• Article •

From Origins to Future: The Evolution and Prospects of Artificial Intelligence in the Reasoning Era

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Abstract: With the release of the OpenAI o1 model, artificial intelligence (AI) technology has ushered in a new era of Reasoning. This article reviews the development history of AI technology, from the early days of symbolic reasoning and logic programming, to the data-driven era of machine learning, and to the current era of deep learning and large models. Driven by the AI technology, the close connection and impact between economic support and policies have been analyzed, as well as the cyclical fluctuations in the development of AI industry. All sectors of industry, academia and research play different roles in the development of AI, and in the context of industrial profit-seeking and national security issues, the international governance variables of AI will further increase. In this context, this paper analyzes the dilemmas and risks of international cooperation in artificial intelligence, as well as the challenges facing the development of industrial ecosystem, and looks forward to the future development and international governance direction of AI.

Keywords: Artificial Intelligence; Era of Reasoning; Global Governance; International Cooperation

1. Introduction

The history of artificial intelligence is an epic tale of ups and downs in the unrelenting pursuit for human intelligence. From mechanical beings in ancient myths to the conception of modern electronic brains, mankind's longing for creating intelligent entities has remained unchanged. Since the mid-20th century, with the birth of digital electronic computers, AI has seen its modern starting point. In 1956, the Dartmouth Conference has first introduced the concept of "artificial intelligence," marking the official establishment of this emerging field. In the following decades, AI has experienced a roller coaster ride from optimistic predictions during its golden age to two AI valleys of severe challenges, reflecting not only the twists and turns of technological progress but also the profound impact of economic and governance.

In the early explorations of AI, scientists tried to simulate the human mind through symbolic reasoning and logical programming. However, problems are gradually emerging with the deepening research of AI, such as computational complexity, the difficulty of commonsense reasoning, and the lack of understanding of the nature of intelligence. AI hit its first low point in the 1970s, when declining government funding and disappointing public expectations hit AI research hard (Galanos, 2023). In the 1980s, with the rise of expert systems (Kastner & Hong, 1984), which can simulate the decision-making process of human experts in specific fields, AI once again enjoyed a boom. However, when users' expectations for AI systems increased and the economic bubble burst into its second trough, the limitations of expert systems promptly became apparent. These cyclical fluctuations reveal the close link between AI development and economic support and policy guidance.

During the early period of AI development, AI was significantly influenced by financial support and policy environment. Thus, the history of AI development is a history of the interaction between technological evolution and social adaptation (Boyd & Holton, 2018). Every technological breakthrough is accompanied by a boom in economic investment and policy adjustments, and it also reflects the lag and insufficiency of governance mechanisms in coping with technological change. With the rise of the Internet and the arrival of big data era, it not only provides new development opportunities for AI, but also poses new challenges to the economic system and social governance (Helbing, 2019).

2. From Machine Learning to the Large Model Era

2.1 The Emergence of Machine Learning: Rationality in Broad Applications

In the 1990s, the rise of the Internet and the advent of the big data era injected new vitality into the development of AI. The internet has not only accelerated the speed of information dissemination but also fostered interdisciplinary collaboration, enabling AI technologies to be more widely applied across various domains such as business, healthcare, education and other fields (Stuart & Peter, 2010). Those kind of technological transformation has not only addressed many limitations of expert systems but also provided fertile ground for new technologies and methodologies to emerge. The widespread adoption of the internet and the exponential growth of data have propelled machine learning algorithms into the mainstream. Their powerful pattern recognition and predictive capabilities have offered new approaches and tools for addressing complex problems.

Compared to the previous era of machine learning, the market's expectations for AI have undergone a shift from optimism to pessimism, and ultimately to a more rational outlook. Throughout the pre-machine learning era, the limitations of AI technologies were gradually revealed, which resulted in a halt in research advancements and a decrease in investment and government enthusiasm， which bring AI development into the winter period. However, breakthroughs in machine learning reignited market expectations, albeit in a more objective and rational manner. People began to focus more critically on the sustainability of the technology and its societal value (Müller & Guido, 2016). During this period, researchers began to explore how computers could automatically learn patterns from data to improve their performance and behavior. The core of machine learning lies in feature engineering, which involves extracting useful features from data to train models. Key research achievements during this stage include algorithms such as decision trees, support vector machines (SVM), and random forests. For instance, SVM and decision tree algorithms have demonstrated outstanding performance in classification and regression tasks, enabling researchers to achieve data-driven decision-making in fields such as healthcare and finance (Bishop, 2006).

