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Research on the Disciplinary Evolution of Deep Learning and the Educational Revelation

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Abstract—**The significant growing popularity of Artificial Intelligence education is coincidence with the aggressive application of AI technology in modern society. Taking articles titled with "deep learning" and their citations from Web of Science core collections as an example, the disciplinary evolution and interdisciplinary progress of this field are analyzed and visualized. The interdisciplinary characteristics of different countries represent different directions and tendencies of scientific research and technique development on deep learning. Following the rule of theoretical and technological development of AI techniques, especially the interdisciplinary, reform of AI education need to focus on interdisciplinary in both education mode and curriculum content, deep integration of research and education, and close cooperation of industry, universities, and research institutes.**

Index Terms—**disciplinary evolution; deep learning; educational revelation; science overlap map.**

I. Introduction

Recent years, artificial intelligence (AI) and the education of AI talents has become a global awareness and caused extensive concern by most of the countries. In the AI Index 2018 Annual Report by Stanford University [1], the percentage of undergraduate students enrolled in introductory AI and Machine-learning (ML) courses is collected by years and compared by institutions, such as University of California-Berkeley (USA), Stanford University (USA), University of Illinois at UrbanaChampaign (USA), University of Washington-Seattle (USA), Carnegie Mellon University (USA), and Tsinghua University (China), National Institute of Astrophysics, Optics and Electronics (Mexico), University of British Columbia (Canada), University of Toronto (Canada), University of Edinburgh (Scotland), University of Science and Technology of China (China), and Shanghai Jiao Tong University (China). Most of these institutions have encountered a significant growing popularity of AI and ML courses since 2016, which is a quite coincidence with the application of AI, such as Machine-learning technology, in modern society during the third thriving of AI. Yann LeCun, Yoshua Bengio, and Geoffrey Hinton discuss the application of deep learning techniques to make up the limitations of conventional machine-learning techniques with the methods of multiple levels of representation and predict future multiple applications of deep learning methods and techniques. [2] Driven by complex application scenarios, like other important techniques of AI, deep learning has strong interdisciplinary characteristics. By digging and visualizing the global academic research data of deep learning, this paper will reveal its disciplinary evolution and discuss the related educational revelation.

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II. Materials and Methods

Raw materials of this paper come from eight Thomson Reuters Web of Science (WoS) core collections. The metrology tool ItgInsight is used to create an overview of disciplinary evolutional paths of deep learning. Visualization tool Pajek is practiced to obtain science overlap maps for both articles titled with "deep learning" and their citations, which show the interdisciplinary progress. Then, the interdisciplinary characteristics of deep learning are compared country by country to display different scientific research and technique development tendencies.

A. Dig data from WoS and count articles and their citations by year

Data were collected from WoS on April 8, 2019. Appling TI=("deep learning") to search English articles in the Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index - Science (CPCI-S), Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH), Book Citation

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Index Science (BKCI-S), Book Citation Index Social Sciences & Humanities (BKCI-SSH), Book Citation Index Social Sciences & Humanities (BKCI-SSH), and Index Chemicus (IC) from 1995 to 2018 (1995 is the year that “deep learning” first emerged in an article’s title). The preliminary search resulted in 2039 records (fig. 1) with h-index 65 and their citations were 16493 records.

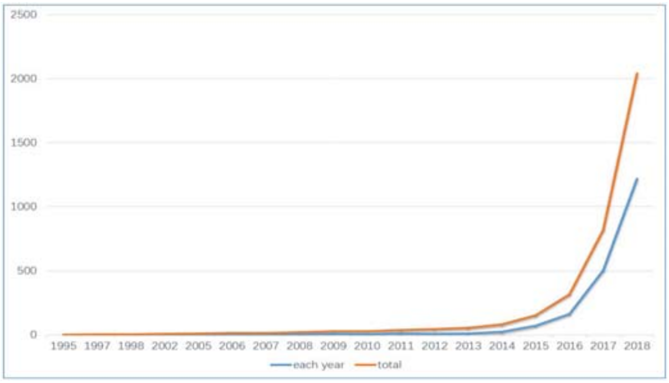

Fig. 1. Yearly and Total Articles of Deep Learning.

