WiseFuse: Workload Characterization, and DAG Transformation for Serverless Workflows

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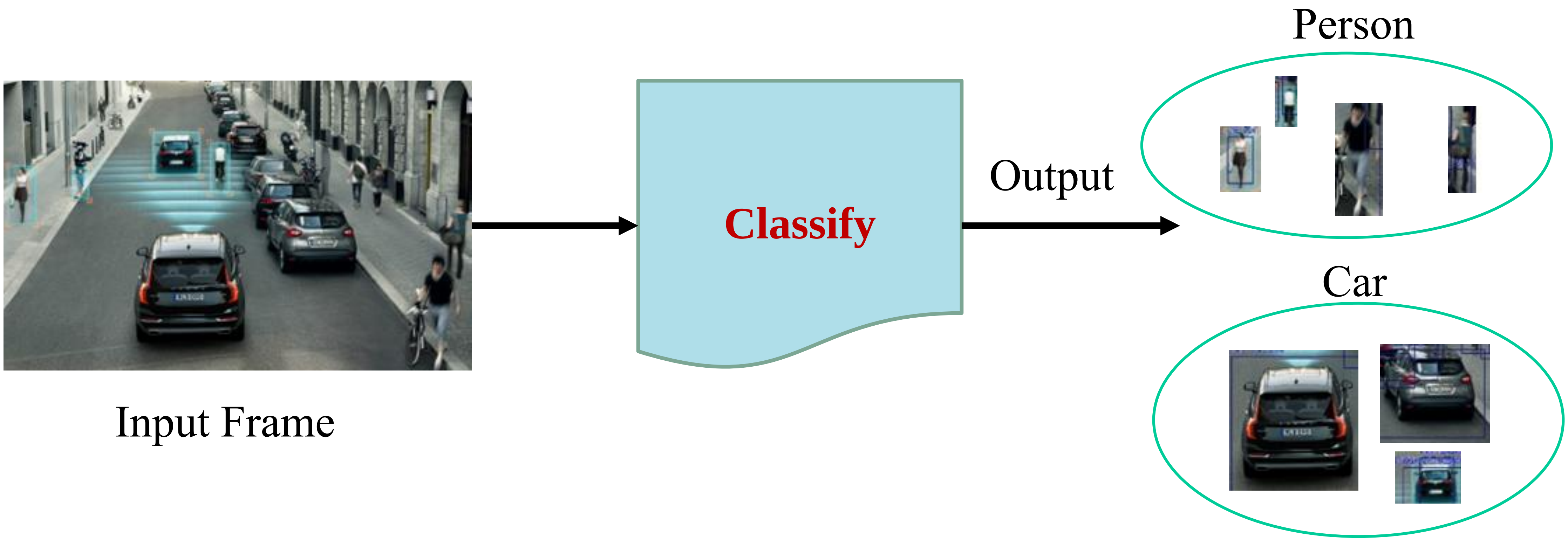
Introduction: Serverless

- Serverless Functions:
  - Users write the code, and platform deploys and executes the function
  - *Pay-as-you-go* model



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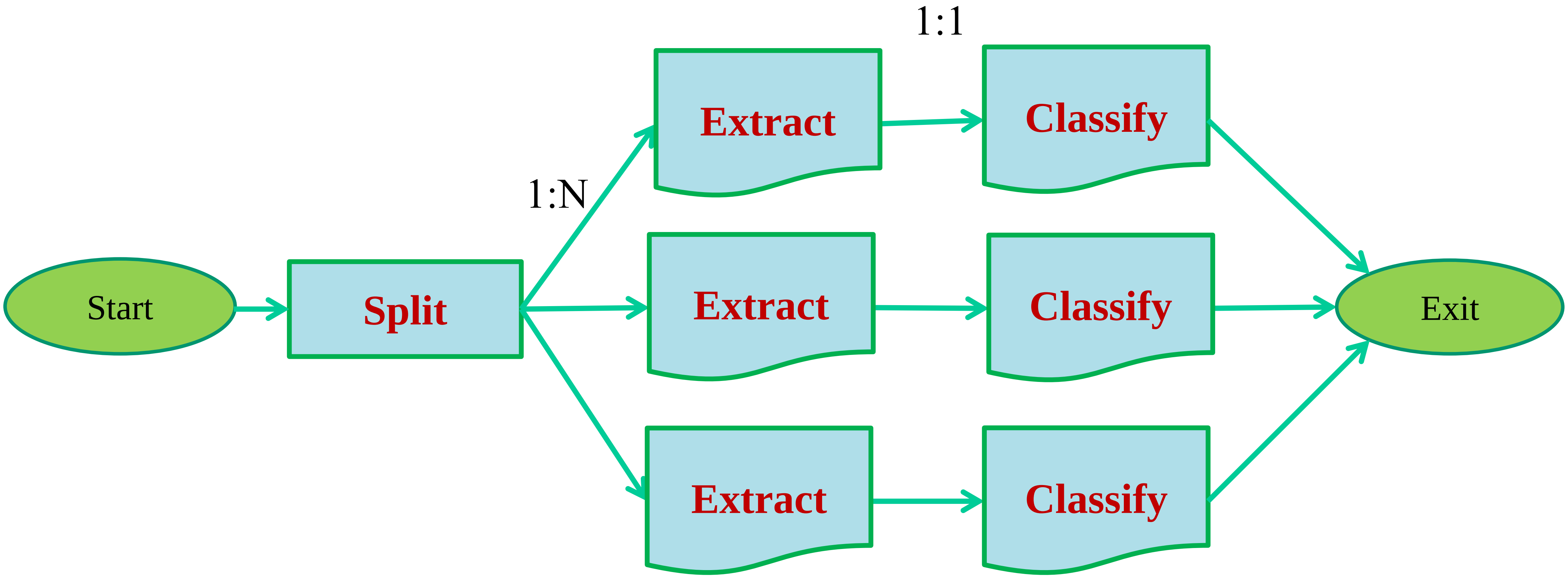
Introduction: Serverless Workflows

- Serverless DAG Example: Video Analytics Pipeline



➢ DAG execution is successful after *all* functions finish execution

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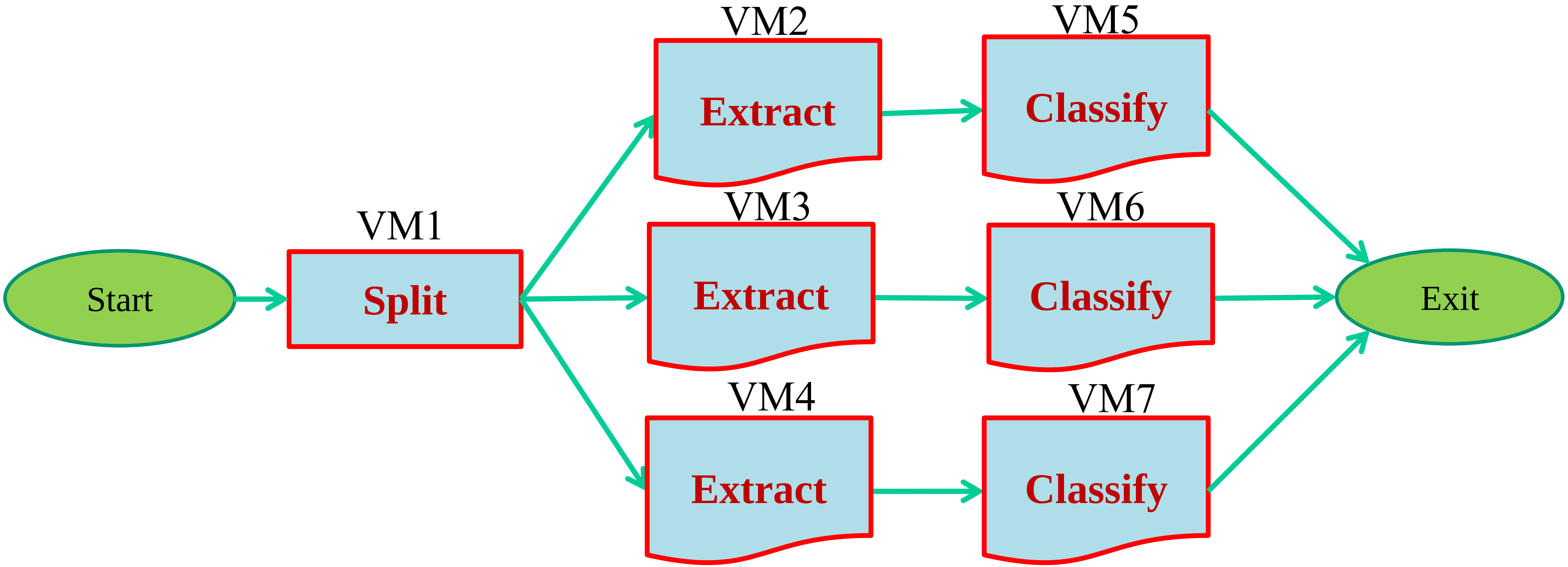
DAG Execution

- Serverless DAG Example: Video Analytics Pipeline



- ➢ Current FaaS platforms execute each function in a *separate* VM
- ➢ Users specify the VM size for each function

