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.

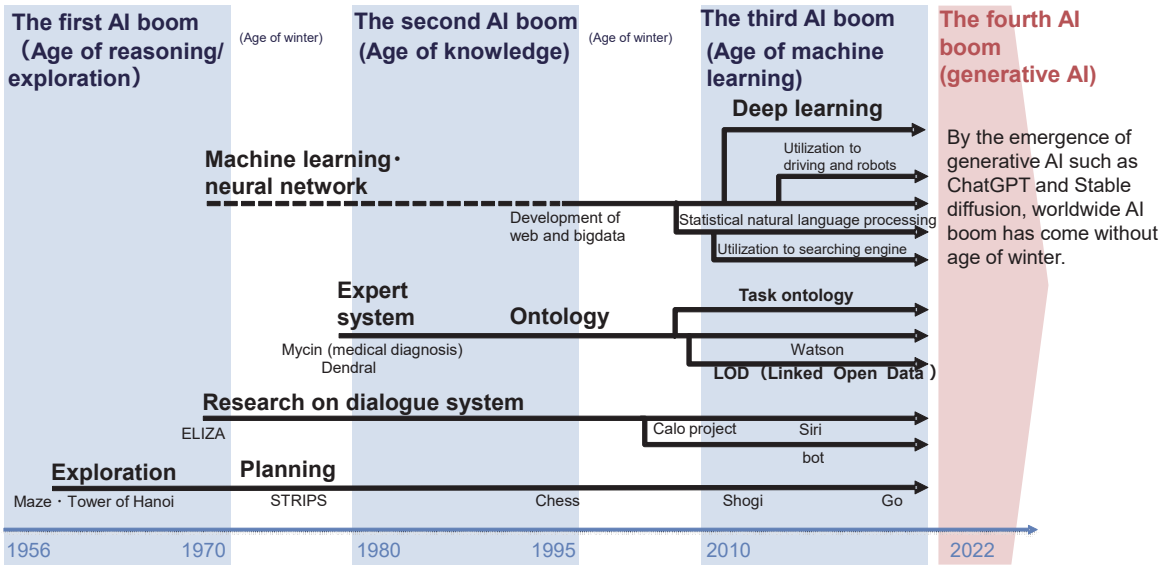
These technologies, which utilize Information Communications Technologies (ICT) / digital such as AI and XR (hereinafter referred as to digital technologies), are anticipated to further transform our social and economic activities. However, the evolution of these technologies also brings challenges and 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].

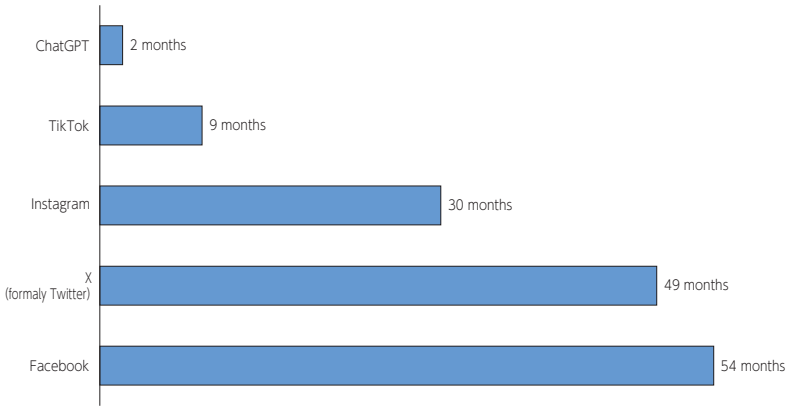
[1] Expert system: A computer system that has specialized knowledge of a particular problem and can reason and make decisions like an expert.
[2] KAMEDA Kenji, "Why did the third AI boom occur? (Part 1) The three waves that caused the third AI boom," BIZ DRIVE, February 28, 2018, NTT East Japan, <https://business.ntt-east.co.jp/bizdrive/column/dr00074-001.html> (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.

