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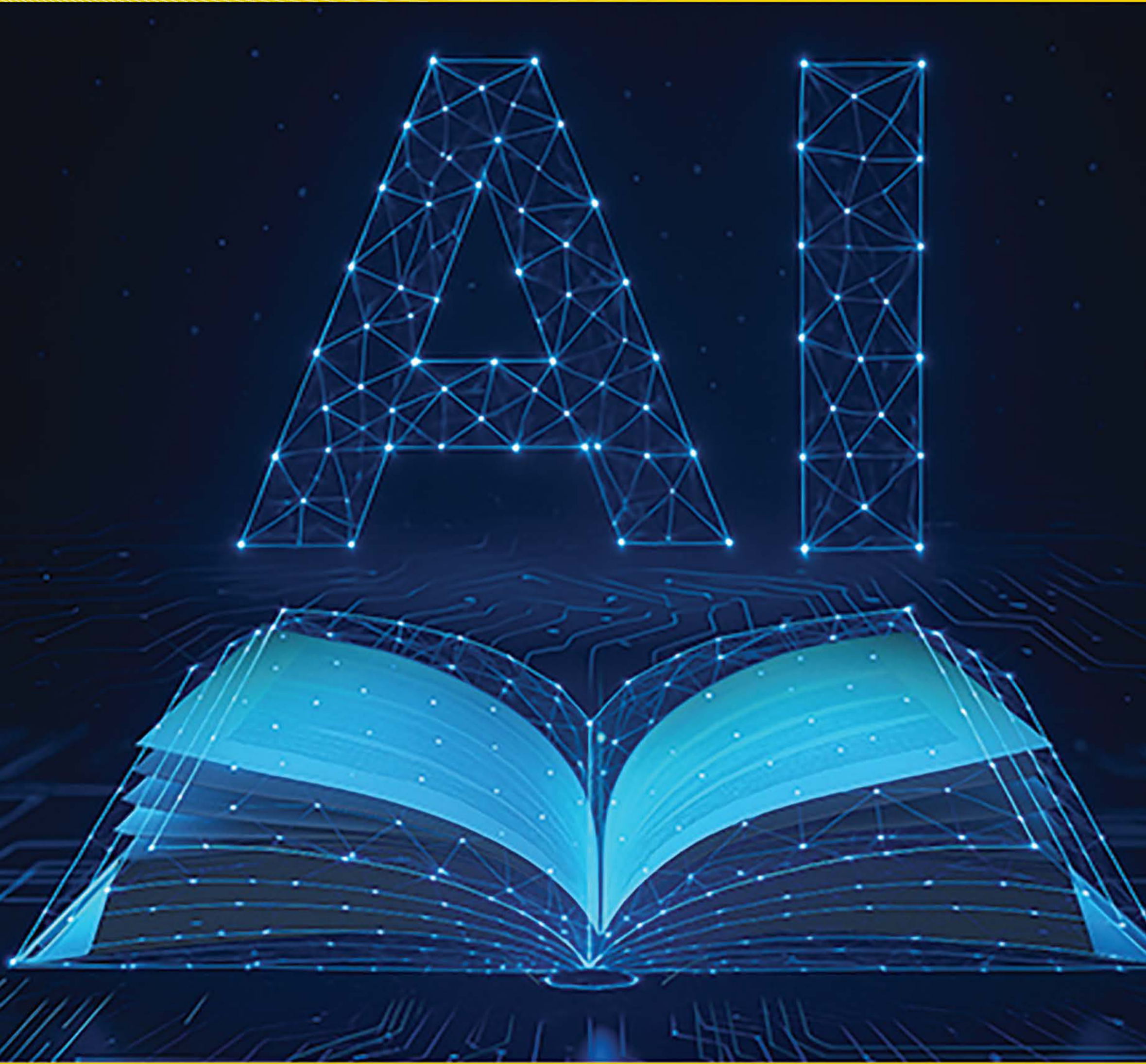
AI in Education Systems Successful Cases and Perspectives

Editors

Vadym I. Slyusar | Yuriy P. Kondratenko



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Editors

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Preface

This River Publishers Rapid book “AI in Education System: Successful Cases and Perspectives” analyses the current state of art and perspectives artificial intelligence (AI) implementation in education sphere focusing on the successful cases and international experiences as well as on the challenges and risks of uncontrolled AI using by students and schoolchildren.

The book consists of seven chapters and provides an overview of the recent developments in AI tools and successful examples of their practical implementation in teaching and learning processes.

The monograph consists of research-analytic-oriented chapters presented by invited high-caliber scientists from different countries (Norway, Poland, Ukraine and the United States of America).

The chapter “*General Characteristics of the Large Language Models and Comparative Analysis*”, by V. I. Slyusar, Z. Gomolka and Y. P. Kondratenko, presents the historical aspects of the of large language models (LLMs) development in the context of their impact on educational processes. Special attention is given to transformer-based models, starting with the emergence of GPT-1 in 2018, Google’s BERT, and their subsequent evolution into models such as GPT-4.5, Claude 3.7, and Gemini 2.0. Particular focus is placed on architectural innovations such as the Mixture of Experts (MoE), which enhance model efficiency, as well as the development of open models, including Meta’s LLaMa and Chinese LLMs that have become competitive with Western technologies. Recent trends in text generation are also discussed, especially the concept of the Large Concept Model and the new dLLM architecture, which enables faster generation and refinement of textual data. Analyzing the current state of LLMs development, it is noted that these models are already fundamentally transforming education, and their continued improvement opens up new possibilities for integration into the educational domain. The conclusion emphasizes the importance of responsible use of LLMs and the need to strike a balance between their efficiency and the potential challenges they may pose.

