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KAIST Innovation Strategy and Policy Institute

The innovation landscape of artificial intelligence

The global competition to build a successful AI ecosystem

CONTENTS

Key insights

The high demand for technology innovation is the driving force of AI growth.

With the advancements in high-performance computing and big data, artificial intelligence (AI) has become a key player in technological innovation. Patents for AI inventions filed in the past 10 years show that the technology of AI has evolved into a wide range of applications and industries. AI technology enables systems to be intelligent enough to interact with people in various areas, such as health care, manufacturing, consumer products, and the automotive industry. The strength of AI is its ability to converge with other technologies to generate superior performance, enabling many conventional technologies to overcome existing limitations and leap forward to provide next-generation solutions to difficult real-world problems.

The competition in AI technology has continuously become more intense.

The pursuit of AI technology has caused heated competition among countries, industries, and sectors. Many countries see AI as a part of a national agenda to make it a growth engine of technology innovation and industrial expansion. Countries and corporations have established their own goals, strategies, and investment plans for AI technology; thus, the real competition is only just beginning. Analysis of trends in invention show that several countries demonstrate outstanding performance, whereas others still need to improve the quality of their AI inventions in various respects.

Building a strong AI ecosystem is the first step toward securing a competitive advantage in AI.

Technology innovation cycles explicitly show that competitive technology comes from strong collaborative research and development (R&D). Therefore, the AI ecosystem of a country will benefit from the strong engagement of multiple stakeholders such as academic universities, research institutes, government agencies and corporations. For best results, the core competencies of AI innovation should be seamlessly integrated, interacting concertedly within the ecosystem. In particular, the collaboration between the research community and industry is critical in building a strong ecosystem. Although AI has been in the market for decades, it has only recently attracted wide attention. Therefore, there may not be enough experience and talent in the AI field to support industrial demand. The role of universities and research institutes involves not only conducting innovative R&D but also training and educating talented personnel to create innovation sources for industry with the use AI technologies. The demands of industry can also stimulate the research community to produce increasingly innovative ideas to overcome real-world challenges.

Countries that build a strong AI ecosystem early on will likely enjoy various benefits. Many countries and corporations are competing for skilled AI talent, which is in limited supply around the world. This talent pool plays a key role in AI innovation by either improving R&D performance or rendering

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Definition of artificial intelligence:

Artificial intelligence is a system that aims to think and act like a human. To qualify as AI, a system should have the capability to recognize its environment and learn, to think about relevant solutions and to undertake actions in order to achieve one or more specific goals. There are many AI technologies, each of which has its own characteristics and capabilities. However, such systems must possess one feature in common: demonstrating intelligence.

Source: Stanford Encyclopedia of Philosophy

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businesses more competitive. This could result in the growth of businesses and the industry, enabling them to offer better jobs and higher compensation. In this way, the AI ecosystem could help to energize the growth of businesses beyond their domestic market and attract more global AI talent. This successful 'virtuous cycle' will accelerate the growth of the AI ecosystem.

The quality of innovation, not its volume, is a critical success factor in technological competitiveness.

Despite the large volume of inventions, only a few outstanding ideas are converted into products and services and subsequently contribute to business growth. Thus, developing innovative AI technology that stands out in the crowd is not a simple task, as patent applications for roughly 140,000 AI ideas have been filed since 2010. (Source: Derwent Innovation™ from Clarivate.) We expect AI technology innovation to become more challenging and the investment risks in AI innovation to grow.

Data analyses show that AI involves a wide spectrum of technologies. Each country has different priorities in development, and sectoral performance within a country is rarely well balanced. Some countries have a large volume of inventions with a limited technological impact, whereas others produce fewer inventions but with greater impact. Although some countries and corporations make a competitive display of announcing their commitment to AI, (see Table 1, page 14), it remains questionable whether these entities actually possess sufficient resources to fully execute their plans.

Future investments in AI should be very strategic.

As is shown in this report, the AI landscape includes many technologies, each of which has unique characteristics, strengths and limitations. From an R&D perspective, innovative ideas should be differentiated from other existing ideas and should demonstrate better performance. Recent trends in AI innovation have evolved into the convergence of existing AI technologies with other technology. Hybrid AI technologies often demonstrate outstanding performance and receive much attention from other researchers and industries. From a business perspective, AI is continuously expanding its areas of application, but to companies interested in pursuing the technology, we recommend answering the following question first: "What do you want to achieve from AI?" There is no one-size-fits-all AI solution. AI is a very sensitive technology, and using it to develop a market-accepted application is never easy. If the wrong technology is selected or the adoption of AI has no clear business objective, the results of your investment may be disappointing. A successful investment strategy should come from a thorough understanding of various technologies and a clear assessment of the problem you want to solve with AI and the surrounding AI ecosystem. The appropriate AI technology is too complicated to develop alone without collaboration with other experts.

Cross-industry learning is important in AI innovation.

The analysis in this report also shows that each industry adopts AI technology in a different way due to each industry's unique characteristics, customers, challenges and data readiness for AI. Some industries are already aggressively employing various AI technologies, while others are using only a limited set of technologies. Although the maturity of AI adoption differs across industries, there is still great potential for AI to grow and demonstrate its outstanding performance in the near future. This analysis provides an idea of which technology to use in your industry. If you are unclear about the business case for AI application, one approach is to benchmark another industry. Although the challenges in the other industry may be different, the underlying nature of the problem will likely be similar.

AI technology may widen the economic gap among countries.

Along with examining the various benefits of AI, this report also raises a potential concern. The top 10 countries produce 92% of the world's total AI inventions, and their total gross domestic product (GDP) represents 41% of the world's total GDP. As previously explained, countries empowered by AI will be in a better position to expand their industrial and economic base to compete with other nations. Conversely, a country that is slow or fails to build a strong AI ecosystem will struggle to reach the same level of AI competence. Technology innovation in AI is currently dominated by a few countries, and this may widen the industrial and economic gap between AI-leading countries and the rest of the world, especially developing nations. AI, which is intended to improve various aspects of people's lives such as health care, safety and well-being, may paradoxically create inequality in the ability to obtain benefits from advanced technologies. At this stage, there is no consensus or plan on how AI's "have" nations might share the technology with the "have nots" for the benefit of all.

Many ethical aspects of AI remain unresolved

AI is intelligent enough to make decisions by itself with minimal human intervention and to deliver impressive performance to accelerate technology. Corporations and countries are budgeting enormous amounts to AI to gain an advantage over the competition. Meanwhile, although AI is recognized as a promising technology for the future, it also has potential downsides.

Researchers have warned of the potential risk of AI systems, which can sometimes make opaque and biased decisions. The behavior of AI systems is affected by algorithm logic or given datasets used for training. For example, AI trained by a biased dataset can run the risk of introducing racial, gender and ethnic discrimination in financial loan applications. In the healthcare industry, many experts are concerned about misuse of privacy data. Another risk invokes the theoretical scenario of the "trolley problem" – a series of thought experiments in ethics and psychology, involving stylized ethical dilemmas of whether to sacrifice one person to save a larger number. Designers face a huge challenge in creating an AI algorithm to control how an autonomous vehicle should behave when facing a split-second choice between possibly killing one person to save many pedestrians, or the other way around.

Researchers and policy makers have been debating AI ethics in order to set guidelines and principles to protect human life, rights and dignity. Some governments are trying to make laws and regulations for AI ethics, but corporations are often opposed, given that such measures can hinder corporate growth. In all, as the ethical aspects of AI draw increasing attention from government and consumers, this topic will become a critical issue for social sustainability.

In 2019, the European Union (EU) released Ethics Guidelines for Trustworthy Artificial Intelligence, which state that violating data governance and posing unacceptable risks with AI can carry fines of up to UD $35M or 6% of an offending company's global annual revenue. This provoked major concern from EU corporate sectors, as these penalties can impede the growth of the AI industry and also put EU companies in an unfavorable position against global competition.

Nevertheless, the focus on AI ethics has become an imperative agenda, and many governments are trying to enact laws and regulations, even while some industry entities may perceive these measures as an obstacle to their growth and often oppose the action. The confrontation between the two opposing factions is ongoing.

In the data

The development of AI has made a significant leap forward in recent years with the substantially increasing volume of AI-related inventions.

Clarivate™ and KAIST have partnered to develop the insights generated in this report, using Clarivate proprietary data from Derwent Innovation™, Derwent World Patents Index™ (DWPI) and Derwent Patent Citation Index™ – tools that provide a comprehensive picture of worldwide patenting activity and influence.

The report's key findings:

- Neural networks and machine learning have been unrivaled in terms of scale and growth (more than 46%), and most other AI technologies show a growth rate of more than 20%.
- Although Mainland China has shown the highest growth rate in AI inventions, the influence of Chinese AI is relatively low. In contrast, the United States holds a leading position in AI-related inventions in terms of both quantity and influence.
- The U.S. and Canada have an industry-oriented AI technology development ecosystem through organic cooperation with both academia and the government. China and South Korea, by contrast, have a government-driven AI technology development ecosystem with relatively low qualitative outputs from the sector.
- The U.S., the United Kingdom, and Canada have a relatively high proportion of inventions in robotics and autonomous control, whereas in Mainland China and South Korea, machine learning and neural networks are making progress. Each country/region produces high-quality inventions in their predominant AI fields, while the U.S. has produced high-impact inventions in almost all AI fields.
- Each industry in the U.S. uses AI technologies differently:
  - Electric and electronic parts: Neural networks, machine learning, and robotics and autonomous control are actively being harnessed in the recent growth of neuromorphic computing and deep learning technologies.
  - Industrial machinery and equipment: Various AI technologies, such as robotics and autonomous control, neural networks, and machine learning are being applied to improve the efficiency and service of smart manufacturing and product devices.
  - Business services: Neural network inventions, including object recognition, are particularly active in developing the process of analyzing unstructured data.
  - Financial industry: The development of human language processing technologies has been accelerated to analyze work content more quickly and accurately.
  - Telecommunications: Robotics and autonomous control technologies have been dominant in this industry. However, neural networks and machine learning have shown the fastest growth rate and have provided more customized services.

