

Research on the Characteristics, Limitations, and Future Directions of Artificial Intelligence

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Abstract. The evolution of artificial intelligence (AI) has sparked widespread discussion regarding its potential to replicate or even surpass human intelligence. However, understanding the fundamental differences between AI and human intelligence is crucial for leveraging AI effectively and responsibly. This paper explores the fundamental differences between AI and human intelligence, focusing on structural, learning, and cognitive disparities. By reviewing the history and current state of AI, the paper highlights that despite significant advancements in specific domains, AI still faces limitations in causal reasoning, generalization, common-sense reasoning, and transparency. Based on these limitations, the paper defines AI's application scenarios, including handling unstructured data and automating repetitive tasks. Furthermore, the discussion extends to the prospects of AI in specific fields such as decision support, healthcare, autonomous driving, and finance, emphasizing collaborative work between humans and AI. Finally, the paper underscores that AI should serve as a tool to assist humans in solving complex problems, with a focus on fairness and safety in its societal applications.

Keywords: Artificial Intelligence, Limitations, Application Scenarios, Future Development.

1. Introduction

Artificial Intelligence (AI) and human intelligence are fundamentally different in terms of their structures, learning mechanisms, and cognitive approaches. While AI excels at processing large datasets and executing specialized tasks with speed and precision, it lacks the nuanced understanding, emotional intelligence, and adaptive reasoning characteristic of human cognition. Recent advancements in deep learning and big data have further highlighted both the potential and limitations of AI compared to human intelligence. This paper aims to elucidate these differences, exploring how AI's distinctive features and inherent constraints influence its practical applications and future development. By examining the interplay between AI and human intelligence, this study seeks to provide insights into effective collaboration between the two, guiding the responsible integration of AI into various domains.

2. The Difference Between Artificial Intelligence and Human Intelligence

2.1. The Structure Difference between Human Brain and AI Model

The human brain is a huge neuron network consisting of 10^{11} neuron cells, each exhibiting extraordinarily complex behavior. In this network, each neuron in the brain can connect with many other neurons in the brain, resulting in as many as 10^{15} synaptic connections. This immense connectivity

enables the brain to perform a wide range of complex tasks. Another key feature of the brain is its plasticity, which allows neural networks to undergo dynamic changes in response to learning and experience, continually adjusting the connections between neurons. The brain's ability to rewire and adapt makes it highly flexible, enabling humans to solve new problems and adjust to changing environments.

In contrast, deep learning models represent a highly simplified version of neural networks. Each node in these networks functions as a basic unit performing simple calculations with weights, biases, and activation values. Besides, signals in AI models can only propagate in a single direction, and the connections between nodes are fixed and sparse compared to the dense connectivity seen in the human brain. AI models operate on static architectures where connections are predetermined and immutable after training, lacking the brain's dynamic adaptability. Learning in AI is achieved through mathematical optimization techniques such as back propagation, which fit the model to data rather than evolving with new experiences.

The neural architecture of the human brain and its network connections are far more complex than those found in AI models. Not only are the neurons in the human brain more intricate than the nodes in AI models, but the number of connections in the human brain also greatly exceeds that of AI models. The vast number of connections and neural plasticity in the human brain allow for continuous adaptation and problem-solving beyond initial learning. In contrast, AI models are limited to their training data and lack the flexible, evolving connectivity seen in human neurons. While AI models are mathematically explainable, the mechanisms by which the human brain operates remain mysterious and not fully understood.

2.2. The Mechanism of Artificial Intelligence

Deep neural networks accomplish complex tasks through multiple layers of nonlinear transformations. Each layer extracts different levels of features, allowing the model to tackle various challenges such as image recognition and natural language processing. These models rely on statistical learning methods and deep neural networks to identify patterns and make inferences. However, unlike human understanding, these methods do not truly "comprehend" the meaning of data—they merely perform pattern fitting based on the data they are trained on. AI learning is fundamentally about fitting data using algorithms and updating models with new data and structures developed by humans. While this iterative process improves accuracy, it fails to generalize beyond trained scenarios, limiting AI's adaptability to new, unseen problems.