With the rapid iteration and in-depth research of technology, machine learning has started to move towards deep learning as a result of the exponential growth in data volume and the notable improvement in processing power. Traditional machine learning techniques depend on comparatively simple model architectures and manually created feature extraction, both of which are becoming less and less effective. By using multi-layer neural networks that imitate the structure of the human brain, deep learning, on the other hand, can automatically learn complex features in data and map raw input to output prediction in an end-to-end manner. This allows for deeper recognition and prediction capabilities and significantly streamlines the feature engineering process. This opens up a new wave of technological innovation and makes it achievable to train and use deeper network architectures.

2.2 Deep Learning Poses Challenges for Data Governance

In the era of deep learning, the scale and complexity of models have made a qualitative leap. Early artificial neural networks typically contained only a few layers of nodes, while modern deep learning architectures may have dozens or even hundreds of hidden layers. This "depth" enables the network to capture more subtle data patterns, thereby achieving more accurate task solving capabilities. For example, deep learning has brought about convolutional neural networks (CNNs) and recurrent neural networks (RNNs), which have achieved breakthroughs in tasks such as image recognition and speech recognition (LeCun et al, 2015). CNNs effectively processes image data through local connections and weight sharing, significantly improving the accuracy and efficiency of image recognition (Krizhevsky et al, 2012). RNN and long short-term memory network (LSTM) have promoted the development of speech recognition and language generation technology by capturing contextual relationships in time series (Hochreiter & Schmidhuber, 1997). The rapid development of deep learning has not only promoted the widespread application of AI in various fields, but also laid a solid foundation for the subsequent era of large models. At the same time, with the widespread application of AI and the surge in data volume, the importance of governance has gradually been recognized. Especially in data governance, effective data governance strategies can not only promote the rational use of data, but also ensure the security and compliance of data, becoming an important part of AI governance (Zwitter, 2014).

3. Enter to the Era of the Large Models

3.1 Shift From Data Governance to AI Technology Governance in the Era of Large Models

Since the Google team introduced the Transformer architecture in 2017, the field of natural language processing (NLP) has undergone a revolutionary change. The Transformer architecture achieves efficient processing of long sequence data through the self-attention mechanism, which not only optimizes the sequence processing efficiency, but also gives birth to a series of pre-trained models such as BERT and GPT, opening the door to the era of large models (Vaswani et al, 2017). The outstanding capabilities of these large models in natural language understanding and generation mark a major leap forward in AI capabilities, while simultaneously raising market expectations and awareness of AI to previously unheard-of levels.

Large models exhibit an emergent intelligence phenomenon that is not yet fully understood. These models, without explicit programming, are capable of self-learning and demonstrating behaviors that surpass expectations. This phenomenon has sparked widespread academic debate and drawn significant attention from the public and investors (Brown et al, 2020). The emergent intelligence and the black-box nature of large models are closely intertwined, rendering the decision-making processes of these models highly opaque (Bommasani et al, 2021). This has brought critical issues of AI governance to the forefront, marking a shift from the focus on data governance in the machine learning era to a growing emphasis on governance of the AI technologies themselves (Vallor, 2022). As the scale of these models continues to expand, their internal complexity and lack of transparency increasingly raise demands for higher standards of data privacy and algorithmic fairness, driving unprecedented attention from governments and societies worldwide toward AI governance (Shin et al., 2023).

3.2 The Bottlenecks of Scaling Laws Urgently Require the Exploration of New Paradigms

The concept of scaling laws proposed by OpenAI attempts to theoretically explain the emergent intelligence and indicates the development direction of large models—namely, achieving significant performance improvements by increasing the number of model parameters and the volume of training data (Kaplan et al, 2020). This theory has sparked intense global competition among technology companies, which have poured substantial investments into a "arms race" for computing power, model parameters, and data. For instance, the outbreak of China's "AI war of hundred models" in 2023 saw numerous companies and research institutions racing to release their own large model products, aiming to secure a foothold in this technological revolution (Ye, 2023). Notably, unlike the earlier machine learning paradigm led by research institutions, the massive demand for computational power in the age of large models has positioned tech companies as the driving force behind AI development. This shift not only reflects the profound impact of technological advances on markets and supply chains, but also intensifies global competition in AI. Those who master advanced AI technologies will have a significant advantage in future technological and market dynamics.

