TAPAS: Thermal- and Power-Aware Scheduling for LLM Inference in Cloud Platforms

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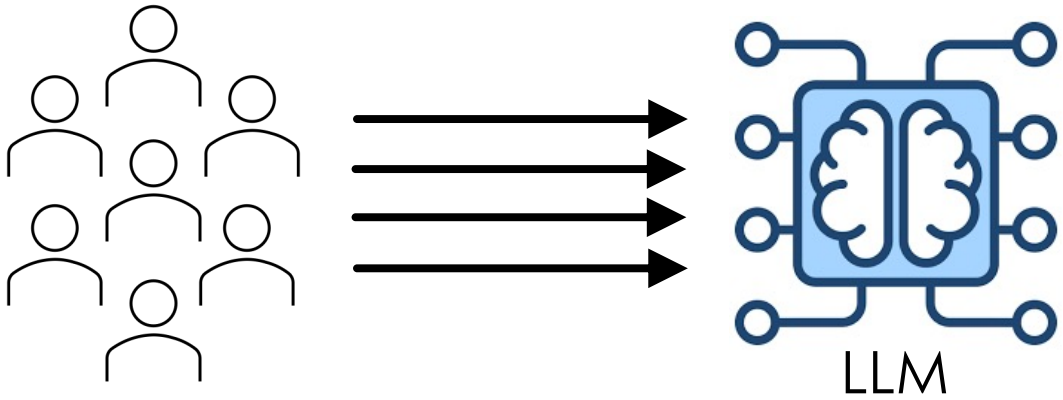
LLM Inference is Emerging in the Cloud

- Modern generative LLMs are turning ubiquitous
  - Use cases: programming, chat-bots, education, healthcare

LLM Inference Stresses Cloud Infrastructure



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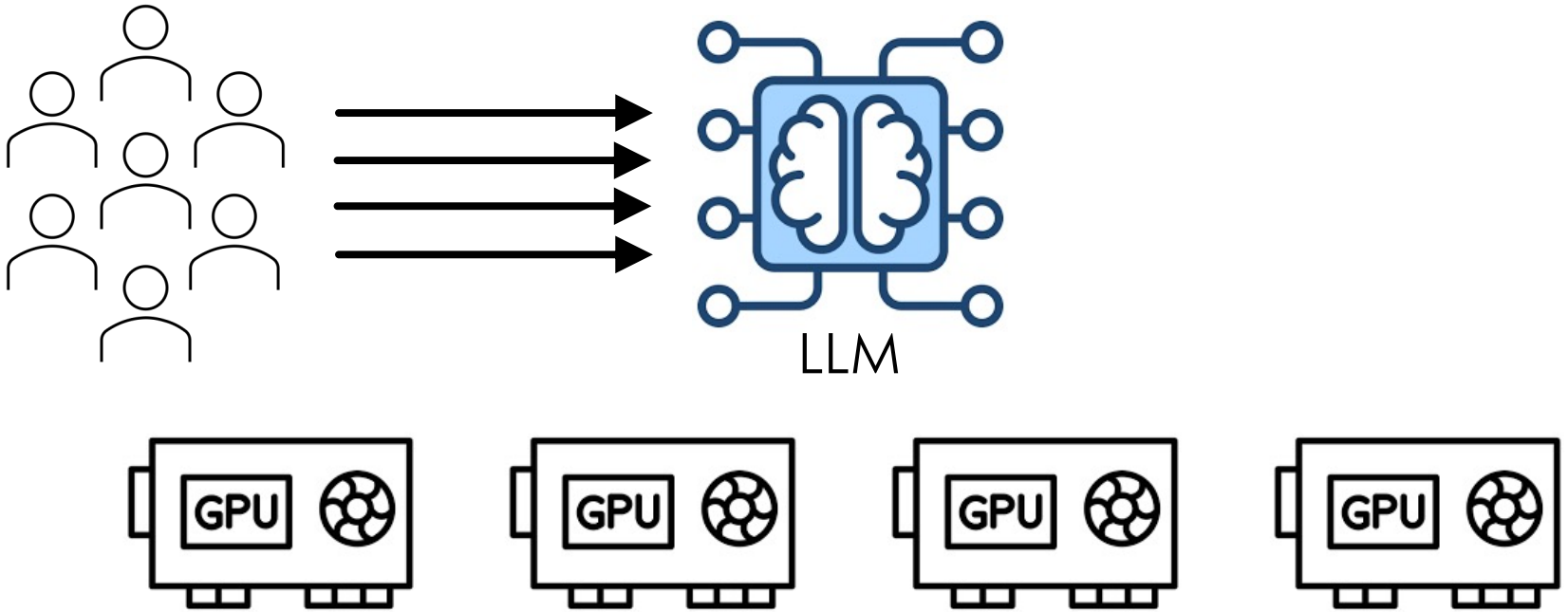

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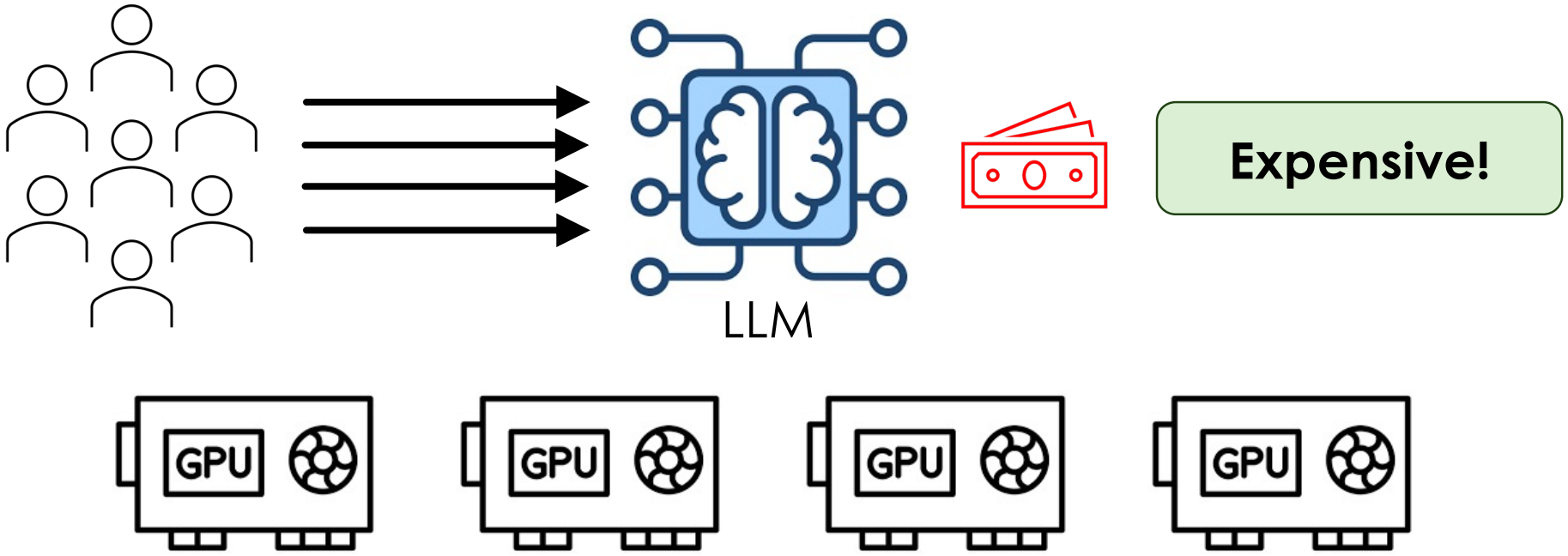

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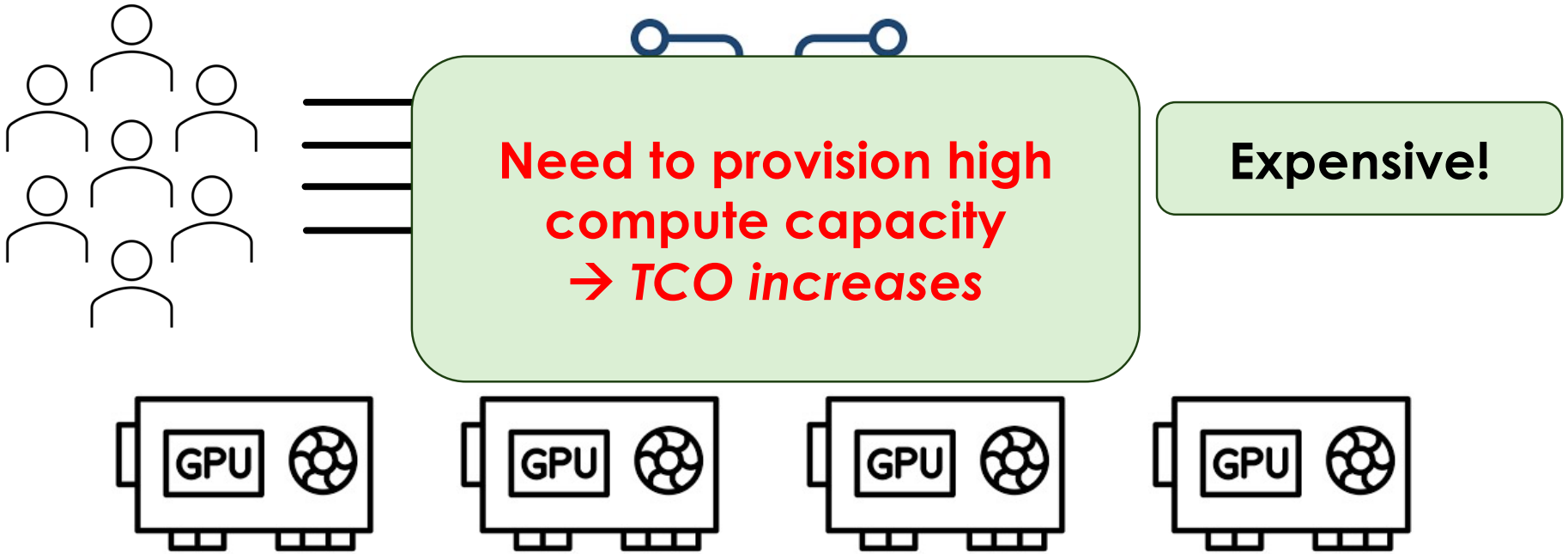

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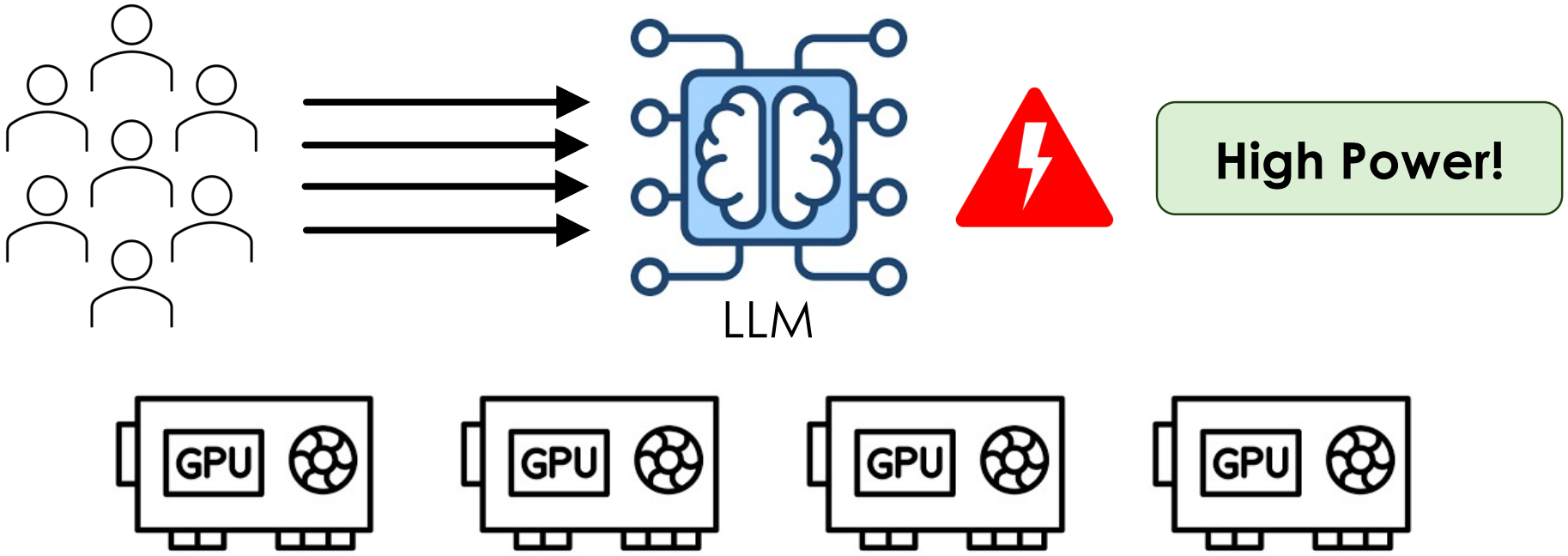

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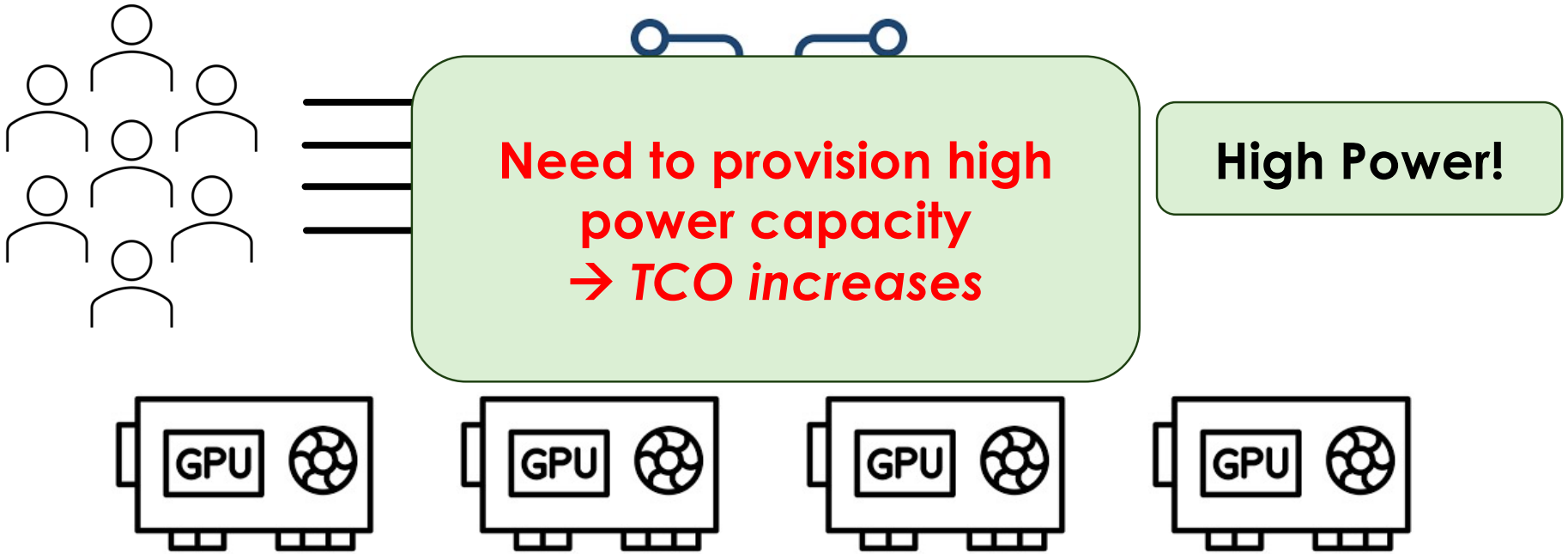

