Hewlett Packard **Labs**

Enabling HPC Scientific Workflows for Serverless

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6th workshop on Containers and new orchestration paradigms for isolated environments in HPC (CANOPIE-HPC) at Supercomputing 2024

Introduction

Serverless Computing

- A computing paradigm that deploys **fast execution functions** on **demand**, **reserving resources** just for the **time to run** the applications.
  - It is very beneficial for **auto-scaling** and **low data-communication** workloads;
  - It encompasses the FaaS (Function as a Service) approach:
    - Functions are deployed inside environments such as containers;
    - Functions respond to events.

HPC/ AI Workflows

- **Scientific jobs**, split in different **coordinated tasks**;
  - We have witnessed a **growing population** of different HPC/ AI workflows;
  - It is difficult but **crucial** to **identify patterns** for **management purposes**;

Motivation

Why is it important **?**

- Infrastructure Cloud computing entities have dealt with the difficulty of managing their resources for handling these many types of workflows;
- Serverless can address the problem above, but do not offer mechanisms to manage workflow invocations.

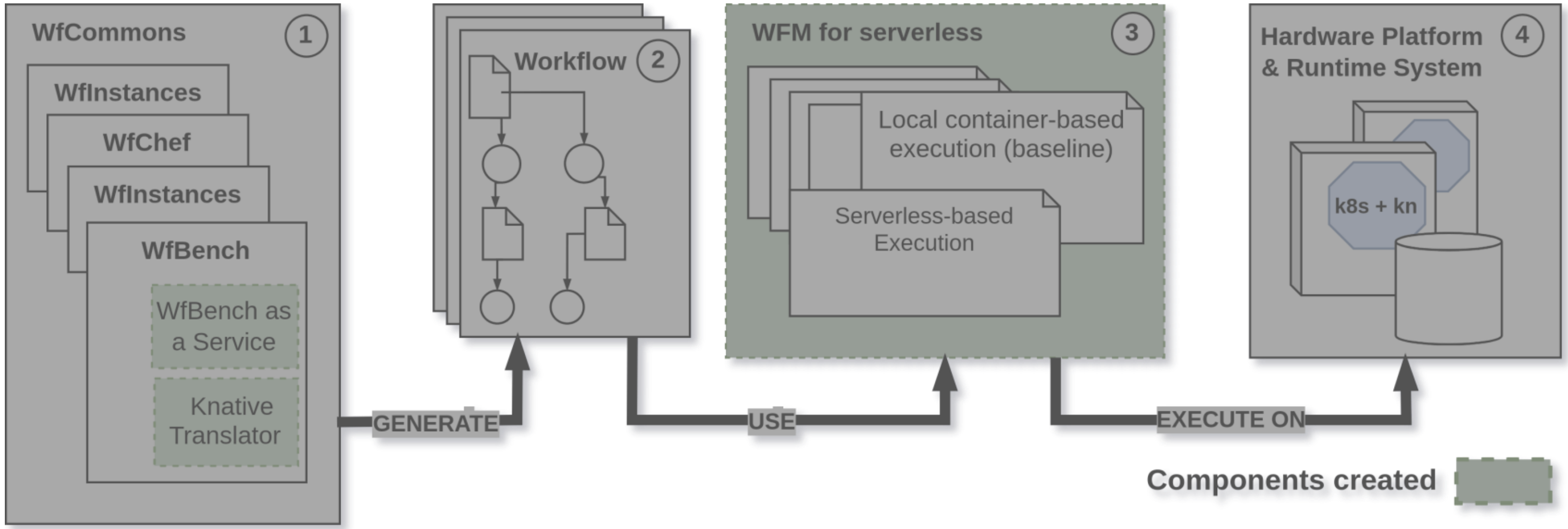
How are we tackling these challenges?

- We propose a framework for executing and evaluating HPC scientific workflows on serverless

What are our contributions?

- A **framework** that enables **HPC scientific workflows** on **serverless computing**, assembling:
  - a **workflow manager for serverless** (evaluated using **Knative**);
  - the **WfCommons framework** (extended)**.**
- An **extensive evaluation**, comparing **serverless and bare-metal containers** in terms of granularity, execution time, power, CPU, and memory usage.

System Architecture



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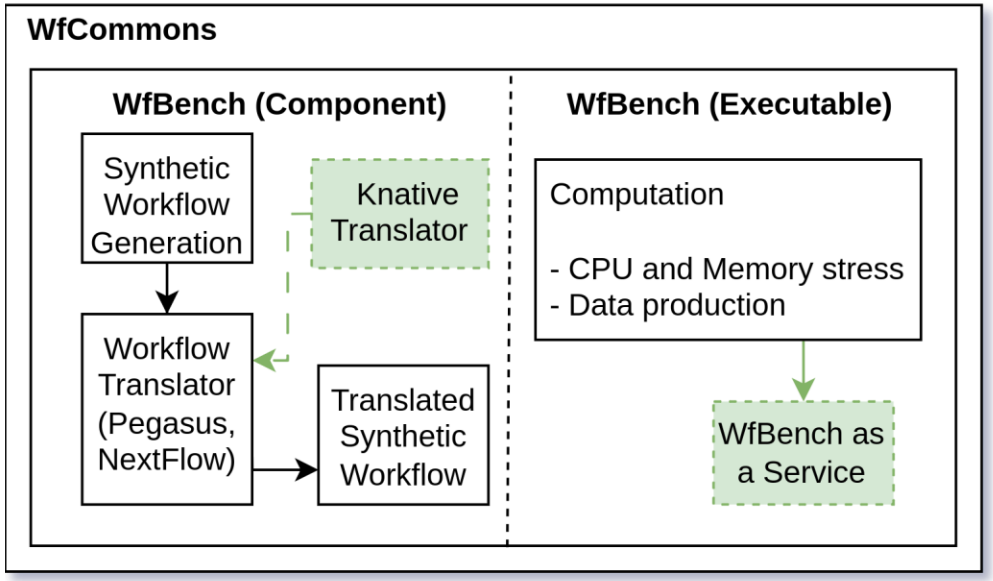

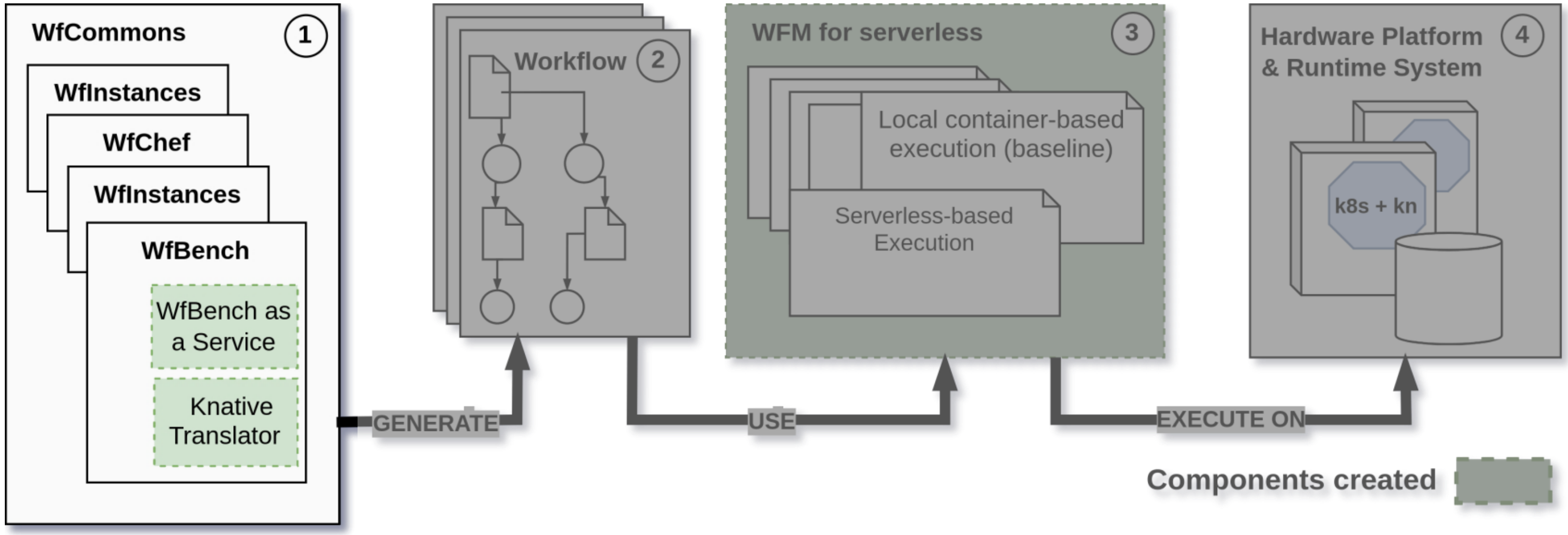

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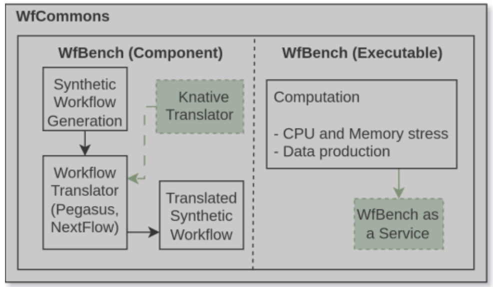