In “*Analysis of Successful AI Applications in the Education Environment*”, Y.P. Kondratenko, M.B. Solesvik, N.Y. Kondratenko and Z. Gomolka note that AI methods and tools create new opportunities to enhance the efficiency of education systems worldwide. This chapter analyzes successful cases of AI implementation and digital transformation in education, focusing on potential applications in learning, teaching, research, and management. Special attention is given to: (a) successful international experience; (b) inter-university cooperation for AI implementation; (c) collaboration between leading AI companies/consortia and educational institutions; and (d) the role of competition in facilitating AI product integration into education.

Y.P. Kondratenko, Y.D. Zhukov, A.I. Shevchenko, O.Y. Zhukova and O.S. Striuk, in the chapter “*AI and Digital Evolution in the Education System of Ukraine,*” discuss the current state of digital transformation and AI introduced in the Ukrainian education system. Among the focuses are STEM education, SMART technologies, online education and the experience of the leading Ukrainian universities in creating neural networks’ ML-laboratory, "Internet of Things" specialization, research laboratory of mechatronics and robotics, innovation ecosystem Sikorsky Challenge, and others. Special attention is paid to (a) innovating shipbuilding education in Ukraine; (b) the development of international academia-business collaboration in navigating shipbuilding 4.0; and (c) analysis of the successful cases and perspectives of AI application in the Ukrainian education system as well as (d) peculiarities of its post-war recovery.

The chapter “*Best Strategies for Bilingual Education: How Can We Explain Their Success?*“ by Claudia Cabrera, Olga Kosheleva, Christian Servin and Vladik Kreinovich, discusses that when designing AI-based tools for education, it is important to take into account the experience of teachers. In this, it is necessary to distinguish between the education features that are justified by the general features of the corresponding education task – these features should be taken into account in AI-based learning as well – and features that are specific only to traditional non-AI teaching. In this chapter, on the important example of bilingual education, the authors show that several empirically successful teaching strategies can be explained in the general context and thus should be implemented in AI-based teaching as well.

In “*Challenges and Risks of Uncontrolled AI Use by Students and Schoolchildren”,* Yuriy Kondratenko, Nina Kondratenko and Vadym Slyusar analyse the advantages and challenges of artificial intelligence implementation in the education system. The perspectives, potential risks, and dangers of AI use for pupils and students in learning processes and social activities are discussed with illustrations of real cases. Special attention is paid to the proposals and recommendations for the successful integration of AI tools, in particular, large language models, to education processes focusing on the adapted tasks, relevant changing university curricula, increasing critical thinking, ethical challenges, and decreasing risks and dangers of uncontrolled use of AI tools by university students and school pupils. The interaction between AI, artificial conscience, and artificial consciousness within the educational process is discussed.

The chapter "*From Machine Learning to Human Learning: What Can Pedagogy Learn from AI Successes*", by Victor Timchenko, Yuriy Kondratenko, Olga Kosheleva and Vladik Kreinovich, discusses that at this moment, so much experience has been accumulated in AI-based machine learning that it is time to start the analysis in the opposite direction – to see what human-based pedagogy can learn from AI successes. In this chapter, the authors provide the first results of such an analysis.

V. I. Slyusar in the chapter "*Perspectives of AI Applications for Improving Learning and Teaching Processes*" presents the concept of an ecosystem of neuro-coworkers within an educational institution as an innovative approach to integrating large language models (LLMs) into the processes of learning, teaching, and administrative management. The prospects of establishing inter-university networks that facilitate knowledge exchange among educational institutions through a centralized system of federated model training are examined. The use of 3D world generation technologies is discussed as a means for visualizing educational material and applying knowledge in practice, particularly in literature, physics, and mathematics. Special attention is given to the role of artificial general intelligence (AGI) in the formation of superknowledge and the transformation of the educational process at the level of researcher training, with a forecasted paradigm shift in the interaction between human intelligence and AI.

The chapters of the monograph have been structured to provide an easy-to-follow introduction to the topics that are addressed, including the most relevant references, so that anyone interested in this field can get started in the area.

This book may be useful for researchers, policymakers, professors and students who are interested in implementation of advanced AI tools to education system.

Let us express our deep appreciation to all authors for their contributions as well as to reviewers for their timely and interesting comments and suggestions. We certainly look forward to working with all contributors again shortly.