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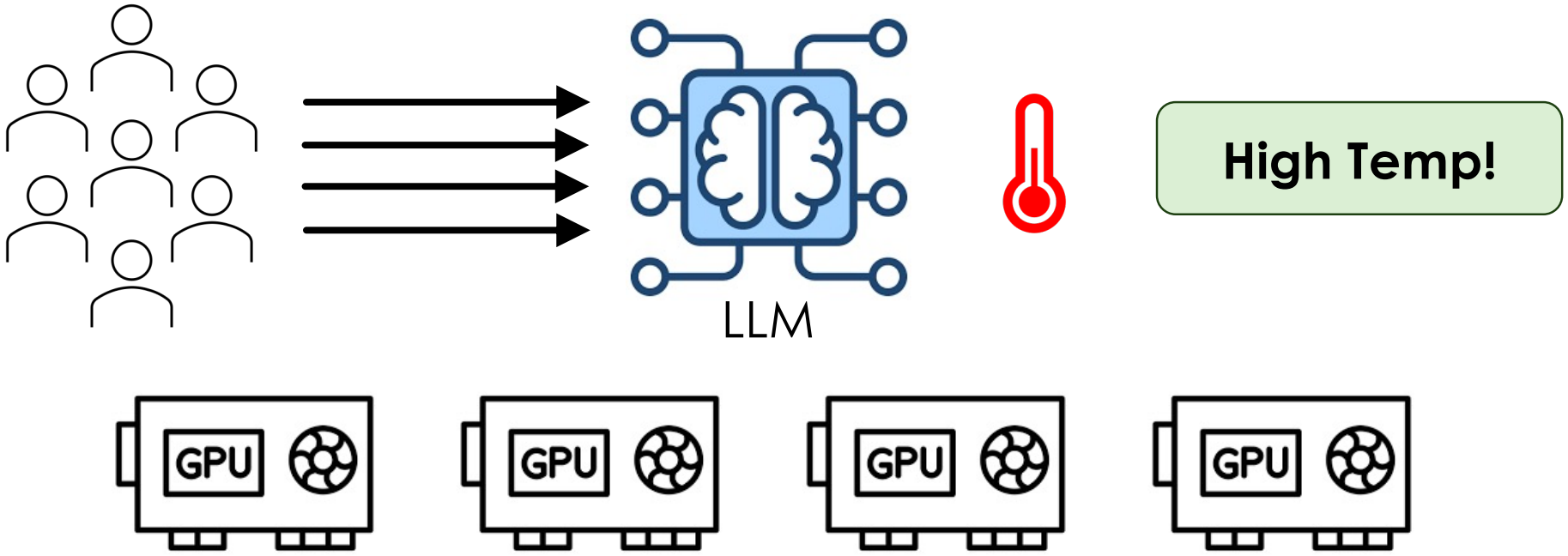

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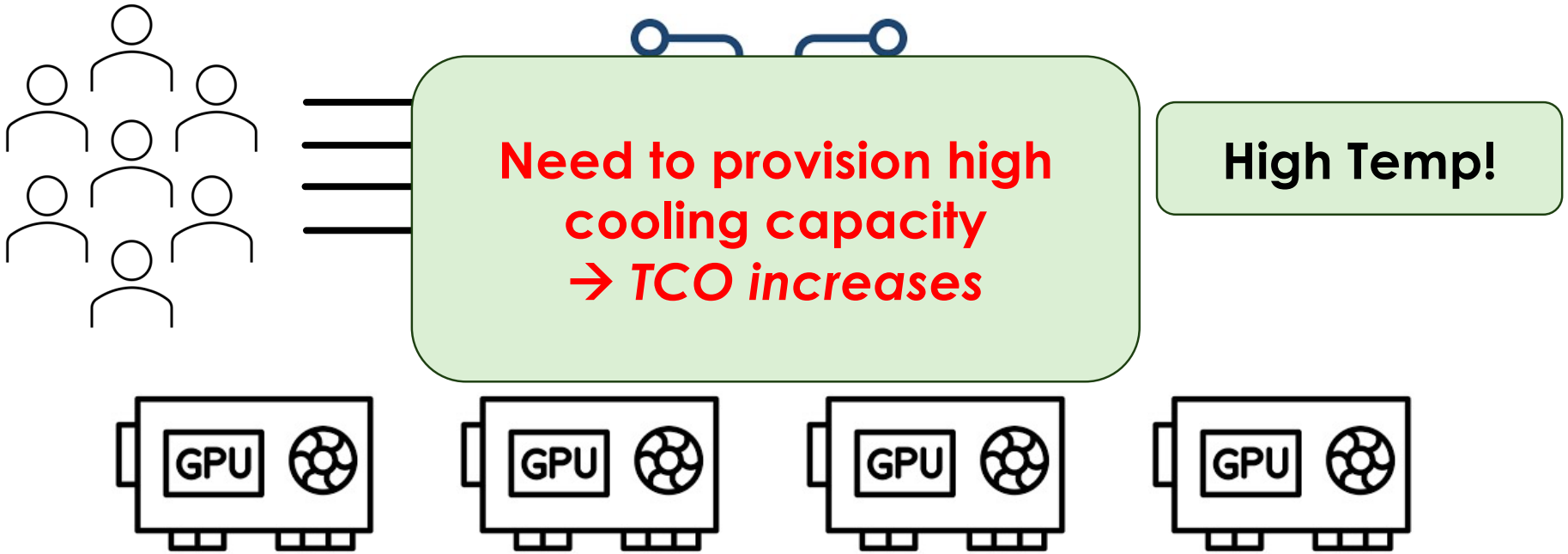
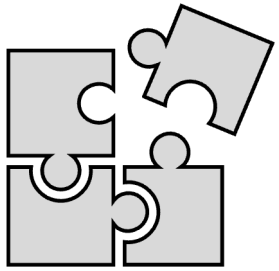


How to Tame the LLMs?

- Lots of work on performance, accuracy, scalability
- LLMs cause the datacenter cost, power, and cooling requirements to skyrocket



Thermal and power efficiency of LLMs is a missing piece of a puzzle!

Contributions

- Characterize thermal and power properties of LLMs and their behavior at production scale
- **TAPAS:** thermal- and power-aware scheduling for LLM inference clusters in the cloud
- Thorough evaluation on a GPU cluster + production traces
  - 30%-40% reduction in peak temperature and power

Goal: Make LLMs Thermal- and Power-Efficient

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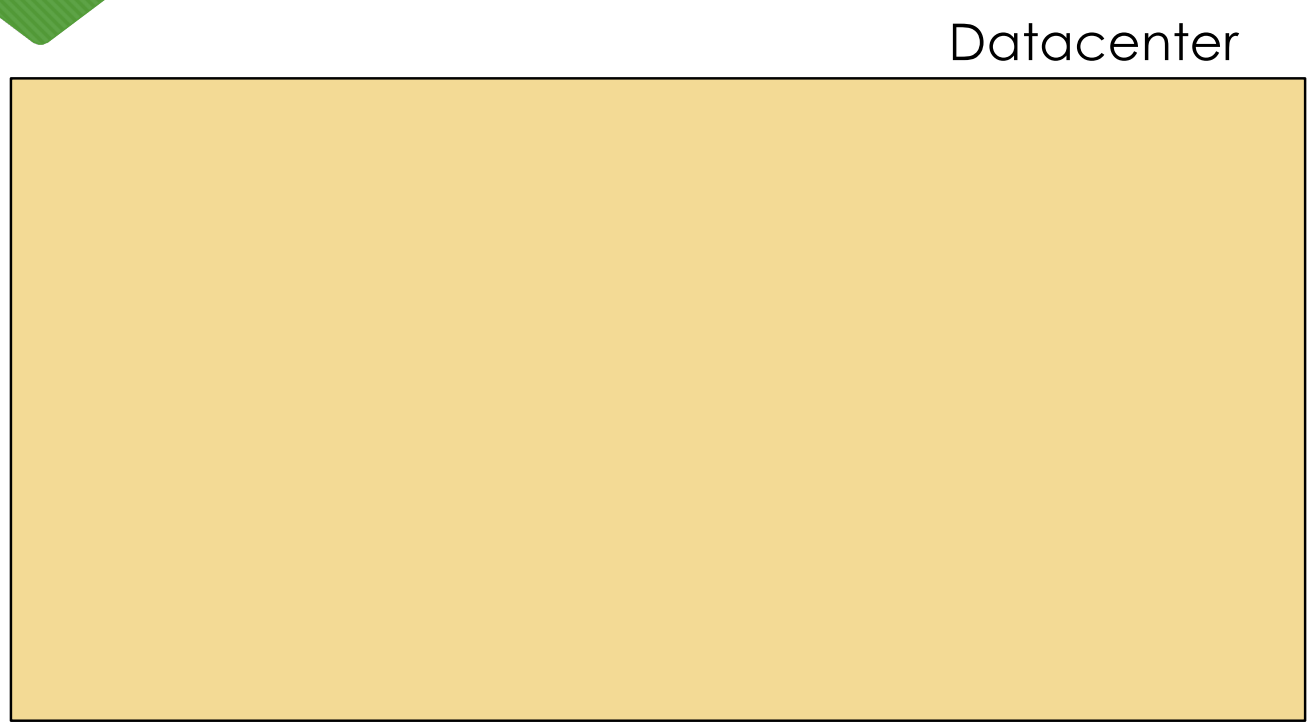
- Challenges
  - Cooling management
  - Power management
  - Workload heterogeneity

Challenge #1: Cooling Management



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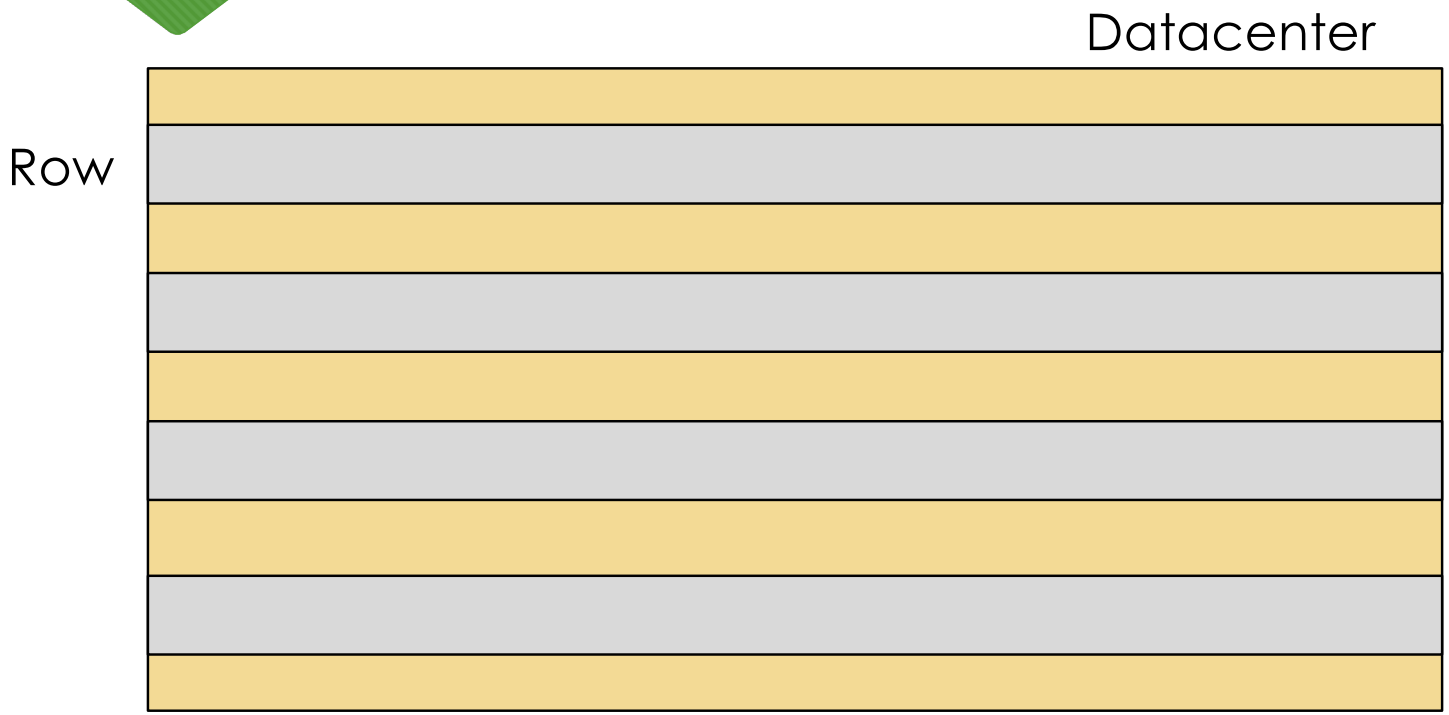

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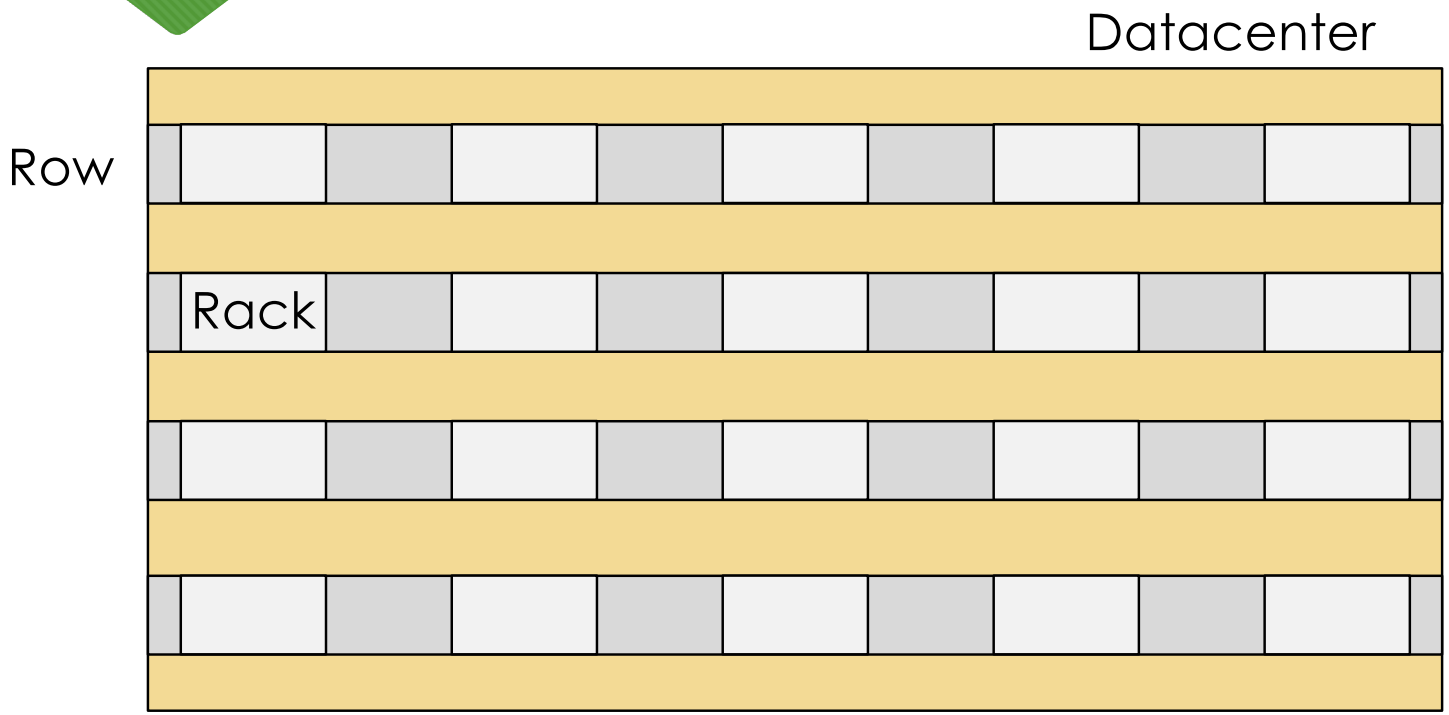