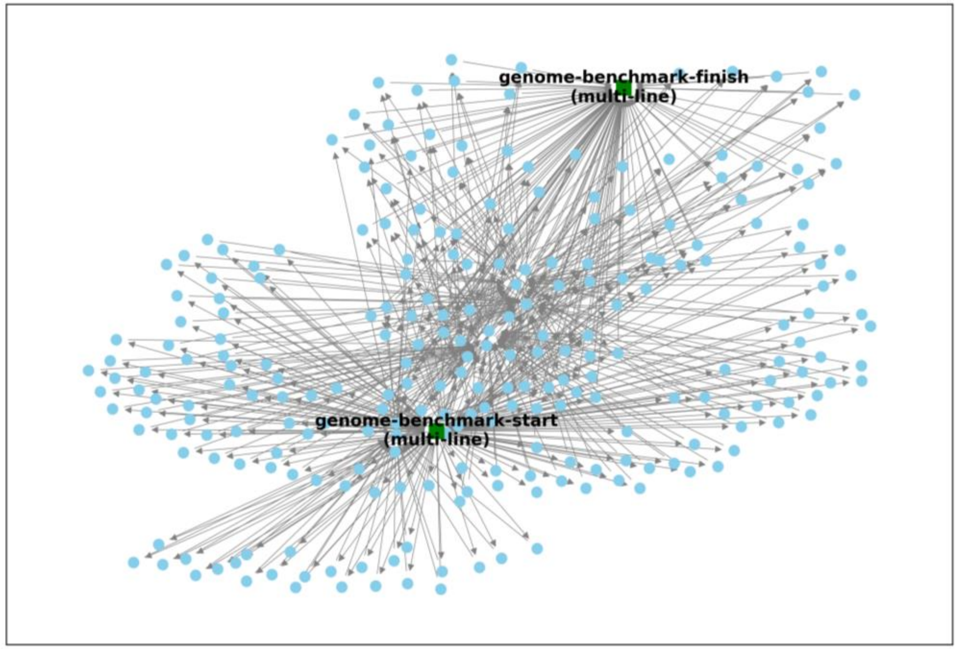
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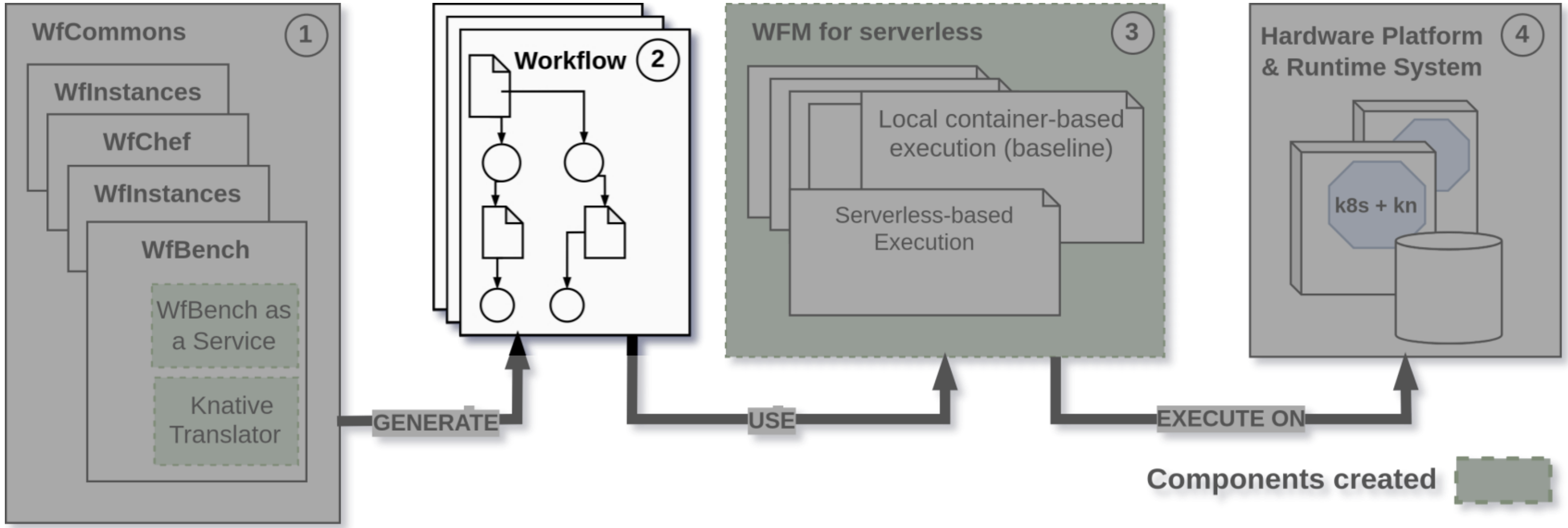

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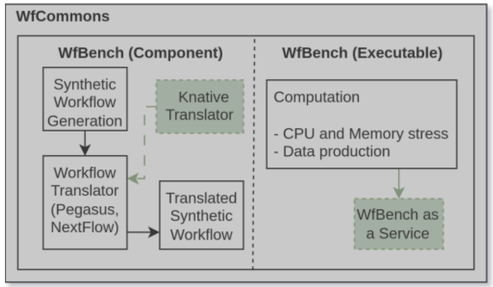


WfCommons

WfBench (Component)

Synthetic Workflow Generation

Knative Translator

Workflow Translator (Pegasus, NextFlow)

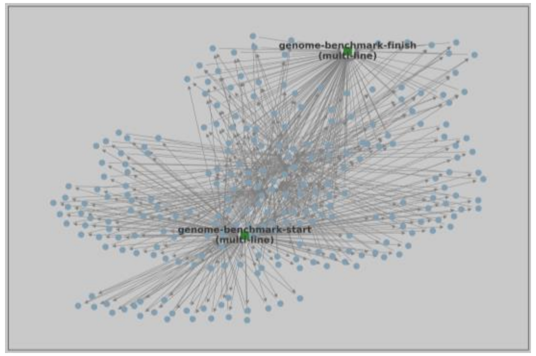
Translated Synthetic Workflow

WfBench (Executable)

Computation

- CPU and Memory stress
- Data production

WfBench as a Service



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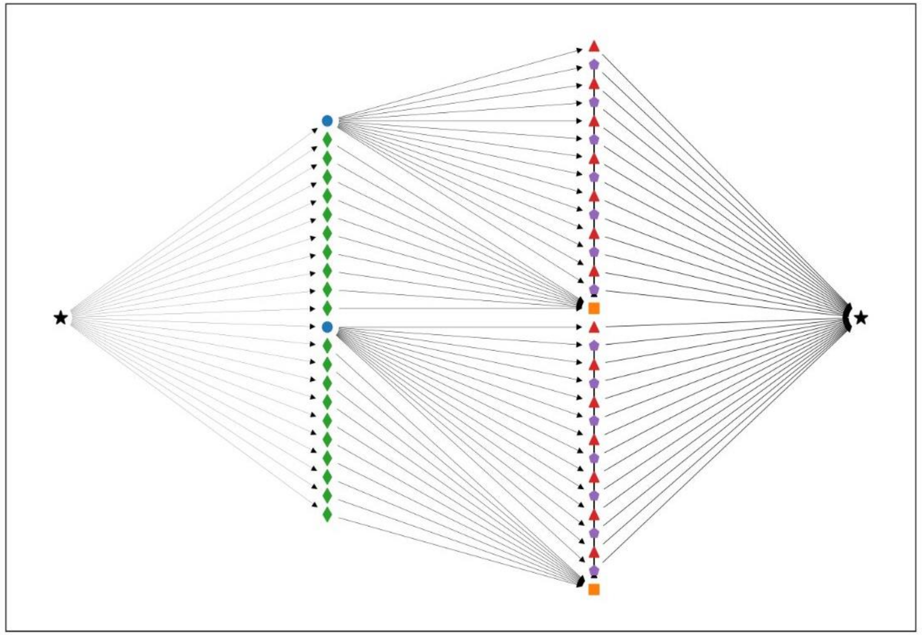
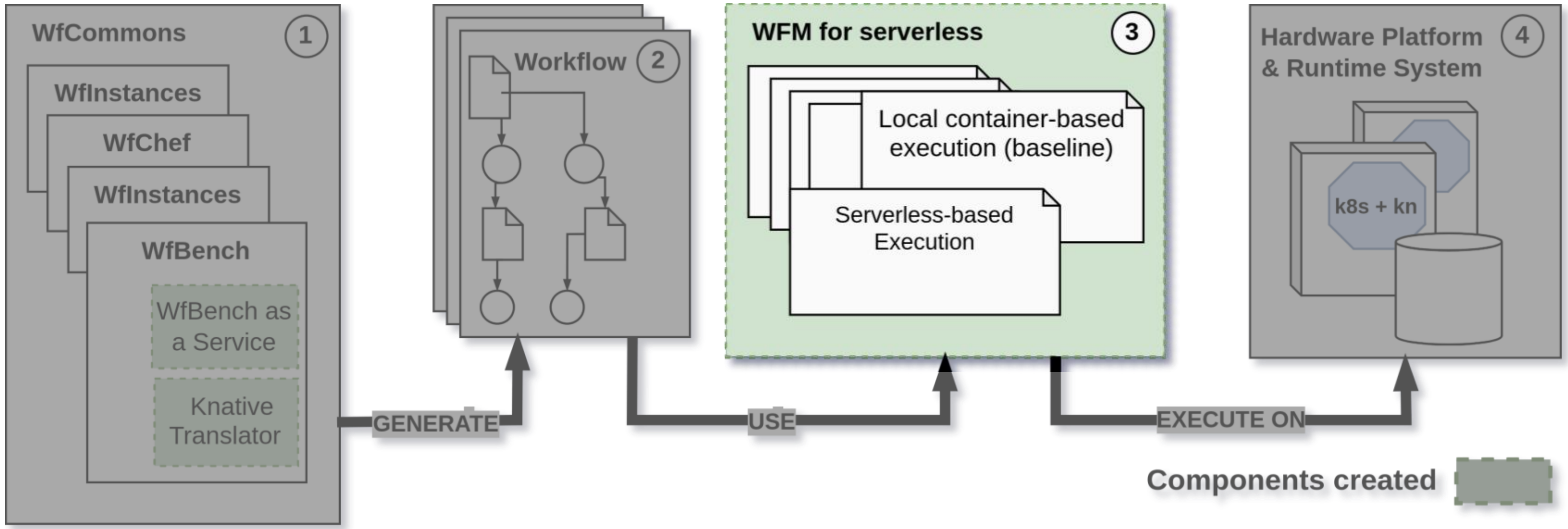




