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FluidFaaS: A Dynamic Pipelined Solution for Serverless Computing with Strong Isolation-based GPU Sharing

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NC STATE UC SANTA CRUZ

What is Serverless Computing?

- Serverless computing popular cloud paradigm
  - Users deploy apps, providers provision resources
- Many benefits
  - Simple and modular programming
  - Automatic resource scaling
  - Pay-as-you-go model
- AWS lambda, Microsoft Azure, IBM Cloud, Google cloud functions

aws Lambda

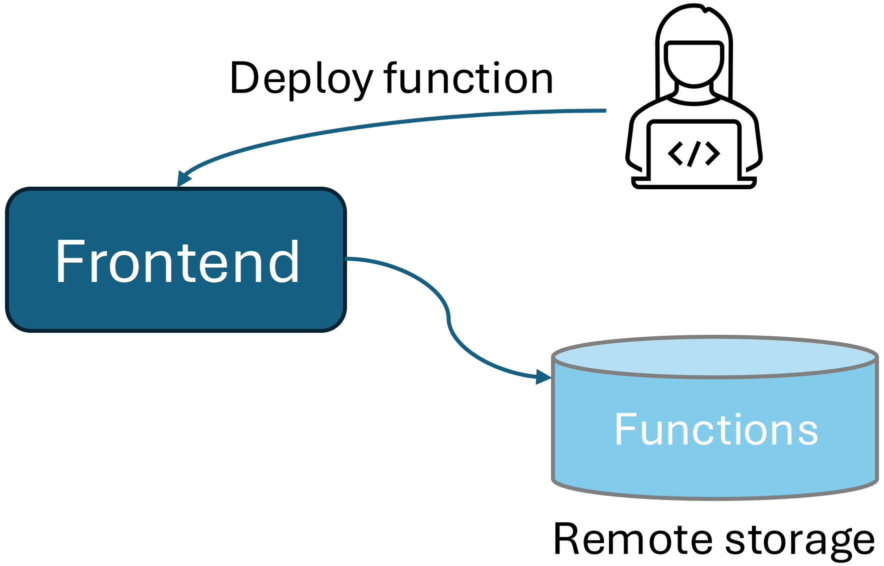
Google Cloud Functions

Azure Functions

APACHE OpenWhisk

…

How Does Serverless Computing Work?



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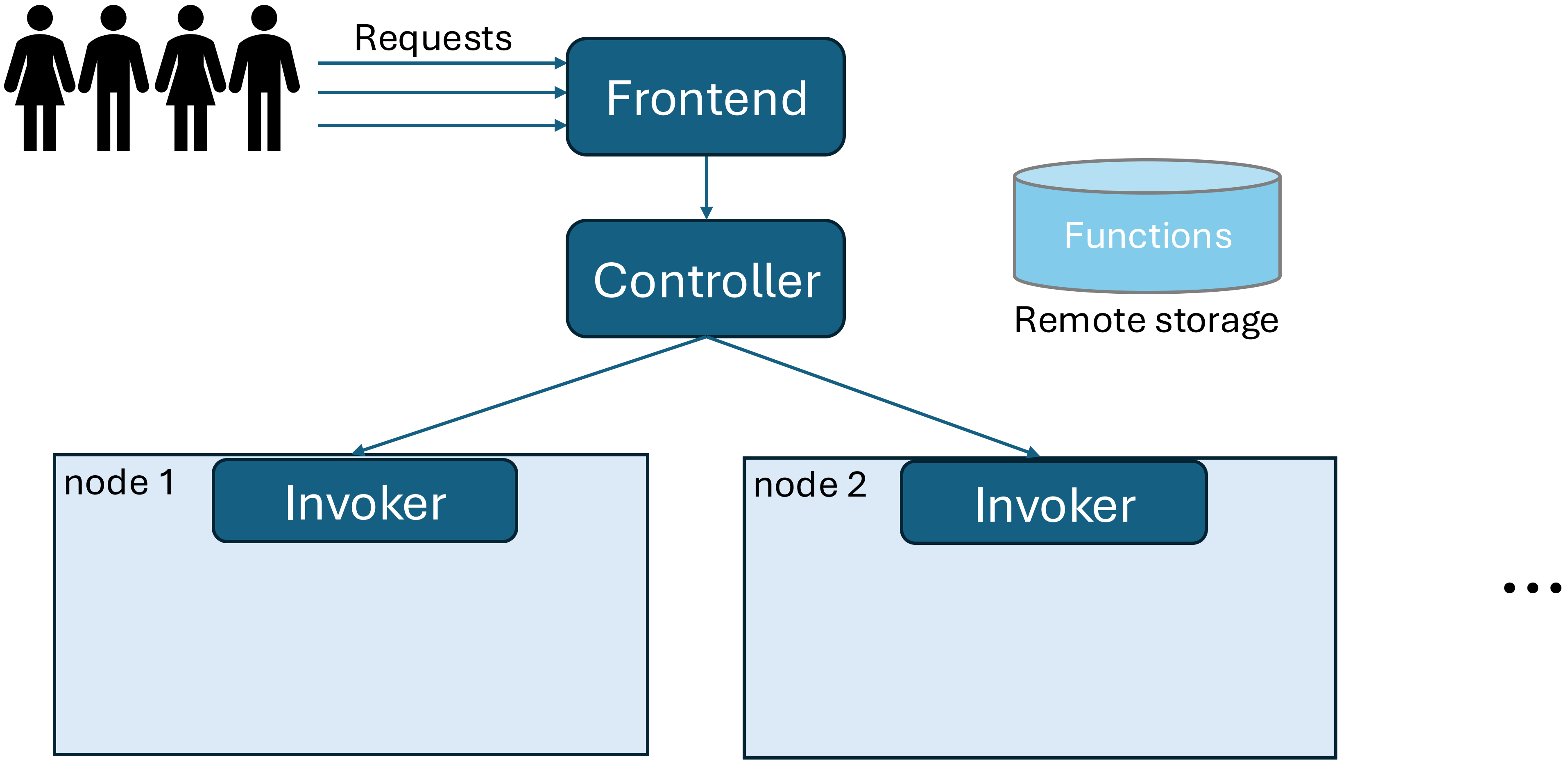