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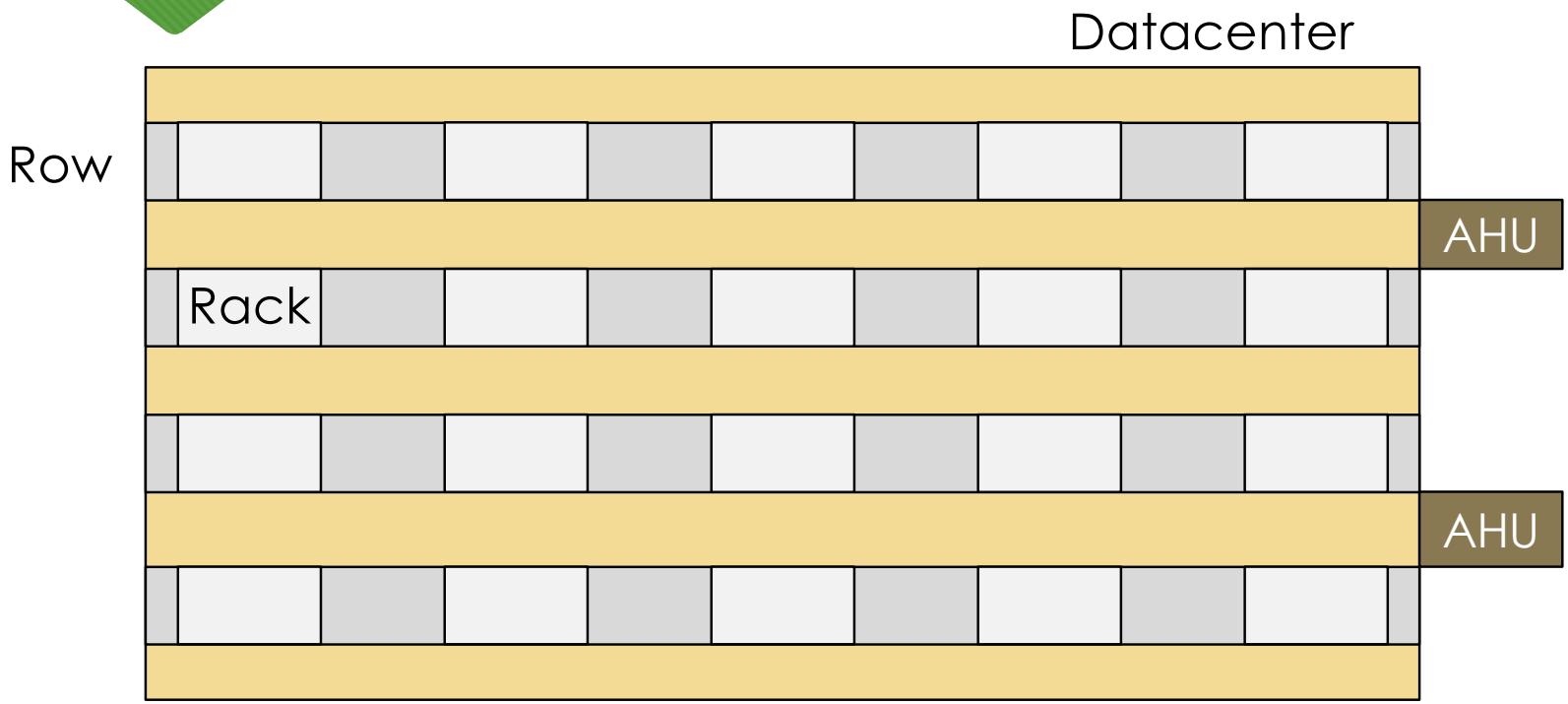

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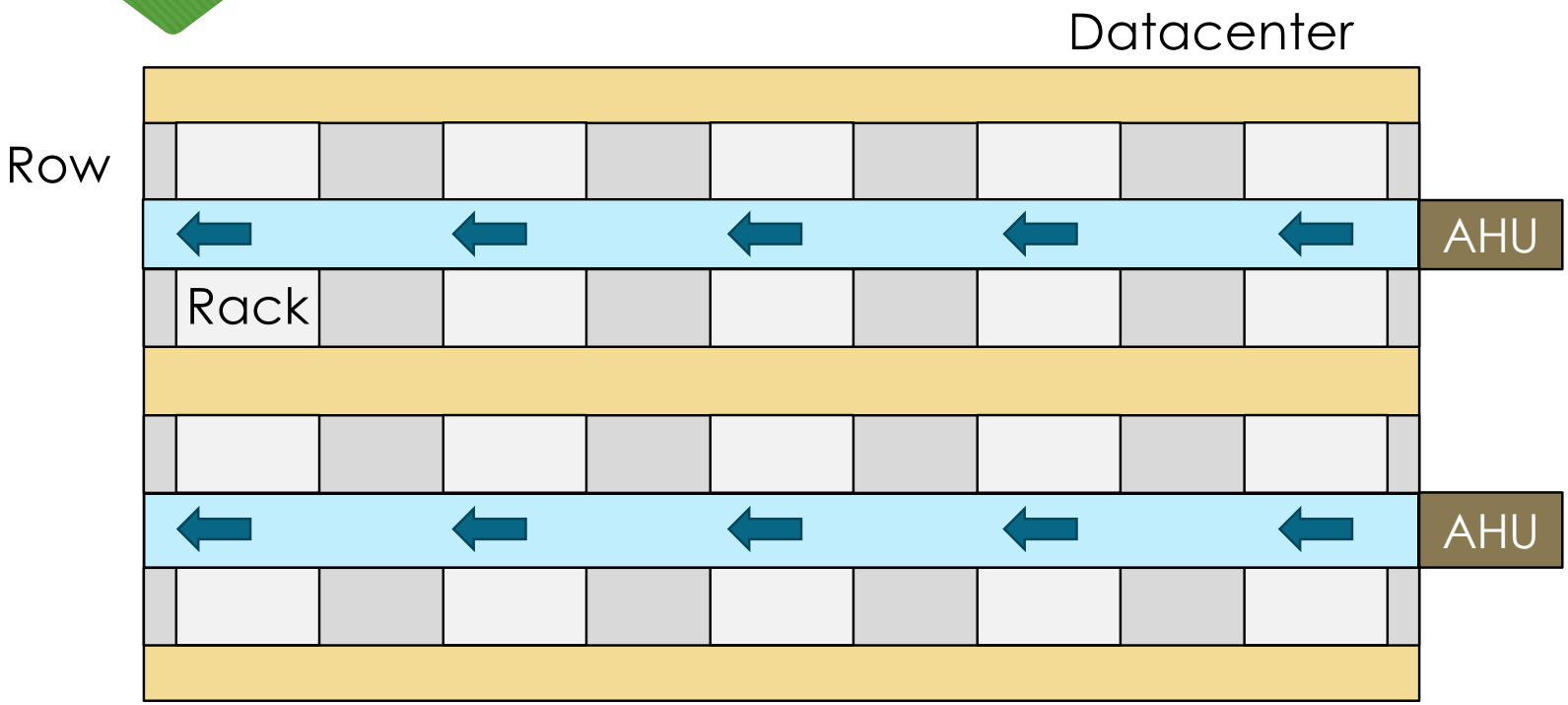

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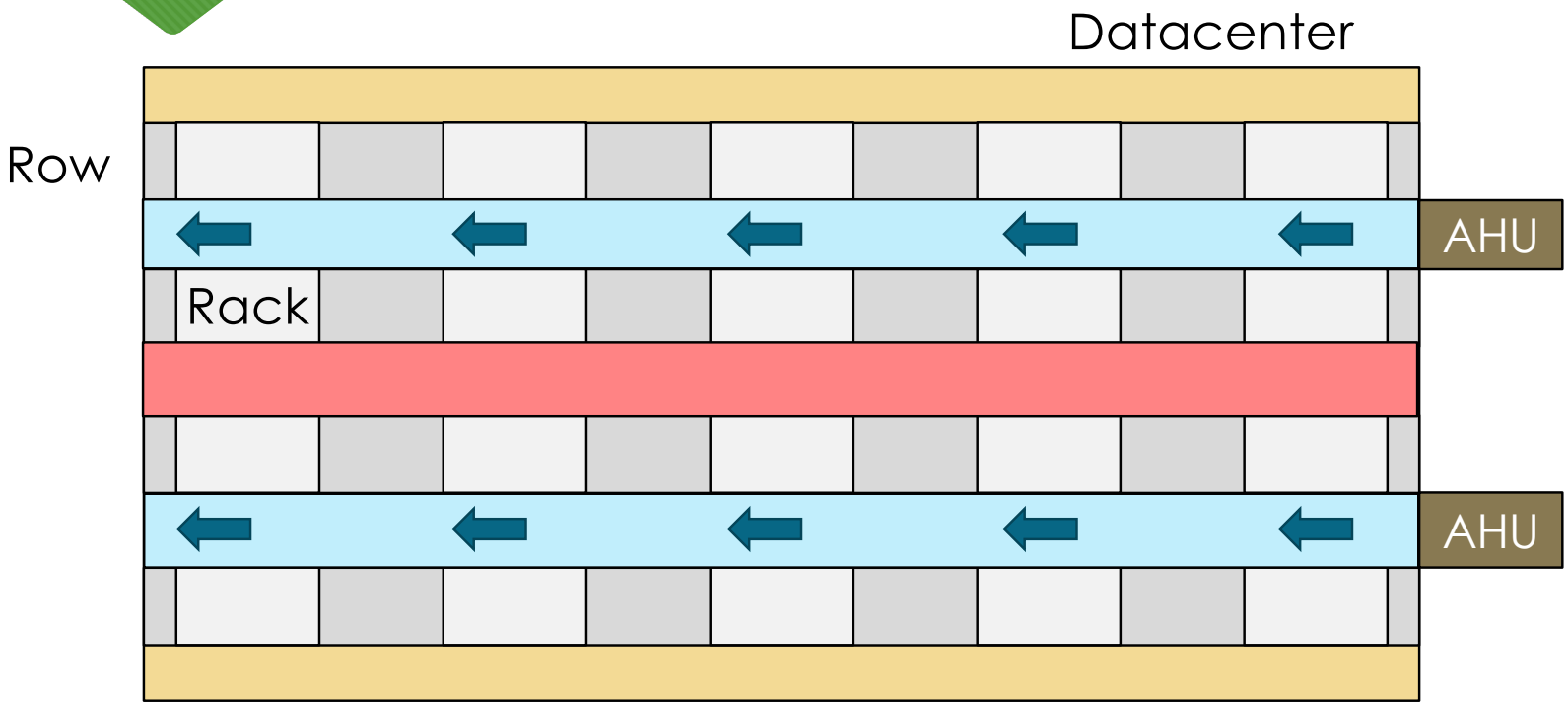
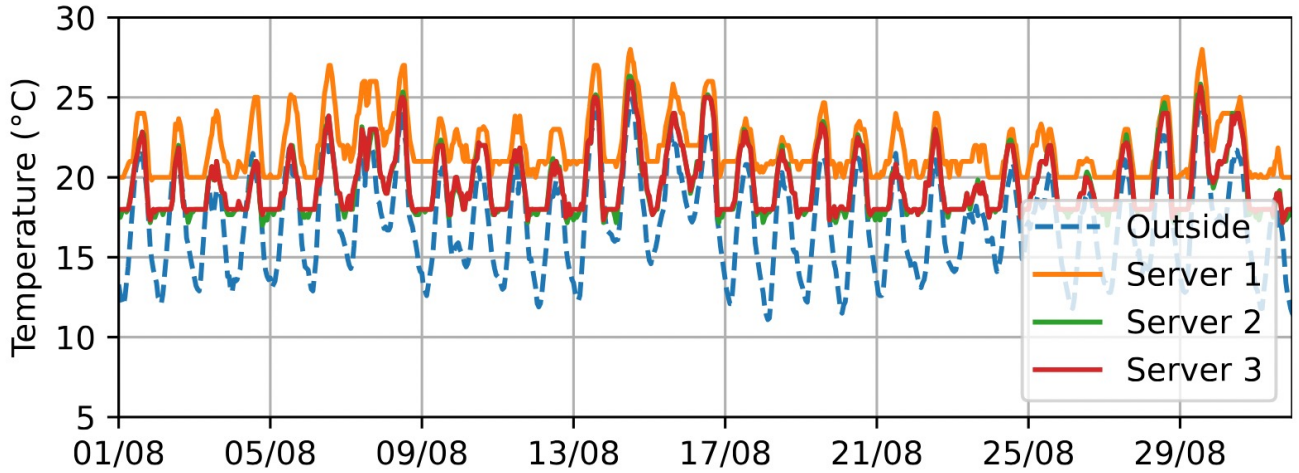


Challenge #1: Cooling Management

- Datacenter operators provision cooling infrastructure to sustain ***peak load***
  - Enough airflow in each aisle to prevent heat recirculation
  - Enough cooling to lower the temperature within operating conditions

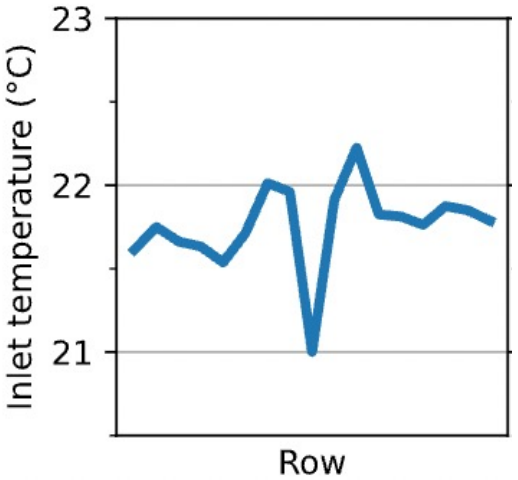
Challenge #1: Thermal Hotspots!

- Temperature of a GPU server depends on:
  1. Outside temperature



Challenge #1: Thermal Hotspots!

- Temperature of a GPU server depends on:
  2. Datacenter layout



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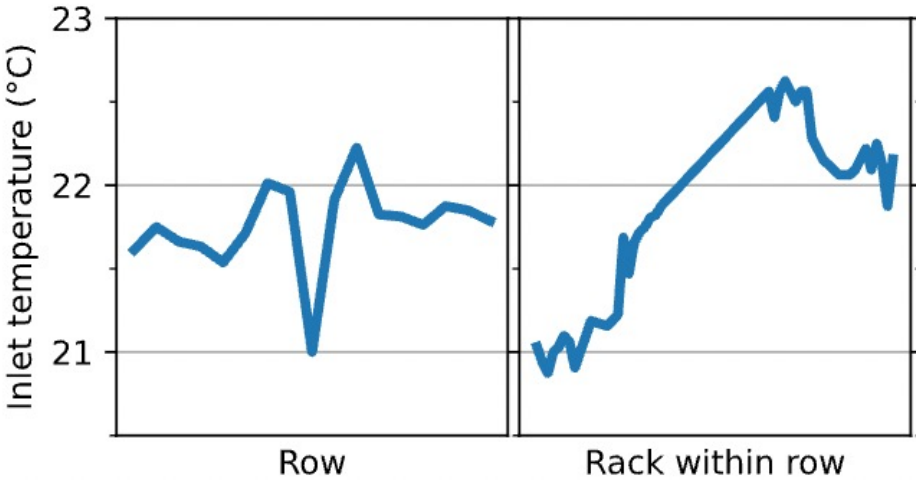

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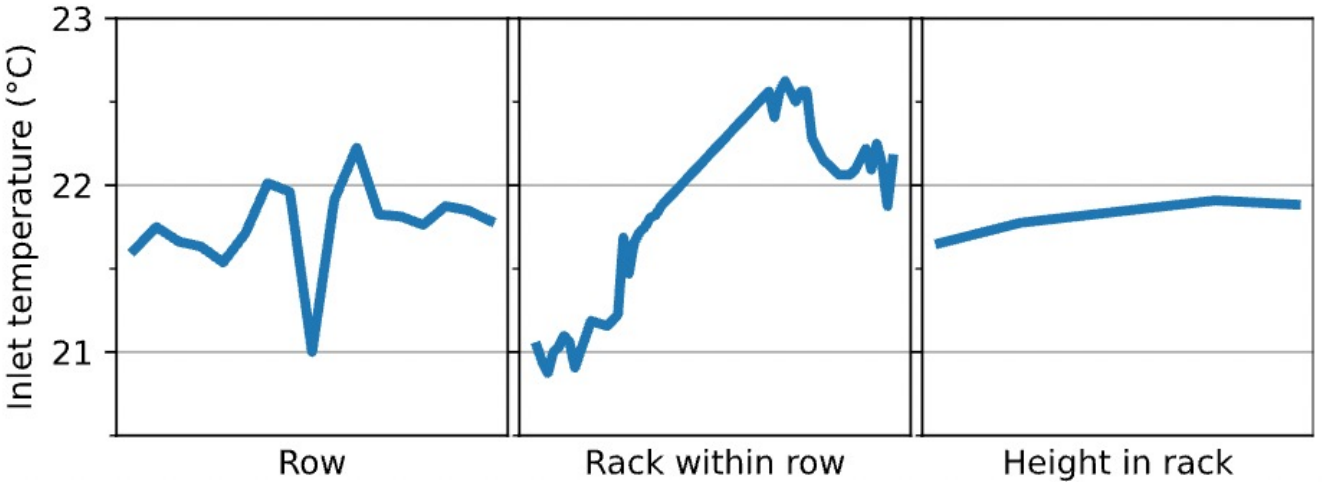

