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30th Anniversary of *Applied Intelligence*: A combination of bibliometrics and thematic analysis using *SciMAT*

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Abstract *Applied Intelligence* is one of the most important international scientific journals in the field of artificial intelligence. From 1991, *Applied Intelligence* has been oriented to support research advances in new and innovative intelligent systems, methodologies, and their applications in solving real-life complex problems. In this way, *Applied Intelligence* hosts more than 2,400 publications and achieves around 31,800 citations. Moreover, *Applied Intelligence* is recognized by the industrial, academic, and scientific communities as a source of the latest innovative and advanced solutions in intelligent manufacturing, privacy-preserving systems, risk analysis, knowledge-based management, modern techniques to improve healthcare systems, methods to assist government, and solving industrial problems that are too complex to be solved through conventional approaches. Bearing in mind that *Applied Intelligence* celebrates its 30th anniversary in 2021, it is appropriate to analyze its bibliometric performance, conceptual structure, and thematic evolution. To do that, this paper conducts a bibliometric performance and conceptual structure analysis of *Applied Intelligence* from 1991 to 2020 using *SciMAT*. Firstly, the performance of the journal is analyzed according to the data retrieved from *Scopus*, putting the focus on the productivity of the authors, citations, countries, organizations, funding agencies, and most relevant publications. Finally,

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the conceptual structure of the journal is analyzed with the bibliometric software tool *SciMAT*, identifying the main thematic areas that have been the object of research and their composition, relationship, and evolution during the period analyzed.

Keywords Science mapping · Journal conceptual structure · Artificial intelligence · Intelligent systems · Applied intelligence · *SciMAT*

1 Introduction

Today, scientific and academic journals are one of the main sources of innovative information, being considered as good vehicles to disseminate and communicate the results of research, projects, and studies. Furthermore, they result in the visibility of the authors and organizations, thus becoming a core mechanism to evaluate these researchers and organizations in terms of their line of research or field of knowledge. Lastly, journals are a prioritized object of study in bibliometric research [20, 26].

In research whose object of examination is academic or scientific journals, there are three main approaches: (i) methodologies and techniques for bibliometric analysis [12, 15, 27], (ii) bibliometric performance analysis of production and authorship [11, 22, 25], and (iii) bibliometric thematic analysis [10, 17, 21, 28]. Additionally, two secondary methods can be added: (a) research focused on in-depth analysis of a single journal [5, 14], and (b) research that analyzes several journals or a significant group of them within a discipline or field of knowledge [13].

In this regard, this paper conducts a bibliometric analysis of authorship, production, and thematic analysis of *Applied Intelligence* (*APIN*), with the particularity that it covers the background of the journal in three periods: 1991–2005, 2006–2015, and 2016–2020.

According to the *APIN* website, "*The international journal of Applied Intelligence (APIN) provides a medium for publishing scientific research and technological achievements accomplished by the international community. The focus of the journal is towards research advances on new and innovative intelligent systems' methodologies and their applications in solving real life complex problems.*". Additionally, the main research areas covered by *APIN* journal are *natural language and speech interfaces, intelligent robotics, learning methodologies, intelligent decision support systems, evolutionary computing, genetic programming, heuristic methods, intelligent searching, agents, optimization, neural networks, mining data and patterns, cognitive interaction, knowledge-based reasoning, modeling, planning and scheduling, classification and clustering, computer vision, fuzzy logic and control*, among others.

Bearing in mind that *Applied Intelligence* celebrates its 30th anniversary in 2021, it is appropriate to analyze its bibliometric performance, conceptual structure, and thematic evolution. This will allow the establishment of a stronger framework for future research strategies and to support the continuity of some research themes [30].

Consequently, the main aim of this paper is to evaluate the evolution of *Applied Intelligence* (*APIN*) from 1991 to 2020 by conducting a bibliometric analysis of authorship and production, emphasizing the identification of the core research themes and their relationship and components by means of a science mapping analysis [2] using *SciMAT* [7]. Furthermore, a science mapping analysis grouping the identified research themes is presented, establishing a reference framework for researchers and future research based on bibliometric networks [1].

Finally, this paper is structured as follows: Section 2 deals with the methodology of the bibliometric analysis, including the dataset. Section 3 shows the performance bibliometric analysis including the main authors, countries, publication, organizations, and funding agencies. Moreover, Section 4 presents a content analysis of *APIN* publications, in three ways: strategic diagrams, thematic networks, and thematic evolution. Finally, Section 5 summarizes the main findings and conclusions about the research conducted in *APIN*.

2 Methodology and dataset

Bibliometric methods are one of the most common and accepted strategies for analyzing the output of basic research. Such methods are increasingly valued as a tool for measuring scientific quality, impact, productivity, and evolution [12, 15, 29].

2.1 Methodology

A specific methodology had been applied to evaluate the performance, conceptual structure, and thematic evolution of the journal, considering the most relevant publications and its impact. It also assesses its performance through analysis of the main bibliometric indicators.

The methodology developed is composed of two parts: bibliometric performance analysis and science mapping analysis. Firstly, performance analysis is based on bibliometric indicators that measure authors' production and the impact achieved. Additionally, the most-cited articles of the journal are identified using the H-Classics approach, which is based on the h-index [15, 18]. Secondly, a conceptual science mapping analysis based on a co-words network [3, 9] is developed using *SciMAT* [7, 24].

Although there are various software tools for analyzing science mapping analysis [2, 6], *SciMAT* was used because it supports the analysis from different approaches: bibliometric performance analysis, strategic diagram, thematic network, and thematic area [7, 24]. The bibliometric methodology used in this paper identifies four phases of analysis within a specified period [8]:

- **Detection of research themes**. For each of the periods analyzed, the research themes are detected by applying a clustering algorithm [9, 19] over a normalized co-words network [4].
- **Visualizing research themes and the thematic networks**. The research themes detected are categorized based on their centrality and density rank values using two specific tools: the strategic diagram and thematic network [3, 16]. Centrality (c) measures the degree of interaction of a network with other networks, and density (d) measures the internal strength of the network. By considering both types of measures, a research field can be visualized as a set of research themes and plotted on a two-dimensional strategic diagram (Figure 1 (a)). Therefore, four types of research themes can be identified [8]:
  - Motor themes (quadrant 1, Q1): The themes within this quadrant are relevant for developing and structuring the research field. They are known as the motor themes of the field, given that they present strong centrality and high density.
  - Highly developed and isolated themes (quadrant 2, Q2): These are strongly related, highly specialized, and peripheral, but they do not have the appropriate background or importance for the field.
  - Emerging or declining themes (quadrant 3, Q3): These themes are relatively weak and have low density and centrality. They mainly represent either emerging or disappearing themes.

  – Basic and transversal themes (quadrant 4, Q4): These themes are relevant for the field of research but are not well developed. This quadrant contains transverse and general basic themes.
- **Discovery of thematic areas**. The research themes are analyzed using an evolution map (Figure 1 (c)), which links the themes of a consecutive period that maintains a conceptual nexus (keywords in common).
- **Performance analysis**. The relative contribution of each research theme and thematic area to the entire field of research is measured quantitatively and qualitatively. It is used to establish the most productive and relevant areas within the field.

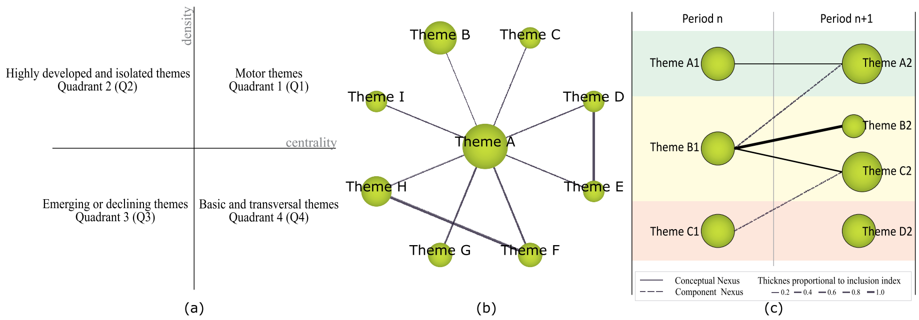

Fig. 1 (a) Strategic diagram, (b) thematic network, and (c) thematic evolution

In addition to the science mapping analysis, the present study seeks to identify the citation classics. For this purpose, the concept of H-Classics proposed by Martínez et al. [23] was used. Therefore, H-Classics is defined as follows: "*H-Classics of a research area 'A' could be defined as the H-core of 'A' that is composed of the 'H' highly cited papers with more than 'H' citations received*" [23].

2.2 Dataset

To collect the raw data of *Applied Intelligence* (*APIN*), *Scopus* was employed as a database since it covers the journal completely across all the years. Thus, the following advanced query was used:

```
ISSN ("1573-7497" OR "0924-669X") AND (LIMIT-TO(DOCTYPE, ‘‘ar’’) OR
LIMIT-TO(DOCTYPE, ‘‘cp’’) OR LIMIT-TO(DOCTYPE, ‘‘re’’))
```

This query retrieved a total of 2,438 publications (articles and reviews) from 1991 to 2020. Furthermore, citations of these publications were also analyzed; these were counted up to 28 December 2020.