Editors:

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List of Abbreviations

AI	Artificial intelligence
AI-PPP	AI-powered presentation platform
AMICO	Advanced Measuring Instruments Company
AR	Augmented reality
AYDU	Aker Yards Design Ukraine
BERT	Bidirectional encoder representations from transformers
BSNU	Petro Mohyla Black Sea National University
CC	Concord Consortium
CNN	Convolutional neural network
CSET	Center for Security and Emerging Technology
CSU	Cleveland State University
E2E	End-to-end
ECCE	Executed, checked, corrected, evaluated
EMIS	Education management information systems
EWUP	East-West University Partnership
FLL	Foreign language learning
GPT	Generative pretrained transformer
INSEA	Institute of Novel Ship Engineering Apprenticeship
IR	Intelligent robotics
IRUM	Internal reskilling/upskilling model
IS	Information systems
ITS	Intelligent tutoring system
KPI	Key performance indicator
KSERU	Knowledge-skills-expertise-reskilling-upskilling
LCM	Large concept model
LLE	Lifelong education
LLM	Large language model
LSTM	Long short-term memory
MDEM	Marine Design Engineering Mykolaiv

MIT	Massachusetts Institute of Technology
ML	Machine learning
MMLU	Massive multitask language understanding
MMMU	Multimodal massive understanding
MoE	Mixture of experts
MT	Machine translation
NLP	Natural language processing
NMT	Neural machine translation
NORA	Norwegian AI Research Consortium
NUOS	Admiral Makarov National University of Shipbuilding
OPT	Open pre-trained transformer
P&ID	Process and instrumentation diagram
RAG	Retrieval-augmented generation
RLHF	Reinforcement learning from human feedback
RNN	Recurrent neural network
ROE	Return on experience
SDEU	Ship Design & Engineering Ukraine
SDG	Sustainable development goal
SEC	Southeastern Conference
SFT	Supervised fine-tuning
SMR	Small modular reactor
STEM	Science, technology, engineering, and mathematics
SU	Saarland University
T2I	Text-to-image
TVET	Technical and vocational education and training
USC	University of South Carolina
VR	Virtual reality
WWW	World Wide Web

1

General Characteristics of the Large Language Models and Comparative Analysis

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Abstract

The history of the development of large language models (LLMs) is examined in the context of their impact on educational processes. The analysis begins with the origins of automatic translation, initiated in 1947, and the first implementations of this idea, including IBM's machine translation experiments in 1954, the creation of the chatbot ELIZA in 1966, and the evolution of neural network architectures that led to modern LLMs. Significant attention is given to transformer-based models, starting with the emergence of GPT-1 in 2018, Google's BERT, and their subsequent evolution into models such as GPT-4.5, Claude 3.7, and Gemini 2.0. The emergence of multimodal LLMs, capable of integrating text, images, and other data types, is described in detail. Particular focus is placed on architectural innovations such as the mixture of experts (MoE), which enhance model efficiency, as well as the development of open models, including Meta's LLaMa and Chinese LLMs that have become competitive with Western technologies. Recent trends in text generation are also discussed, especially the concept of the large concept model (LCM) and the new dLLM architecture, which enables faster generation and refinement of textual data. Analyzing the current state of

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LLM development, it is noted that these models are already fundamentally transforming education, and their continued improvement opens up new possibilities for integration into the educational domain. The conclusion emphasizes the importance of responsible use of LLMs and the need to strike a balance between their efficiency and the potential challenges they may pose.

Keywords: Large language model, LLM, AI, GPT, BERT, LLaMa, large concept model, LCM.

1.1 Introduction

In scientific literature, increasing attention is being devoted to the development of artificial intelligence (AI) technologies in the context of transforming educational processes. One of the most promising directions in this field is the application of LLMs. These neural network-based models are trained on vast volumes of textual data, enabling them to effectively process natural language and address a wide range of text-related tasks. To better understand the LLM phenomenon, it is useful to briefly delve into the history of their development. Naturally, there is no need to examine the entire history of computational automation, which spans several millennia and has already been repeatedly covered in numerous publications. The task is simplified thanks to the works [1, 2], which indicate that the history of LLMs can be traced back to March 1947, when Warren Weaver first shared his ideas on using computers for natural language processing in translation tasks. Weaver proposed this possibility in a letter to cyberneticist Norbert Wiener, with whom he was working at the time on a joint book, and also in a conversation with British crystallographer Andrew Booth, who was visiting the United States to study computer developments. Booth proved to be a very attentive interlocutor and, by 1948, had implemented Weaver's ideas in experiments on "mechanical translation" using punch cards in collaboration with Richard Richens [2].

Let us now examine these historical aspects in more detail, following the perspective of works [1, 2] and other publications on similar topics, while supplementing them with new data that will help better understand the essence of LLMs and their capabilities through the lens of educational needs.