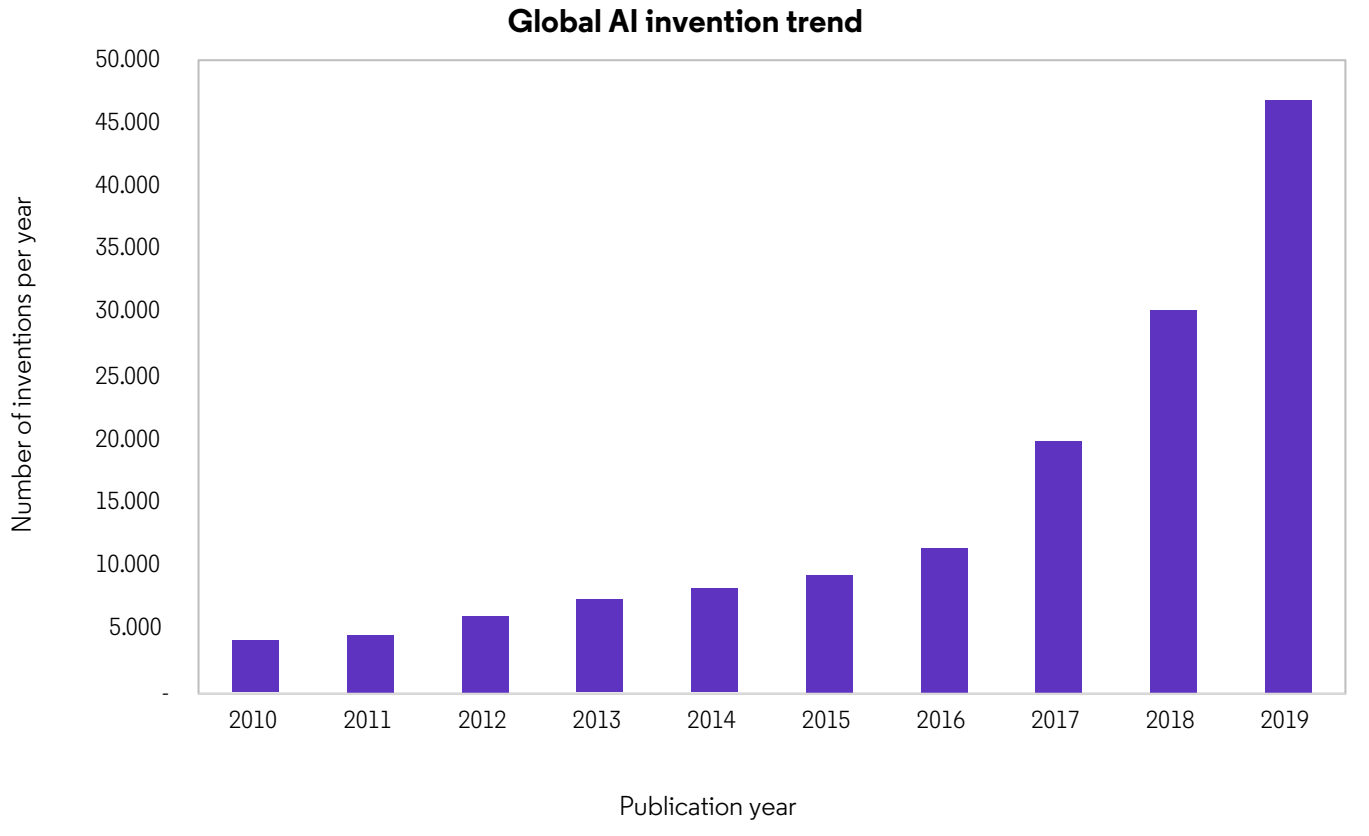
Big wave: Digital innovation and AI

The evolving landscape of AI innovation

High-tech IT technologies, such as big data, the Internet of Things, and AI, are accelerating the digital transformation by leading an intelligent hyper-connected society and enabling the convergence of technology and business. With the rapid growth of AI innovation, AI applications are also expanding in various ways across industries and in our lives.

As technological expectations in industries and society rise, many AI-related fields have seen large-scale investment because of the fierce competition between countries and companies for AI innovation. However, without the proper strategy, the continuous evolution of AI and the different characteristics of each technology may result in inefficient investing. Therefore, it is necessary to establish a systematic strategy and policy direction for AI technology innovation.

Figure 1. Number of global AI inventions (2010–2019)*



Source: Derwent Innovation™ from Clarivate

* Inventions and patents: The same invention idea can be applied to multiple patent applications in different countries. For example, if the same invention idea is filed in Korea, the US, and Japan, the number of inventions is one, but the number of patents is three. Therefore, to analyze the performance of AI technology innovation, we analyze the number of inventions.

The number of AI invention filings has increased rapidly in recent years. The number of AI patent filings has grown exponentially. The competition to dominate AI technology in the market is very intense compared to other technologies.

This report objectively analyzes the landscape of technology innovation based on AI inventions* around the world and provides guidelines for constructing a systematic strategy to develop AI technology. Through various analyses, this report attempts to discover what efforts could be made around the world for best results.

Approximately 147,000 AI technology inventions were filed worldwide between 2010 and 2019, and the number of published inventions demonstrated a very high compound annual growth rate of approximately 31.2%, according to analysis conducted using Derwent™ data. This suggests that related R&D and technology innovations are rapidly increasing as AI technologies find application in various fields. In addition, research is actively being conducted on social and industrial phenomena that have followed the introduction of AI.

Studies on the AI impact and new insights: Do we have a J-curve?

As new AI technologies are used in society and industry, academic research has increased rapidly since 2018, as the data sources cited on this page discuss The overall research results suggest an important direction in the process of preparing for the digital transformation across firms and industries.

AI is classified as a general-purpose technology (GPT) that can be used in various industrial applications, such as engines, electricity and computers. This implies that AI has been evaluated as a technology that can dramatically transform work time, production and even everyday life. As a GPT, AI has the economies of scale and economies of scope with a high potential for creating a new disruptive industry.

AI can be used in a wide range of industries (a quality referred to as 'pervasiveness'), and as it continues to evolve, the cost of using the technology will most likely fall, enabling rapid improvements (that is, improvement potential). AI also supports new business models and product and service innovations (i.e., innovational complementarities).[1]

Recent AI research

- Although AI reduces the demand for human labor, it raises productivity and creates new jobs through lower production costs, accumulated capital and advanced automation.[2]

- Based on experiments on patent examination, machine learning has high prediction accuracy in fields similar to data input but comparatively low accuracy in other fields. More efficient results are likely when the input of experts in the field is combined with machine learning.[3]

- During the early stages of AI introduction, it was predicted that productivity would decrease due to the time and cost required at the beginning of the adoption and transformation process.[4] Interestingly, this J-curve phenomenon in AI introduction was empirically found at small and medium-sized enterprises (SMEs) in South Korea.[5]

[1] Gambardella, Alfonso and Anita M. McGahan. "Business-model innovation: General purpose technologies and their implications for industry structure." Long Range Planning 43.2–3 (2010)

[2] Acemoglu, D., & Restrepo, P. (2018). The race between man and machine: Implications of technology for growth, factor shares, and employment. American Economic Review, 108(6), 1488-1542.

[3] Choudhury, P., Starr, E., & Agarwal, R. (2020). Machine learning and human capital complementarities: Experimental evidence on bias mitigation. Strategic Management Journal, 41(8), 1381-1411.

[4] Brynjolfsson, E., Rock, D., & Syverson, C. (2021). The productivity J-curve: How intangibles complement general purpose technologies. American Economic Journal: Macroeconomics, 13(1), 333-72.

[5] Lee, Y., Kim, T., Choi, S., & Kim, W. (2021). When does AI pay off? AI-adoption intensity, complementary investments, and R&D strategy. Working paper

AI will continuously evolve by interacting with adjacent technologies and applications. Digital convergence will accelerate the growth of AI technology in various applications and industries.

Recent studies have investigated the impact of AI adoption on the demand for labor and corporate performance at a deeper level with firm-level microdata.

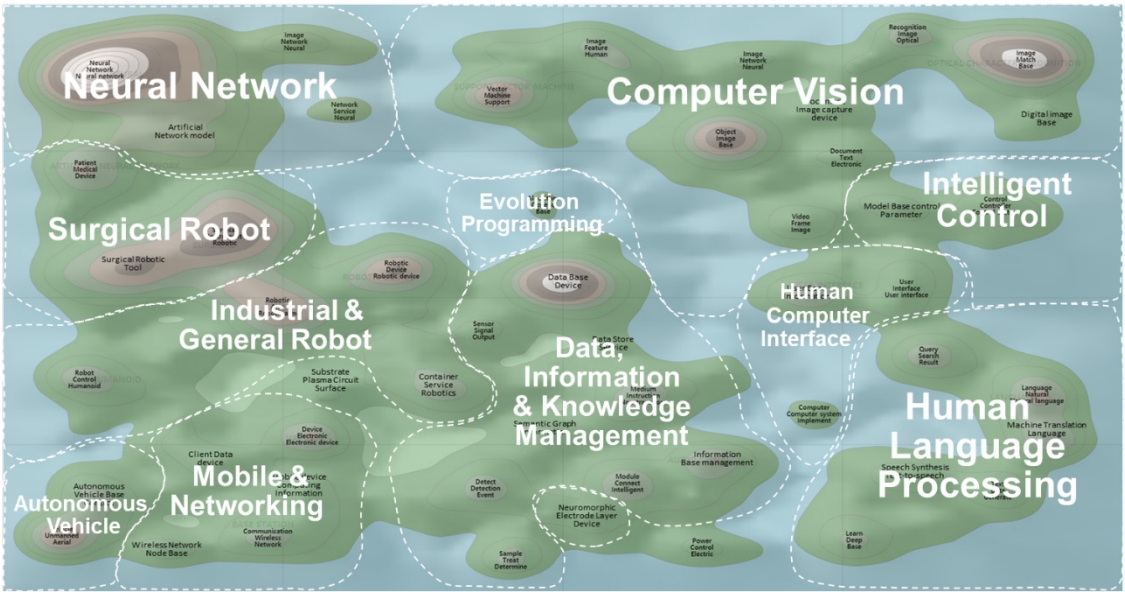
In addition, we expect that, based on these findings, the early stage of AI will bring various industrial and social changes, such as decreases in the value of related stocks, an increase in premiums for AI-related highly skilled technicians, the entry and exit of companies (mergers and acquisitions), and the successful growth of SMEs and startups. As the development and use of AI technologies expand, many social issues will emerge. Therefore, in addition to promoting technology innovation, keeping a close eye on these phenomena and preparing in advance are important in a technology-oriented society.

AI technology landscape

Since 2010, AI technology innovation has actively progressed in various fields. As shown in the map analysis in Figure 2, based on Derwent™ data, various AI technologies have been developed.

- The map is derived through a big-data analysis of AI-related inventions.[6] More patent applications have been filed in the sectors with higher peaks. Selecting a specific peak region on the map reveals more detail on the patent portfolio for that region.
- The relative proximity between the peaks reveals the relationship between technologies. For example, Mobile & Networking and Robot technologies are located next to Autonomous Driving technology. Moreover, Neural Networks and Information Processing technologies are located next to fields pertaining to robotics.
- Similarly, in the lower right of Figure 2, fields pertaining to data and information management, as well as to human/computer interfaces, are adjacent to research on human language processing.

Figure 2. Landscape map of AI technologies



Source: Derwent Innovation™ from Clarivate

[6] Clarivate Derwent Innovation DWPI/DPCI. A portfolio of inventions included in the top 30% of the world's CPI (Combined Patent Impact) index among 2010–2019 inventions.

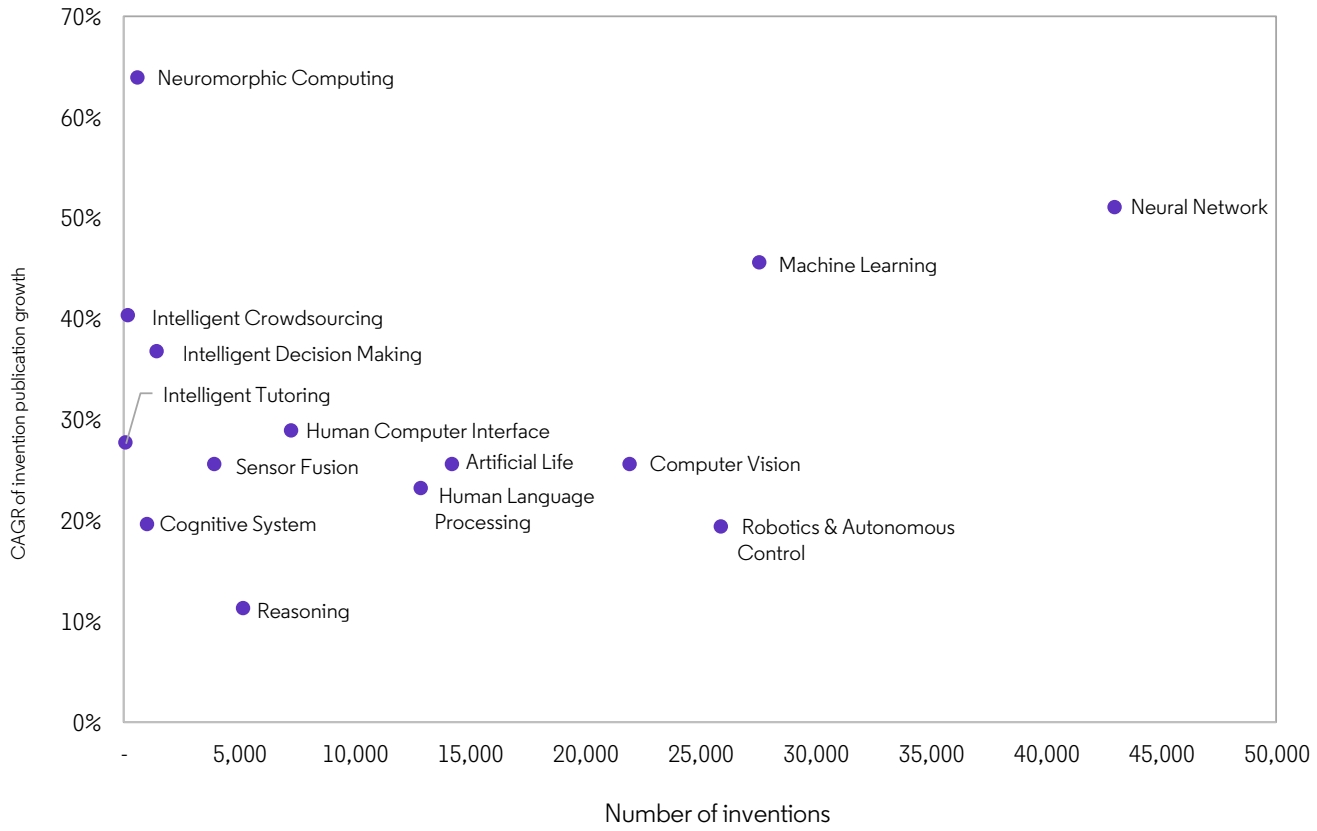
In Figure 3, we have further divided the AI technologies into 14 categories, and analyzed the invention volume and the rate of invention growth.