However, as the parameter scale of large models continues to expand, the bottlenecks they face are becoming increasingly prominent, which has also led to the discussion of whether the scaling laws theory is invalid becoming a hot topic in the AI industry. The current surge in computing power demand, data challenges, and the increase in training and reasoning costs caused by the growth of model parameters have become important obstacles to further expanding the scale of models. For example, the Meta team pointed out in the paper on LLaMA3 that even in the top data centers, maintaining the stability of ultra-large-scale GPU clusters is a major problem, and frequent failures caused by hardware loss have seriously restricted the further expansion of the model (Smith, 2023). In addition, "Large Language Monkeys: Scaling Inference Compute" emphasizes that expanding inference computations simply by increasing the number of generated samples does not fundamentally solve the essential problem of models, which is that they are still "typing" tools based on statistical probability, lacking true creative and logical reasoning capabilities (Hestness et al, 2023). Therefore, AI research may need to seek more essential innovation in algorithms and architectures, and need to seek a new paradigm that enables AI to have inspiration, creativity and logical reasoning ability to break through the current bottlenecks, rather than merely relying on the accumulation of computational power and model parameters.

4. Entering the Reasoning Era

However, the exploration of new paradigms has high risks, because various factors such as initial costs, learning effects, coordination effects and adaptive expectations will lead to increasing returns, and investors are unable to see the future benefits, so many enterprises are discouraged. This also leads to the phenomenon that the development of technology and industry often enters the path dependence. In the large model technology or method based on the Transformer architecture is widely adopted, even if there is a better alternative, it is difficult to change its dominant position. Therefore, the industry rushed to follow OpenAI's operation mode, and developed a large number of application products based on large language models, which intensified the situation of homogeneous product competition. The emergence of OpenAI o1 becomes an important attempt to break out of the original technical framework and explore the path of reasoning technology.

4.1 New Paradigms for Reasoning Models

The release of OpenAI o1 reasoning model marks the advent of a new era in AI development characterized by advanced reasoning capabilities. OpenAI o1 model represents a new model paradigm and working principle, from the language as the core to the chain of thought (CoT), which enables the model to carry out more in-depth and orderly thinking process (OpenAI, 2024). By using this technique, the model can develop methods to address problems gradually instead of making decisions based on itself instantaneous probabilistic forecast like earlier models did. Which indicates that the o1 model can approach complex problems in a more nuanced and methodical manner, resulting in behavioural patterns that are more akin to those of human intellectual ability.

A notable distinction between the o1 model and earlier large language models, such as GPT-4, lies in their learning and inference mechanisms. Traditional large language models excel at generating text based on statistical probabilities but often lack true logical reasoning and innovation capabilities. In contrast, the o1 model learns to "think slowly" through reinforcement learning, engaging in extended reasoning processes. This innovation not only enhanced the model's performance on a specific tasks but also signifies a significant advancement in AI, transitioning from basic pattern recognition to advanced intelligent reasoning.

The emergence of the o1 model signifies the onset of the "reasoning era" in AI. This era is marked by the development of models that can perform complex reasoning tasks with greater accuracy and efficiency. This development has not only advanced AI capabilities but also spurred innovation across the industry. In response to this paradigm shift, other AI companies have developed models that offer competitive performance at more accessible costs. Notably, the DeepSeek series has emerged as a significant player under the reasoning era. DeepSeek's R1 model, for instance, has demonstrated performance comparable to leading models like OpenAI's o1, but at a fraction of the cost. The models of different enterprises together confirm that AI has entered the era of reasoning, making people exposed to more accessible and efficient AI solutions, which will further expand AI applications in various fields.

However, the advent of these advanced AI models also presents new challenges. The complexity and opacity of models like o1 and DeepSeek raise concerns about their interpretability and control. The intricate decision-making processes inherent in these models make it difficult to fully understand their reasoning, leading to potential risks in their deployment across sensitive areas. In this case, if solely tech company holds the core technology, it may raise concerns about the risk of intelligence, especially when the model is widely applied in many social spheres. Moreover, the rapid advancement of AI technologies will intensified global competition, with nations and corporations striving to lead in AI development. This competition has implications for economic and technological landscapes, potentially exacerbating disparities in AI capabilities and access.

4.2 New Path for Large Model Scaling Law: Inference Scaling Law

With the release of o1, OpenAI also proposed a new scaling law for inference, which states that the performance of the model continues to improve with the increase of reinforcement learning time and inference time (OpenAI, 2024). Different from the traditional scaling law of computing power, model parameters, and data, the new inference scaling law emphasizes the positive impact of investment in training time and inference time on model performance. The emergence of this new paradigm opens a new path for the development of large models.