B. Disciplinary evolution by Itginsight

Eli B. Cohen and Scott J. Lloyd use different theories of evolution to describe the development, creation, and diminishment of disciplines and predicte the development of transdiscipline and its predominance in the near future. [3] This paper focuses on the evolution of disciplines with the topic of deep learning. During the period of 1995-2018, some of the disciplines appeared, developed, or vanished, but the overall evolution followed several paths. In 1989, Norman P.Hummon and Patrick Dereian firstly proposed the mainstream of an area of scientific research by the connective threads and links of its network. [4] Then the methods of Node Pair Projection Count, Search Path Link Count, and Search Path Node Pair which Hummon and Dereian used were widely applied in many fields, such as the study of the history of fuel cell research [5], global nanotechnology patenting [6], and the patent citation network taking wind motors technology [7].By using the metrology tool ItgInsight (visualinsight.itg.com), the disciplinary evolution of deep learning can be visible.

C. Science Overlap Map and Visualization

Science overlap map is launched by Ismael Rafols, Alan L. Porter, and Loet Leydesdorff [8] and is applied in mapping WoS categories [9] and generating global journal maps with WoS data [10], with the visualization by Pajek (vlado.fmf.uni-lj.si/pub/networks/pajek/). This paper will use Pajek to create science overlap map of deep learning titled articles and their citations.

D. Country to country comparison

Based on the data, Excel is used to analyze each year’s research articles on deep learning and count the number of each subject areas. Compare the number of articles and disciplines country by country and draw a radar map for visual analysis.

III. Results

This part will show the results of each method for analyzing the disciplinary evolution of deep learning.

A. Descriptive statistics of disciplines

Articles whose titles include “deep learning” are crossing 173 WoS Subject Categories (Wos totally has 252 Subject Categories in 2019) by this research. The top twenty categories and their article numbers plot in Fig. 2.

The top relative discipline is Engineering-Electrical & Electronic, which includes 451 articles. Six categories of Computer Science such as Artificial Intelligence(308), Information Systems(239), Interdisciplinary Applications(220), Theory & Methods(119), Software Engineering(108), and Hardware & Architecture(68) are among the top twenties. The fifth is Telecommunications, which includes 177 articles. Therefore, deep learning tightly relates to scientific researches in computer science, electrical & electronic science, and information science. However, it is not ignored that deep learning theories and technologies are widely applied in disciplines such as Medical Imaging, Biology, Instrumentation, Optics, Neurosciences, Chemistry, Physics, Materials Science, Health Care Science, and Education.

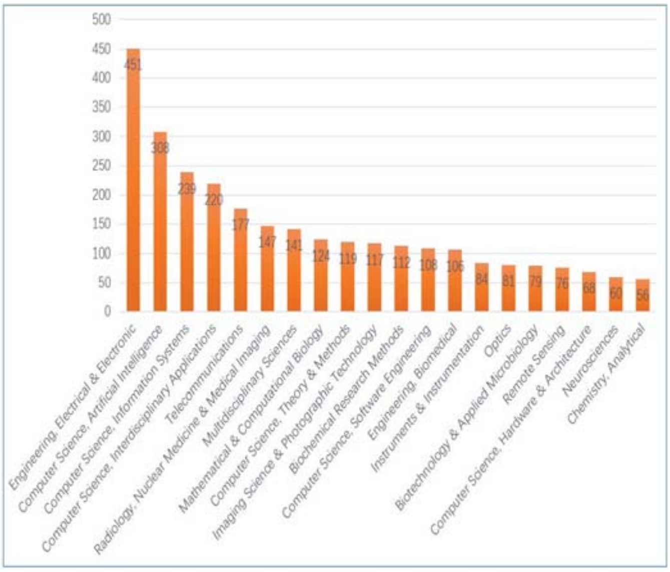

Fig. 2. Top twenty subject categories from 1995 to 2018.

The citations of 2039 articles are crossing 220 WoS Categories by this research and the top applied disciplines are Electrical & Electronic, Computer Science, Telecommunication, Imaging Science, Remote Sensing, Radiology Nuclear Medicine Medical Imaging, Optics, etc.