In conclusion, AI models and the human brain have fundamental structural differences. The human brain is much more complex than AI models, and it is capable of doing all kinds of challenging tasks. Though AI models are not as strong as humans, they have their own advantages, such as identifying patterns in large datasets and functioning continuously without rest—capabilities beyond those of the human brain. However, it cannot fully replace human intelligence, creativity, and adaptability. The fundamental differences in understanding, reasoning, and learning underscore that AI should be seen as a complementary asset rather than a substitute for human capabilities.

2.3. Current Limitations of AI

AI excels at identifying correlations within data but struggles to understand causality, which often leads to biased or flawed conclusions. While correlations can reveal patterns, they do not imply cause-and-effect relationships, making AI prone to misinterpreting data. Such inability to perform causal reasoning renders AI vulnerable to decision-making errors, especially in complex scenarios where understanding cause and effect is crucial. This limitation can result in biased predictions and unintended consequences, particularly when AI models are applied to real-world decision-making tasks.

Currently, most of the AI models are built for a specific task, limiting their ability to transfer knowledge across different domains or adapt to new or unfamiliar environments. Unlike humans, who can adapt learned knowledge to various contexts, AI's generalization capabilities are limited to scenarios similar to its training data. AI models typically perform poorly when confronted with data they have not

encountered during training. This lack of robustness highlights the models' reliance on specific patterns observed during training and underscores their inability to handle unknown challenges. Moreover, AI heavily depends on large-scale datasets to function effectively, and its performance degrades significantly when data is scarce or biased. Data distribution issues can cause AI to make incorrect predictions, especially when the training data does not represent the diversity of real-world situations.

AI models lack the capacity to understand the physical world well enough to make predictions about basic aspects of it—to observe one thing and then use background knowledge to figure out what other things must also be true, which means that machines don't have common sense [1]. Unlike humans, AI cannot draw upon a vast array of everyday knowledge to interpret situations, making it ineffective in scenarios that require intuitive understanding. Besides, modeling common-sense reasoning is highly complex and cannot be adequately captured by standard algorithms or neural networks. The absence of common-sense reasoning in AI leads to limitations in interpreting context, understanding language nuances, and making sound judgments in everyday scenarios.

The decision-making processes of many AI models, particularly deep learning networks, are often opaque and difficult to interpret. This black-box nature raises significant concerns about the transparency, accountability, and fairness of AI decisions, especially in sensitive areas such as healthcare, finance, and criminal justice.

3. AI Applications and Future Directions

3.1. AI Application Scenarios

With the advantages and limitations of AI models, their application scenarios can be described as follows:

AI's powerful pattern recognition capabilities enable it to solve problems that traditional explicit programming cannot handle, which gives it a wide range of applications and a promising future. This is particularly evident in the field of deep learning, where models can learn from data and achieve better results than those obtained through traditional feature engineering. AI is excellent at discovering intricate structures in high-dimensional data [2]. This ability allows tasks to be solved without fully understanding how to implement them, as seen in applications such as image recognition, speech recognition, and natural language processing. Unlike explicit programming, which relies on predefined rules, AI automatically extracts features from data, making it particularly suitable for these tasks. Moreover, when faced with highly complex or ambiguous tasks, AI's iterative training approach allows it to adapt and refine its models over time, making it more effective than traditional programming, which struggles to enumerate all possible rules and scenarios.

Just like any other machines and computer programs, AI models can be distributed and do not require rest and operate continuously. AI systems can work around the clock without interruption, making them ideal for high-intensity, continuous work or real-time monitoring applications. For example, AI can operate nonstop in industrial production, automated customer service, and real-time data analysis.

Additionally, AI is well-suited for managing large volumes of repetitive tasks, such as data sorting, document processing, or automatic classification of images. In contrast, humans are prone to fatigue and errors during prolonged repetitive tasks.

Besides these scenarios that AI can handle, there are some scenarios out of its capacity.