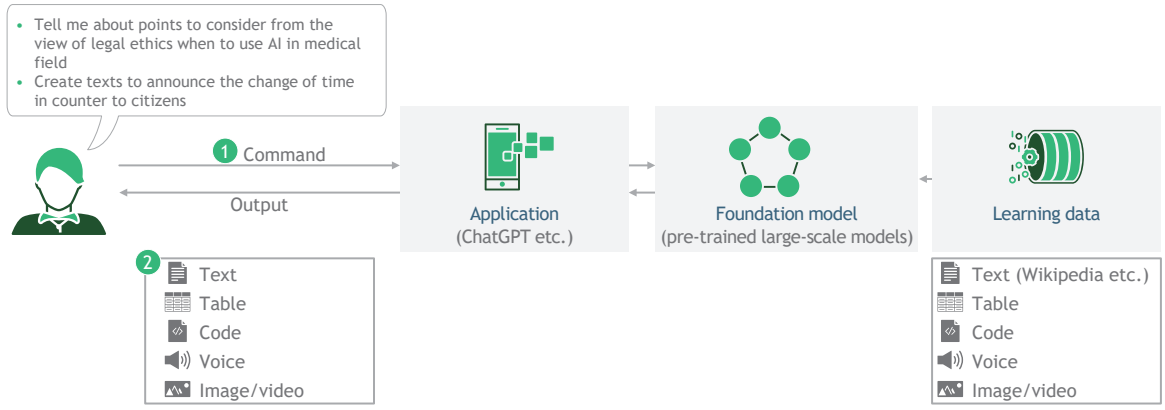
Figure 1-3-1-2 Period to take in order to acquire one million users in each service



(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

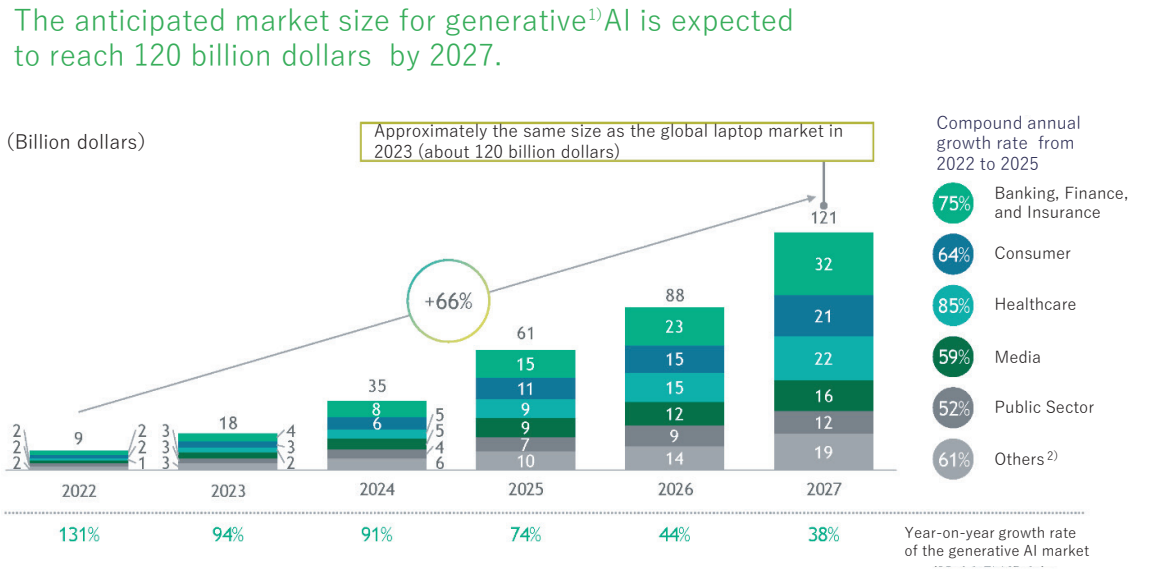
[5] Graphics Processing Unit. Originally developed for graphics processing, its high parallel processing capabilities make it suitable for large-scale computational processing such as deep learning in AI.
[6] Center for Research and Development Strategy in Japan Science and Technology Agency, "New Trends 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)