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- Temperature of a GPU server depends on:
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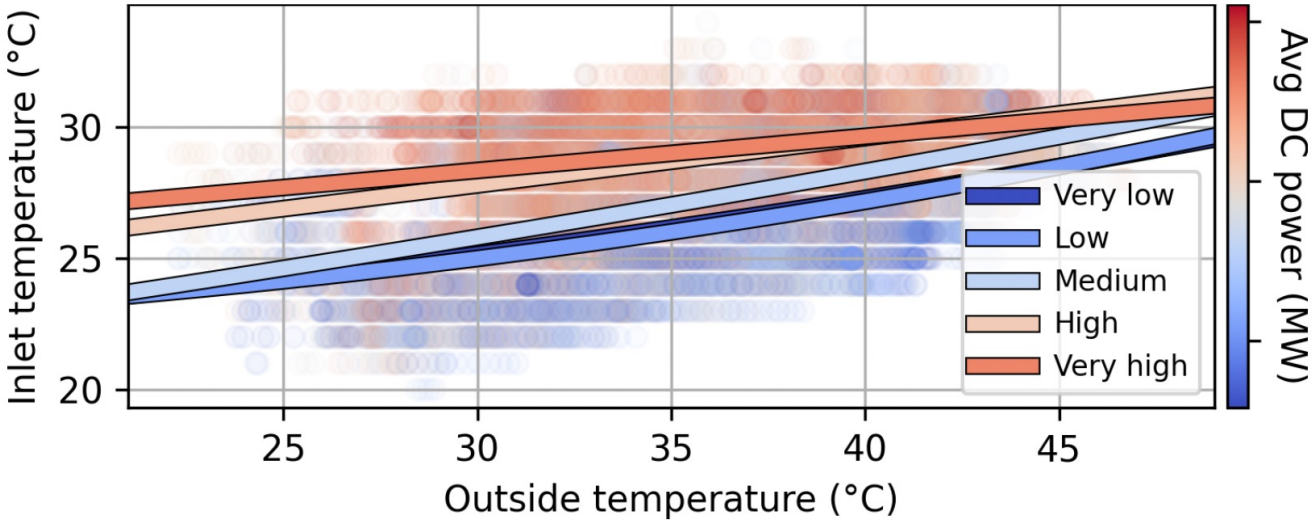

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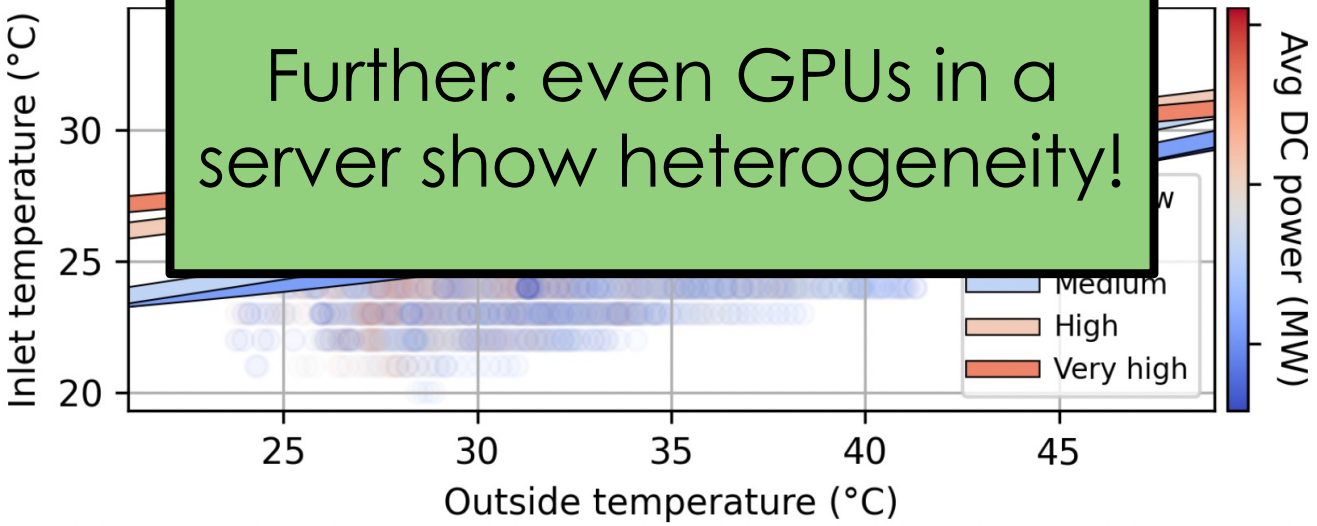
- Temperature of a GPU server depends on:
  3. Server's load

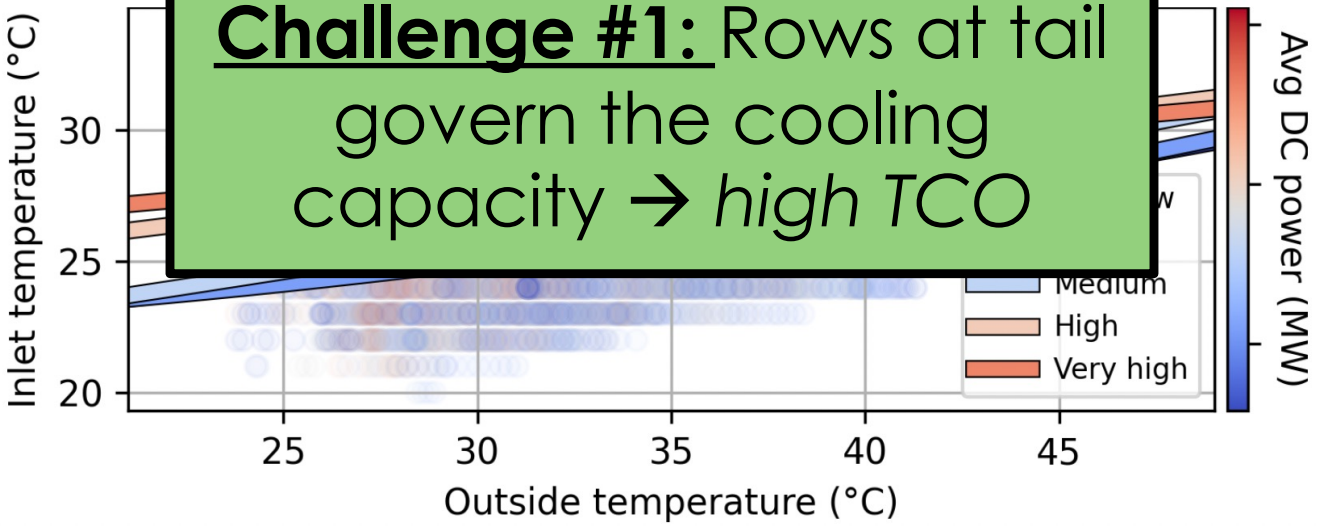
Further: even GPUs in a server show heterogeneity!



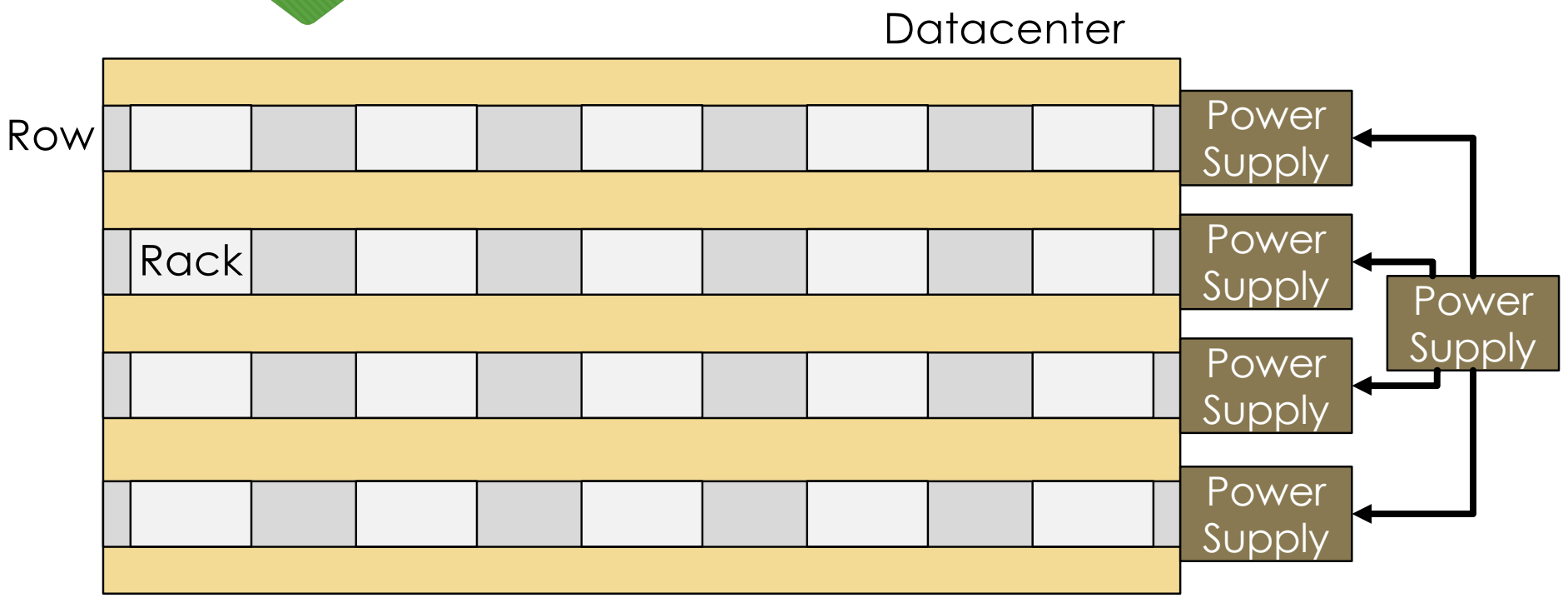
Challenge #1: Thermal Hotspots!

- Temperature of a GPU server depends on:
  3. Server's load

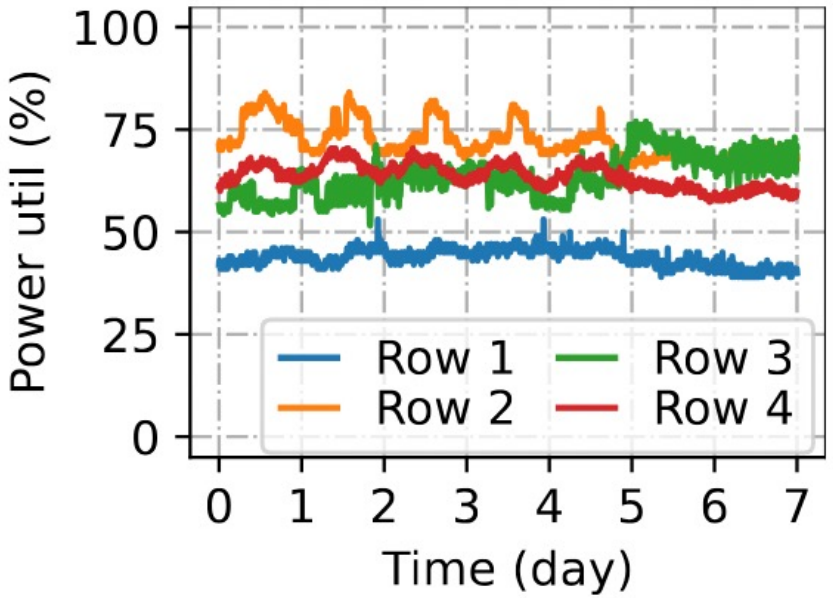
Challenge #1: Rows at tail govern the cooling capacity → *high TCO*



Challenge #2: Power Management



Challenge #2: Power Imbalance!



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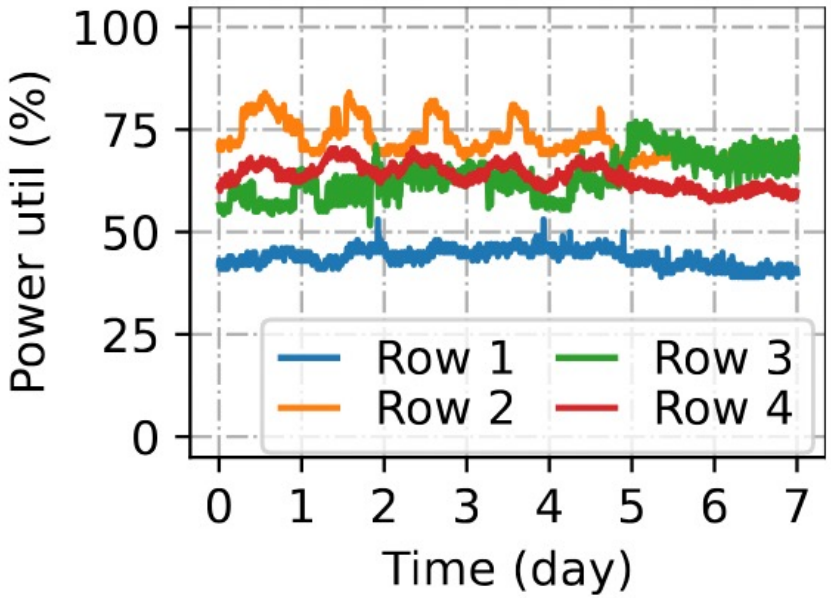

