	7	47	121	301-400	162
18	University of Oxford	UK	572	25.584	44,73	66	13	40	91	9	5
19	University of Texas Austin	USA	586	25.196	43,00	67	16	46	91	39	79
20	University of Toronto	Canada	664	25.099	37,80	71	20	50	106	24	20
21	Ecole Polytechnique Federale de Lausanne	France	641	25.075	39,12	75	17	53	114	-	18
22	Indian Institute of Technology	USA	956	24.350	25,47	53	6	22	64	-	221
23	National University of Singapore	Singapore	1.121	23.617	21,07	63	9	35	101	101-150	22
24	University of Granada	Spain	879	21.856	24,86	70	9	44	102	301-400	461-470
25	City University of Hong Kong	PRC	1.098	20.008	18,22	62	5	28	91	201-300	107
26	University of Edinburgh	UK	669	18.174	27,17	54	9	30	64	45	17
27	KU Leuven	Belgium	643	18.067	28,10	52	7	22	53	96	82
28	Purdue University	USA	637	17.871	28,05	64	8	36	81	60	101
29	Georgia Institute of Technology	USA	680	17.728	26,07	63	12	36	77	99	106
30	Tsinghua University	PRC	1.060	16.909	15,95	55	5	20	62	101-150	47

Source: Own elaboration.

Abbreviations are available in Table 1.

Artificial Intelligence is the most influential area of Computer Science research, since it is the one that has received the greatest number of citations. It is also the second area with the greatest number of publications, just behind Interdisciplinary Applications. For this reason, the results for Artificial Intelligence do not differ from Global Results.

The institution that has received more citations and the highest h-index in this field is the Massachusetts Institute of Technology (MIT) with 81,953 citations and an h-index of 128, followed by the University of California Berkeley with 70,459 citations. Moreover, this university had the highest average citation rate per paper. The second-best h-index is achieved by Carnegie Mellon University (118), which is also the institution that is third in the

number of citations. These three institutions dominate the number of citations in the field and comprise approximately 22% of citations. It is worth mentioning that the first five institutions constitute 32% of all Artificial Intelligence citations. Note that American institutions have more citations from published articles than other organizations from other countries.

Analyzing the T50, T100 and T250 ranking results, the Massachusetts Institute of Technology (MIT) is in the top positions with 253 papers in the T50 ranking of the category, followed by Carnegie Mellon University with 235 of the papers in the T50. The same institutions have 154 and 131 papers in the T100 ranking, respectively, and 63 and 51 papers in the T250 ranking, respectively. Note that all the institutions of the category have an h-index bigger than 52, reflecting its influence and productivity.

3.3. Cybernetics

According to the definition of the WoS, "Computer Science, Cybernetics" includes resources that focus on the control and information flows within and between artificial (machine) and biological systems. Resources in this category draw from the fields of artificial intelligence, automatic control, and robotics. Cybernetics is the area with the fewest number of journals in the Computer Science field. In fact, the number of research papers published has experienced a slight increment between the time span of 15 years (1997–2011), presenting some ups and downs throughout the said time period [34].

Table 3 shows the most influential institutions among this category.