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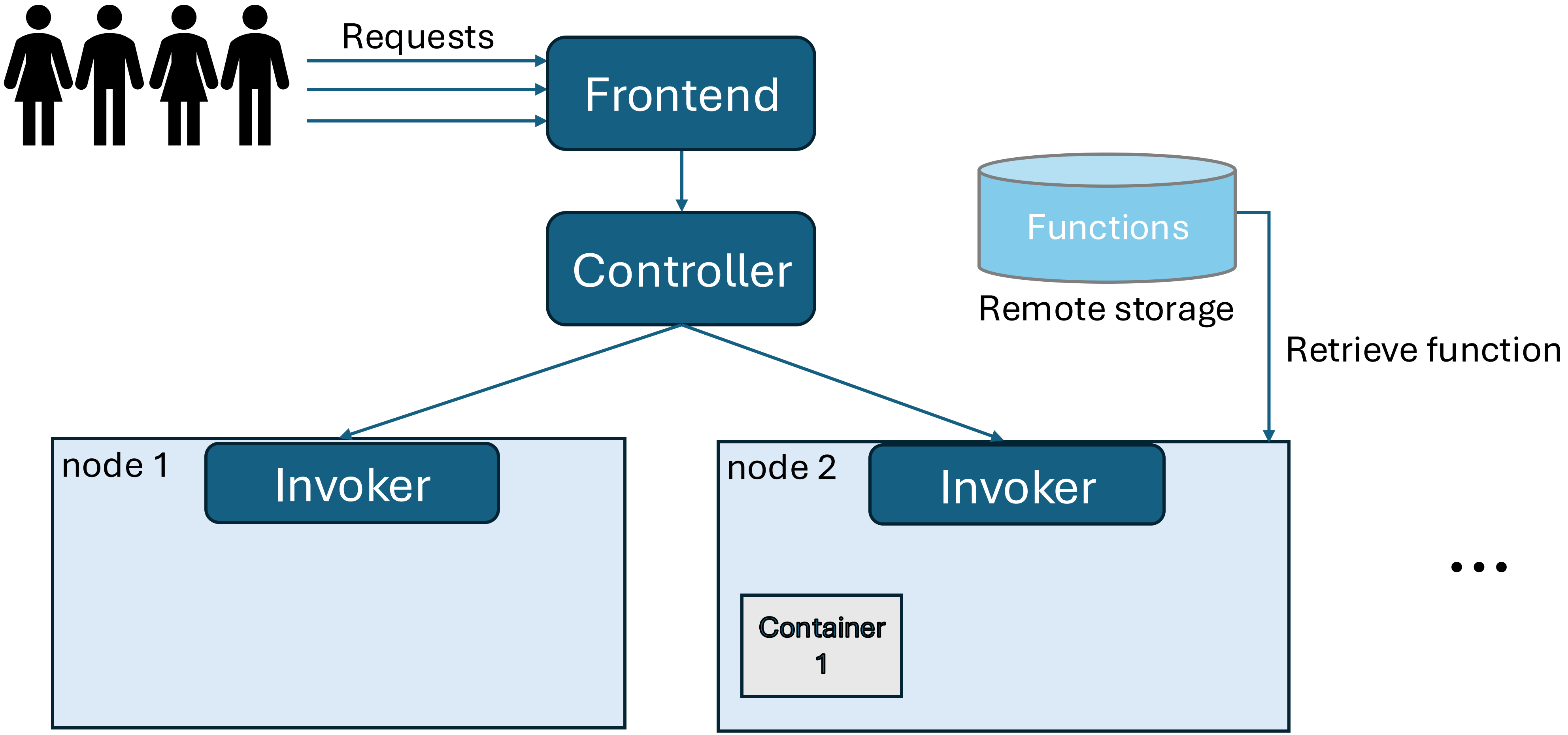

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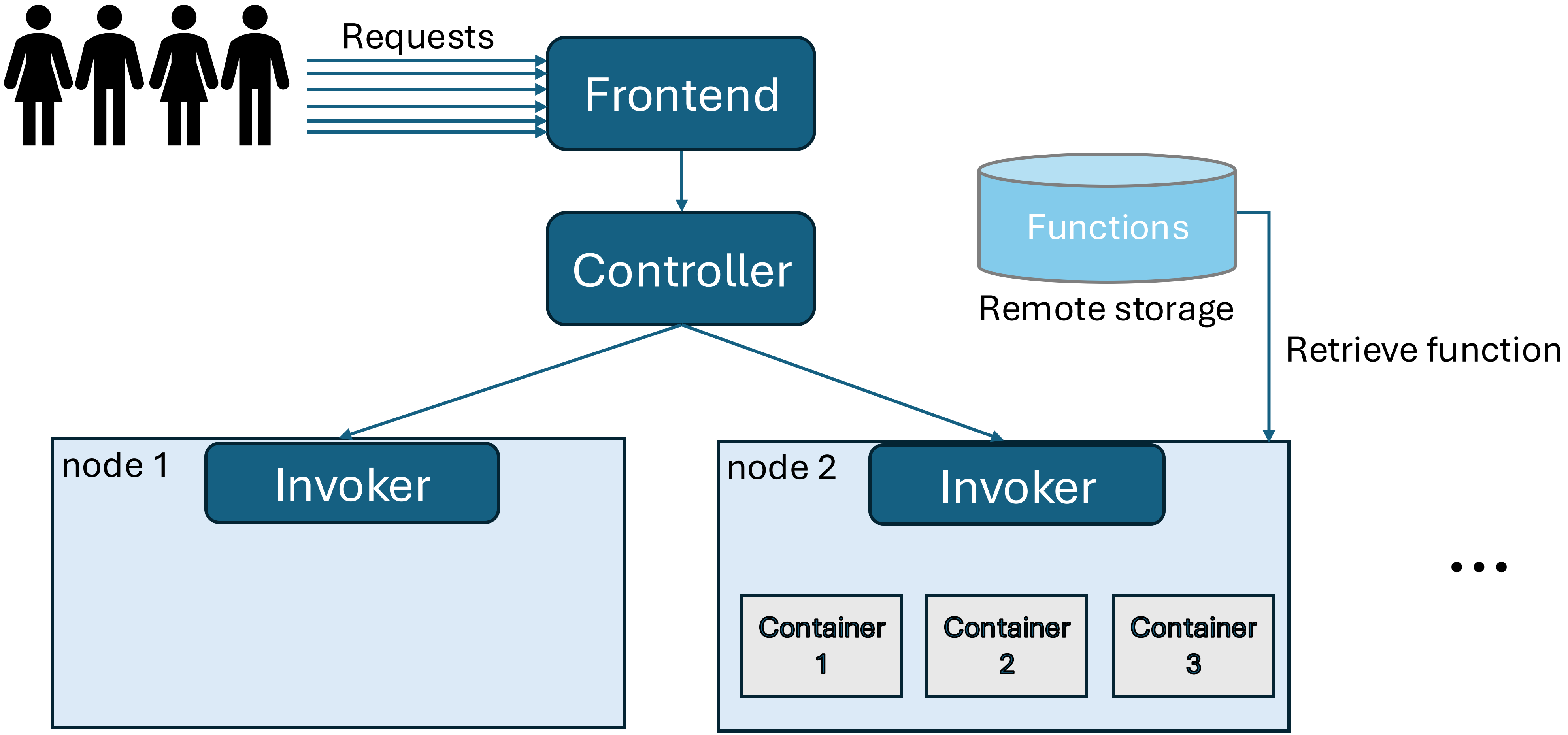
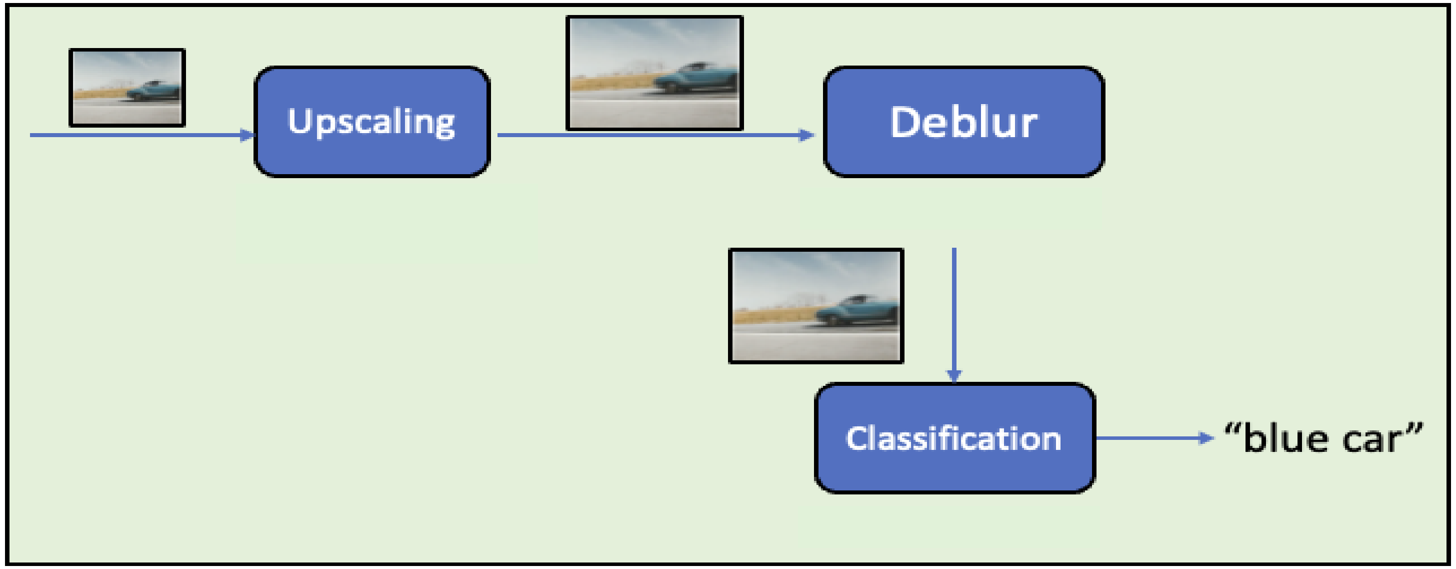
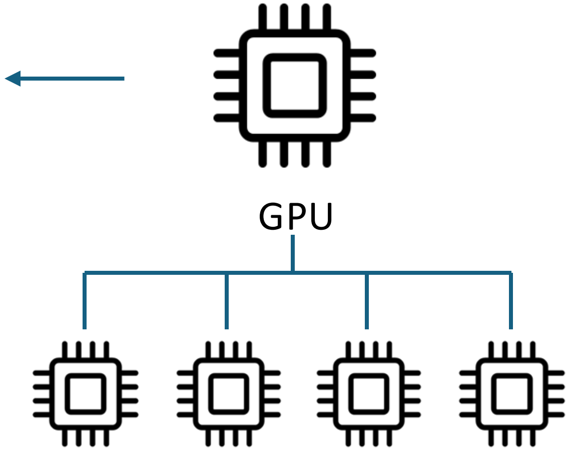


