

A Focused Analysis of the Intersection of Machine Learning and Intelligent Decision

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Abstract: Machine learning and intelligent decision are important research topics, and the effective combination of the two is a current research hotspot. To further understand the outcomes of the collision of the two fields, this paper comprehensively analyzes the research dynamics of intelligent decision and machine learning from a scientometric perspective using two tools, VOS viewer and CiteSpace. This study provides a holistic insight that helps researchers to better understand the research field. The data analysis of the article is based on 2218 documents retrieved from the Web of Science database from 1990 to 2021. The paper investigates the collaborative network, bibliographic coupling of intelligent decision, and machine learning, revealing the distribution, and closeness of research in the field in terms of countries/regions, institutions, and authors. Further, the paper reveals the research hotspots and research frontiers of the topic through a series of visualization tools such as burst detection. On this basis, the article further discusses the current challenges and possible directions.

Keywords: Machine Learning; Intelligent Decision; Bibliometric Analysis; Burst Detection Analysis; Evolutionary Analysis.

1. Introduction

Due to the complexity of the decision-making problem, one is usually confronted with data with uncertainty, incompleteness, and dynamics in the decision-making process. These data usually contain some low-dimensional structural features in the form of extremely high-dimensional representations (Anandkumar et al., 2012). Machine learning (ML) is generally defined as a process of self-improvement of a system that can automatically learn data, retrograde, and extract complex patterns from it to make intelligent decisions. Famili (1990) first explored the operation of ML in intelligent manufacturing systems. Since then, other scholars have embarked on extended research on the application of ML in the field of intelligent decision (ID). Early studies mainly centered on improving ML algorithms, such as heuristic decision trees (Shaw et al., 1992), neural networks (Nakasuka et al., 1994), and inductive algorithms (Freedman et al., 1998). The application area has also focused on scheduling systems such as production and transportation (Nogami et al., 1996) due to economic and technological developments.

With the rapid development of information technology, especially the Internet, the Internet of Things, and cloud computing, various forms of data are constantly being generated in various application areas. In addition to further applications in scheduling and manufacturing systems, the medical field (Thomas et al., 2007; Khashman, 2009; Khashman, 2010; Sizilio et al., 2012), wireless network terminals (Jiang et al., 2017; Wang et al., 2020; Sarker et al., 2020; Sliwa et al., 2021; Giral et al., 2021; Oshima et al., 2021), Internet of Things (Zhang et al., 2015; Liang et al., 2017; Lei et al., 2020; Zhang et al., 2020; Hassan et al., 2021), and building predictive models have been expanded (Ali et al., 2018; Kouadio et al., 2018; Prasad et al., 2018; Yaseen et al., 2019; Cui et al., 2020). ML extends the ability to process data and information to provide decision-makers with scientific decision support, helping to improve the accuracy, objectivity, and science of decision making (Mjolsness & DeCoste, 2001).

This paper delves into the intersection focus of two major

fields, ML and ID, and scientifically analyzes the data sources using VOS viewer and CiteSpace tools to help researchers explore future research directions of interest.

The article is structured as follows: Section 2 explains the scope of the study and data sources. Section 3 provides a general analysis of the field. Section 4 provides an in-depth analysis in terms of two dimensions: keywords and critical incident detection analysis. Section 5 summarizes the content of the article.

2. Scope and Data Source

In the context of the information age and the new generation of wireless networks, ML methods are geared toward more complex and multidimensional massive data, and ID is being applied in more fields. Researchers are trying to build intelligent application models with more complex algorithms to improve the efficiency of life production. To help more scholars understand the field, we selected 32 years of publication data on the development of the field since 1990 and conducted a bibliometric analysis of it.

Considering the authority and comprehensiveness of citation data, we choose the Web of Science (WoS) database as our data source. At the same time, searching with WoS is simple and precise, and the search results contain relevant information such as papers and citation records, helping users to grasp accurate data information. A search of the WoS core database for the keywords "Machine learning" and "Intelligent decision" yielded a total of 2,218 search results, ranging from 1990 to 2021. We exported all the retrieved literature in the form of full records with cited references as our data source for analysis and research.

