Scalable Programming Models and Strategies for Efficient High-Performance Serverless in Hybrid and Heterogeneous Systems

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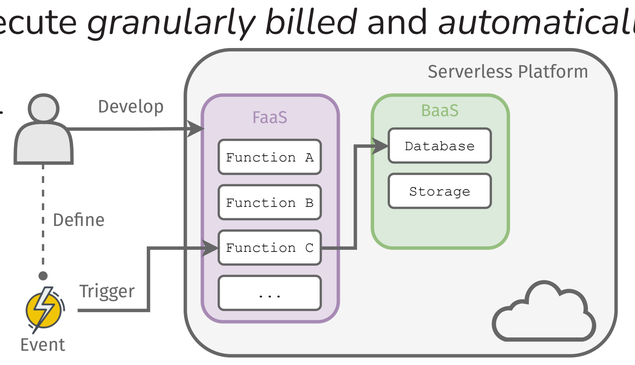
SCAN ME

Problem Statement

- **Problem:** Current HPC infrastructures are constrained by strict resource allocation systems and rigid programming models.
- **Idea:** The serverless execution model enables fine-grained application decomposition, leading to:
  - Improved resource utilization.
  - Easier deployment of highly distributed parallel applications.
  - *Statelessness* allows for virtually unlimited horizontal scaling.
- **Challenges:** In order to effectively exploit the serverless paradigm to support HPC applications, several challenges must be addressed:
  - Lack of high-level parallel programming models suited for serverless.
  - Complexities in managing highly parallel workloads and support function composition in serverless environments.
  - Limited support for accelerators (e.g., GPUs, FPGAs).

Serverless Computing

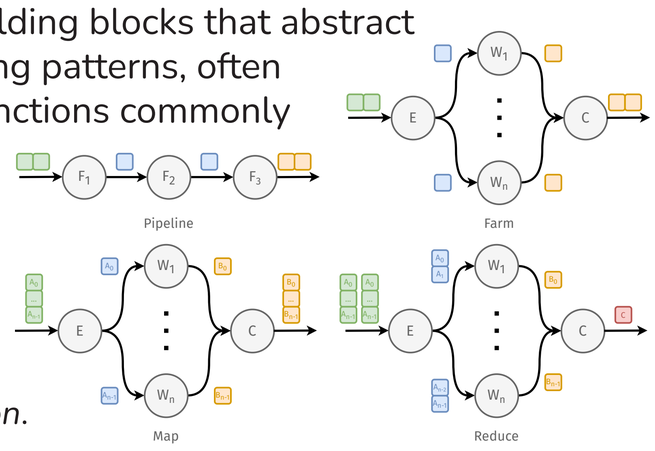
- **Serverless Computing:** It is a form of cloud computing that allows users to deploy and execute *granularly billed* and *automatically scaled* applications, without having to address the underlying operational logic.



- The typical workflow of a serverless application consists of the following steps:
  1. A pre-defined event triggers a serverless function that was bound to it earlier.
  2. The serverless platform prepares the *execution environment* for the triggered function to run.
  3. After the execution is completed, the serverless platform releases the resources previously acquired.
- The execution environment typically relies on *containers* or other forms of *lightweight virtualization*.

Skeletal Programming

- **Algorithmic Skeletons:** Introduced by Murray Cole in the late 1980s, algorithmic skeletons are building blocks that abstract common parallel programming patterns, often derived from higher-order functions commonly found in functional programming.



- **Key features:**
  - *Separation of Semantics and Implementation.*
  - *Correctness by Construction.*
  - *Abstraction of low-level parallelism mechanisms.*
- **Transformation Rules:** Different skeleton compositions can represent the same computation but exploit parallelism differently. Transformation rules define semantic equivalences, helping developers identify optimal compositions for performance.