ML on Serverless Computing

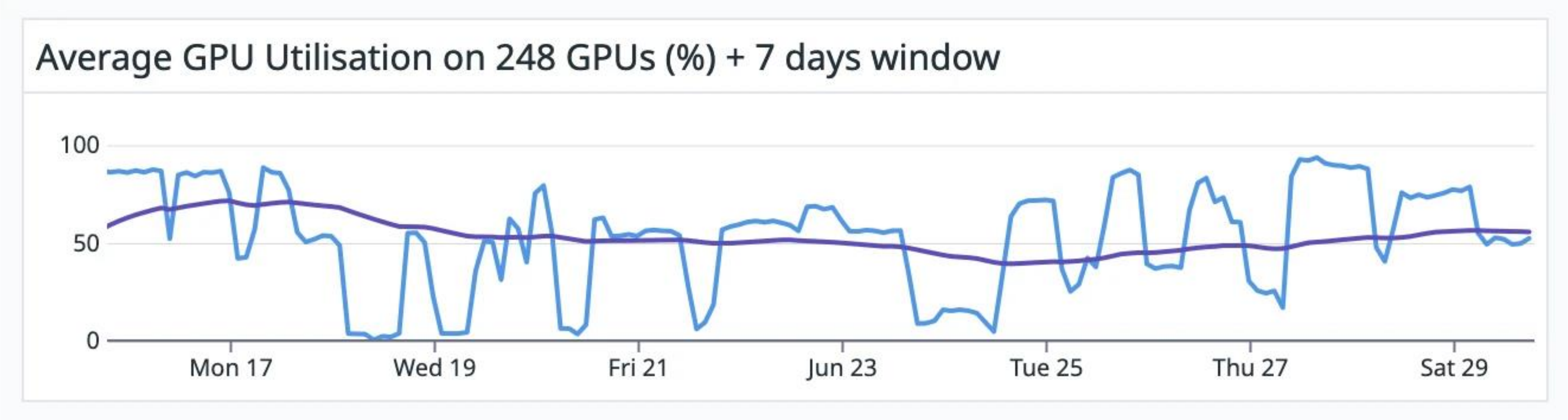


Deep learning inference application



GPU sharing

GPU in Serverless Computing

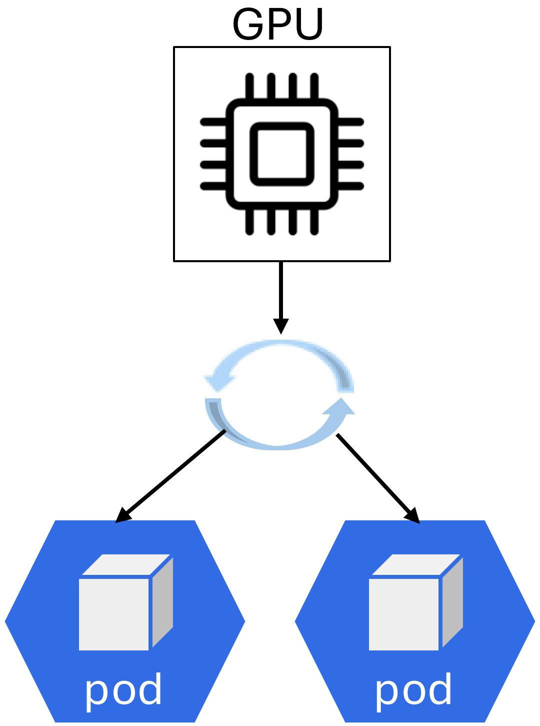


Low GPU utilization

[1] source: https://www.photoroom.com/inside-photoroom/so-you-want-to-rent-an-nvidia-h100-cluster-2024-consumer-guide

GPU Sharing

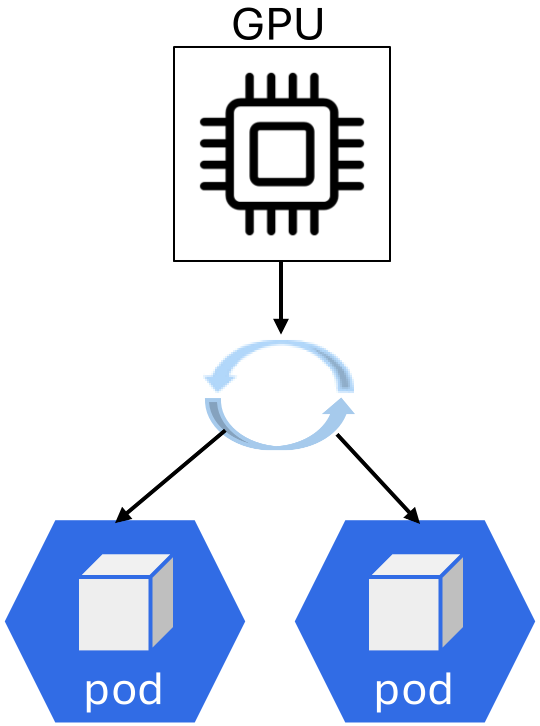
Time Sharing



Not solve underutilization

GPU Sharing

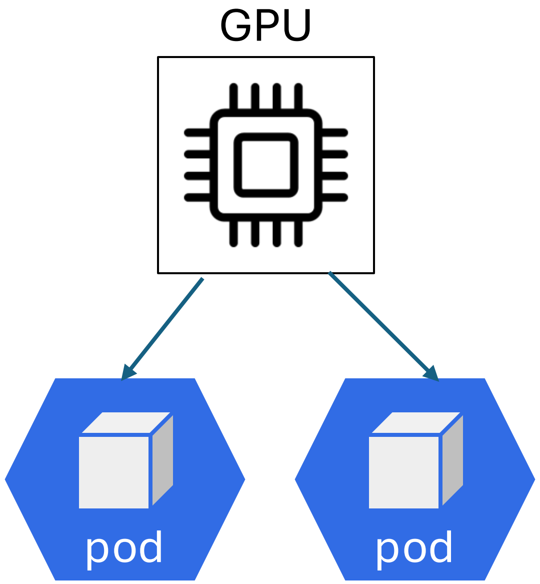
Time Sharing



Not solve underutilization

Spatial Sharing

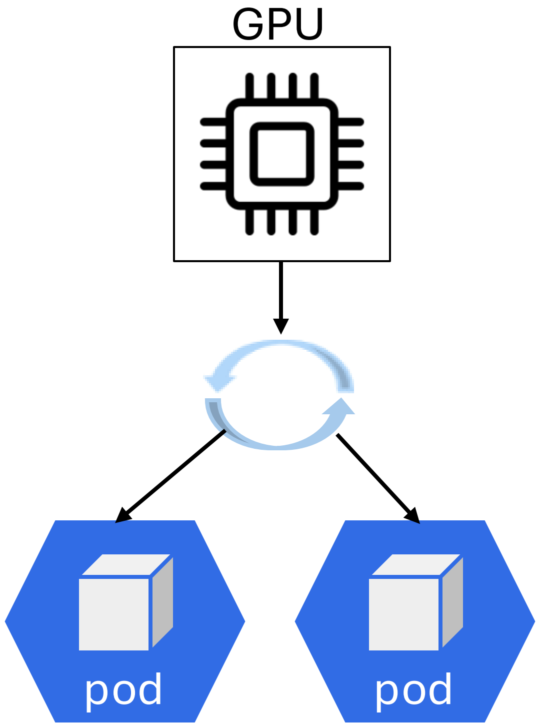
Multi-Process Service (MPS)