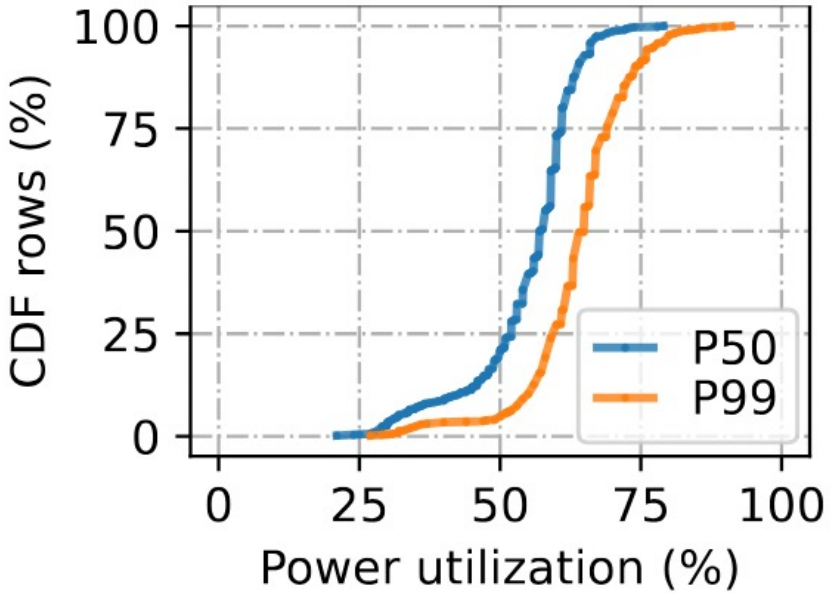

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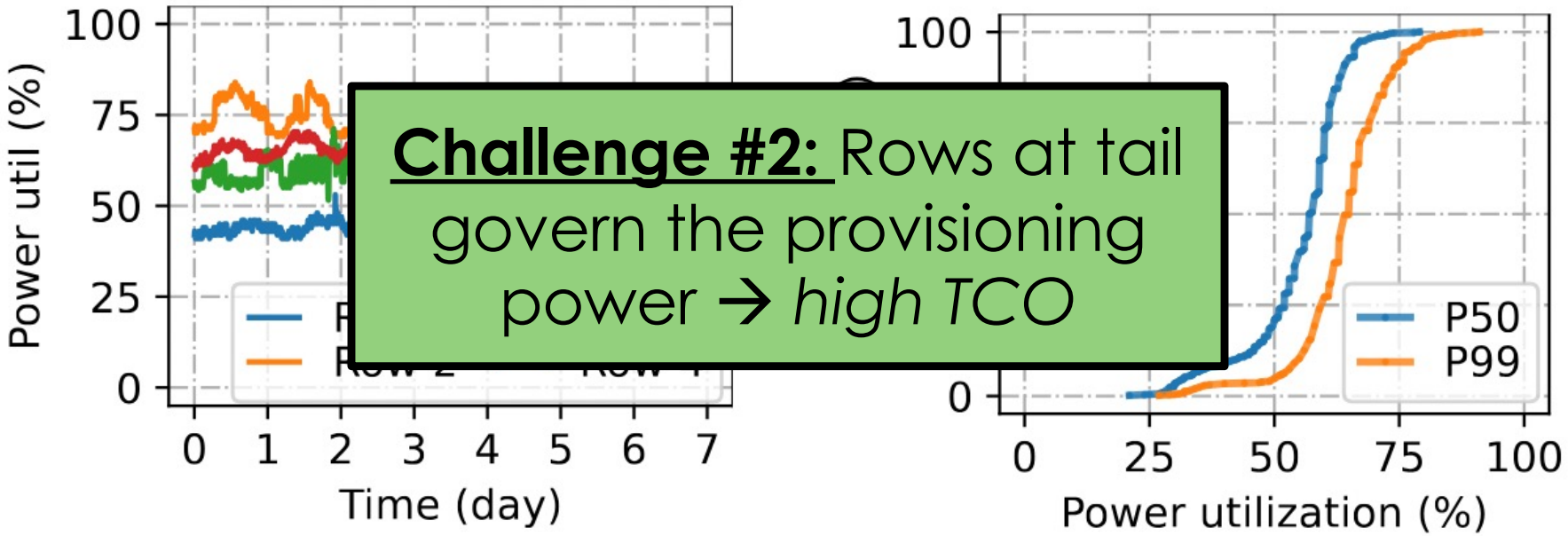
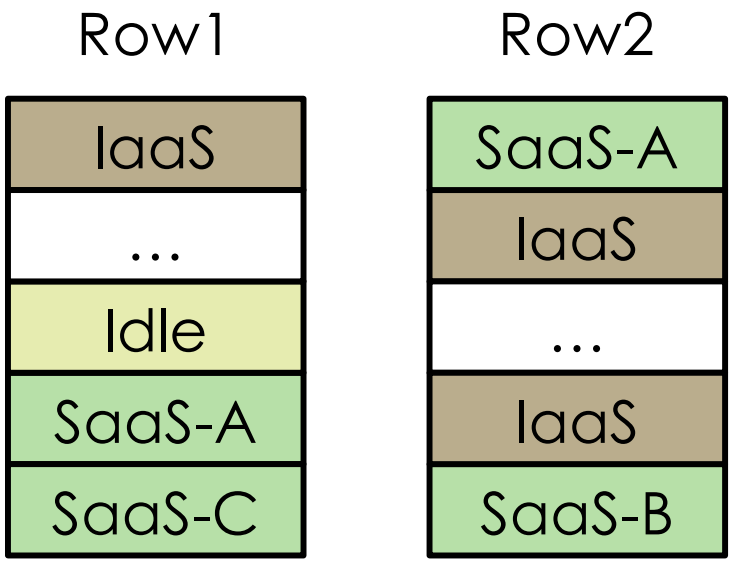


Challenge #2: Rows at tail govern the provisioning power → *high TCO*

Challenge #3: Heterogeneous Workloads



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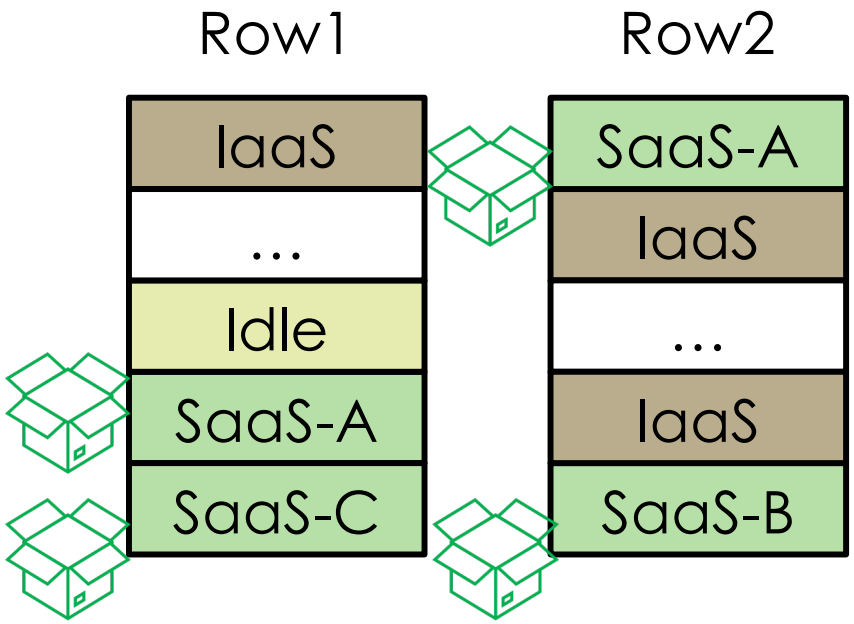


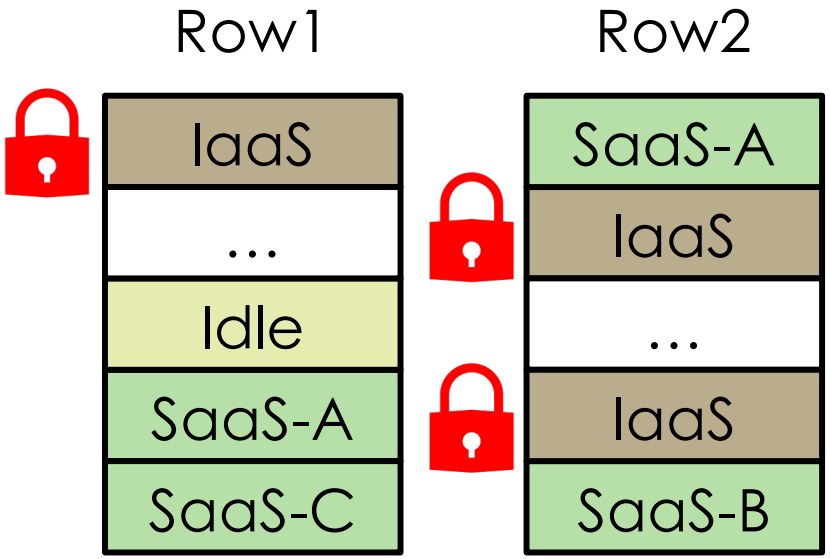
SaaS services

First-party

Good visibility

Good flexibility

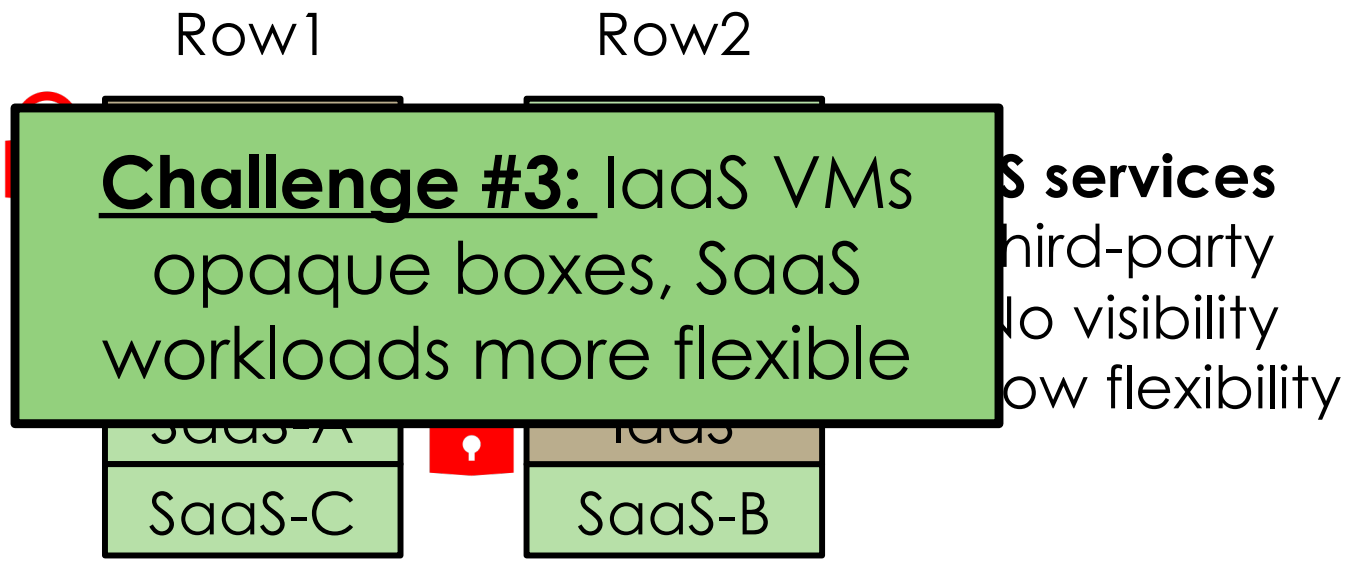
Challenge #3: Heterogeneous Workloads



IaaS services

- Third-party
- No visibility
- Low flexibility

Challenge #3: Heterogeneous Workloads



Challenge #3: IaaS VMs opaque boxes, SaaS workloads more flexible

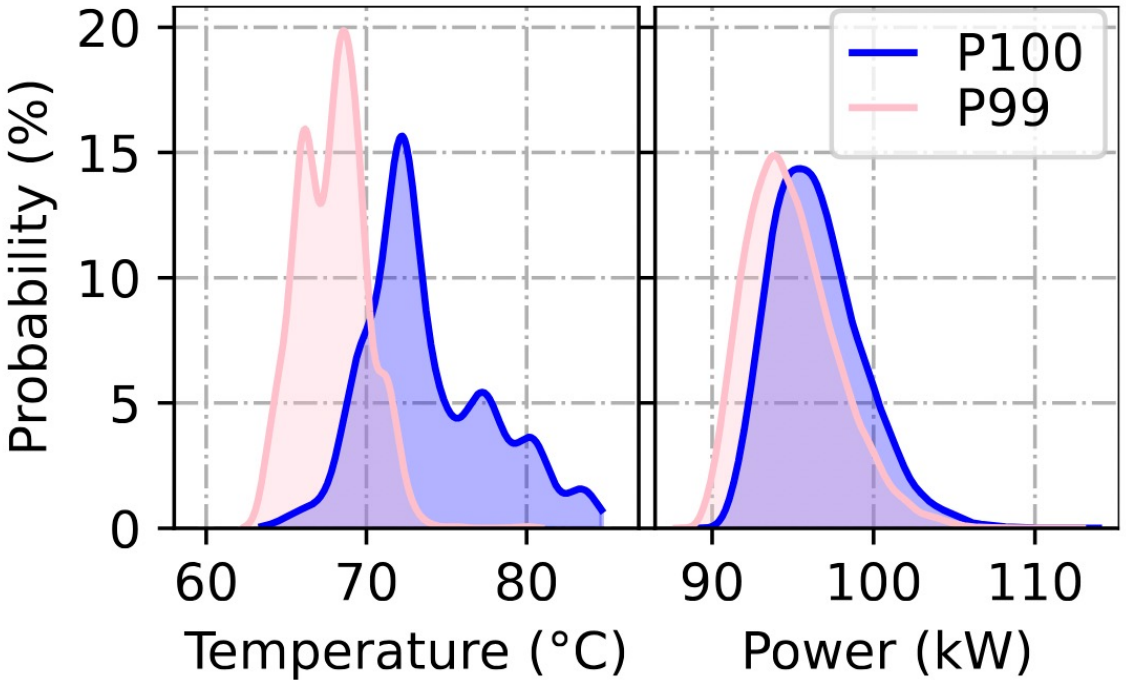
S services
hird-party
lo visibility
ow flexibility

How to Address the Challenges?

- Thermal- and power-aware:
  - Workload placement
  - Instance configuration
  - Request scheduling

Opportunity #1: Smart Workload Placement

- 100K random VM placements
- Generate diverse thermal and power distributions



Opportunity #1: Smart Workload Placement

- 100K random VM placements
- Generate c
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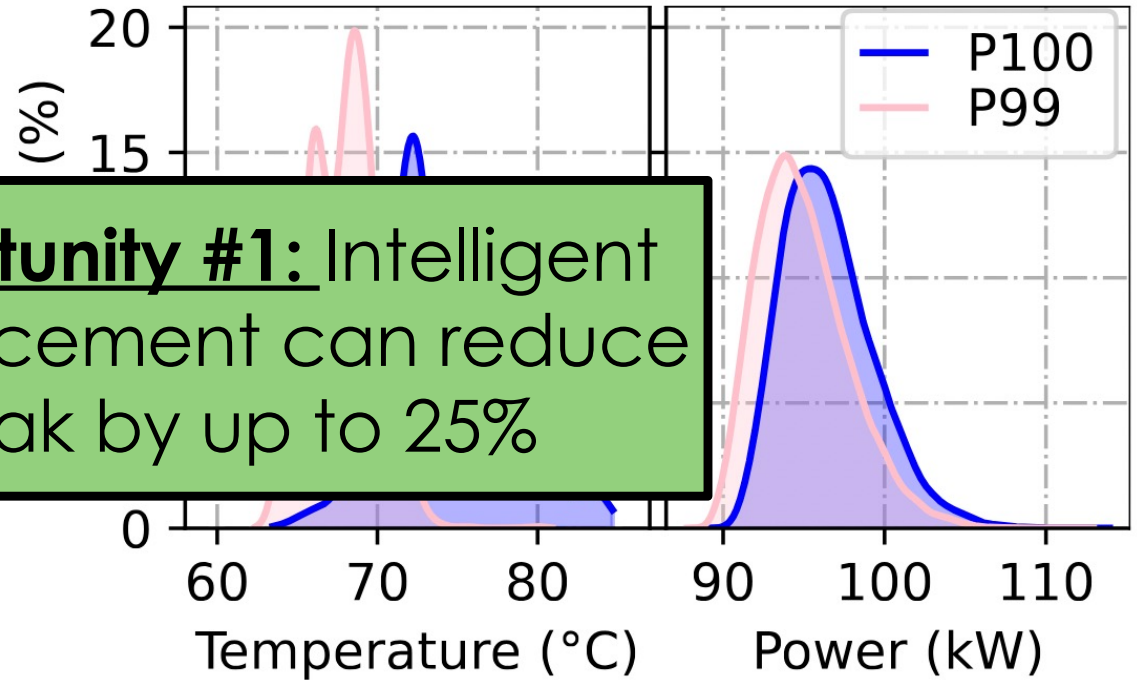
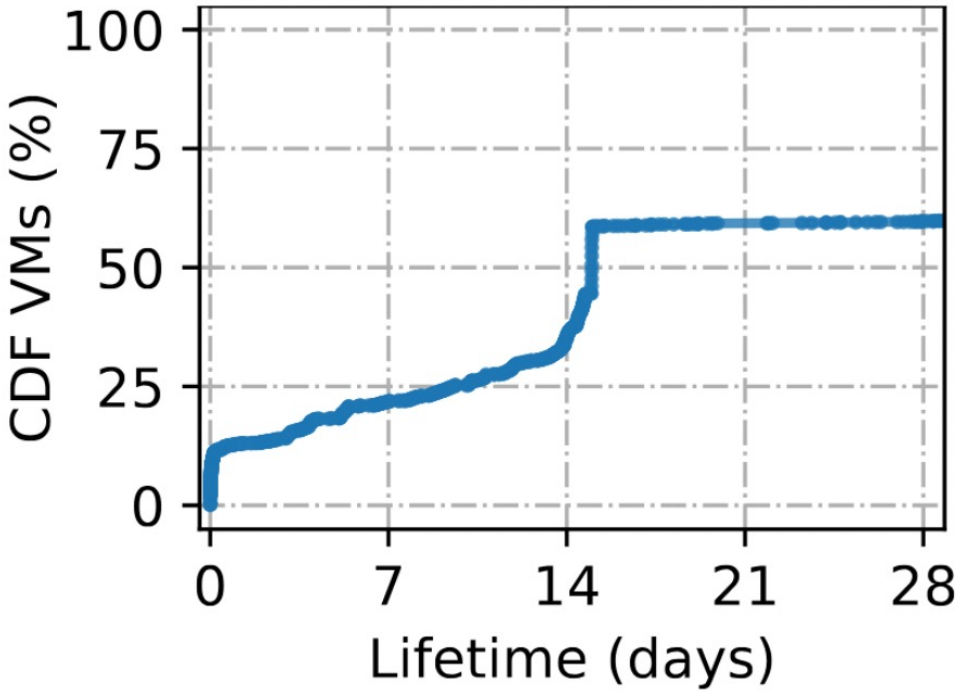
Opportunity #1: Intelligent VM placement can reduce peak by up to 25%