Table 3. Cybernetics

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	MIT	USA	156	6.272	40,21	42	4	16	34	3	1
2	Stanford University	USA	113	5.219	46,19	30	4	9	19	2	7
3	Max Planck Society	Germany	132	4.967	37,63	36	1	11	26	-	-
4	CNRS	France	298	3.469	11,64	27	0	3	16	-	-
5	Carnegie Mellon University	USA	124	2.943	23,73	28	1	5	16	62	66
6	University College London	UK	153	2.843	18,58	29	0	7	17	20	6
7	IBM	USA	123	2.667	21,68	22	2	2	7	-	-
8	US Department of Defense	USA	99	2.633	26,60	23	1	5	9	-	-
9	Osaka University	Japan	74	2.629	35,53	19	2	5	6	78	55
10	University of California Berkeley	USA	78	2.466	31,62	24	1	5	18	4	27
11	University of Southern California	USA	104	2.413	23,20	25	1	5	10	51	130
12	University of Maryland College Park	USA	106	2.222	20,96	26	0	3	15	43	121
13	Technical University of Munich	Germany	122	2.143	17,57	24	0	4	10	49	54
14	Czech Academy of Sciences	Czech R	471	2.136	4,54	20	0	2	7	-	-
15	Georgia Institute of Technology	USA	111	2.054	18,50	21	1	1	6	99	106
16	University of Pittsburgh	USA	85	1.788	21,04	21	1	2	9	65	110
17	INRIA	France	92	1.736	18,87	18	2	2	5	-	-
18	CNR	Italy	79	1.708	21,62	16	1	6	10	-	-
19	University of Twente	Netherlands	88	1.622	18,43	20	0	3	9	301-400	212
20	Penn State University	USA	102	1.598	15,67	20	0	3	9	58	111
21	University of Edinburgh	UK	77	1.531	19,88	19	2	3	6	45	17
22	University of North Carolina	USA	109	1.523	13,97	21	0	0	7	-	-
23	University of Nottingham	UK	95	1.521	16,01	21	0	1	7	101-150	77
24	Purdue University	USA	152	1.492	9,82	21	0	0	2	60	101
25	Virginia Polytechnic Institute State University	USA	81	1.473	18,19	22	0	1	8	201-300	355
26	Royal Institute of Technology	Sweden	82	1.448	17,66	17	0	4	6	201-300	-
27	University of Cambridge	UK	85	1.430	16,82	19	0	2	9	5	2
28	University of Washington	USA	76	1.426	18,76	20	1	2	5	-	-
29	Delft University of Technology	Netherlands	102	1.292	12,67	20	0	1	5	201-300	86
30	Pierre Marie Curie University Paris	France	157	1.242	7,91	16	1	1	3	35	114

Source: Own elaboration.

Abbreviations are available in Table 1.

The institution that has received more citations and the highest h-index in this field, as in the previous category, is the Massachusetts Institute of Technology (MIT) with 6,272 citations and an h-index of 42, followed by Stanford University with 5,219 citations. Moreover, this university had the highest average citation rate per paper. The second-best h-index is achieved by the Max Planck Society

(36), an institution that is third in the number of citations. The top five institutions comprise of 32.7% of all citations in this field. Though Asian countries have led Cybernetics research [5], the most influent and productive organizations are American and British, which combine for 65% of the total number of citations received by the TOP 30 (American institutions accounts for 54.6% of all citations, while

British institutions account for the remaining 10.4%). The remaining 9 countries with a presence in TOP 30 received a very small percentage of citations.

Analyzing the T50, T100 and T250 ranking results, the Massachusetts Institute of Technology (MIT) is in the top position with 34 papers in the T50 ranking of the category, followed by the Max Planck Society with 26 of the papers in the T50. The same institutions have 16 and 11 papers, respectively, in the T100 ranking, and 4 and 1 papers, respectively, in the T250 ranking. Note that all the institutions of the category have an h-index higher than 15, the lowest of all categories analyzed, reflecting the small influence that this area has in the Computer Science field.

3.4. Hardware and Architecture

According to the definition of WoS, "Computer Science, Hardware & Architecture" covers resources on the physical components of a computer system: main and logic boards, internal buses and interfaces, static and dynamic memory, storage devices and storage media, power supplies, input and output devices, networking interfaces, and networking hardware such as routers and bridges. Resources in this category also cover the architecture of computing devices, such as SPARC, RISC, and CISC designs, as well as scalable, parallel, and multi-processor computing architectures. The number of papers published in this area has experienced uneven growth. In fact, according to [35], it appears to be an area of increasing irregularity.

Table 4 shows the most influential institutions among this category.