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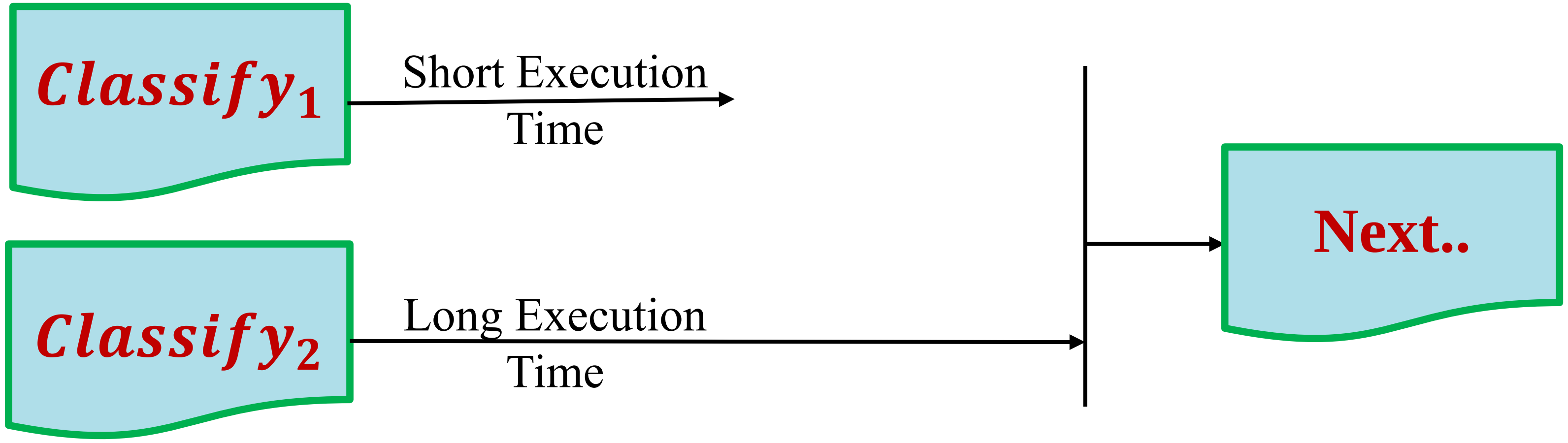
Performance Bottlenecks

- Two major performance bottlenecks:
  1. Communication latency between in-series functions

  2. Computation skew among in-parallel invocations within the same stage



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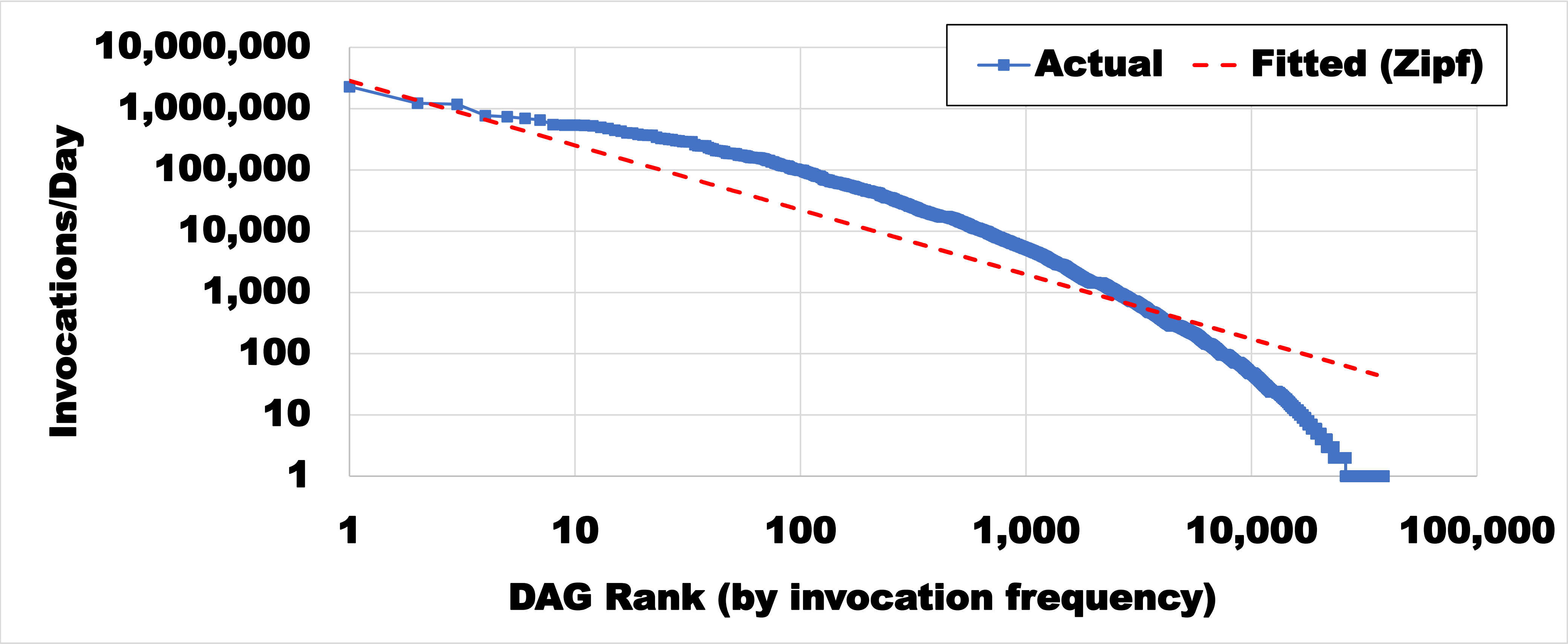
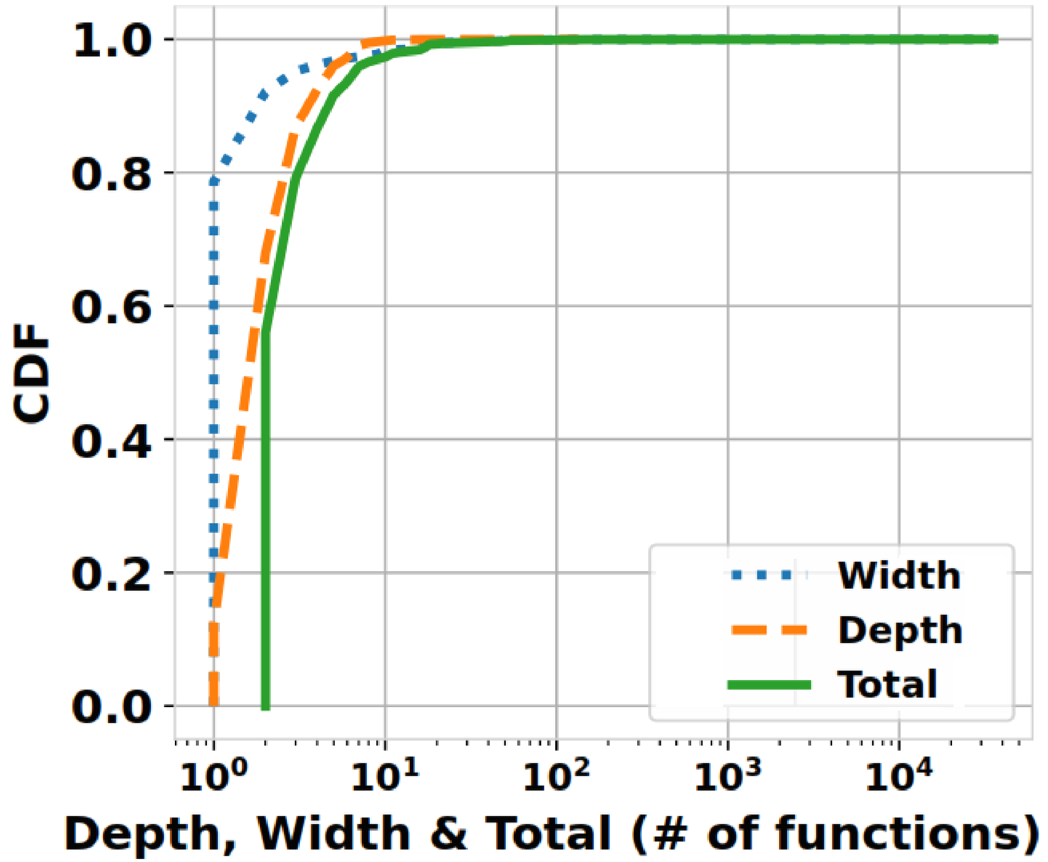
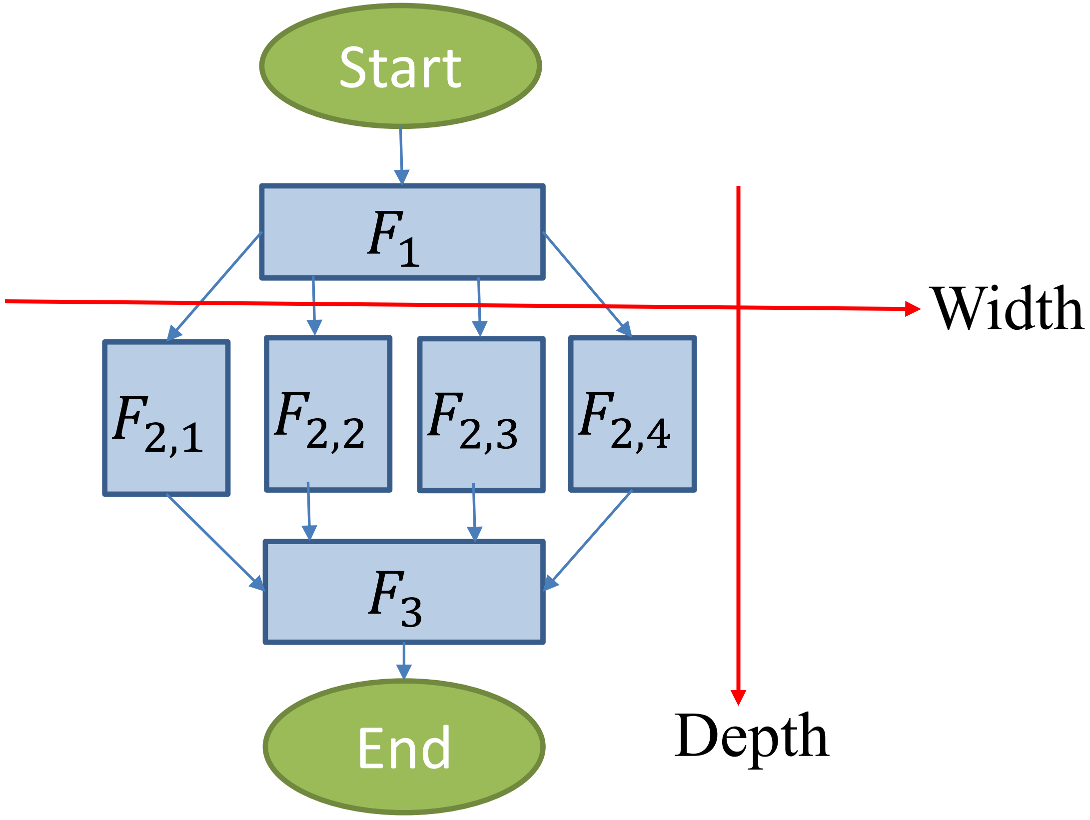
Workload Characterization (1/3)