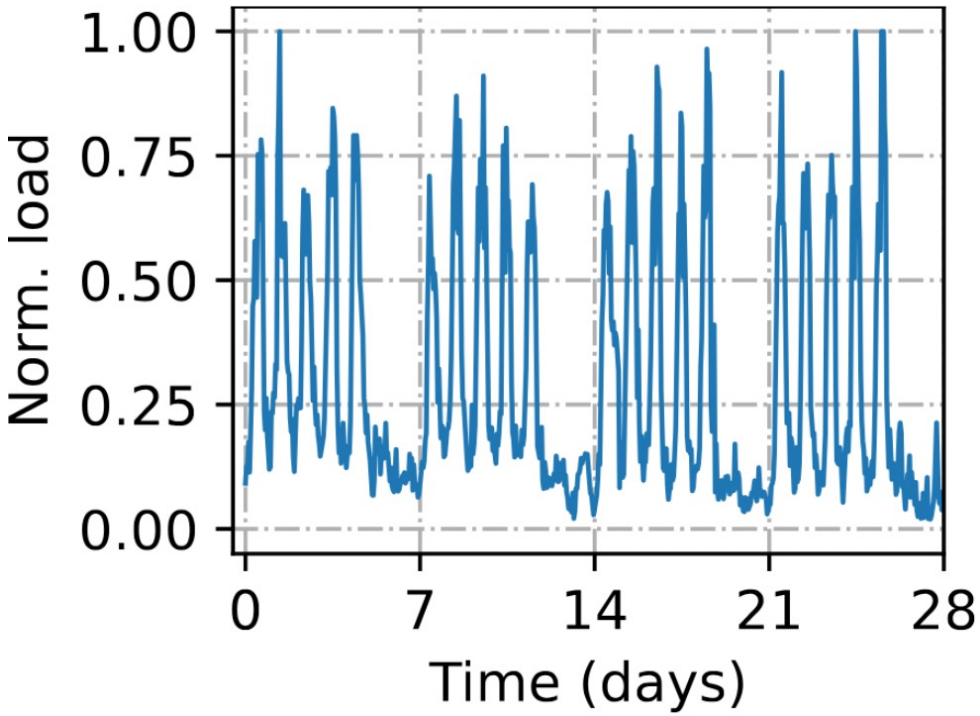
Opportunity #1: Smart Workload Placement

- LLM inference VMs are long lived



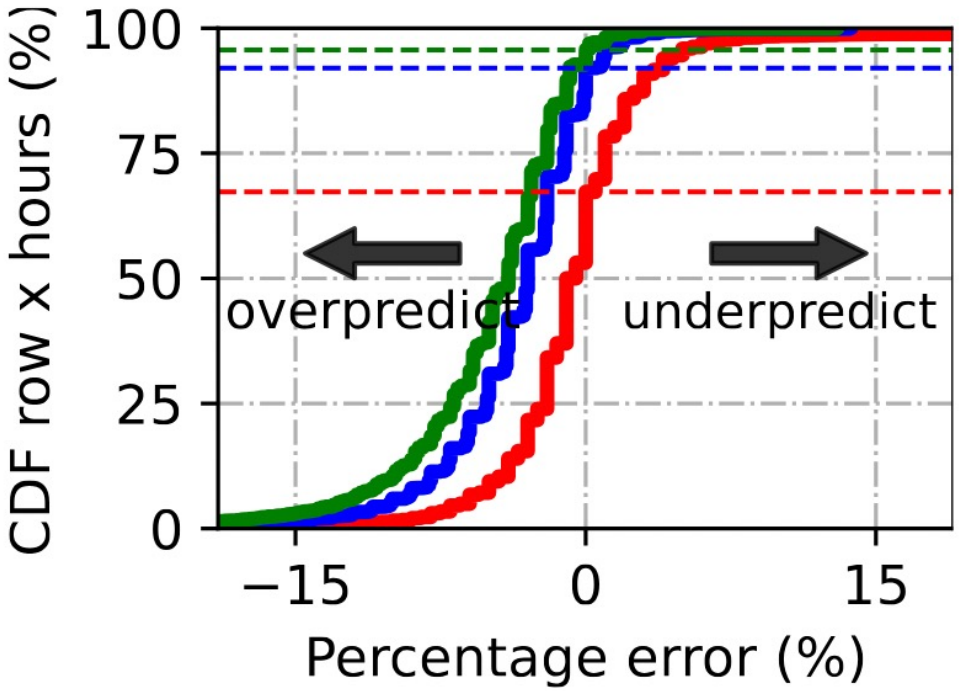
Opportunity #1: Smart Workload Placement

- LLM inference loads are periodic



Opportunity #1: Smart Workload Placement

- Long-lived instances with periodic loads → high predictability
- Accuracy over 90%



Opportunity #2: Tune Flexible SaaS LLM VMs

Knob	Power	Temp	Perf	Quality

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Knob	Power	Temp	Perf	Quality
Model Size ↓	↓	↓	↑	↓↓

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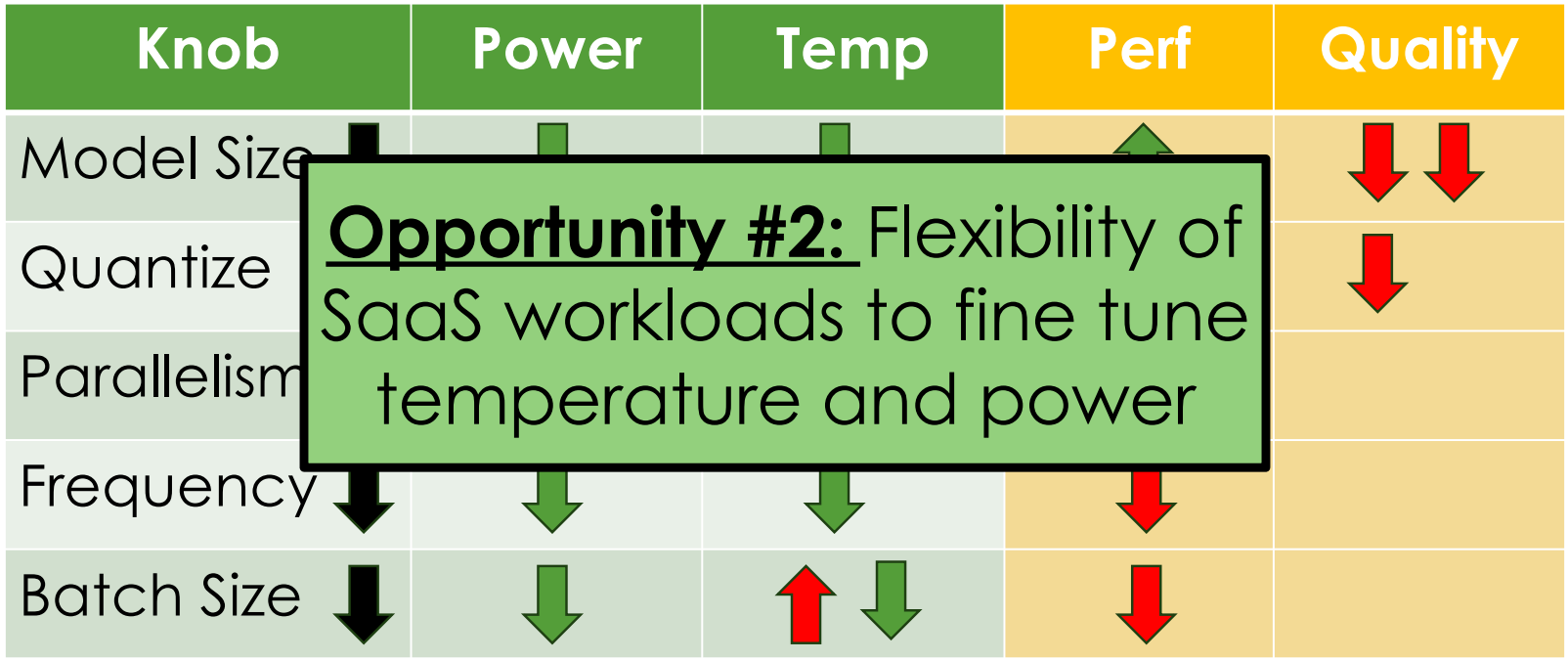

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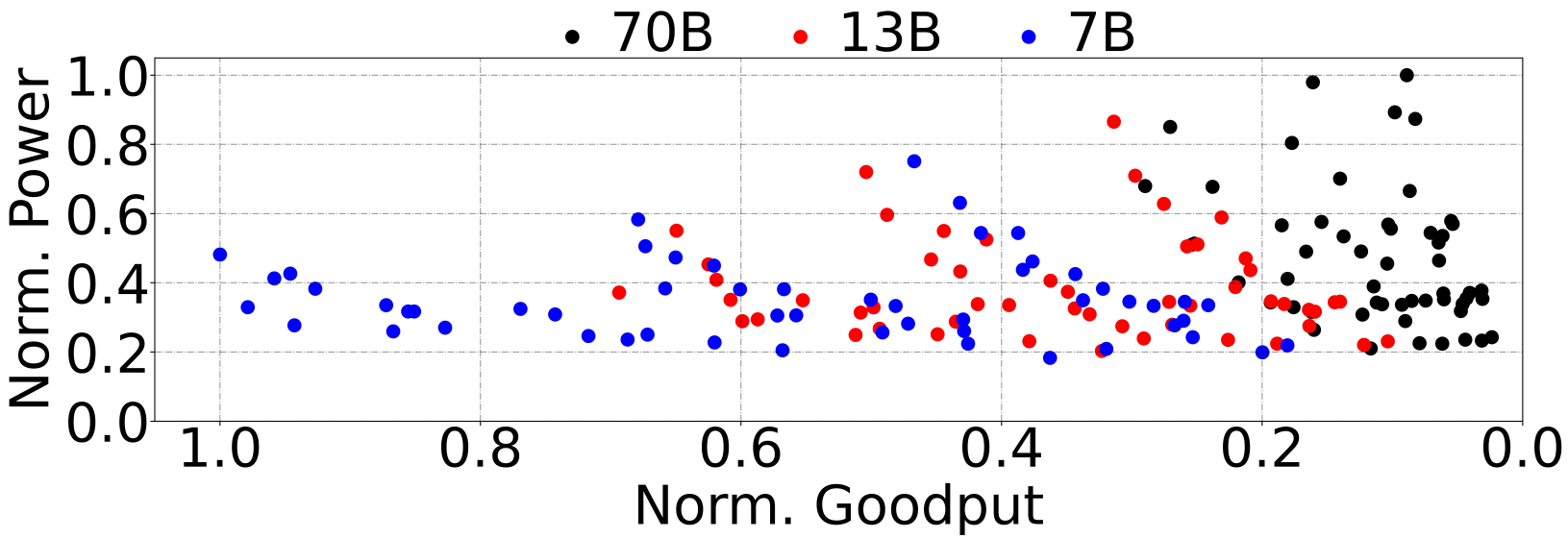

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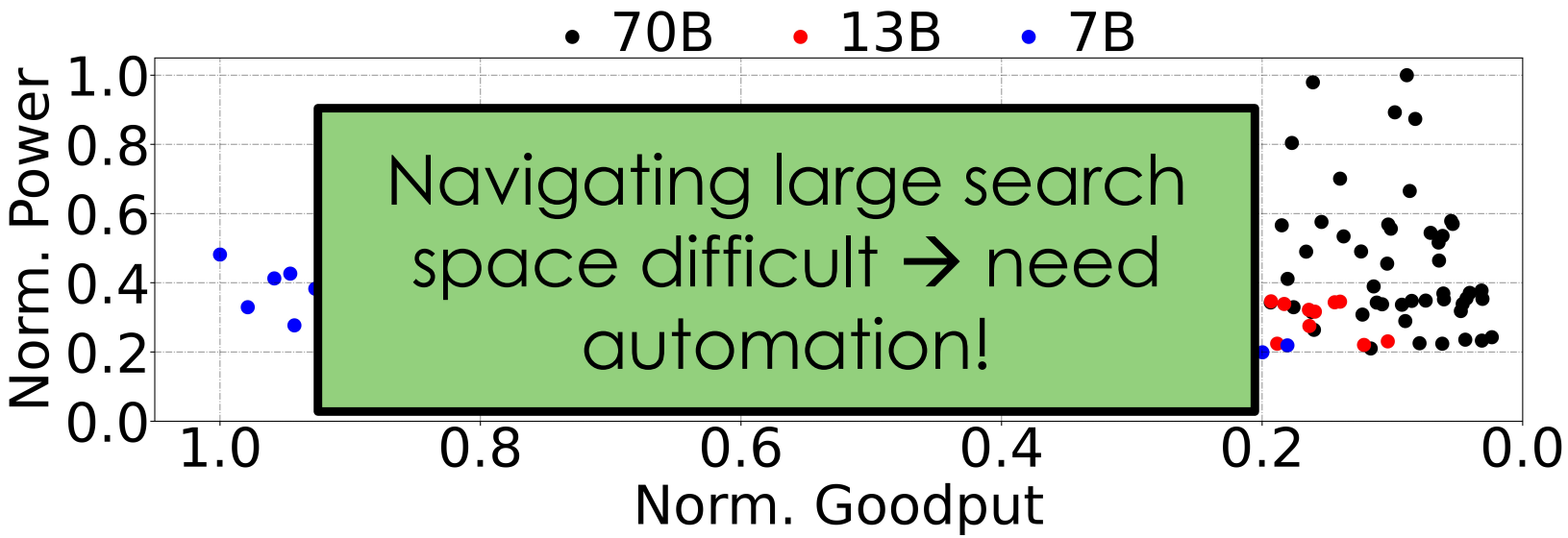
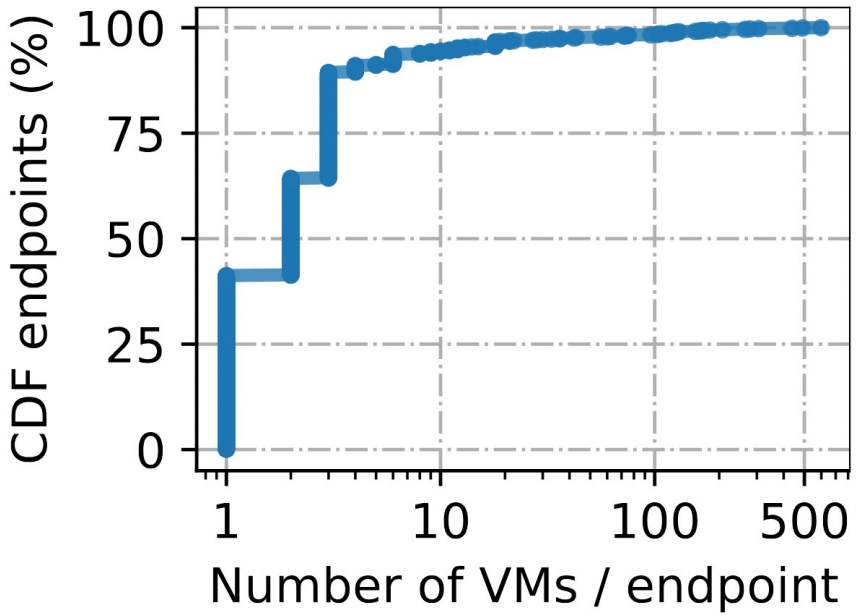