1.2 The Phenomenon of Large Language Models (LLM) and a Brief History of Their Development

1.2.1 The initial stage in the history of LLMs

The history of LLMs, initiated by W. Weaver and taken up by A. Booth, quickly gained momentum. In 1949, newspapers reported that Harry Huskey had also considered the possibility of machine translation using the SWAC computer in Los Angeles [1, 2]. In subsequent years, machine translation research began at the University of Washington (Erwin Reifler), the University of California, Los Angeles (Victor Oswald and Stuart Fletcher), the RAND Corporation, and the Massachusetts Institute of Technology (MIT) [1, 2]. In July 1949, in Carlsbad (New Mexico), W. Weaver presented his memorandum titled “Translation” [3], in which he summarized his views on the prospects of automatic text translation. Of course, this was only an initial conceptual description, and Weaver acknowledged the serious limitations of the simplified approach to solving the task of textual translation. The memorandum noted that the problem of ambiguous word interpretation in translation could be addressed by analyzing the immediate context on both sides of the central word in question. This is essentially how modern LLMs now operate – equipped with attention mechanisms and positional encoding of words. In his optimistic conclusions regarding the future of automatic translation, W. Weaver relied on the McCulloch-Pitts theorem (1943) concerning the mathematical modeling of recursive neural structures in the human brain [2]. In a simplified interpretation, the essence of this theorem can be reduced to the assertion that a neural network model with formally defined regenerative loops, implemented via a computer (Turing machine), is capable of deriving any logical conclusion from a finite set of data. Essentially, the McCulloch-Pitts theorem explains the “intelligence” of modern LLMs and refutes the claims of some researchers who argue that LLMs can only generate conclusions directly encountered during their training. W. Weaver, for his part, saw in this theorem the potential for a formal solution to the problem of automatic translation, based on the logical structure of language syntax and the mathematical computability of logical inference. Supporting this was the finding in [3] that neural networks can implement any computable function that can be executed on a Turing machine. This became a turning point in the development of the general theory of artificial neural networks and LLMs.

According to [2], the reaction to W. Weaver's memorandum was mixed. Some authorities outright rejected the very idea of automating translation, holding views similar to those of professional translators today who fundamentally oppose machine translation. Other experts were less sceptical. One of those who picked up on W. Weaver's proposals was E. Reifler [2], who, over the following months, introduced the concepts of pre-editing and post-editing and proposed the use of regularized languages. An important outcome of Weaver's memorandum was the organization of the first-ever conference on machine translation, held in June 1952 [2]. Further conceptual roots of LLMs can be traced to January 1954, when IBM and Georgetown University collaborated on the first machine translation system, which automatically translated 60 Russian sentences into English using a dictionary of 250 words [1]. Although this experiment was rudimentary, it demonstrated the feasibility of computational language processing and spurred governmental investment in machine translation. Another significant milestone in the history of LLM development was the 1966 demonstration by Joseph Weizenbaum from MIT of the first chatbot psychotherapist, ELIZA [4]. It functioned as a virtual conversational partner that mimicked a psychotherapist using a simple technique of rephrasing user inputs and applying template-based questions. This created the illusion that the bot was conducting a meaningful dialogue. Communication with ELIZA did not occur through a screen but via an electric typewriter connected to a remote computer, with the bot's responses printed out. Despite such a limited interface, some users began to feel an emotional connection with ELIZA and engaged in sincere conversations. This experiment was the first to show that human-machine communication could occur in natural language. At the same time, the most important discovery was that people tend to attribute meaning to chatbot messages on their own, assuming that the machine imbues the text with intent. This phenomenon later became known as the "ELIZA effect," which modern chatbots, such as the one described by Shevchenko et al. [4], have significantly amplified.

The subsequent innovations that contributed to the development of modern LLMs were driven by fundamental breakthroughs in neural network architectures during the 1980s–2000s. In particular, recurrent neural networks (RNNs) emerged in 1986 [5], introducing memory mechanisms for processing textual sequences. The limitations of RNNs due to the vanishing gradient problem were partially addressed in 1997, when S. Hochreiter and J. Schmidhuber invented long short-term memory (LSTM) [6], which employed control mechanisms to retain contextual information over long sequences. The 2010s saw a rapid advancement in deep learning capabilities, spurred by improvements in hardware, datasets, and algorithms. Among the critical milestones was the release of the Stanford CoreNLP toolkit in 2010 [7], which standardized tools for named entity recognition. With the launch of Google Brain in 2011 [8], large-scale neural network training became more accessible, and the introduction of Word2Vec (2013) [9] and GloVe (2014) [10] enabled vector-based representations of semantic relationships.

1.2.2 The transformer era

The earliest attempts to create language models based on large text corpora can be found in works [11, 12]. However, the true breakthrough came with the introduction of the transformer architecture, proposed in 2017 [13], which laid the fundamental groundwork for the development of the first LLMs, such as GPT-1 [14] by OpenAI and BERT by Google [15]. It is worth noting that, in fact, the name “GPT” originated thanks to OpenAI’s competitors at Google. Radford et al. [14] at OpenAI described the results of training an unnamed language model based on a 12-layer transformer architecture that included only the decoder part and 12 masked self-attention heads. The context window for inference was limited to 512 tokens. Although the number of model parameters was not explicitly stated in [20], calculations show that it amounted to approximately 117 million. The training dataset used was BooksCorpus, with a total volume of 5 GB, comprising over 7000 unique books of various genres with long sequences of continuous text. In [14], the existing concept of “Generative Pretraining” [16] was used, which was applied to transformers for the first time. Interestingly, however, the authors of [14] did not use the abbreviation GPT or its full form, generative pretrained transformers. Only in October 2018 did the preprint [15] on the BERT language model from Google become the first publication in which the term GPT was officially introduced to describe the model created by OpenAI. It remained in use until the release of OpenAI’s next model, GPT-2, in 2019. To differentiate the first model from the new version, the term GPT-1 began to be used for the original model.