In the past three years, the number of inventions in artificial neural networks** has been unsurpassed in terms of scale and growth rate. Currently, machine learning and various technical areas are also rapidly developing.

- In particular, neuromorphic computing technology***, which is based on the convergence of computers and biology, has the fastest growth rate.
- Although the speed of innovation differs among the AI technologies, most areas have had a rapid growth rate of more than 20% since 2010. Besides machine learning and neural networks, other AI technologies are also developing in various fields.
- AI technologies with different characteristics are rapidly developing, and the strengths, weaknesses and potential for each technology are different. It is helpful to establish a strategy to use the appropriate AI technology based on the industry or application field.

Machine learning and neural networks are key contributors in the AI technology arena. However, other AI technologies have grown quickly in recent years. Each technology plays a role in various applications.

Figure 3. Growth trends in AI technologies (2010–2019)



Source: Derwent Innovation™ from Clarivate

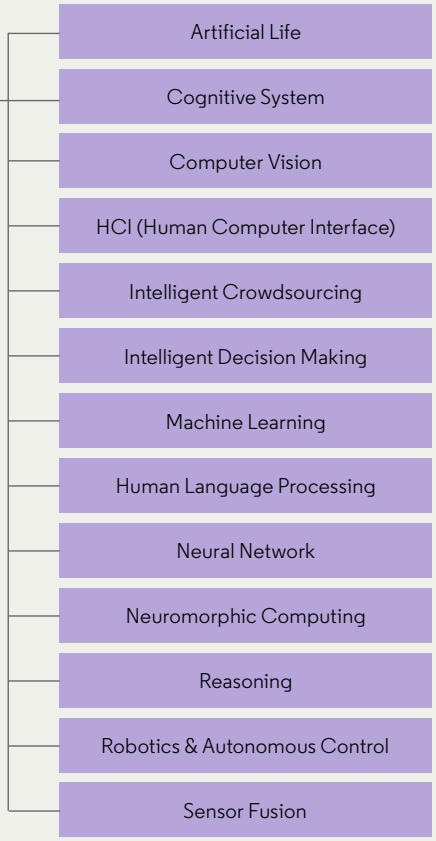
** This is a statistical learning algorithm inspired by biological neural networks, in particular animal brains.

*** This is a software and hardware system of technology that mimics the neurobiological structure, and its physical architecture and design principles are based on the biological nervous system.

- When a firm designs an AI technology innovation strategy, it must make a strategic judgment on whether to advance into a mature technology area, where technology innovation has already been developed, or into an immature technology area, where such innovation has yet to develop. The risks of technology development in a mature area are low, but the competitive advantage may not last long. By contrast, the risk associated with development is high in an immature technology area, but a company can benefit from competitive advantage if development succeeds. Therefore, close cooperation with leading institutions or universities in technology innovation may be necessary.

- As technology development has become more intense and the innovation cycle has shortened in recent years, the risks in new innovations**** that will monopolize the market in a short period have also increased. The risks of technology development due to investing in mature technology areas with a strong technical foundation are low, but these risks are high in terms of market opportunities. Therefore, it is useful to ascertain the current state of the market and technology of the relevant industry and to strategically determine the direction of technology development.

Artificial Intelligence Technology



AI technology classification

We researched AI technology taxonomy in various research papers, consulting reports and other public sources. AI technology taxonomy is complex because it is continuously evolving, and the taxonomy can be categorized into multiple technologies. We identified over 60 AI sub-technologies and categorized them into 14 types. We incorporated various AI areas, some of which have been developing for a long time and others that have only been attracting attention in recent years. In our patent data analysis, we observed that the digital convergence of AI with its own technology as well as other technologies is very active. As AI technology taxonomy continuously evolves, so will our effort to keep up to date on technology classification.

**** The grant rate of the United States Patent and Trademark Office (USPTO) in 2019 was approximately 51%. Therefore, approximately 49% of the 590,000 USPTO applications in 2019 were rejected, and approximately US $2.4B was wasted in filing fees alone (including application processing attorneys' fees). Considering the R&D cost and time required for the development of rejected patent technology, an extraordinary amount of resources have been wasted.

AI innovation

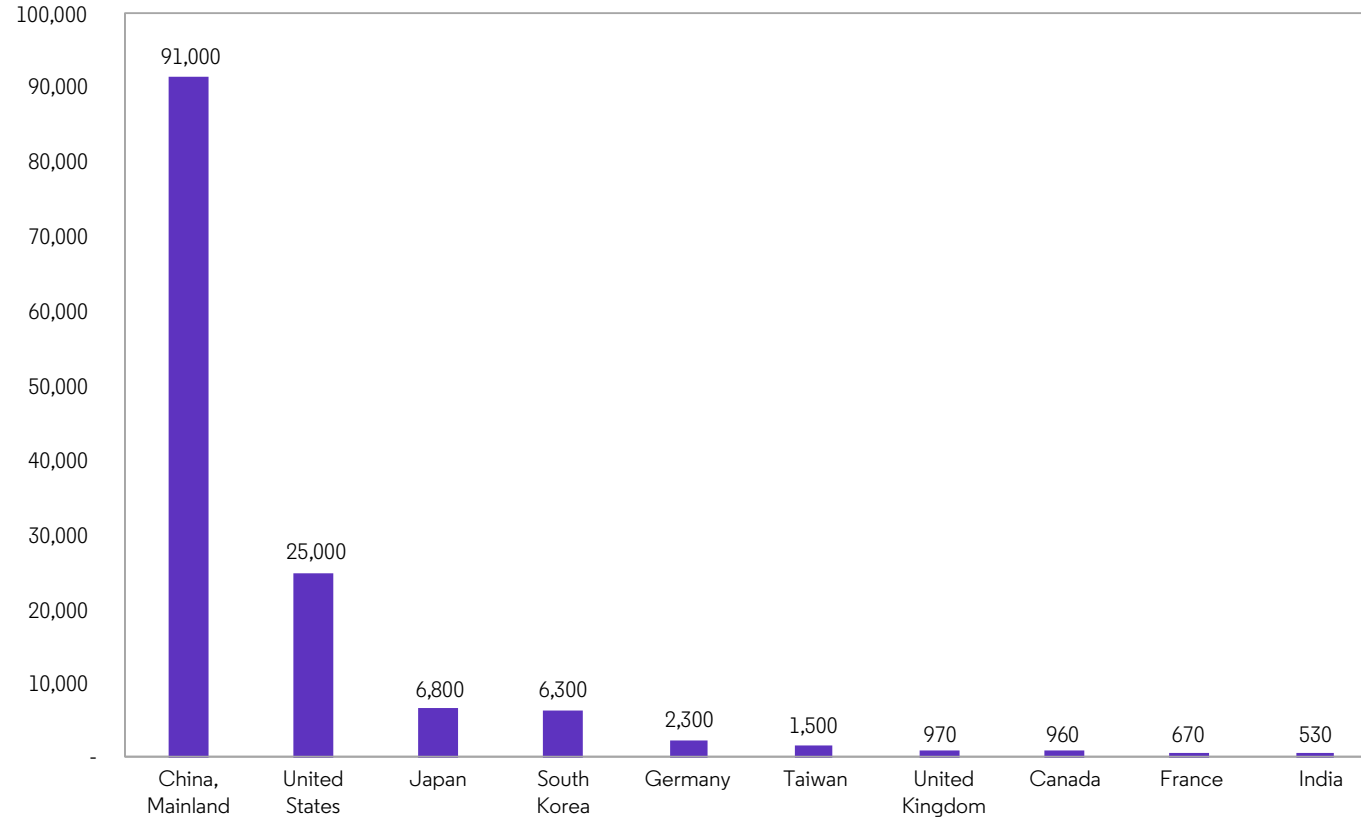
Who is leading, who is growing and what is emerging?

Mainland China and the U.S. are the leading countries/regions in the number of AI inventions filed. However, because of the nature of intellectual property, the competency of the filings comes from the quality of the inventions, not the volume.

Many countries recognize the social and industrial impact of AI technology and actively promote the necessary innovation. The following analysis examines the achievements of the top 10 countries around the world based on the number of AI technological inventions from 2010 to 2019.

Figure 4, based on Derwent™ data, compares the number of each country's AI inventions in the past 10 years. AI inventions in the 10 countries amount to approximately 13.6 million, constituting 92% of the world's total. In other words, AI technological capabilities are concentrated in only a few countries. In addition, the GDP of the top 10 countries in 2018 accounted for approximately 41% of the global GDP.[7] Considering that high-tech innovation is the driving force of future industrial development, the industrial and economic gap between countries in the future is likely to become more substantial, and a significant imbalance is probable.

Figure 4. Number of AI inventions by country/region (2010–2019)



Source: Derwent Innovation™ from Clarivate

[7] According to World Bank data, the global GDP in 2018 was US$135.76 trillion. The total 2018 GDP of the 10 countries leading AI innovation was US$55.8 trillion.