WfCommons 1

WfInstances

WfChef

WfInstances

WfBench

WfBench as a Service

Knative Translator

Workflow 2

WFM for serverless 3

Local container-based execution (baseline)

Serverless-based Execution

Hardware Platform & Runtime System 4

k8s + kn

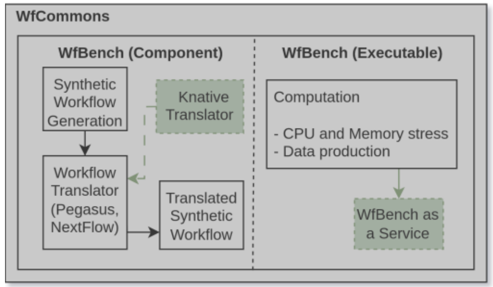
GENERATE

USE

EXECUTE ON

Components created

System Architecture



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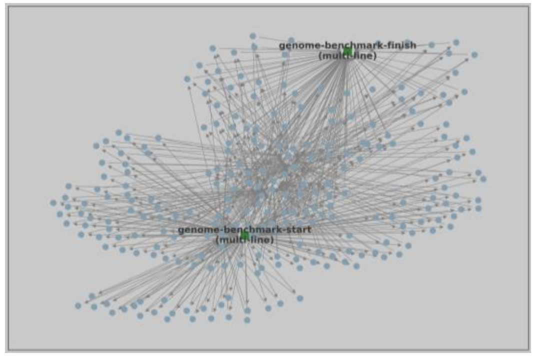

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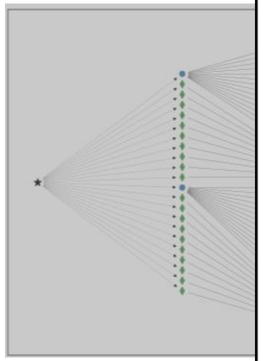
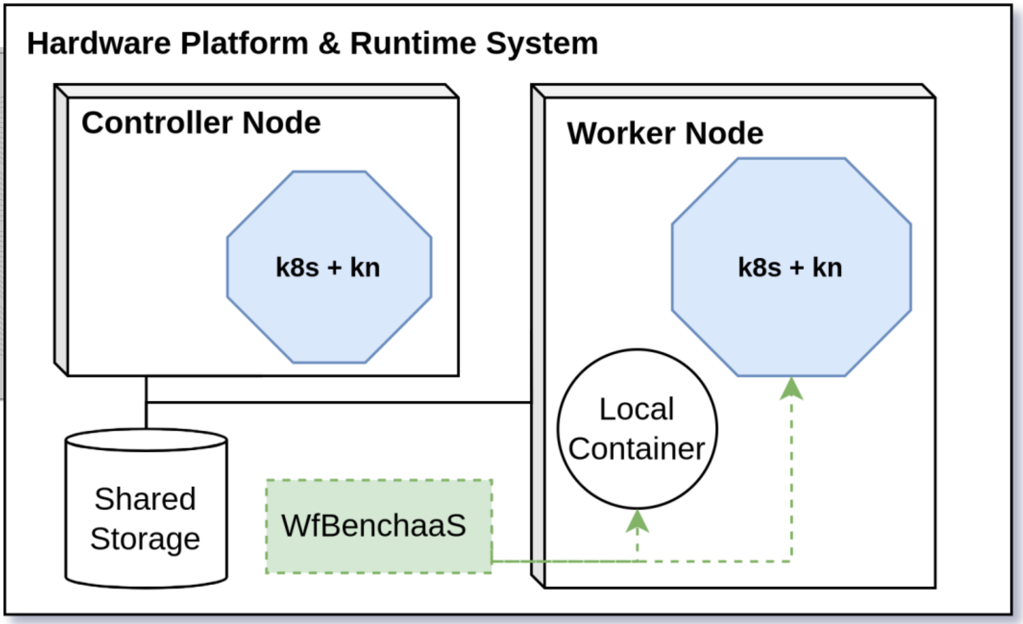