Returning to the aforementioned BERT model (bidirectional encoder representations from transformers) by Google [15], it should be noted that its release marked a significant milestone. With 340 million parameters, BERT outperformed previous models on 11 NLP tasks. The implemented method of bidirectional processing allowed the model to analyze entire sentences rather than just token sequences. This enabled a more nuanced understanding of linguistic phenomena. Within 18 months, BERT began handling 90% of

English-language queries on Google, demonstrating its scalability in real-world applications. The release of BERT effectively initiated a competition among LLM developers to build more advanced models – an arms race that has become an integral part of AI advancement for the long term.

In response to the release of BERT, OpenAI developed GPT-2 in 2019 [16], which was significantly scaled up compared to GPT-1 and released in four versions: small (117 million parameters, the same size as GPT-1), medium (345 million parameters, comparable to BERT), large (762 million parameters), and extra-large (1.5 B parameters – the most frequently referenced version of GPT-2). In addition to the increase in size, the architecture was improved, and the context window was expanded to 1024 tokens. Layer normalization was introduced at various stages of the model to enhance stability. The model was trained on a dataset of approximately 40 GB, sourced from a wide range of web pages. As a result, GPT-2 demonstrated substantial improvements in language generation quality, coherence, and versatility. Its ability to produce highly realistic text raised the first concerns regarding potential misuse. This initially led OpenAI to withhold the full version of the model from public release. However, the restrictions were later lifted, and GPT-2 gained recognition as a strong statement of OpenAI's ambition to dominate the LLM domain. The term "Large Language Model" (LLM) gained widespread popularity following the release of OpenAI's preprint on its next model, GPT-3 [17], published in 2020. This work described GPT-3 as a language model with 175B parameters and extensively examined its capabilities across various NLP tasks. Although the concept of large language models had existed earlier, it was this publication that catalyzed the widespread adoption of the term "LLM." It came to denote language models trained on vast text corpora, capable of processing, understanding, and generating text. Notably, the dataset used to train GPT-3 reached 4 TB of data – and this was not yet the upper limit.

The appearance of GPT-3 prompted the entry of a new player into the race for the best LLM – Meta AI Research, which released the Open Pre-trained Transformer (OPT-175B) language model in May 2022 [18]. OPT-175B had the same number of parameters as GPT-3, but it was trained on a dataset containing 180 B tokens, which did not prevent it from demonstrating performance comparable to GPT-3. The main result of the OPT-175B release was the publication not only of the model's code and trained weights but also of a complete operations log that documented the difficulties encountered by developers during the training process. The OPT-175B model was released under a non-commercial license and intended for use by researchers. While full access to the 175B model required submitting an application, smaller versions with 125 million to 30B parameters could be downloaded as part of the HuggingFace Transformers library. In general, it should be acknowledged that the release of OPT-175B undermined OpenAI's monopoly and triggered a significant acceleration of work in the LLM field. The transformer deep learning architecture ultimately became the de facto standard for LLMs, and impressive results were achieved based on it. A significant part of the research was focused on models with an autoregressive decoder only, such as GPT-3 and PaLM, which could perform on par with humans in many NLP and natural language understanding (NLU) tasks.

At present, there is a substantial body of scientific literature dedicated to various aspects of LLMs. These studies demonstrate that LLMs can be effectively utilized for tasks such as machine translation, text generation, summarization with follow-up content-aware dialogue in a question-answer format, and many other functions relevant to educational processes. Further improvements in LLMs, particularly after OpenAI provided public access to ChatGPT on November 30, 2022 [19], have helped further unlock their potential and facilitated their integration into society. The initial ChatGPT service was based on the GPT-3.5 LLM with 175B parameters [19] and marked the first practical attempt to fine-tune an LLM using reinforcement learning from human feedback (RLHF). In January 2023, the number of active monthly ChatGPT users exceeded 100 million for the first time. This milestone enabled OpenAI to introduce exclusive access to its model via the ChatGPT Plus subscription ($20/month), representing the first major attempt at large-scale commercialization of LLM-based services.

In March 2023, with the transition to GPT-4, OpenAI [20] surpassed the threshold of 1 trillion LLM parameters, introduced paid API access to its models for third-party developers, and integrated a plugin ecosystem. The capability to combine text and image processing in GPT-4 was significantly enhanced in September 2023 with the launch of integrated DALL-E 3 image generation access for ChatGPT Plus subscribers. This milestone firmly established the trend in LLM development toward multimodality and enabled OpenAI to gain a decisive lead over its competitors.

1.2.3 Multimodal LLMs

Multimodal LLMs are language models capable of processing and integrating information from various types of data, such as text, images, audio, and video. This approach enables the development of universal systems that can interact with diverse forms of information and provide more natural and multifaceted user interaction. One of the first multimodal LLMs was VisualBERT [21], which combined the previously mentioned BERT language model with visual data processing. This enabled effective handling of text-image combinations and opened up a range of new tasks, such as visual question answering, image captioning, and retrieving images based on textual queries. VisualBERT laid the foundation for further developments in the field of multimodal models, demonstrating the feasibility of integrating various data types into a single system. It is worth noting that similar capabilities can be found in convolutional neural networks (CNNs). For instance, in [22, 23], it is shown that the same neural networks, initially trained for image classification, can also be used for text classification and segmentation. Furthermore, authors [24] explore neural networks for classifying audio signals that simultaneously utilize spectrogram images and time-domain signal sequences analogous to textual sequences. The basis of this phenomenon lies in the formal invariance of digital data processing in neural networks, regardless of the semantic content embedded in the data.

