

Executive summary

Artificial intelligence (AI) is increasingly driving important developments in technology and business, from autonomous vehicles to medical diagnosis to advanced manufacturing. As AI moves from the theoretical realm to the global marketplace, its growth is fueled by a profusion of digitized data and rapidly advancing computational processing power, with potentially revolutionary effect: detecting patterns among billions of seemingly unrelated data points, AI can improve weather forecasting, boost crop yields, enhance detection of cancer, predict an epidemic and improve industrial productivity.

AI is the new electricity. I can hardly imagine an industry which is not going to be transformed by AI.

Andrew Ng, [Landing AI and deeplearning.ai](#)

Technology trends can be discerned through patent analytics

Drawing on WIPO's expertise in patent data analytics, this first publication in the series WIPO Technology Trends investigates the trends in the emerging AI era: it analyzes patent, scientific publishing and other data to review past and current trends in AI, while offering insights into how innovation in this field is likely to develop in the coming years.

This publication is among the first to systematically research trends in AI technology in order to discover which fields show the largest amount of innovative AI activity, which companies and what institutions are leading AI development, and the location of future growth markets.

WIPO has devised a new framework for the understanding of developments in the field, with AI-related technologies grouped to reflect three dimensions of AI: techniques used in AI, such as machine learning; functional applications, such as speech processing and computer vision; and application fields, including telecommunications and transportation.

For each of these areas, this report provides data and analysis that identify trends, key players, geographical spread and market activity, including acquisitions and litigation. In addition, it includes contributions from AI experts from across the globe, addressing issues such as existing and potential uses and impact of AI technology, legal and regulatory questions, data protection and ethical concerns.

AI-related inventions are booming, shifting from theory to commercial application

Since artificial intelligence emerged in the 1950s, innovators and researchers have filed applications for nearly 340,000 AI-related inventions and published over 1.6 million scientific publications.

Notably, AI-related patenting is growing rapidly: over half of the identified inventions have been published since 2013.

While scientific publications on AI date back decades, the boom in scientific publications on AI only started around 2001, approximately 12 years in advance of an upsurge in patent applications. Moreover, the ratio of scientific papers to inventions has decreased from 8:1 in 2010 to 3:1 in 2016 – indicative of a shift from theoretical research to the use of AI technologies in commercial products and services.

Some areas of AI are growing more quickly than others...

Machine learning is the dominant AI technique disclosed in patents and is included in more than one-third of all identified inventions (134,777 patent documents). Filings of machine learning-related patent have grown annually on annual average by 28 percent, with 20,195 patent applications filed in 2016 (compared with 9,567 in 2013).

The machine learning techniques revolutionizing AI are deep learning and neural networks, and these are the fastest growing AI techniques in terms of patent filings: deep learning showed an impressive average annual growth rate of 175 percent from 2013 to 2016, reaching 2,399 patent filings in 2016; and neural networks grew at a rate of 46 percent over the same period, with 6,506 patent filings in 2016.

Among AI functional applications, computer vision, which includes image recognition, is the most popular. Computer vision is mentioned in 49 percent of all AI-related patents (167,038 patent documents), growing annually by an average of 24 percent (21,011 patent applications filed in 2016).

Those AI functional applications with the highest growth rates in patent filings in the period 2013 to 2016 were AI for robotics and control methods, which both grew on average by 55 percent a year.

The growth rates observed in the identified AI-related patent data are noticeably higher than the average annual growth rate for patents across all areas of technology, which was 10 percent between 2013 and 2016.

...and many AI patents include inventions that can be applied in different industries...

AI-related patents not only disclose AI techniques and applications, they often also refer to an application field or industry. Analysis shows that many sectors and industries are exploring the commercial exploitation of AI. Twenty application fields were identified in the present analysis and at least one was mentioned in 62 percent of the total identified AI patent data. These include, in order of magnitude: telecommunications (mentioned in 15 percent of all identified patent documents), transportation (15 percent), life and medical sciences (12 percent), and personal devices, computing and human–computer interaction (HCI) (11 percent). Other sectors featuring in the results include banking; entertainment; security; industry and manufacturing; agriculture; and networks (including social networks, smart cities and the Internet of things).

