Research Article

Strengthen of a Scientific Field in Latin America: Evolutionary Computation

María Elena Luna-Morales[1,*], Miguel Ángel Pérez-Angón[2], Evelia Luna-Morales[1]

[1]Cinvestav-IPN, General Coordination of Bibliographic Services, 07000 Mexico City, MEXICO.
[2]Cinvestav-IPN, Department of Physics, 07000 Mexico City, MEXICO.

ABSTRACT

We carried out a bibliometric analysis of the research production in the field of evolutionary computation in Latin America (LA) for the period 1980-2020. The bibliometric method is applied with a quantitative review of the published literature. The search for publications was carried out in the Web of Science database through the terms that are most commonly used to identify this field of study. The data analysis the data analysis used Microsoft Office tools (excel and Access) to organize our data were used to organize our data: authors, institutions, journals, countries and thematic categories. It was completed with VOS Viewer 1.8.16 to generate a co-authorship network map of authors, and the development of base maps for collaboration by countries. We have identified the first Latin American publications in the journals Archivos de Biologia y Medicina Experimentales and Desarrollo Economico-Revista de Ciencias Sociales; this research field reached a consolidation in the 2000s with the opening of the first graduate programs in this geographical region; there is an extraordinary number of LA scholars active in this research field and an increasing number of academic institutions mainly from Brazil, Mexico, Argentina, Chile and Colombia; while the Asian and European production in this research field is about 30%, the respective LA contribution is just 4.9%. The present study attempts to document the progress of evolutionary computation in Latin America, an issue that has gained relevance for society, especially in recent years. No studies have been generated that cover the Latin American region, and therefore it is hoped that these findings will be useful for the development of scientific and public policies and also for other future work.

Keywords: Evolutionary computation, Strengthen Scientific field, Latin America, Scientific production, Bibliometric study.

INTRODUCTION

There are several factors involved in the maturity of a new research field:[1-3] a substantial scientific production and impact by a solid network of scholars, the support of graduate programs, as well as the recognition of external communities of scholars.[4-6] The research collaboration has been considered as an essential tool to construct a scientific community and leads to the development of cognitives structures shared by all its members.[7]

The bibliometric method has been used to measure the evolution of scientific fields. The main element of analysis is the bibliographic data on published Works:[8] original articles, reviews, books, book chapters, proceedings, as well as the indicators generated from this analysis: impact factors, number of citations, frequency of publications, institutional statistics, etc.[9]

Evolutionary computation

This branch of computational science is oriented to the study of bio-inspired metaheuristics which are stochastic search and optimization techniques. Such properties constitute "algorithms that are supported in two concepts: exploration and exploitation of the search space".[10-13] The foundation of this new research field lies in algorithms with a structure close to the Darwinian principles of evolutionary biology.[14] This scheme is supplemented with the principles of modern genetics and selectionism.[10] The combination of these three theories is called Neo-darwinism or modern synthesis of genetics.[15,16]

The genetic algorithm, which is also called evolutionary algorithm, was generated in the first decades of the XX century. The first works on the evolution of biological systems by computers were published in the mid XX century.[15,16] Holland and Schwefel were pioneers in the development of new informatic models in genetics.[17] Their work constitued the fundation of evolutionary computation in the published litearture. The applications of computational software were first developed by

R.M. Friedberg.[18] LA this field of research was initiated in the 1970 decade.[10]

Literature review

There are three basic processes in the field of evolutionary computation that were developed in the 1960-1970 decades:[11] (i) evolutionary programming, (ii) evolution strategies, and (iii) genetic algorithms. This field of research has become a transdisciplinary approach with multiple applications. In particular, in Latin America (LA) the interest in this field started in the decade of 1980 with diverse applications: texts clustering,[19] drinking water access,[20] industry management,[21] stock market prediction,[22] scheduling,[23] electricity supply,[24] manufacturing,[25] data mining.[26]

The published production in this field of research includes the following topics: definitions, basic concepts,[27] development of algorithms,[28] optimization of algorithms or genetic programing,[29] application of artificial intelligence,[30] evolutionary optimization, multi-objectives and hiper-heuristic.[11] The trandisciplinary relation of evolutionary computation has been also studied.[31] However, there are very few bibliometric analysis on this research field: bussiness inteligence in the agricultural sector,[32] data visualization, data networks, genetic programation, software developments and analysis of computation journals.[33-35] Hoevere, as far as we know, there are no studies on the bibliometry of evoluitionary computation. This precisely the aim of the present study is to characterize the progress of this field of research through the analysis of the WoS databases. In particular, we are interested in answering the followin points: which were the first research publications in this research fiueld? when does this field reached its maturity? which are the principal research collboratrions? In the following section the respective search strategics are presented, as well as our results and conclusions.