The further development of the ideas introduced in VisualBERT was realized in 2021 through the multimodal model ViLT [25]. In the same year, OpenAI introduced its first multimodal LLM, CLIP [26]. During its training on a large number of text-image pairs, contrastive learning was used to create a shared embedding space for texts and images, enabling tasks such as image classification via text prompts and illustration retrieval based on descriptions. Another project from OpenAI, DALL-E [27], demonstrated the ability to generate images based on textual descriptions. This marked a significant advancement in the field of generative models capable of combining textual and visual information. Building on this experience, OpenAI quickly transformed GPT-3.5 and its successor GPT-4 into the multimodal service GPT-4v, setting a kind of standard for all competitors in the LLM space.

The emergence of many alternative LLMs led to the realization of the idea of combining them using the mixture of experts (MoE) approach, which was advanced by the developers of the Mistral LLM family in their model Mixtral [28]. According to authors in [29], one of the earliest works promoting this architectural concept is considered to be the one in [30]. In the corresponding expert system structure, the output weight vectors of several experts were managed via a specialized gating mechanism. This approach evolved in the context of LLMs such as Mixtral to enhance efficiency and adaptability to various tasks. The core idea of MoE is to distribute input data among different "expert" models based on their specialization. Each expert is optimized to process a specific type of information. After the task is performed by a selected subset of experts, their outputs are aggregated using a gating mechanism that determines the contribution of each expert to the final model output. The remaining experts remain inactive, thus conserving computational resources.

1.2.4 Historical overview of the LLM models Gemini, Claude, and Grok

After the release of GPT-4, several leading companies introduced alternative LLMs that set new standards in the field of AI. Each of these models has a unique developmental trajectory, architecture, and training approach, but all are aimed at achieving high performance and offering a wide range of capabilities.

LLM Gemini is a family of multimodal LLMs developed by the unified team of Google Research and DeepMind following their merger. The Gemini project succeeded Google's earlier AI efforts (such as the PaLM 2 and LaMDA [31] models) and was first introduced in December 2023, when Google announced the release of Gemini 1.0 in three scale variants: Ultra, Pro, and Nano [32]. In early 2024, an update, Gemini 1.5, was released. The Gemini 1.5 Pro version received enhanced performance and an expanded context window of up to 1 million tokens, becoming publicly available in May 2024. This context size became the largest in the industry, allowing the model to "remember" massive volumes of information when solving tasks. The core of the Gemini model was trained simultaneously on different data types (texts, images, audio, code, and video). This represented a significant departure from previous approaches where separate specialized components were trained for each modality, enabling Gemini to analyze images without relying on external OCR systems. Gemini Ultra was the first LLM to surpass human expert performance on the large-scale MMLU (Massive Multitask Language Understanding) knowledge benchmark, scoring 90.0%, compared to $\sim$89% for human experts. This demonstrated the model's ability for deep understanding across various domains (mathematics, physics, history, law, medicine, etc.) and complex logical reasoning, which is highly beneficial in educational contexts. Additionally, on the MMMU (MultiModal Massive Understanding) benchmark, Gemini Ultra achieved 59.4%, the highest score at that time. The development of this LLM line continued with the release of Gemini 2.0 at the end of 2024. In just a short time, Gemini evolved from a prototype to a second-generation model, establishing itself as a key AI platform within the Google ecosystem. Gemini 2.0 introduced new features such as "Deep Research" mode for in-depth exploration of complex topics and further performance enhancements (this version is twice as fast as 1.5 Pro on many tasks). Overall, Gemini has earned a reputation as one of the most powerful and versatile LLMs, approaching the capabilities of OpenAI models and even surpassing them in some metrics.

The Claude models, developed by the company Anthropic (founded by former OpenAI employees), are distinguished by their focus on safety and ethical AI systems. The first version of Claude was officially launched in March 2023 [33]. At launch, Anthropic introduced two variants: Claude, a fully functional high-performance model, and the lighter Claude Instant, designed for speed and cost-efficiency. These models stood out for their better resistance to harmful or inappropriate prompts and a more "obedient" conversational style compared to their contemporaries. In the following months, Claude quickly evolved into Claude 2, which was released in July 2023. At that point, the context window was increased to 100k tokens (the previous version had a context of around 9k tokens). In October 2023, Anthropic introduced Claude 2.1 with a context window of up to 200k tokens. The next major release Claude 3 was announced in March 2024. Claude 3 was launched as a full suite of models of various sizes and purposes: at the top tier of performance was Claude 3 Opus, the mid-tier model was Claude 3 Sonnet, and the compact, fast model was Claude 3 Haiku. The Claude 3 models gained multimodal capabilities and could interpret photos, charts, diagrams, PDF documents, and more. According to Anthropic, at the time of release, Claude 3 Opus outperformed competing models on most standard academic benchmarks – from MMLU (undergraduate-level knowledge) to GSM8K (basic mathematics) and GPQA (graduate-level logical reasoning). According to Anthropic's assessments, the newer versions of Claude were much less prone to unnecessary refusals to answer (so-called cautious or overguarded rejections). Concerned with the safety and reliability of responses, Anthropic developed a new approach called Constitutional AI for training the model to follow a predefined set of values and guidelines when responding to queries. This essentially became the first practical attempt to implement the concept of artificial conscience [34–36], in which a separate critic model reviewed and corrected the primary model's outputs during training. This method allowed Claude to be more "obedient" without the risk of learning undesirable behavior from human error or bias. In practical terms, this means that when asked about questionable or potentially dangerous topics, Claude tries to follow explicitly defined rules (e.g., not aiding illegal activity, avoiding hate speech), rather than relying on a rigid list of prohibitions. After the launch of the third generation, Anthropic continued to iterate: by fall 2024, Claude 3.5 was released, followed by Claude 3.7 (announced in September 2024).

