Chapter 3

History of Digital Technologies

Technological advancements have extended human capabilities and enhanced what we can achieve. Artificial Intelligence (AI), which replicates human intellectual activities through computers, has continued to evolve over its 70-plus years of development and is increasingly permeating business activities and daily life. Generative AI, which saw rapid adoption around 2022, is a remarkable example of this evolution. Generative AI can autonomously perform a wide range of tasks by generating text and images like a human, bringing significant transformations to various businesses, including advertising, marketing, and content creation. In our daily lives, natural language interfaces are becoming more prevalent, with smart speakers and chatbots integrating seamlessly into our routines and significantly altering our lifestyles. Furthermore, AI is expected to advance even further when combined with other technologies and services such as XR (Extended Reality) and robotics. For instance, XR technology using generative AI can provide immersive virtual environments, creating new value experiences in education and entertainment. AI-equipped robots are also making significant contributions across various fields, from manufacturing to caregiving, by automating tasks and supporting people's lives.

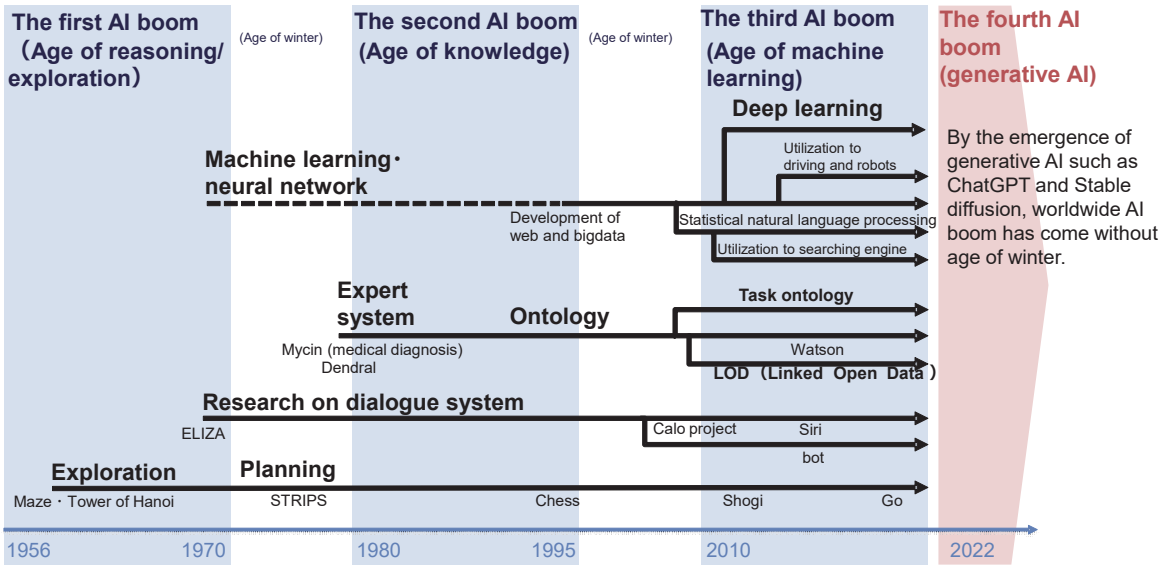
These technologies, which utilize Information Communications Technologies (ICT) / digital such as AI and XR (hereinafter referred as to digital technologies), are anticipated to further transform our social and economic activities. However, the evolution of these technologies also brings challenges and risks. The rapid advancement of generative AI has raised concerns about privacy violations, data breaches, and the spread of dis-/mis-information, prompting global discussions on regulations and rules. As the potential and risks of digital technologies, especially generative AI, garner unprecedented attention, it is crucial to address these challenges and risks while advancing the development and utilization of digital technologies to benefit society as a whole, including business activities and daily life. In light of this understanding, the 2024 White Paper on the Information and Communications in Japan features a special section that reviews the evolution, current status, challenges, and future prospects of digital technologies. It also discusses the necessary measures to "live in harmony" with digital technologies.

Section 1 History of development of AI and impacts of generative AI

1. History of development of AI

The history of AI began in the 1950s and has experienced several cycles of booms and winters. The first AI boom, which started with exploration and reasoning, led to the incorporation of technologies such as speech recognition in the second AI boom. The third AI boom introduced innovative technologies such as deep learning, paving the way for practical AI applications to permeate society. The rapid proliferation of generative AI around 2022 marked the onset of what is now referred to as the fourth AI boom **(Figure 1-3-1-1)**.