DATA AND METHODS

The present study uses the method associated to the systematic review of the published literatura on the field of evolutionary computation by Latinamerican researchers using the WoS databases. This method three different types of reviews use: analysis of dominio, analysis based in theories, and analysis of methods. The first case involves five stages:[36] estructured review, review based in frames of reference, quantitative bibliometric review, theories review, and finally a hibrid review. However, in the present work we will use the bibliometric review as an essential tool to analyze different trends in this new field of research.[37]

In this framework, the general aim of the present work is to determine the evolution of the Latin America output in the field of evolutionary computation, dando respuesta a las preguntas: which were the first research publications in this research fiueld? when does this field reached its maturity? which are the principal

research collboratrions? Figure 1 shows the flow chart followed for literature search, retrieval, organization and analysis. The model applied is SPAR-4-SLR.[14]

Assembling

We use the databases of the Web of Science (WoS) in the period 1980-2020. In particular, for characterizing the consolidation process the evolution of the Latin America output in the field of volutionary computation. The productivity and impact will correspond to the publications and citations in mainstream journals included in WoS. The publications were retrieved by matching the names of the Latin American institutions with the articles from the WoS databases. Our search strategy included the following features:

TS=(Algoritmos evolutivos or Computación evolutiva or computo evolutivo or algoritmos genéticos or Programacion Evolutiva or Estrategias Evolutivas or Programacion evolutiva or Estrategias de evolucion or Evolutionary Computing or Genetic Algorithms or Evolutionary Programming or Evolutionary Strategies or Evolutionary algorithms or Evolutionary programming or Evolution strategies) AND CU=(Argentina, or Belice or Bolivia or Brazil or Chile or Colombia or Costa Rica or Cuba or Ecuador or El Salvador or Guatemala or Jamica or Honduras or Mexico or Nicaragua or Panama or Paraguay or Peru or Puerto Rico or Republica Dominicana or Uruguay or Venezuela). Belize was considered due to its influence in terms of language and culture.
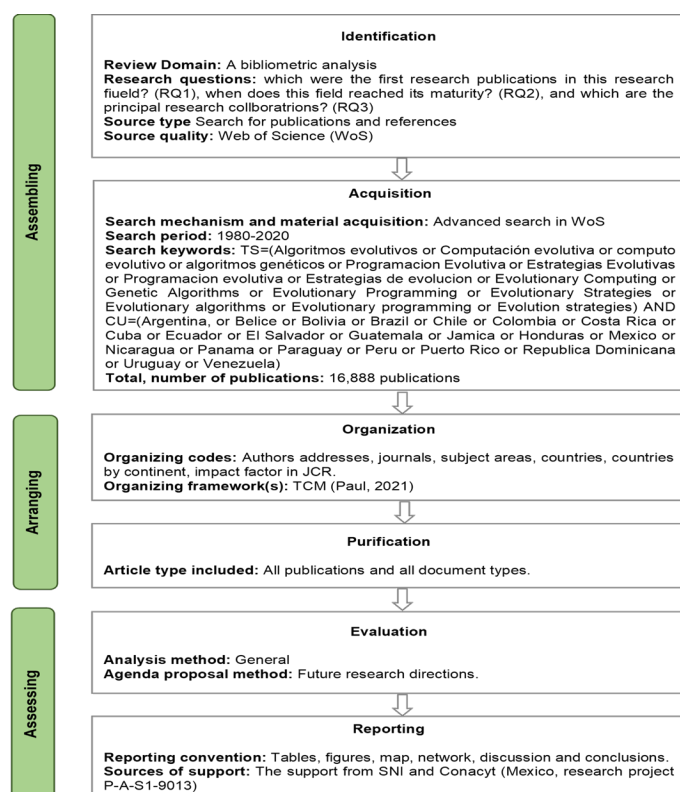

Figure 1: Diagram of flow for the search, retrieve, organization and analysis of the published literature on evolutionary computation. Model SPAR-4-SLR.

Our search retrieved 16,888 documents in the period 1980-2020. The data set includes all different types of documents published in the WoS journals. The bibliometric review was completed with the data from the published production on this field of research by LA researchers.

Arranging

The 16,888 documents were retrieved in blocks of 500 documents and were included in an Excel spreadsheet with normalized data: authors addresses, titles of journals, subject areas, country of the journal. We were interested in keeping extra data on each journal such as its impact factor in JCR, the respective quartile and country of edition. In particular, if the country corresponds to the LA region. Our data sample was translated to an Access file that made esay our data analysis. We needed to perform a double counting in order to determine the data on production by country and institution.

The assignment of the number of publications by continent was performed with the same methodology used for the case of LA publications: the WoS filters were used in order to label the production per year for each continent. Finally, we built the matrices required to use the VOSViewer software in the generation of network maps. Also, free software was used free for the developmen to the maps the LA collaborations with the countries of other continents.

Assessing

Our results are supported by a bibliometric analysis of the published production on evolutionary computation by LA researchers: evolution of the number of articles and the respective number of citations, distribution of authors and institutions, journals and areas of knowledge, as well as scientific collaborations.

RESULTS

Production and scientific impact

We have included in Table 1 the LA production and impact for the period 1980-2020 in the field of evolutionary computation. Our search indicates that the first LA documents in this field were published in 1980. The data included in this table shows that it was not until 1991 when the LA output started a steady trend. The number of citations per year is impressive. The average number of citations increased from 59 citations per article in 1991 to 65 citations per article in 2003 but in 2012 has reached just 27 citations per article. Of course, the latter result is expected to increase in the near future.