- Top 5% most frequent DAGs:
  - Constitute 95% of all DAG invocations
  - Invocation rate ≥ 1.6K/day

Workload Characterization (2/3)





- DAG structure: short but wide
  - Max Depth: 47 in-series stages
  - Max Width: 10.9K in-parallel invocations

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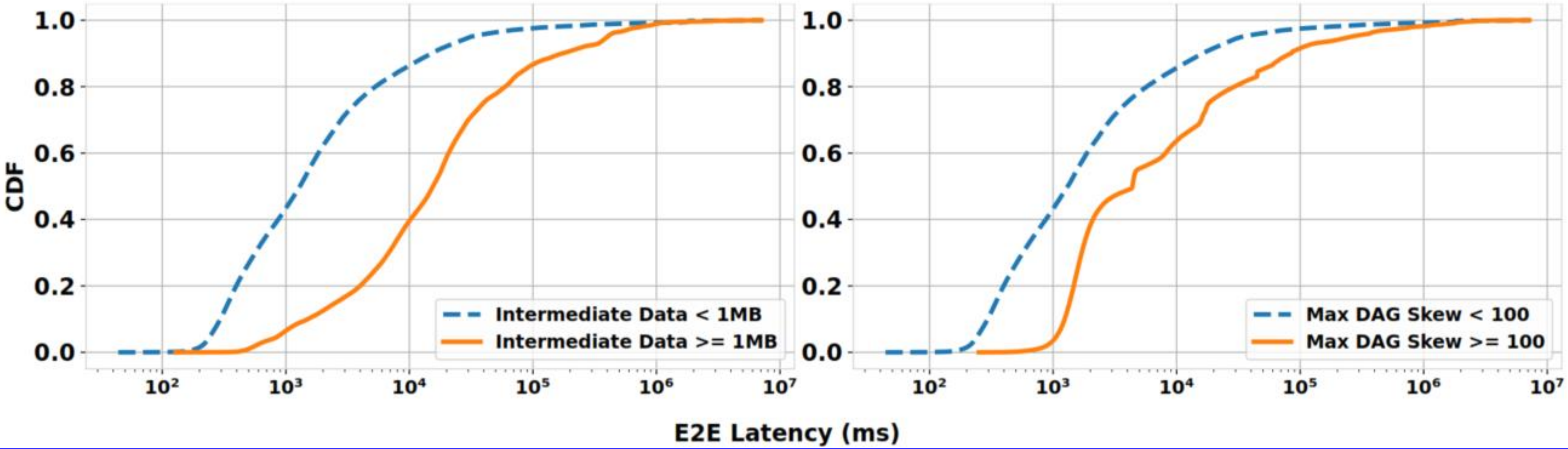
Workload Characterization (3/3)

Real workload traces from Azure Durable Functions



• DAGs with intermediate data size ≥ 1MB have 9.5× higher median latency than DAGs with size < 1MB.	• DAGs with skew ≥ 100 have 17× higher median latency than DAGs with skew < 100

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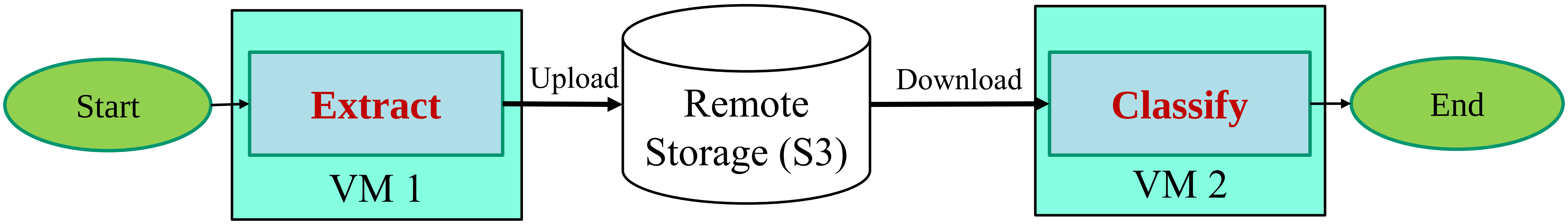
Fusion (1/2)



- Direct communication between serverless functions is infeasible
- Accordingly, asynchronous communication through remote storage is used
  - Can add significant delay to the e2e latency since intermediate data sizes are growing

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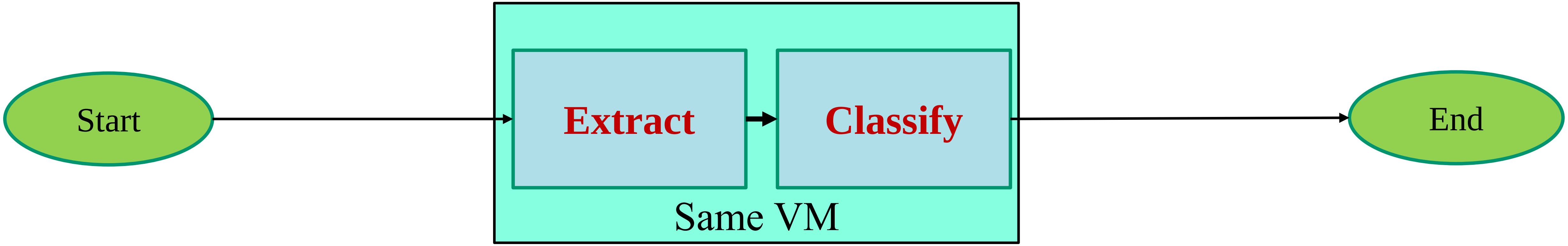
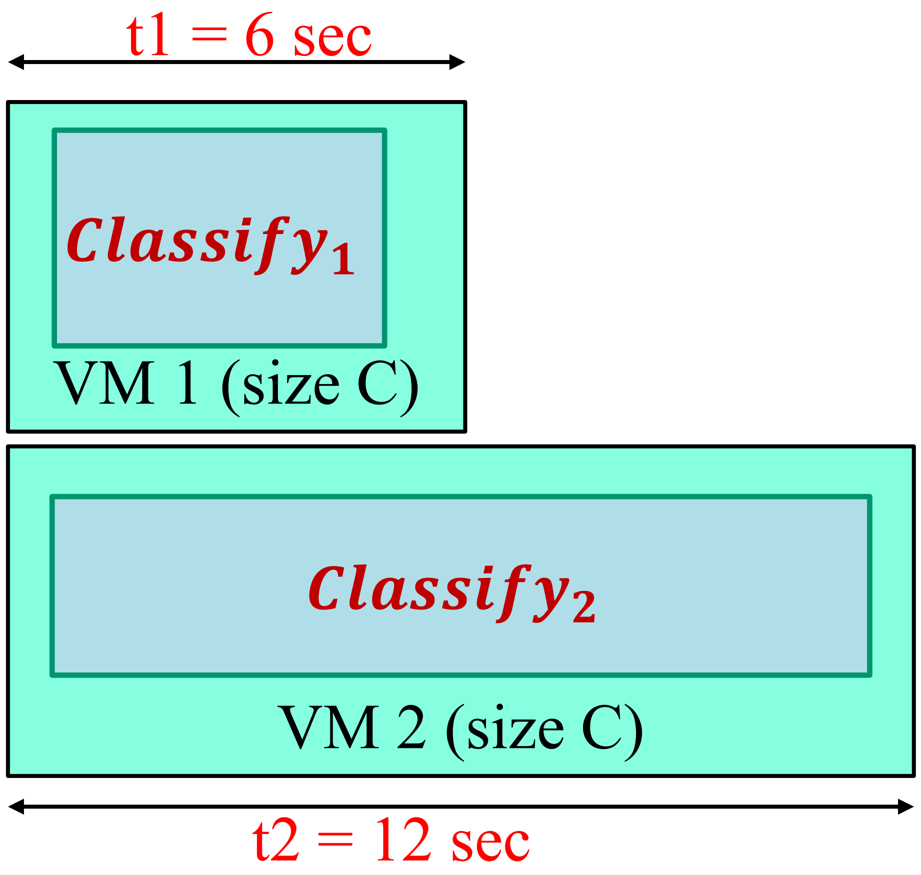
Fusion (2/2)



- Our solution: **Fusion**
  - By fusing the sending and receiving functions together, we can execute them in one VM and leverage local data passing → reduce the e2e latency

➢ Challenge: increases cost if the functions have different resource requirements

Bundling (1/2)