Figure 1-3-1-1 Overview of technology of AI and big data



(1) The first to third AI booms and the AI winters

A The first AI boom (from late 1950s to 1960s): the era of reasoning and search

The term "Artificial Intelligence" was proposed by J. McCarthy, a university professor in the U.S., at the Dartmouth Conference held in 1956. The concept of artificial intelligence was established, and the term AI became recognized among scientists. From the 1960s, research and development in AI became active, focusing on "Reasoning" and "Search." "Reasoning" involves representing and executing human thought processes using symbols, while "Search" involves investigating procedures and options to achieve a goal and finding the optimal solution. Problems were described in a form suitable for computers, and solutions were presented using methods such as search trees. However, due to limitations in computational power and data processing capabilities of computers at the time, modeling human intelligence was difficult. Consequently, AI of that era could only solve simple puzzles and mazes, known as "Toy Problems," and faced challenges in practical application, leading to the first AI winter.

B The second AI boom (from 1980s to 1990s): the era of knowledge

In the 1980s, with the advancement of computer performance and the emergence of expert systems[1], AI research and development became active again in various countries. However, the amount of data required for computer learning was enormous, and the performance of computers at the time could not handle it. As a result, AI could only mimic a portion of expert knowledge and could not address complex problems. Additionally, it required significant effort to manually describe learning data in a way that computers could understand. Consequently, AI research faced another winter.

C The third AI boom (from 2000s to present): the era of machine learning

In the 1990s, websites were made public, and in the 2000s, networks began to spread to households, leading to a dramatic increase in data circulation. This made it possible to obtain large amounts of data for research. Furthermore, improvements in computational processing power enabled the handling of vast amounts of information (big data), which significantly contributed to the evolution of machine learning, leading to the current third AI boom[2]. One of the methods of machine learning, deep learning, is a technology that develops the concept of neural networks, which simulate the workings of the human brain. Deep learning has enabled capabilities such as image recognition, natural language processing, and simulations. Its applications have expanded to include identifying human faces from camera images and optimizing autonomous driving in robots[3,4].

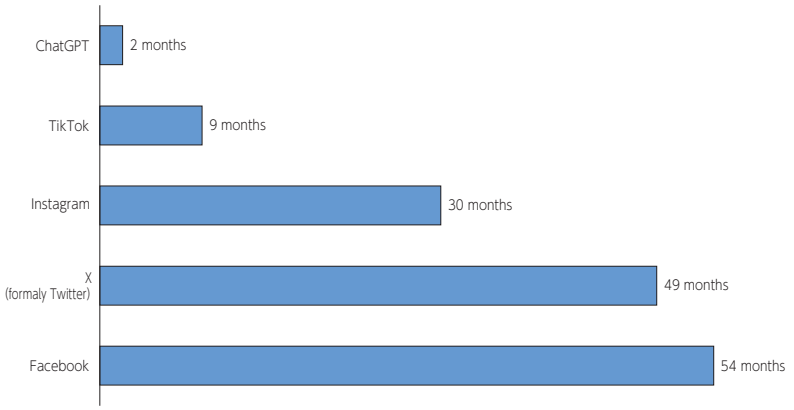
[1] Expert system: A computer system that has specialized knowledge of a particular problem and can reason and make decisions like an expert.
[2] KAMEDA Kenji, "Why did the third AI boom occur? (Part 1) The three waves that caused the third AI boom," BIZ DRIVE, February 28, 2018, NTT East Japan, <https://business.ntt-east.co.jp/bizdrive/column/dr00074-001.html> (accessed on March 22, 2024)
[3] KAMEDA Kenji, "Why did the third AI boom occur? (Part 3) What is deep learning that changed the common sense of AI?", BIZ DRIVE, April 16, 2018, NTT East Japan, <https://business.ntt-east.co.jp/bizdrive/column/dr00074-003.html> (accessed on March 22, 2024)
[4] NTT East Japan, "Introduction to deep learning | Explanation of the mechanism, what can be done, and the introduction process," August 3, 2022, <https://business.ntt-east.co.jp/content/cloudsolution/column-306.html> (accessed on March 22, 2024)

2. Impacts of generative AI

(1) Rapid progress and dissemination of generative AI

The advent of deep learning as a foundational technology has led to a significant improvement in AI performance, giving rise to AI that can autonomously generate various types of content. "Generative AI" is a collective term for AI technologies that can autonomously generate text, images, sound, and more. This field gained particular attention following the announcement of the conversational AI "ChatGPT" by OpenAI in 2022. ChatGPT acquired one million users in just five days and surpassed 100 million users within two months of its release, demonstrating an astonishing rate of user expansion compared to previous online services and platforms **(Figure 1-3-1-2)**. In addition to OpenAI, numerous companies, ranging from major corporations to startups, have announced the development of generative AI, sparking a global race in AI development.