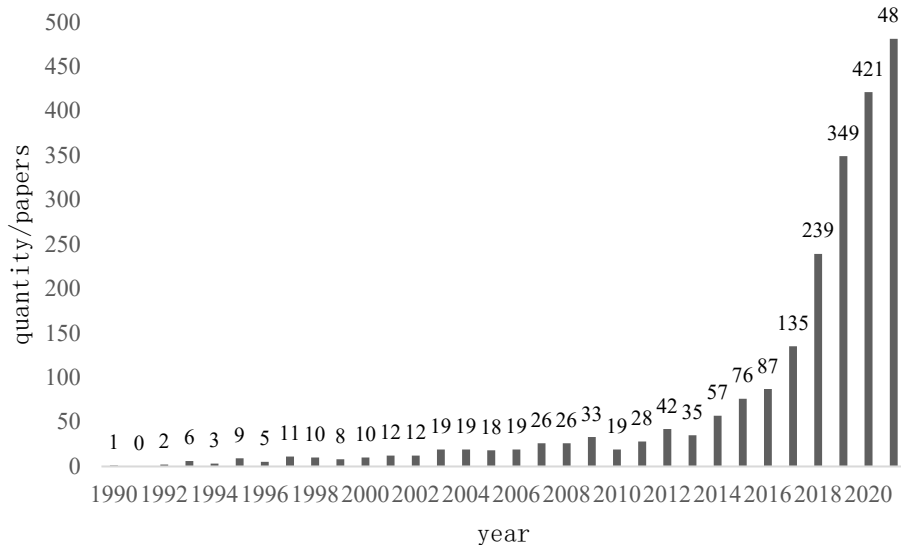
3. General Analysis of ML and ID

In this section, we provide a general analysis of the development of the field in two dimensions, encompassing the underlying data characteristics as well as the state of collaboration in the field. The study period starts in 1990 and ends in 2021, and the data source is 2,218 documents over 32

years.

3.1. Basic Statistical Characteristics Related to ML and ID

The basic analysis helps us to explore the initial



Source: Web of Science

Fig 1. The number of published papers per year

The change in the number of papers published shows a three-stage growth trend, from 1990 to 2013, the number of papers published each year was less than 50, and the cumulative number of papers published during these fourteen years was 373, accounting for 16.82% of the total number of literatures. The number of papers published in 2014 exceeded 50 for the first time, and since then, the annual number of papers published has been on a yearly upward trend. The growth rate was evident from 2017 to 2019, with the number

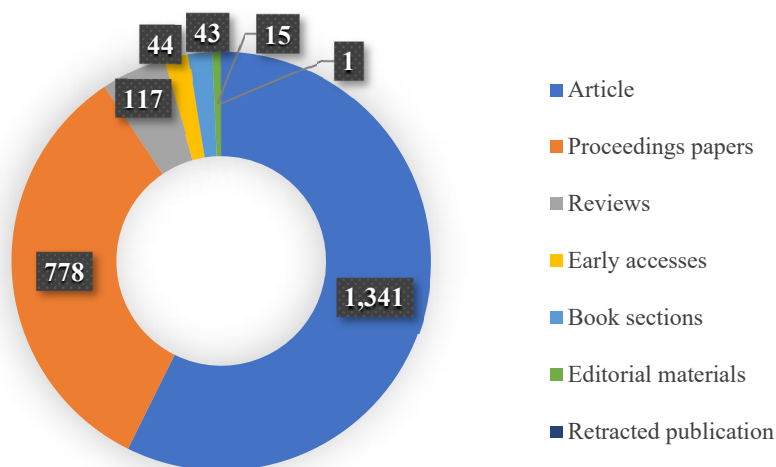
development of the field and contains three sections: annual publication status, analysis of types of literature and research directions, and analysis of prolific countries, institutions, and authors.

3.1.1. Annual Indicators of Documents

rising by more than 100 articles compared to the previous year, and the growth rate gradually slowed down after 2019. As of the search date of January 2022, a total of 2,218 relevant documents were published in the related fields.