In this context, the *APIN* publications were downloaded as plain text and imported into *SciMAT* software to build the knowledge base for science mapping analysis. Thus, the bibliographic information stored by *Scopus* (authors, affiliations, abstract, keywords, date of publication, citations achieved, and references, among others) was saved for each publication, which allows analysis of the data, identification of relationships and, consequently, better results in the analysis of the science maps. In addition, to guarantee and improve the quality of the raw data, a revision process was applied, analyzing, correcting, and merging the concepts that have the same meaning or represent the same idea (i.e., “SUPPORT-VECTOR-MACHINE”, “SUPPORT-VECTOR-MACHINE-(SVM)” and “SVM-SUPPORT-VECTOR-MACHINE” were merged as “SUPPORT-VECTOR-MACHINE”).

As a next step, the *SciMAT* period manager was used to avoid data flatness. The best approach when analyzing the evolution of the data is to evaluate it year by year, but on occasion it is advisable to group them in periods in order to generate a sufficient amount of publications for analysis. In this case, the best option was to divide the time span into three comparable periods. Therefore, the whole period (1991–2020) was split into 1991–2005, 2006–2015, and 2016–2020, with 421, 696, and 1,321 publications, respectively.

3 Bibliometric performance analysis of *APIN*

This section evaluates the bibliometric performance of *APIN* journal in terms of publication, citations, and impact. The bibliometric performance analysis is structured into four sections: (i) whole production and impact of published documents; (ii) production of authors, countries, organizations, and funding agencies; (iii) H-Classics analysis; and (iv) content analysis of the publications by means of science mapping analysis.

3.1 Impact, publications, and citations

The impact achieved by *Applied Intelligence* (*APIN*) journal on *Scopus* and *Web of Science* from 1991 to 2020 is presented in Table 1. Furthermore, the position (quartile) in the Artificial Intelligence research category is included. It is important to highlight that the evolution of the impact factor of *APIN* journal has been very positive, positioning this journal among most relevant journals in the Artificial Intelligence category.

In this regard, Figure 2 shows the distribution of publications per year achieved by *APIN* journal during the period 1991–2020. Since the first year, three milestones in the development of the journal can be observed. The first milestone considers the first historical maximum in terms of annual publications after a period of growth of three consecutive years (2012). The second milestone is related to the newer maximum of number of publications after a period of growth of three consecutive years (2018), and the third corresponds to the historical maximum achieved by the journal (2020). It is important to highlight that these milestones duplicate the production of publications and maintain this level in the following years.

Moreover, Figure 3 shows the distribution of citation count achieved by those publications from 1991 to 2020 according to *Scopus*. Until 2014, the pattern of citations received by year is positive with a lower growth rate than in subsequent years, achieving in the last year around 2,000 citations. In this connection, from 2015, when around 1,500 citations are reached, the citations received have increased constantly until reaching around 6,500 citations in 2020, with a higher growth rate than in previous years. Therefore, it could be predicted that citation count will continue improving in the coming years.

The number of publications and citation distribution showed a positive growth trend from 1991 to 2020. During this period, a total of 31,855 citations (including self-citations) were achieved, and the average citation count per publication is 13.06.

Table 1 *APIN* journal impact factor

Year	Scopus (SJR)			Web of Science (JCR)		
1991	n/a	n/a	n/a	n/a	n/a	n/a
1992	n/a	n/a	n/a	n/a	n/a	n/a
1993	n/a	n/a	n/a	n/a	n/a	n/a
1994	n/a	n/a	n/a	n/a	n/a	n/a
1995	n/a	n/a	n/a	n/a	n/a	n/a
1996	n/a	n/a	n/a	n/a	n/a	n/a
1997	n/a	n/a	n/a	0.268	Q3	▲
1998	n/a	n/a	n/a	0.326	Q3	▲
1999	0.236	Q3	▲	0.291	Q3	▼
2000	0.231	Q3	▼	0.420	Q3	▲
2001	0.380	Q3	▲	0.493	Q3	▲
2002	0.422	Q3	▲	0.686	Q2	▲
2003	0.520	Q2	▲	0.776	Q3	▲
2004	0.344	Q3	▼	0.477	Q4	▼
2005	0.304	Q3	▼	0.569	Q3	▲
2006	0.287	Q3	▼	0.329	Q4	▼
2007	0.349	Q3	▲	0.500	Q4	▲
2008	0.366	Q3	▲	0.775	Q4	▲
2009	0.416	Q3	▲	0.988	Q3	▲
2010	0.517	Q2	▲	0.893	Q3	▼
2011	0.477	Q2	▼	0.849	Q3	▼
2012	0.726	Q2	▲	1.853	Q2	▲
2013	0.865	Q2	▲	n/a	n/a	n/a
2014	1.014	Q1	▲	n/a	n/a	n/a
2015	0.618	Q2	▼	1.215	Q3	▲
2016	0.649	Q2	▲	1.904	Q2	▲
2017	0.600	Q2	▼	1.983	Q2	▲
2018	0.651	Q2	▲	2.882	Q2	▲
2019	0.726	Q2	▲	3.325	Q2	▲

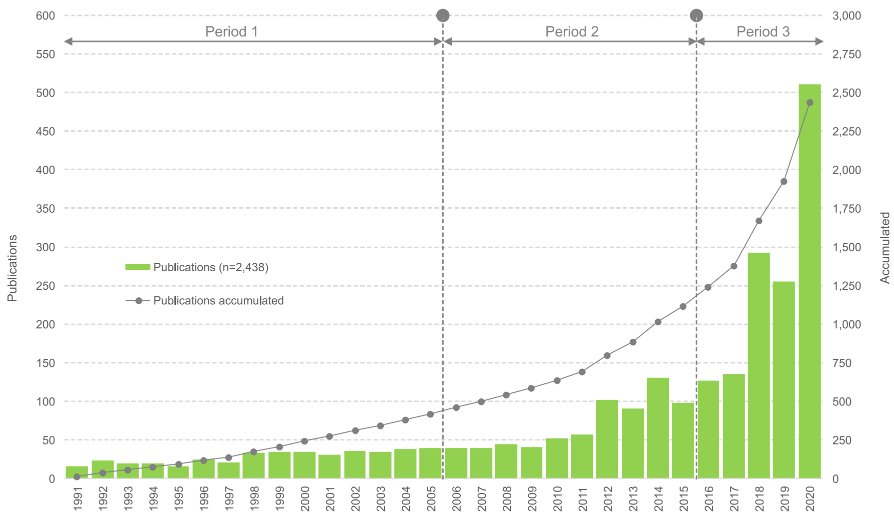

Fig. 2 Distribution of publications by year from 1991 to 2020

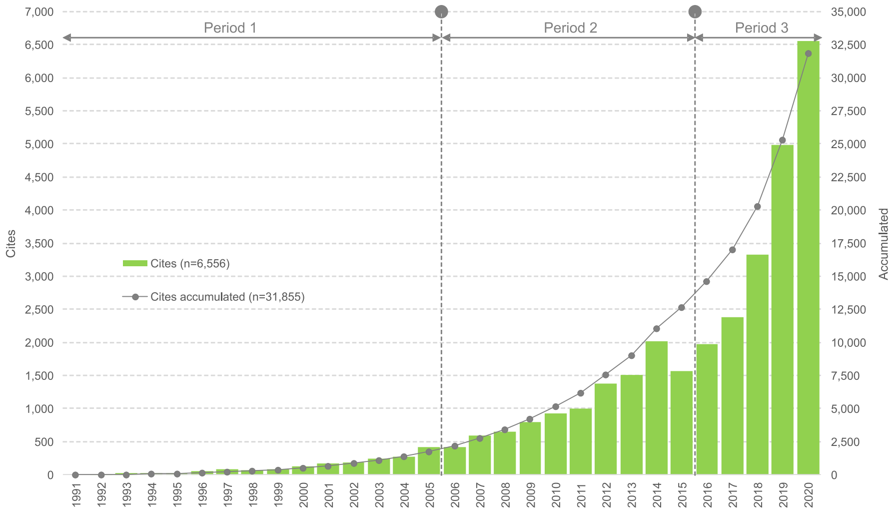

Fig. 3 Distribution of citations by year from 1991 to 2020

3.2 Most productive and cited authors, geographic distribution of publications, organizations, and research areas

To understand the *APIN* journal evolution, it is also important to know which are the most productive and cited authors, their geographic distribution, affiliation, and funding agencies.

Table 2 presents the most productive and most cited authors during the whole period 1991–2020. There was a tie in some positions between various authors, thus all of them have been included in alphabetical order. It is important to mention that only three of the most productive authors are among the most cited authors: Hong, T.-P. (15 publications and 409 citations), Deng, Y. (10 publications and 436 citations), and Garg, H. (10 publications and 442 citations). This situation reflects two scenarios, the first one related to most productive authors and the second to most cited authors. Both scenarios promote the growth and development of the field and the journal.