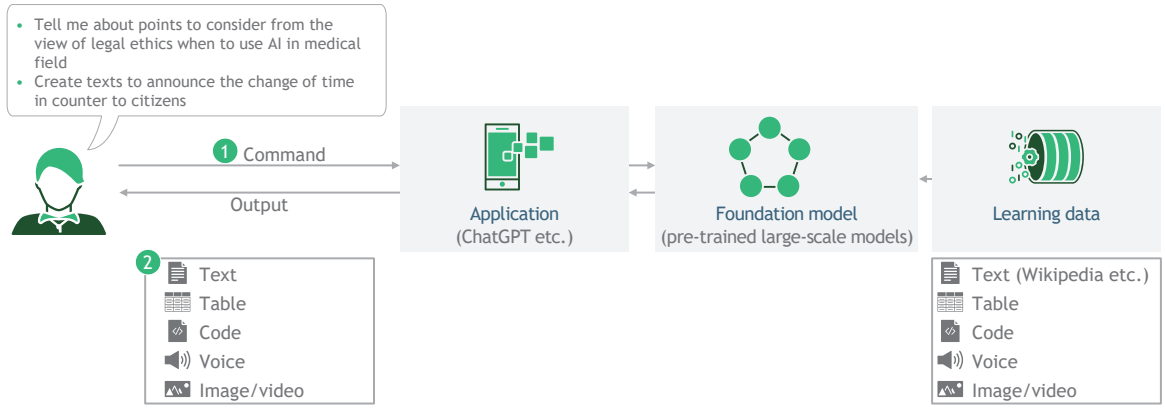
Figure 1-3-1-2 Period to take in order to acquire one million users in each service



(Source) Prepared based on Reuters etc.

Generative AI allows for easy utilization without the need for user adjustments or skills, enabling natural language instructions to be given for the generation of diverse outputs in various formats, including text, images, and videos (multimodal) (Figures 1-3-1-3 and 1-3-1-4).

Figure 1-3-1-3 Overview of generative AI



1 Easy to give natural language instructions (universal use without user-side adjustments or learning)

2 Obtain various forms of output (text/table/code/voice/image/video)

(Source) Analysed based on Boston Consulting Group, Bommasani et al."On the Opportunities and Risks of Foundation Models, " Center for Research on Foundation Models, " Center for Research on Foundation Models, 2021

Figure 1-3-1-4 Patterns and functions in major generative AI services

Major services	Functions
Text generative AI	
ChatGPT/GPT-4 (OpenAI) Bard (Google) Bing Chat (Microsoft) Copilot (Microsoft)	・Enquiry, summary, calculation, change in the way to tell, translation, knowledge discovery etc. ・Creation of dialogue contexts mixing with searching ・Support of programming etc.
Video generative AI	
StableDiffusion Midjourney Adobe Firefly Gen-2	・Creation of images, partial image editing, automatic image coloring, line art extraction ・Creation of video
Sound generative AI	
MusicGen Synthesizer V So-Vits-SVC	・Creation of music and effect sounds ・Creation of voice ・Conversion of voice, conversion of language in voice
Others	
—	・Creation of 3D objects ・Creation of molecular structure etc.

(Source) Prepared based on publicly available materials

Several factors contribute to the current AI boom. Firstly, the development and scaling of deep learning and transformer models have significantly improved model accuracy in tasks such as natural language processing and image generation. The emergence of foundational models and large language models (LLMs), trained on vast amounts of data, has eliminated the need for retraining models for new tasks, simplifying development and usage while enabling AI to handle more complex tasks, thereby increasing its recognized utility. Additionally, advancements in cloud computing and GPUs[5] have expanded computational resources, and the open-sourcing of AI development has made it accessible to general developers and companies, facilitating broader application across various fields. Moreover, the provision of user-friendly interfaces and APIs (Application Programming Interfaces) has made AI interactions more intuitive and accessible, allowing users to obtain information and perform tasks more easily. The high versatility and multimodal capabilities of AI, enabling it to handle various data formats and inputs and process multiple tasks simultaneously, have further enhanced its utility. Efforts to align AI behavior with human intentions and values (so-called AI alignment) have also progressed, fostering environments where AI collaborates with humans, promoting AI adoption across many industries[6,7] **(Figure 1-3-1-5)**.

Figure 1-3-1-5 Technical factors laying in generative AI boom

Factor	Details
Emergence of large-scale language models and foundational models	A model capable of understanding and generating human language. It learns from large amounts of text data and can generate natural text.
Open sourcing	The source code is publicly available, allowing anyone to access, use, and improve it for free, promoting the spread of technology and innovation.
User interface (UI)	It offers an intuitive and user-friendly interface, designed to enable non-technical users to easily operate AI tools.
Provision by API	It facilitates the integration of AI functions into other applications through a programming interface, allowing for diverse development.
High versatility and multimodal functionality	It has the ability to handle multiple modes, including text, images, and audio, enabling the processing and generation of various types of data.