B. Disciplinary evolution

According to Fig. 1, after “deep learning” firstly appearing in an article’s title in 1995, the quantity of related articles grew very slow until 2015. The yearly total number is 81 from 1995 to 2014, 72 in 2015, 164 in 2016 (two times of year 1995-2014), 503 in 2017, and 1219 in 2018 (fifteen times of year 1995-2014). The disciplinary evolution of deep learning from 1995 to 2014 plots in Fig. 3 and from 1995 to 2018 plots in Fig. 4.

C. Overlap maps, trends, and comparisons

The subject overlap maps (Fig. 5 and Fig. 6) show the cross-discipline tendency of the articles titling and citing "deep learning" from 1995 to 2018. Firstly, from 1995 to 2014, the number of articles grew very slow and the number of disciplines distributed in sparse area. In 2015 and 2016, the disciplines started to converge to computer science, electrical & electronic science, and information science. Meanwhile, deep learning techniques applied to more fields. In 2017 and 2018, the number of articles climbing rapidly and an interdisciplinary participation trend is firmly shaped. The spread of disciplines in subgraph 2017-2018 is approached the distribution in subgraph 1995-2018, which proves its recent boom.

D. Interdisciplinary by Countriess

Among the top five countries (China, USA, South Korea, UK, and Australia) interdisciplinary of deep learning method and techniques plots in Fig. 7. Since the top three disciplinary (computer science, electrical & electronic science, and information science) are inseparable with deep learning and its main applicable fields (the numbers are several times to other fields), they are absent from this graph in order to see other fields and cross-discipline relations more clearly.

China and the USA are the leading country in research of deep learning and its interdisciplinary application. In the USA, deep learning is more likely to appear in the subject categories such as Radiology, Nuclear Medicine & Medical Imaging; Biochemical Research Methods; and Engineering, Biomedical. While, in China, deep learning links to Remote Sensing; Imaging Science & Photographic Technology; and Biochemical Research Methods. South Korea prefers Instruments & Instrumentation Radiology and Nuclear Medicine & Medical Imaging. The UK is about Engineering, Biomedical; Mathematical & Computational Biology; and Radiology, Nuclear Medicine & Medical Imaging.

IV. Educational Revelation

Around the time when Google AlphaGo defeated the worlds top ranking Go player in 2016, global enthusiasm and confidence for AI is rekindled. AI related theories and techniques are broadly developed and applied by governments, corporations, universities, and other institutions. Under such circumstances, AI talents are undoubtedly precious resources for each country. However, the long-term cultivation of talents and the urgent needs for AI talents become a pair of contradictions. Therefore, it is vital to reform the education model for AI talents by extremely following the rule of theoretical and technological development, especially the interdisciplinary of AI researches and education.

A. Interdisciplinary: from Form to Content

From the NEET program of MIT School of Engineering to the multi-disciplinary undergraduate program of some universities in China, education in AI related fields is influenced by the "New Engineering Education" idea and has focused on interdisciplinary. Many universities gradually explore new teaching form, curriculum outline, practice mode, and teacher allocation for interdisciplinary education. The next step of interdisciplinary education is the crossing and integration of content in each single course or in a certain course group, which is a breakthrough in the construction of both knowledge and students' thinking with frontier science and technology dynamics.

B. Deep integration: research and education

Colleges and universities, especially the top research universities, shoulder the important task of original, frontier, and subversive innovation of science and technology. Therefore, it is a suitable way to create a combination of research and education, promoting educational innovation by cutting-edge scientific researches and inspiring scientific research from educational interaction. Leading scholars will be encouraged to participate in new textbook compilation and new curriculum design that integrate the latest interdisciplinary scientific research progress and emerging knowledge into classes.

C. Strengthen cooperation: industry, universities, and research institutes

AI technology and education are closely tied the application scenarios, such as automobile manufacturing, health care and medical industry, transportation, and education. There are a large number of complex application scenarios in the society and industry. Therefore, through a new round of in-depth cooperation of industry, universities, and research institutes will facilitate students' education beginning from the classroom, actively practicing in different scenarios, being benefit from the cultivation of interdisciplinary knowledge, and achieving by the improvement of personal capability and multiple quality. Through this cooperation, potential AI talents will better understand the application scenarios and plan their future.