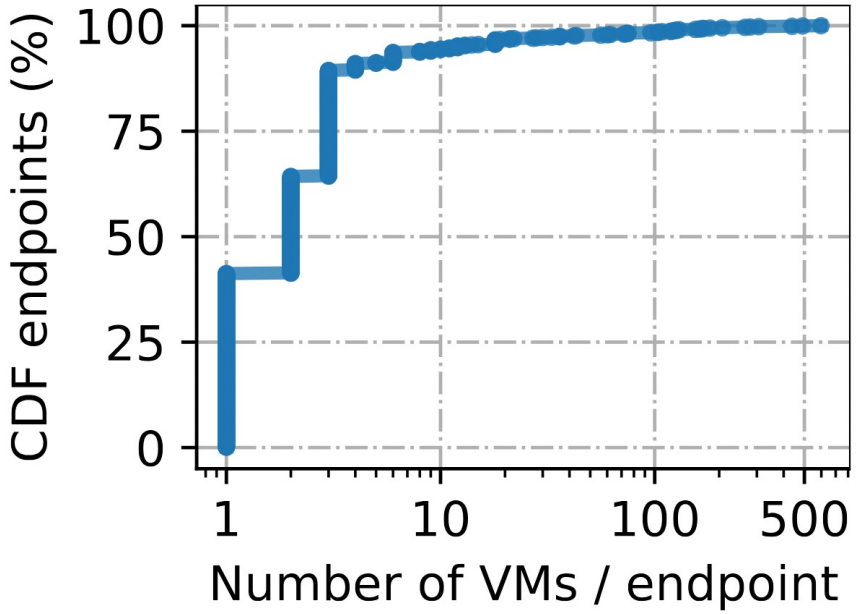
Opportunity #3: Smart Request Routing

- LLM inference service spans many VMs



Opportunity #3: Smart Request Routing

- LLM inference service spans many VMs
- VMs of a given service can be placed in different rows



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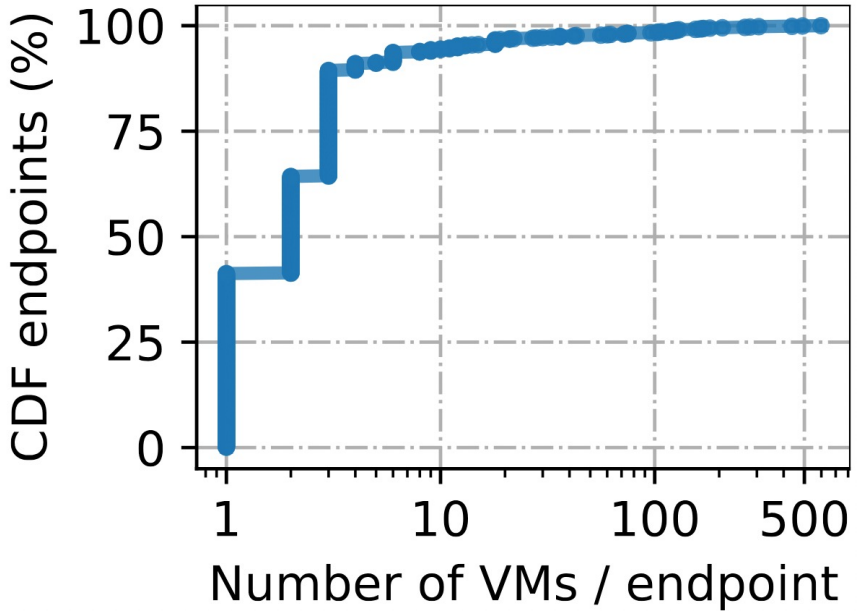
- VMs of a given service can be placed in different rows
- Load balance the requests in a thermal- and power-aware manner



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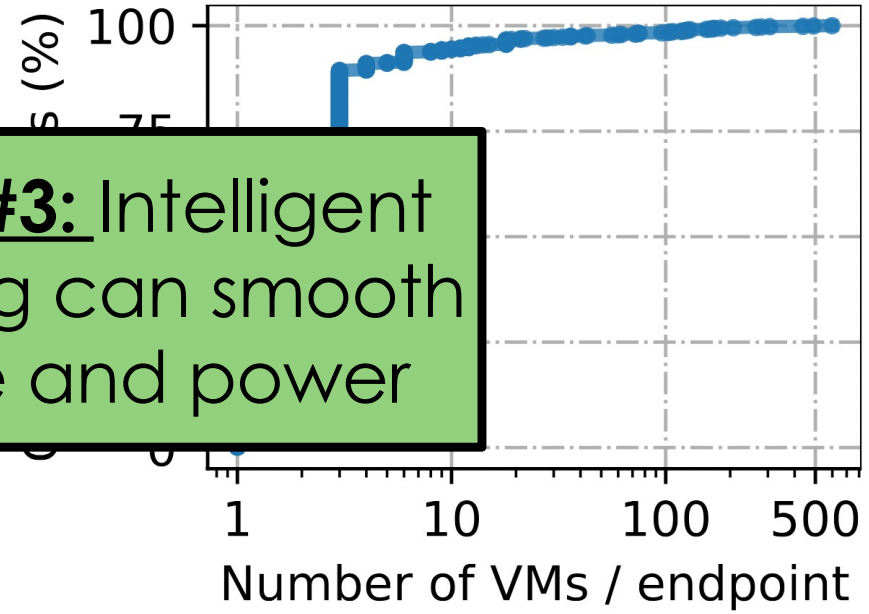
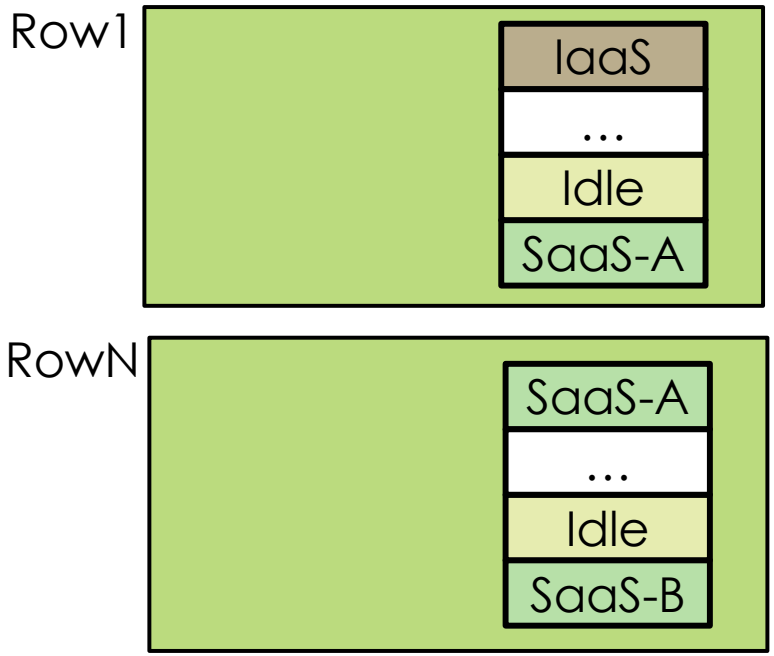
- LLM inference service spans many VMs
- VMs of a gi… be placed i…
- Load balan… in a thermal- and power-aware manner

Opportunity #3: Intelligent request routing can smooth temperature and power



TAPAS: Thermal- and Power-Aware Scheduling for LLM Inference in the Cloud

TAPAS: VM Placement



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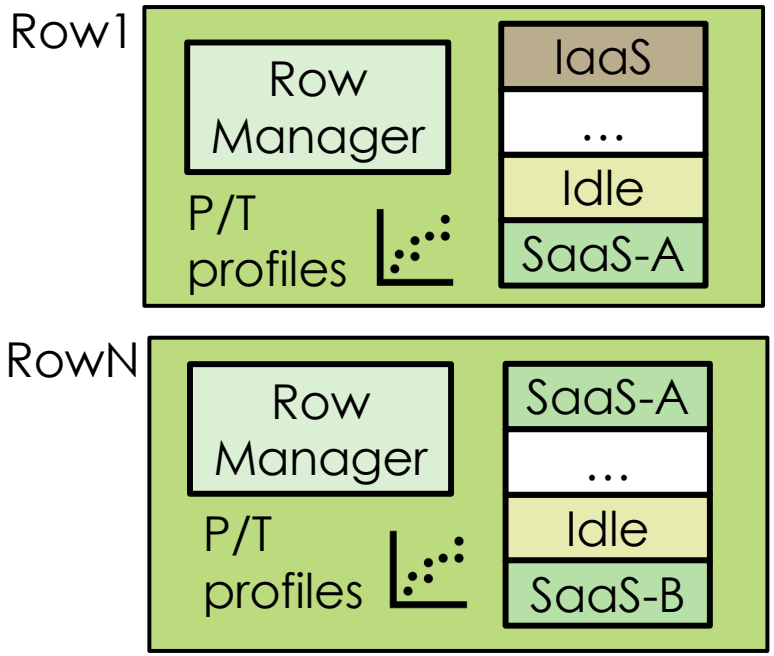

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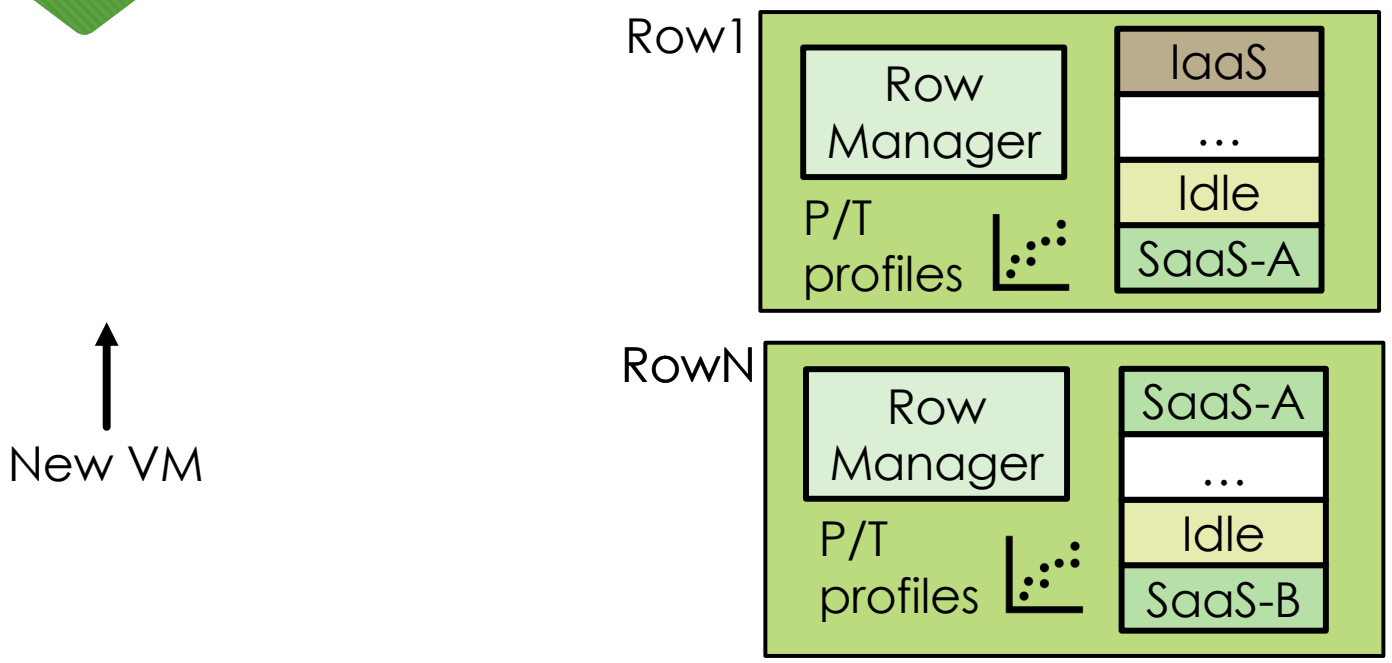