(Source) Prepared based on publicly available materials

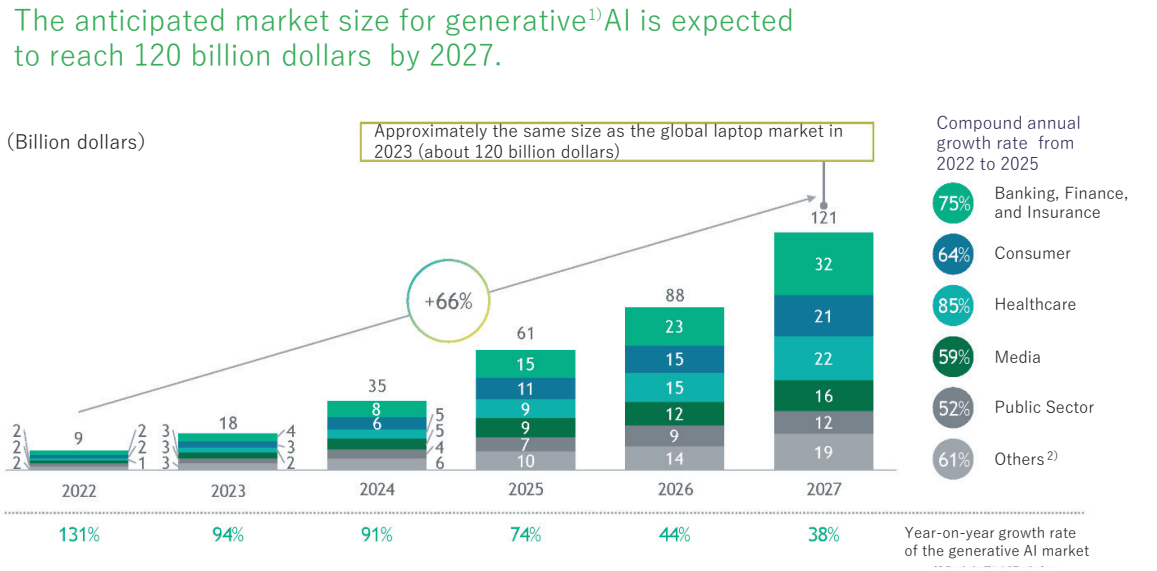
[5] Graphics Processing Unit. Originally developed for graphics processing, its high parallel processing capabilities make it suitable for large-scale computational processing such as deep learning in AI.
[6] Center for Research and Development Strategy in Japan Science and Technology Agency, "New Trends in Artificial Intelligence Research 2," July 2023, <https://www.jst.go.jp/crds/pdf/2023/RR/CRDS-FY2023-RR-02.pdf> (accessed on March 22, 2024)
[7] SHIOZAKI Junichi, "The Future Landscape Changed by Generative AI," Nomura Research Institute, December 2023, <https://www.nri.com/jp/knowledge/report/lst/2023/souhatsu/1201> (accessed on March 22, 2024)

(2) Economic effects by generative AI

The advent of generative AI has significantly impacted our intellectual activities, enabling transformations in various work domains, including content creation, customer support, and construction, as well as work domains which were previously challenging for traditional AI to apply. It is said that "the emergence of generative AI is arguably one of the most significant revolutions in human history. The greatest risk for companies is not utilizing it due to security concerns; rather, they should aim to become generative AI-first companies in the next era."[8]

According to a paper published by OpenAI and the University of Pennsylvania on March 17, 2023, 80% of workers will have at least 10% of their tasks affected by large language models, and 19% of workers will see 50% of their tasks impacted. The influence of LLMs is predicted to be particularly significant in high-wage professions and industries with high entry barriers, such as data processing, insurance, publishing, and funds. On the other hand, generative AI also has the potential to unlock significant business opportunities. According to an analysis by the Boston Consulting Group, the market size for generative AI is expected to reach 120 billion dollars by 2027. The largest markets will be "Finance, Banking, and Insurance," followed by "Healthcare" and "Consumer" **(Figure 1-3-1-6)**.

Figure 1-3-1-6 Market size of generative AI (estimated)



1: TAM = Total Addressable Market, Maximum attainable market size, the total market size that current generative AI can serve
2: Others include industrial goods, energy, and telecommunications markets.