Many AI-related technologies can find use across different industries, as shown by the large number of patents in AI that refer to multiple industries. Transportation is prominent not only in the overall results, it also features among those fields showing the highest growth rates in AI-related patent applications, with a 33 percent annual growth between 2013 and 2016 (8,764 filings in 2016). Rapidly emerging within the transportation category are aerospace/avionics (67 percent annual growth, with 1,813 filings in 2016) and autonomous vehicles (42 percent annual growth, with 5,569 filings in 2016). The boom in transportation technologies becomes more evident when we look at trends over the period 2006–2016: representing just 20 percent of applications in 2006, by 2016 it accounted for one-third of applications (more than 8,700 filings).

While not showing the same high rate of growth as transportation, patent filings in AI-related telecommunications still grew annually by an average of 23 percent between 2013 and 2016, with 6,684 filings in 2016. Within telecommunications, the most growth

was seen by computer networks/Internet (17 percent) and radio and television broadcasting (17 percent). Life and medical sciences grew by 12 percent in the same period, with 4,112 filings in 2016, including medical informatics (18 percent growth) and public health (17 percent growth). Personal devices, computing and HCI grew an average of 11 percent annually between 2013 and 2016, with 3,977 filings in 2016, and within this category notable growth occurred in the sub-field of affective computing (37 percent), which recognizes human emotion.

Other sectors and sub-categories within sectors with notable growth in patent filings include: smart cities (47 percent annual growth); agriculture (32 percent); computing in government (30 percent); and banking and finance (28 percent).

...while certain AI techniques, applications and industries appear to be closely linked.

Nearly 70 percent of inventions related to AI mention an AI technique, application or field in combination with another. The most frequent combinations in patent filings are: deep learning with computer vision; computer vision with transportation, telecommunication and security; ontology engineering with natural language processing; and machine learning with life and medical sciences. These combinations suggest areas to watch for rapid developments in AI in the near future.

Companies, in particular those from Japan, the United States of America (U.S.) and China, dominate patenting activity

Companies represent 26 out of the top 30 AI patent applicants, while only four are universities or public research organizations. This pattern applies across most AI techniques, applications and fields. Of the top 20 companies filing AI-related patents, 12 are based in Japan, three are from the U.S. and two are from China. Japanese consumer electronics companies are particularly heavily represented.

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IBM and Microsoft are leaders in AI patenting across different AI-related areas

IBM has the largest portfolio of AI patent applications with 8,290 inventions, followed by Microsoft with 5,930. Both companies' portfolios span a range of AI techniques, applications and fields, indicating that these companies are not limiting their activity to a specific industry or field. Rounding out the top five applicants are Toshiba (5,223), Samsung (5,102) and NEC (4,406). The State Grid Corporation of China has leaped into the top 20, increasing its patent filings by an average of 70 percent annually from 2013 to 2016, particularly in the machine learning techniques of bio-inspired approaches, which draw from observations of nature, and support vector machines, a form of supervised learning.

In certain techniques and fields, the highest numbers of patent applications originate from companies with a high degree of specialization and expertise in that field. Examples include Baidu, which ranks highly for deep learning, Toyota and Bosch, which are prominent in transportation, and Siemens, Philips and Samsung in life and medical sciences. Some well-known companies that do not feature among the top overall players in AI patents are nonetheless prominent in certain areas; these include Facebook and Tencent in networks and social networks. Industry expertise and access to specialized data may explain why certain companies lead in specific industries.

Universities contribute significantly to AI research in specific fields, with Chinese universities dominating

Despite the dominance of companies in AI, universities and public research organizations play a leading role in inventions in selected AI fields such as distributed AI, some machine learning techniques and neuroscience/neurorobotics.

Chinese organizations make up 17 of the top 20 academic players in AI patenting as well as 10 of the top 20 in AI-related scientific publications. Chinese organizations are particularly strong in the emerging technique of deep learning. The leading public research organization applicant is the Chinese Academy of Sciences (CAS), with over 2,500 patent families and over 20,000 scientific papers published on AI. Moreover, CAS has the largest deep learning portfolio (235 patent families). Chinese organizations are consolidating their lead, with patent filings having grown on average by more than 20 percent per year from 2013 to 2016, matching or beating the growth rates of organizations from most other countries.