- Each invocation execute in a separate VM
- Straggler dominates the e2e latency

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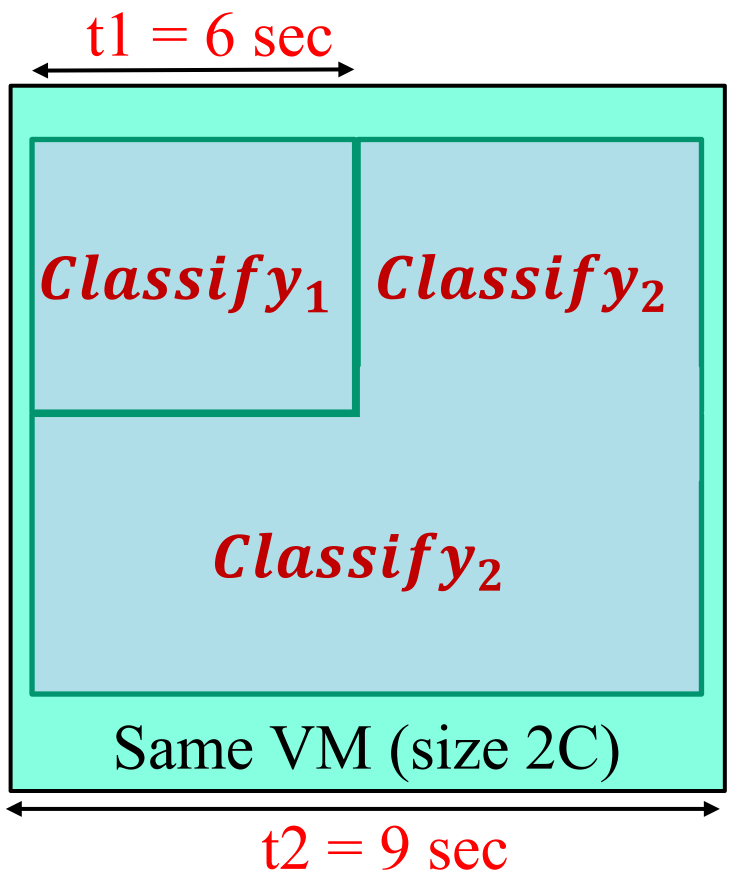
Bundling (2/2)



- Our solution: **Bundling**
  - Execute both invocations in one VM
  - Straggler gets additional resources after fast invocation finishes execution

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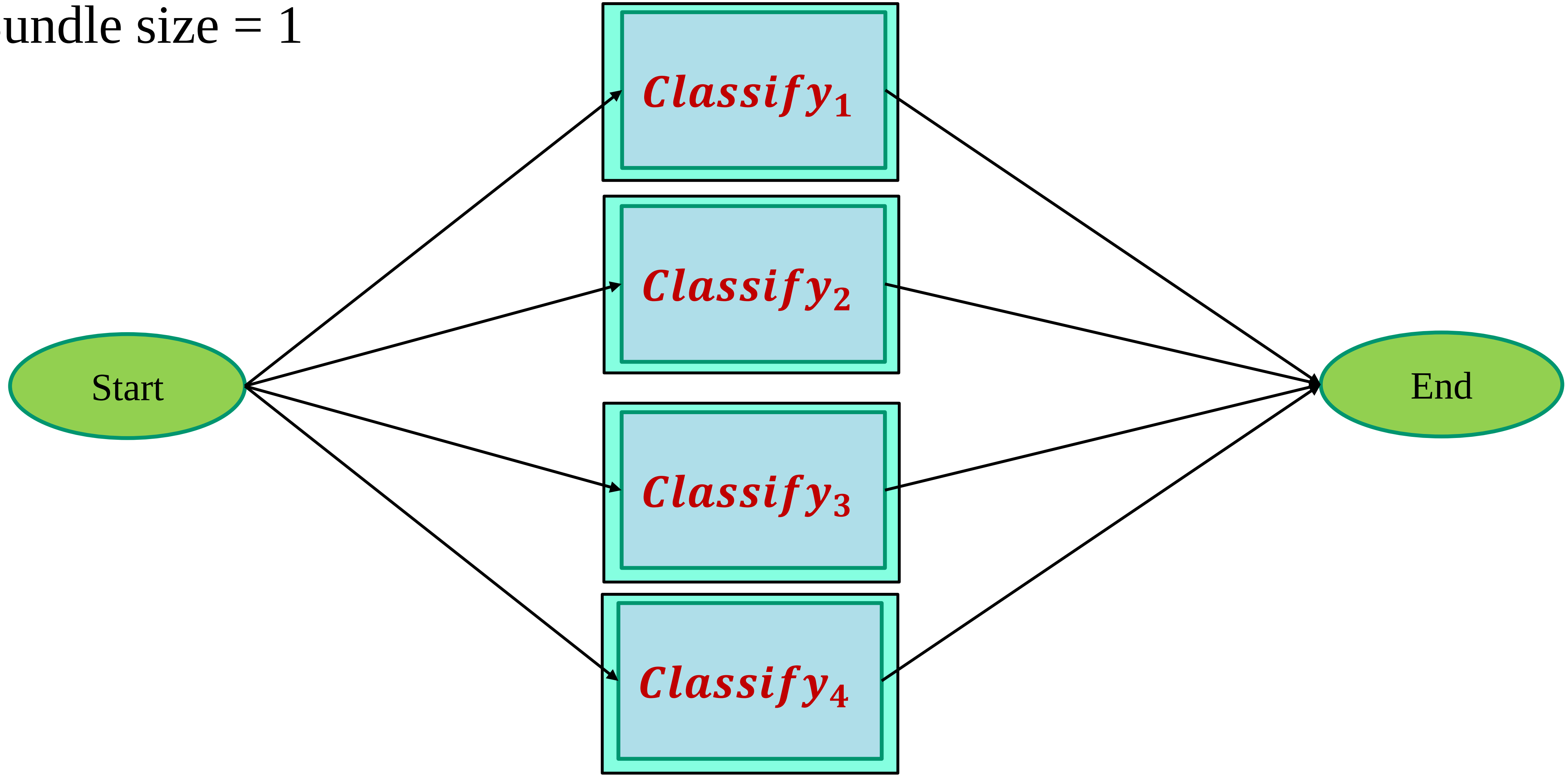
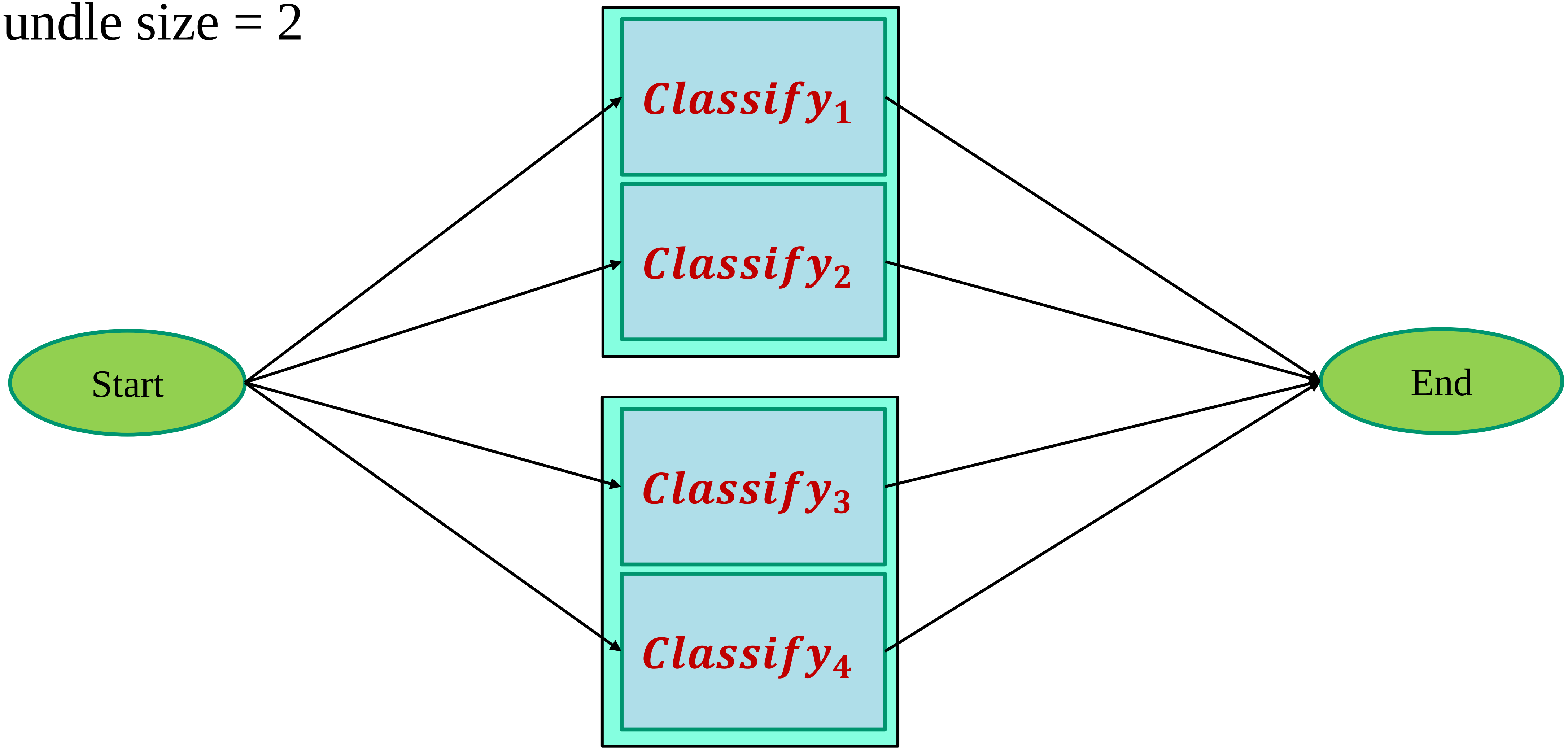
Selecting the bundle size