According to our bibliometric search, the first document published in the scientific literature was 1964. We registered just 53 new publications in the following 12 years but afterwards the respective growth dynamics became impressive as it is shown in Table . It is important to notice that in LA most of the graduate

programs were funded in the 1970 decade. Our findings will show that some of these programs contributed with a substantial contribution to the research production in this field of knowledge. This was also true in other research fields.[27]

Geographical distribution

The distribution of publications by countries of LA is included in Table 2. While Brazil has contributed with 48.4% of this output, the following four LA countries (Mexico, Argentina, Chile and Colombia) have a similar contribution (44.5%) to the whole LA output. The respective number of publishing institutions corresponds to a similar share: 41.6% in both cases. This LA trend has been observed in others research fields.[38]

Scientific production

Figure 2 depicts the evolution of the scientific production in mainstream journals in the field of evolutionary computation for different geographical regions. Asia and Europe have the largest production (39.1% and 30.6%, respectively), while USA and Canada contribute with 18% of the whole production. The Latin American region contributes with just 4.9% of this production. We can appreciate also in Figure that since 2000 there a steady increase of the scientific production in this research field an all-geographical region. While Coello[11] has pointed out that the original ideas on evolutionary computation arised in the 1950-60 decades, we can appreciate in Figure that a steady increase in the respective scientific production only started in the 2000 decade.

The LA research production in this field involves 63.2% of original papers, 3.8% in proceedings, 2.5% in review articles and book chapters. The original articles were published in 3,358 journals, of these 10.9% are regional and the rest mainstream journals. The latter, most of them in the first JCR quartiles: 35.4% in the first quartile and 31.8 in the second quartile. In Table 3 we have included the distribution of the LA production published in these journals. PLOS ONE and Astronomy and Astrophysics

Table 1: Distribution of the number of publications and the respective citations per year in the LA output for evolutionary computing (1980-2020).

Years	Publications	Citations
1980-1990	5	11
1991-1994	57	2377
1995-1998	248	6953
1999-2002	608	24566
2003-2006	1403	51822
2007-2010	2461	5572
2011-2014	3529	14735
2015-2018	5538	55399
2019-2020	3039	11516
TOTALS	16888	281721

Table 2: Distribution of the number of publications and active institutions for the LA countries in the field of evolutionary computation (1980-2020).

| Country	Number Institutions	Publications	% Institutions	% Publications
Brazil	1547	15244	41.6	48.4
Mexico	424	6657	11.4	21.1
Argentina	512	2807	13.8	8.9
Chile	263	2601	7.1	8.3
Colombia	348	1947	9.3	6.2
Cuba	123	475	3.3	1.5
Venezuela	91	429	2.4	1.4
Ecuador	141	425	3.8	1.3
Uruguay	59	332	1.6	1.1
Panama	18	177	0.5	0.6
Costa Rica	38	148	1.0	0.5
Peru	46	105	1.2	0.3
Bolivia	36	53	1.0	0.2
Guatemala	13	19	0.3	0.1
Paraguay	10	17	0.3	0.1
Jamaica	5	15	0.1	0.0
Nicaragua	7	10	0.2	0.0
Dominican Republic	7	8	0.2	0.0
El Salvador	5	6	0.1	0.0
Honduras	3	5	0.1	0.0
Belize	0	0	0.0	0.0
Puerto Rico	0	0	0.0	0.0
TOTALS	3722	31512	100.0	100.0
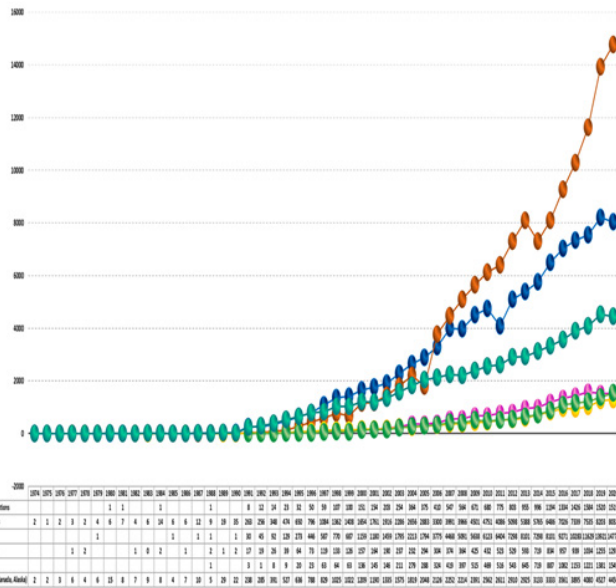
Figure 2: Evolution of the number of scientific production on evolutionary computation by geographical region (1974-2020).

have published the largest number of articles in this research field (about 200 papers each). The mainstream journals with the largest number of citations correspond to Nature, Monthly Notices of the Royal Astronomical Society and Astronomy and Astrophysics. In Table there are no regional journals because the number of published documents in this field is very low: only 11% of the total production was published in regional journals.

Subject areas

There is also a diversity of subject areas included in the LA production in this research field. Table 4 shows the subject areas that reached at least 1% of the whole production. The most representative subject areas correspond to Computer Science and Engineering, each with 20.9% (13.7%) and 6.6% (11.7%) of the production (citations), respectively. From the diversity of themes inlcuded in Table , we can conclude that this research field has a transdisciplinary approach with disciplines that include Ecology, Management Science, Mathematics, Physics, Chemistry, Genetics and Heridity and even Astronomy and Astrophyics.

Table 3: Distribution of the mainstream journals with the highest LA output and impact in the field of evolutionary computation. The corresponding JCR quartiles are included (1980-2020).