In terms of internationalization, *APIN* has the participation of 77 countries from five continents, shown in Figure 4. Among the most productive countries, a balance can be observed between European, Asian, and American countries, strengthening the international impact of the *APIN* journal. This fact also coincides with the performance presented by the most productive organizations. During the whole period 1991–2020, China appears as the most productive country, with 814 publications, followed by the United States and India, with 274 and 213 publications, respectively. In this way, the most productive organizations were *Ministry of Education China*, *Harbin Institute of Technology*, *Shandong Normal University*, *Kyung Hee University*, and *Amirkabir University of Technology* (Table 3). Consequently, Asian and American funding agencies where the most involved in the journals, as is apparent from Table 4.

Bearing in mind the previous results, the most relevant authors, countries, organizations, and publications are analyzed below in terms of citations according to the h-index and H-Classics.

Table 2 Most productive and most cited authors (1991–2020)

Publications	Author(s) (Cites)	Citations	Author(s) (Publications)
16	Meybodi, M.R. (290)	716	Mirjalili, S. (6)
15	Hong, T.-P. (409)	450	Kononenko, I. (4)
14	Lee, S. (398)	442	Garg, H. (10)
13	Fournier-Viger, P. (172); Vo, B. (143)	436	Deng, Y. (10)
12	Dai, Q. (74); Wu, X. (164)	409	Hong, T.-P. (15)
11	Alhajj, R. (262); Lee, Y.-K. (241); Lin, J.C.-W. (100); Treur, J. (87); Xu, Y. (183)	402	Robnik-Šikonja, M (1); Šimec, E. (1)
10	Deng, Y. (436); Ding, S. (126); Fujita, H. (168); Garg, H. (442); Granmo, O.-C. (142)	398	Lee, S. (14)
9	Cuevas, E. (255); Jia, W. (119); Qu, R. (221)	340	Ross, B.J. (4)
8	Chen, L. (133); Jonker, C.M. (75); Kim, M. (33); Lee, H.-M. (93); Oommen, B.J. (88); Yang, C. (77); Yazidi, A. (38)	321	Wang, X. (6)
7	Djenouri, Y. (26); Le, B. (77); Ma, Z.M. (64); Maldonado, S. (45); Obeid, N. (74); Saha, S. (56); Singh, A. (46); Son, L.H. (247)	308	Aljarah, I. (4)

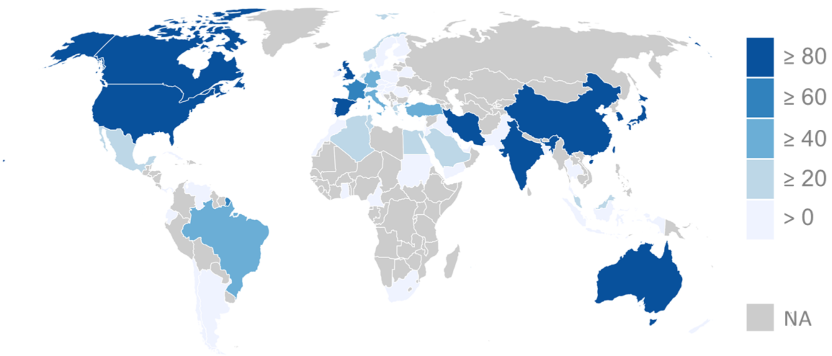

Fig. 4 World map of most productive countries (1991–2020)

3.3 Most relevant publications, authors, countries, and organizations

The H-Classics method [23], based on the well-known h-index [18], serves as an impartial criterion to systematize the identification of the classic papers of any research field. This method is used to determine the classic papers in the *APIN* journal, understood as those that

Table 3 Most productive countries and organizations (1991–2020)

Publications	Country(ies)	Publications	Organization(s) Publications
814	China	44	Ministry of Education China
274	United States	32	Harbin Institute of Technology
213	India	30	Shandong Normal University
140	Iran	28	Kyung Hee University
132	South Korea	27	Amirkabir University of Technology
125	Spain	26	China Agricultural University
121	United Kingdom	23	Northeastern University (China); Nanjing University
119	Taiwan	21	Hefei University of Technology; Nanjing University of Aeronautics and Astronautics; Sichuan University
107	Canada	20	Institute of Electrical and Electronics Engineers (IEEE)
85	Australia	18	Central South University; Chongqing University; Universidad Carlos III de Madrid

Table 4 Most productive funding agencies (1991–2020)

Publications	Funding agencies
468	National Natural Science Foundation of China (China)
75	Fundamental Research Funds for the Central Universities (China)
37	National Research Foundation of Korea (South Korea)
26	National Science Foundation (United States)
25	Natural Sciences and Engineering Research Council of Canada (Canada)
24	China Postdoctoral Science Foundation (China)
21	Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brasil); Natural Science Foundation of Jiangsu Province (China)
20	Ministerio de Ciencia e Innovación (Spain); Natural Science Foundation of Shandong Province (China)
19	Japan Society for the Promotion of Science (Japan); National Science Council (Taiwan)
17	Engineering and Physical Sciences Research Council (United Kingdom); National Basic Research Program of China (973 Program) (China)

have attracted a high citation rate, and therefore, identify the authors, countries, organizations, and funding agencies that have contributed the most.

The corpus obtained from the *Scopus* database has an h-index of 67. Using this h-index score as a reference, the relevant publications were identified and are listed in Appendix A, Table 10. In terms of citations, its distribution showed a positive developmental trend. Thus, a total of 7,793 citations (including self-citations) were recorded, and the average citation count per cited article is 116.31. Thus, the distribution of the most relevant publications and the total number of citations for the *APIN* journal from 1991 to 2020 is shown in Figure 5.

The main authors are Mirjalili, S. (four publications), Aljarah, I. (two publications), Cho, S.B. (two publications), Cordón, O. (two publications), Cuevas, E. (two publications), Deng, Y. (two publications), Faris, H. (two publications), Garg, H. (two publications), Saremi, S. (two publications), Setiono, R. (two publications), Zhang, S. (two publications), and Zhou, Z.H. (two publications). It should be highlighted that Mirjalili, S., Deng, Y., and Garg, H.

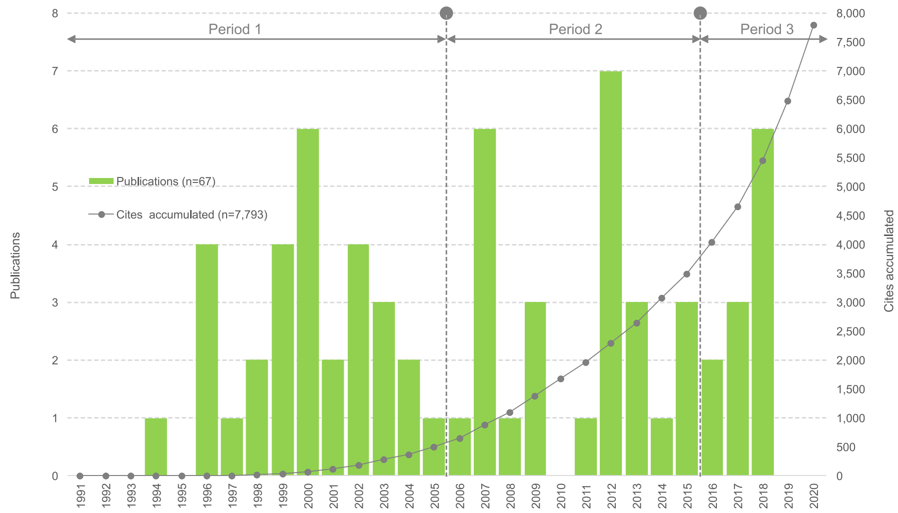

Fig. 5 Distribution of most cited publications by year from 1991 to 2020

are consistent in both sections, viz. the most productive and cited authors and most relevant authors.

With regard to production by countries, China (12 publications), the United States (9 publications), Australia (6 publications), Germany (6 publications), Spain (5 publications), the United Kingdom (5 publications), Canada (4 publications), Mexico (4 publications), South Korea (4 publications), France (3 publications), India (3 publications), Japan (3 publications), Jordan (3 publications), Malaysia (3 publications), Slovenia (3 publications), Taiwan (3 publications), Egypt (2 publications), Italy (2 publications), and Singapore (2 publications) are the most productive countries in terms of most relevant publications.

Furthermore, the most productive organizations identified in this section are *Griffith University* (four publications), *Brock University* (three publications), *Northwestern Polytechnical University* (three publications), *Nanjing University* (three publications), *Institute of Electrical and Electronics Engineers, IEEE* (two publications), *Thapar Institute of Engineering & Technology* (two publications), *Universität Leipzig* (two publications), *Universidad de Guadalajara* (two publications), *Cairo University* (two publications), *University of Nottingham* (two publications), *Yonsei University* (two publications), *National University of Singapore* (two publications), *Universidad de Granada* (two publications), *University of Southern California* (two publications), *University of Georgia* (two publications), *The University of Jordan* (two publications), and *The University of Nottingham Malaysia Campus* (two publications).

