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Optimizing Scientific Simulations with Python-Driven Parallelism on Azure Batch: A Hybrid Cloud Architecture for High-Performance Computing

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Abstract: *Scientific computing applications often demand high-performance environments capable of processing large-scale simulations with precision and speed. This paper presents a hybrid cloud architecture that integrates on-premise systems with Microsoft Azure Batch to execute computationally intensive scientific workloads. By leveraging Python-based parallelism libraries such as Dask and multiprocessing, the framework enables scalable and distributed execution of simulation tasks without the complexity of manual resource orchestration. Azure Batch is utilized to provision and manage compute pools dynamically, offering elasticity, job queuing, and auto-scaling for cost-effective resource utilization. A robust job submission pipeline is designed using Azure Storage, Python APIs, and Azure Queue, facilitating seamless data ingestion and result aggregation. The architecture is validated through experiments simulating fluid dynamics and material science models, showcasing significant reductions in execution time compared to traditional single-node processing. The results confirm the viability of the proposed system in accelerating time-to-insight for research-intensive applications. This study contributes a modular, cloud-optimized approach for high-performance scientific simulations that minimizes infrastructure overhead while maintaining computational rigor and reproducibility.*

Keywords: Hybrid Cloud Computing, High-Performance Computing (HPC), Azure Batch, Python Parallelism, Scientific Computing, Dask, Multiprocessing, Job Scheduling, Azure Storage, Parallel Processing, Workflow Automation