Table 4. Hardware and Architecture

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	AT&T	USA	794	29.269	36,86	77	14	55	126	-	-
2	University of California Berkeley	USA	610	27.760	45,51	77	18	57	108	4	27
3	IBM	USA	1.267	27.124	21,41	73	12	50	124	-	-
4	MIT	USA	514	23.119	44,98	69	18	41	93	3	1
5	Georgia Institute of Technology	USA	497	19.538	39,31	53	9	25	58	99	106
6	University of Illinois Urbana Champaign	USA	733	17.518	23,90	65	9	35	90	28	63
7	Carnegie Mellon University	USA	516	16.590	32,15	59	6	30	66	62	66
8	Stanford University	USA	546	15.693	28,74	64	7	33	77	2	7
9	University of Southern California	USA	517	14.093	27,26	54	7	25	57	51	130
10	US Department of Energy	USA	428	13.676	31,95	40	6	22	32	-	-
11	University of California Los Angeles	USA	497	11.785	23,71	54	3	23	60	12	37
12	Intel Corporation	USA	738	10.734	14,54	48	4	15	46	-	-
13	University of Michigan	USA	539	10.479	19,44	49	3	17	49	22	23
14	University of Texas Austin	USA	543	10.427	19,20	49	4	15	48	39	79
15	Purdue University	USA	625	10.022	16,04	45	3	18	41	60	101
16	University of California San Diego	USA	484	8.986	18,57	45	2	13	43	14	59
17	University of Massachusetts Amherst	USA	341	8.332	24,43	43	3	15	36	101-150	281
18	Princeton University	USA	377	7.925	21,02	41	3	13	37	6	9
19	University of Waterloo	Canada	529	7.538	14,25	41	2	7	34	201-300	168
20	University of Maryland College Park	USA	400	7.450	18,63	39	2	16	30	43	121
21	Alcatel Lucent	France	306	7.177	23,45	44	3	17	38	-	-
22	Duke University	USA	296	6.472	21,86	40	1	13	33	31	26
23	CNRS	France	661	6.272	9,49	38	0	5	26	-	-
24	University of Wisconsin Madison	USA	304	6.007	19,76	38	2	11	29	24	42
25	University of Minnesota Twin Cities	USA	382	5.812	15,21	39	0	9	27	30	-
26	National Chiao Tung University	PRC	561	5.608	10,00	34	1	8	19	301-400	203
27	INRIA	France	377	5.557	14,74	36	2	11	28	-	-
28	Technion Israel Institute of Technology	Israel	322	5.204	16,16	34	0	11	24	78	189
29	University of California Santa Barbara	USA	305	4.755	15,59	36	0	7	22	41	132
30	Northwestern University	USA	291	4.749	16,32	36	1	9	22	28	34

Source: Own elaboration.

Abbreviations are available in Table 1.

The institution that has received the most citations is AT&T. This institution, together with the University of California Berkeley, are the ones with the highest h-index (77). The University of California Berkeley also had the highest average citation rate per paper. The top five institutions comprise 35% of all Hardware & Architecture citations. The United States has produced the highest number of papers [17]. In all, 80% of organizations in this ranking are American universities. These universities constitute the first 200 positions of both the ARWU and QS rankings, meaning that highly prestigious American universities are the most influential in this area.

Analyzing the T50, T100 and T250 ranking results, AT&T is in the top position with 126 papers in the T50 ranking of this category, followed by International Business Machines (IBM) with 124. In contrast, the University of California Berkeley is the institution with the largest number of papers in the T100 and T250, with 57 and 18 papers, respectively. Regarding the T250, the University of California Berkeley shares the lead with the Massachusetts Institute of Technology (MIT).

All the institutions of this category have an h-index higher than 33.

3.5. Information Systems

Information Systems is third most important area in Computer Science research by number of citations. According the WoS, "Computer Science, Information Systems" covers resources that focus on the acquisition, processing, storage, management, and dissemination of electronic information that can be read by humans, machines, or both. This category also includes resources for telecommunications systems and discipline-specific subjects such as medical informatics, chemical information processing systems, geographical information systems, and some library science.

Table 5 shows the most influential institutions in Information Systems field.