Hardware Platform & Runtime System

Controller Node

k8s + kn

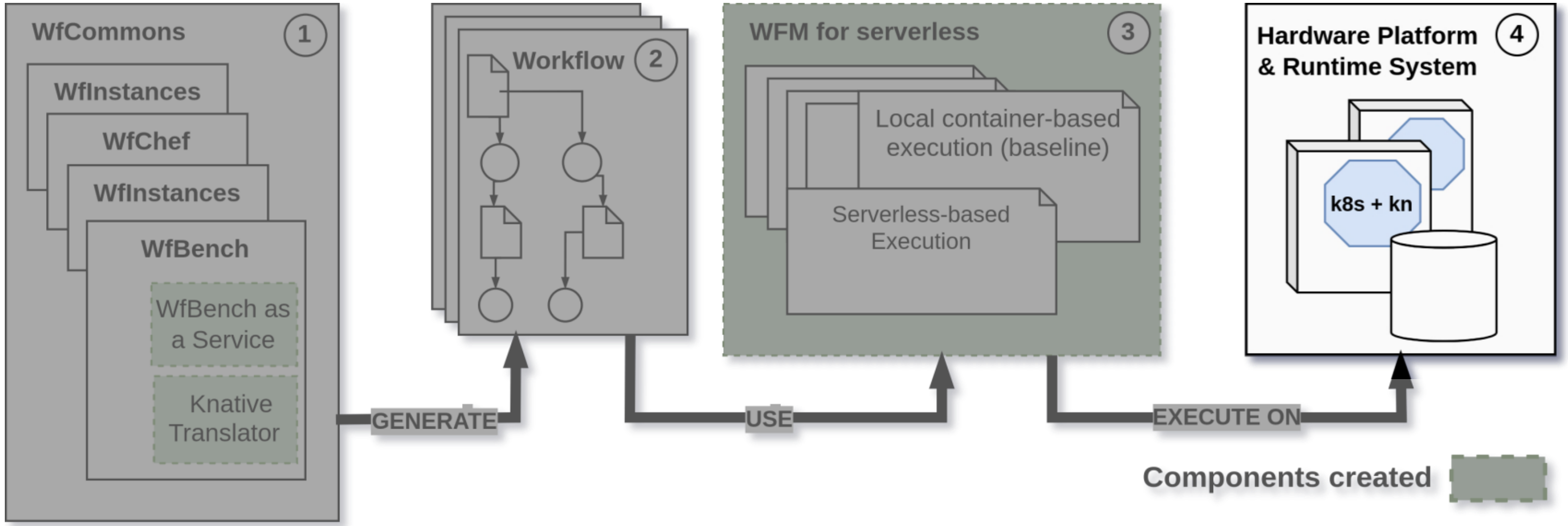
Worker Node

k8s + kn

Local Container

Shared Storage

WfBenchaaS



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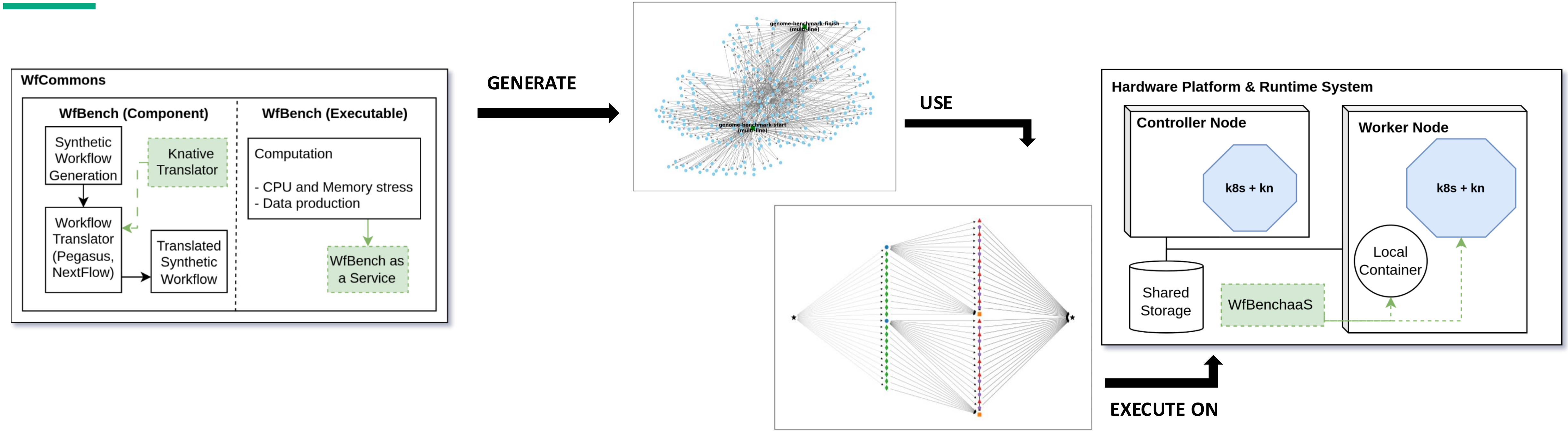
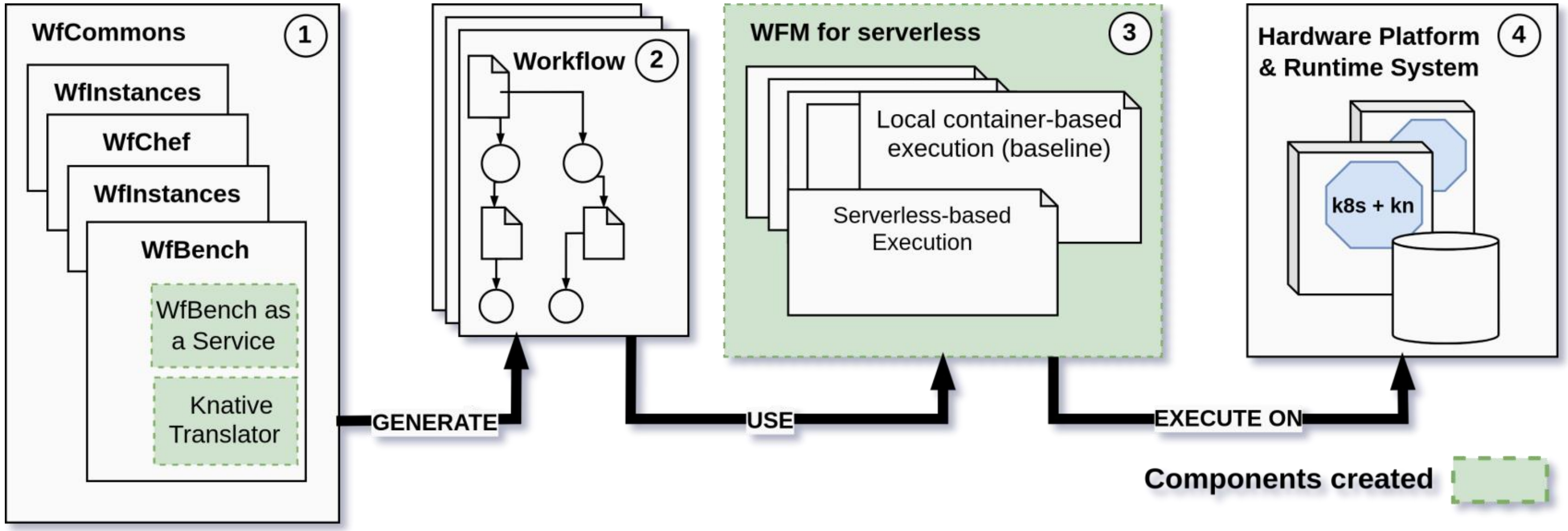
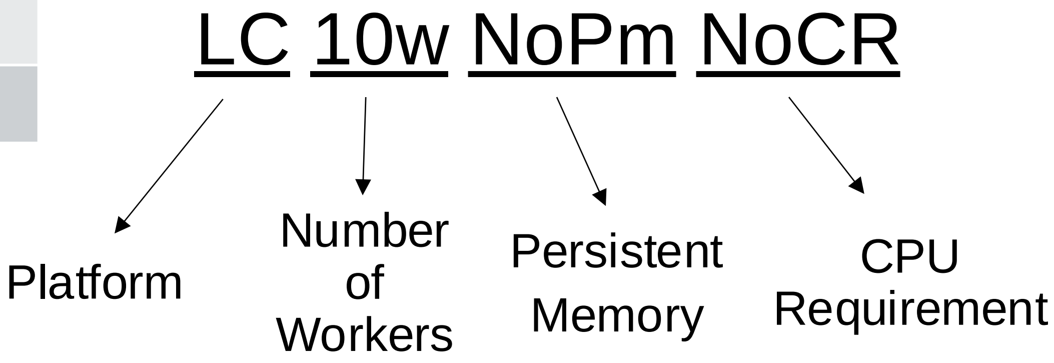




DoE and Methodology

Parameter	Value
Platform	Bare-metal local containers, Knative
Workflow	Blast, Bwa, Cycles, Epigenomics, Genomes, Seismology, Srasearch
Workflow size	250, 500, 1000 tasks
CPU stress	100%
Number of workers	1, 10 workers
Function's granularity	Coarse-grained, fine-grained
Persistent Memory	With, without

Knative	Local Containers
Kn1wPM, Kn1wNoPM, Kn10wNoPM, Kn1000wPM,	LC1wPM, LC1wNoPM, LC10wNoPM , LC10wNoPmNoCR, LC1000wPM
Total of experiments	140 experiments



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Experimental Results: Fine-grained Serverless and Local Containers

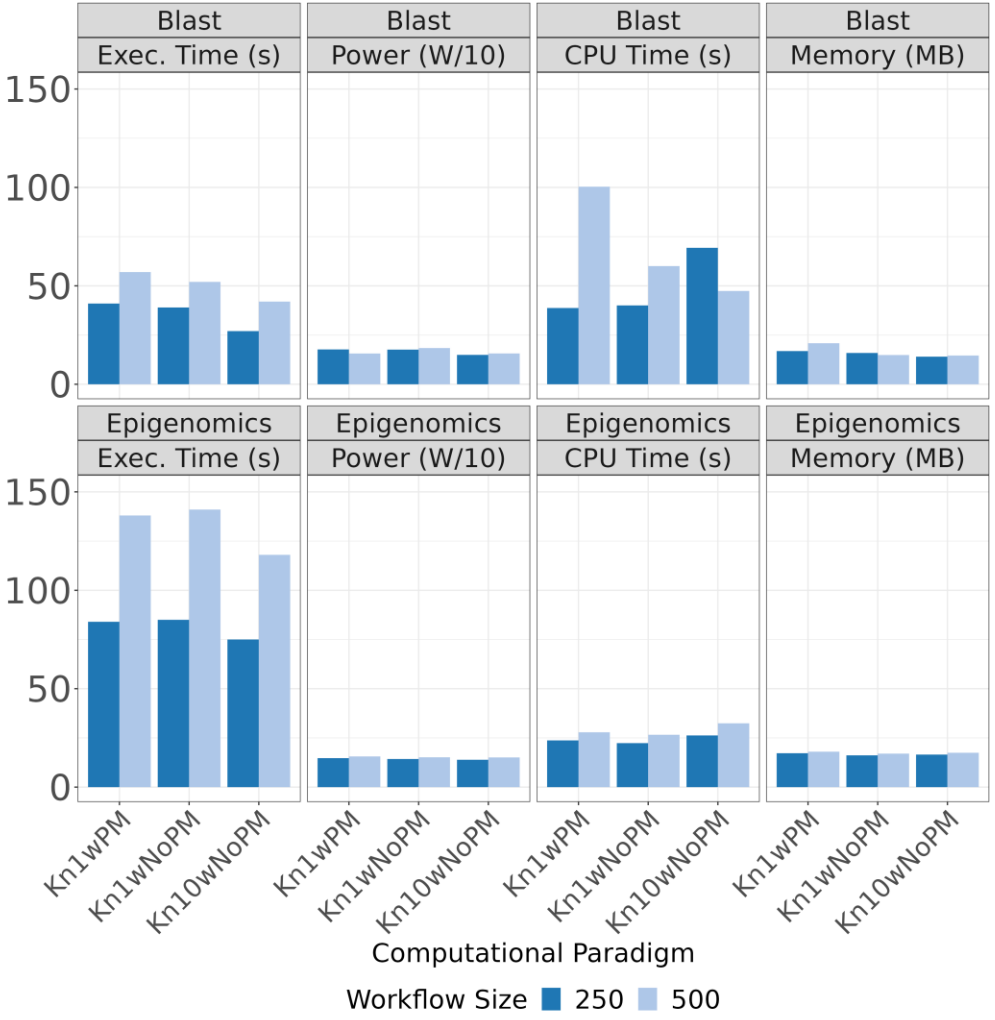

Fig. 4: Comparison between different setups for the Serverless Computational Paradigm.