Finally, *National Natural Science Foundation of China* (five publications), *Natural Sciences and Engineering Research Council of Canada* (three publications), *Australian Research Council* (two publications), *Ministry of Education of the People's Republic of China* (two publications), *National Science Foundation of US* (two publications), and *Office of Naval Research of US* (two publications) are the funding agencies with the most publications within H-Classics.

4 Science mapping of *Applied Intelligence* journal

The following section provides an overview of the conceptual structure of *Applied Intelligence* (*APIN*) journal through science mapping analysis complemented with a performance analysis. This overview is structured into two complementary subsections: (i) thematic analysis by period and (ii) a conceptual evolution analysis.

4.1 Thematic analysis

APIN journal research themes are presented below, identifying and visualizing the core themes from 1991 to 2020. Then, for each period, a strategic diagram is shown, including the number of documents that each theme concentrates, number of citations, h-index, and average citations achieved by each one.

During the *first period 1991–2005* (Figure 6), the journal was focused on 16 research themes. Taking into account their performance measures (Table 5), the most productive themes (more than 100 publications) are the motor themes DATA-MINING (109) and KNOWLEDGE-REPRESENTATION (103), and the basic and transversal themes MATHEMATICAL-MODELS (167), LEARNING-ALGORITHMS (142) and PATTERN-RECOGNITION (106). In line with this, the most cited themes (more than 2,000 cites) are the motor themes DATA-MINING (3,310), INFORMATION-RETRIEVAL-SYSTEMS (2,538) and KNOWLEDGE-REPRESENTATION (2,115), and the basic and transversal themes LEARNING-ALGORITHMS (3,297) and MATHEMATICAL-MODELS (2,838).

Table 5 Themes performance for the 1991–2005 period

Theme	Quadrant	Publications	h-index	Cites	Avg.
MATHEMATICAL-MODELS	Q4	167	28	2,838	16.99
LEARNING-ALGORITHMS	Q4	142	30	3,297	23.22
DATA-MINING	Q1	109	30	3,310	30.37
PATTERN-RECOGNITION	Q4	106	23	1,772	16.72
KNOWLEDGE-REPRESENTATION	Q1	103	25	2,115	20.53
INFORMATION-RETRIEVAL-SYSTEMS	Q1	89	29	2,538	28.52
DECISION-THEORY	Q4	79	20	1,883	23.84
GENETIC-ALGORITHM	Q4	65	25	1,951	30.02
CONSTRAINT-THEORY	Q3	58	20	1,586	27.34
COMPUTER-VISION	Q1	56	15	668	11.93
NATURAL-LANGUAGE-PROCESSING-SYSTEMS	Q2	26	9	605	23.27
FEEDFORWARD-NEURAL-NETWORKS	Q3	26	12	494	19.00
EVOLUTION-STRATEGIES	Q2	15	11	353	23.53
THEOREM-PROVING	Q2	15	7	316	21.07
DATA-HANDLING	Q2	10	8	588	58.80
SIMULATED-ANNEALING	Q2	10	6	185	18.50

The theme INFORMATION-RETRIEVAL-SYSTEMS is a motor theme with high impact and number of documents. It is mainly related to different aspects of the retrieval information systems, such as the types of case reasoning (i.e., conversational, interactive, etc.), user interfaces, query languages, and database systems.

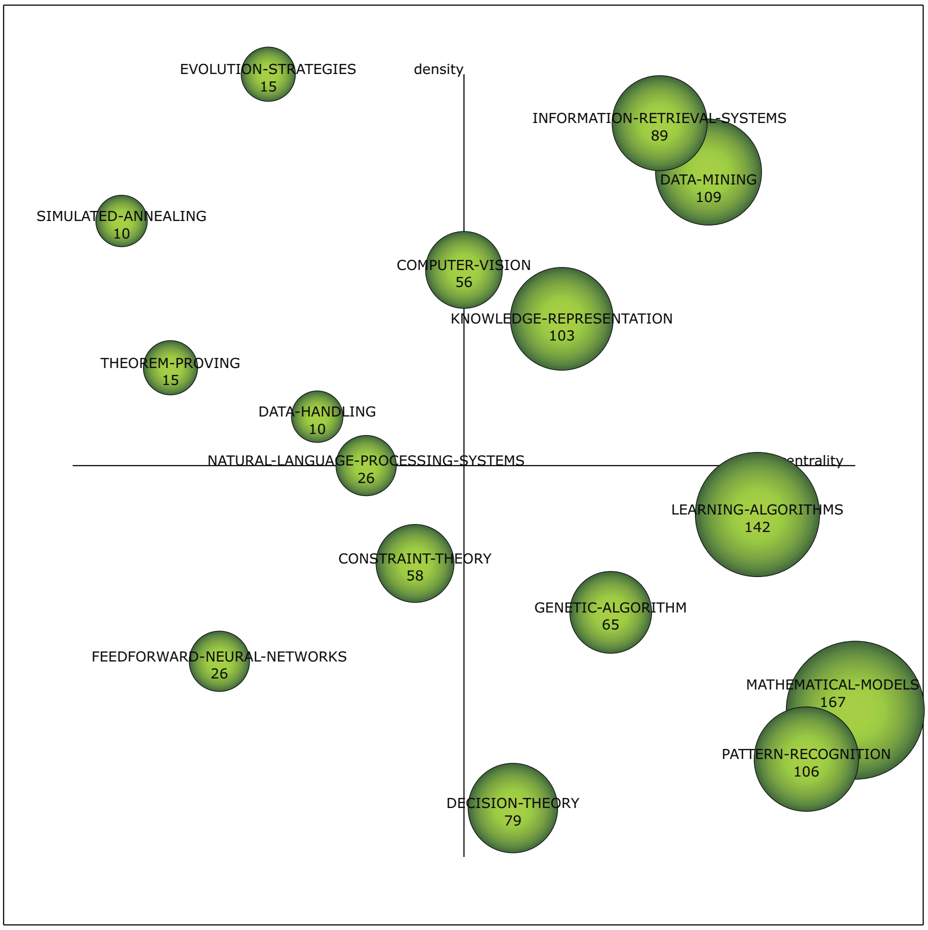

Fig. 6 Strategic diagram for the 1991–2005 period

The themes LEARNING-ALGORITHM and DATA-MINING are the ones with the highest citation rates, and also ranked in the top of most productive themes. Although both are very related, the former is more focused on feature selection, regression analysis, decision trees, neural networks, and, in general, inference systems. On the other hand, the DATA-MINING theme delves into text mining, web mining, association rules, and self-organizing maps.

COMPUTER-VISION is a theme with a low citation rate in comparison with the other themes, focused on main computer vision problems, such as, object recognition, robots, sensors and actuators, and image analysis.

The theme KNOWLEDGE-REPRESENTATION mainly delves into knowledge-based systems and techniques such as formal logic, formal languages, computational linguistic, and structured knowledge. It could be considered as highly cited, producing also a high number of documents.

The theme GENETIC-ALGORITHM has low document production, but it is ranked second in terms of average citations. It is mainly focused on different evolutionary techniques, methods, and application fields such as electric power distribution, air traffic control, and collision avoidance, among others.

MATHEMATICAL-MODELS is related to knowledge modeling, data fusion and aggregation, fuzzy sets, and computer simulation. It also covers some aspects of the decision-making model, complementing the theme DECISION-THEORY. Both themes achieved high impact rates, mainly due to their relation with the decision-making process.

Finally, the theme PATTER-RECOGNITION is also one of the most cited, covering different aspects related to machine learning, knowledge acquisition, feature extraction, and graph theory.

During the *second period 2006–2015* (Figure 7), 16 research themes were identified and presented in the strategic diagram with their performance measures. According to the performance measures presented in Table 6, the most productive themes (more than 100 documents) are the motor theme SUPPORT-VECTOR-MACHINE (113) and the basic and transversal themes GENETIC-ALGORITHM (154), NEURAL-NETWORKS (119), and MULTI-AGENT-SYSTEM (119). Moreover, the most cited themes (more than 2,000 cites) are the motor themes SUPPORT-VECTOR-MACHINE (2,857) and the basic and transversal themes GENETIC-ALGORITHM (3,241), NEURAL-NETWORKS (2,783), MULTI-AGENT-SYSTEM (2,275), and PARTICLE-SWARM-OPTIMIZATION (2,195).