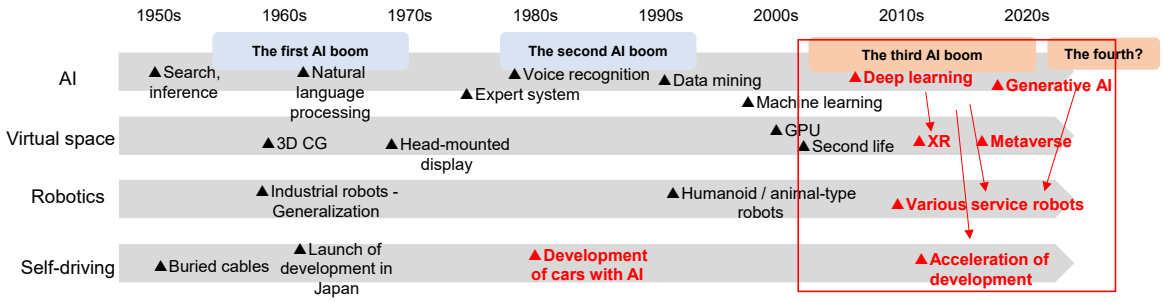
(Source) Boston Consulting Group "The CEO's Roadmap on Generative AI" (March 2023)

[8] According to Shota Imai, who has majored in Technology Management Strategy at the Graduate School of Engineering at the University of Tokyo, "We are no longer at the stage of debating whether generative AI is useful or not. We are at a turning point where if we do not use it, we could be left several times behind our competitors in no time. In the software industry, generative AI has already achieved overwhelming improvements in productivity." (Interview conducted on March 11, 2024)

Section 2 Evolving technologies along with the progress of AI

The evolution of AI, as reviewed in the previous section, is also influencing other technologies. Particularly, the development of deep learning during the third AI boom has contributed to the development of virtual space services using XR, service robots, autonomous driving, and more. The advent of generative AI further supports the advancement of these technologies **(Figure 1-3-2-1)**.

Figure 1-3-2-1 Changes in evolving technologies along with the progress of AI



(Source) Prepared based on publicly materials

The functions that AI performs in actual services can be broadly categorized into three types: "Identification," "Prediction," and "Execution." The application of these functions spans various industrial sectors, such as manufacturing and transportation. For example, in the case of autonomous driving, it combines various functions like image recognition, voice recognition, situational judgment, and route analysis in a manner suitable for the transportation sector to achieve practical implementation[1]. Similarly, in robotics, multiple functions are combined to achieve practical implementation **(Figure 1-3-2-2)**.

Here, we will discuss the trends in virtual spaces (the metaverse and digital twin), robotics, and autonomous driving, which are further advancing in practical implementation by incorporating generative AI.

Figure 1-3-2-2 Functional area of practical implementation of AI

Identification	Accuracy of prediction	Execution
•Voice recognition •Image recognition •Video recognition •Language analysis	•Numerical prediction •Matching •Intention prediction •Need prediction	•Expression generation •Design •Optimazation of behaivor •Automation of work

(Source) MIC (2016) "Research survey on the effects on employment and work style by evolution of ICT"[1]

(1) Virtual spaces (the metaverse and digital twin)

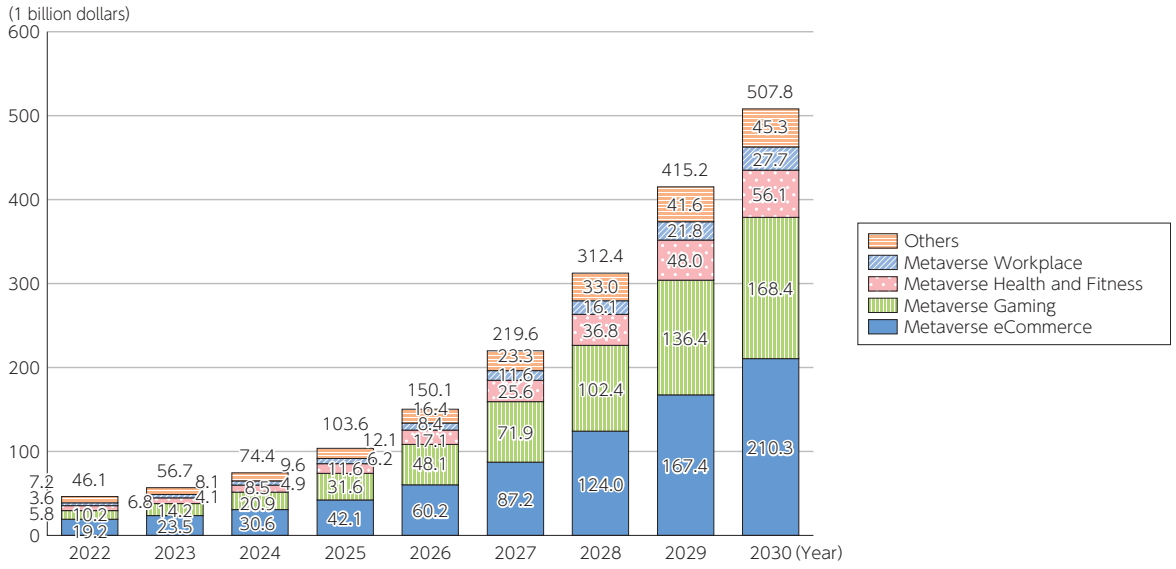
The metaverse is a virtual world created on the Internet, where users can interact with others through avatars that represent themselves. Although it is a virtual space, services that link the metaverse with the real world are being tested, such as purchasing items in the metaverse that are later delivered to the user's home. Additionally, there is growing anticipation for its use as a virtual workspace in B2B applications[2].