In contrast, the discussion on the failure of scaling law for traditional large models has entered a heated stage, mainly due to the bottleneck of computing power and data. However, the new inference scaling law provides new possibilities for the development of large models. Although the current scaling law of large models has shown a slowing trend, it is still possible to achieve further performance improvement by optimizing inference time and training time. Speaking at the TED AI conference in

San Francisco, Noam Brown, a researcher working on o1 at OpenAI, said that " It turned out that having a bot think for just 20 seconds in a hand of poker got the same boosting performance as scaling up the model by 100,000x and training it for 100,000 times longer."

In addition to the development of inference scaling law itself, whether there is a mutual promoting relationship between inference scaling law and traditional scaling law of computing power, model parameters and data is a problem worthy of in-depth discussion. At the moment, these two scaling laws seem to be relatively independent, but o1 model scaling nowadays has two dimensions: training time and testing (inference) time. Perhaps predictably, future studies may reveal the mechanisms by which they interact. If we can find the synergy between these two scale laws, it will provide a broader space for the development of artificial intelligence. This dual-drive model is not only expected to solve the current technical bottleneck, but may also open up a whole new era of intelligence.

5. New Pathways and Challenges of Overcoming Data Bottlenecks

With the development of AI technology entering the era of large models, data has become an important resistance to its further development, and this has become a general consensus in the academic community. Although there is a large amount of data on the Internet, statistics show that the data can be effectively used in common crawl only accounts for 6%-9% of the data on the whole network. In addition, a large amount of unstructured data within enterprises cannot be used, resulting in extremely limited data available for training (Pablo et al, 2022).

Therefore, how to break through the data bottleneck has become the key to achieve breakthroughs in large model research and development and technological improvement. With the release of reasoning era, it provides a new solution to solve the problem of data shortage to some extent. First, through the synthetic data can improve the available data limitations, including the use of human intervention to improve the data quality, to increase the amount of data available for training. Second, synthesize data through models, that is, use large models to accelerate the generation of synthetic data. Reasoning model through chain thinking, can make the model reflect on its way of thinking, thus generating new data. However, compared with manual qualified data, its quality is relatively low, and it still needs to be improved through technological progress.

Admittedly，the advent of the era of reasoning can not directly solve the technical card points in the development of AI, and it will also bring new problems. Due to the relatively serious data homogeneity, the training effect is not good, and the spread of false information in the process of AI training may not only lead to misleading and confusing information, but also lead to ethical and legal problems. Furthermore, the widespread application of generated data could exacerbate social inequality since it makes it easier for individuals and tech giants with advanced AI technology to create and use high-quality data, while underfunded groups may be excluded. These factors are the direct cause of the intelligence gap between countries and regions and will continue exist.

6. Potential Risks and governance Dilemmas of International Governance in the Era of AI

The rapid development of AI has brought not only technological innovation, but also challenges to global supply chains, international markets, geopolitical situations and even the traditional international order (Anwer & Hosen, 2024). The widening of the digital divide caused by technology is reflected in different levels of the international community. Strengthening national strategic scientific and technology authority has become an unavoidable decision to deal with worldwide competitiveness, due to the macrotrend of growing global scientific and technological competition. The trend and role of tech companies to achieve technological frontier breakthroughs and join the technological competition have become more prominent under these pressures and trends in order to meet the strategic needs of intensified international competition.

6.1 The Imbalance in Resource Allocation Has Widen the AI Gap

Driven by business logic, AI concentrates an extensive amount of capital, computing power, data, and other resources in the giant technology companies. This can also influence how governments and businesses make decisions, which may lead to an imbalance in the distribution of innovation resources. With more abundant capital and technical resources, leading AI technology enterprises have rapidly occupied a dominant position in the industry and market in terms of technology research and development, data set resources, and algorithm application. Furthermore, the state may be unduly swayed towards applied research and development with short-term commercial value when deciding on technology development strategies and allocating resources, neglecting basic research and other crucial areas related to long-term development, when commercial investment and market reverse become decisive factors affecting industrial policy related to AI. For the countries of the global South, computing infrastructure is still an important obstacle to whether the country can truly access AI, so this will also lead to the global intelligence gap will be further widened (Garcia, 2024).