Performance interference & Security concern

GPU Sharing

Time Sharing



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Spatial Sharing

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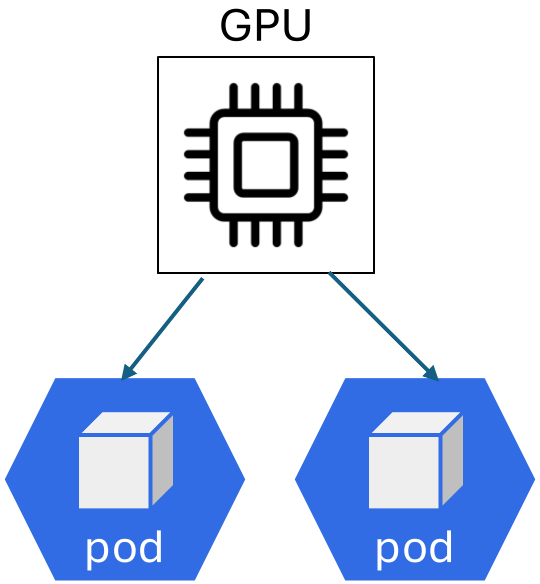
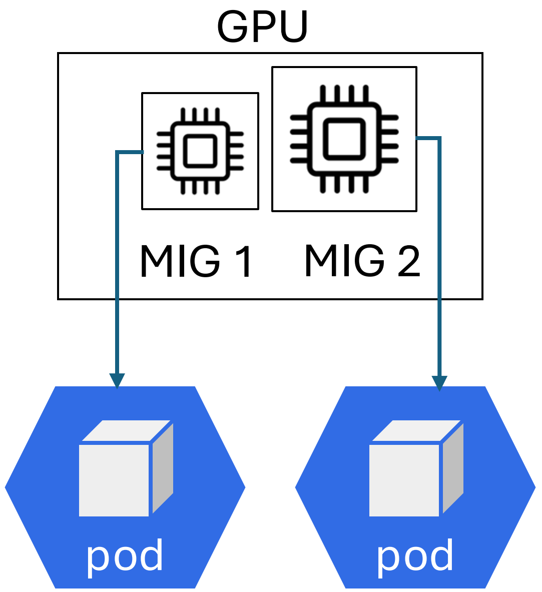


Performance interference & Security concern

Multi-Instance GPU (MIG)



Hardware isolated & performance and security guarantee

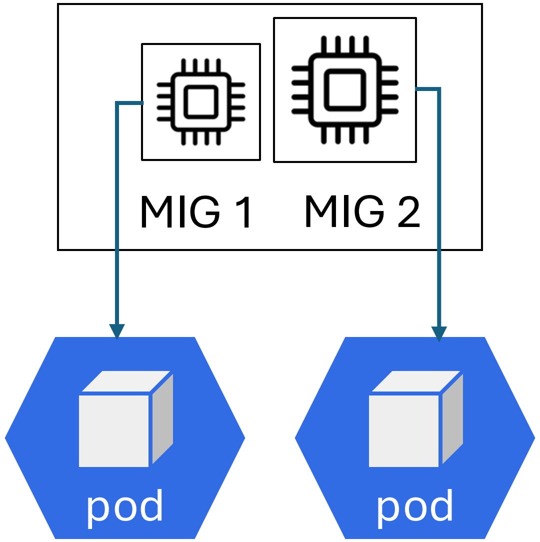
GPU Sharing

- MIG is preconfigured and reconfigure takes time
- MIG partitions example

Profile Name	Fraction of Memory	Fraction of SMs	Number of instance
MIG 1g.10gb	1/8	1/7	7
MIG 2g.20gb	2/8	2/7	3
MIG 3g.40gb	4/8	3/7	2
MIG 4g.40gb	4/8	4/7	1
MIG 7g.80gb	Full	7/7	1

Good for Serverless

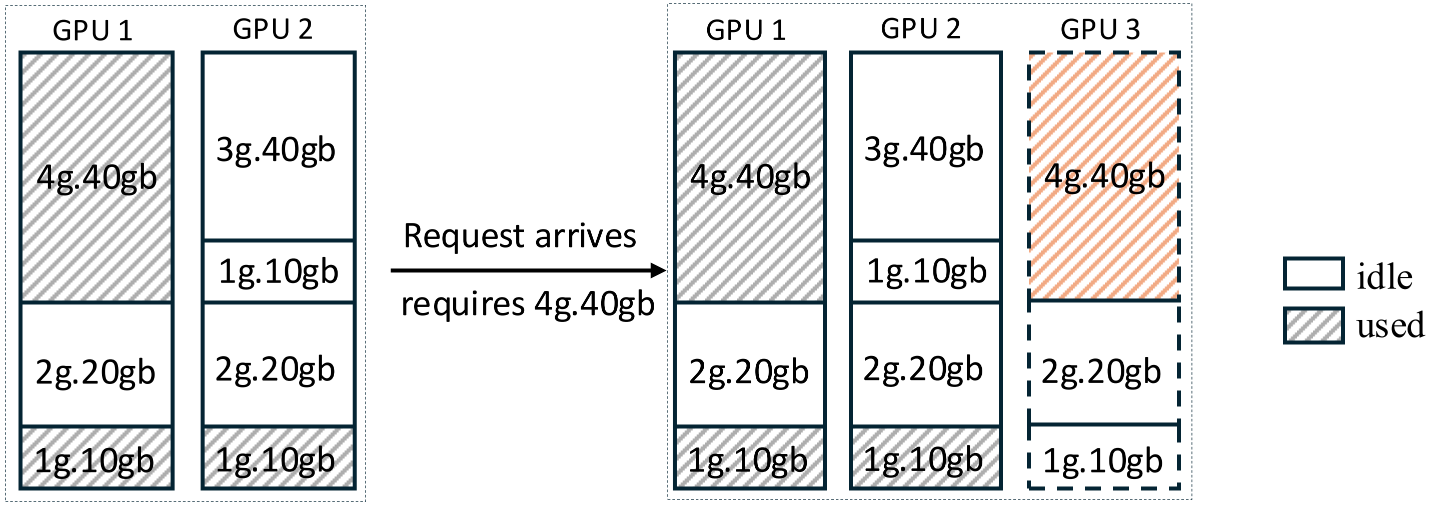
Multi-Instance GPU (MIG)



Hardware isolated & performance and security guarantee

Gaps for using MIG in Serverless ML

- **Gap #1: MIG underutilization caused by resource fragmentation**
  - Rigid MIG partition cause the MIG underutilized
  - Dynamic reconfiguration during runtime is impractical