AI's lack of reasoning ability and interpretability presents significant limitations in tasks involving decision-making and ethical considerations. AI performs poorly in tasks requiring a deep understanding of causality, especially in complex decision-making scenarios such as legal judgments or ethical choices in medical diagnoses. For example, the utility of AI tools for medical imaging is limited without any explanation of this output, as it does not unveil the reasoning process, limitations, and biases [3]. Humans can integrate common sense, experience, and ethical considerations into their decisions, areas where AI falls short. Additionally, in high-risk environments like military operations or major traffic management, AI's decisions lack reliable interpretability and causal inference, potentially leading to severe consequences. Human intervention is thus necessary in these contexts.

Humans can spontaneously generate needs and ideas, which AI fails to do so. Although AI can generate art, music, or text, its creative outputs are often based on existing data and patterns, lacking the originality and emotional depth found in human creativity. AI's creativity is limited to recombining existing knowledge rather than producing genuine innovation. When faced with new problems or unfamiliar situations, AI relies solely on existing data for reasoning, whereas humans can adjust their thinking flexibly and propose novel solutions. This flexibility gives humans a significant advantage in handling complex and dynamic environments. Human creativity is often influenced by cultural, emotional, and social backgrounds, aspects that AI struggles to comprehend. Although AI chatbots on average outperform humans, the best humans can still compete with them [4]. This limitation makes it challenging for AI to produce true innovation in fields such as art, literature, and other areas that require emotional depth.

3.2. *Current AI Applications*

There are numerous AI-related applications in use today, such as chatbots, AI art generators, and self-driving cars. While these technologies are impressive, they are often seen as evolutionary rather than revolutionary. They tend to enhance existing processes or provide new ways of doing things rather than solve previously unsolvable problems.

For example, chatbots can improve customer service by handling routine inquiries and providing 24/7 assistance, significantly reducing the workload of human customer service agents and increasing efficiency. However, the core task of answering customer questions has always been possible—AI just makes it faster and more scalable.

Similarly, AI art generators have become popular for creating digital artworks quickly. These tools can generate stunning images from text prompts, democratizing the creative process and making it accessible to more people. Yet, they do not replace the creative thinking and artistic expression of human artists; instead, they serve as additional tools for designers and artists to enhance their work or inspire new ideas.

In the case of self-driving cars, AI enables vehicles to navigate without direct human control, which holds the promise of reducing traffic accidents and improving road safety. However, the fundamental function of driving has not changed—vehicles are still moving from point A to point B. What AI brings is the ability to automate this process, potentially making transportation more efficient and accessible, especially for those unable to drive.

These applications illustrate how AI is reshaping industries by optimizing processes, increasing productivity, and offering alternative solutions. However, their true impact is often in the enhancement of existing capabilities rather than in creating entirely new possibilities.

Actually, AI is capable of more than these applications as it has the potential to be revolutionary in fields such as production environments and research environments.

In production environments, many fields involve data-driven prediction and classification tasks, which align well with the strengths of AI. For example, in the field of weather forecasting, the Pangu weather forecasting model has demonstrated revolutionary improvements over traditional Numerical Weather Prediction (NWP) methods. In terms of RMSE (lower is better), Pangu-Weather typically reports values that are 10% lower than those of traditional NWP methods, while being more than 10,000 times faster [5]. This breakthrough has significant implications for agriculture, disaster management, and daily activities.

In research environments, there are even more complex problems waiting for AI to solve. One significant example is the AlphaFold protein structure prediction model, which has addressed a challenge that has puzzled the field of biology for more than 50 years. Predicting the 3D structure of proteins based solely on their amino acid sequences was a problem that scientists had grappled with for decades. Alpha Fold is the first computational method that can regularly predict protein structures with atomic accuracy, even when no similar structures are known [6]. It enables researchers to better understand biological processes and accelerate drug discovery, demonstrating AI's potential to push the boundaries of scientific research.

These examples show that while many current AI applications focus on optimizing existing tasks, the technology's potential to revolutionize industries and solve longstanding problems is already evident in specialized fields like weather forecasting and biology. These are some of the most impactful applications of AI—not just enhancing existing capabilities but transforming entire industries and subjects. Such advancements possess great potential to dramatically change the public's lives by addressing complex challenges and opening new avenues for innovation.