- Bundle size = 1



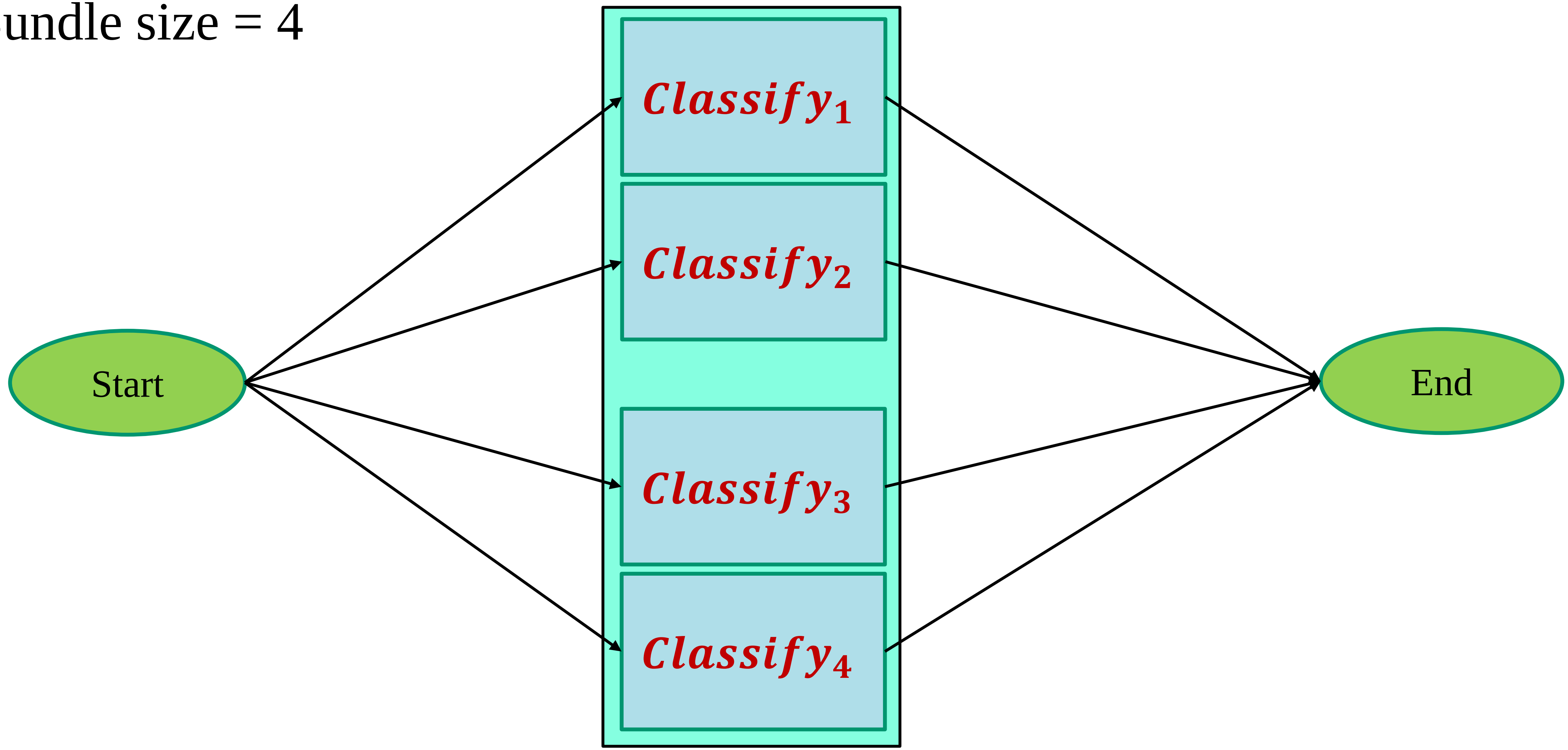
Selecting the bundle size

- Bundle size = 2



Selecting the bundle size

- Bundle size = 4



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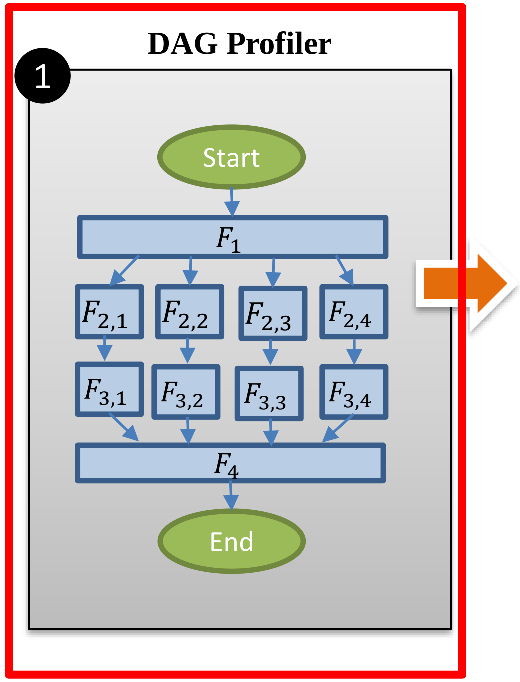
Summary of Main Insights

- Workload Characterization:
  - Top 5% most frequent DAGs constitute 95% of all DAG invocations
  - Serverless DAGs are short but wide

- Two major performance bottlenecks:
  - Communication latency between in-series functions → Fusion
  - Computation skew among in-parallel invocations → Budling

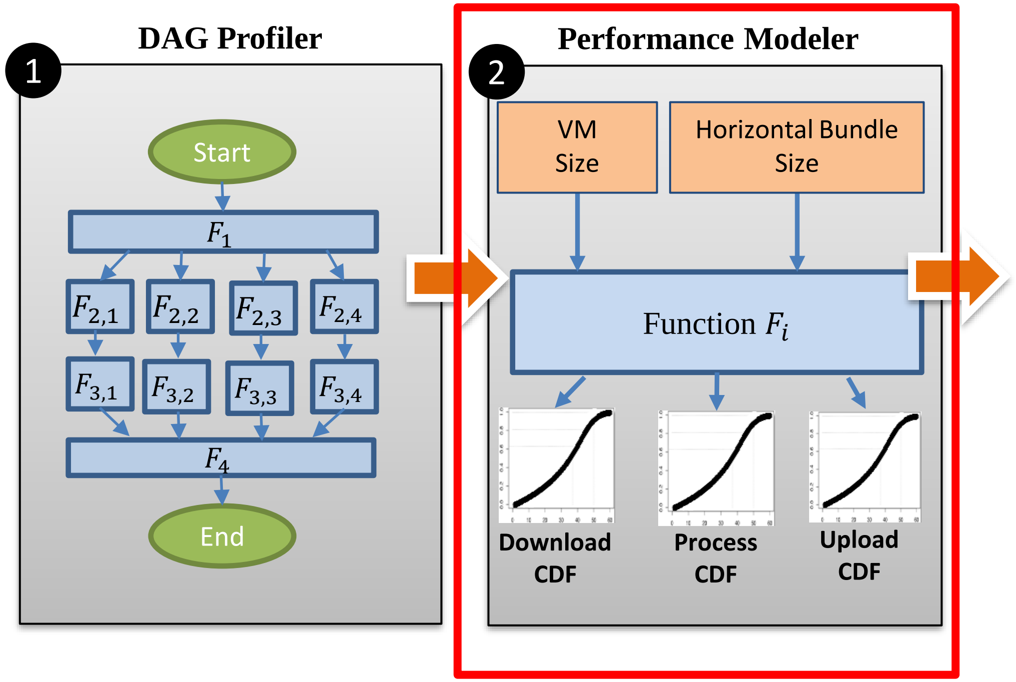
WiseFuse's Design (1/4)



- First, the DAG Profiler captures the execution time for each function and the entire DAG
  - Information already collected by the platform for billing

- We represent the execution time for each function and the entire DAG as a distribution (CDF)
  - Captures the runtime variability

WiseFuse's Design (2/4)



- Second, our modeler breaks down the function's runtime into download, processing, and upload components

- Our modeler also takes into account the correlation between in-series and in-parallel functions

- We use the function profiles to estimate e2e latency, and estimate the impact of Fusion and Bundling

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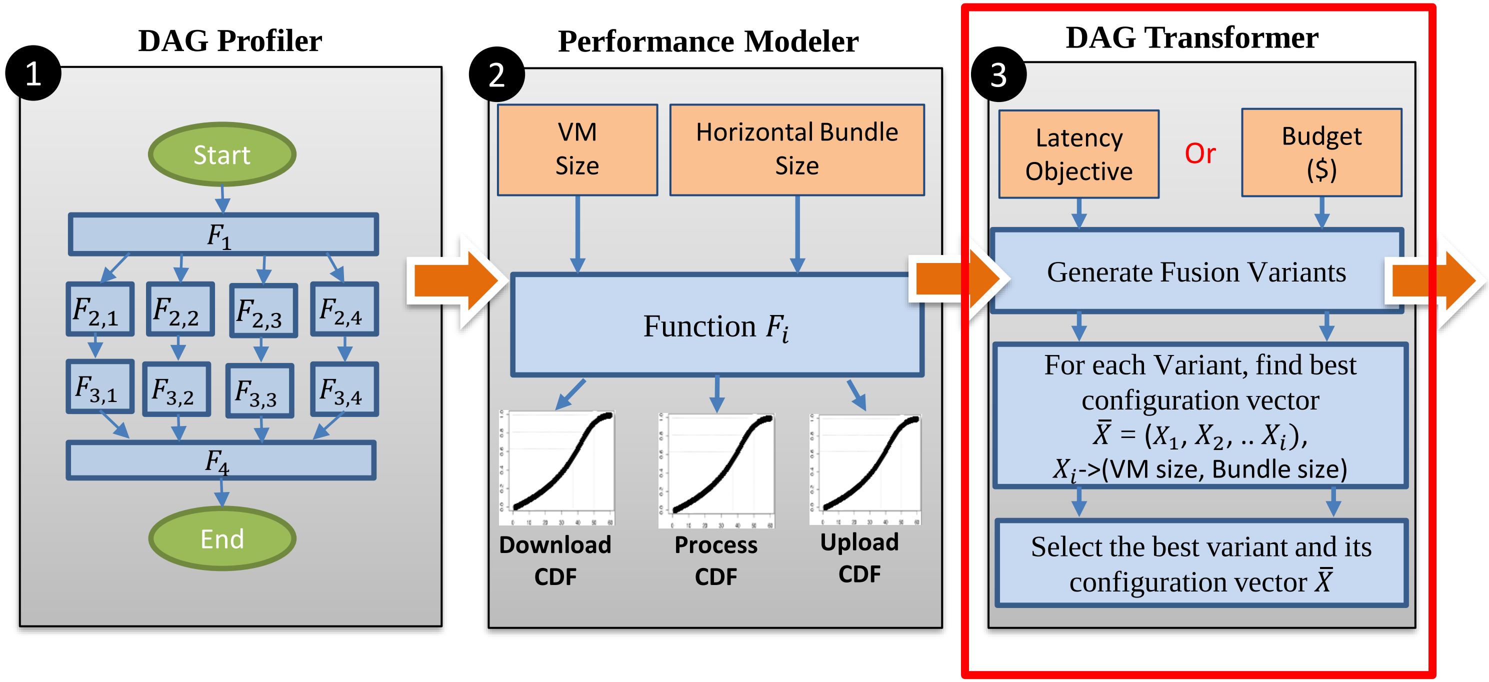
WISEFUSE's Design (3/4)



