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Real-time data Processing and Decision-Making Frameworks for Autonomous Systems

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11. Real-time data Processing and Decision-Making Frameworks for Autonomous Systems

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Abstract

As autonomous systems become increasingly prevalent across various sectors, the integration of edge and cloud computing has emerged as a critical strategy for optimizing real-time data processing and decision-making. This chapter explores the architectural models and decision-making frameworks that leverage both edge and cloud resources to enhance the performance, efficiency, and scalability of autonomous systems. By examining case studies from autonomous vehicles, drones, and robotics, this work highlights the practical implementations and benefits of edge-cloud integration. The discussion includes a detailed analysis of real-time data fusion techniques that combine multi-sensor inputs, addressing challenges related to interoperability and standardization. Key issues such as latency, computational load, and data consistency are examined, along with ongoing efforts to develop standardized frameworks and protocols. This chapter provides valuable insights into the current state of edge-cloud integration and outlines future directions for research and development, emphasizing the importance of seamless interoperability and robust decision-making in autonomous applications.

Keywords: Edge Computing, Cloud Computing, Autonomous Systems, Real-time Data Fusion, Interoperability, Standardization.

Introduction

The rise of autonomous systems has marked a transformative shift across various industries, including automotive, aerospace, healthcare, and manufacturing [1]. These systems, which encompass technologies such as self-driving vehicles, drones, and intelligent robots, rely heavily on advanced computing capabilities to operate effectively in dynamic environments [2]. Central to the development and efficiency of these systems was the integration of edge and cloud computing, which plays a pivotal role in managing the immense volume of data generated and processed [3]. Edge computing involves processing data closer to the source of generation, thereby reducing latency and enabling real-time responses [4]. Conversely, cloud computing provides centralized processing power and storage, supporting complex analytics and long-term data management [5]. Together, these technologies form a synergistic framework that enhances the performance and scalability of autonomous systems [6].

The integration of edge and cloud computing involves various architectural models, each with its own advantages and challenges [7]. Centralized architectures rely on cloud computing for data processing and decision-making, which can introduce latency and dependence on network reliability [8]. In contrast, decentralized architectures leverage edge computing to handle data

processing locally, reducing latency but potentially facing limitations in computational resources [9,10]. Hybrid models seek to combine the strengths of both approaches, balancing real-time processing with scalable, centralized analytics [11]. The choice of architecture impacts not only the efficiency and responsiveness of autonomous systems but also their ability to handle diverse and complex tasks [12,13]. Understanding these models was crucial for designing systems that are both resilient and adaptable to evolving operational demands [14].

Real-time data fusion was a critical component of autonomous systems, enabling the integration of data from multiple sensors to form a comprehensive understanding of the environment [15]. Techniques such as Kalman filters, particle filters, and machine learning algorithms are employed to combine sensor inputs, addressing challenges related to data synchronization, noise, and uncertainty [16]. The effectiveness of these techniques directly influences the accuracy and reliability of decision-making processes [17]. For instance, in autonomous vehicles, data from LIDAR, radar, and cameras must be fused to detect obstacles and navigate safely. Similarly, drones and robots rely on real-time data fusion to execute tasks with precision. The development of robust data fusion methods was essential for enhancing the capabilities of autonomous systems and ensuring their operational success.