No.	Journals	Publications	Quartile	No.	Journals	Citations	Quartile
1	Plos One	237	Q2	1	Monthly Notices of the Royal Astronomical Society	9608	Q1
2	Astronomy and Astrophysics	202	Q1	2	Nature	7656	Q1
3	Expert Systems with Applications	170	Q1	3	Astronomy and Astrophysics	7184	Q1
4	Applied Soft Computing	166	Q1	4	IEEE Transactions on Evolutionary Computation	6344	Q1
5	IEEE Latin America Transactions	133	Q4	5	Expert Systems with Applications	4666	Q1
6	Information Sciences	93	Q1	6	IEEE Transactions on Power Systems	4046	Q1
7	Monthly Notices of the Royal Astronomical Society	86	Q1	7	Plos One	3873	Q2
8	Scientific Reports	79	Q1	8	Astrophysical Journal	3522	Q1
9	IEEE Access	77	Q2	9	Astronomy and Astrophysics Supplement Series	3000	Q3
10	Electric Power Systems Research	72	Q2	10	Applied Soft Computing	2925	Q1
11	Astrophysical Journal	68	Q1	11	Information Sciences	2923	Q1
12	Soft Computing	67	Q2	12	Science	2800	Q1
13	Computers and Operations Research	61	Q2	13	Journal of Biogeography	2355	Q1
14	Mathematical Problems in Engineering	57	Q3, Q4	14	Astrophysical Journal Supplement Series	2294	Q1
15	Ieee Transactions on Power Systems	56	Q1	15	Proceedings of the National Academy of Sciences of The United States of America	2273	Q1
16	Ieee Transactions on Evolutionary Computation	50	Q1	16	European Journal of Operational Research	2144	Q1
17	Energies	47	Q3	17	Computer Methods in Applied Mechanics and Engineering	1726	Q1
18	Genetics and Molecular Research	47	Q4	18	Australian Journal of Botany	1672	Q3
19	International Journal of Electrical Power and Energy Systems	46	Q1	19	Ecology Letters	1442	Q1
20	Swarma and Evolutionary Computation	46	Q1	20	Administrative Science Quarterly	1414	Q1
21	Applied Sciences-Basel	45	Q2, Q3	21	International Journal of Electrical Power and Energy Systems	1390	Q1
22	Bmc Genomics	43	Q2	22	Astronomical Journal	1328	Q1
23	Neurocomputing	41	Q1	23	Biological Reviews	1308	Q1
24	Frontiers in Microbiology	40		24	Molecular Ecology	1294	Q1
25	European Journal of Operational Research	40	Q1	25	Genetics	1274	Q2
26	Computers and Industrial Engineering	40	Q1, Q2	26	Chemometrics and Intelligent Laboratory Systems	1235	Q1, Q2

Table 4: Distribution of the main subject areas (number of documents and citations) involved in the LA output in the field of evolutionary computation (1980-2020).

Subjects	Publications	%	Subjects	Citations	%
Computer Science	5722	20.9	Computer Science	61616	13.7
Engineering	4540	16.6	Engineering	52570	11.7
Environmental Sciences and Ecology	995	3.6	Astronomy and Astrophysics	29033	6.5
Operations Research and Management Science	775	2.8	Environmental Sciences and Ecology	27664	6.2
Science and Technology - Other Topics	745	2.7	Science and Technology - Other Topics	22539	5.0
Mathematics	723	2.6	Operations Research and Management Science	15100	3.4
Biochemistry and Molecular Biology	620	2.3	Genetics and Heredity	14162	3.2
Physics	593	2.2	Biochemistry and Molecular Biology	14033	3.1
Chemistry	586	2.1	Plant Sciences	12730	2.8
Genetics and Heredity	531	1.9	Evolutionary Biology	11595	2.6
Automation and Control Systems	519	1.9	Chemistry	11402	2.5
Astronomy and Astrophysics	485	1.8	Mathematics	9809	2.2
Zoology	482	1.8	Business and Economics	8818	2.0
Plant Sciences	475	1.7	Physics	8354	1.9
Energy and Fuels	472	1.7	Life Sciences and Biomedicine - Other Topics	7999	1.8
Mathematical and Computational Biology	460	1.7	Zoology	7205	1.6
Evolutionary Biology	439	1.6	Energy and Fuels	6389	1.4
Agriculture	384	1.4	Biotechnology and Applied Microbiology	6138	1.4
Business and Economics	373	1.4	Agriculture	6021	1.3
Telecommunications	371	1.4	Mechanics	5996	1.3
Life Sciences and Biomedicine - Other Topics	293	1.1	Automation and Control Systems	5449	1.2
Materials Science	280	1.0	Microbiology	5031	1.1
Biotechnology and Applied Microbiology	266	1.0	Pharmacology and Pharmacy	4802	1.1

Collaboration Patterns

Figure 3 depicts the collaboration network of authors for the LA production in this research field. It is easy to identify some of the leading authors in the network: Carlos Artemio Coello Coello, Oscar Castillo and Erik Cuevas from Mexico; Leandro dos Santos, Frederico G. Guimares and Ricardo Takahasi from Brazil; and Patricia Melin from Mexico. This map depicts the collaboration network of just 25 publications of the more representative authors in this research field. The color code indicates the different authors involved in the network and their connection to other authors.

We have included in Figure 4 the map corresponding to the LA collaboration with other countries. We have included for each country the number of papers published in this period, as well as the number of countries for each continent involved in the LA collaboration and the respective percentage. There is a high percentage (64%) of the number of publications published within the same LA countries. As expected, the countries with

an intense LA collaboration are Brazil, Mexico, Argentina, Chile and Colombia. The collaborations with Europe and North America contribute with 19% and 11%, respectively. There is a weak collaboration with Asia (3.4%). We include in Table 5 the list of countries of each continet involved in the LA collaboration in this research field. The countries wuth the largest number of publications with LA countries are USA, Spain, England, Germany, Italy, Portugal and China.