Table 5. Information Systems

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	Stanford University	USA	1.018	52.764	51,83	95	23	89	188	2	7
2	MIT	USA	966	48.630	50,34	91	38	84	161	3	1
3	AT&T	USA	1.107	44.673	40,36	87	24	77	144	-	-
4	University of California Berkeley	USA	820	43.452	52,99	84	34	71	134	4	27
5	University of Illinois Urbana Champaign	USA	896	32.471	36,24	73	19	53	110	28	63
6	University of Maryland College Park	USA	809	26.314	32,53	69	14	49	100	43	121
7	IBM	USA	1.149	25.709	22,38	72	16	50	106	-	-
8	University of Michigan	USA	623	24.460	39,26	48	10	24	47	22	23
9	University of Minnesota Twin Cities	USA	548	24.245	44,24	69	14	48	93	30	-
10	University of California Los Angeles	USA	606	23.178	38,25	57	12	38	63	12	37
11	Princeton University	USA	563	22.758	40,42	68	21	45	91	6	9
12	Harvard University	USA	904	22.506	24,90	73	10	51	104	1	4
13	Technion Israel Institute of Technology	Israel	801	22.222	27,74	66	12	37	98	78	189
14	Alcatel Lucent	France	938	20.339	21,68	59	11	35	70	-	-
15	University of Southern California	USA	712	18.856	26,48	67	11	40	95	51	130
16	University of California San Diego	USA	600	14.155	23,59	53	7	24	57	14	59
17	University of Texas Austin	USA	535	14.094	26,34	55	9	30	59	39	79
18	University of Toronto	Canada	529	14.079	26,61	50	10	24	50	24	20
19	Columbia University	USA	758	13.896	18,33	55	5	26	59	8	14
20	CNRS	France	1.091	13.861	12,70	46	7	15	43	-	-
21	University of Waterloo	Canada	804	13.459	16,74	47	4	16	46	201-300	168
22	Georgia Institute of Technology	USA	605	12.767	21,10	46	6	20	46	99	106
23	National University of Singapore	Singapore	898	12.702	14,14	50	4	19	50	101-150	22
24	University of North Carolina	USA	894	12.664	14,17	51	5	16	53	-	-
25	Cornell University	USA	485	12.146	25,04	52	4	24	53	13	19
26	Chinese University of Hong Kong	PRC	538	11.547	21,46	41	2	10	31	151-200	46
27	City University of Hong Kong	PRC	660	11.322	17,15	48	4	18	48	201-300	107
28	University of Washington	USA	525	10.793	20,56	49	6	17	48	-	-
29	University of Washington	USA	509	10.638	20,90	49	6	17	48	15	65
30	Carnegie Mellon University	USA	620	10.271	16,57	49	5	19	49	62	66

Source: Own elaboration.

Abbreviations are available in Table 1.

The institution that has received the most citations and the highest h-index in this field is Stanford University with 52,764 citations and an h-index of 95, followed by the Massachusetts Institute of Technology (MIT) with 48,630 citations and an h-index of 91. The University of California Berkeley had the highest average citation rate per paper (52.99), followed very closely by Stanford University and the Massachusetts Institute of Technology (MIT) with 51.83 and 50.34, respectively. These three institutions are the only ones that exceed a ratio of 50 citations per paper. The first five institutions dominate the number of citations in the field with almost 34% of all citations.

American institutions dominate both the number of publications and citations received in this field. These institutions have produced 72% of all publications and have received almost 81% of all citations received in the TOP 30. The other countries that participate in this ranking have a rather testimonial presence. In fact, only 6 countries, in addition to the United States, have a presence in the TOP 30.

Analyzing the T50, T100 and T250 ranking results, Stanford University is in the top position in the T50 and T100 rankings, with 188 and 89 papers, respectively, followed by the Massachusetts Institute of Technology (MIT) with 161 and 84 papers, respectively. This last institution leads the T250 ranking with 38 publications. All the institutions of the category have an h-index higher than 40. Additionally, the universities that are in this classification are prestigious, according to the ARWU and QS rankings. It worth noting that the most productive organizations are not necessarily the most influential, such as with the Centre National de

la Recherche Scientifique (CNRS). This means that the articles published in Information Systems by the different organizations are highly cited.