Table 6 Themes performance for the 2006–2015 period

Theme	Quadrant	Publications	h-index	Cites	Avg.
GENETIC-ALGORITHM	Q4	154	30	3,241	21.05
NEURAL-NETWORKS	Q4	119	27	2,783	23.39
MULTI-AGENT-SYSTEM	Q4	119	25	2,275	19.12
SUPPORT-VECTOR-MACHINE	Q1	113	30	2,857	25.28
FORECASTING-TECHNOLOGIES	Q4	81	23	1,591	19.64
CLUSTERING-ALGORITHMS	Q4	79	27	1,932	24.46
PARTICLE-SWARM-OPTIMIZATION	Q4	77	27	2,195	28.51
EVOLUTIONARY-ALGORITHMS	Q4	73	24	1,918	26.27
DATA-MINING	Q1	68	21	1,364	20.06
CASE-BASED-REASONING-APPROACHES	Q2	41	16	801	19.54
FEATURE-EXTRACTION	Q3	31	15	764	24.65
PREDICTIVE-CONTROL-SYSTEMS	Q2	27	12	487	18.04
ROUTING-ALGORITHMS	Q2	25	14	548	21.92
ROBOTIC-APPLICATIONS	Q2	15	9	183	12.20
DEMPSTER-SHAFER-EVIDENCE-THEORY	Q2	8	6	256	32.00
COMPUTER-AIDED-INSTRUCTION	Q2	7	5	129	18.43

In this period, there are a great number of themes related to bio-inspired algorithms, such as GENETIC-ALGORITHM, EVOLUTIONARY-ALGORITHMS, and PARTICLE-SWARM-OPTIMIZATION. The theme GENETIC-ALGORITHM ranked first in citation rates, and the other bio-inspired themes also achieve a high number of citations. Although the three themes cover topics related to bio-inspired computation, each one is focused on specific aspects. In that sense, the theme GENETIC-ALGORITHM focused on heuristic and multiobjective algorithms, genetic programming, and some specific problems such as the salesman problem. PARTICLE-SWARM-OPTIMIZATION is mainly focused on different optimization problems using this technique. On the other hand, EVOLUTIONARY-ALGORITHMS

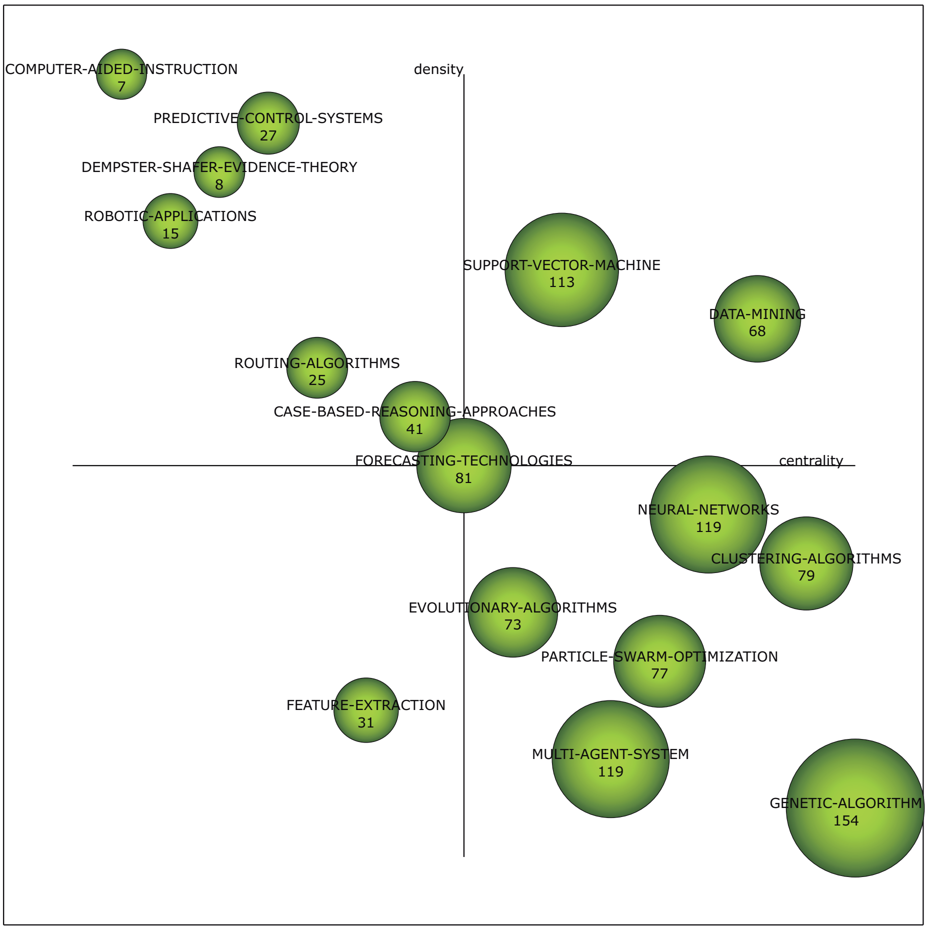

Fig. 7 Strategic diagram for the 2006–2015 period

is related to some evolutionary approaches such as differential evolution, bee colony, specific multiobjective algorithms, and some features such as the fitness function and mutation operators.

The SUPPORT-VECTOR-MACHINE theme is the second ranked according to the citations achieved. It is mainly related to pattern recognition and learning algorithms, and some techniques such as kernel functions.

The theme DATA-MINING is one of the principal motor themes in this period, with a moderate impact rate. As in the previous period, it is related to association rules and text mining, but in this period it incorporates new techniques such as frequent pattern mining, data handling, and aspects focused on privacy.

NEURAL-NETWORKS is mainly related to learning systems with specific models such as backpropagation. It also shows an interest in complex problems related to networks protocols and sensors networks. Taking into account its performance measures, it ranked third in citation rate.

The theme CLUSTERING-ALGORITHMS is ranked third in terms of average citations, and it delves into some specific problem such as image segmentation, computational complexity, and use of different kinds of clustering techniques such as fuzzy c-means.

MULTI-AGENT-SYSTEMS is among the highly cited themes, and it joins some of the most relevant themes of the previous period (INFORMATION-RETRIEVAL and DECISION-THEORY). The theme is mainly focused on aspects related to the decision-making process under an intelligent agent and multiagent environment.

During the *third period 2016–2020* (Figure 7), 26 research themes were identified and presented in the strategic diagram. The research themes covered in this period are an evolution of the previous periods, and therefore, they will drive the future research of the *APIN* journal. Taking into account the performance measures presented in Table 6, the most productive themes (more than 100 documents) are the motor themes FEATURE-EXTRACTION (210), DATA-MINING (132), FORECASTING-TECHNOLOGIES (117), and FUZZY-SETS (110) and the basic and transversal themes DEEP-LEARNING (331), EVOLUTIONARY-ALGORITHMS (234), LEARNING-ALGORITHMS (223), PARTICLE-SWARM-OPTIMIZATION (220), and ITERATIVE-METHODS (185). Moreover, the most cited themes (more than 2,000 citations) are the basic and transversal themes EVOLUTIONARY-ALGORITHMS (2,153) and PARTICLE-SWARM-OPTIMIZATION (2,148).

Table 7 Themes performance for the 2016–2020 period

Theme	Quadrant	Publications	h-index	Cites	Avg.
DEEP-LEARNING	Q4	331	21	1,687	5.10
EVOLUTIONARY-ALGORITHMS	Q4	234	22	2,153	9.20
LEARNING-ALGORITHMS	Q4	223	18	1,245	5.58
PARTICLE-SWARM-OPTIMIZATION	Q4	220	24	2,148	9.76
FEATURE-EXTRACTION	Q1	210	22	1,772	8.44
ITERATIVE-METHODS	Q4	185	18	1,197	6.47
DATA-MINING	Q1	132	16	811	6.14
FORECASTING-TECHNOLOGIES	Q1	117	15	688	5.88
FUZZY-SETS	Q1	110	20	1,381	12.55
SUPPORT-VECTOR-MACHINE	Q2	97	16	884	9.11
SOCIAL-NETWORKING-(ONLINE)	Q1	66	14	530	8.03
SCHEDULING-AND-CONTROL-TECHNOLOGIES	Q3	46	13	406	8.83
IMAGE-SEGMENTATION	Q3	45	6	188	4.18
UNCERTAINTY-ANALYSIS	Q3	42	12	466	11.10
COLLABORATIVE-FILTERING	Q2	41	9	265	6.46
FUZZY-LOGIC	Q4	38	9	285	7.50
OPTICAL-RESOLVING-POWER	Q2	38	5	109	2.87
FUZZY-RULES	Q4	35	8	277	7.91
SUPPORT-VECTOR-REGRESSION	Q2	31	9	160	5.16
FACE-RECOGNITION	Q3	28	5	101	3.61
INTRUSION-DETECTION	Q2	22	7	135	6.14
MULTI-OBJECTIVE-OPTIMIZATION-PROBLEMS	Q1	18	7	265	14.72
DEMPSTER-SHAFER-EVIDENCE-THEORY	Q2	16	9	351	21.94
MOTION-PLANNING	Q2	16	7	127	7.94
DATA-PRIVACY	Q2	14	6	83	5.93
LABEL-CORRELATIONS	Q2	13	3	21	1.62