Distribution of academic institutions

Finally, in Table 6 we have included the LA academic instituions with the largest activity in this reserach field. Most of these institutions correspond to Brazil, Mexico, Argentina, Chile and Colombia, mainly public and privte universities, as well as research centers.[9] The lack of specific public policies in this reserach field has not promoved the creation of newe reserach groups in this field in other LA countries.[39]

Table 5: Scientific collaboration among LA countries and other continents (1980-2020).

No.	European (19.5%) Country	Collaboration by assignment direction	African (0.7%) Country	Collaboration by assignment direction	Asian (3.4%) Country	Collaboration by assignment direction	Latin American (64%) Country	Collaboration by assignment direction	North American (11%) Country	Collaboration by assignment direction	Oceania (1.2%) Country	Collaboration by assignment direction	European/Asian (0.2%) Country	Collaboration by assignment direction
1	Spain	2181	South Africa	132	Peoples R China	458	Brazil	15244	USA	4984	Australia	519	Russia	108
2	France	1580	Egypt	38	Japan	250	Mexico	6657	Canada	681	New Zealand	87	Georgia	3
3	England	1214	Kenya	18	India	205	Argentina	2807	Greenland	1	Papua N Guinea	6		
4	Germany	1031	Nigeria	17	Iran	120	Chile	2601			New Caledonia	4		
5	Italy	834	Morocco	16	South Korea	92	Colombia	1947			Fiji	2		
6	Portugal	568	Tunisia	15	Israel	86	Cuba	475						
7	Netherlands	327	Uganda	14	Saudi Arabia	71	Venezuela	429						
8	Belgium	254	Algeria	9	Taiwan	64	Ecuador	425						
9	Switzerland	231	Tanzania	8	Malaysia	59	Uruguay	332						
10	Scotland	194	Cameroon	7	Pakistan	40	Panama	177						
11	Sweden	185	Ghana	7	Turkey	39	Costa Rica	143						
12	Denmark	148	Mozambique	7	Singapore	33	Peru	105						
13	Austria	136	Dem Rep Congo	5	Thailand	28	Bolivia	53						
14	Finland	97	Eritrea	5	Vietnam	19	French Guiana	19						
15	Czech Republic	86	Madagascar	5	U Arab Emirates	17	Guatemala	19						
16	Poland	82	Senegal	5	Indonesia	16	Paraguay	17						
17	Norway	62	Zambia	5	Cyprus	12	Jamaica	15						
18	Greece	54	Zimbabwe	5	Philippines	12	Haiti	10						
19	Hungary	54	Angola	4	Bangladesh	10	Nicaragua	10						
20	Ireland	44	Benin	4	Kazakhstan	8	Dominican Rep	8						

No.	European (19.5%)		African (0.7%)		Asian (3.4%)		Latin American (64%)		North American (11%)		Oceania (1.2%)		European/Asian (0.2%)	
	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction	Country	Collaboration by assignment direction
21	Wales	39	Botswana	4	Lebanon	7	El Salvador	6						
22	Slovenia	35	Namibia	4	Iraq	6	Honduras	5						
23	Romania	33	Burkina Faso	3	Sri Lanka	6	St Kitts & Nevi	3						
24	North Ireland	29	Rwanda	3	Nepal	4	Suriname	2						
25	Luxembourg	27	Cape Verde	2	Cambodia	3	Bahamas	1						
26	Slovakia	22	Ethiopia	2	Jordan	3	Belize	1						
27	Lithuania	19	Malawi	2	Oman	3	Guyana	1						
28	Estonia	17	Cote Ivoire	1	Qatar	3	Trinidad Tobago	1						
29	Croatia	14	Gambia	1	Bhutan	1								
30	Bulgaria	10	Liberia	1	Brunei	1								
31	Latvia	7	Mali	1	Hong Kong	1								
32	Serbia	7	Mauritius	1	Myanmar	1								
33	Ukraine	7	Seychelles	1										
34	Iceland	6												
35	Malta	4												
36	Armenia	3												
37	Bosnia (BIH)	2												
38	Belarus	1												
39	Moldova	1												
40	Monaco	1												
Totals	9646		352		1678		31513		5666		618		111	

Table 6: Distribution of the research collaborations by LA institutions in the field of evolutionary computation (1980-2020).