3.1.2. Types and Research Directions

According to the analysis in the WoS, publications related to ML and ID are classified into 7 types, shown in Figure 2.



Source: Web of Science

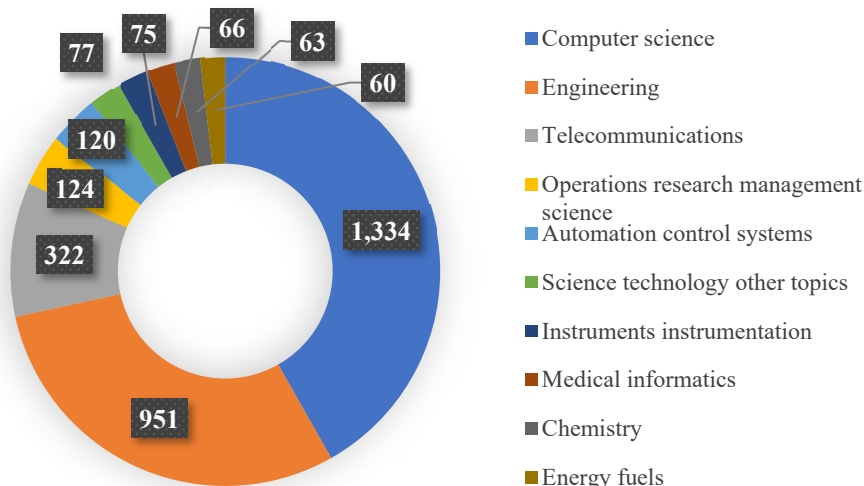
Fig 2. Types of publications related to ML and ID

The most type of publication is an article with the number 1341, which occupies a comparatively great proportion of all documents. Secondly, 778 publications are proceedings papers, and 117 of them are reviews. Besides, there are 44 early accesses, 43 book sections, 15 editorial materials, and 1 retracted publication. Article and proceeding papers are the main choices for researchers. Figure 3 shows the top 10

research directions of publications related to ML and ID.

The most popular research directions are computer science (1,334) and engineering (951), which account for a high proportion of the total number. And they are followed by telecommunications (322), operations research management science (124), automation control systems (120), science technology other topics (77), instruments instrumentation

(75), medical informatics (66), chemistry (63), and energy fuels (60).



Source: Web of Science

Fig 3. The top 10 research directions of the publications related to ML and ID

3.1.3. Prolific Countries/Regions, Institutions, Authors

Table 1. Top 12 prolific countries/regions

Rank	Country /Region	Number	Percentage
1	China	464	20.92
2	USA	411	18.53
3	India	242	10.91
4	Australia	130	5.86
5	England	129	5.82
6	Canada	86	3.88
7	Saudi Arabia	86	3.88
8	Spain	79	3.56
9	South Korea	72	3.25
10	Pakistan	69	3.11
11	Iran	63	2.84
12	Taiwan (China)	58	2.61

Table 1 shows that China is the most prolific country/region in terms of published literature in past collision studies in both fields, with 464 publications, accounting for 20.92% of all literature, followed closely by the United States with 411 publications, accounting for 18.53% of all literature. China and the United States are also the only two countries in the top 12 prolific countries/regions with more than 400 publications. India and Australia ranked third and fourth with 242 and 130 publications, respectively, while the United Kingdom ranked fifth with 129 publications. The top five prolific countries have published a total of 1,376 papers, accounting for 62.04% of the total literature in this field, making a significant contribution to the research and development of this field. Other prolific countries in order are Canada, Saudi Arabia, Spain, South Korea, Pakistan, Iran, and Taiwan (China).

Table 2 shows the top 12 most prolific institutions. The most prolific institution is Tsinghua University with 26 publications in this field. Four Chinese schools are listed among the top twelve most prolific institutions, and China is also the most prolific country in this field.