Another concept is the "Digital Twin," which involves recreating elements of the real world in a virtual space based on data collected from the real world. While both the metaverse and digital twin exist in virtual spaces, the key difference lies in their purpose and content. The metaverse does not necessarily replicate real-world elements and is often used for communication, gaming, and social interaction through avatars in a virtual environment. In contrast, a digital twin is a solution designed to simulate real-world scenarios, making it useful for conducting simulations that are difficult to perform in the real world[3].

The market size of the metaverse is projected to expand from 46.1 billion dollars in 2022 to 507.8 billion dollars by 2030 **(Figure 1-3-2-3)**.

[1] MIC, "Report on Research and Study on the Impact of ICT Evolution on Employment and Work Styles," March 2016, <https://www.soumu.go.jp/johotsusintokei/linkdata/h28_03_houkoku.pdf>
[2] Nikkei X Trend, "What is the Metaverse? Will it Really Spread? Eight Points to Understand the Basics," April 14, 2022, <https://xtrend.nikkei.com/atcl/contents/skillup/00008/00020/> (accessed on March 22, 2024)
[3] MIC, "The 2023 White Paper on Information and Communications in Japan" <https://www.soumu.go.jp/johotsusintokei/whitepaper/r05.html>

Figure 1-3-2-3[4] Market size of the metaverse



(Source) Statista [4]

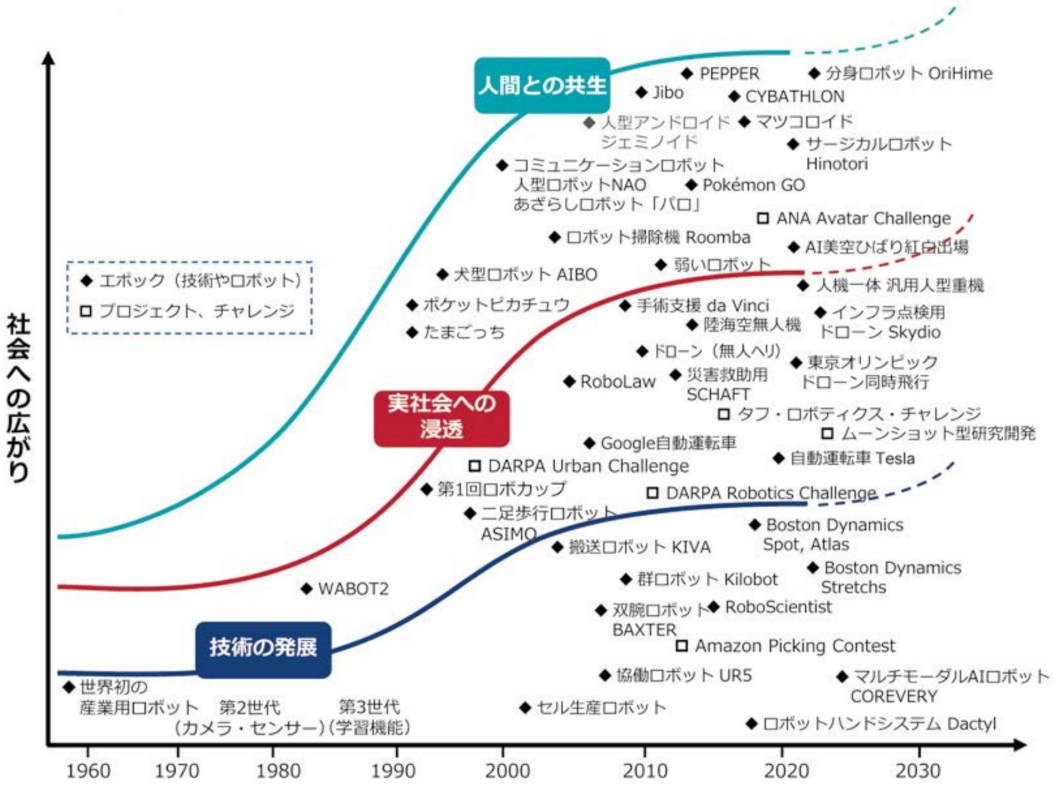
By utilizing generative AI, certain processes in the creative activities within the metaverse, such as automatic generation of 2D images and 3D models, as well as program creation support, can be simplified. This is expected to lower the technological and knowledge barriers, leading to an expansion of users. Additionally, the use of machine learning techniques such as Generative Adversarial Networks (GAN) enables individuals without design experience to create their own avatars and more, potentially giving rise to a vast economic sphere within the virtual space.