Institutions	Publications	Country
Univ Sao Paulo (USP)	1594	Brazil
Univ Nacional Autónoma de México (UNAM)	1059	Mexico
Univ Estatal de Campinas (UNICAMP)	762	Brazil
Univ Fed Minas Gerais (UFMG)	760	Brazil
Centro de Investigacion y de Estudios Avanzados (Cinvestav)	686	Mexico
Univ Fed Rio de Janeiro UFRJ	590	Brazil
Univ Fed Rio Grande do Sul UFRGS	451	Brazil
Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)	449	Argentina
Instituto Politecnico Nacional (IPN)	391	Mexico
Univ Chile	384	Chile
Univ Fed Parana (UFPR)	374	Brazil
Univ Fed Pernambuco (UFPE)	361	Brazil
Univ Estado Paulista (UNESP)	360	Brazil
Univ Fed Rio Grande do Norte (UFRN)	342	Brazil
TecNM-IT Tijuana	340	Mexico
Univ Buenos Aires	333	Argentina
Instituto Tecnologico de Estudios Superiores Monterrey ITESM)	319	Mexico
Univ Brasilia	304	Brazil
Univ Nacl Colombia	297	Colombia
Pontificia Univ Catolica Chile	293	Chile
Pontificia Univ Catolica Parana	292	Brazil
Univ Fed Goias (UFG)	292	Brazil
Univ Fed Uberlandia (UFU)	261	Brazil
Univ Fed Santa Catarina (UFSC)	254	Brazil
Univ Fed Vicosa	230	Brazil
Univ Estado Rio de Janeiro (UERJ)	225	Brazil
Pontificia Univ Catolica Rio de Janeiro	224	Brazil
Univ Fed Sao Carlos (UFSCAR)	219	Brazil
Universidad de Guadalajara (UdeG)	215	Mexico
Univ Nacl La Plata (UNLP)	208	Argentina
Fdn Oswaldo Cruz (Fiocruz)	203	Brazil
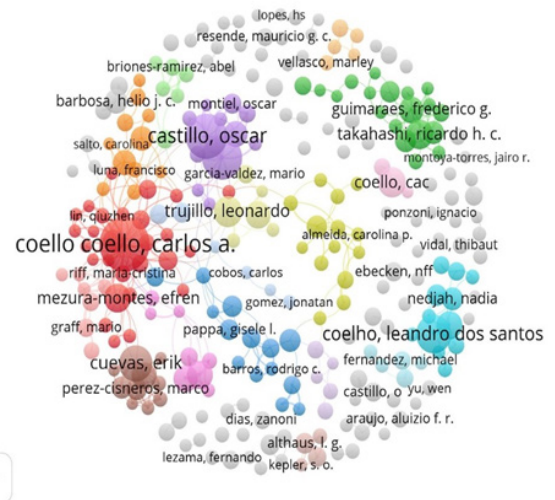
Figure 3: Research network of authors for the LA production in the field of evolutionary computation (1980-2020).
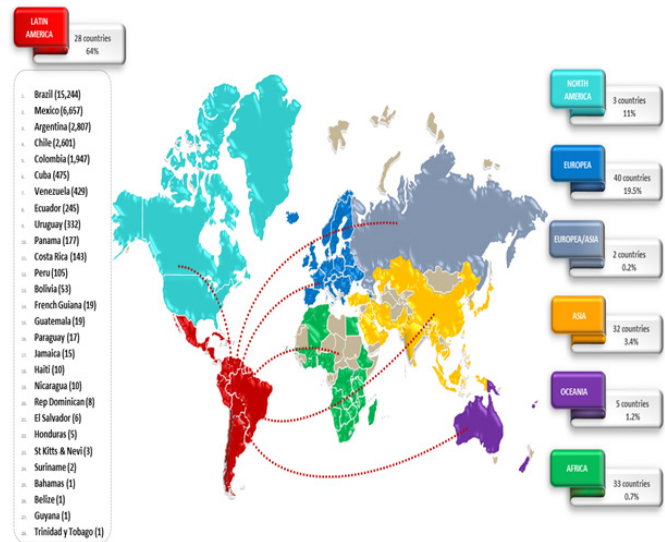
Figure 4: Collaboration map by LAcountry in the field of evolutionary computation (1980-2020).

DISCUSSION AND CONCLUSION

The scientific activity in LA has been scarce compared with the research production in developed countries.[38] Some authors have emphasized that this situation involves two factors: (1) there is a low investment in science and technology in most of the LA countries, and (2) the research infrastructure is deficient with a very low number of active researchers.[40-42] Even more, the LA governments and enterprises prefer to buy new technology instead of promoving the research activity within their own countries.[43]

In this context, it is impressive the research activity carried out in some LA countries like Brazil, Mexico, Argentina, Chile and Colombia, in the field of evolutionary computation. Most of this activity has been developed with international collaborators[41]

with an impressive number of publications that have also generated a great deal of citations. In LA, this research field has been recognized as a frontier subject within a transdisciplinary approach.[11] Our findings indicate that there is a steady growth of publications and citations in this research field. This output became important since the 1990s, 30 years after the first publications in this field appeared in mainstream journals. The consolidation of this research field is evident since the year 2000 with a large number of scholars and institutions active in several LA countries.[42] The LA academic institutions, like universities and research centers, have been the most productive in subject areas like genetic algorithms, metaheuristics, neural networks, epidemiology, education research, star formation, and others.

Several public policies have boosted this area of knowledge. In particular, the Union of South American Countries (UNASUR) have contributed to improve the scientific activity in this geographical region.[43] Some areas of knowledge have received increasing attention since 1990, in particular the social studies of science, computational sciences, and the applications of technological infrastructure.[44] The research in computational sciences has been supported traditionally by some LA governments as a tool to improve the economic growth, as it has been the case in developed countries.[45] Blandon has emphasized that the academic communities should make a better effort in improve the industrial progress in each country. This is particularly true in the case of evolutionary computation in the software and hardware sectors.

To summarize our results, it was found that there are very few analyses of the LA production on evolutionary computation. In the present work we have used the bibliometric method in order to determine the evolution of this research field. However, there are some other aspects of this research field that need to be analyzed such as the characterization of graduated programs. Finally, our findings indicate there is an impressive increase in the number of publications in this research field, and in our opinion a question is relevant: Is there enough infrastructure in LA in order to attend this pattern?