Table 2. Top 12 prolific institutions

Rank	Institution	Country	Number
1	Tsinghua University	China	26
2	Swinburne University of	Australia	20
3	King Abdulaziz University	Saudi	19
4	Chinese Academy of	China	17
5	Sejong University	South	16
6	Beijing Univ of	China	16
7	Chittagong Univ	Bangladesh	16
8	King Saud University	Saudi	15
9	Nanyang Technological	Singapore	14
10	The Hong Kong Polytechnic	China	13
11	Islamic Azad University	Iran	13
12	University of Southern	Australia	13

This is followed by the Swinburne University of Technology and King Abdulaziz University, with 20 and 19 publications respectively. Australia and Saudi Arabia, with

two schools on the list, ranked fourth and seventh, respectively, among the most prolific countries. Bangladesh and Singapore each have one school on the list, but they are not in the top twelve list of high-producing countries.

Sarker is from the Chittagong University of Engineering and he has published 15 related papers from 2018 to 2021, making him become the most prolific author in the field. He is mainly engaged in the application of machine learning-based decision model building in mobile network terminals, such as network security intrusion detection models and context-aware prediction models, and has notable achievements in this field in recent years. Seven of the top 12 prolific authors are from China, and Chinese scholars have done extensive research in this area.

3.2. Cooperation Network of ML and ID

This section builds a network through the VOS viewer tool to describe collaborative relationships between countries,

institutions, and authors related to the publication.

Table 3. Top 12 prolific authors

Ran	Autho	Numbe	Ran	Autho	Numbe
1	Sarker	15	7	Zhang	7
2	Zhang	13	8	Wang	7
3	Li Y	13	9	Khan A	6
4	Khan	9	10	Sharma	5
5	Deo	8	11	Chen Y	5
6	Liu Y	7	12	Chen X	5

3.2.1. Countries/Regions Collaboration Network

To clarify the collaboration between countries/regions for the study of synergistic publications between 1990 to 2021, the mapping tool VOS viewer was used to construct the countries/regions collaboration network and the result is presented in Figure 4.