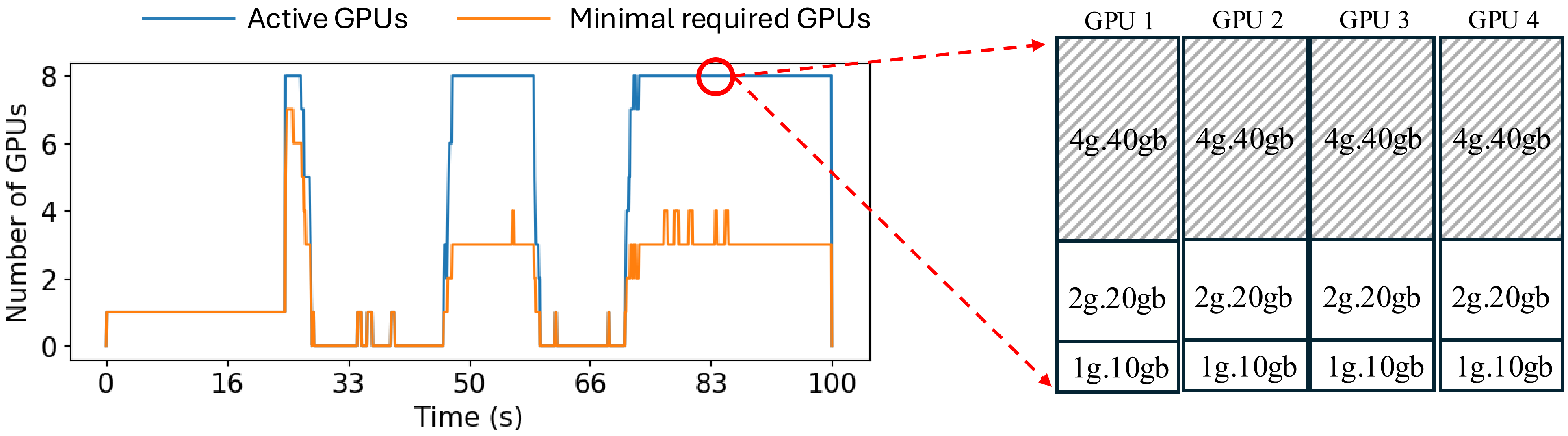


(a) System status

(b) Default assignment

Gaps for using MIG in Serverless ML

❖ Gap #1: MIG underutilization caused by resource fragmentation

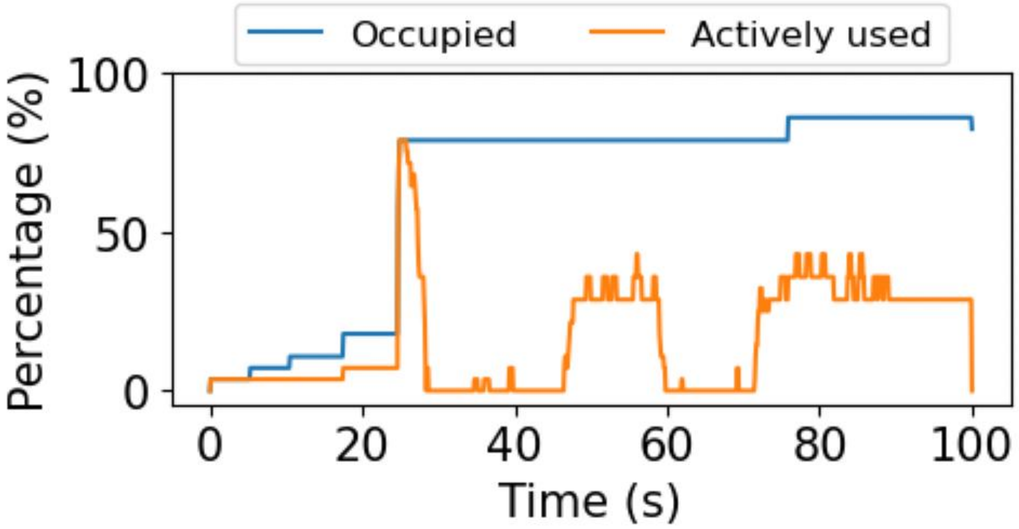


GPU 1	GPU 2	GPU 3	GPU 4
4g.40gb	4g.40gb	4g.40gb	4g.40gb
2g.20gb	2g.20gb	2g.20gb	2g.20gb
1g.10gb	1g.10gb	1g.10gb	1g.10gb

Only 4g.40gb is utilized

Gaps for using MIG in Serverless ML

- **Gap #2: MIG underutilization caused by exclusivity in warm state**
  - **Keeping a model active and precludes its resources from being used.**



Average active percentage is 16.1%, MIGs operate at less than 35% for 90% of time.

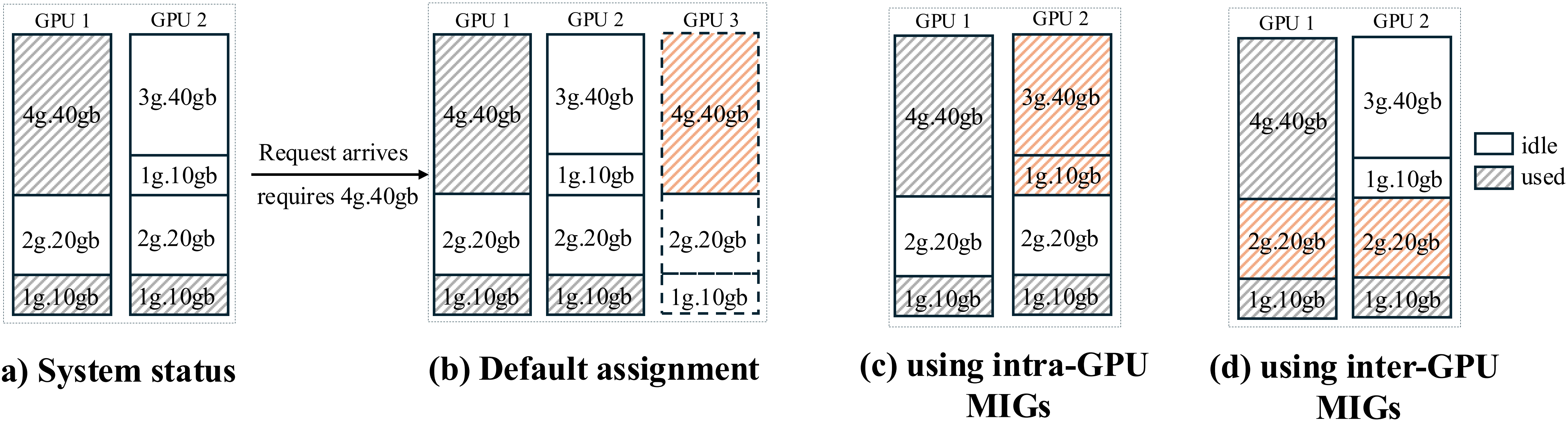
FluidFaaS

- **Underutilization caused by resource fragmentation**
  - **Automatic pipeline construction on-the-fly**

- Underutilization caused by **exclusivity in warm state**.
  - Hotness-aware eviction-based time sharing