AI innovation policy by country/region

As innovation in AI technology grows rapidly around the world, leading countries/regions are announcing various strategies and investment plans to secure leadership in the field. Although each region has different expectations and requirements for AI technology, the challenges are similar in terms of industrial structure, the conditions of each country's AI technology innovation ecosystem, and the goal of pursuing industrial and social development with technology leadership.[8]

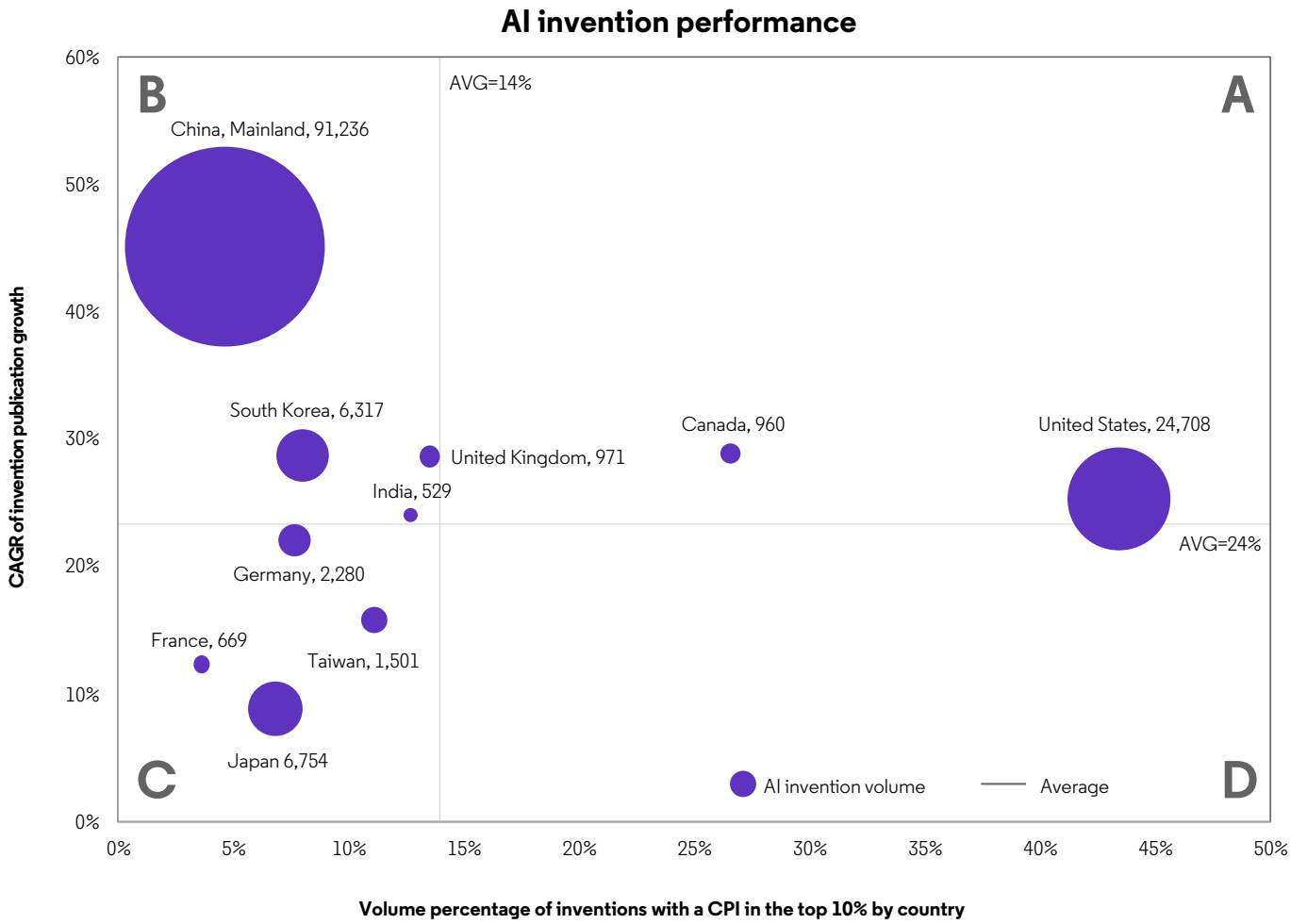
Most countries/regions are planning not only to invest in R&D but to cultivate AI human resources. In terms of investments, the U.S. leans toward private-sector innovation investment, whereas Mainland China favors large-scale government investment.

Table 1. Overview of national AI strategies

Country	Major Strategies
Canada	• Announced the 'Pan-Canadian AI strategy' in 2017 • US $950M investment plan for AI supercluster initiative • Aims to strengthen AI research capabilities and foster talent
China, Mainland	• Announced the 'New Generation Artificial Intelligence Development Plan' in 2017 • Build the value of core AI industries to exceed 1 trillion RMB (about USD 154B) by 2030 • Included AI as a key item in 'Grand Vision for China'
United Kingdom	• 2018 AI Sector Deal announced • Strengthening R&D in the public and private sectors • Strengthening education in science, technology, engineering, and mathematics • Nurturing AI talent and leading data ethics issues
EU	• Fostering the public and industry for technical competency development and technology application • Establishing an ethics and legal system in preparation for the changes that will appear with AI • Union plans to invest US $1.2B per year
France	• Plan to invest US $1.85B to achieve a leading position in the AI field by 2022. • Strengthening the AI ecosystem and attracting global talent in open data • Strengthening AI capabilities in the healthcare field with open data policy • Deregulation for advancement of AI technology, enactment of AI ethics regulations, and expansion of financial support
Germany	• Focusing on AI research and emphasizing strategies for transferring research results to the industry • Establishment of research institutes and strengthening of R&D cooperation with France • Expansion of regional clusters and SME support
Japan	• Establishment of national AI strategy committee • Presented AI technology strategy for 2017 • Established an AI roadmap (Expanding data-based AI and building an ecosystem in various domains)
South Korea	• US $1.9B investment plan by 2022 • Establishing an AI-specialized graduate school and fostering experts by 2022 • Ordering large-scale projects in the fields of national defense, medical care, and public safety • Building an AI industry environment
Taiwan	• Announced 'AI Action Plan' in 2018 • Plan to invest about US $178M won over 4 years • Training experts and attracting talent through AI talent program • Utilization in the industry and building an AI innovation hub through government-led AI projects
United States	• No strategy announced specifically for AI, but presented a number of recommendations for relevant laws and R&D • Implementing public R&D and worker support policies to maintain leadership

[8] "An Overview of National AI Strategies", Medium.com, 2018.

Figure 5. AI invention performance by country/region



Source: Derwent Innovation™ from Clarivate

Figure 5 shows the technological influence of each country or region based on its quantitative performance in AI technological invention and Combined Patent Impact (CPI).*****

- The U.S. is the second largest after Mainland China in terms of quantity, and the top 10% for CPI account for approximately 43% of all inventions, indicating where the world's leading AI innovation performance occurs. The U.S. has a leading position in AI technology innovation because it produces a high quantity of inventions that boast high quality and wide influence.
- Mainland China has the largest scale of AI inventions in the world, and the growth rate in the number of inventions is progressing very rapidly. However, the nation scores relatively low in terms of influence, compared with the top 10% for CPI performance. Mainland China is still experiencing primarily quantitative growth as opposed to world-class technological development.
- For Canada, although the number of AI inventions is low, it is increasing rapidly, and in terms of qualitative growth, it is second to the U.S.

Countries/regions in Quadrant A have relative competitiveness in AI technology. Countries in Quadrants B and C may need to pursue the development of more impactful inventions, depending on the strategy and AI ecosystem of the country.

Country volume: number of inventions first filed at the country.

***** CPI (Combined Patent Impact): The CPI Index, an index of influence calculated using Clarivate DWPI/DPCI, shows the importance of patents to companies/applicants who own specific inventions and the influence on the relevant technology fields. The index is calculated by referring to

- In terms of both the growth rate of AI inventions and the number of inventions in the top 10% for CPI, countries in Quadrant A, such as the U.S., Canada, and the United Kingdom (U.K.), are leaders compared to countries that rank high in quantitative growth.

- South Korea ranks fourth in the world in terms of the number of AI inventions and has developed many innovations. However, only 8% of South Korea's inventions fall into the top 10% of CPI while the average top 10% CPI of the 10 countries are 14%. Although the number of South Korea's AI inventions is growing rapidly, its qualitative performance remains lower than that of the leading countries.

- Ultimately, technological competitiveness in the global market depends not on the quantity of technology innovation but on how high-quality technology is obtained. In fact, applications for many patents are continuously being filed, but the number of patents actually granted is limited, and the competition to produce the few excellent patents and core technologies that can become recognized as a standard is fierce.

- South Korea's lack of technological influence compared with the overall invention scale is an issue that must be addressed. All countries are pushing for technology innovation with limited resources; therefore, now it is urgent to establish a strategy that can lead to qualitative growth based on superior technology rather than quantitative growth.

- To achieve superior inventions, it is important to secure legal rights in a wide market by filing applications for patents in many countries. Therefore, the level of overseas filing of a technological invention can be used as an index to gauge the quality of the technology. Figure 6 shows the proportion of domestic/overseas applications for inventions in each country.

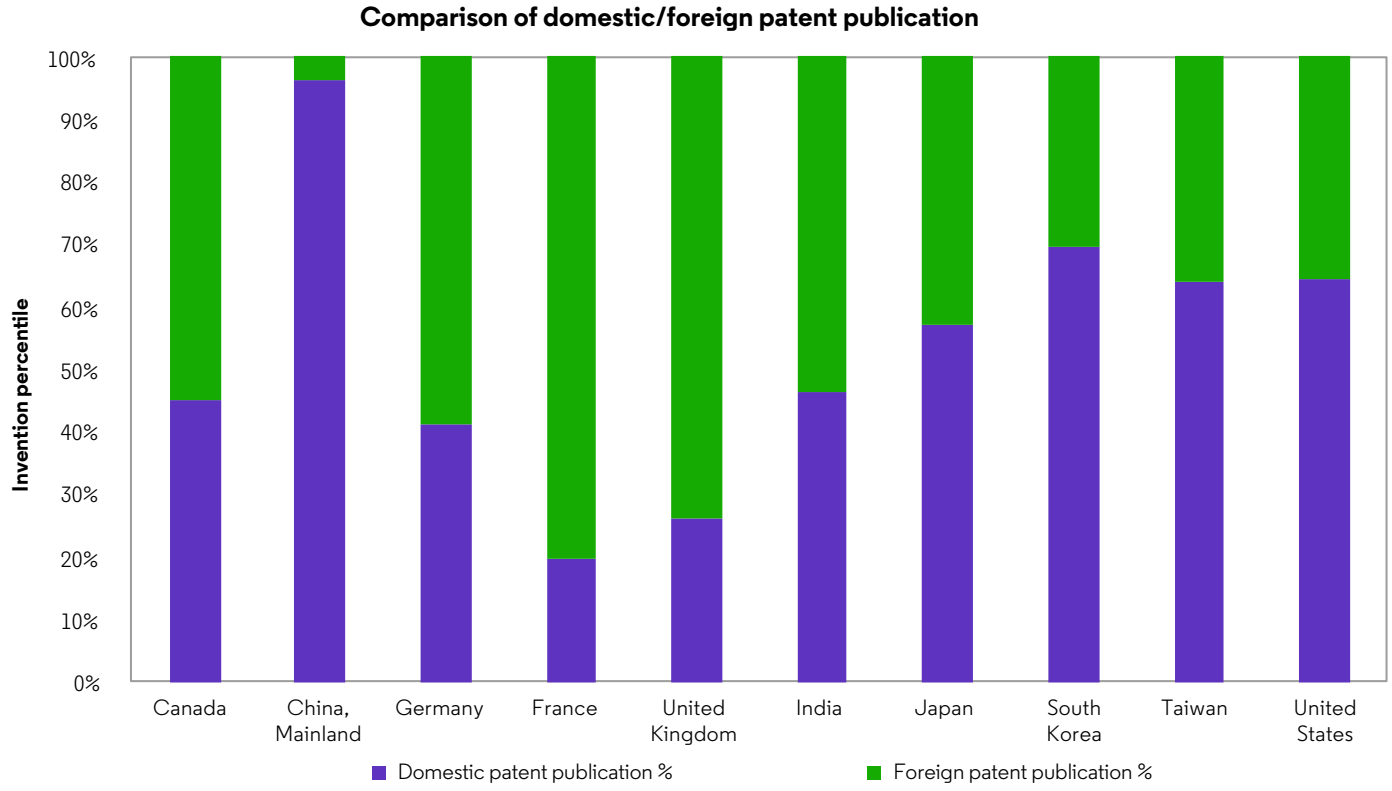
- Considering the vast size of Mainland China's domestic market, its AI technology innovation focuses on the domestic market rather than overseas markets.

- Meanwhile, in South Korea, Taiwan, Japan, and the U.S., domestic applications account for approximately 60% of the total applications. The U.S. has an appealing high-tech market that attracts overseas innovative technologies, and South Korea and Taiwan desperately need to enter overseas markets for business growth. Even countries with similar domestic/overseas filing rates face different implications depending on their industrial structure and market size.