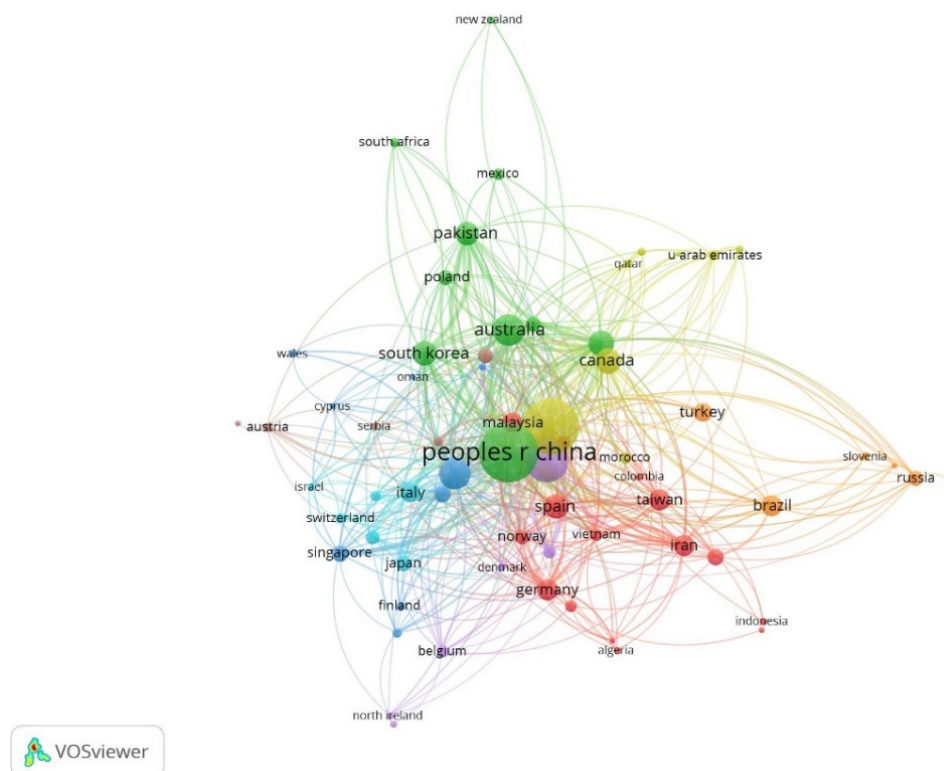


Fig 4. The countries/regions collaboration network from 1990 to 2021

In total, there are 66 country/region programs divided into 8 categories, with different colors representing different categories. In Figure 4, the most collaborative countries/regions in each category are China, the USA, the UK, Spain, Brazil, Italy, Egypt, and Scotland. The node size indicates the number of publications after standardization, and the link refers to the collaborative relationship between the two countries/regions being connected. Among them, China, the United States, India, the United Kingdom, and Spain are among the top 12 highly productive countries. The stronger the link, the more collaboration between the two countries/regions is indicated. Thus, the United States is the most collaborative country, with cooperation between 51 countries/regions, including Canada. China often cooperates with Australia, South Korea, and Pakistan. There are strong ties between Italy and Japan, Ireland, Sweden, and Switzerland. There are also strong cooperative ties between Spain, Taiwan, China, Norway, Germany, and Iran.

3.2.2. Institutions Collaboration Network

In the following, we also construct an institutional cooperation network through VOS viewer to explore the cooperation relationship between institutions, and the result is shown in Figure 5.

Throughout the study period, the 116 publishing institutions were divided into 14 categories. In Figure 5, Tsinghua University is the most prolific institution in this field, which has good collaborative relationships with many domestic universities such as CAS, Hong Kong Polytechnic University, Beijing University of Posts and Telecommunications, Southeast University, and Xiamen University, as well as close ties with many international universities such as the University of Illinois, the University of Florida, and the University of Southampton. The Swinburne University of Technology is the most collaborative institution in its category and has the highest intensity of collaboration, with Chittagong University of Engn & Technol, CSIRO, Newcastle University, and many

other institutions. The cooperation between institutions in this field is diversified and closely linked.

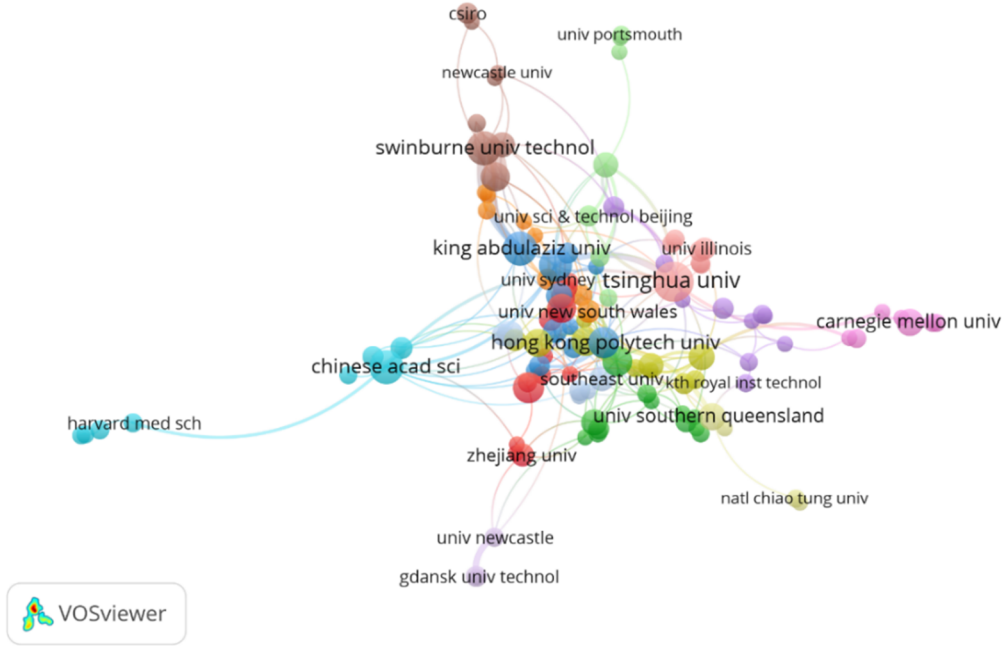


Fig 5. The institution collaboration network from 1990 to 2021

3.2.3. Authors Collaboration Network

Similarly, we construct author collaboration networks and

analyze the collaboration between authors.