3.3. Future Prospects of AI

The future development of AI holds immense potential, shaping a world where AI can continue to enhance productivity, solve complex problems, and integrate more deeply into daily lives. However, the path forward must balance innovation with responsibility, taking into account both the opportunities and challenges that AI presents. Some key areas of focus for AI's future include:

Continuous improvement in AI technology can make existing applications, such as chatbots and self-driving cars, more reliable and user-friendly. For instance, further advancements in natural language processing (NLP) can enable chatbots to better understand context, providing more accurate and empathetic responses. Similarly, refining the algorithms behind autonomous vehicles can make them safer and more adaptable to diverse driving conditions, ultimately leading to wider adoption. These enhancements would not only improve user experience but also contribute to greater public trust in AI technologies.

Beyond enhancing current applications, a critical focus should be on discovering revolutionary AI use cases that address previously unsolvable challenges. As seen with AlphaFold's contribution to protein structure prediction and the Pangu weather model's impact on forecasting, AI has the potential to make groundbreaking advances in various fields. Encouraging cross-disciplinary research and fostering innovation could lead to new AI applications in areas such as climate change mitigation, advanced medical diagnostics, and space exploration. These applications could push the boundaries of what is possible, offering new ways to solve global challenges and improve human life.

As AI becomes more powerful and pervasive, it is crucial to establish safeguards to prevent its misuse, such as the creation of deepfakes or the deployment of AI-driven misinformation campaigns. This involves not only technical measures, like developing better detection algorithms, but also legislative frameworks that hold individuals and organizations accountable for malicious uses of AI. Additionally, careful consideration is needed when deploying AI in areas where it lacks competence, such as complex ethical decision-making or highly creative tasks. Clear guidelines and ethical standards should be set to ensure that AI complements human decision-making rather than replacing it where human judgment is crucial.

While AI has achieved remarkable success in practical applications, it is essential not to lose sight of the importance of fundamental research. Even when AI models like AlphaFold can solve specific problems with high accuracy, a deeper understanding of the underlying scientific principles remains critical. For example, while AlphaFold accurately predicts protein structures, researchers must continue to explore the mechanisms of how amino acids fold into proteins to improve the interpretability and reliability of these predictions. Deepening people's understanding of these processes will enable the refinement of AI models and ensure that they are not only accurate but also aligned with scientific principles. This approach will help build more transparent and trustworthy AI systems.

These focus areas emphasize a balanced approach to AI development—enhancing current technologies, seeking new frontiers, managing risks, and deepening our understanding of the underlying science. As AI continues to evolve, its future will depend on how well humans integrate these aspects, ensuring that the technology serves humanity's best interests while addressing the complex challenges it brings.

4. Conclusion

This article has explored the distinct characteristics, limitations, and future directions of artificial intelligence (AI) compared to human intelligence. While AI demonstrates remarkable capabilities in

pattern recognition, data processing, and handling repetitive tasks, its fundamental differences from human intelligence—such as the lack of causal reasoning, common sense, and creative thought—highlight its inherent limitations. AI excels in specific, data-driven environments but falls short in areas that require deep understanding and adaptability.

The current constraints of AI, such as insufficient generalization, inability to perform common-sense reasoning, and lack of transparency, underscore the need for careful integration of AI into complex decision-making processes. AI should be viewed not as a replacement for human intelligence but as a powerful tool that enhances human capabilities. By automating routine tasks and providing data-driven insights, AI can free humans to focus on creativity, strategic thinking, and complex problem-solving.

AI's strengths lie in data-driven environments with prediction and classification tasks, where collaboration between humans and AI can leverage each other's strengths to address challenges across various fields, including healthcare, finance, and autonomous systems. To maximize AI's potential while mitigating its risks, it is crucial to develop ethical frameworks, improve the interpretability of AI models, and maintain human oversight in critical areas. The integration of AI into society should prioritize human-centered values, ensuring that AI serves as a beneficial and safe assistant, enhancing human decision-making and enabling people to tackle the complex challenges of the modern world.

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