(2) Robotics

The development of robots began in the 1960s for industrial use, serving as substitutes for human assistance and dangerous tasks in industrial and military applications. Since the 1990s, robots have been developed and utilized not only for industrial purposes in factories but also for service applications in general society, such as caregiving, cleaning, and delivery. In personal and household settings, various robots like cleaning robots and companion robots have become more widespread **(Figure 1-3-2-4)**.

[4] https://www.statista.com/outlook/amo/metaverse/worldwide

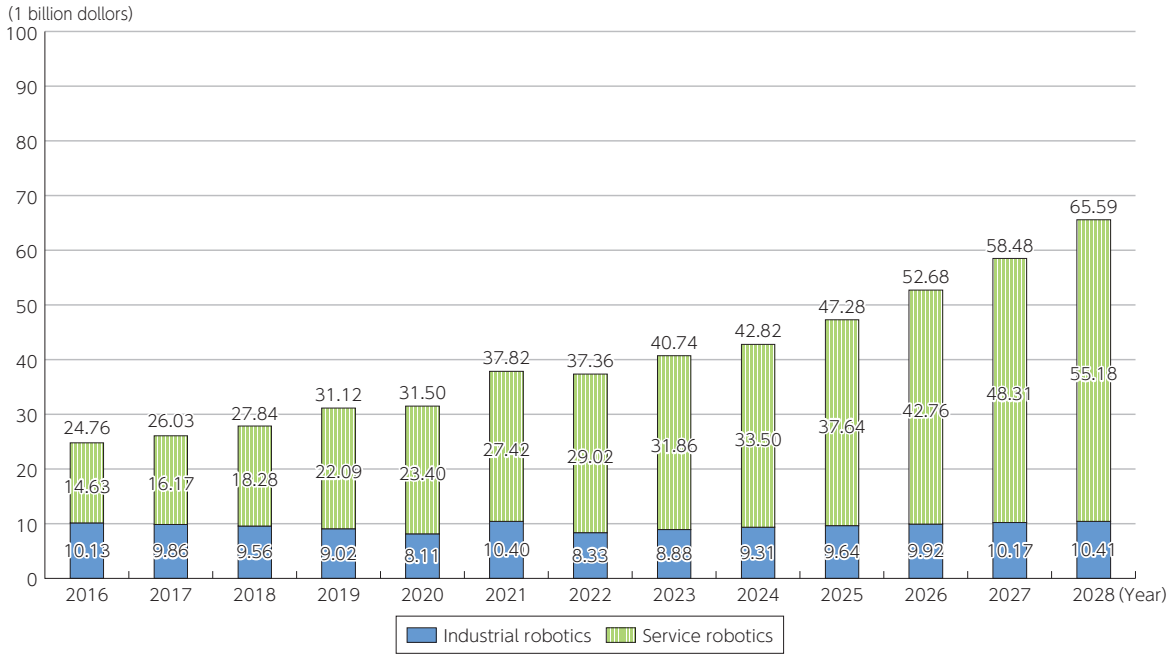
Figure 1-3-2-4 Trend of research and development of robotics



(Source) Center for Research and Development Strategy, Japan Science and Technology Agency Overview report of research and development in the field of systems and information science(2023)

The global robot market is expected to see significant revenue growth, reaching 42.82 billion dollars by 2024. Among various segments, service robotics is projected to dominate with a market size of 33.5 billion dollars in 2024. This field is expected to grow at a compound annual growth rate (CAGR) of 11.25% from 2024 to 2028, reaching an estimated market size of 65.59 billion dollars by 2028 **(Figure 1-3-2-5)**.