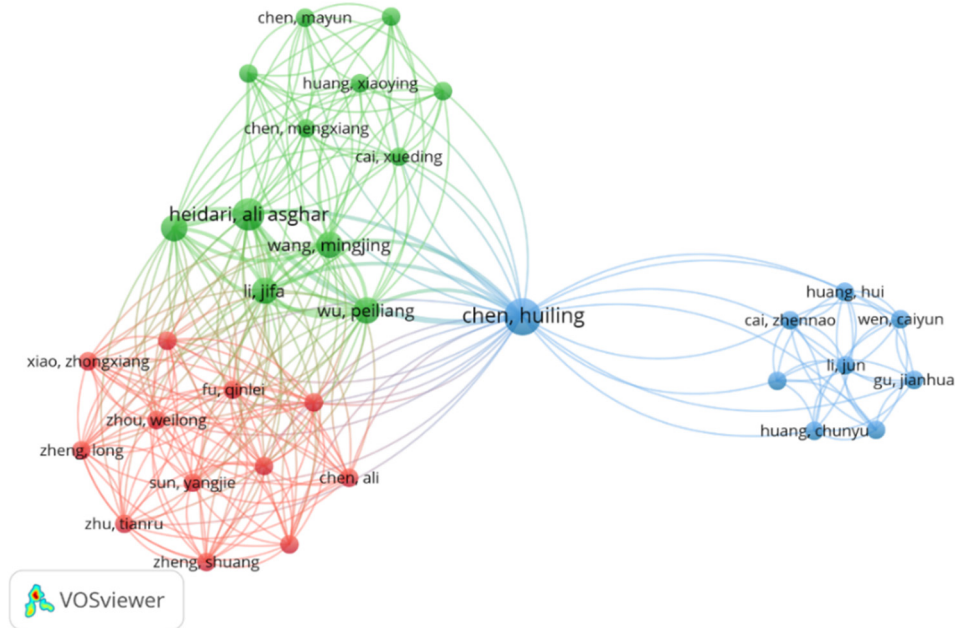


Fig 6. The author's collaboration network from 1990 to 2021

Setting a minimum value of 1 for inter-author collaboration, the 33 authors were classified into 3 categories throughout the period, with two categories having stronger ties between authors. The vast majority of authors were Chinese, suggesting that Chinese scholars prefer to collaborate collaboratively in the field. Chen is the most strongly connected scholar, and the scholars' research focuses on the application of ML in clinical healthcare.

4. Deep Analysis of ML and ID

Using CiteSpace, this section provides an in-depth study of the development of the field over the entire period from the dimensions of keyword co-occurrence analysis and burst detection analysis to help scholars grasp the research hotspots

in the field.

4.1. Co-occurrence Analysis

Keyword analysis is an important tool to grasp the hot spots of ML and ID development. Co-occurrence analysis is an analysis method to quantify the co-occurrence information in various literature, which is used to reveal the content association and implicit features of the literature. Figure 7 shows the co-occurrence network of keywords.

According to CiteSpace, we obtained 208 keywords. The frequency of keyword occurrences is proportional to the size of the nodes. In Figure 7, the largest cluster of keywords is ML, which appears 729 times, in addition to neural networks, predictive models, algorithms, categorization, deep learning, support vector machines, decision trees, and big data, among

other keywords that appear frequently. Thus, many publications related to ID and ML aim to improve ML algorithms to deal with prediction problems related to humans, management, medicine, and selection.

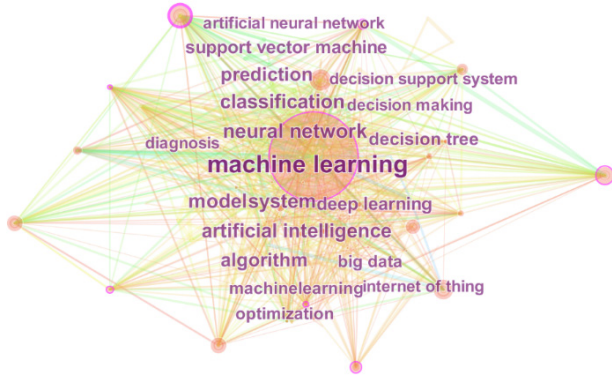


Fig 7. A co-occurrence network of keywords in ML and ID

4.2. A Cluster Analysis of Keywords

To better understand the hot topics in the field of ID and ML, keywords are clustered and analyzed in this section.

