

EDGE COMPUTING AND MACHINE LEARNING: OPTIMIZING DECENTRALIZED SYSTEMS

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Анотація

Периферійні обчислення у поєднанні з машинним навчанням (Edge AI) представляють собою зміну парадигми в обробці даних. Замість того, щоб покладатися виключно на централізовані хмарні сервери, ця технологія дозволяє обробляти дані локально на пристроях, зменшуючи затримку та використання пропускної здатності мережі. У цій роботі розглядається інтеграція моделей машинного навчання у децентралізовані системи, висвітлюється оптимізація продуктивності та потенційні сфери застосування у сучасному IT-середовищі.

Ключові слова: машинне навчання, периферійні обчислення, інтернет речей, децентралізація, штучний інтелект.

Abstract

Edge computing combined with machine learning (Edge AI) represents a paradigm shift in data processing. Instead of relying solely on centralized cloud servers, this technology allows data to be processed locally on devices, significantly reducing latency and bandwidth usage. This paper explores the integration of machine learning models into decentralized systems, highlighting performance optimization, architectural challenges, and potential applications in modern IT environments.

Keywords: machine learning, edge computing, Internet of Things, decentralization, artificial intelligence.

Introduction

In recent years, the rapid proliferation of smart devices and the Internet of Things (IoT) has led to an exponential increase in the volume of generated data. Traditionally, this data is transmitted to centralized cloud servers for processing, analysis, and storage. However, this centralized approach presents several critical bottlenecks. High latency, excessive bandwidth consumption, and growing privacy concerns make cloud-only architectures increasingly inefficient for real-time applications.

To address these limitations, edge computing has emerged as a viable solution. By moving computational power closer to the data source – the "edge" of the network – organizations can process information locally. When combined with Machine Learning (Edge AI), this decentralized approach allows devices to make autonomous, intelligent decisions in real-time without relying on a constant connection to a central server. This paper examines the role of Edge AI in modern IT infrastructure, detailing its benefits, the technical challenges of deploying ML models on resource-constrained devices, and its future implications.

Research results

The primary advantage of implementing machine learning in decentralized edge environments is the dramatic reduction in latency. In critical systems, such as automated manufacturing, autonomous vehicles, or real-time cybersecurity monitoring, the delay caused by sending data to a cloud server and waiting for a response can be detrimental. Edge AI ensures that data is processed on local servers or directly on embedded systems, enabling instantaneous responses.

Another significant benefit is the optimization of network bandwidth. Instead of transmitting raw, heavy datasets across the network, edge devices analyse the data locally and only send the processed results or critical anomalies to the cloud. This not only reduces the load on network infrastructure but also significantly enhances data privacy and security. Since sensitive information remains on the local device or a decentralized home server, the risk of large-scale data breaches during transmission is minimized.

However, deploying ML models in decentralized systems introduces specific engineering challenges. Most edge devices lack the substantial computational power, memory, and energy resources found in traditional data centres. Consequently, standard machine learning models must be adapted. Techniques such as model quantization, pruning, and knowledge distillation are employed to compress complex neural networks into lightweight versions that can run efficiently on edge hardware without a significant loss in accuracy.

Currently, Edge AI is being successfully integrated into various domains. In predictive maintenance, sensors equipped with ML algorithms analyse equipment vibrations and temperatures to predict failures before they occur, eliminating the need for constant cloud communication. In smart environments, localized data processing allows for immediate adjustments to environmental controls, optimizing energy consumption autonomously.

Despite the hurdles related to hardware limitations and the complexity of managing decentralized networks, the ongoing advancements in specialized AI accelerators (such as NPUs) and more efficient ML algorithms are rapidly expanding the capabilities of edge computing.

Conclusion

The integration of machine learning into edge computing architectures marks a crucial evolution in decentralized systems. By enabling localized, intelligent data processing, Edge AI successfully addresses the latency, bandwidth, and privacy limitations inherent in cloud-centric models. While the deployment of these systems requires specialized optimization techniques to accommodate resource-constrained hardware, the continuous development of lightweight algorithms ensures a scalable future. Ultimately, as the demand for real-time, autonomous decision-making grows, decentralized machine learning will become a foundational component of modern IT infrastructure.

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