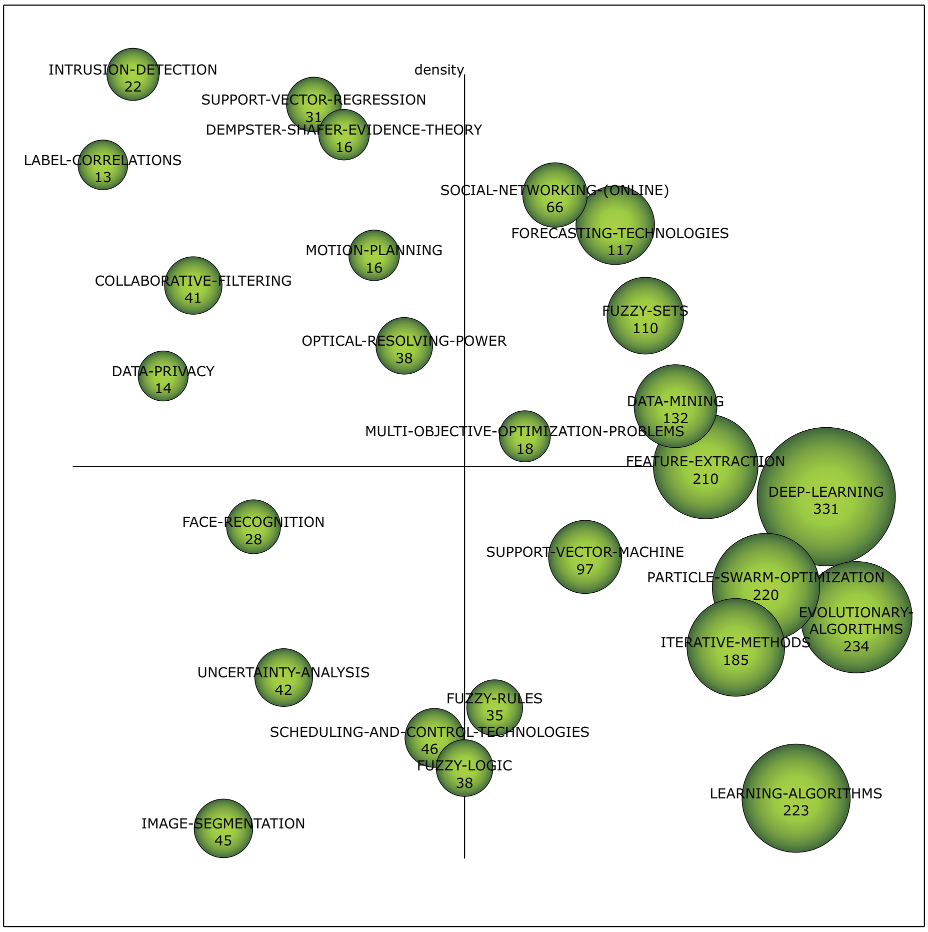

Fig. 8 Strategic diagram for the 2016–2020 period

The theme SOCIAL-NETWORKING-(ONLINE) emerges with great strength as a motor theme, covering aspects related to social network analysis, community detection (clustering on networks), population dynamics, and how to maximize influence in social networks. It also covers some aspects related to automata theory.

The theme FORECASTING-TECHNOLOGIES mainly delves into time series analysis with special emphasis in electronic trading, financial markets, and stock prices.

The theme FUZZY-SETS concentrates the topics related to the process of decision-making using fuzzy sets and logic, and intuitionistic fuzzy techniques, and specifically focused on multi-criteria problems.

The theme DATA-MINING, as in the previous periods, is considered a motor theme. Now it is related to novel techniques such as pattern mining, association rules, utility mining, and sentiment analysis.

FEATURE-EXTRACTION gained strength in this period, being composed of new themes related to feature selection and extraction problems, high-dimensional data, and how applying this method could affect the performance and accuracy of classification systems.

DEEP-LEARNING emerges as an important theme in this period, covering different types of learning systems based on deep neural networks such as convolutional neural networks, reinforcement learning, and transfer learning, among others

The theme SUPPORT-VECTOR-MACHINE concentrates the effort of the community in the development of new methods and models of support vector machine (SVM), such as least-squares or twin SVM. It is also focused on specific problems such as quadratic programming. Regarding the application fields, it is commonly used in multiclass classification.

The theme EVOLUTIONARY-ALGORITHMS now concentrates all the aspects related with evolutionary strategics, such as differential evolution, evolutionary computation, bee colony, and genetic algorithms. It also covers aspects related to multiobjective and many-objective optimizations, and global optimization at a large scale. The theme PARTICLE-SWARM-OPTIMIZATION covers a specific bio-inspired topic, with special emphasis on metaheuristics algorithms, also using fuzzy inference. A very related theme is MULTI-OBJECTIVE-OPTIMIZATION-PROBLEMS, which is a very specialized theme focused on finding Pareto-optimal solutions.

The theme ITERATIVE-METHODS is focused on complex networks and graph theory, and also the application of extreme learning system in the knowledge acquisition process.

In summary, taking into account the strategic diagrams (Figures 6-8) and their performance measures (5-7), Table 8 presents the main research themes developed and their performance according to the number of documents from 1991 to 2020. These results are aligned with the aim and scope of the *APIN* journal, in which the following are identified as relevant themes within the journal: natural language and speech interfaces, learning methodologies, intelligent decision support systems, evolutionary computing, genetic programming, neural networks, data mining and patterns, fuzzy logic and control, feature selection, and forecasting, scheduling, and planning technologies, as well as other relevant themes.

Finally, according to the results obtained and taking into account the main research themes related to the most cited themes, it could be stated that the publications and research themes covered by the *Applied Intelligence* (*APIN*) journal are linked, with strong synergies between them.

4.2 Conceptual evolution map of *APIN* journal

Once the three periods have been analyzed, and their different themes described, it can be shown how they have evolved over the years. In this sense, this section describes the conceptual evolution of the *APIN* journal over the three periods studied.

For this purpose, Figure 9 shows an evolution map, where each column shows the themes of a given period; the first column corresponds to the initial period, and the last column corresponds to the final period. In this sense, two themes from two consecutive periods will be connected if they have keywords in common. To clarify the map, themes that have no evolution with adjacent periods have been removed. Moreover, it is important to remember that the size of the spheres is proportional to the number of publications identified in each theme, and the colored areas represent the clusters of themes pertaining to the same thematic area. A solid line means that both themes share one of their central keywords, and a dotted line means that both themes share some peripheral keyword [8].

Thus, according to the thematic evolution, the *APIN* journal focused its research during the three periods on five global thematic areas: (i) data mining, (ii) learning systems, (iii) bio-inspired algorithms, (iv) decision-making under uncertainty, and (v) robotics and computer vision. Since thematic areas are composed of themes, and those are associated with

Table 8 *APIN* journal conceptual structure from 1991 to 2020

Theme	P1: 1991-2005	P2: 2006-2015	P3: 2016-2020
DATA-MINING	Q1 | 109 | 3,310 | 30	Q1 | 68 | 1,364 | 21	Q1 | 132 | 811 | 16
GENETIC-ALGORITHM	Q4 | 65 | 1,951 | 25	Q4 | 154 | 3,241 | 30	
LEARNING-ALGORITHMS	Q4 | 142 | 3,297 | 30		Q4 | 223 | 1,245 | 18
DEMPSTER-SHAFER-EVIDENCE-THEORY		Q2 | 8 | 256 | 6	Q2 | 16 | 351 | 9
EVOLUTIONARY-ALGORITHMS		Q4 | 73 | 1,918 | 24	Q4 | 234 | 2,153 | 22
PARTICLE-SWARM-OPTIMIZATION		Q4 | 77 | 2,195 | 27	Q4 | 220 | 2,148 | 24
SUPPORT-VECTOR-MACHINE		Q1 | 113 | 2,857 | 30	Q2 | 97 | 884 | 16
FEATURE-EXTRACTION		Q3 | 31 | 764 | 15	Q1 | 210 | 1,772 | 22
FORECASTING-TECHNOLOGIES		Q4 | 81 | 1591 | 23	Q1 | 117 | 688 | 15
DECISION-THEORY	Q4 | 79 | 1,883 | 20		
EVOLUTION-STRATEGIES	Q2 | 15 | 353 | 11		
MATHEMATICAL-MODELS	Q4 | 167 | 2,838 | 28		
CLUSTERING-ALGORITHMS		Q4 | 79 | 1,932 | 27	
MULTI-AGENT-SYSTEM		Q4 | 119 | 2,275 | 25	
NEURAL-NETWORKS		Q4 | 119 | 2,783 | 27	
ROUTING-ALGORITHMS		Q2 | 25 | 548 | 14	
DEEP-LEARNING			Q4 | 331 | 1,687 | 21
FUZZY-LOGIC			Q4 | 38 | 285 | 9
FUZZY-SETS			Q1 | 110 | 1,381 | 20
ITERATIVE-METHODS			Q4 | 185 | 1,197 | 18
UNCERTAINTY-ANALYSIS			Q3 | 42 | 466 | 12
COMPUTER-VISION	Q1 | 56 | 668 | 15		
DATA-HANDLING	Q2 | 10 | 588 | 8		
INFORMATION-RETRIEVAL-SYSTEMS	Q1 | 89 | 2,538 | 29		
PATTERN-RECOGNITION	Q4 | 106 | 1,772 | 23		
SIMULATED-ANNEALING	Q2 | 10 | 185 | 6		
CASE-BASED-REASONING-APPROACHES		Q2 | 41 | 801 | 16	
ROBOTIC-APPLICATIONS		Q2 | 15 | 183 | 9	
IMAGE-SEGMENTATION			Q3 | 45 | 188 | 6
MOTION-PLANNING			Q2 | 16 | 127 | 7
SCHEDULING-AND-CONTROL-TECHNOLOGIES			Q3 | 46 | 406 | 13
CONSTRAINT-THEORY	Q3 | 58 | 1,586 | 20		
FEEDFORWARD-NEURAL-NETWORKS	Q3 | 26 | 494 | 12		
KNOWLEDGE-REPRESENTATION	Q1 | 103 | 2,115 | 25		
NATURAL-LANGUAGE-PROCESSING-SYSTEMS	Q2 | 26 | 605 | 9		
THEOREM-PROVING	Q2 | 15 | 316 | 7		
COMPUTER-AIDED-INSTRUCTION		Q2 | 7 | 129 | 5	
PREDICTIVE-CONTROL-SYSTEMS		Q2 | 27 | 487 | 12	
COLLABORATIVE-FILTERING			Q2 | 41 | 265 | 9
DATA-PRIVACY			Q2 | 14 | 83 | 6
FACE-RECOGNITION			Q3 | 28 | 101 | 5
FUZZY-RULES			Q4 | 35 | 277 | 8
INTRUSION-DETECTION			Q2 | 22 | 135 | 7
LABEL-CORRELATIONS			Q2 | 13 | 21 | 3
MULTI-OBJECTIVE-OPTIMIZATION-PROBLEMS			Q1 | 18 | 265 | 7
OPTICAL-RESOLVING-POWER			Q2 | 38 | 109 | 5
SOCIAL-NETWORKING-(ONLINE)			Q1 | 66 | 530 | 14
SUPPORT-VECTOR-REGRESSION			Q2 | 31 | 160 | 9