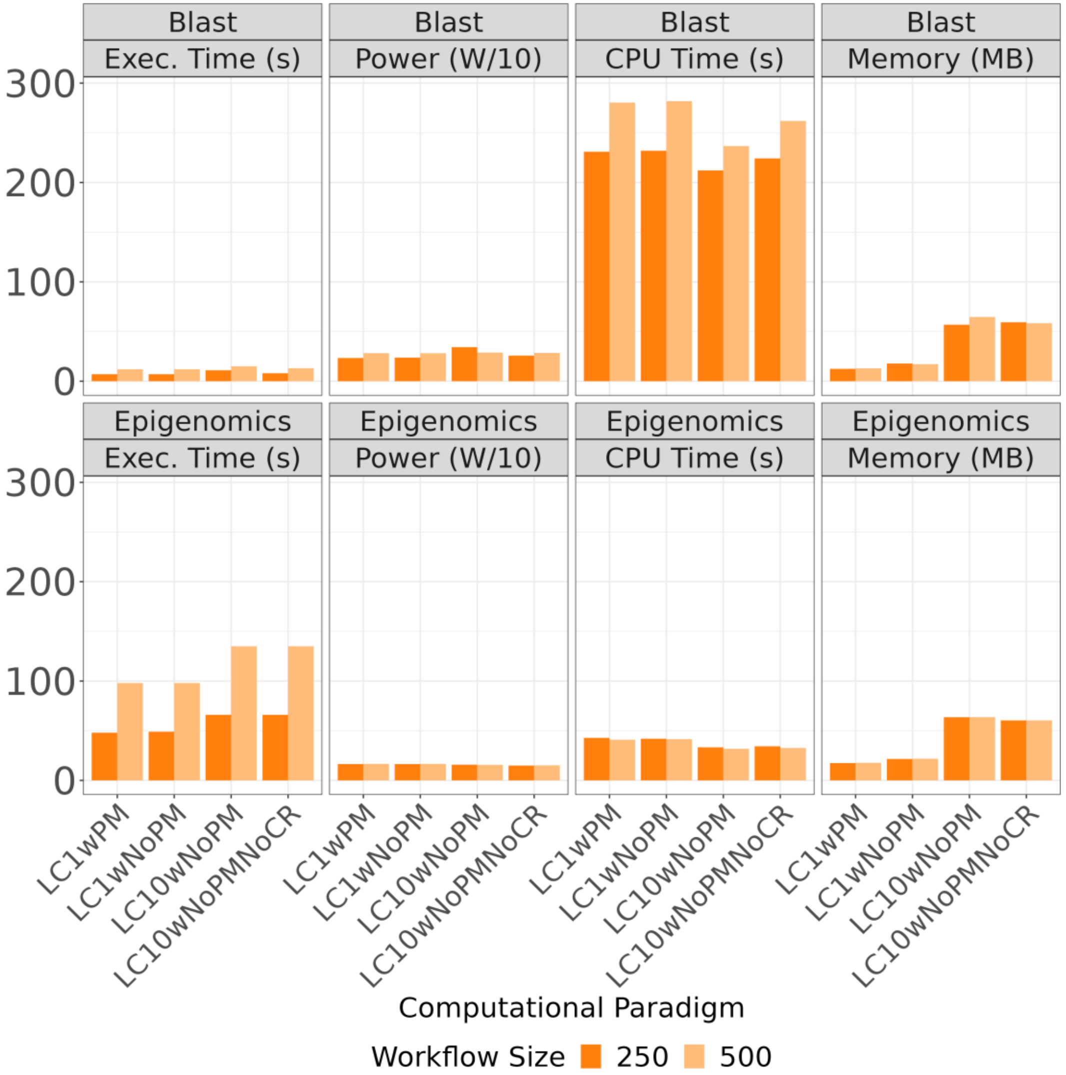

Fig. 5: Comparison between different setups for the Local Containers.

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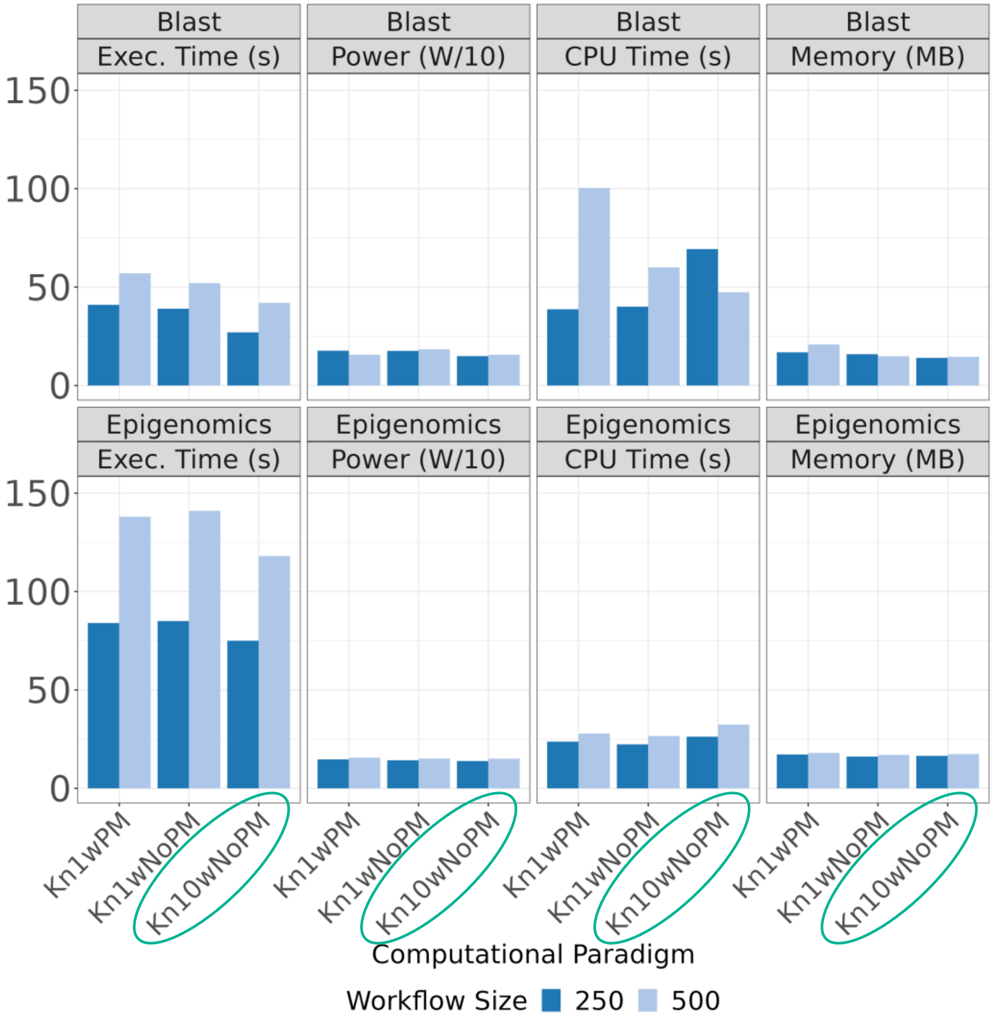

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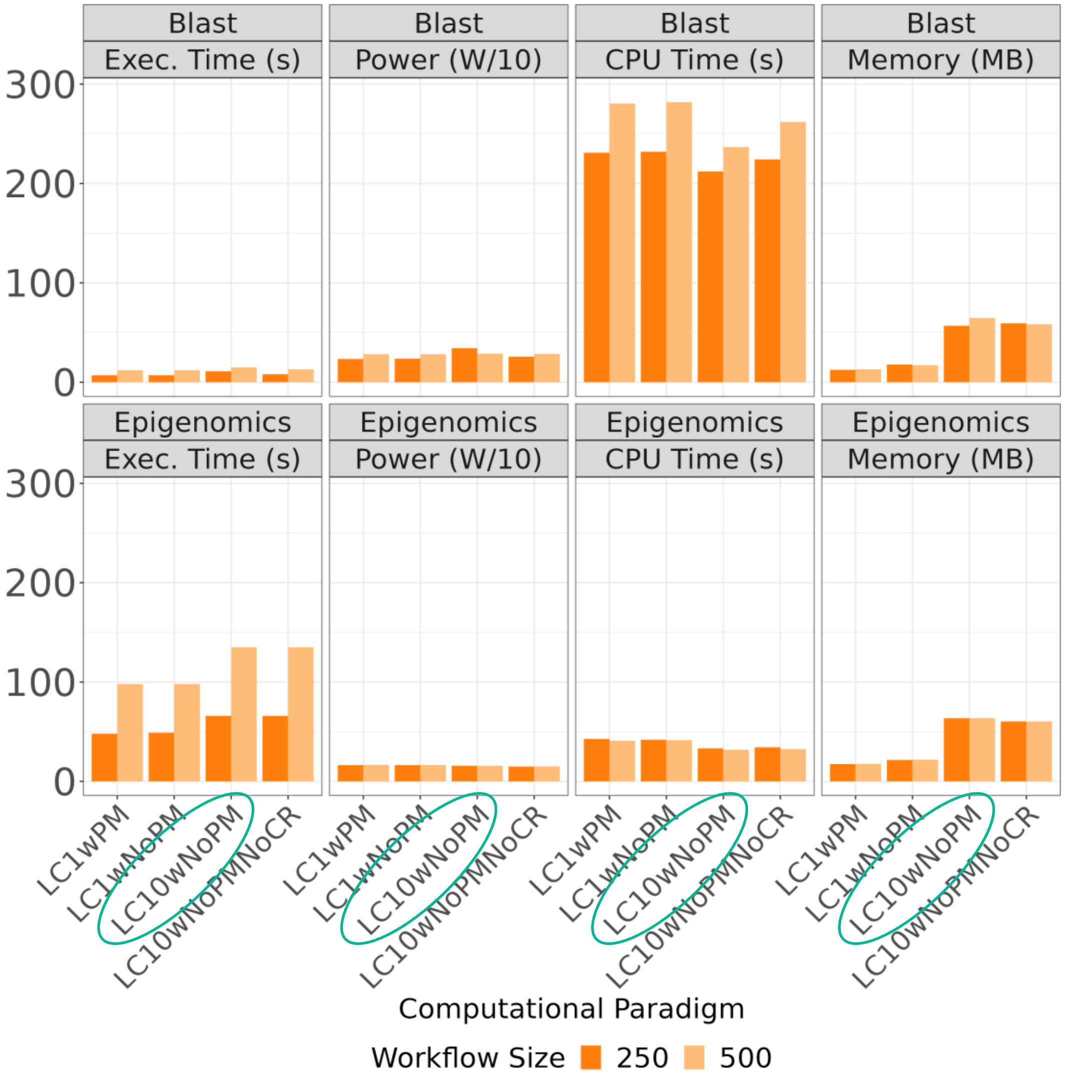