- For countries such as the U.S. and Mainland China, as well as countries in the EU, which have large domestic markets, domestic patent applications have significant advantages. However, regions that cannot develop superior technologies need innovation strategies to enter overseas markets. For South Korea, Taiwan and Japan, it is important to embark on a strategic approach to business with the consideration of overseas expansion for innovative technologies.

It is critical to file patent applications in foreign countries or regions, especially when the domestic market is not very large. Patents that cover a wider market provide more benefits than those only filed domestically. Patents filed in multiple countries have a higher potential value.

Figure 6. Ratio of domestic/international applications for inventions

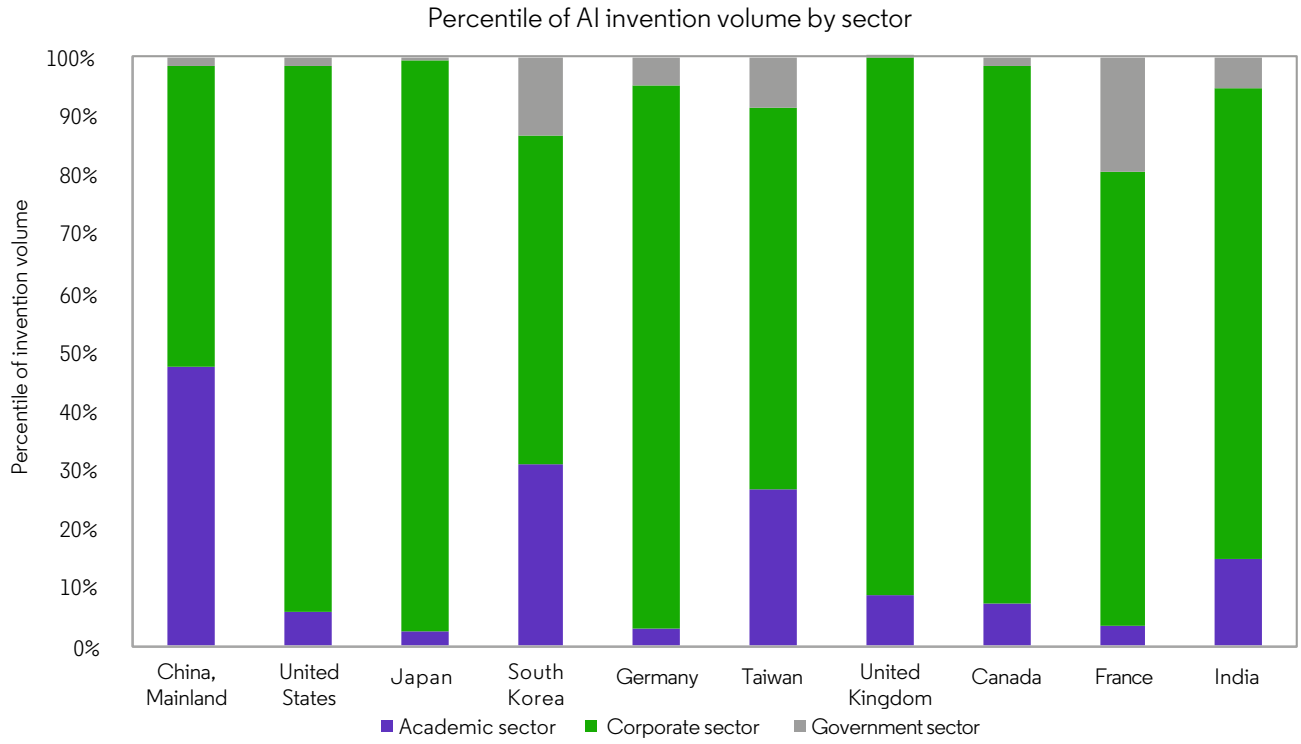


Source: Derwent Innovation™ from Clarivate

AI innovation by sector

The technology innovation ecosystem in a country consists of the academic, government and corporate sectors. The academic sector includes universities that nurture and prepare talent for conducting basic and advanced research. The government sector includes government-funded research institutes that seek in-depth R&D and technology commercialization in a specific field. Figure 7 shows the ratio of the number of AI inventions by sector in each country/region.

Figure 7. Relative distribution of the number of AI inventions by sector



Source: Derwent Innovation™ from Clarivate

Synergy among academic/government research institutions and firms is important for building a sustainable AI ecosystem. The synergy effect is strongly dependent on the quality, not volume, of inventions in each sector. Having a high volume with low quality creates less synergy with other sectors.

- The U.S., Japan, Germany, the U.K., Canada and France produce more than 90% of the industry-oriented AI technological development, whereas Mainland China, South Korea, and Taiwan produce a relatively high proportion of AI technological development at universities and government research institutes. Meanwhile, in Mainland China, a large number of AI inventions are created at universities.

- Globally, R&D for AI at government-funded research institutes is relatively limited. This shows that AI research is part of the activities conducted at various research institutes, rather than deriving from research institutes that specialize in AI.

- In many regions, AI technology innovation is led by industry. Although it is difficult to determine the ratio between sectors, it is an effective technological development strategy to form an AI innovation ecosystem within which the sectors organically cooperate with one another while maintaining their respective technical capabilities.

Figure 8 illustrates the performance of the AI inventions in the top 10% for CPI in each sector. This has implications for which sectors produce better technology innovation.

- The U.S. and Canada demonstrate impressive results in CPI performance in all three sectors, with indexes well above 10%. This implies that the AI innovation ecosystem in these countries boasts excellent capabilities. The organic cooperation of the corporate and academic sectors strengthens the AI technology innovation capacity of these countries. The development of industry, human resource training and employment can create a virtuous circle and, in turn, practical alignment.

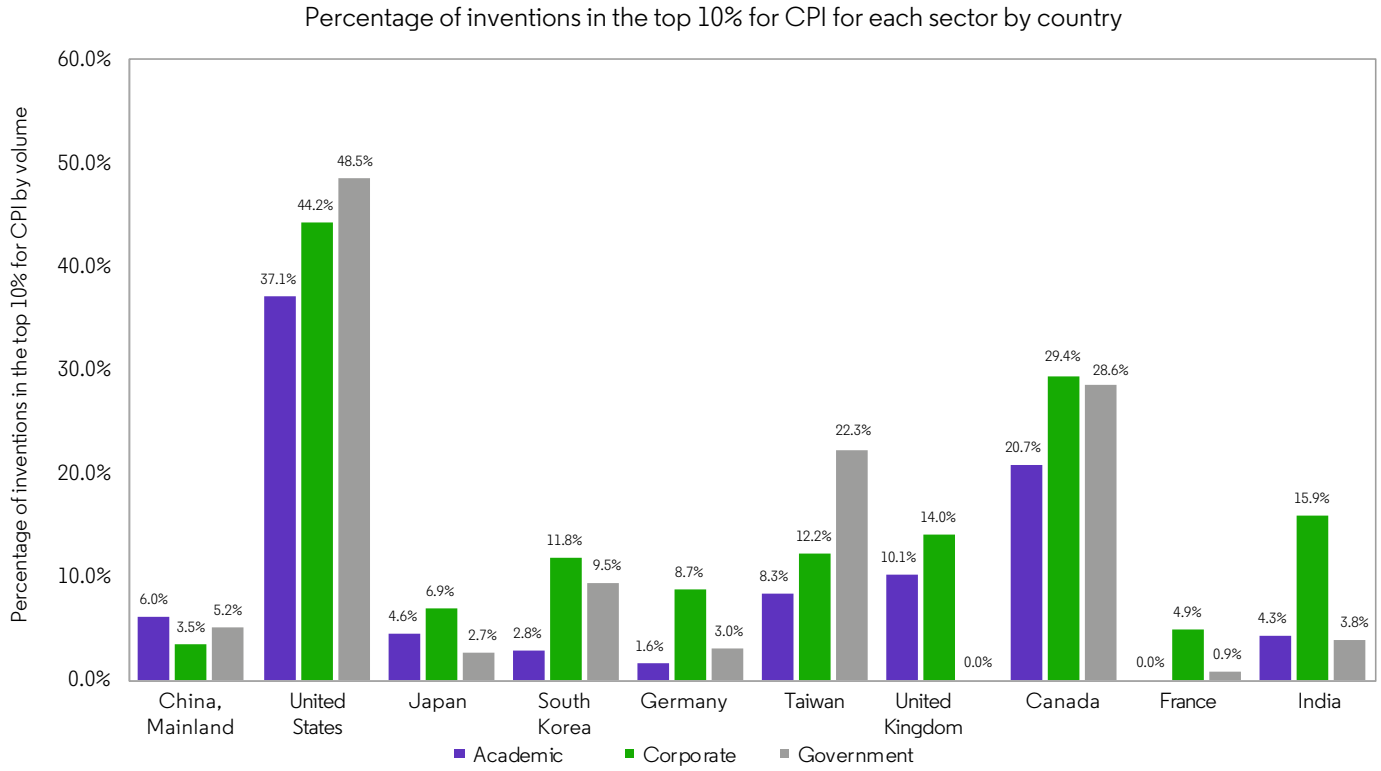
- In South Korea, the CPI performance of industrial and government-funded research institutes on average is as high as 10%, but the performance of universities is very low. The proportion of AI technology in South Korea's universities is high, but the influence is low, as is the proportion of AI technology at government-funded research institutes. Therefore, the ecosystem has demonstrated limited qualitative performance in AI technology innovation.

- Mainland China boasts the world's largest number of AI inventions, but the CPI performance in each sector is only approximately 5%, with low-quality innovation performance. Mainland China is still focusing on quantitative growth; therefore, China's challenge is to attain superior technology through innovation.

- The previous exhibit (Figure 5) shows that the scale of the AI technology innovation in Japan is slightly larger than that of South Korea, but its national CPI performance index is lower than that of South Korea. The reason for this is that the performance of each sector is lower in Japan than that in South Korea. Taiwan and Canada, which have fewer AI inventions than South Korea, have a number of technologies that show excellent influence in all sectors and maintain a sectoral balance.

The academic performance of AI quality in the U.S. and Canada is very high. Even though the volume of Canadian AI technology is small, the country's performance, in terms of quality, is very high, as shown in Quadrant A of Figure 5. The academic sector is the source of innovation in the country/region.

Figure 8. Share of inventions in the top 10% for CPI by sector



Source: Derwent Innovation™ from Clarivate

Each country/region has a different AI focus. North America and European regions have strong AI inventions in robotics and automation. Japan and Taiwan are relatively strong in computer vision, while Mainland China excels in neural networks and machine learning. Some countries may need to revise their AI technology focus for their industrial growth.

Trends in AI technology in the major countries/regions

AI involves various technologies, and Figure 9 illustrates the invention scale of each country/ region for six major AI technologies which covers 86% of total AI inventions volume.

- Countries such as the U.S., the U.K., France, Germany and Canada produce a relatively high proportion of robotics and autonomous control technology inventions. This suggests that industries such as manufacturing, automobiles and aviation actively use AI technologies related to intelligent robots or autonomous control.
- In South Korea, AI technology innovation related to neural network, machine learning and computer vision – which can be applied in many different fields – is increasingly prominent.
- In Mainland China, as in South Korea, machine learning, neural network and computer vision technology innovations are actively progressing. Mainland China shows the largest volume percentile of artificial life among the listed countries.
- Companies are pursuing various business expansion by strengthening market competitiveness through AI technology innovation and moving into overseas markets and new businesses. The AI technology distribution by country shows not only the countries that dominate each technology but also the technologies each country wants to dominate. An analysis of the fields in which innovation is actively taking place indicates the future implications.