For better analysis, we used CiteSpace for cluster analysis and obtained keyword clusters for 8 publications. The top three clusters were "internet", "classification" and "COVID-19", indicating that data networks are the most important part of ID and ML, which has been widely used by researchers. In addition, networks are also the main tool for ML and ID for behavior prediction. Notably, "COVID-19" is the third-largest cluster, indicating that researchers have used ML and ID to effectively respond to emergent healthcare and resource-related problems in the context of novel coronavirus pneumonia. Prediction is the fourth-ranked cluster, with many researchers applying ML to the field of intelligent prediction.

The other clusters are "extreme learning machine", "trust", "model" and "covering algorithm".

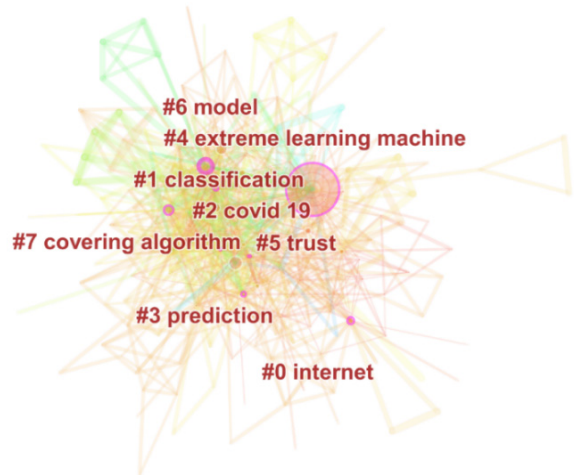


Fig 8. A cluster analysis of keywords in ML and ID

4.3. Burst Detection Analysis

Citation burst detection analysis reflects explosive data that have attracted widespread academic attention over a while and is used in this section to reflect the dynamics of publications related to ML and ID.

Table 4 lists the top 12 cited authors with the strongest citation bursts. Quinlan, as a cited author, has the maximum strength (18.94). Also, he has the longest citation burst, 14 years from 1990 to 2014. Only three of the top fifteen cited authors have an intensity of more than 10, Quinlan, Mitchell, and Vapnik. In addition, in Table 4, the closest citation burst ended in 2018, indicating that none of the top twelve highly cited authors is still in a citation burst.

Table 4. Top 12 cited authors with the strongest citation bursts from 1990 to 2021

Rank	Cited	Strength	Begin	End	1990-2021
1	Quinlan JR	18.94	1990	2014	
2	Mitchell TM	15.32	1994	2013	
3	Vapnik VN	11.16	2005	2014	
4	Goldberg DE	7.70	2003	2013	
5	Zadeh LA	6.82	2002	2018	
6	Guyon I	5.71	2012	2018	
7	Burges CJC	5.16	2005	2014	
8	Michalski RS	5.13	1994	2004	
9	Dietterich TG	5.12	2007	2018	
10	Fayyad U	4.39	2000	2016	
11	Kohonen T	4.33	2009	2012	
12	Joachims T	4.18	2007	2012	

Table 5 provides information on the top 12 most frequently cited journals over the period from 1990 to 2021 that have been cited most frequently over a certain period. C4.5 Programs for Machine Learning has the highest intensity of 25.23. C4.5 Programs for Machine Learning is dedicated to helping learn data mining C4.5 algorithms, as well as classification systems and other Machine Learning, has the longest citation burst, lasting 14 years from 1990 to 2014, and the start of the citation burst is the same as the start of the field's development, making it the first journal to dabble in

ML and ID, and having a wide influence in the early development of the field. The AI Mag citation explosion continued into 2018, and it is the most recent citation explosion to date. AI Mag was founded in 1980 and focuses on international advances in artificial intelligence. None of the top 15 highly cited journals had a citation burst that lasted until today, suggesting that they lack the impact on ML and ID that they have today.