FluidFaaS

❖ Design point #1: Automatic pipeline construction on-the-fly



(a) System status

(b) Default assignment

(c) using intra-GPU MIGs

(d) using inter-GPU MIGs

Decompose the workflow into multi MIGs

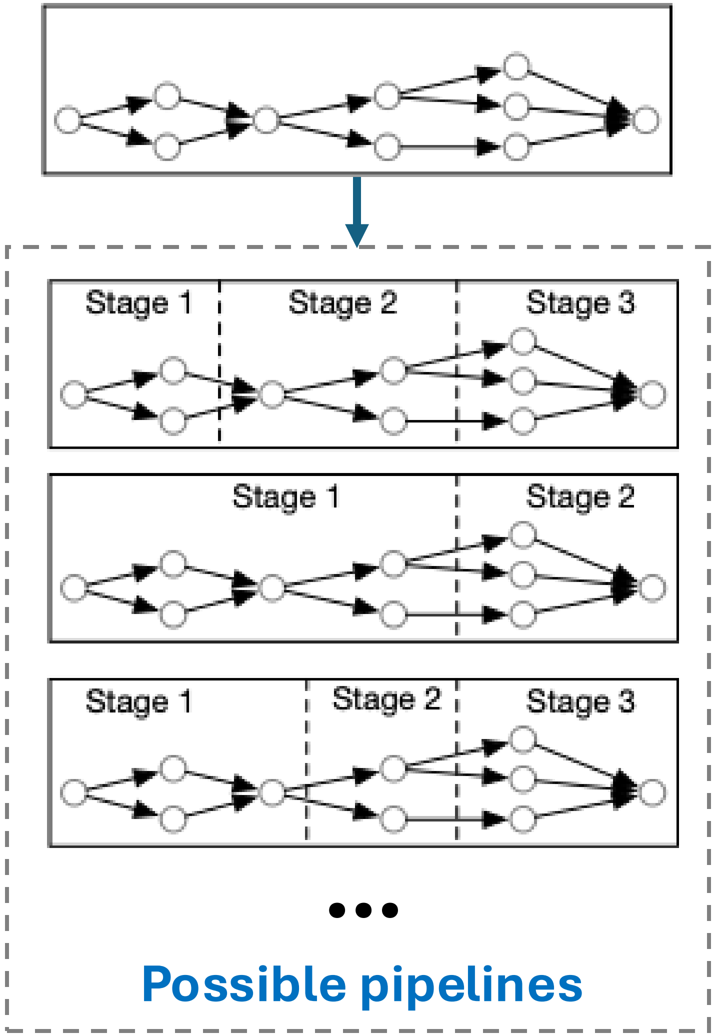
Programming support

One process one MIG (flexibility & throughput)

Runtime support

FluidFaaS – Automatic Pipeline Construction on-the-fly

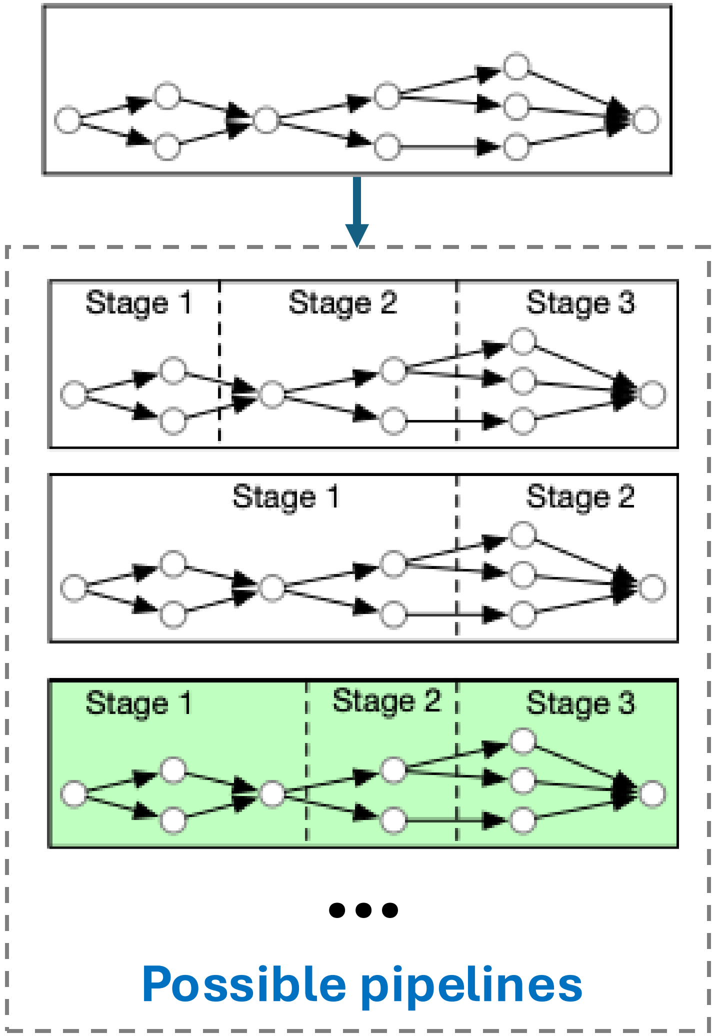
❖ **Programming Support:** transparent to users and adaptable at runtime.



Program support defines the minimal block.

FluidFaaS – Automatic Pipeline Construction on-the-fly

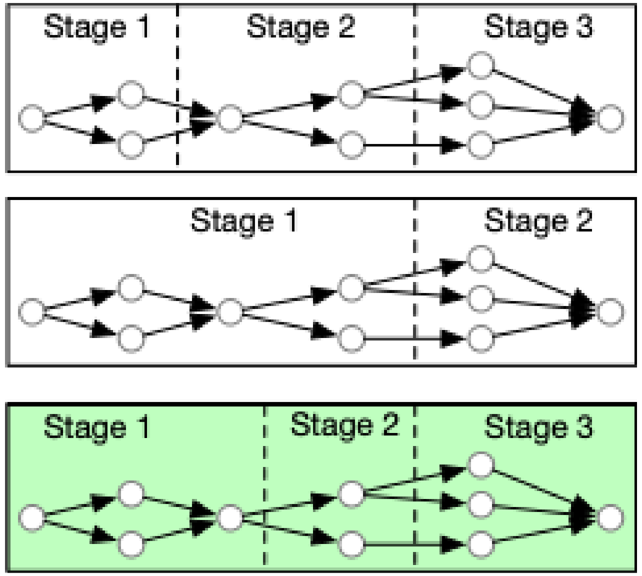
❖ **Runtime Support:** balanced pipeline and adaptive to resource availability

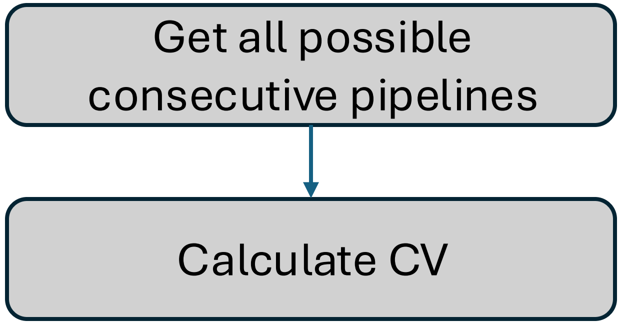


Runtime support construct the pipeline and provide the interface to run the pipeline.