- Afterwards, the DAG Transformer identifies:
  - In-series stages that experience high communication latency → can benefit from Fusion.
  - Parallel stages that experience execution skew → can benefit from Bundling

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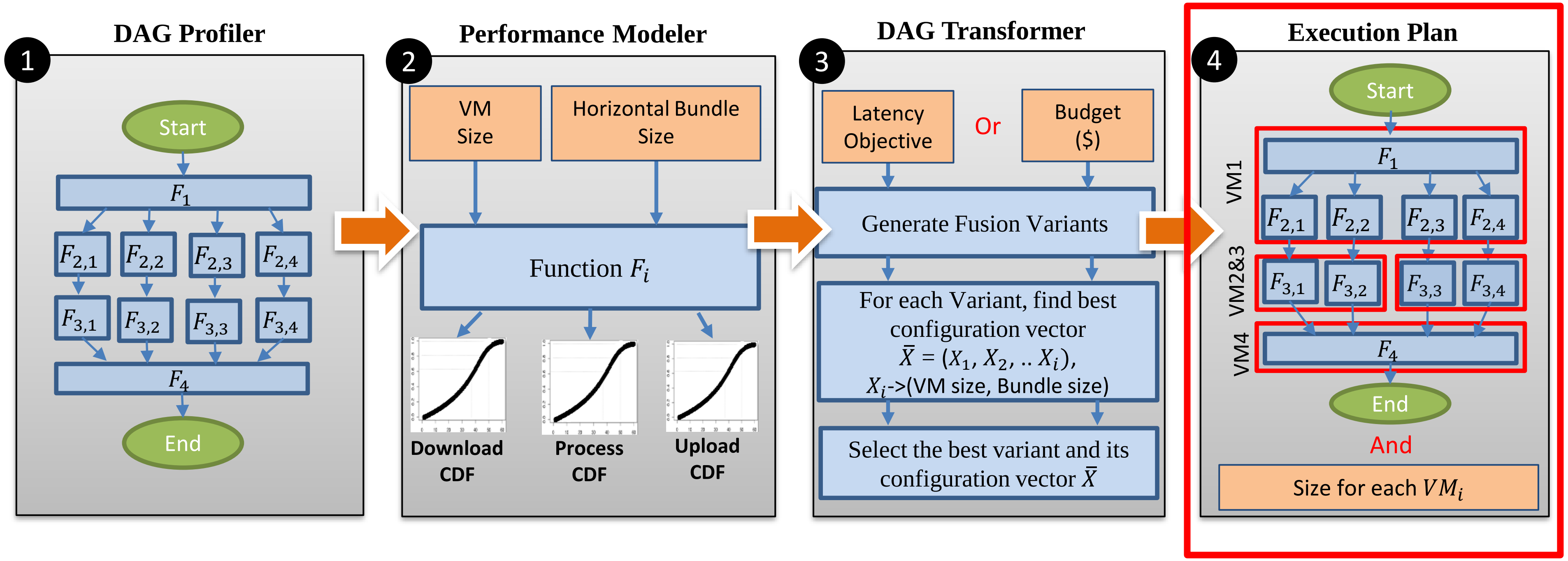
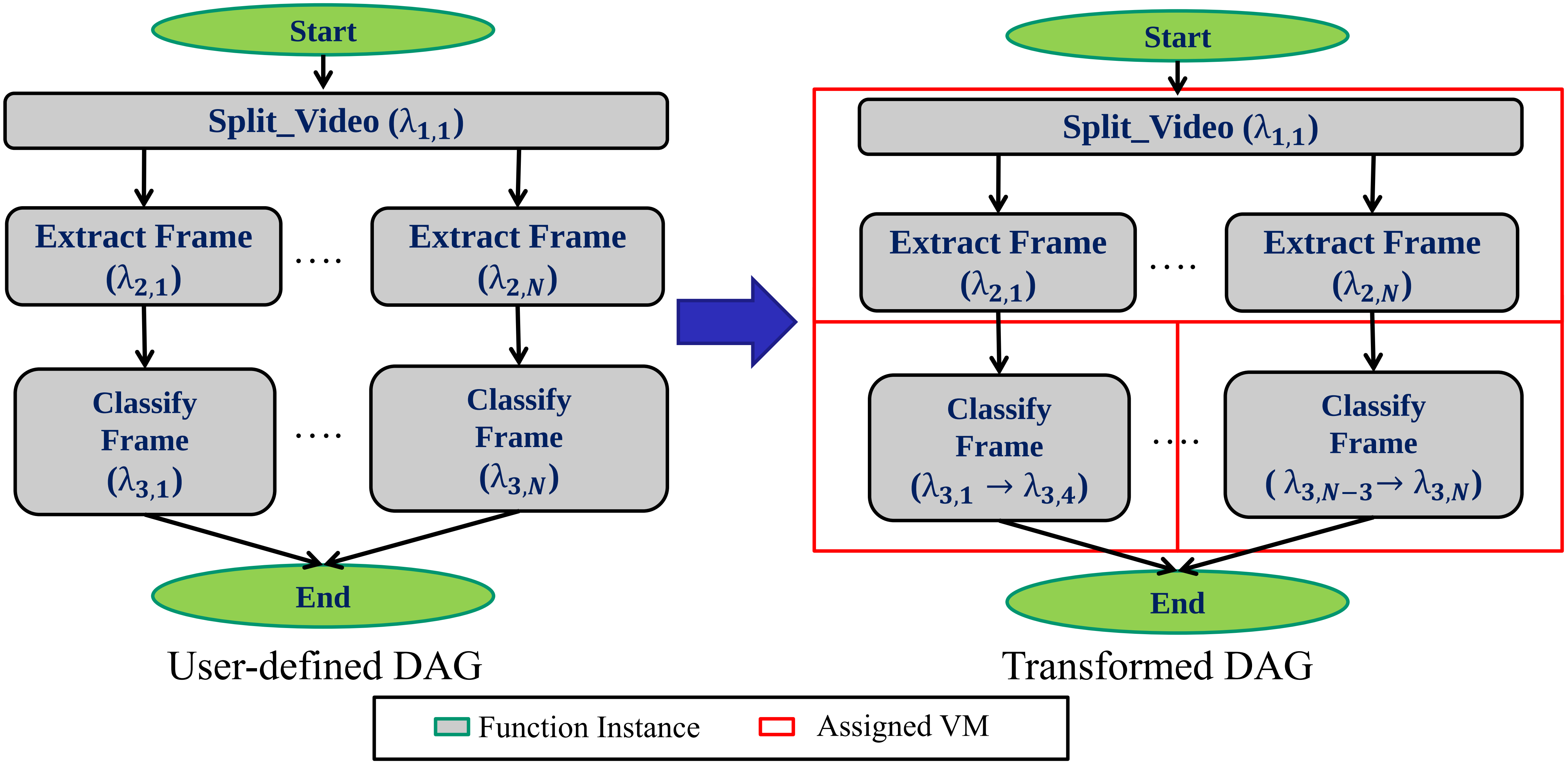
WISEFUSE's Design (4/4)



- Finally, the Transformer uses Dynamic Programming to find the best execution plan for the DAG
- The Execution Plan describes:
  1. Which stages to be Fused together
  2. How many parallel invocations within a stage to be bundled together
  3. The VM size to allocate for each function or function bundle

DAG Transformation



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Evaluation

- We evaluate WISEFUSE on three applications on AWS Lambda

- Model estimation accuracy (using 300 profiling runs):
  - Error in P95 e2e latency: **≤ 13%**
  - Error in estimating the impact of Fusion on e2e latency **≤ 3.4%**
  - Error in estimating the impact of Bundling on e2e latency **≤ 7%**

- Recall: 95% of all invocations are for the top 5% most frequent DAGs
  - invocation rate ≥ 1.6 K per day
  - 300 runs are collected in 5 hours or less

Evaluation: Comparison to Baselines and Related Works

We evaluate the following approaches on AWS Lambda:

1. Three latency target settings for WISEFUSE

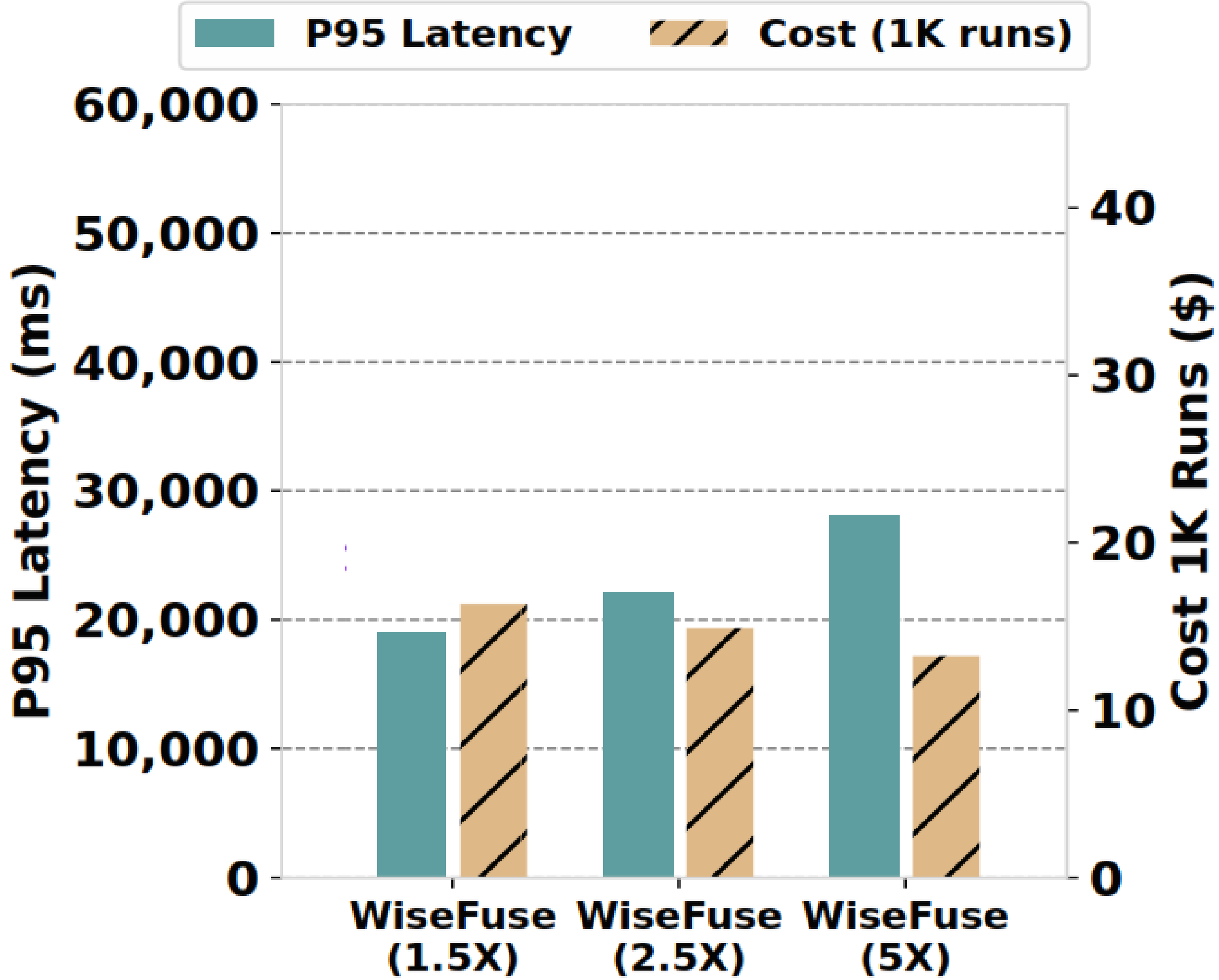
2. User-Max/User-Min: user-defined using max/min VM sizes

3. Sonic (ATC'21): Selects between three data passing methods for communication

4. Photons (SoCC'20): Colocates parallel invocations together to improve the memory utilization

5. FaastLane (ATC'21): Executes the entire DAG within a single VM

Evaluation with Video Analytics Application (1/5)



- WISEFUSE adjusts the execution plan based on the user specified latency target
  - Higher latency target → Lower cost

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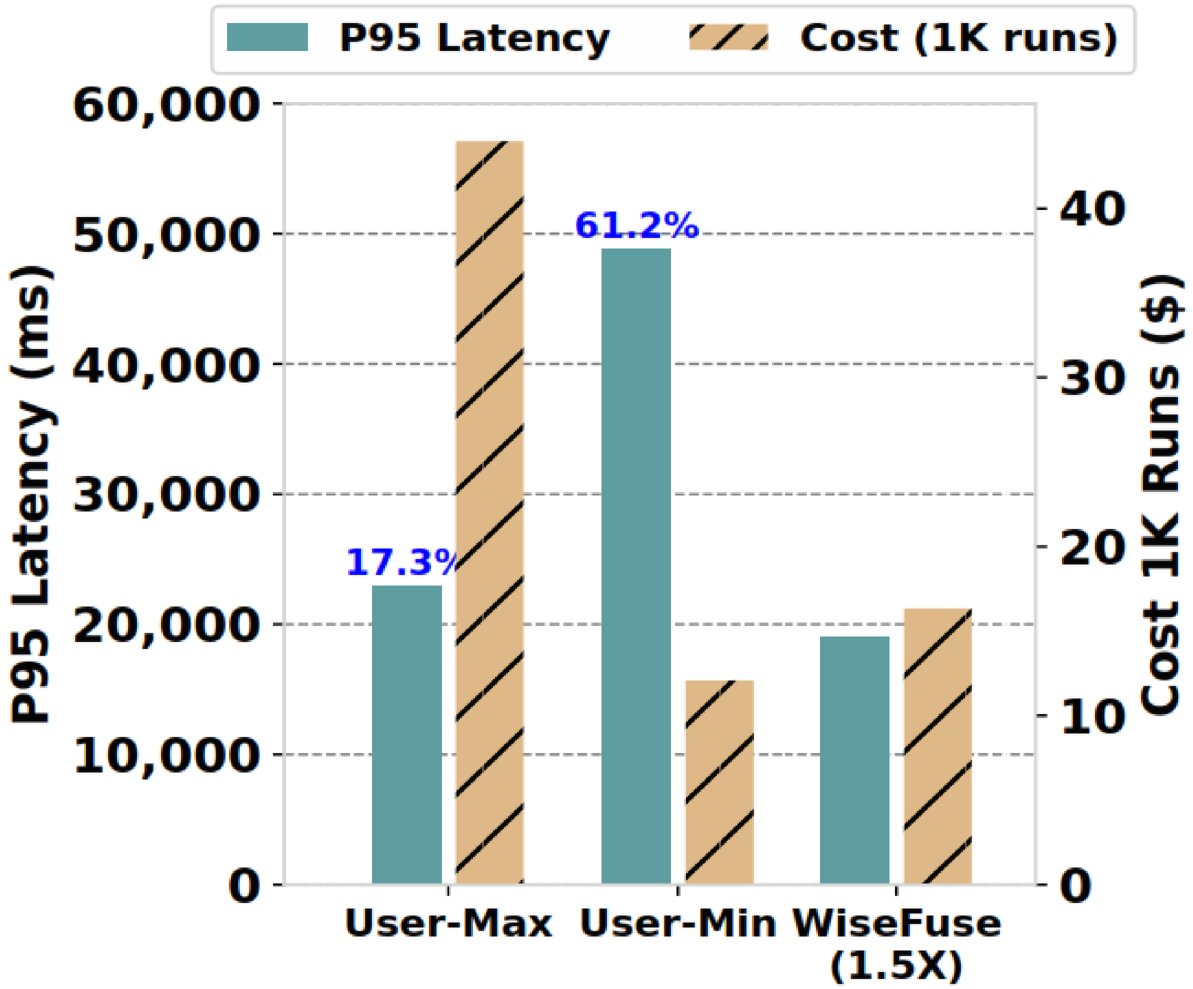
Evaluation with Video Analytics Application (2/5)



- WISEFUSE achieves 63% lower cost than User-Max
- WISEFUSE achieves 61% lower P95 latency than User-Min

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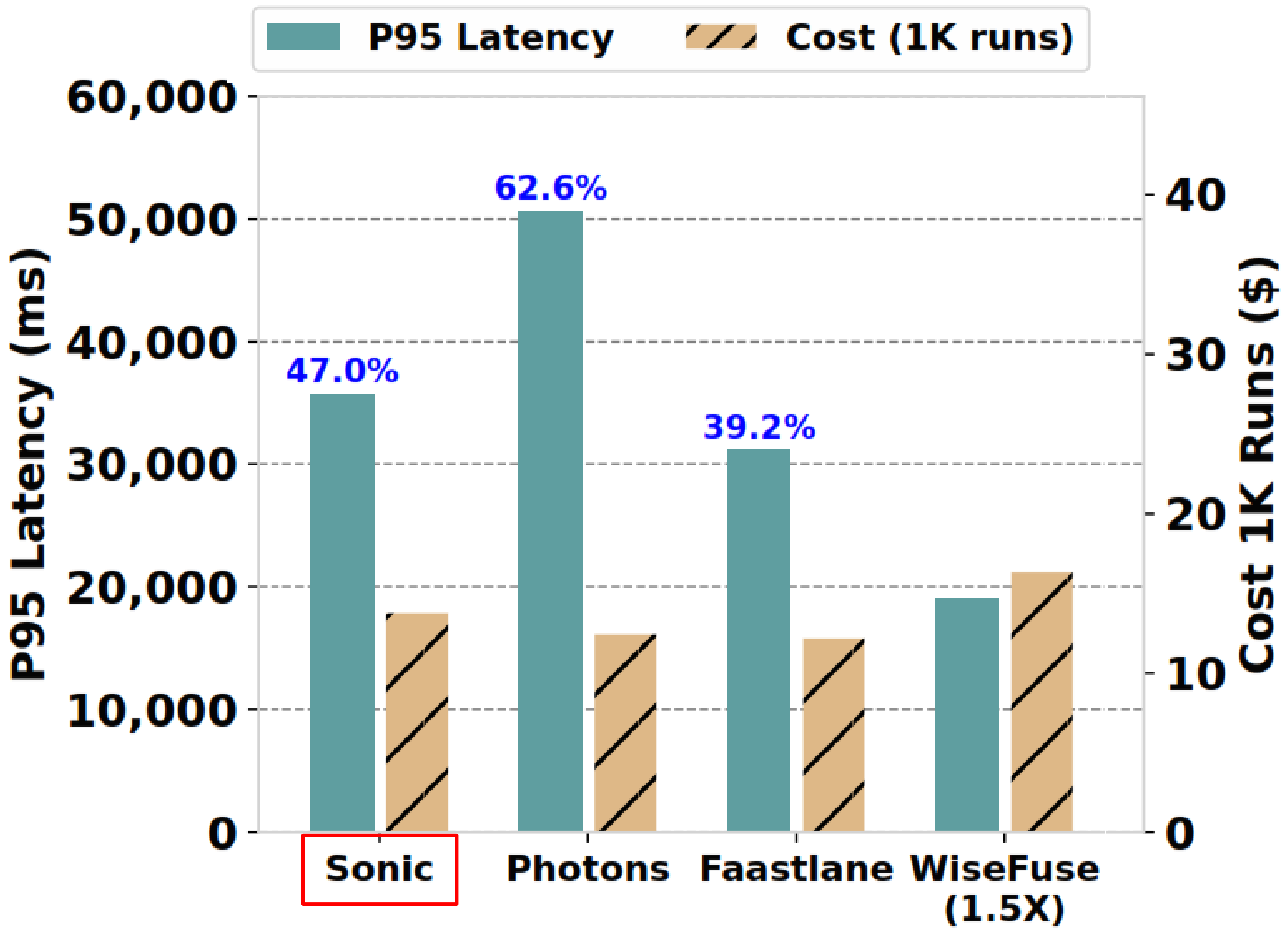
Evaluation with Video Analytics Application (3/5)