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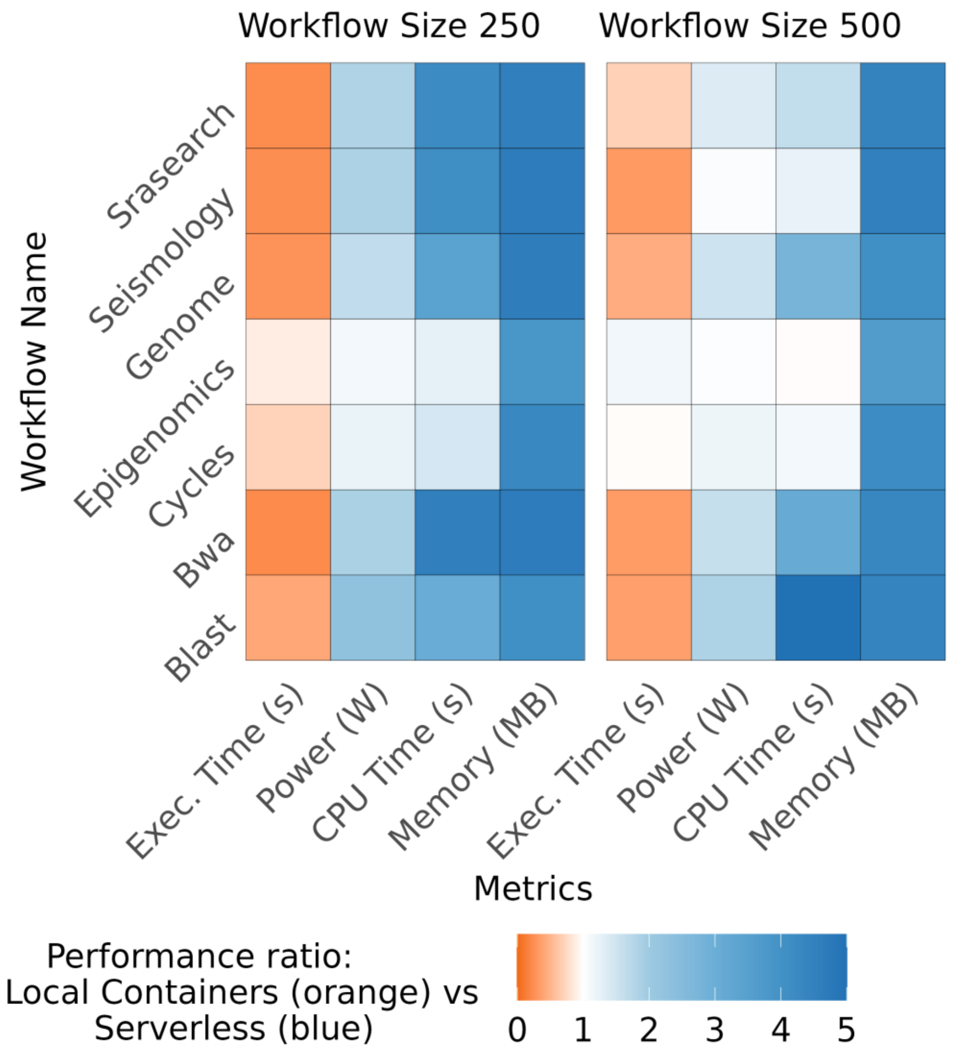
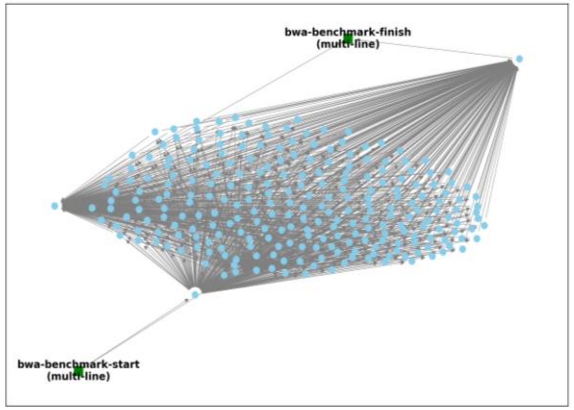


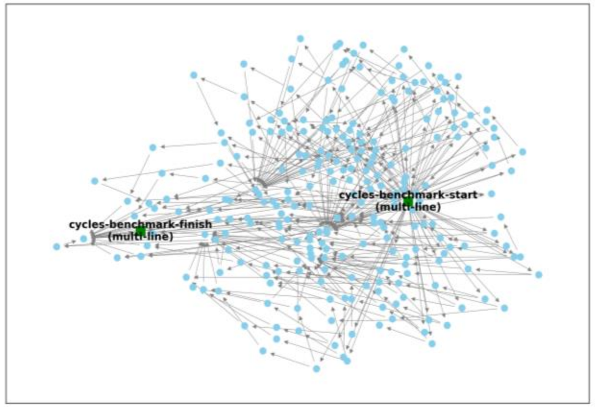
Fig. 7: Comparison between all workloads in best setups for Serverless and Local Container Computational Paradigms.

Experimental Results: Towards Workflow Characterization

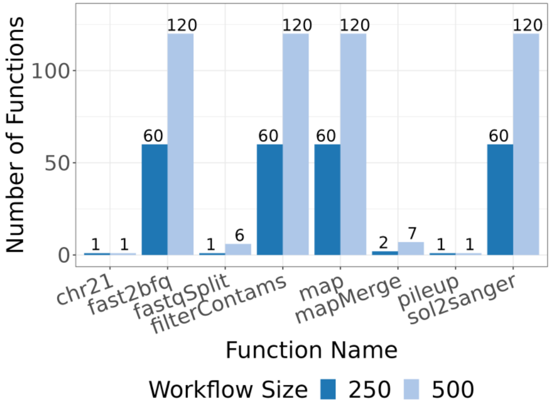
Group A (Dense DAGs)

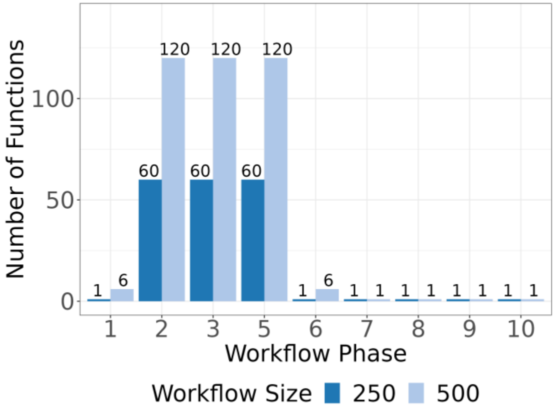


Group B (Sparse DAGs)



Dag Decompositions





Workflows	Common Performance
Blast, BWA, Genome, Seismology, SraSearch (Dense)	• Gain up to 5x in CPU and Memory Usage • Gain in Power Usage by 1 - 2x • Lose to bare-metal local containers for execution time by -1x
Cycles, Epigenomics (Sparse)	• Gain up to 5x in Memory Usage • Match or slightly gain in Power and CPU. • Match or slightly lose to bare-metal local containers for execution time.

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Conclusions (1) – The Framework

- We propose a framework for **executing** and **evaluating HPC scientific workflows** on **serverless** platforms:
  - a **serverless workflow manager** and
  - an **extension of the WfCommons framework** to translate traditional workflows into **serverless-compatible versions**.
- We empower researchers with new tools to study the performance of various HPC scientific workflows across multiple metrics, and scenarios

Conclusions (2) - Function's Granularity and Auto-scaling

- We evaluate **coarse-grained** scenarios for serverless.
  - The management of CPU and memory is simpler:
    - We can evaluate bigger workflows;
  - The results from serverless are closer to the bare-metal local containers;
  - However, the resource usage is not optimal for serverless as it is when using fine-grained resources.

- **Fine-grained** resources management and **auto-scaling** result in **better resource utilization**, however, we highlight that **it is more challenging**:
  - New processes can become either empty or underutilized due to mismatches between the action of creating new processes and finishing older processes;
    - More resources are used, and limits of memory and CPU may be reached.
  - Investigating different combination of parameters, we can do a better use of it.
    - We achieved good trade-offs of resource usage and execution time.

Conclusions (3) - Serverless for HPC/AI Scientific Workflows

- HPC scientific workflows can **significantly benefit from serverless** in terms of resource efficiency (CPU, memory, and power) while maintaining performance levels close to traditional execution times.
    - Still, not all evaluated workflows showed these benefits uniformly.

- We should recall that workflows can be composed of different steps and types of functions, not all of them are necessarily ideal for serverless execution.

- Therefore, it is likely that in some cases, a mapping of different execution paradigms per workflows might be a better choice.
    - The optimal strategy for complex workflows might be **combining executions** on **serverless and bare-metal local containers** for different tasks or groups of tasks.

Future Work

- We intend to leverage this study and **include more aspects of serverless**, by:
  - investigating the impacts of using **external distributed data storage;**
  - studying the impacts of serverless on **multi-workflows** invocation and **multi-cluster** scenarios.

- In addition to Knative, we will **explore other serverless platforms**, such as Globus Compute, AWS Lambda, Google Cloud Functions, and Azure.