Figure 9. Distribution ratio of the number of inventions by AI field

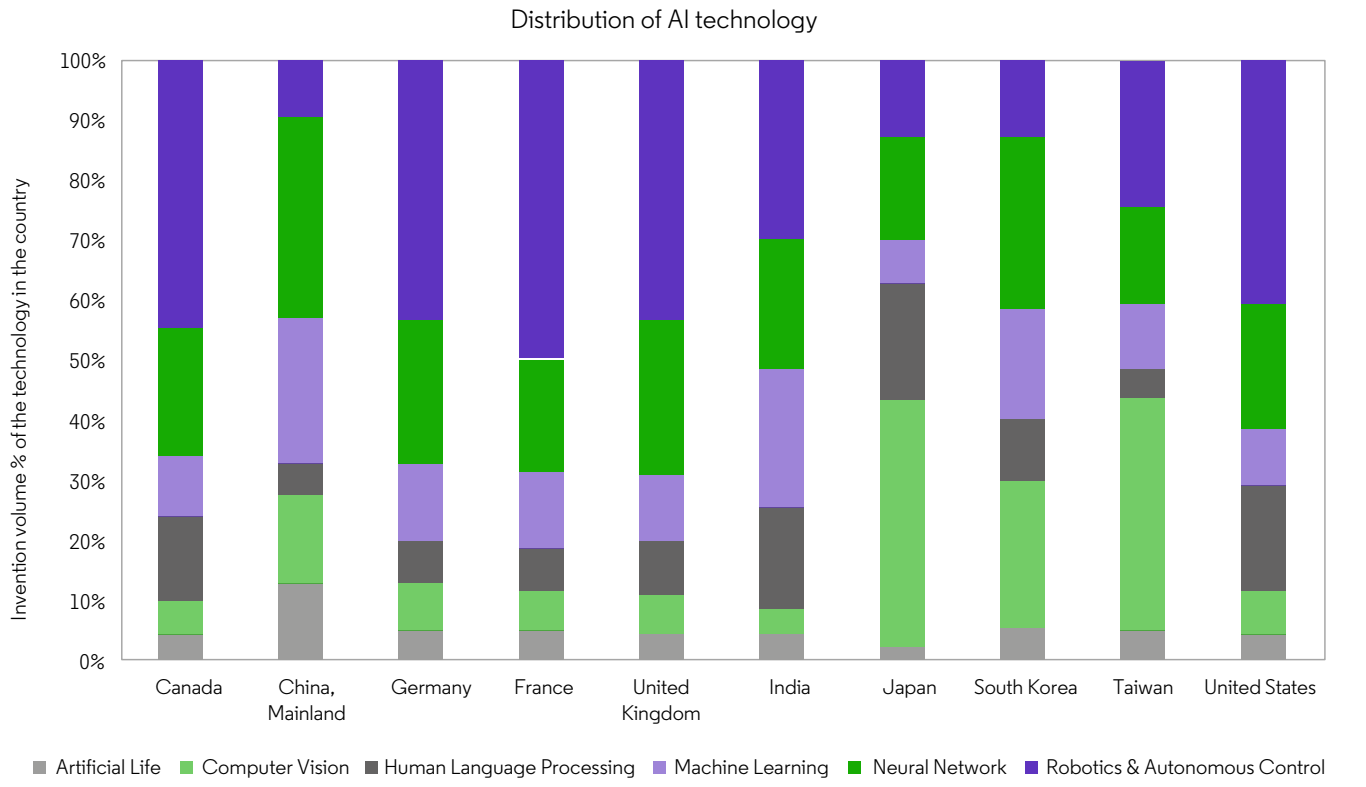


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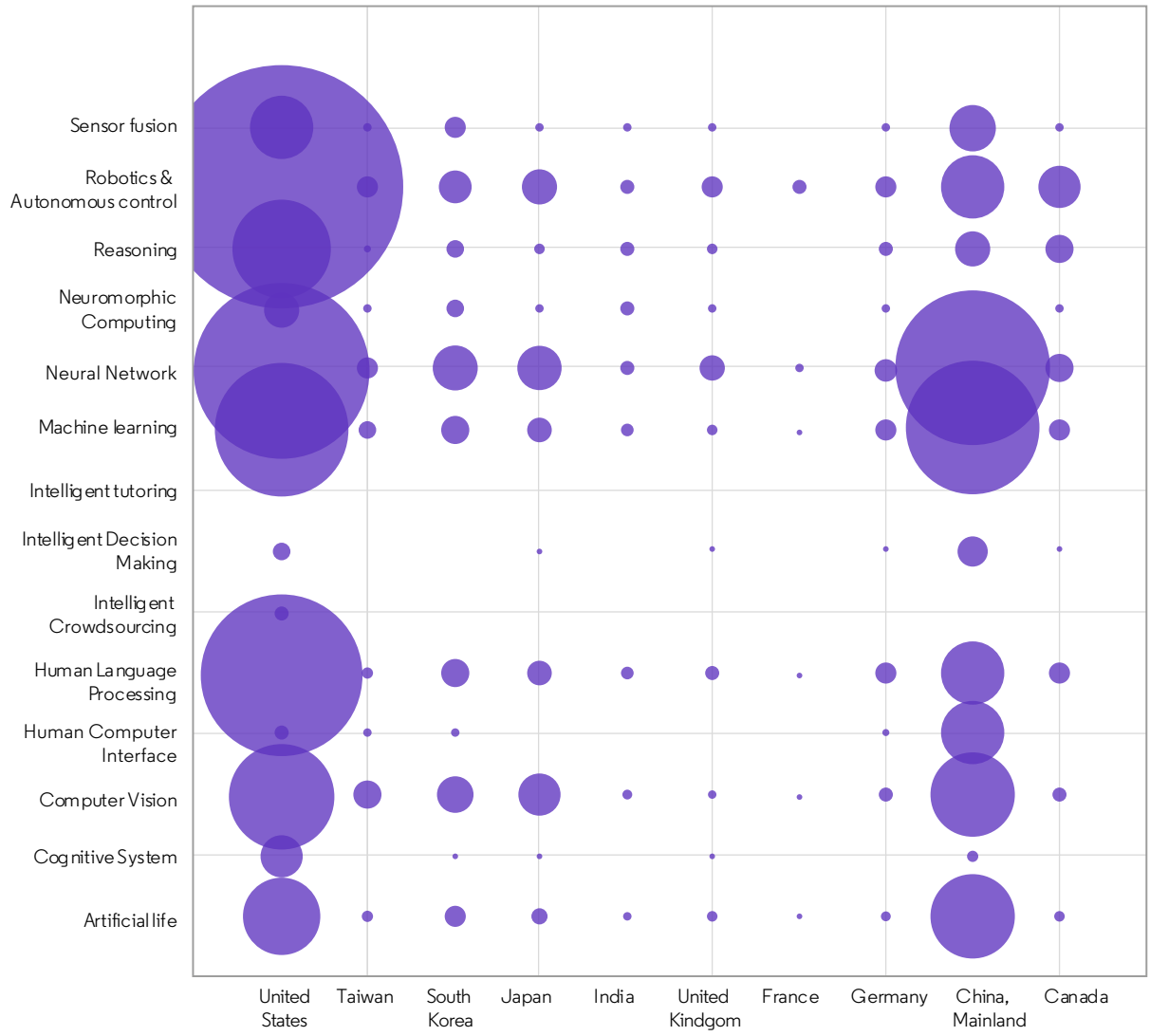
Figure 10. Number of inventions ranked in the top 10% by AI field



Source: Derwent Innovation™ from Clarivate

Influential AI technologies by sector in major countries/regions

- Figure 10 illustrates the number of inventions ranked in the top 10% for CPI by AI technology and by country. As mentioned earlier, CPI is an indicator that shows which technology is qualitatively superior. The CPI performance scores indicate how technological competitiveness is actually distributed across countries and between technologies. The U.S. has absolute predominance in the number of inventions in the top 10% for CPI. In the fields of robotics and autonomous control, machine learning, and neural networks in particular, the U.S. has produced many inventions with superior competitiveness compared with other countries. In the areas of neuromorphic computing, cognitive systems, and sensor fusion, the U.S. has produced an overwhelming number of inventions ranked in the top 10% for CPI.

- Mainland China has produced many inventions with high CPI performance in machine learning and neural networks. Although Mainland China accounts for the highest number of AI inventions in the world, the number of inventions ranked in the top 10% for CPI performance is only 41% of that of the U.S.

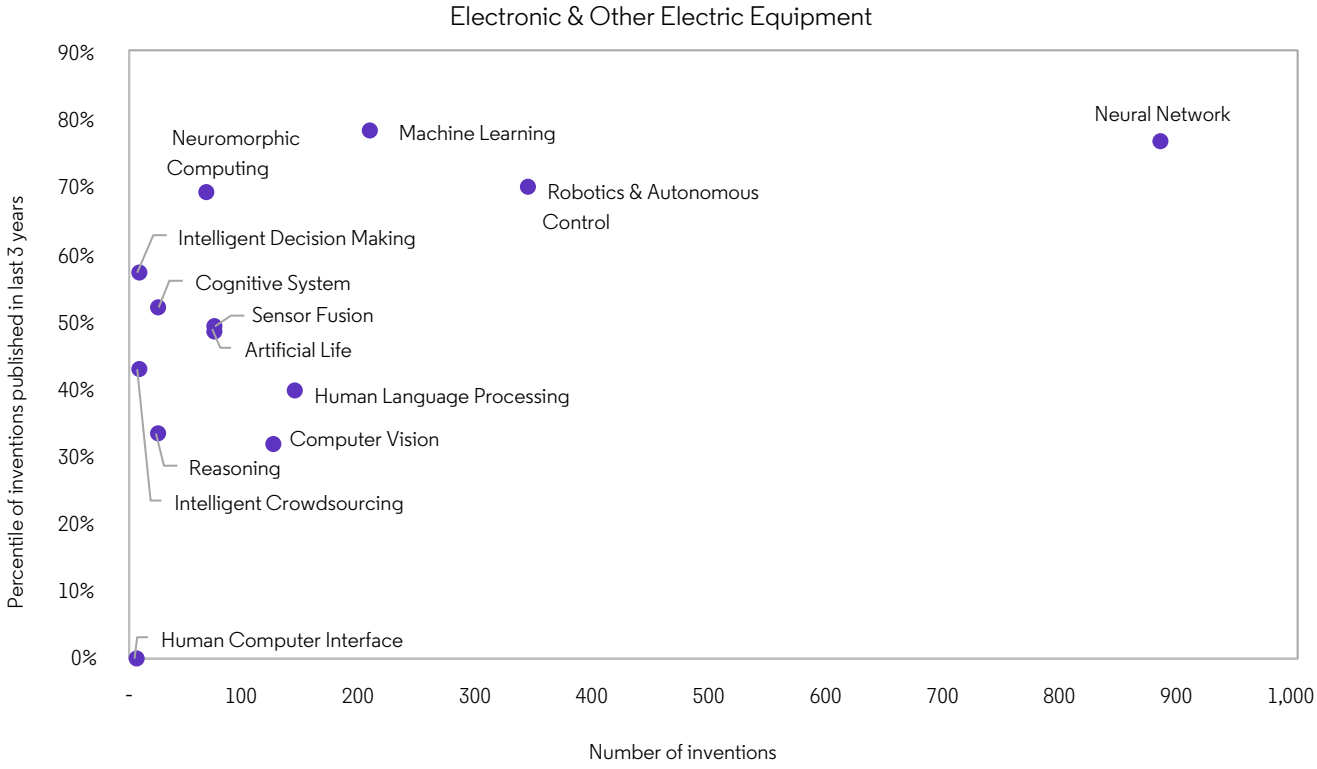
Each country/region has a different AI focus. North America and European regions have strong AI inventions in robotics and automation. Japan and Taiwan are relatively strong in computer vision, while Mainland China excels in neural networks and machine learning. Some countries may need to revise their AI technology focus for their industrial growth.

AI technology in major U.S. industries

How is the U.S. performing across industries?

Based on our analysis, the U.S. is performing well globally, not only in terms of the scale of AI technological inventions but also in terms of influence, and a majority of AI technological inventions come from U.S. manufacturing. This analysis identifies the AI technologies used in the major industries in the U.S. and their level of industrial application. Industries are identified using the SIC (Standard Industry Classification) system, and the analysis focuses on major industries in the U.S.