The Republic of Korea's Electronics and Telecommunications Research Institute (ETRI) stands out as second in patent filing among universities and public research organizations and ranks among the top 30 patent applicants overall.

There are 167 universities and public research organizations ranked among the top 500 patent applicants. Of these, 110 are Chinese, 20 are from the U.S., 19 from the Republic of Korea and 4 from Japan. Four European public research organizations feature in the top 500 list; the highest-placed European institution is the German Fraunhofer Institute, which is ranked 159th, while the French Alternative Energies and Atomic Energy Commission (CEA) is in 185th position.

The U.S. and China are the main targets for AI patent filing...

The U.S. and China are the two most popular offices for filing AI patents, in line with

patenting trends in other fields, followed by Japan. These three offices account for 78 percent of total patent filings. There has been an increasing use of WIPO's PCT System, which allows patent applicants to file in multiple jurisdictions by filing a single application. The PCT route ranks fourth among the top targets for AI patent filings.

...but filings are increasingly international

Many patent applications are extended to more than one jurisdiction. One-third of all AI patent applications are filed in additional jurisdictions after their first filing and 8 percent are filed in five or more jurisdictions.

Out of the top three filing offices, 40 percent of patent applications first filed in Japan and 32 percent of patent applications first filed in the U.S. are subsequently also filed elsewhere. Just 4 percent of patent applications first filed in China are subsequently filed in other jurisdictions.

Chinese companies and universities currently tend to file in China only, compared with applicants from other countries, particularly the U.S.

Acquisitions complement internal research and IP strategies

In total, 434 companies in the AI sector have been acquired since 1998, with 53 percent of acquisitions having taken place since 2016. The number of acquisitions identified in the AI sector has increased every year since 2012, reaching 103 in 2017. Although Alphabet (including Google, DeepMind, Waymo and X Development) ranks 10th in the number of inventions filed, with 3,814 in total, it ranks 1st in terms of acquisitions of AI companies. Apple and Microsoft have also been active in acquisitions.

Certain companies, such as IBM and Intel, target mature companies. The majority of acquired companies are, however, startups with small or non-existent patent portfolios. This suggests that targets are being acquired

for other assets, including talent, data, know-how and other IP.

Cooperation in AI research is limited, but so is conflict

In many cases, organizations that cooperate in research are credited as co-assignees on patent applications. However, none of the top 20 applicants shares ownership of more than 1 percent of its AI portfolio with other applicants.

Overall, the amount of litigation identified in the report is relatively low (less than 1 percent of patents being litigated), which may be due to the fact that products have not yet come to the market and infringement may be difficult to prove. There have been 1,264 AI patent families identified in litigation, with 74 percent of cases in the U.S., and 4,231 in patent opposition cases worldwide. The top three plaintiffs in litigation over AI patents are Nuance Communications, American Vehicular Sciences and Automotive Technologies International.

Technology trends can inform policymaking on the future of AI

The analysis presented in this report offers new insights into trends in AI innovation. It shows the extent to which artificial intelligence is playing an increasingly important role in a range of technological and other activities. The potential societal impact of AI has already been identified – and much more is to come. In this regard, AI must be viewed in conjunction with its expected effect on the workforce, the economy and society as a whole.

Policymakers will have to move quickly to keep up with AI-related developments and shape the direction of AI's evolution. A variety of stakeholders will have to reflect on the correct policy mix to maximize the widest possible benefits from AI, with particular focus on AI-related strategies, policies, laws and regulations addressing legal and ethical considerations; access to and ownership of digital data and its effect on IP systems; availability of an appropriately skilled

workforce; and investment strategy and related funding.

This report documents how AI-powered technologies are rapidly entering global markets and brings together viewpoints from experts at the cutting edge of AI. It is a contribution that aims to provide decision-makers in the public and private sectors with an improved knowledge base for discussions on the future of AI and the policy and regulatory framework for this fast-moving area.

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