6.2 Regulatory Dilemma

Review the history, each technological revolution will promote the long-term growth of human society and economy, and the current AI is also widely regarded by the international community as an emerging revolutionary technology. In the early stage of technology development, although it is easier to control it, it is not easy to formulate effective control measures due to the lack of full understanding of its potential social harm. Conversely, when the negative social effects of technology become apparent, control often becomes costly and slow. Therefore, while pursuing the innovative potential of AI development, countries need to recognize the importance of effective regulation of the technology (Collingridge, 1982).

In the field of AI, the lack of effective regulation may lead to the proliferation of standards and norms, exacerbate the instability, unreliability and security of the technology, and hinder the further development and application of the technology. Some scholars also call on AI enterprises to introduce internal audit mechanisms, so that technology developers and enterprise management decision-makers are aware of the existence of risks at different levels, and integrate management norms into the research and development process to ensure the healthy development of AI. Expand to the international level, the trend of the industrial side to seek profits from capital and the rise of national sovereign AI (Mügge, 2024) construction have become an important dilemma that hinders the alignment of AI international governance. Therefore, some scholars also put forward the point of view of agile governance, which needs to pay attention to industrial development and supervision at the same time, and try to keep the same pace (2018). However, to grasp the parallel scale and rhythm of regulation and AI development has become an important issue to ensure the sound and sustainable development of AI, and it is also an issue that the international community needs to solve jointly through close dialogue and exchanges.

6.3 Difficulties and Risks in International Cooperation on AI

In the context of increasingly fierce global competition in technology, geopolitical factors have become an unavoidable consideration for tech enterprises, and when domestic protectionist sentiment spreads, it will further hinder normal international scientific exchanges and cooperation. This will undoubtedly increase tension and confrontation in international relations, increase market and technological barriers, make it more difficult for countries to reach consensus on AI standards, ethical norms and regulatory policies, and weaken the foundation for international cooperation in addressing common challenges. At present, countries around the world have reached some basic consensus in the field of AI to promote the "AI for Good" and the development of responsible AI, but it is difficult to reach a specific and effective regulatory framework in the field of governance (ITU, 2017).

An open and inclusive international cooperation mechanism has always been a key factor in promoting technological innovation and application transformation, and technological development is the result of open source contribution to international cooperation, “small yard high fence” (Cavangh, 2023), decoupling industry chain breaking are not conducive to the overall development and progress of the industry. Technology blockade is not conducive to the development and progress of technology, but will increase the cost of enterprise research and development, in contrast to encourage open source can promote technological innovation and knowledge sharing, in order to further integrate the industrial wisdom to promote a deeper integration of the industrial chain and common development at higher level. Recently, the international community generally recognizes the international governance of AI under the United Nations framework, and the promotion of AI capacity building in developing countries through strengthening international cooperation is expected to become a new international consensus (United Nations, 2024), may leading to the next stage of AI international governance.

6.4 Industrial Ecological Development Dilemma

From the perspective of long-term development of technology, the sustainable and healthy development of AI needs to rely on a benign ecosystem, and this ecosystem is usually composed of a number of interrelated and interdependent subjects such as technology research and development institutions, technology enterprises, regulators, investors and users. In international technology competition, countries with a healthy ecosystem can attract domestic and foreign investment and innovators, foster local technology companies, and help the country play a greater role in global science and technology innovation and standards setting. At present, with the monopoly advantages of capital, technology and talents, some tech enterprises control the upstream and downstream of the industrial chain through mergers and acquisitions, patent authorization and other ways. If coupled with government related strategic competitive pressure and protectionist policies, the monopoly position of technology giants will be further strengthened, and the action space and voice of other actors in the industrial ecosystem will be further squeezed. The lack of a benign interactive industrial ecology may lead to the lack of impetus for technological innovation and the weakening of industry resilience will continue to worsen, which will further affect the country's overall innovation capacity and international competitiveness.

7. Conclusion

At present, we are still constantly exploring the route of AI development, and we are constantly bumping into data bottleneck on the road of exploration, such as the problem of data wall, scaling law failure and so on. A large number of researchers are still exploring different AI architectural paths, there still have long way to go to reach the AGI ultimate goal. But as countries focus on governance, there still need a balance through the path between the research innovation and regulation. It is worth mentioning that, responsive governance from policy makers to ensure that its positive impact is maximized. At the same time reduce the potential risk and negative impact. The path of AI development requires the joint efforts of policy makers, technology developers and all sectors of society to build a flexible, inclusive and forward-looking governance system under the framework of a broader international multilateral platform to continuously evolve, assess and adapt to the new challenges posed by AI.

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Availability of Data and Materials

None.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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