Figure 11. AI inventions in the U.S. electronics/electronic components industry



Source: Derwent Innovation™ from Clarivate

AI technology in Electronics & Other Electronic Equipment

- In the U.S. electronics and electronic parts industry, AI technologies related to neural networks, machine learning and robotics and autonomous control are actively being harnessed. The use of neuromorphic computing technology has recently begun, and the application of deep learning technology is dominant in machine learning.
- In the electronic components industry, various AI technologies are being used to expand the function of the components. Advancements in AI chip technology are the leading component innovation that can be applied in fields such as autonomous driving. Component functions are becoming increasingly intelligent, and the component innovations required for robots (or autonomous objects) that provide various types of connectivity are also being produced.
- In addition, companies that innovate communication semiconductors are entering into strategic alliances with automobile companies to promote the development of natural language processing components. Semiconductor companies are also developing components for real-time data processing by incorporating sensor fusion technology to make autonomous driving technology more comprehensive.
- The intelligent electronics/electronic components industry, which incorporates AI technology, is an important infrastructural industry that will play a key role in the digital transformation. The U.S. is actively promoting AI technology innovation in its basic industry.

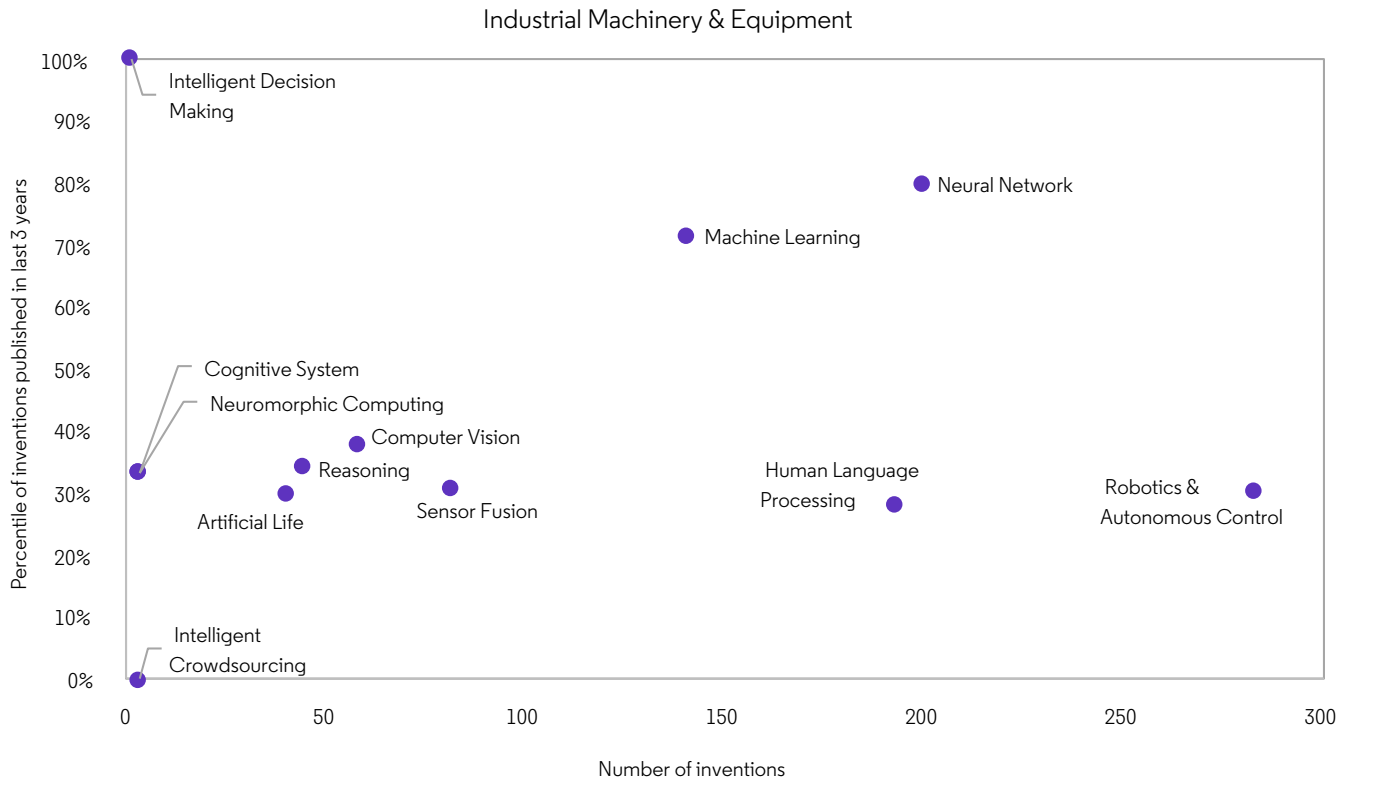
AI technology in manufacturing (Industrial Machinery & Equipment) industry

- In U.S. industrial machinery and equipment manufacturing, robotics and autonomous control technology are finding application, and the technology associated with neural network and machine learning is also rapidly progressing. In addition, human language processing technology has been in continuous use in manufacturing, and the implementation of other AI technologies – including computer vision, sensor fusion and reasoning, which form the basis of smart manufacturing – is also on the rise.

- Human language processing has seen notable innovations in the technology of optical character recognition as well as machine translation. Within machine learning, supervised learning and self-learning technologies are being developed, and deep learning, reinforcement learning and semi-supervised learning technologies are currently being implemented.

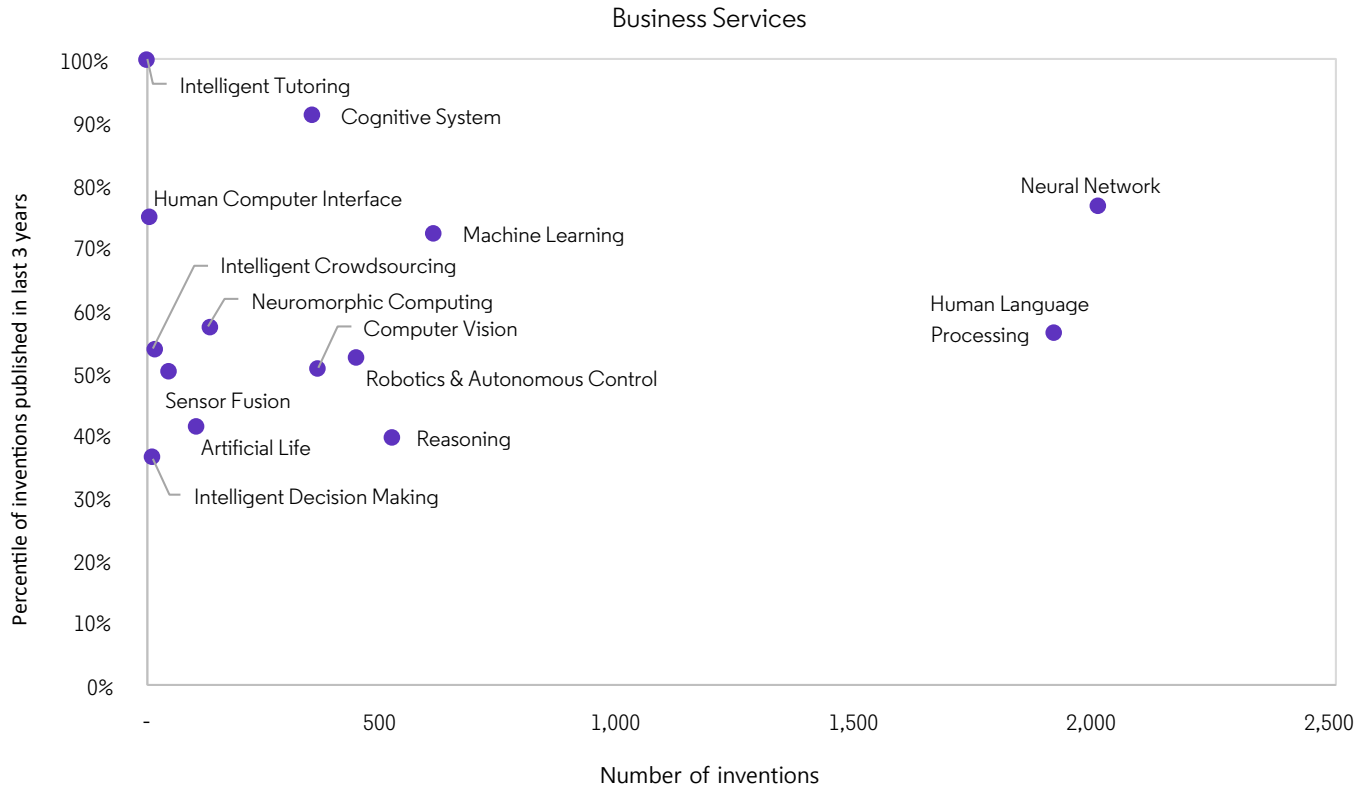
- In industrial machinery and equipment manufacturing, various AI technology innovations are under development to improve the efficiency and service of smart manufacturing and product devices. AI technology is not only used to streamline internal processes to improve product functions, but also to enhance customer service. Machine learning technology is applied to process customer-service invoices, identify the causes of existing and new problems and handle customer complaints quickly and efficiently.

Figure 12. AI inventions in U.S. manufacturing



Source: Derwent Innovation™ from Clarivate

Figure 13. AI inventions in U.S. business services



Source: Derwent Innovation™ from Clarivate

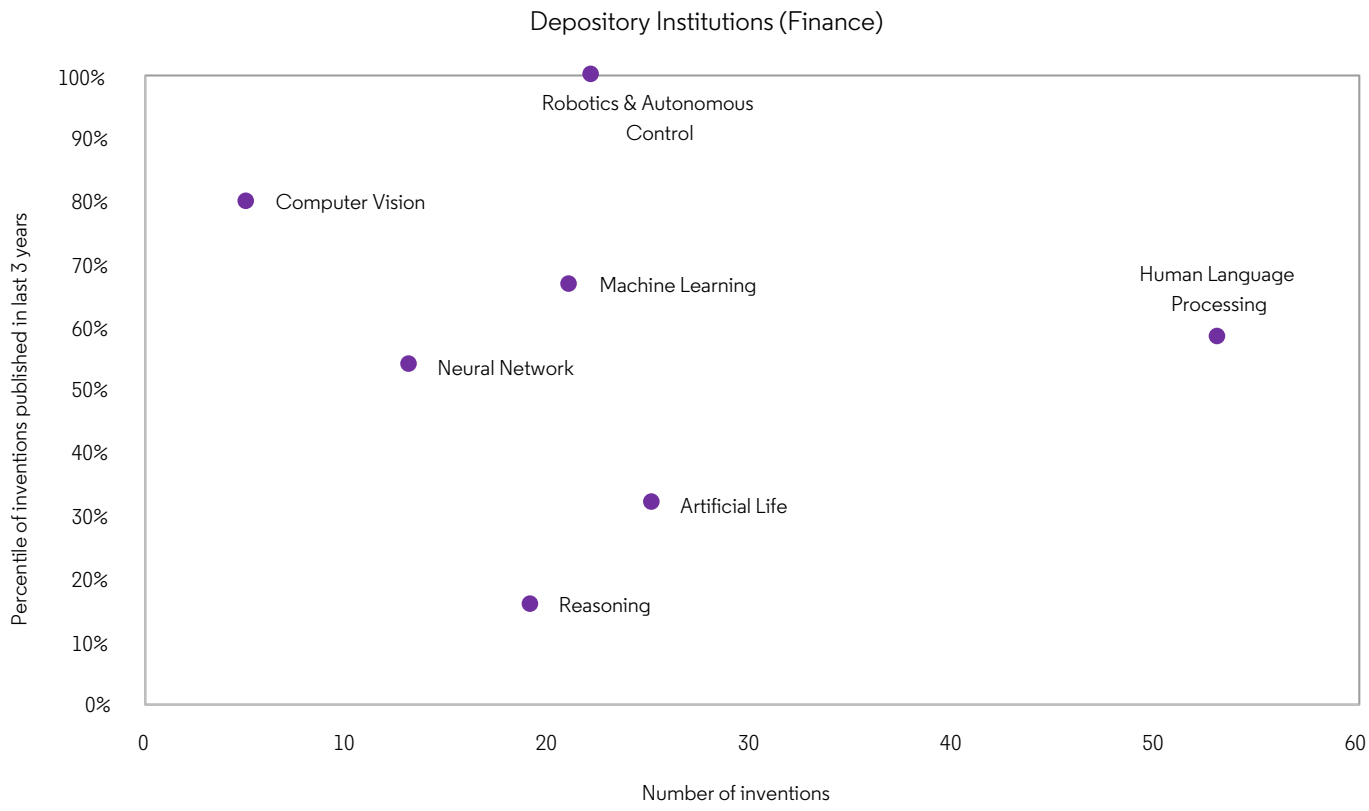
AI technology in business services

- In U.S. business services, as shown in Figure 13, neural network technology and human language processing technology are being prolifically applied, and interest in cognitive systems and the human-computer interface has grown.
- The quantity of AI inventions in platform services is much higher compared with other industries. In platform services, neural network technology innovation is actively progressing to advance the process of analyzing linguistic emotions and various types of unstructured data. In particular, to improve deep neural networks, 3D models are being used to create unexpected situations to develop object recognition technology. These models serve to create photographic images of complex environments to help develop the ability to accurately distinguish target objects.