- Finally, we expect that all these directions can lead us to the **characterization of HPC scientific workflows on serverless.**

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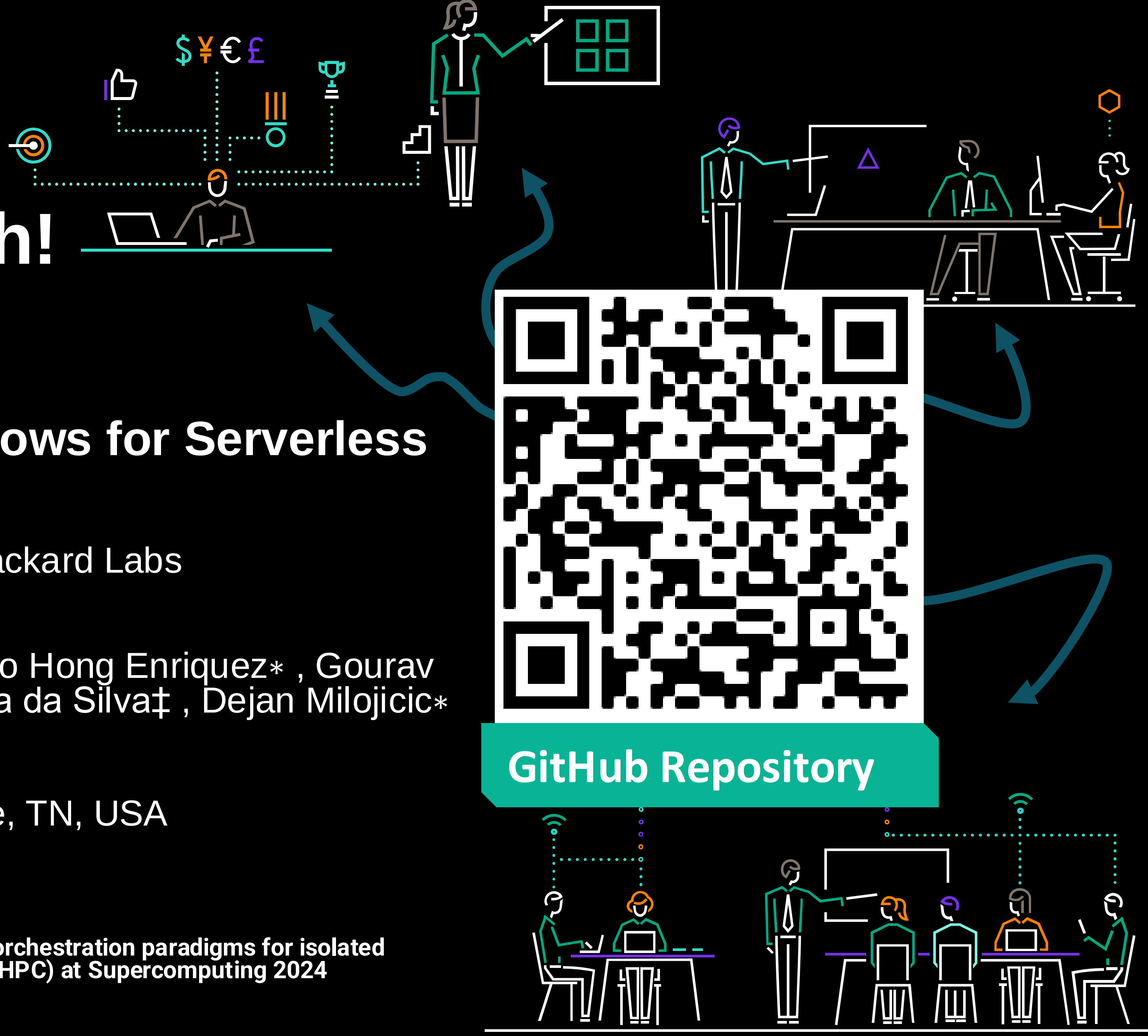
Thank you very much!
Any questions?



GitHub Repository

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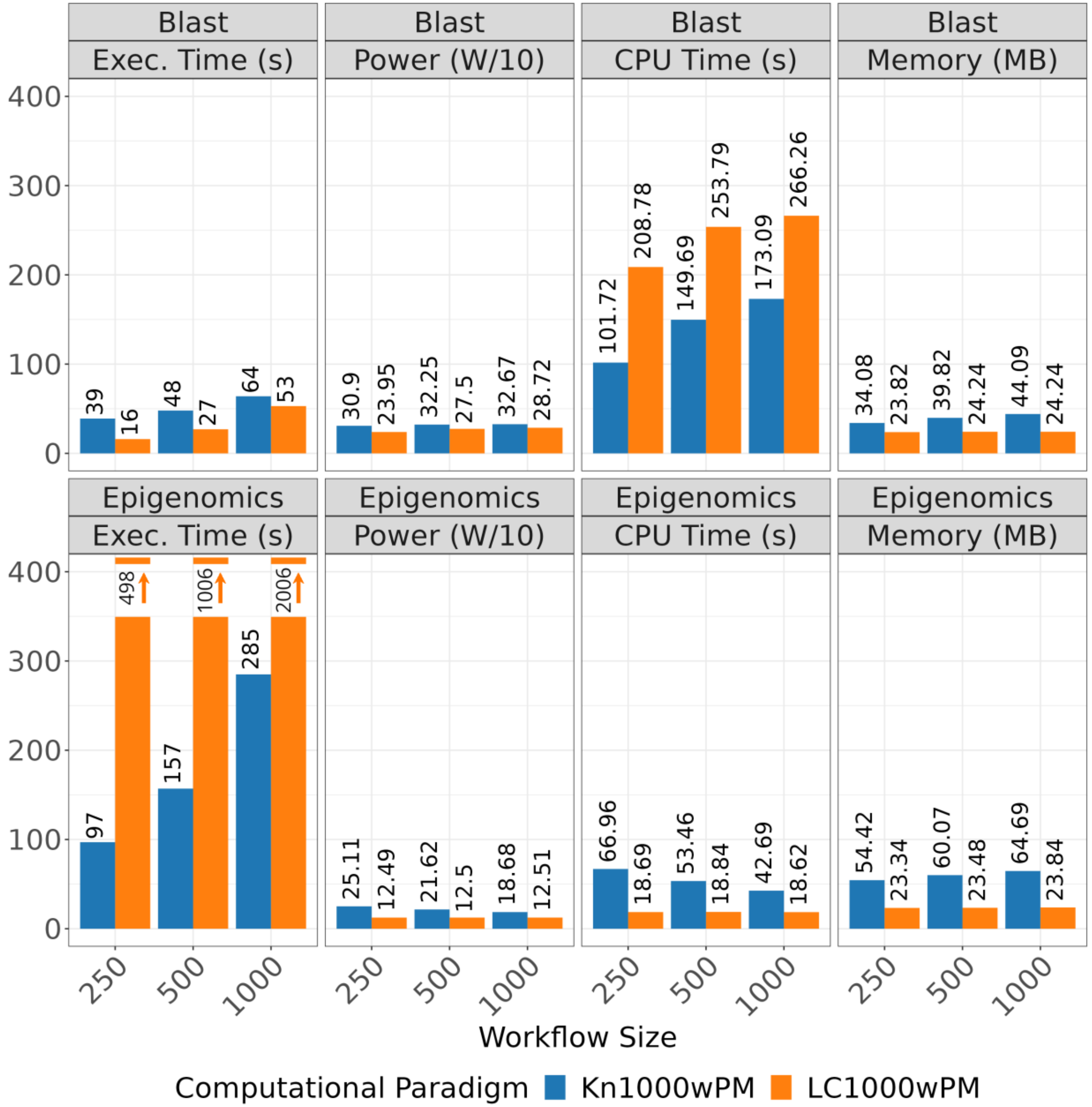
Experimental Results: Coarse-grained executions



