

CHAPTER 1 THE EVOLUTION AND FOUNDATIONS OF MACHINE LEARNING

Nor Erne Nazira Bazin and Zuriahati Mohd Yunos

1.1 INTRODUCTION TO MACHINE LEARNING

Machine learning (ML) has progressively evolved from a specialised academic field to a driver of transformation across industries. Innovations in healthcare, agriculture, finance, education, and public services are driven by ML, changing how organisations process data, make decisions, and automate complex workflows. In recent advancements, ML's achieved scalability and adaptability, especially through large language models (LLMs), multimodal systems, transformer architectures, TinyML, edge ML, and low-code/no-code artificial intelligence (AI) platforms. These developments enable the use of large, diverse datasets, support deployment at the edge, and facilitate the efficient scaling of intelligent automation.

With this progression, the emergence of generative AI, advanced ML for security, and edge deployment shifted how these technologies are applied. Together, these efforts push forward applications that grow more accessible over time. They also become more sustainable and customizable to better address specific needs in various fields. This

overall path establishes ML as a solid foundation for digital shifts, positioning it as a key driver.

Recently, ML experienced rapid expansion for both scope and applicability. LLMs such as OpenAI's Generative Pre-Trained Transformer (GPT) family and DeepSeek's R1 exhibit major advances in language understanding, content generation, and interactive problem-solving (Ibrahim et al., 2025). In multitask systems, multimodal AI can now combine text, images, audio, and sensor data. This integration supports complex applications in autonomous transportation, precision medicine, and adaptive human-computer interaction (Huynh et al., 2025; Santos et al., 2024).

At the same time, the rise of edge computing frameworks pioneered by NVIDIA and other industry leaders has enabled the deployment of ML models on devices with limited resources. Drones, wearable technologies, and internet of things (IoT) ecosystems can now process information locally rather than relying solely on the cloud. This new ability reduces latency, improves privacy, and enables real-time decision-making in fast-changing environments (Khouas et al., 2024).

The role of ML is becoming extremely crucial in supporting major systems that boost societal resilience. In disaster management, predictive analytics is increasingly used to improve preparedness, allocate resources more effectively, and strengthen urban resilience (Patel, 2025). In meteorology, models such as Google's GenCast have improved predictive accuracy by as much as 20 per cent. These benefits highlight the potential of ML to advance weather forecasting and guide infrastructure design (Santos et al., 2024).

These innovations collectively demonstrate how ML is shifting from narrow, specialised uses into deeper roles within key social and industrial structures. Studies show that it has progressed beyond merely being a helpful side tool. Now, it functions as a key driver of overall digital transformation. Such developments have deep effects on technological progress, fundamental infrastructure setups, and how policies are formulated.

Although the progress in the ML field has been significant, a critical gap persists between ML theory and its real-world implementation. While theoretical advancements are the backbone of ML algorithms, translating these models into practical solutions requires overcoming challenges related to data quality, model interpretability, computational efficiency, and ethical considerations. Issues such as biased training data, model transparency, and the environmental impact of large-scale AI computations have further established new requirements for responsible AI development (Bender et al., 2021; Murphy, 2022). The emergence of ethical AI frameworks and responsible AI initiatives further highlights the need for fairness and accountability in ML applications. Figure 1.1 shows ML as a subset of AI.

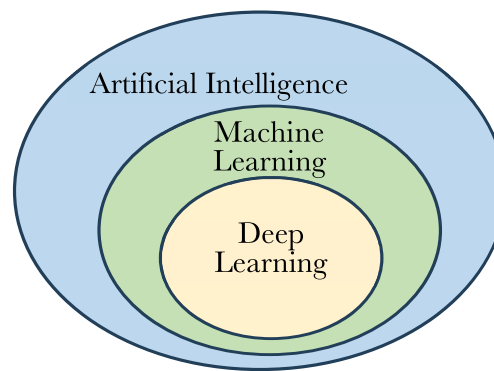


Figure 1.1 Artificial intelligence, machine learning, and deep learning

Looking forward, dealing with these challenges is as important as pushing for new technical advances. The road ahead for ML rests on more than improvements in algorithms and raw computing power. It leans more towards creating systems that earn trust, are transparent on how they work, and match up with what society really requires. The dynamic exchange between theory and practice shapes the evolution of ML. Theoretical frameworks provide the foundation for innovation in the algorithm; however, it is through real-world application that limitations are visible, suggesting further refinement. This cycle can be observed in areas such as medical imaging, autonomous systems, and supply chain optimisation, where ML has already reshaped industrial and social practices. The impact of ML