ACKNOWLEDGEMENT

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

1. Bourdieu P. El campo científico. Redes: revista de estudios sociales de la ciencia. 1994;1(2):129-60.

2. Bourdieu P. Las formas de capital. En: JG Richardson (Ed.), el Manual de la teoría y la investigación para la sociología de la educación. Nueva York: Green Wood Press; 1994. p. 241-58.

3. Bourdieu P. El oficio del científico: ciencia de la ciencia y reflexividad / Curso del College de France 2000-2001 (Traducción de Jouaquín Jordá). Barcelona: Anagrama; 2003. p. 1-12.

4. Merton RK. La sociología de la ciencia: investigaciones teóricas y empíricas. Recopilación e introducción de Norman W. Storer. Madrid: Alianza Editorial; 1973.

5. Zucker LG. Institutional theories of organization. Annual Review of Sociology. 1987;13:443-64. https://www.jstor.org/stable/2083256

6. Fagerberga J, Verspagen B. Innovation studies. The emerging structure of a new scientific field. Research Policy. 2009;38(2):218-33.

7. Guarido-Filho ER, Machado da Silva C, Rossoni L. The social and intellectual dimensions in the construction of scientific knowledge: the institutional theory in organization studies in Brazil. BAR. Curitiba. 2010;7(2):136-54.

8. Tomás-Górriz, V. y Tomás-Casterá, V. La Bibliometría en la evaluación de la actividad científica. Hospital a Domicilio. 2018;2(4): 145-63. DOI:10.22585/hospdomic.v2i4.51.

9. Espinosa, M Alexandra C; Romero, Efrén R; Flórez, Leidy Y G; Guerrero, Cesar D. Revista Ibérica de Sistemas e Tecnologias de Informação. 2020;1137(28):110-22.

10. Santana-Quintero L, Coello-Coello, CA. Una introducción a la computación evolutiva y algunas de sus aplicaciones en economía y finanzas. Revista de Métodos Cuantitativos para la economía y la empresa. 2006;2:3-26.

11. Coello-Coello C.A. Introducción a la computación evolutiva. En: Coello Coello, Carlos Artemio (Ed). Computación Evolutiva. 2da ed. México: Academia Mexicana de Computación; 2019. http://delta.cs.cinvestav.mx/~ccoello/compevol/tarea5-2018.pdf

12. Rojas MG, Olivera AC, Carballido, JA, Vidal PJ. A Memetic Cellular Genetic Algorithmfor Cancer Data Microarray Feature Selection. IEEE latin America Transactions.2020;18(11):1874-1883. https://ieeexplore.ieee.org/abstract/document/9398628

13. Pineda-Cortés LA. La computación en México por especialidades académicas. México: Academia Mexicana de Computación; 2017. p. 297.

14. Melián-Batista B, Moreno-Pérez JA, Moreno-Vega JM. Introducción a la computación evolutiva. Números, Revista de Didáctica de las Matemáticas. 2009;71:21-27. https://1library.co/document/q73l5eny-introduccion-computacion-evolutiva-numeros-revista-didactica-matematicas.html

15. Fraser AS. Simulation of Genetic Systems by Automatic Digital Computers I. Introduction. Australian Journal of Biological Sciences. 1957a;10(4):484-91. https://doi.org/10.1071/BI9570484

16. Fraser AS. Simulation of Genetic Systems by Automatic Digital Computers II. Effects ofLinkage on Rates of Advance Under Selection. Australian Journal of Biological Sciences. 1957b;10(4):150-62. https://doi.org/10.1071/BI9570492

17. Fogel DB. Evolutionary Computation. The Fossil Record. Selected Readings on the History of Evolutionary Algorithms. New York; 1998.

18. Bremermann HJ. Optimization through evolution and recombination. In M. C. Yovits, G. T. Jacobi and G. D. Goldstein (Eds.). Self-Organizing Systems. Washington DC: Spartan Books; 1962. p. 93-106. http://www-public.int-evry.fr/~gibson/Teaching/CSC4504/ReadingMaterial/Bremermann62.pdf

19. Afonso AR. Brazilian Portuguese Text Clustering Based on Evolutionary Computing. IEEE Latin America Transactions. 2016;14(7):3370-7.

20. Rincón J. Aplicación de algoritmos genéticos en la optimización del sistema de abastecimiento de agua de Barquisimeto-Cabudare. Avances en Recursos Hidráulicos. 2006;14:25-38. https://www.redalyc.org/pdf/1450/145020399002.pdf

21. Velez-Langs O, Santos C. Sistemas Recomendadores: Un enfoque desde los algoritmos genéticos. Industrial Data. 2006;9(1):23-31.

22. https://www.redalyc.org/pdf/816/81690104.pdf

23. Rodríguez MP, Cortes KA, Méndez AB, Garza HH. Análisis de portafolio por sectores mediante el uso de algoritmos genéticos: caso aplicado a la Bolsa Mexicana de Valores Sectorial portfolio analysis with genetic algorithms: case applied to the Mexican Stock Exchange. Contaduría y Administración. 2015;60(1):87-112.