The youngest among the three LLMs discussed in this subsection is Grok. The company xAI was founded by Elon Musk in 2023 with the ambition of "understanding the true nature of the universe" through AI. Musk, known for his criticism of excessive restrictions in chatbots, aimed to create a model that was both powerful and less censored. The first mentions of Grok appeared at the end of 2023, when xAI launched a limited beta access to Grok 1. Reportedly, the early version of the model was trained on data from the social media platform X (formerly Twitter), giving Grok-1 [37] a certain "internet-savvy" character and awareness of contemporary memes and news. In 2024, the Grok project significantly accelerated: an improved version, Grok 1.5, was released, followed by a variant called Grok-1.5 Vision with image support, as well as a smaller model, Grok-1.5 mini, designed for faster responses. Sequential releases included Grok 2 (with a dedicated Grok-2-Vision mode and an agent system under the codename "Aurora"). The culmination came with the official release of Grok 3 in February 2025. xAI claimed that the early version of Grok 3 outperformed competitors – including OpenAI's models and China's DeepSeek model – in a series of tests on mathematics, science, and programming. Throughout 2024, xAI secured significant investments and built a "Colossus" supercomputer powered by thousands of NVIDIA GPUs to train Grok. The model advanced at a remarkably rapid pace: from an initial prototype of $\sim$33 billion parameters in 2023 to an estimated trillion-parameter scale in Grok 3. It is worth noting that xAI takes a rather secretive approach to technical details – no full technical reports or papers about Grok's architecture or datasets have been published. However, Grok 3's architecture is described as "hybrid" or "live," meaning the model has the ability to learn continuously and adapt without catastrophic forgetting. xAI integrated a so-called Deep Search module into Grok – a built-in search engine that provides the model with access to up-to-date online information while responding to queries. As a result, Grok combines generative capabilities with information retrieval features, aiming to always deliver "fresh" and factual responses. Additionally, a "Big Brain" mode is mentioned, which allocates additional computing resources for particularly difficult questions, allowing the model to "think deeper" before responding. This resembles a dynamic adjustment of reasoning steps or expert allocation during task execution. According to some reports, Grok 3 also applies the

MoE (mixture of experts) approach to scale its performance. Although xAI has not confirmed this officially, independent reviews point to "significant architectural improvements" in Grok 3 related to speed and efficiency, and MoE is considered a likely component. As a result, the model's hardware metrics are impressive: Grok 3 is estimated to contain 2.7 trillion parameters and was trained on a dataset of approximately 12.8 trillion tokens. If these figures are accurate, Grok 3 is one of the largest LLMs to date. Such size may be attributed to the use of MoE architecture. The context window of Grok 3 is reportedly around 128k, which is less than that of Claude or Gemini, but still allows the handling of very long conversations or documents. The Grok 3 presentation emphasized the model's "advanced logical reasoning." This aligns with the trend of adding chain-of-thought reasoning to LLMs, where the AI generates intermediate steps in its reasoning. Likely, as with other models, Grok's final fine-tuning involved human feedback (RLHF) to improve the quality of responses. According to OpenCV and other sources, Grok 3 delivers 20% higher accuracy and 25% faster responses than models like ChatGPT (GPT-4). Importantly, the model also consumes approximately 30% less energy due to architectural optimizations.

Overall, the emergence of Gemini, Claude, and Grok has significantly influenced the development of the AI industry, triggering a new wave of competition and laying the groundwork for future technological trends. While at the beginning of 2023 the LLM market was essentially led by a single company (OpenAI with GPT-4), by 2024–2025 the situation had shifted toward multiple centers of innovation. Now, companies such as Google, OpenAI, Anthropic, xAI, as well as Chinese firms (e.g., Alibaba Cloud with the Qwen models [38] or the startup DeepSeek [39]) are competing for dominance. This competition drives all players to accelerate improvements, ultimately benefiting users and businesses by providing access to more powerful and diverse AI systems.