V. Conclusion

Based on the research data from WoS core collections, this paper create an overview of disciplinary evolutional paths of deep learning, visualize the interdisciplinary progress by science overlap maps, and analyze the interdisciplinary characteristics by country-country comparison. Researches on deep learning boomed from 2015. Both the articles titling deep learning and their citations show great interdisciplinary tendency, especially in recent years, which encounter the third thriving of AI research and education. Following the rule of theoretical and technological development of AI techniques, especially the interdisciplinary, reform of AI education need to focus on interdisciplinary in both education form and curriculum content, deep integration of research and education,

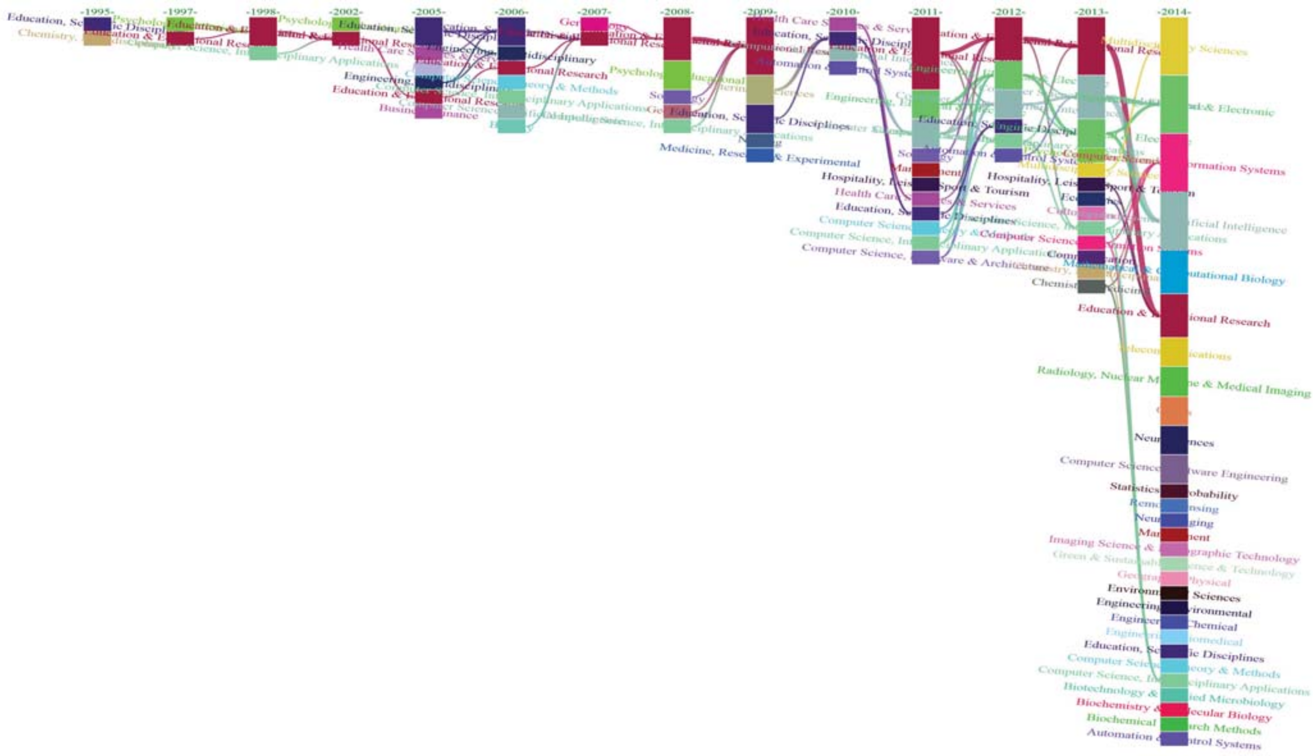

Fig. 3. Disciplinary evolution of Deep Learning from 1995 to 2014.