24. Suárez V, Guerreo A, Castrillón O. Programación de Horarios Escolares basados en Ritmos Cognitivos usando un Algoritmo Genético de Clasificación No-dominada, NSGA-II / Scheduling of School Hours based on Cognitive Rhythms using a Non-dominated Sorting Genetic Algorithm, NSGA-II. Información tecnológica. 2013; 24(1):103-114.https://dx.doi.org/10.4067/S0718-07642013000100012

25. Borges-Vasconcellos D, Puch-González P, Frías-González G. Control de demanda eléctrica aplicando algoritmos genéticos / Control of electric demand applying genetic algorithms. Ingeniare. Revista chilena de ingeniería. 2017;25(3):389-398. http://dx.doi.org/10.4067/S0718-33052017000300389

26. Delgado E, Cortés CJ, Duarte O. Aplicación de algoritmos genéticos para la programación de tareas en una celda de manufactura. Ingeniería e Investigación. 2005;25(2):24- 31. http://polipapers.upv.es/index.php/RIAI/article/view/9257/9280

27. Schab E, Rivera R, Bracco L, Coto F, Cristaldo P, Ramos L, Rapesta N, Nuñez J.P, Retamar S, Casanova C, De Battista A. Minería de datos y visualización de información. InXX Workshop de Investigadores en Ciencias de la Computación (WICC 2018, Universidad Nacional del Nordeste), 2018. http://sedici.unlp.edu.ar/bitstream/handle/10915/67382/Documento_completo.pdf-PDFA.pdf?sequence=1

28. Tinós R. Artificial neural network based crossover for evolutionary algorithms. Applied Soft Computing. 2020;95:106512. https://doi.org/10.1016/j.asoc.2020.106512

29. Cruz-Salinas AF, Perdomo JG. Self-adaptation of genetic operators through genetic programming techniques. In: Proceedings of the Genetic and Evolutionary Computation Conference 2017;913-920. DOI: 10.1145/3071178.3071214

30. Zenil-Chávez H. Computación ecolutiva y sistemas complejos adaptativos: la sopa primigenia de las conductas inteligentes emergentes. Ciencia. 2005; abril-junio: 70-81.

31. Marrero A, Segredo EY, León C. Combinación de computación evolutiva y aprendizaje automatizado en la resolución de problemas de optimización. In: Conference: Doctoral Consortium (october 2018, Granada, CAEPIA). 2018:1-7.

32. Osorio CO, Vanegas ET, Valencia-Arias A. Inteligencia de negocios en el sector agrario: un análisis bibliométrico. En: Diálogos de Ciencias Sociales, Económicas y Administrativas: Perspectivas, tendencias y retos. 2020. Bogotá: Universidad de Asturias, Pp. 142-54.

33. Shen L, Xiong B, Li W, Lan F, Evans R, Zhang W. Visualizing Collaboration Characteristics and Topic Burst on International Mobile Health Research: Bibliometric Analysis. JMIR Mhealth Uhealth. 2018;6(6):e135. doi: 10.2196/mhealth.9581. PMID: 29871851; PMCID: PMC6008511.

34. Raza B, Ahmad R, Nasir MH, Fauzi SS. Socio-Technical Congruence as an Emerging Concept in Software Development: A Scientometric Analysis and Critical Literature Review. 2021. IEEE Access, 9: 129051-129077. 10.1109/ACCESS.2021.3113637

35. De Lorenzo A, Bartoli A, Castelli M, Medvet E, Xue B. Genetic programming in the twenty-first century: a bibliometric and content-based analysis from both sides of the fence. Genetic Programming and Evolvable Machines. 2020;21:181-204.

36. Paul J, Criado AR. The art of writing literature review: ¿What do we know and what do we need to know? International Business Review. 2020;29(4):101717. https://doi.org/10.1016/j.ibusrev.2020.101717

37. Paul J, Lim WM, O'Cass A, Hao AW, Bresciani S. Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR4-SLR). International Journal of Consumer Studies, 2021;45(5):1147-62. https://doi.org/10.1111/ijcs.12695

38. Albornoz M. Desarrollo y políticas públicas en ciencia y tecnología en América Latina. Revista de Investigaciones Políticas y Sociológicas. 2009;8(1):65-75. https://www.redalyc.org/pdf/380/38011446006.pdf

39. Valles M del C, Jasso J, Nuñez I. (Coords). Ciencia, tecnología, innovación y desarrollo. México: FCE: UNAM; 2016. 214 p.

40. Quintanilla-Montoya AL. La ciencia y su producción de conocimiento en América Latina. Investigación Ambiental. 2010;2(1):83-91. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7587644 https://www.sciencedirect.com/science/article/pii/S0186104215721480

41. Cepeda-Ávila KS, Pazmiño-Iturralde L, Medrano-Freire E. Evolución de la Investigación Científica en América Latina. Revista Científica Mundo de la Investigación y el Conocimiento. 2018;2(2):464-476. DOI: 10.26820/recimundo/2. 2018;(2):464-76.

42. Kreimer P, Vessuri H. Latin American science, technology, and society: a historical and reflexive approach. Tapuya: Latin American Science, Technology and Society. 2018;1(1):17-37. DOI: 10.1080/25729861.2017.1368622

43. Lemarchand GA. Scientific productivity and the dynamics of self-organizing networks: Ibero-American and Caribbean Countries (1966–2013). En: M. Heitor, H. Horta and J. Salmi (eds.), Trends and Challenges in Science and Higher Education. 2016;3:29-46. https://link.springer.com/content/pdf/10.1007/978-3-319-20964-7.pdf

44. Lozano M. El nuevo contrato social sobre la ciencia: retos para la comunicación de la ciencia en américa latina. Razón y Palabra. 2008;65(13):1-19. https://www.redalyc.org/pdf/1995/199520724009.pdf

45. Blandón JC. Tendencias en ciencias de la computación. Entre Ciencia e Ingeniería. 2021;14(27):19-28. https://doi.org/10.31908/19098367.0002