3.6. Interdisciplinary Applications

According to the WoS, "Computer Science, Interdisciplinary Applications" includes resources concerned with the application of computer technology and methodology to other disciplines, such as information management, engineering, biology, medicine, environmental studies, geosciences, arts and humanities, agriculture, chemistry, and physics.

This area is the most productive in Computer Science research, since it is an interdisciplinary area that embraces articles from many knowledge areas.

Table 6 shows the most influential institutions among this category.

Table 6. Interdisciplinary Applications

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	US Department of Energy	USA	2.806	102.687	36,60	123	58	160	355	-	-
2	CNRS	France	3.692	55.574	15,05	87	17	66	222	-	-
3	Stanford University	USA	1.114	40.362	36,23	88	25	75	164	2	7
4	University of California Berkeley	USA	895	36.227	40,48	76	22	54	121	4	27
5	University of California Los Angeles	USA	701	34.905	49,79	74	17	48	113	12	37
6	NASA	USA	900	34.129	37,92	84	25	74	141	-	-
7	University of Illinois Urbana Champaign	USA	875	32.856	37,55	58	8	27	72	28	63
8	MIT	USA	1.098	30.621	27,89	80	12	59	139	3	1
9	Los Alamos National Laboratory	Mexico	763	29.918	39,21	73	14	48	112	-	-
10	University of Minnesota Twin Cities	USA	830	24.277	29,25	62	14	38	81	30	-
11	University of Michigan	USA	974	23.004	23,62	68	7	35	112	22	23
12	University of Oxford	UK	603	22.666	37,59	55	12	26	68	9	5
13	Harvard University	USA	791	22.525	28,48	72	10	49	106	1	4
14	University of North Carolina	USA	1.375	22.345	16,25	62	10	43	83	-	-
15	KU Leuven	Belgium	996	22.178	22,27	58	9	29	81	96	82
16	Carnegie Mellon University	USA	863	21.647	25,08	71	8	43	113	62	66
17	Imperial College London	UK	1.030	21.546	20,92	68	4	33	97	22	3
18	University of Cambridge	UK	774	20.149	26,03	60	7	27	82	5	2
19	INRIA	France	923	19.295	20,90	68	7	39	94	-	-
20	National University of Singapore	Singapore	1.236	17.430	14,10	55	1	18	70	101-150	22
21	Max Planck Society	Germany	707	17.356	24,55	59	9	30	69	-	-
22	US Department of Defense	USA	1.067	17.101	16,03	52	6	21	59	-	-
23	University of Montreal	Canada	911	17.087	18,76	54	5	20	62	101-150	-
24	Indian Institute of Technology	India	1.635	17.025	10,41	51	0	10	55	-	221
25	Swiss Federal Institute of Technology Zurich	Switzerland	690	16.095	23,33	54	9	25	60	19	12
26	University of Texas Austin	USA	801	16.083	20,08	53	7	28	58	39	79
27	Purdue University	USA	997	15.750	15,80	54	4	16	61	60	101
28	Chinese Academy of Sciences	PRC	1.360	14.874	10,94	50	0	9	51	-	-
29	Penn State University	USA	760	14.451	19,01	52	7	19	53	58	111
30	University of Florida	USA	660	14.221	21,55	54	3	28	59	78	193

Source: Own elaboration.

Abbreviations are available in Table 1.

This area is the only one that does not have any companies among the 30 most productive organizations. One of the reasons for this is that journals of this category are multidisciplinary, so companies like International Business Machines (IBM), Microsoft or AT&T publish articles in more specialized areas of Computer Science.

The institution that has received more citations is the United States Department of Energy (DOE). Additionally, this institution had the highest h-index (123), with values much higher than the rest of universities, and leads the T50, T100 and T250 ranking results with 355, 160 and 58 papers, respectively. The University of California Los Angeles had the highest average citation rate per paper.

The top five institutions constitute 34% of all citations. The United States is the most productive country and the one that receives the most citations. Next are France and the UK. In this regard, it should be noted that this category has the largest number of countries within the TOP 30. Specifically, universities from 11 countries are part of the TOP 30.

Note that all the institutions of the category have an h-index higher than 49.