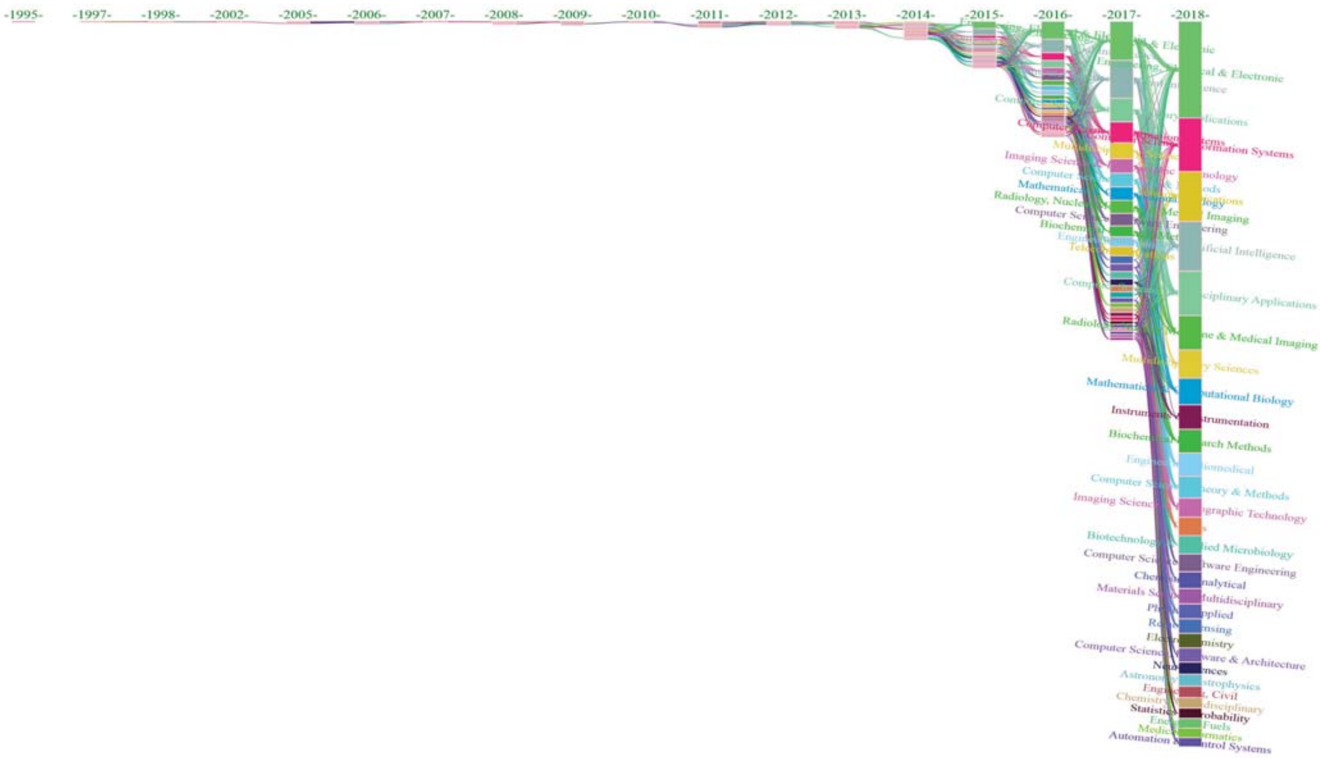

Fig. 4. Disciplinary evolution of Deep Learning from 1995 to 2018.