Table 5. Top 12 cited journals with the strongest citation bursts from 1990 to 2021

Rank	Cited Journals	Strength	Begin	End	1990-2021
1	C4.5 Programs Machine	25.23	1998	2016	
2	Artificial Intelligence	21.47	1994	2012	
3	Machine Learning	18.91	1990	2014	
4	Commun Acm	11.89	1996	2011	
5	J Artif Intell Res	10.82	1999	2014	
6	Int J Prod Res	10.27	1993	2013	
7	Mach Lean	9.20	1996	2004	
8	Classification Regre	8.35	1997	2016	
9	AI Mag	6.43	1996	2017	
10	Neural Networks Comp	6.25	2001	2014	
11	Appl Artif Intell	5.67	1999	2008	
12	Adv Knowledge Discov	3.94	2000	2006	

Next, we examine the reference relationships between ML and ID from 1990 to 2021 and construct a visual reference network through CiteSpace to further elaborate the reference relationships, displayed in Figure 9.

The range of references and citations is proportional to the

size and color of the node. The larger the node, the wider the range of references, the darker the color, and the more citations. Thus, as shown in Figure 9, Quinlan, Lecun, and Han have their typical publications.

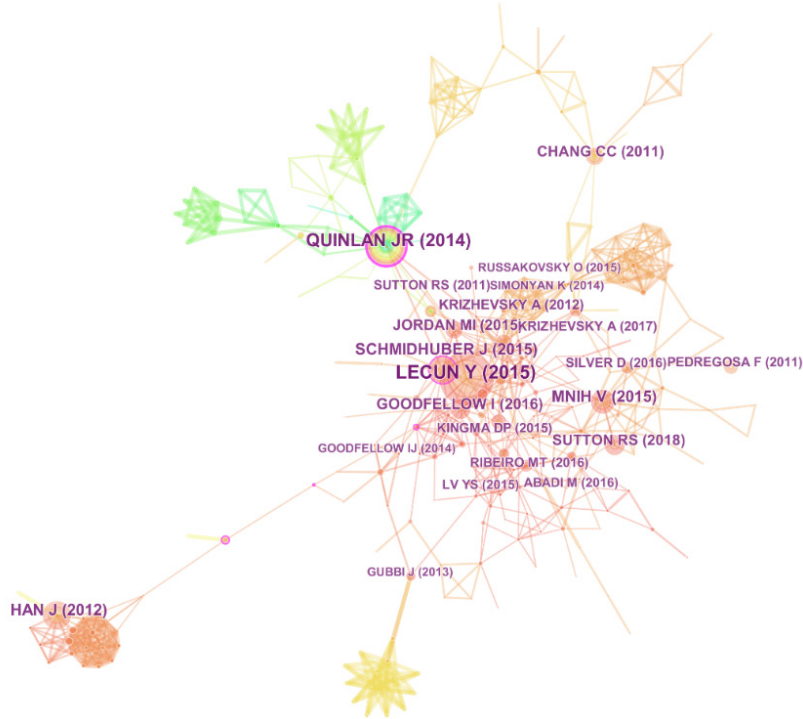


Fig 9. A visualization of the reference network

5. Conclusion

In this document, we analyze the focus of the field's development during the past 32 years through bibliometric methods to help scholars understand the trends in the field. Based on all the analyses we have conducted in the field of ML and ID, we have identified some problems and developmental characteristics of the field and obtained the following conclusions:

- (1) In recent years, the number of papers on this topic has grown explosively, but the growth rate has slowed down.
- (2) The current research hotspot is the deep integration of ML and ID to build deep neural networks and apply them to the analysis activities of mobile network applications. ML

algorithms are moving from single to multiple directions, and the application areas of decision-making are gradually widening.

ML and ID help us to improve adaptivity and decision effectiveness. Scholars have tried to build more flexible and complex models to cope with uncertain decision situations, while the emergence of big data and next-generation wireless networks has opened more possibilities for the development of the field. However, the synergistic relationship among scholars is not very close, partly characterized by individual and team-based development, which may be caused by the diversity of ML algorithms and the wide range of application fields.

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