AI technology in finance

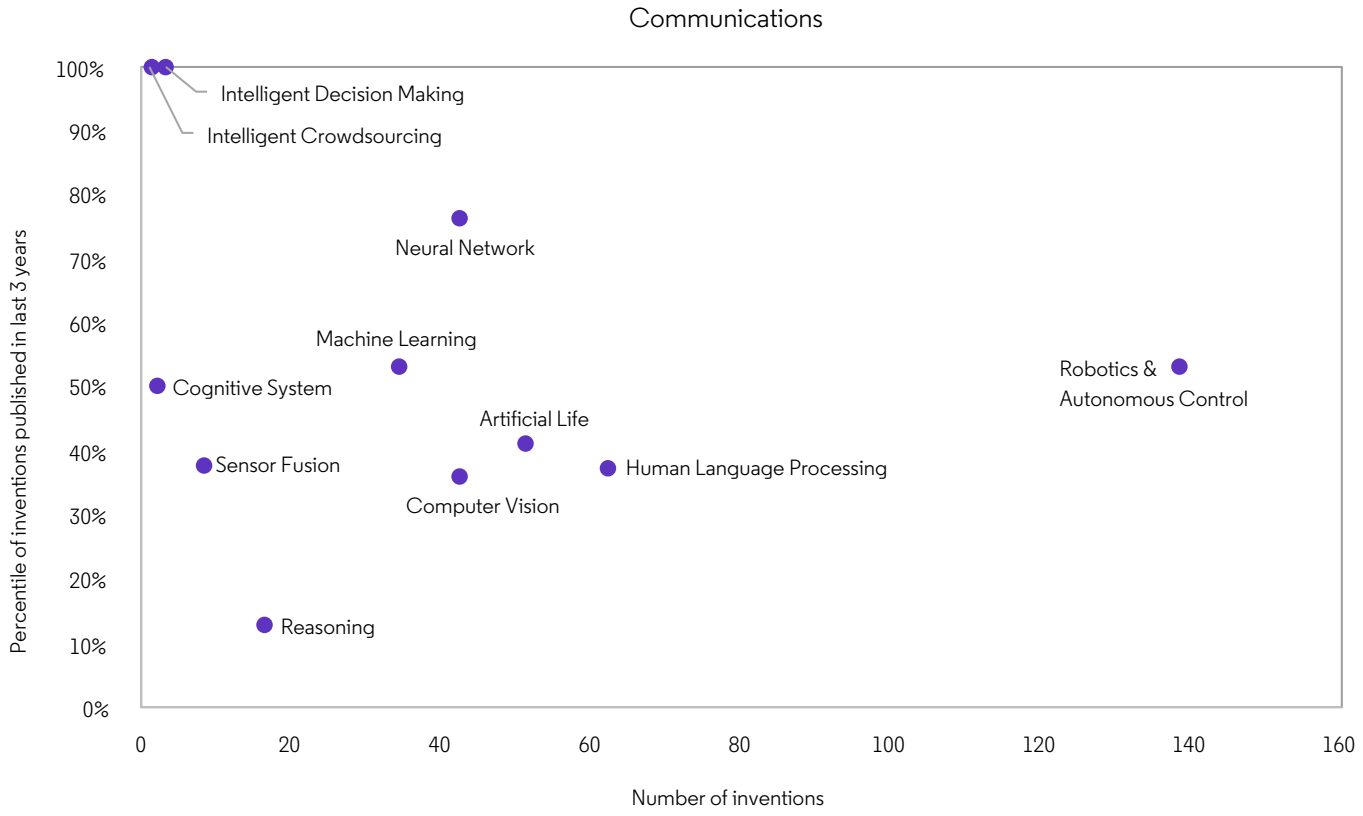
- In the U.S. financial industry, human language processing technology has been continuously implemented, and innovations in robotics, machine learning and AI are currently in progress. Service competitiveness is increased by using intelligent agent technology and robot advisor customer service. Moreover, AI technology is being introduced to more quickly and accurately analyze work performed by humans.
- Due to the nature of the financial industry, the development of AI algorithms that can perform sophisticated analyses based on large-scale data is also ongoing. Neural network technology is required to refine analyses, and ontology technology is required to make computers recognize concepts.

Figure 14. Status of AI inventions in the U.S. financial industry



Source: Derwent Innovation™ from Clarivate

Figure 15. Status of AI inventions in the U.S. telecommunications industry



Source: Derwent Innovation™ from Clarivate

AI technology in communications

- In the U.S. telecommunications industry, inventions in robotics technology are showing substantial results in terms of quantity, but the number of inventions in neural networks demonstrates the most rapid growth rate. The use of a system that maintains a large-scale network environment autonomously operated and the embedding of intelligent agents in various communication devices are spurring the establishment of an intelligent network environment.
- Subsequently, technology innovations, such as machine learning, AI, human language processing and computer vision, are showing high growth rates. The main field in AI is self-organizing intelligent agent technology, but computer vision has also made remarkable progress in object recognition technology.
- The communications industry is the foundation for the platform industry; thus, neural network technology is used to provide more advanced services. In addition, machine learning technology is actively being applied to solve various customer-service problems based on communication, and to quickly and accurately determine customer requirements.
- In manufacturing, developments in telecommunications are similar to those in the electronic components industry. Both industries must not only develop products but also respond accurately and efficiently to the emergence of defects.

Global changes and major issues

Insights on future AI strategy

The race to build a competitive AI ecosystem

As the competition in AI innovation intensifies, our analysis demonstrates that the U.S. is investing enormous sums in AI and leading in AI inventions in terms of quantity and quality. Mainland China is quickly approaching the same level in terms of scale. South Korea, Japan, Canada and European countries are also actively pursuing AI innovation, but are far behind the U.S., both quantitatively and qualitatively.

- Starting in 2017 and 2018, several countries announced strategies and policies for AI technology innovation and large-scale investment plans. Many countries seek to hire AI talent, strengthen R&D capabilities, and increase industrial competitiveness based on AI technology. However, each country creates its own policies with different AI innovation strategies and priorities.

- The driving forces in building a sustainable AI innovation ecosystem are national strategies and investments. A country's future AI capabilities will be determined by how quickly and robustly it develops its own AI ecosystem and how well it transforms existing industry with AI technologies.

- Countries that build a successful AI ecosystem have the potential to accelerate growth while absorbing the AI capabilities of other countries. AI talents are already moving to countries with advanced AI ecosystems, and in some cases, companies are also transferring R&D functions overseas to develop competitive AI technologies. Eventually, the establishment of a flourishing ecosystem will determine the sustainable growth in the future and further widen the AI innovation gap between countries.

Sectoral cooperation is the key to a successful AI ecosystem

AI innovation is progressing at universities, government-funded research institutes and companies, but with different characteristics and roles. Universities and government research institutes focus on conducting R&D, developing original technologies, and developing AI talent, whereas companies continue to innovate by applying AI technologies at various industrial sites.

- Technology innovation based on excellent R&D can provide a sustainable competitive advantage through the synergistic effects of cooperation among sectors. Therefore, it is necessary to solidify the structure of cooperation between sectors.

- South Korea and Mainland China produce relatively large proportions of AI technologies at universities, but the influence of the technologies must be further developed.

- Increasing the influence of technology requires a focus on the development of fundamental AI technology that can address various industrial challenges by relying

on the strength of universities, which have an environment that can withstand high risk.

- At the same time, it is also important to consider the unique characteristics of AI as a GPT, with applications in various industries and a corresponding transformation in existing production and service processes as well as the creation of new business models.

Increasing AI diversity and strategic AI portfolio management

AI technology has developed into various sub-technologies, and each technology has different characteristics, advantages and disadvantages in solving problems. Therefore, it is important to select the appropriate AI technology to address a given problem in order to form a future AI technology strategy.

- The invention of AI technology can be largely divided into inventions of original technology based on R&D, and inventions of technology applied to a specific field using the original technology. When developing AI technology, it is important to invent the initial technology, which is fundamental for innovation, but as the applications for AI technology continue to expand, the inventions of applied technology must be continuously developed as well.

- In the future, the types of AI technologies may gradually increase through the convergence of various technologies and through efforts to develop new AI capabilities by integrating the advantages of each area. Various types of modified AI technologies will emerge in response to increases in the complexity of the problems facing AI technology.

- Therefore, rather than focusing on specific AI technologies, it is important to spontaneously pursue R&D and innovation focused on various types of AI technologies. In this process, understanding the limitations of each AI technology and incorporating the strengths of other AI technologies to overcome their limitations is also an important part of AI innovation for the future. In this context, AI-leading countries with diverse types of AI technologies will gain an increasing technological competitive advantage.

AI cross-integration as a key strategy for industry

Although the AI technologies used across industries vary based on the characteristics of each area, most industries are accelerating the adoption of AI technologies.

- From the perspective of industry, AI technologies can be divided into those that enhance efficiency in internal processes, those that strengthen product functions, and those that expand functionality and service areas. Depending on the degree of accumulation of internal corporate data, the field of AI technology differs by industry, and the product function diversifies the advancements into other industries.

- Some industries have already introduced significant AI technologies, but others are still in the early stages. Even within the same industry, there are differences in the fields and levels applied based on the maturity of the company's AI capabilities. However, the overall trend is one in which companies in various industries are accelerating the digital transformation by using AI technologies to enter new businesses or to design products/services that advance internal operations.

- When a company considers the introduction of AI for new product development and the advancement of internal operations, examining and benchmarking the use of AI will be helpful in establishing future AI technology strategies in not only the same industry but also other industries.

- Beyond benchmarking other companies and industries in the introduction of AI, it is important to view the introduction of AI from the perspective of creating new services and markets. Therefore, in a field in which convergence is actively progressing, a more extensive and detailed analysis is required beyond examples of AI technology introduction in specific industries.

As this report has discussed, AI technology now permeates many aspects of our lives. As researchers constantly pursue novel technologies and applications, more wonders are certain to follow. What is less certain is how the global pursuit of AI will play out.

Will the regions now dominant in influence maintain their stature as other nations gain ground in terms of quantity and impact? How will research institutes, universities, corporations and nations forge their AI strategies and navigate a complex path that might require a balance between competitiveness and collaboration? As more decision making and control are relinquished to AI, how will the attendant ethical questions be resolved?

As AI researchers continue to transform our world, the accumulated data deriving from their innovation and its influence will tell the tale.

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