3.7. Software Enginnering

The objectives of this research area are software principles and techniques [12]. According to the

WoS, "Computer Science, Software Engineering" includes resources that are concerned with the programs, routines, and symbolic languages that control the functioning of the hardware and direct its operation.

Table 7 shows the most influential institutions among this category.

Table 7. Software Engineering

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	IBM	USA	3.520	84.602	24,03	133	44	179	367	-	-
2	MIT	USA	1.346	48.240	35,84	99	38	98	207	3	1
3	Stanford University	USA	1.118	40.573	36,29	99	24	98	206	2	7
4	Carnegie Mellon University	USA	1.375	38.949	28,33	90	26	81	161	62	66
5	University of California Berkeley	USA	1.112	32.120	28,88	81	24	61	141	4	27
6	AT&T	USA	913	29.369	32,17	83	16	68	140	-	-
7	Microsoft	USA	1.248	24.014	19,24	73	14	42	97	-	-
8	University of Maryland College Park	USA	893	21.144	23,68	67	12	41	101	43	121
9	US Department of Energy	USA	1.051	20.581	19,58	61	13	35	75	-	-
10	Cornell University	USA	667	20.128	30,18	63	13	40	80	13	19
11	University of Illinois Urbana Champaign	USA	795	19.138	24,07	67	6	37	97	28	63
12	Princeton University	USA	523	18.843	36,03	60	11	37	78	6	9
13	INRIA	France	1.320	17.776	13,47	59	6	30	74	-	-
14	University of Washington	USA	655	16.664	25,44	65	8	38	84	15	65
15	Georgia Institute of Technology	USA	844	16.444	19,48	60	9	29	84	99	106
16	University of North Carolina	USA	936	16.242	17,35	55	6	21	67	-	-
17	Tel Aviv University	Israel	623	15.371	24,67	64	4	33	81	151-200	195
18	New York University	USA	533	14.906	27,97	62	7	32	79	27	41
19	Purdue University	USA	941	14.159	15,05	53	4	20	63	60	101
20	CNRS	France	1.291	13.231	10,25	48	3	15	41	-	-
21	University of Southern California	USA	517	13.033	25,21	54	6	22	62	51	130
22	University of Texas Austin	USA	613	12.929	21,09	53	4	24	57	39	79
23	Technion Israel Institute of Technology	Israel	609	12.338	20,26	49	7	26	49	78	189
24	University of Wisconsin Madison	USA	524	11.805	22,53	54	5	21	62	24	42
25	Rutgers State University	USA	459	11.315	24,65	53	4	21	55	52	278
26	University of British Columbia	Canada	516	10.504	20,36	51	3	18	57	37	43
27	Iniversity of Michigan	USA	526	10.086	19,17	51	5	14	51	22	23
28	University of Minnesota Twin Cities	USA	426	10.035	23,56	45	4	12	43	30	-
29	University of California Irvine	USA	469	9.886	21,08	53	5	21	55	47	152
30	University of Toronto	Canada	444	9.447	21,28	52	2	16	56	24	20

Source: Own elaboration.

Abbreviations are available in Table 1.

The institution that has received more citations and the highest h-index in this field is International Business Machines (IBM) with 84,602 citations and an h-index of 133, followed by the Massachusetts Institute of Technology (MIT) with 48,240 citations and an h-index of 99. It can be seen how the first institution practically duplicates the number of citations of the second. Stanford University had the highest average citation rate per paper (36.29), followed very closely by the Massachusetts Institute of Technology (MIT) (35.84). The first five institutions dominate the number of citations in the field with 39% of all citations.

American institutions dominate research in this field. In fact, 24 of the 30 institutions that appear in the TOP 30 are from the United States. In addition, American institutions that occupy the TOP 10 receive 57% of all TOP 30 appointments. Despite this, [11] indicated that over a 40-year period (1968-2009), approximately 60% of the Software Engineering literature has been contributed by only 7% of all countries, and the share of American contributions to this discipline has declined from 71.43% (in 1980) to 14.90% (in 2008). Meanwhile, China is the country with the biggest share of growth

in the number of publications (from 0.82% of the entire Software Engineering publications in 1991 to 13.82% in 2009).