Research Methodology

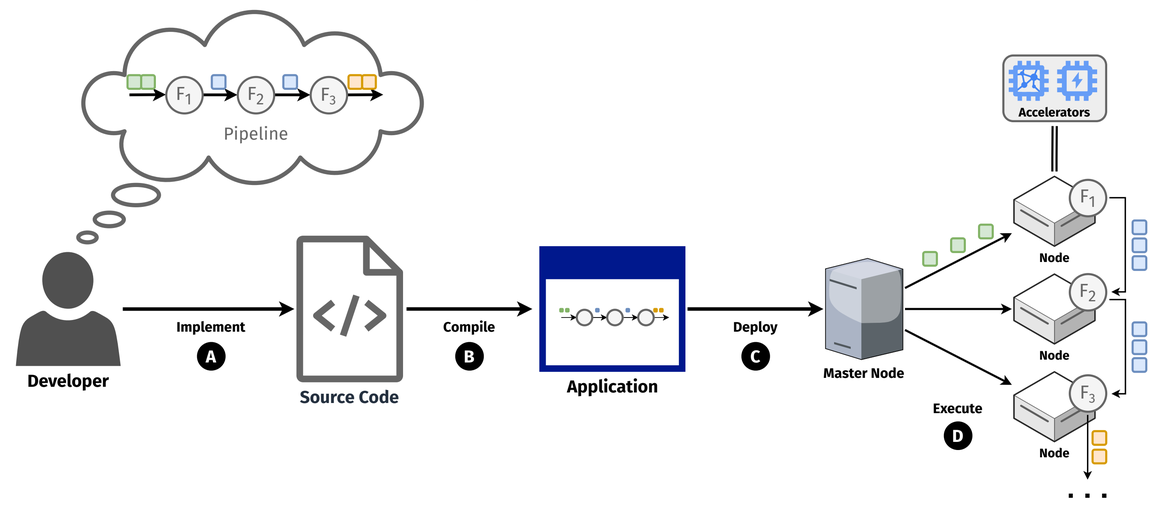
Main Objective:
To develop a novel *methodology* for the development and execution of parallel and distributed applications that leverage the serverless execution model, targeting hybrid HPC/Cloud infrastructures. In order to achieve that, we are currently addressing the following objectives:

Goal A: Skeleton-based Programming Model
- Develop a high-level parallel programming model based on algorithmic skeletons, tailored for serverless.
- Skeletons provide abstraction for parallelism, simplifying scaling and processes coordination.

Goal B: High-Performance Serverless Framework
- Design a lightweight, high-performance serverless framework optimized for parallel workloads.
- Prioritize low resource footprint and efficient communication mechanisms.

Goal C: Integration of Heterogeneous Accelerators
- Develop a high-level interface for seamless offloading of compute-intensive tasks to accelerators (e.g., GPUs, FPGAs).
- Enable efficient use of accelerators in serverless platforms.

Proposed Workflow:



A The user design a parallel application in terms of skeletons.

B The application code is compiled into a suitable format.

C The application is deployed on the high-performance serverless framework.

D The framework executes the application and manages function instantiations.

Preliminary Results and Next Steps

- **First Results:**
  - Conducted a survey on literature related to virtualization approaches and accelerator support in serverless architectures.
  - Started implementing a framework prototype using unikernels and leveraging *Cloud-Hypervisor* and *Firecracker* for lightweight virtualization.

- **Next Steps:**
  - Formalize the design of the proposed skeleton-based parallel programming model.
  - Start experimenting with the proposed programming model and prototype high performance serverless framework.
  - Add support to performance modeling through algorithmic skeletons *transformation rules*.

PUBLICATIONS

Besozzi, Valerio. *"**PPL: Structured Parallel Programming Meets Rust**"*. In *2024 32nd Euromicro International Conference on Parallel, Distributed and Network-Based Processing (PDP)*, pp. 78-87, 2024. doi:10.1109/PDP62718.2024.00019.

Besozzi, Valerio, and Patrizio Dazzi. *"**Boosting Serverless Computing: A Survey on Architecture Designs and Accelerator Support for Serverless Platforms**"*. In *2024 30th International European Conference on Parallel and Distributed Computing (Euro-Par 2024)*. Accepted for publication.

MORE INFORMATION

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