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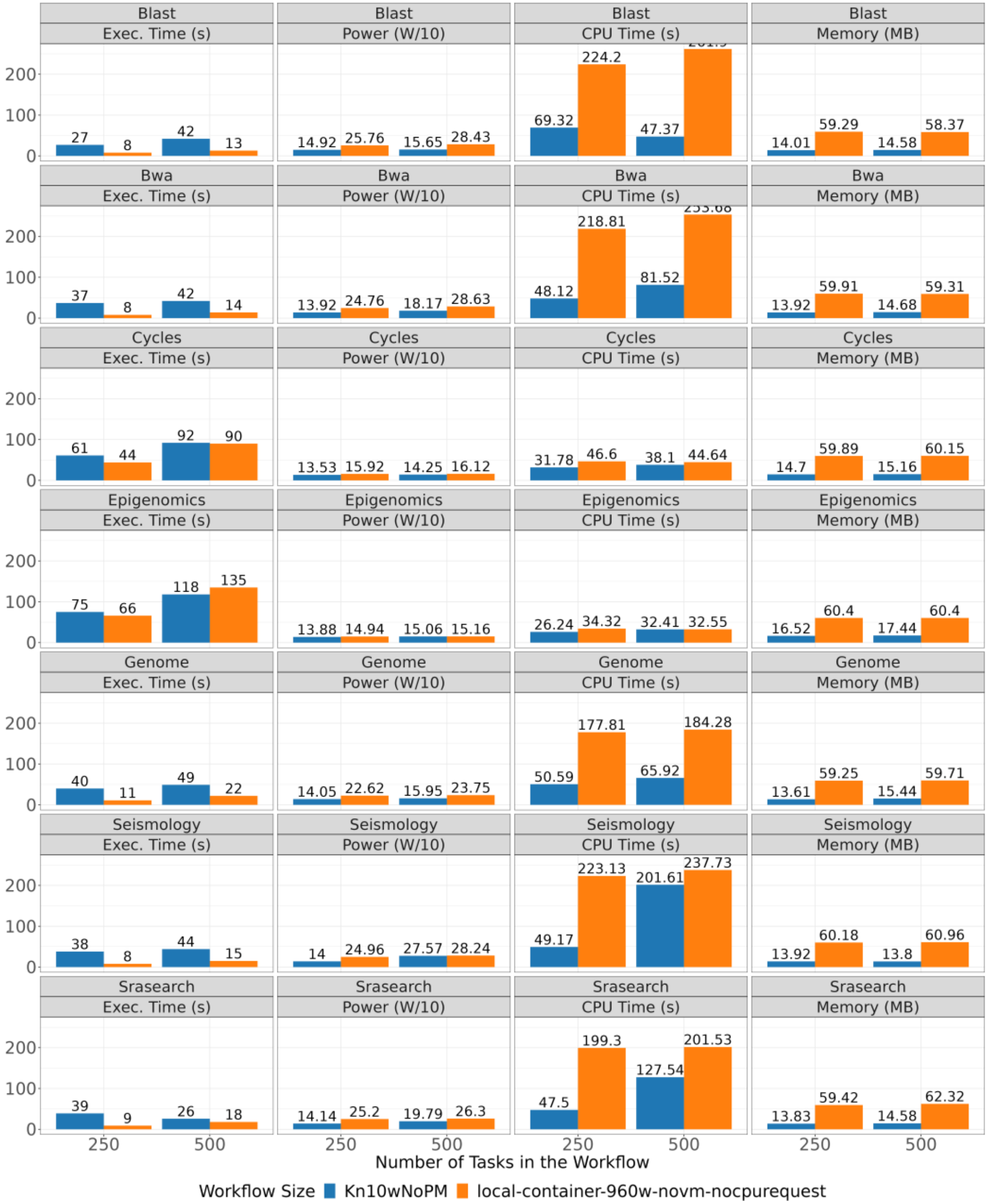
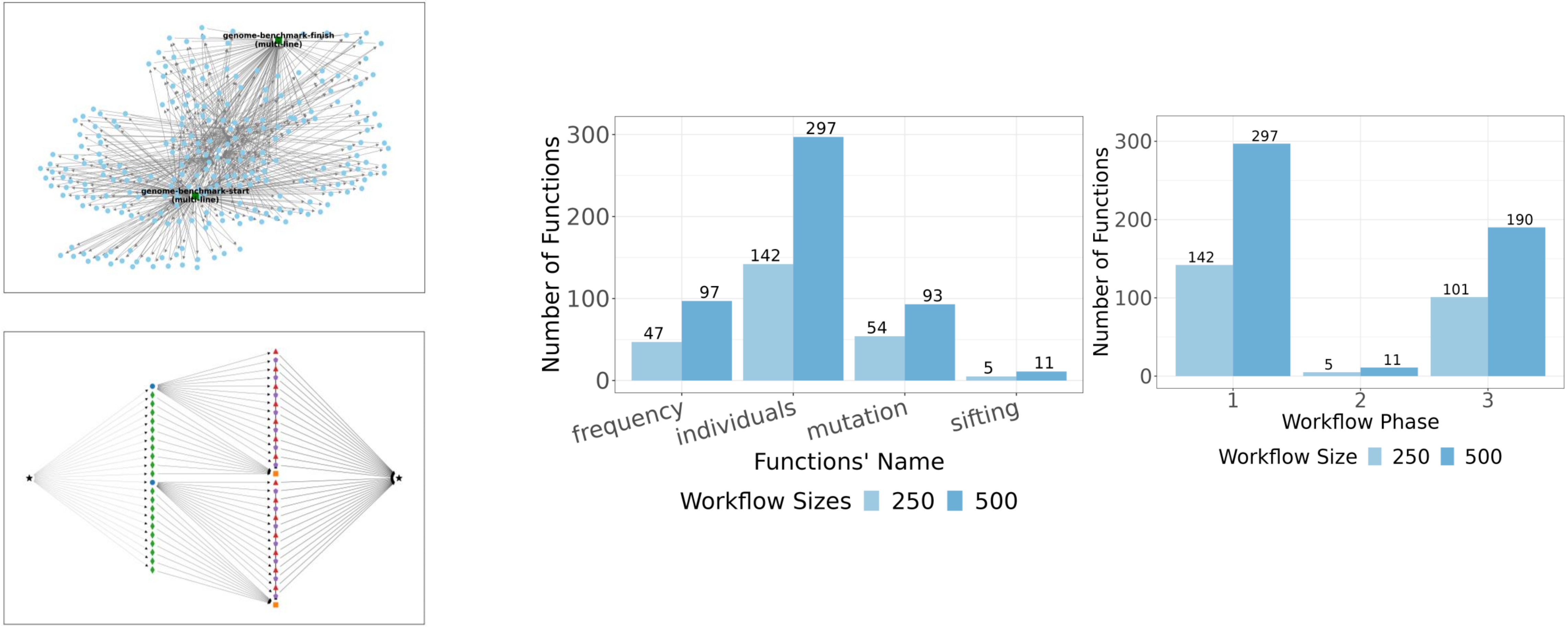


Experimental Results: Towards Workflow Characterization

Fig. 3: Different workflows, its phase density in number of in functions, and its composition in function’s name and quantity.



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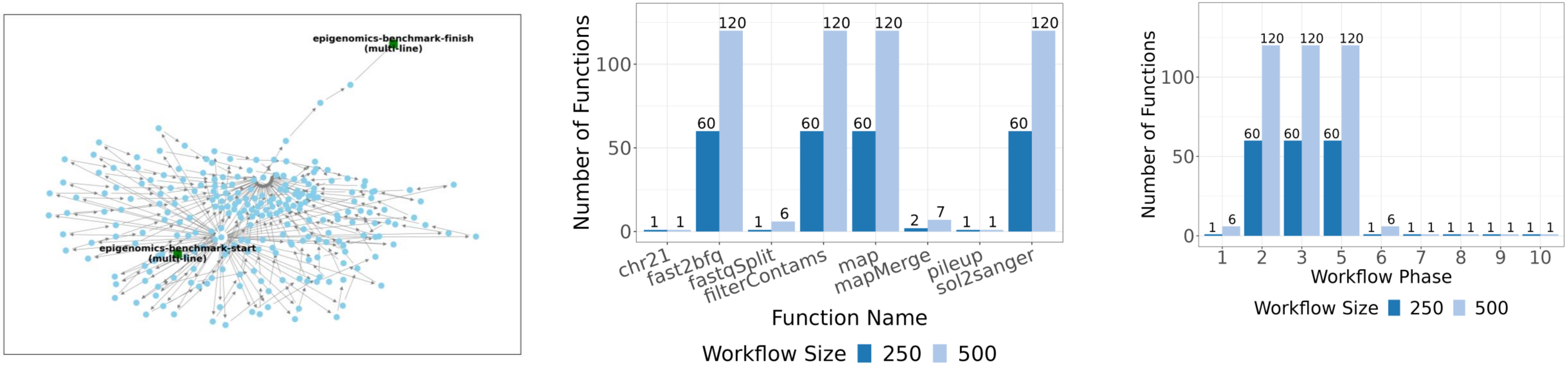

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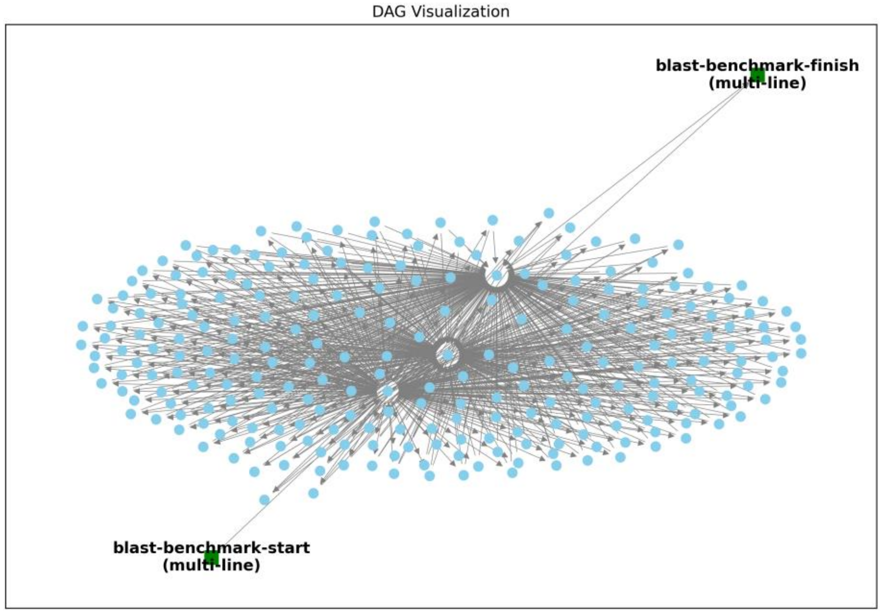
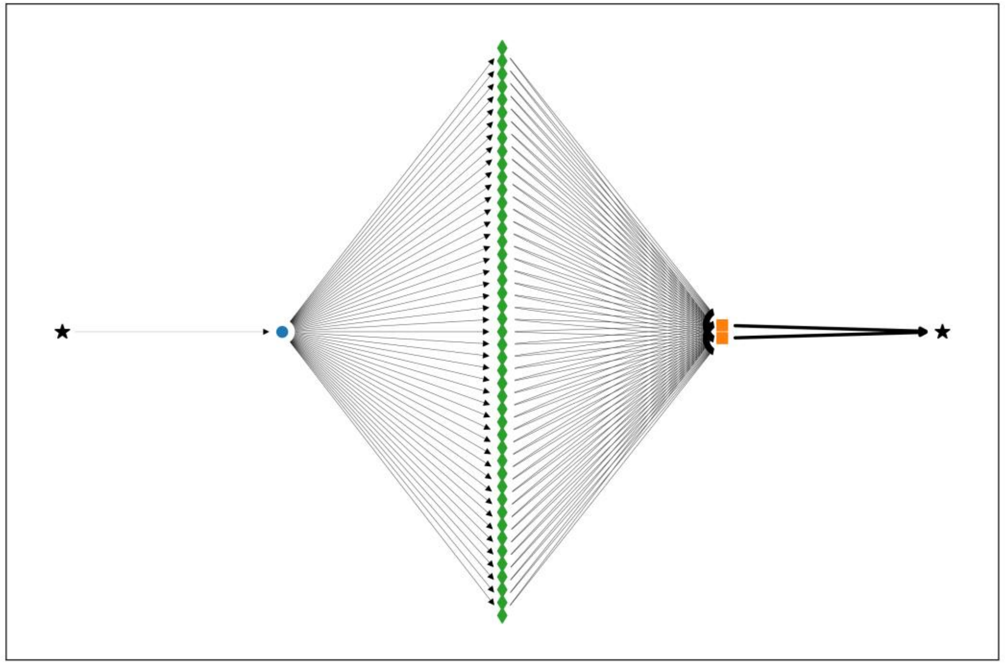
Workflow characterization for serverless (4)





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