Analyzing the T50, T100 and T250 ranking results, International Business Machines (IBM) is in the top position in the T50, T100 and T250 rankings, with 367, 179 and 44 papers, respectively, followed by the Massachusetts Institute of Technology (MIT) with 207, 98 and 34 papers, respectively. All institutions of this category have an h-index larger than 44 It is also relevant to note that only the first 10 organizations of the ranking have more than 10 articles with more than 250 citations.

3.8. Theory and Methods

According to the WoS, "Computer Science, Theory & Methods" includes resources that emphasize experimental computer processing methods or programming techniques such as parallel computing, distributed computing, logic programming, object-oriented programming, high-speed computing, and supercomputing.

Table 8 shows the most influential institutions among this category.

Table 8. Theory and Methods

R	Institution	Country	TP	TC	TC/TP	H	≥250	≥100	≥50	ARWU	QS
1	CNRS	France	2.495	30.400	12,18	67	12	35	102	-	-
2	IBM	USA	1.202	26.056	21,68	69	14	44	120	-	-
3	MIT	USA	791	19.281	24,38	59	8	34	75	3	1
4	Stanford University	USA	510	19.242	37,73	61	14	44	81	2	7
5	University of California Berkeley	USA	612	17.882	29,22	61	16	33	79	4	27
6	AT&T	USA	622	16.888	27,15	61	5	31	79	-	-
7	INRIA	France	1.327	13.991	10,54	52	3	12	54	-	-
8	Tel Aviv University	Israel	796	13.227	16,62	54	2	19	58	151-200	195
9	University of Illinois Urbana Champaign	USA	655	11.822	18,05	53	4	18	57	28	63
10	Cornell University	USA	409	11.242	27,49	52	10	26	53	13	19
11	New York University	USA	486	10.616	21,84	48	7	14	45	27	41
12	University of Toronto	Canada	448	10.539	23,52	48	8	21	46	24	20
13	Carnegie Mellon University	USA	524	9.580	18,28	44	5	18	36	62	66
14	Max Planck Society	Germany	418	8.986	21,50	36	5	11	23	-	-
15	Technion Israel Institute of Technology	Israel	689	8.981	13,03	43	0	17	37	78	189
16	Universite Paris Saclay Comue	France	845	8.484	10,04	41	1	6	29	-	-
17	University of Edinburgh	UK	379	8.385	22,12	39	6	16	29	45	17
18	University of Waterloo	Canada	707	8.245	11,66	41	0	10	34	201-300	168
19	US Department of Energy	USA	591	8.011	13,55	40	2	12	30	-	-
20	University of Maryland College Park	USA	435	7.896	18,15	36	2	5	24	43	121
21	Imperial College London	UK	346	7.880	22,77	33	4	7	25	22	3
22	Princeton University	USA	365	7.869	21,56	45	4	17	41	6	9
23	University of Texas Austin	USA	390	7.782	19,95	41	4	12	33	39	79
24	Microsoft	USA	451	7.686	17,04	36	5	13	24	-	-
25	Weizmann Institute of Science	Israel	390	7.650	19,62	42	2	14	34	101-150	-
26	Purdue University	USA	431	6.542	15,18	38	2	11	26	60	101
27	Indian Institute of Technology	India	584	6.398	10,96	39	1	11	30	-	221
28	Rutgers State University	USA	389	6.344	16,31	38	2	10	24	52	278
29	University of North Carolina	USA	466	6.243	13,40	40	2	8	27	-	-
30	CNR	Italy	340	6.084	17,89	26	3	6	13	-	-

Source: Own elaboration.

Abbreviations are available in Table 1.

The institution that has received more citations is the Centre National de la Recherche Scientifique (CNRS) with 30,400 citations, followed by International Business Machines (IBM) with 26,056 citations. With respect to the h-index, the two previous institutions also lead the rankings but exchange their positions. Stanford University had the highest average citation rate per paper (37.73), followed by the University of California Berkeley (29.22). The first five institutions dominate the number of citations in the field with 33% of all citations.