Note: The results are expressed as follows: Quadrant | Publications | Citations | h-index

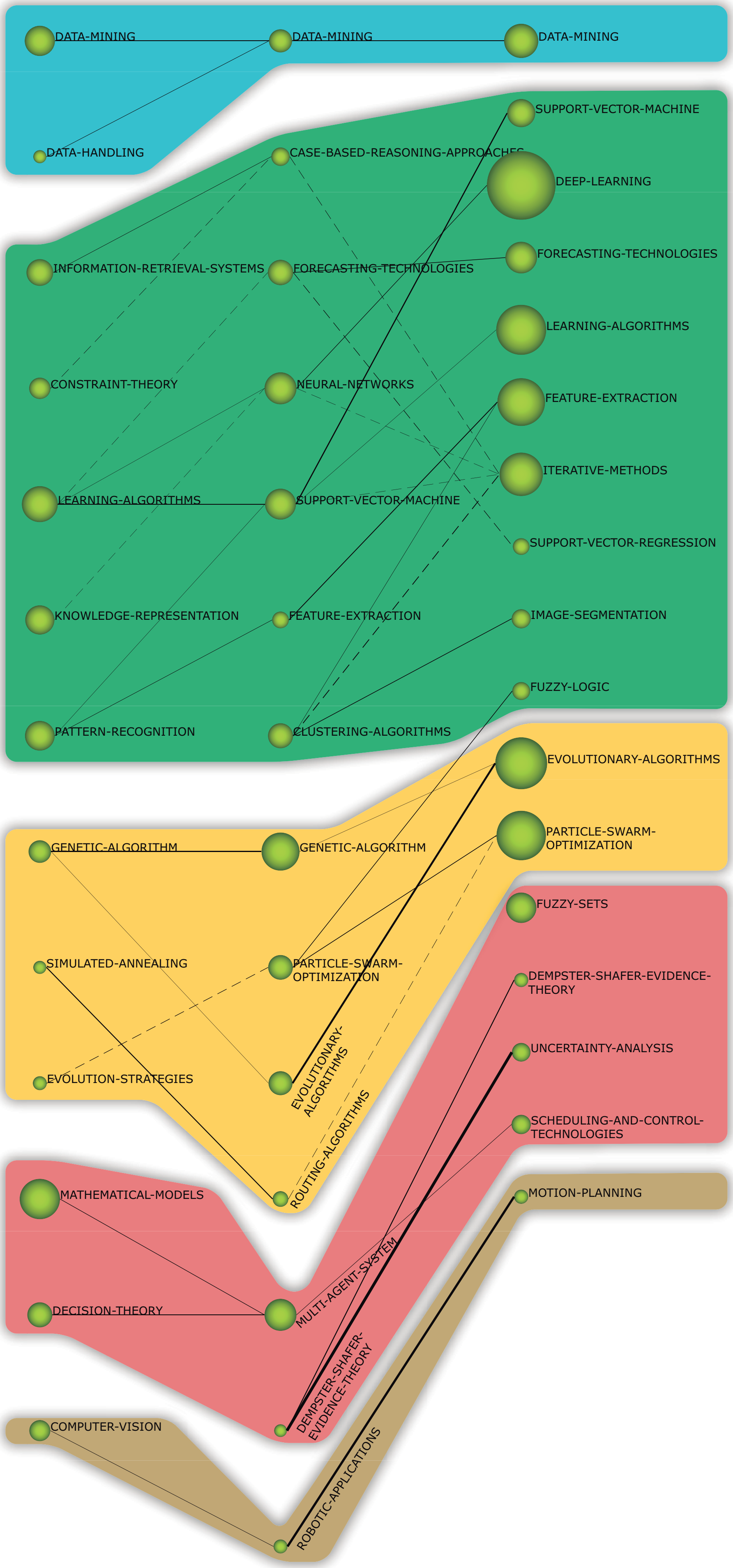

Fig. 9 *APIN* journal thematic evolution from 1991 to 2020

documents, some bibliometric performance measures could be computed for each thematic area. In that sense, Table 9 presents the number of publications, citations, and h-index for each one.

Table 9 Thematic areas performance

Thematic area	Publications	Cites	h-index
Data mining	315	5852	36
Learning systems	1376	18831	57
Bio-inspired algorithms	687	11161	47
Decision-making under uncertainty	520	8540	44
Robotics and computer vision	87	978	17

Data mining is a very strong thematic area. Although it is very related to the thematic area learning systems, it has maintained a constant research line during the whole period. Firstly, its was related to text mining, web mining, association rules, and self-organizing maps, and the different problem of data handling. In the next period, the thematic area kept similar research topics, and added new ones such as frequent pattern mining or aspects focused on privacy. Finally, it focused on novel techniques such as pattern mining, association rules, utility mining, and sentiment analysis.

The thematic area ***learning systems*** is the largest one and, therefore, the thematic area with the highest impact rates. It covered all the aspects related to learning algorithms, knowledge representation, and data preprocessing. In that sense, in the first years, it was more focused on general aspects of learning systems, and pattern recognition problems. It also covered some aspects related to information retrieval systems, but this line was not kept in the following period. In the second period, the thematic area covered a wide range of specific techniques, such as neural networks, support vector machine, clustering, or forecasting. In the last period, the thematic area again increased its number of themes, focusing now on similar topics as in the previous period, and adding new ones, such as deep learning or image segmentation. This thematic area is a good example of the thematic evolution of the journal, starting with general machine learning problems, and evolving later to the current machine learning techniques. The areas of application also evolved. For example, in the last period, we can see an effort of using deep learning techniques for computed tomography images, and use of learning systems applied to electronic trading.

The thematic area ***bio-inspired algorithms*** covered mainly topics related to genetic algorithms, evolution algorithms, and evolution strategies. It also deals with other bio-inspired algorithms such as particle swarm optimization, bee colony, simulated annealing, and differential evolution, among others.

Although the thematic area ***decision-making under uncertainty*** was not directly composed of decision-making themes, the themes it comprised mainly cover different aspect of this process using fuzzy sets to model the uncertainty in the decision process. In the first period, it delved into knowledge modeling, data fusion, and aggregation. In the second period, it evolved to the decision-making process under intelligent agent and multiagent environments. In the last period, it covered also topics such as intuitionistic fuzzy sets and multicriteria problems.

Finally, the thematic area ***robotics and computer vision*** is the smallest one, mainly focused on computer vision in different robotics problems.

5 Conclusions

The evolution of *Applied Intelligence* (*APIN*) journal has been positive since its beginning. Moreover, given the large volume of publications and citations received, as well as the research themes identified and their evolution in the main databases, it is expected that the interest of the scientific community in this journal will continue or even keep growing over the coming years.

Regarding relevant bibliometric measures, the *APIN* journal presents an h-index of 67, an indicator that reflects the high impact of their publications and their use by the community. This group of publications concentrates 7,793 citations (including self-citations) and presents an average citation count of 116.31.

According to the conceptual analysis developed using *SciMAT*, five main thematic areas are identified: (i) data mining, (ii) learning systems, (iii) bio-inspired algorithms, (iv) decision-making under uncertainty, and (v) robotics and computer vision. It should be highlighted that, mainly, *APIN* journal was focused during the whole period on different aspects related to the global learning problem using different machine learning and data mining algorithms.