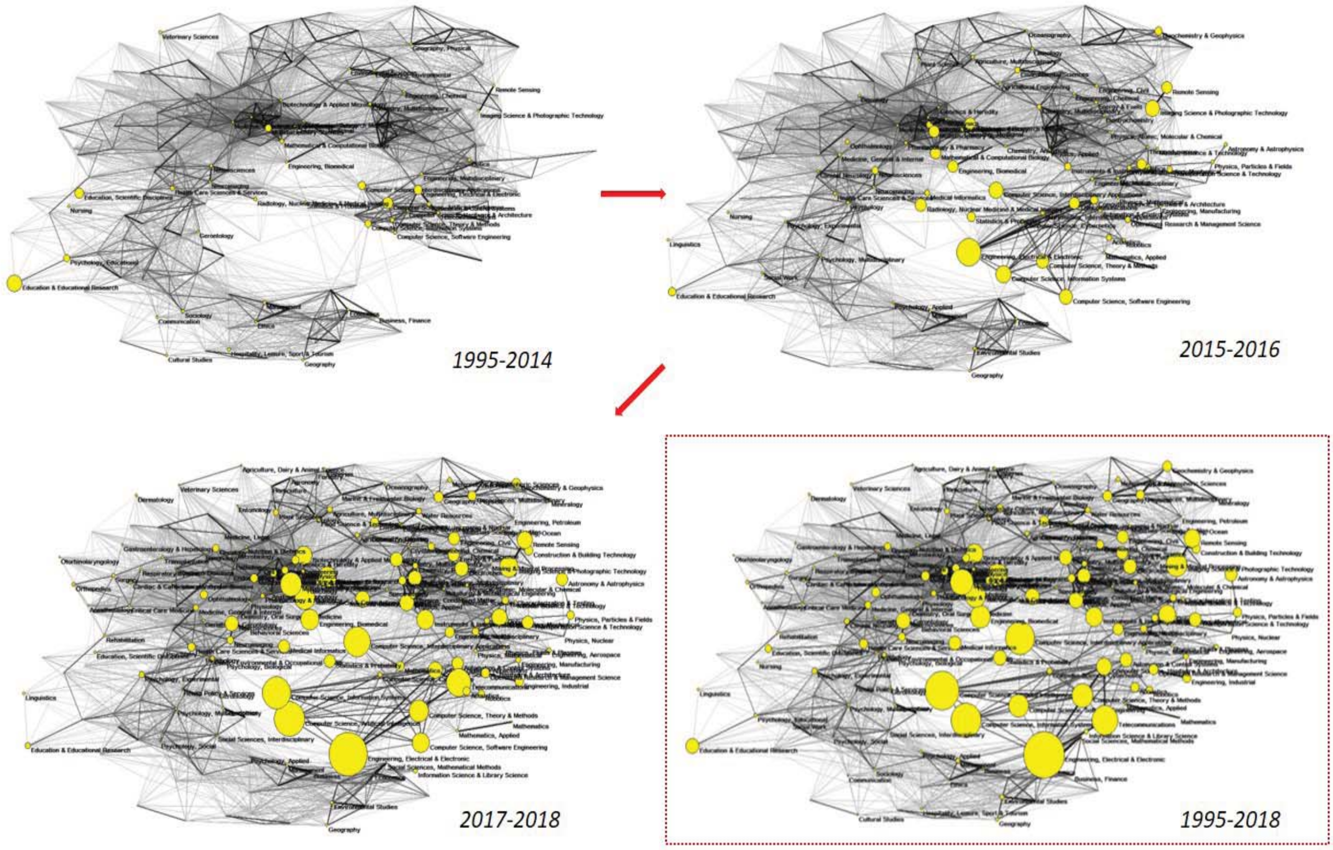

Fig. 5. Articles titling Deep Learning from 1995 to 2018.

