Adaptive Orchestration of Distributed Computing under Fluctuating Resource Availability

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Scientific computing infrastructures are expected to deliver increasing amounts of computing capacity while also reducing energy consumption, cost and environmental impact. This creates a practical conflict: many scientific workloads still require reliable access to computing resources, but the most sustainable operation of these resources may depend on fluctuating conditions such as renewable energy availability, site load, maintenance windows and temporary resource shortages. A system that assumes all resources are always available is therefore poorly matched to future federated computing environments.

The research addressing these challenges is carried out in the context of SUSFECIT, Sustainable Federated Compute Infrastructures (an ErUM-Data project), and focuses on adaptive orchestration for distributed computing. The central research question is how an orchestration system can react automatically when the available computing capacity changes over time, while still preserving reliability and long-term delivery of promised computing power. The work connects two complementary directions. First, the Breathing Cluster concept, developed by KIT, allows cluster capacity to change according to renewable energy availability. Second, the Dynamic Limiter keeps track of whether the expected amount of computing has actually been delivered. If delivery falls behind because a site was unavailable, occupied by other users or intentionally reduced due to energy constraints, the missing capacity is treated as a backlog that can be recovered later when resources become available again.

The Dynamic Limiter is being implemented as a capacity-accounting and recovery mechanism for the COBalD/TARDIS orchestration framework. It compares expected and delivered computing capacity over time. When delivery is below the planned trajectory, it computes a recovery demand and raises the requested capacity above nominal. The same mechanism is relevant for the energy-aware operation: if a Breathing Cluster reduces capacity during periods of low renewable energy availability, the orchestrator can later increase demand when clean energy or spare capacity returns.