On analyzing these themes and their relationship, it could be mentioned that the development of the *APIN* journal will mainly support the following global artificial intelligence areas: advanced diagnosis, big data (including mining data and patterns, and data management), evolutionary computing, fuzzy logic and control, genetic programming, intelligent decision support systems, learning methodologies, modeling, natural language and speech interfaces, neural networks, smart vision and robotics, use of distributed and parallel processing, and uncertain information processes, among others.

Bearing in mind the above mentioned, two different research and development scenarios can be identified according to the Technology Readiness Levels (TRL) classification—on the one hand, the themes related to basic principles, concept and application formulation, and concept validation (research phase). Learning, genetic, routing, clustering, and evolutionary algorithms are some of the most interesting themes in this field and are being promoted by smart or advanced technologies under the Industry 4.0 umbrella. These algorithms are strongly related to other knowledge areas such as multiagent system, neural networks, particle swarm optimization, support vector machine, deep learning, and iterative methods. Nevertheless, this research requires case studies that show its potential, benefits, and implementation.

On the other hand, the remaining themes are aligned to first implementation, industrialization detailed scope, and extensive implementation (development and deployment phase). These themes are linked to intelligent technologies, and they are oriented to key technology covered by smart industries. These technologies are oriented to control, automation, robotics, and intelligence and cover knowledge areas such as artificial vision, expert systems, simulation, and advanced analytic. In this way, these technologies take into consideration other general aspects such as scalability, accessibility, compatibility, and connection.

Both scenarios need to adapt to rapid technology evolution, considering the main challenges of industrial and economic sectors such as energy, electronic, communications, manufacturing, and food, among others. To do that, these developments and research have to consider four approaches: vertical (related to production systems, smart products, and high-value-added services), horizontal (related to capability to connect and scale the advanced capabilities), through-organization (throughout the entire value chain, covering the entire product life cycle), and acceleration through exponential technologies (mass-market application reducing the cost of implementation and updating).

Finally, it is important to note that this analysis allows the identification of common themes that can be used to achieve the research lines related to the purpose and objectives of *Applied Intelligence* journal. Moreover, as future research, a global analysis could be carried out, taking into account a yearly time span to understand the evolution of each theme as its thematic network.

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In the Appendix A

Appendix A H-Classics

Table 10: List of H-Classics of *APIN* journal

Rank	Title (publication year, first author)	Citations
1	Overcoming the myopia of inductive learning algorithms with RELIEFF (1997, Kononenko, I.)	402
2	Multi-objective genetic algorithms for vehicle routing problem with time windows (2006, Ombuki, B.)	301
3	How effective is the Grey Wolf optimizer in training multi-layer perceptrons (2015, Mirjalili, S.)	273
4	Population size reduction for the differential evolution algorithm (2008, Brest, J.)	249
5	Fuzzy risk analysis based on the ranking of generalized trapezoidal fuzzy numbers (2007, Chen, S.-J.)	218
6	Authorship attribution with support vector machines (2003, Diederich, J.)	211
7	Audio-visual speech recognition using deep learning (2015, Noda, K.)	210
8	Introduction to financial forecasting (1996, Abu-Mostafa, Y.S.)	182
9	Possibility theory in constraint satisfaction problems: Handling priority, preference and uncertainty (1996, Dubois, D.)	180
10	Generalized evidence theory (2015, Deng, Y.)	176
11	Hybrid clustering analysis using improved krill herd algorithm (2018, Abualigah, L.M.)	170
12	Multi-objective ant lion optimizer: a multi-objective optimization algorithm for solving engineering problems (2017, Mirjalili, S.)	169
13	Imputation of missing data in industrial databases (1999, Lakshminarayan, K.)	156
14	A memetic approach to the nurse rostering problem (2001, Burke, E.)	152
15	Scalable techniques from nonparametric statistics for real time robot learning (2002, Schaal, S.)	151
16	Conversational case-based reasoning (2001, Aha, D.W.)	144
17	Grasshopper optimization algorithm for multi-objective optimization problems (2018, Mirjalili, S.Z.)	134
18	A new approach and system for attentive mobile learning based on seamless migration (2012, Zhang, D.-G.)	134
19	Data mining and machine oriented modeling: a granular computing approach (2000, Lin, T.Y.)	128
20	Multi-dimensional modal logic as a framework for spatio-temporal reasoning (2002, Bennett, B.)	121
21	A novel chaotic salp swarm algorithm for global optimization and feature selection (2018, Sayed, G.I.)	119
22	Artificial intelligence and Environmental Decision Support Systems (2000, Cortés, U.)	118

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Table 10 – *Continued from previous page*

Rank	Title (publication year, first author)	Citations
23	Qualitative spatial reasoning using orientation, distance, and path knowledge (1996, Zimmermann, K.)	115
24	Exception handling in workflow systems (2000, Luo, Z.)	110
25	Multi-instance learning based web mining (2005, Zhou, Z.-H.)	108
26	DBSMOTE: density-based synthetic minority over-sampling technique (2012, Bunkhumpornpat, C.)	106
27	Predicting student failure at school using genetic programming and different data mining approaches with high dimensional and imbalanced data (2013, Márquez-Vera, C.)	105
28	An intelligent system for automated breast cancer diagnosis and prognosis using SVM based classifiers (2009, Maglogiannis, I.)	100
29	An algorithm based on counterfactuals for concept learning in the Semantic Web (2007, Iannone, L.)	98
30	All the truth about NEvAr (2002, Machado, P.)	98
31	A novel feature selection method based on normalized mutual information (2012, Vinh, L.T.)	96
32	Training feedforward neural networks using multi-verse optimizer for binary classification problems (2016, Faris, H.)	95
33	An enhanced Support Vector Machine classification framework by using Euclidean distance function for text document categorization (2012, Lee, L.H.)	95
34	Dynamic vehicle routing using genetic algorithms (2007, Hanshar, F.T.)	95
35	Local search genetic algorithms for the job shop scheduling problem (2004, Ombuki, B.M.)	93
36	Agent-based cloud service composition (2013, Gutierrez-Garcia, J.O.)	91
37	An optimization algorithm inspired by the States of Matter that improves the balance between exploration and exploitation (2014, Cuevas, E.)	90
38	Fuzzy control of HVAC systems optimized by genetic algorithms (2003, Alcalá, R.)	90
39	Incremental feature selection (1998, Liu, H.)	89
40	Solving electrical distribution problems using hybrid evolutionary data analysis techniques (1999, Cordón, O.)	88
41	Am empirical analysis of optimization techniques for terminological representation systems—or: making KRIS get a move on (1994, Baader, F.)	88
42	Stock market prediction with multiple classifiers (2007, Qian, B.)	87
43	Shell-neighbor method and its application in missing data imputation (2011, Zhang, S.)	85
44	Multi-instance clustering with applications to multi-instance prediction (2009, Zhang, M.-L.)	84
45	Connection number of set pair analysis based TOPSIS method on intuitionistic fuzzy sets and their application to decision making (2018, Kumar, K.)	83
46	Cancer classification using ensemble of neural networks with multiple significant gene subsets (2007, Cho, S.B.)	83
47	Towards creative evolutionary systems with interactive genetic algorithm (2002, Cho, S.-B.)	82
48	Predicting chemical parameters of river water quality from bioindicator data (2000, Džeroski, S.)	81
49	A coevolutionary algorithm for balancing and sequencing in mixed model assembly lines (2000, Kim, Y.K.)	79
50	Connectionist inductive learning and logic programming system (1999, Avila Garcez, A.S.)	78
51	Ant colony optimization with global pheromone evaluation for scheduling a single machine (2003, Merkle, D.)	76
52	Generalized and group-based generalized intuitionistic fuzzy soft sets with applications in decision-making (2018, Garg, H.)	75
53	A modified combination rule in generalized evidence theory (2017, Jiang, W.)	74
54	A multi-threshold segmentation approach based on artificial bee colony optimization (2012, Cuevas, E.)	74
55	Semi-parametric optimization for missing data imputation (2007, Qin, Y.)	73

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Table 10 – *Continued from previous page*

Rank	Title (publication year, first author)	Citations
56	A genetic algorithm for vehicle routing with backhauling (1996, Potvin, J.-Y.)	73
57	Sensor dynamic reliability evaluation based on evidence theory and intuitionistic fuzzy sets (2018, Song, Y.)	72
58	Agent-based design model of adaptive distributed systems (1998, Fujita, S.)	72
59	Using TF-IDF to hide sensitive itemsets (2013, Hong, T.-P.)	71
60	FSfRT: forecasting system for red tides (2004, Fdez-Rtverola, F.)	71
61	A graph coloring constructive hyper-heuristic for examination timetabling problems (2012, Sabar, N.R.)	70
62	Cooperative driving: an ant colony system for autonomous intersection management (2012, Wu, J.)	68
63	An improved distance-based total uncertainty measure in belief function theory (2017, Deng, X.)	67
64	Advances in SHRUTI—a neurally motivated model of relational knowledge representation and rapid inference using temporal synchrony (1999, Shastri, L.)	66
65	A least squares support vector machine model optimized by moth-flame optimization algorithm for annual power load forecasting (2016, Li, C.)	65
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