➢ WISEFUSE achieves 47% lower P95 latency over Sonic

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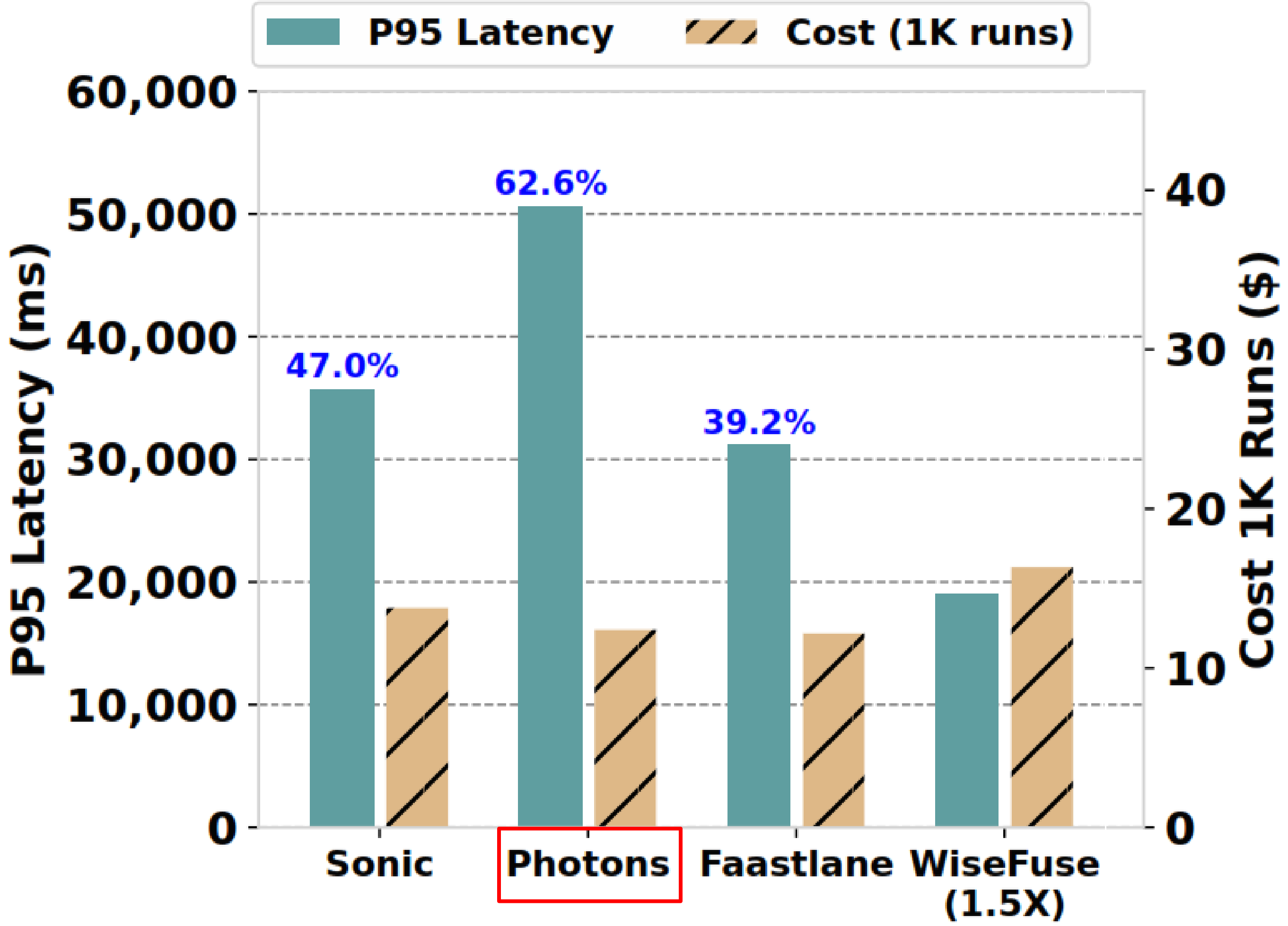
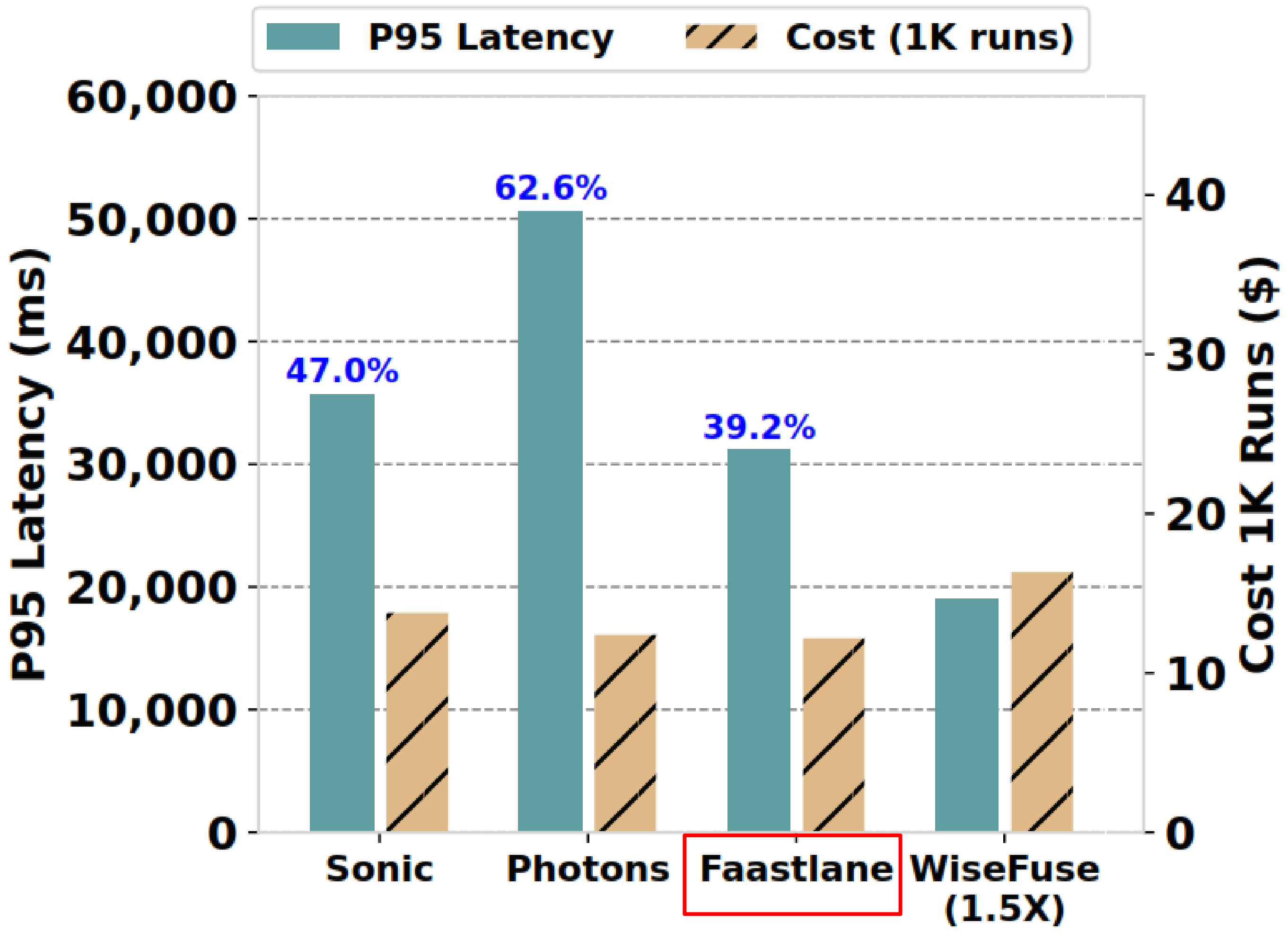
Evaluation with Video Analytics Application (4/5)



➢ WISEFUSE achieves a lower P95 latency by 62% compared to Photons

Evaluation with Video Analytics Application (5/5)



➢ WISEFUSE achieves 39% lower P95 latency compared to Faastlane

Conclusion

- Workload characterization for serverless DAGs in Azure Durable Functions

- Two major performance bottlenecks in serverless DAGs:
  1. Communication latency between in-series functions → Fusion
  2. Computation skew among in-parallel function invocations → Bundling

- WISEFUSE uses *Fusion* and *Bundling* operations to derive an optimized execution plan that meets a user-defined latency SLO with low cost

- Experimental evaluation on AWS Lambda
  - WISEFUSE is superior in meeting tail latency targets with reduced costs
  - WISEFUSE (Video Analytics) has lower P95 latency by 47%, 62%, and 39% compared to Sonic, Photons and Faastlane respectively