Distributed Orchestration in a Computing Continuum

Stefano Galantino

Distributed computing has evolved significantly with the emergence of paradigms like cloud, edge, and fog computing, which bring computing capabilities closer to the end-user to address modern application demands for low latency, geographical distribution, and resource efficiency. Despite these advancements, the current state-of-the-art solutions are predominantly siloed, limiting the seamless integration of resources across diverse infrastructures. This dissertation builds on the concept of the *computing continuum*, an architectural paradigm that eliminates these silos by unifying resources across the compute layers into a single, dynamic, and transparent computational environment. The work is situated within the European Horizon project FLUIDOS (Flexible, scaLable, secUre, and decentralIseD Operating System), which builds the foundation of this research.

The FLUIDOS architecture builds upon Kubernetes and Liqo to establish a decentralized meta-operating system capable of dynamic resource sharing and intent-based orchestration. This dissertation presents key innovations in the design and implementation of the computing continuum, focusing on the REAR (Resource Advertisement and Reservation) protocol, which facilitates resource discovery and negotiation across heterogeneous environments. The REAR protocol introduces a flexible mechanism for dynamic resource advertisement, ensuring that resources can be utilized based on application-specific intents, energy consumption patterns, and cost models.

The thesis further investigates cost-aware task allocation, presenting a novel scheduling framework that minimizes application deployment costs while meeting performance requirements. Experimental evaluations demonstrate that the proposed framework significantly enhances resource utilization, reduces costs, and maintains compliance with user-defined constraints. Additionally, the research addresses energy efficiency within the continuum, proposing an energy-aware orchestration mechanism that dynamically adjusts workload placement based on power consumption and carbon footprint considerations.

This approach integrates carbon-aware scheduling strategies, enabling the execution of tasks in environmentally sustainable locations and timeframes.

Resilience is another critical dimension explored in this work. The dissertation introduces a fault-tolerant orchestration framework designed to ensure the high availability of mission-critical applications, such as electrical grid monitoring. By dynamically redistributing workloads during network failures or infrastructure outages, the framework maintains service continuity, demonstrating its efficacy through real-world experiments conducted in collaboration with RSE (Ricerca sul Sistema Energetico). These experiments highlight the capability of the computing continuum to support distributed and fault-tolerant applications in complex and resource-constrained environments.

This dissertation provides a comprehensive exploration of the computing continuum, encompassing its architectural foundations, enabling technologies, and key application scenarios. The FLUIDOS framework exemplifies how distributed orchestration can address the challenges of scalability, sustainability, and reliability in modern computing. By integrating innovative protocols like REAR, cost-aware and energy-efficient task allocation strategies, and resilience mechanisms, the computing continuum emerges as a transformative paradigm for future distributed systems.