FluidFaaS – Automatic Pipeline Construction on-the-fly

❖ **Runtime Support: balanced pipeline and adaptive to resource availability**



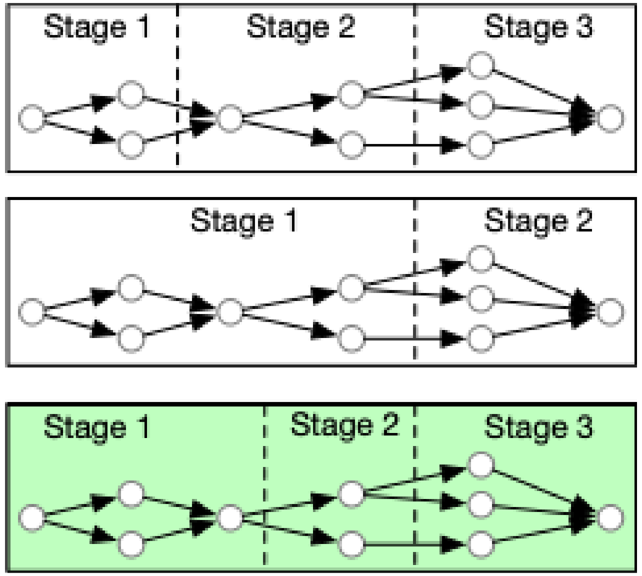


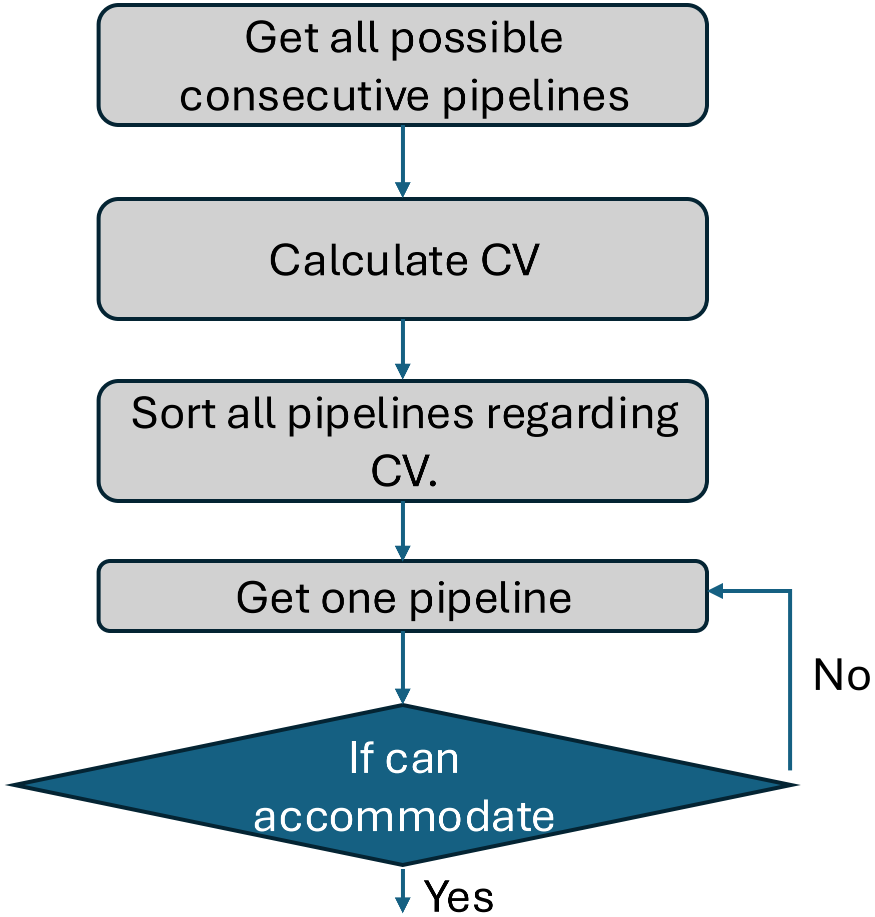
Get all possible consecutive pipelines

Calculate CV

FluidFaaS – Automatic Pipeline Construction on-the-fly

- **Runtime Support: balanced pipeline and adaptive to resource availability**
  - **Coefficient of variation (CV)**





Get all possible consecutive pipelines

Calculate CV

Sort all pipelines regarding CV.

Get one pipeline

If can accommodate

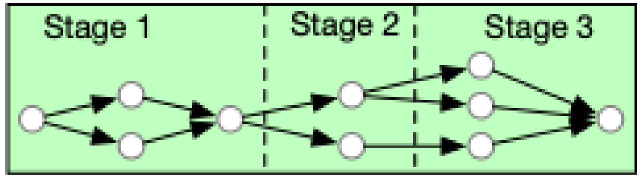
No

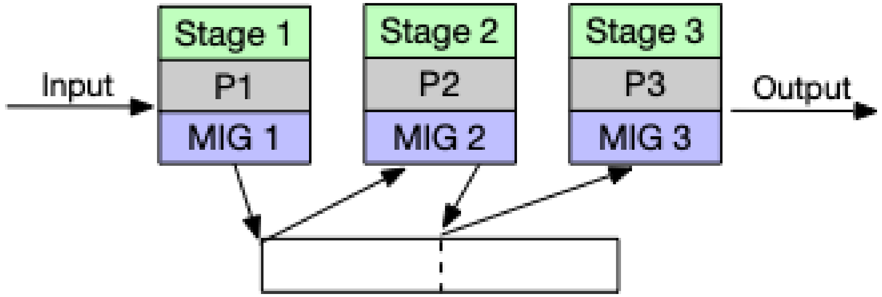
Yes

$CV = std(t_1, t_2, \dots, t_n)/\text{mean}(t_1, t_2, \dots, t_n),$ lower is better.

FluidFaaS – Automatic Pipeline Construction on-the-fly

- **Runtime support:** transparent to users and adaptable at runtime.
  - Create a separate process for each MIG
  - Communicate via shared memory.
  - Reside in Invoker





Shared memory in host

FluidFaaS

- Underutilization caused by **resource fragmentation**
  - Automatic pipeline construction on-the-fly

- **Underutilization caused by exclusivity in warm state.**
  - **Hotness-aware eviction-based time sharing**

FluidFaaS - Hotness-aware Eviction-based Time Sharing

- Design principle: improve MIG utilization
  - interleaved usage of MIG slice through eviction.

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    - Time sharing state: not actively busy instance (i.e., utilization below 30%).

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  - Heterogeneity-aware request routing.
    - urgent to exclusive and non-urgent to the time sharing instance.

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  - Heterogeneity-aware request routing.
    - urgent to exclusive and non-urgent to the time sharing instance.
  - Pipeline migration
    - migrate pipeline instance to non-pipeline when large MIG slices are available.

Evaluation

- **Methodology:**
  - Hardware
    - 8 * A100 (80 GB)
    - 1g.10gb + 2g.20gb + 4g.40gb

Evaluation

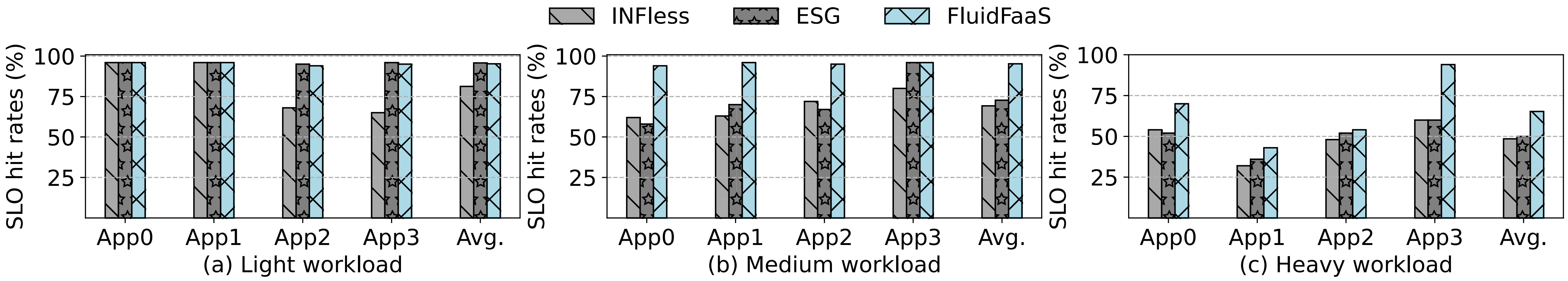
- **Methodology:**
  - **Hardware**
    - **8 * A100 (80 GB)**
    - **1g.10gb + 2g.20gb + 4g.40gb**
  - **Application**
    - **ML inference applications**

Evaluation

- Methodology:
  - Hardware
    - 8 * A100 (80 GB)
    - 1g.10gb + 2g.20gb + 4g.40gb
  - Application
    - ML inference applications
  - Baseline.
    - ESG (HPDC24) – most resource efficient MIG, no pipeline.
    - INFless (ASPLOS22) – MPS based Serverless platform, no pipeline.

Evaluation

- **Evaluated metrics: SLO hit rates.**



(a) Light workload

(b) Medium workload

(c) Heavy workload

91% high in medium workloads.

61% high in heavy workload.