Figure 1-3-2-5 Market size of robotics



(Source) Statista "Statista Market Insights"[5]

[5] https://www.statista.com/outlook/tmo/robotics/worldwide

The expansion of robot development and utilization has progressed in tandem with the advancement of AI. Robots are considered intelligent mechanical systems with three key elements: sensors (perception/recognition), intelligence/control systems (decision-making), and actuators (action). By combining deep learning-based AI with reinforcement learning, the recognition capabilities of robots have significantly improved, allowing them to collect and analyze large amounts of data from cameras and sensors. AI is already being used in production sites for quality inspection and predictive maintenance of equipment. The practical application of caregiving and customer service robots is also advancing. Voice recognition and natural language generation technologies have enabled natural interactions between humans and household robots.

Furthermore, there are attempts to use generative AI as action-generating AI for decision-making and actuators. This involves interpreting multimodal information such as language and images, allowing robots to understand the surrounding environment from camera footage and perform physical actions to achieve user commands. However, challenges remain in the physical movements of robots, and research on tactile feedback, soft hardware development, and safe force control is crucial. It is expected that it will take more time for practical implementation in society[6,7].

Typically, programming is required to operate robots, but in the future, if generative AI can program itself through dialogue with humans, it is anticipated that robots will be able to understand human language and be programmed instantly, leading to a future where robots can be controlled more intuitively.

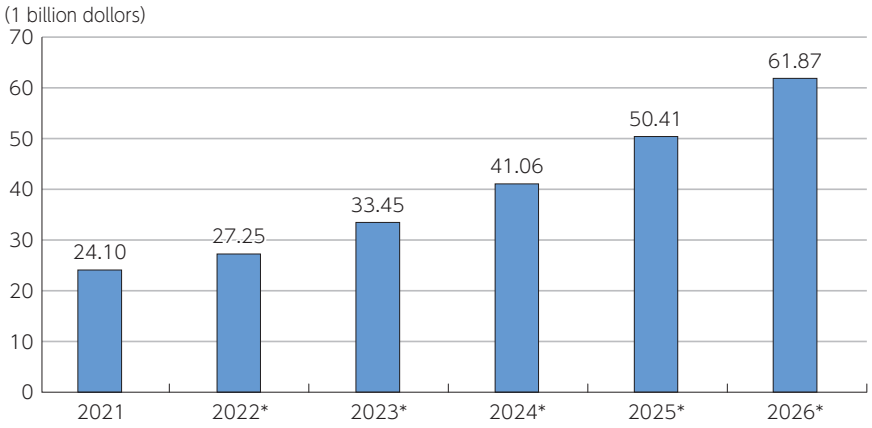
(3) Autonomous driving technology

In autonomous driving technology, AI is utilized in the three processes of perception, decision-making, and action by the system. AI processes information from cameras and sensors installed in vehicles to recognize the surrounding environment and safely navigate the vehicle, avoiding pedestrians and obstacles. Generated AI is also used for prediction and decision-making, considering the behavior of vehicles and pedestrians ahead and determining how the vehicle should be controlled based on this information. AI also plays a crucial role in supporting safe driving in vehicles.

Furthermore, the learning capabilities of generated AI enable advanced route optimization, and its speech recognition technology is also utilized, allowing drivers to give commands to the vehicle using their voice[8,9]. The realization of fully autonomous driving in the future will require not only image recognition but also the recognition of other modalities such as voice, enabling communication with passengers. As a result, there is a growing trend of integrating generated AI into vehicles.

The global market size of autonomous driving vehicles exceeded 24 billion dollars in 2021. The market is expected to continue growing, reaching a size of approximately 62 billion dollars by 2026 **(Figure 1-3-2-6)**.

Figure 1-3-2-6 Market size of autonomous driving technology



The year with * means the prediction.

(Source) Statista[10]

[6] NIKKEI Tech Foresight, "Infrastructure models will be multimodal and integrated with robots: 24-year outlook," January 24, 2024, <https://www.nikkei.com/prime/tech-foresight/article/DGXZQOUC239XV0T20C24A1000000> (accessed on March 22, 2024)
[7] SHINDO Tomonori, "Editor-in-Chief's Outlook for 2024 (No. 11) Will Robots Change with Large-Scale Language Models? - Robots and AI in 2024 -," Nikkei xTECH, January 19, 2024, <https://xtech.nikkei.com/atcl/nxt/column/18/02668/112800011/> (accessed on March 22, 2024)
[8] NEC, "Examples of AI technology used in automobiles, such as autonomous driving, and future challenges," <https://www.nec-solutioninnovators.co.jp/ss/mobility/column/07/index.html> (accessed on March 26, 2024)
[9] Jidounten LAB, "Autonomous Driving and AI (Latest 2023 Edition)," July 7, 2023, <https://jidounten-lab.com/u_35766> (accessed on March 26, 2024)
[10] https://www.statista.com/statistics/428692/projected-size-of-global-autonomous-vehicle-market-by-vehicle-type/