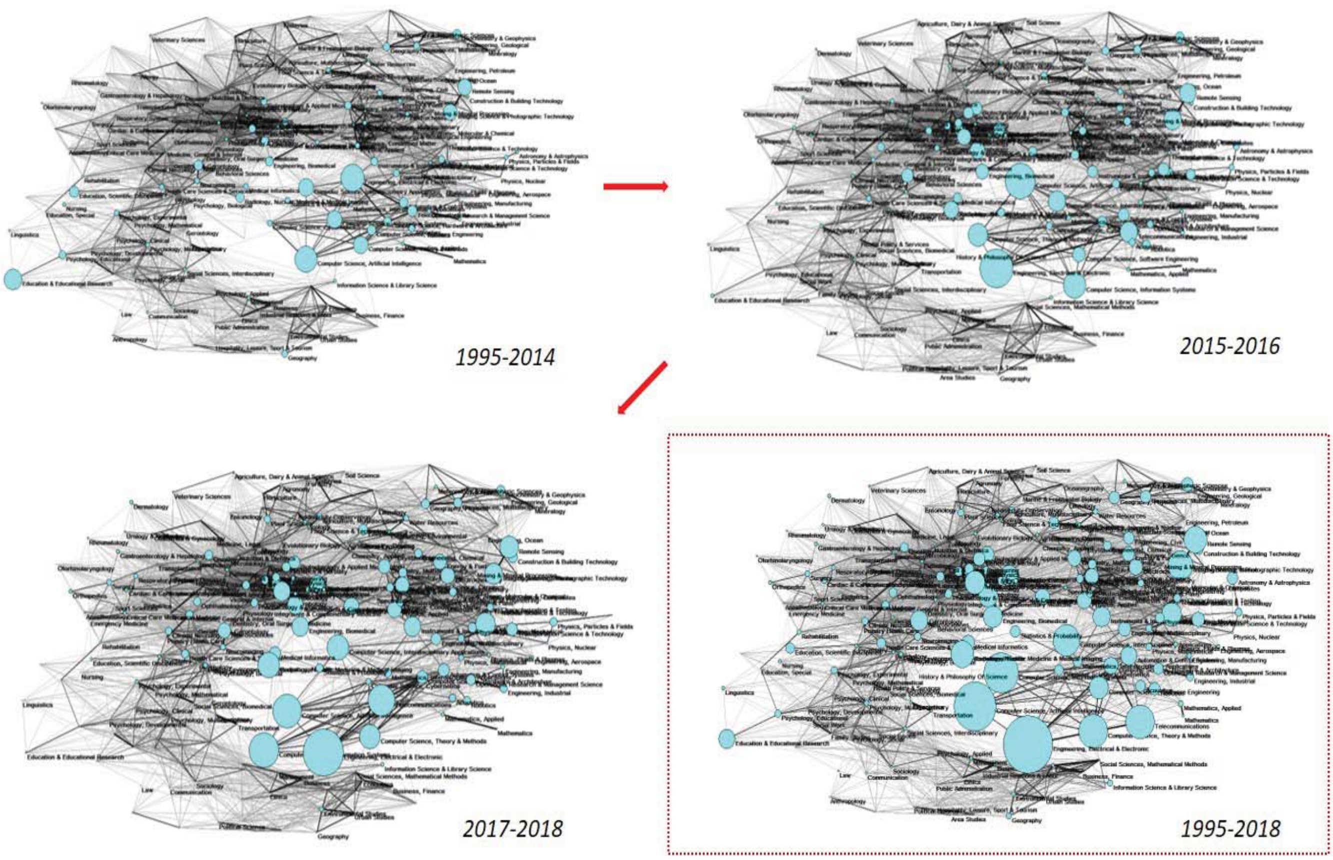

Fig. 6. Articles citing Deep Learning from 1995 to 2018.

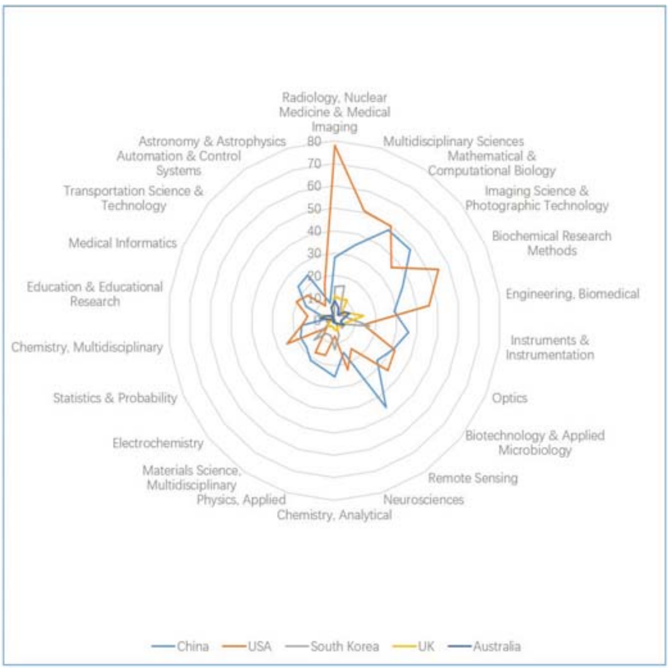

Fig. 7. Interdisciplinary by Countries from 1995 to 2018.

and close cooperation of industry, universities, and research institutes.

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