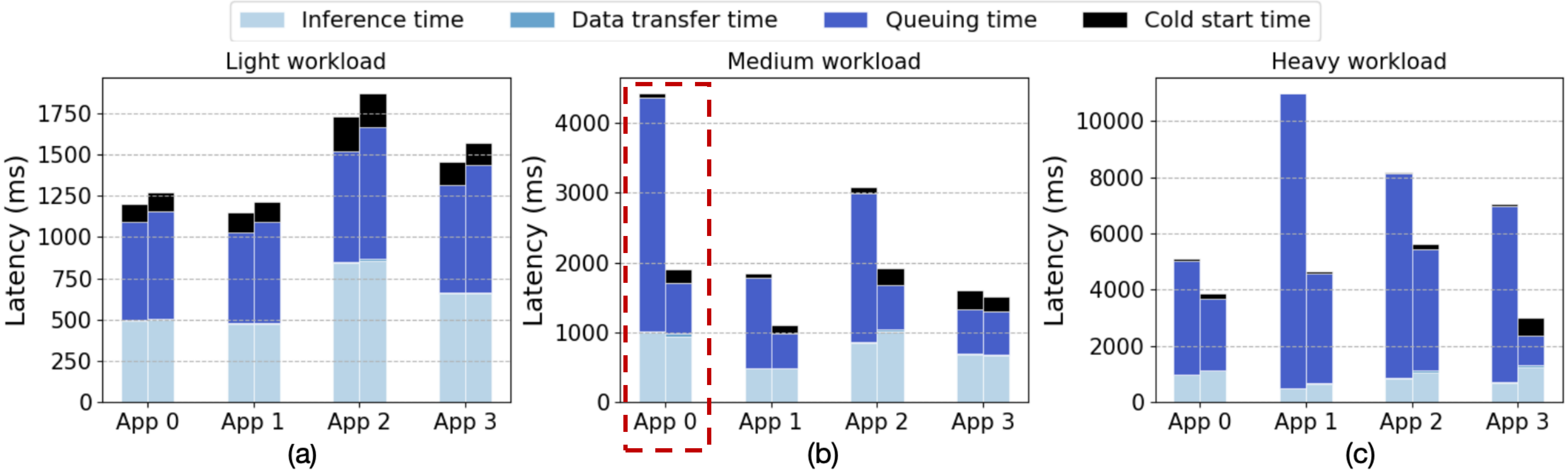
INFless and ESG similar performance due to non-pipeline execution model.

[1] Xinning Hui, etc. ESG: Pipeline-Conscious Efficient Scheduling of DNN Workflows on Serverless Platforms with Shareable GPUs , 2024, HPDC.

[2] Yanan Yang, etc. INFless: a native serverless system for lowlatency, high-throughput inference. 2022, ASPLOS.

Evaluation

- **Evaluated metrics:** End-to-end latency breakdown.



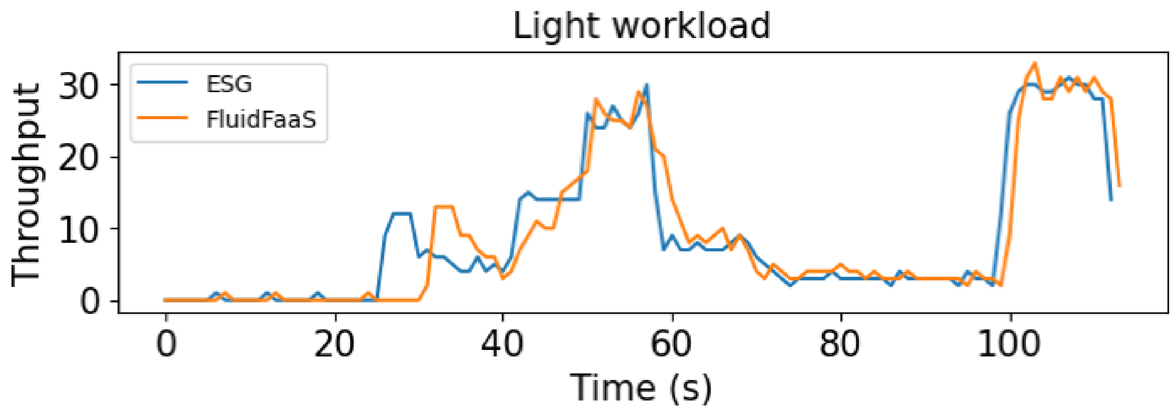
ESG (left) vs. FluidFaaS (right)

2.36x lower latency than ESG.

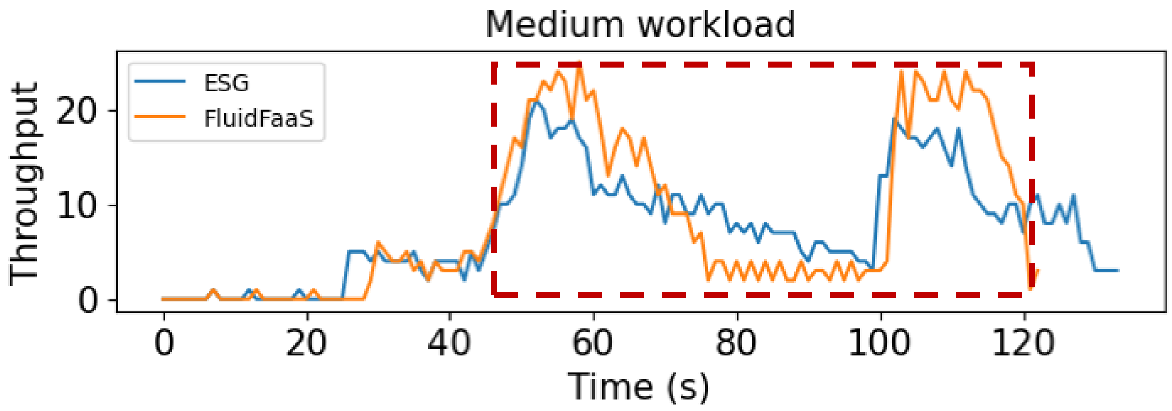
Data transfer time is negligible.

Evaluation

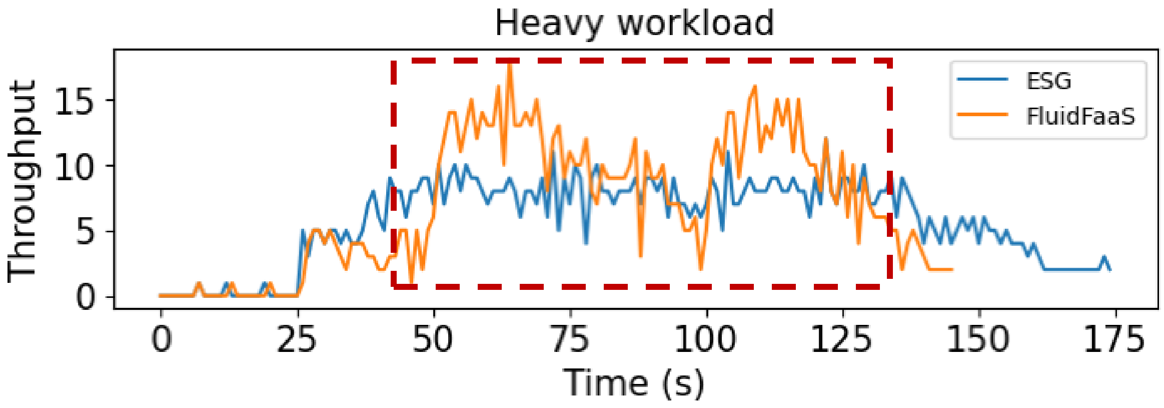
❖ **Evaluated metrics: Throughput**



Light workload



Medium workload



Heavy workload

75% higher in heavy workload.

25% higher in medium workload.

Conclusion

- Identifies the fundamental reason for severe GPU under-utilization, **MIG resource fragmentation** and **exclusive keep-alive policy**.
- Give **programming support** and **runtime support** to enable **on-the-fly pipeline construction.**
- Propose **Hotness-aware eviction-based time sharing**.
- Empirically show **25%-75%** improvement in system throughput and improving up to **90%** SLO hit rates.

Thanks for your time!

Questions are more than welcomed!