Although American institutions dominate this field, the presence of European institutions is noteworthy. This implies that Asian countries are less influential and productive in this area.

Analyzing the T50, T100 and T250 ranking results, International Business Machines (IBM) is in the top positions of the T50 and T100 (with 120 and 44 papers, respectively), while the University of California Berkeley leads the T250 ranking (with 16 papers).

Although all the institutions of this category have an h-index higher than 25, this research area is the one with the lowest average of citations per published article.

4. Conclusions

This study aims to characterize Computer Science research institutions indexed in the WoS database between 1991 and 2015. This analysis illustrates the results obtained under a wide range of bibliometric indicators. It is very useful to see the general results from a broader perspective than the Journal Citation Reports of the WoS. Particularly, this is very useful for PhD students and newcomers in the field in order to obtain a general orientation of the leading institutions in Computer Science.

The results provide a general picture of the current position of the leading institutions in this field for the seven categories analyzed. In all, 78 institutions have a presence in the elaborated ranks. Of these, only 5 institutions (Massachusetts Institute of Technology (MIT), University of California Berkeley, Stanford University, Centre National de la Recherche Scientifique (CNRS) and Carnegie Mellon University) appear in the eight elaborated ranks. Of these institutions, 4 are from the United States and 1 from France. This last institution is a research center, while the first four institutions are universities.

Another 6 institutions have a presence in seven of the eight ranks analyzed. Of these institutions, 2 were not ranked among the most influential for Interdisciplinary Applications (International Business Machines (IBM), University of Maryland College Park), two in the Cybernetics (University of Texas Austin and University of Illinois Urbana Champaign), and two in information system (INRIA and Purdue University). Of these institutions, four are universities, one is a research center and the other one is a company.

The 11 institutions mentioned above are present in the overall ranking. Four of these institutions hold the top five positions in the ranking, while 7 of them are in the Top 10. Another 3 institutions are located between positions 11 and 20 of that ranking, and the last institution are located in the 28th position.

The Massachusetts Institute of Technology (MIT), University of California Berkeley, Stanford University and International Business Machines (IBM) have the highest number of citations, which shows the largest absolute influence. However, some other institutions achieve better results when looking to other indicators. For example, according to the number of papers, the leading institution is the Centre National de la Recherche Scientifique (CNRS). This indicates that the institutions considered in the study have different profiles with a wide variety of objectives.

The results also indicate Artificial Intelligence is the most influential category, although Interdisciplinary Applications is the largest. Another important fact is that 31 institutions only have a presence in a single ranking of those presented. Of these, 35% are only present in the Cybernetics Theory and Methods category, while the Information Systems category is the one with the smallest ratio (3%) of institutions not present in other ranks.

American universities are the most influential of those investigated, but there is a wide range of institutions that published in this area. Companies and research centers from different countries like France, Germany, China, Japan or South Korea are important in research. However, there are no South American or African countries in the rankings.

Regarding the three continents represented in the different rankings elaborated, Centre National de la Recherche Scientifique (CNRS) is the most important institution from Europe, Technion Israel Institute of Technology from Asia and Massachusetts Institute of Technology (MIT) from United States.

The global rankings also show that research centers and companies have little published presence in the Computer Science field, but they are in high positions of the presented rankings. In fact, universities represent 63% of all published papers, while research centers and companies account for 31% and 6%, respectively.

In conclusion, the findings and suggestions of this study can help scientific researchers understand the performance and trends of Computer Science research. With the help of these findings, researchers can make informed decisions regarding their research directions in terms of identifying top disciplinary institutions and choosing research exchange platforms.

Some of the limitations of our paper are similar to those found in other papers [29]. First, this study only accounted for journals indexed in the WoS without considering other databases. However, the material published in the WoS may be sufficiently representative of state-of-the-art research for the analyzed fields.

Despite these limitations, the paper provides a starting point for future bibliometric studies in these fields. Future research could include bibliometric studies focused on the identification of the main authors, countries and published documents.

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