1.2.5 Open sources LLMs

Similar to proprietary models, the development history of open-source LLMs can also be conventionally divided into several stages, each marked by specific technological breakthroughs, shifts in openness policies, and their impact on public ecosystems. OpenAI's decision not to release the code for GPT-3 led to increased activity within the open-source community. In response to closed models, EleutherAI released GPT-Neo and GPT-J (2021), which became the first open analogues to GPT-3. After the launch of

ChatGPT, many companies and research groups began developing their own alternatives. On February 24, 2023, Meta (formerly Facebook AI Research) introduced the LLaMA (Large Language Model Meta AI) family [40], which included four versions with 7B, 13B, 33B, and 65B parameters. These models were trained on 1.4 trillion tokens from open sources such as websites, GitHub repositories, Wikipedia, and others. The main difference from competitors was optimization: LLaMA used a more efficient transformer architecture, which allowed it to achieve GPT-3-level performance with significantly fewer parameters. Meta made LLaMA available to researchers by request, but on March 3, 2023, the model's weight files were unauthorizedly leaked online via BitTorrent, becoming a pivotal event for open-source LLMs. Taking advantage of this, the community quickly adapted the model for use, creating modifications, including integration with the HuggingFace Transformers library and support for running on local hardware.

After the success of the first version, Meta released LLaMA 2 in July 2023 [41], this time officially with open access. The list of main LLaMA 2 versions was reduced to three sizes: 7B, 13B, and 70B. LLaMA 2 quickly became the foundation for numerous open-source projects, including models such as Mistral, Falcon, Zephyr, and many others. In April 2024, Meta introduced LLaMA 3 with 8B and 70B parameter models, followed in July 2024 by LLaMA 3.1, which included models with 8B, 70B, and 405B parameters. The version timeline was further updated in September 2024 with the release of the first multimodal models, LLaMA 3.2 Vision, in 11B and 90B sizes, as well as small language models (SLMs) for text processing with 1B and 3B parameters. LLaMA 3.3 was introduced on December 6, 2024, in a single 70B size; however, due to architecture and training optimizations, this LLM outperformed LLaMA 3.1 405B in some benchmarks. In recognition of Meta's efforts, it should be noted that its LLaMA models became a significant milestone in the development of open language models, providing developers with access to powerful tools for working with NLP.

At the same time, another sharp shift in the balance of power in the LLM domain occurred at the end of December 2024 due to the emergence of several Chinese LLMs: first DeepSeekV3, then DeepSeek R1, and Qwen 2.5 Max, which seized the initiative and opened new opportunities for research, development, and commercial use of language models. Their appearance significantly challenged the dominance of leading models such as OpenAI's GPT-4o, o1, and o3-mini, accelerating the announcement and deployment of new services and LLM versions, the history of which is only beginning. Notably, this includes the presentation of GPT-4.5 on February 27, 2025

[42], the anticipated release of DeepSeek R2 and other models in spring 2025, and the expected debut of the LLaMA 4 family in April 2025. The further development of LLMs, alongside the improvement of their multimodal capabilities, is increasingly characterized by their transformation into large action models based on MoE configurations that combine various types of content processing and generation experts with so-called action agents. These agents are tasked with functions such as creating class schedules, weekend or vacation plans, and other service-oriented actions, which will be discussed in greater detail in chapter 2.

Another notable trend in LLM evolution is the original approach proposed by Meta researchers [43], known as the large concept model (LCM). The key distinction between LCMs and the previously discussed LLMs lies in replacing the traditional next-token prediction with the generation of conceptual units at the level of whole sentences or even entire text corpora. This approach is more radical than token set generation and enables the LCM to track deep semantic relationships and the overall topology of a text. The authors of [43] emphasize that this shift to conceptual-level prediction lays the groundwork for new capabilities in content generation quality, particularly in tasks requiring abstract reasoning and deep comprehension of contextual interrelations.

On the other hand, a fundamentally different approach compared to traditional language models is represented by the new generation of diffusion-based text generators – dLLM [44]. These models start from a noisy block of text and iteratively refine it over multiple stages. This allows for parallel text generation, significantly increasing processing speed (for instance, the Mercury Coder model demonstrates a 5–10x improvement over known LLMs), while also enhancing the global coherence of the generated output. Iterative refinement enables error correction even after the initial generation phase. The dLLM architecture is fully compatible with existing RAG (Retrieval-augmented generation) scenarios and agent-based systems, opening up possibilities for integration into various AI applications. More detailed forecasts regarding the development of LLMs and their transformation into AGI will be discussed in Chapter 7.

1.3 Conclusion

Due to space constraints in this section, many other important players in the LLM field, who have made and continue to make significant contributions to the development of AI, remain outside the scope of the presented historical overview. On the one hand, it is evident that a detailed account of LLM history deserves a separate publication; on the other hand, the turbulence of LLM evolution quickly introduces corrections and leads to the obsolescence of facts previously regarded as cutting-edge achievements, along with the corresponding conclusions. For this reason, the current overview pays less attention to the present state of LLM development – an omission that will be partially addressed in the following chapters of this book. Nevertheless, the conducted analysis indicates that the existing potential of LLMs is entirely sufficient for their effective application and can bring about radical changes in the field of education and science [45–51]. Based on the evolution described above, it is reasonable to expect that LLMs will become even more powerful, integrated, and useful in the coming years. At the same time, the importance of a responsible approach to their use in education will grow, as will the need to strike a balance – one that developers of Claude have attempted to achieve, and which all participants in the LLM race must now take into account.

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