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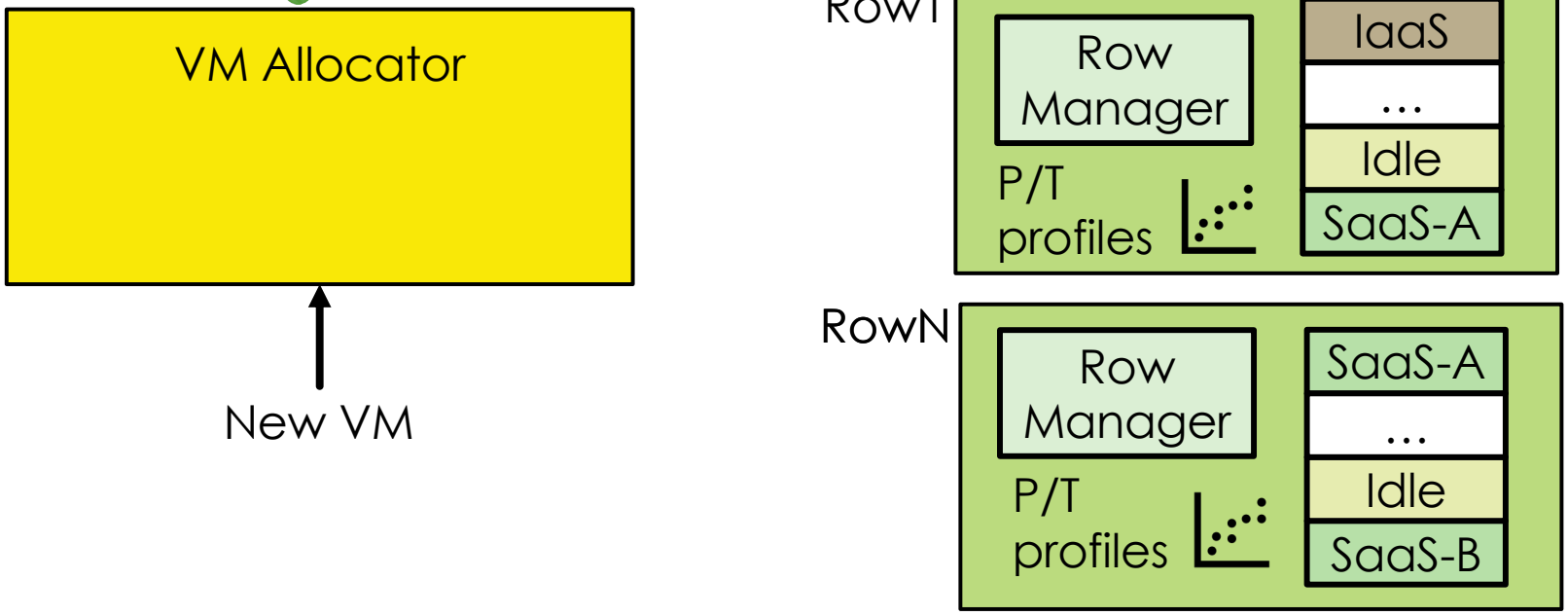
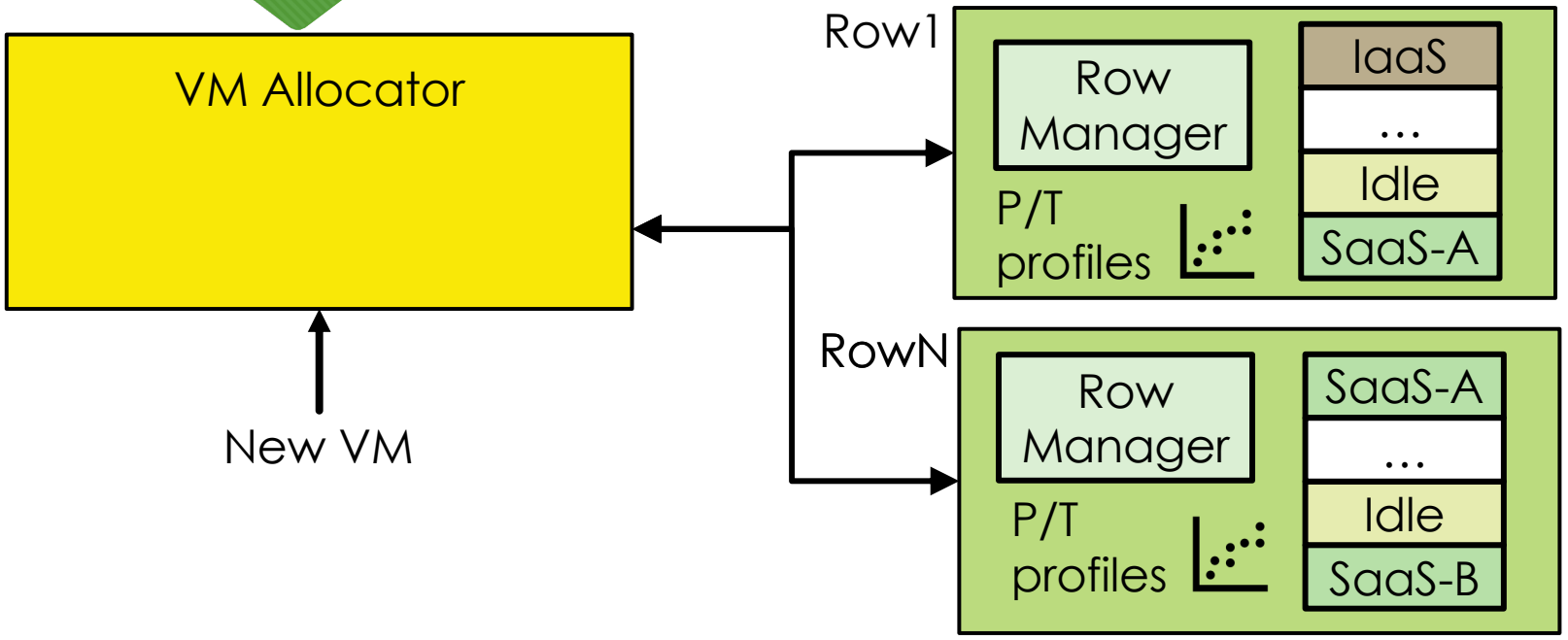
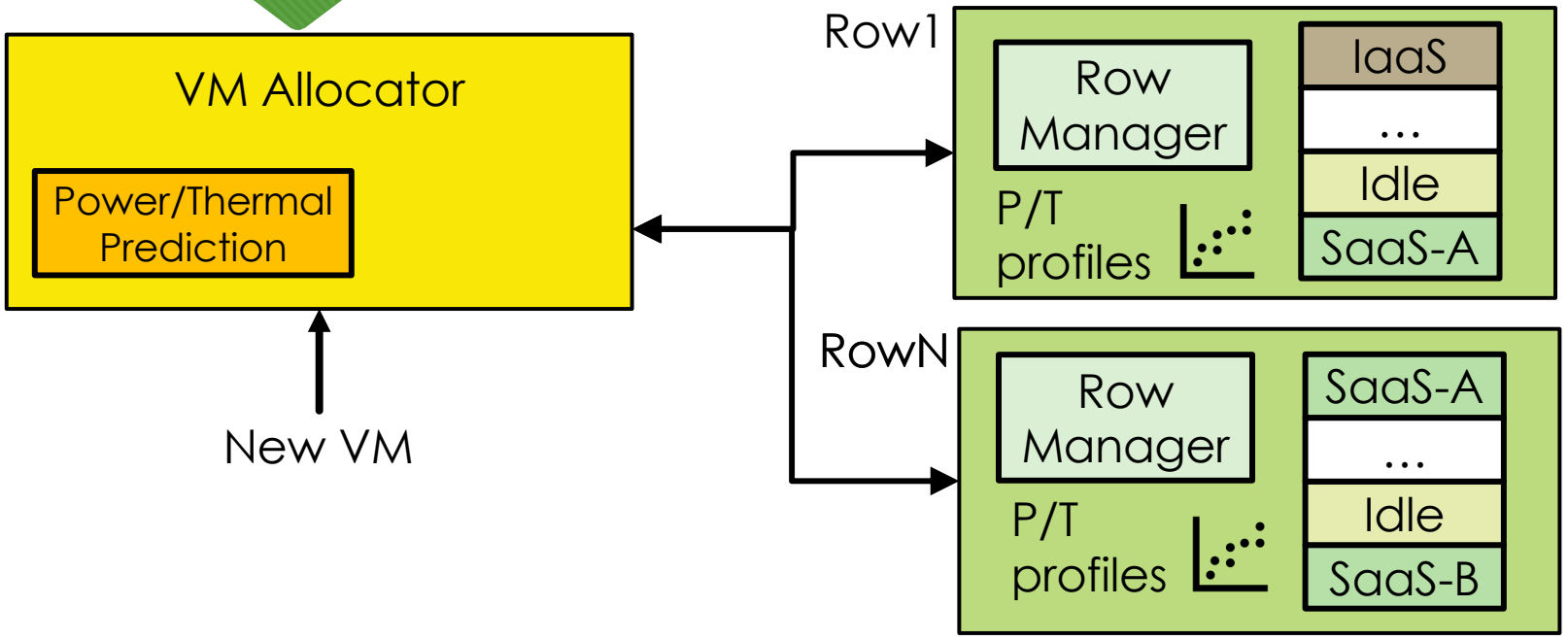


TAPAS: VM Placement



TAPAS: VM Placement



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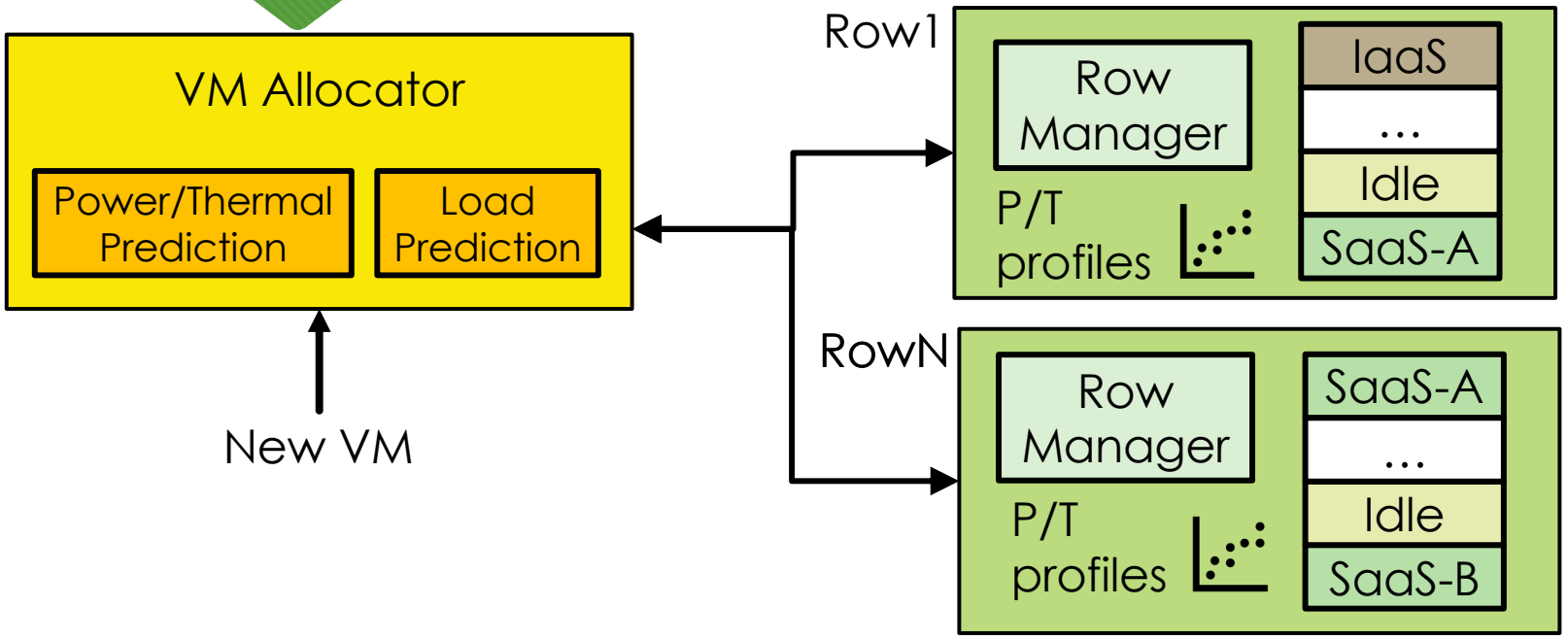
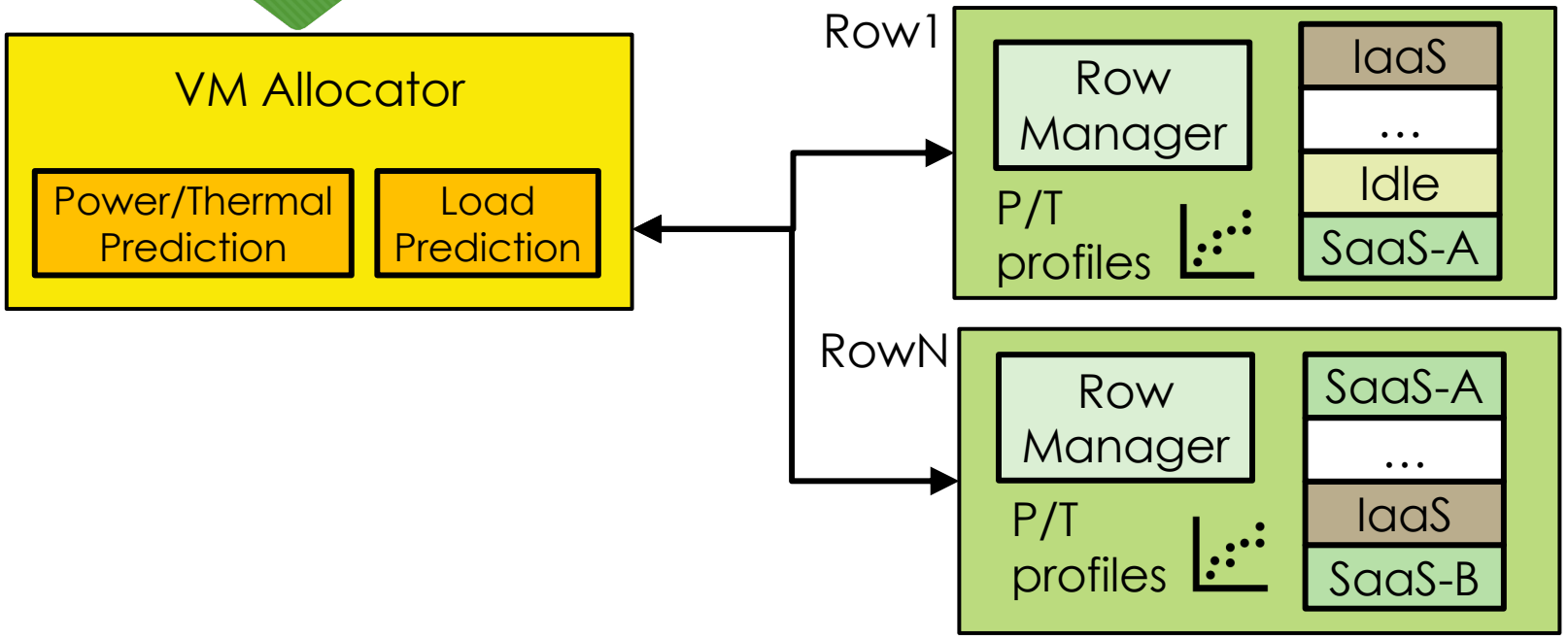
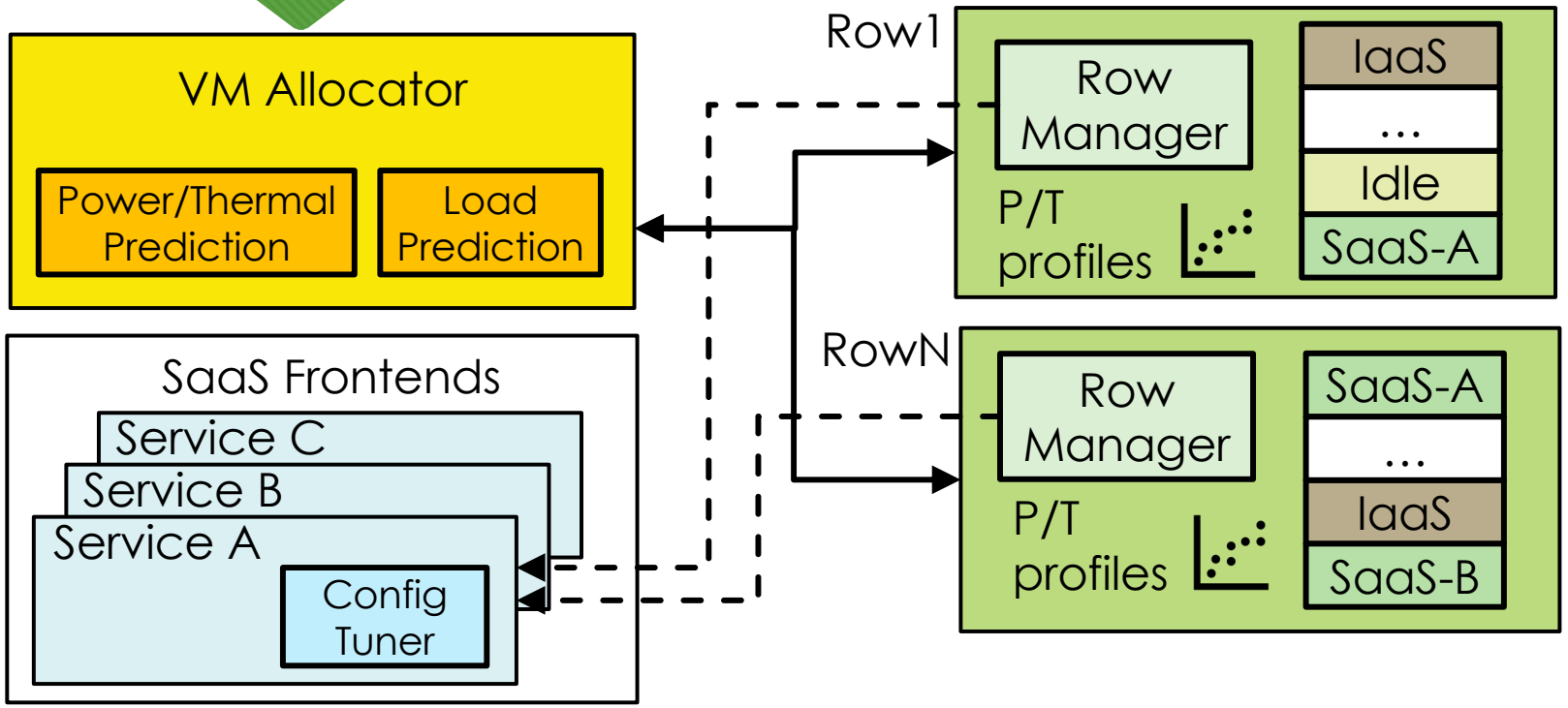


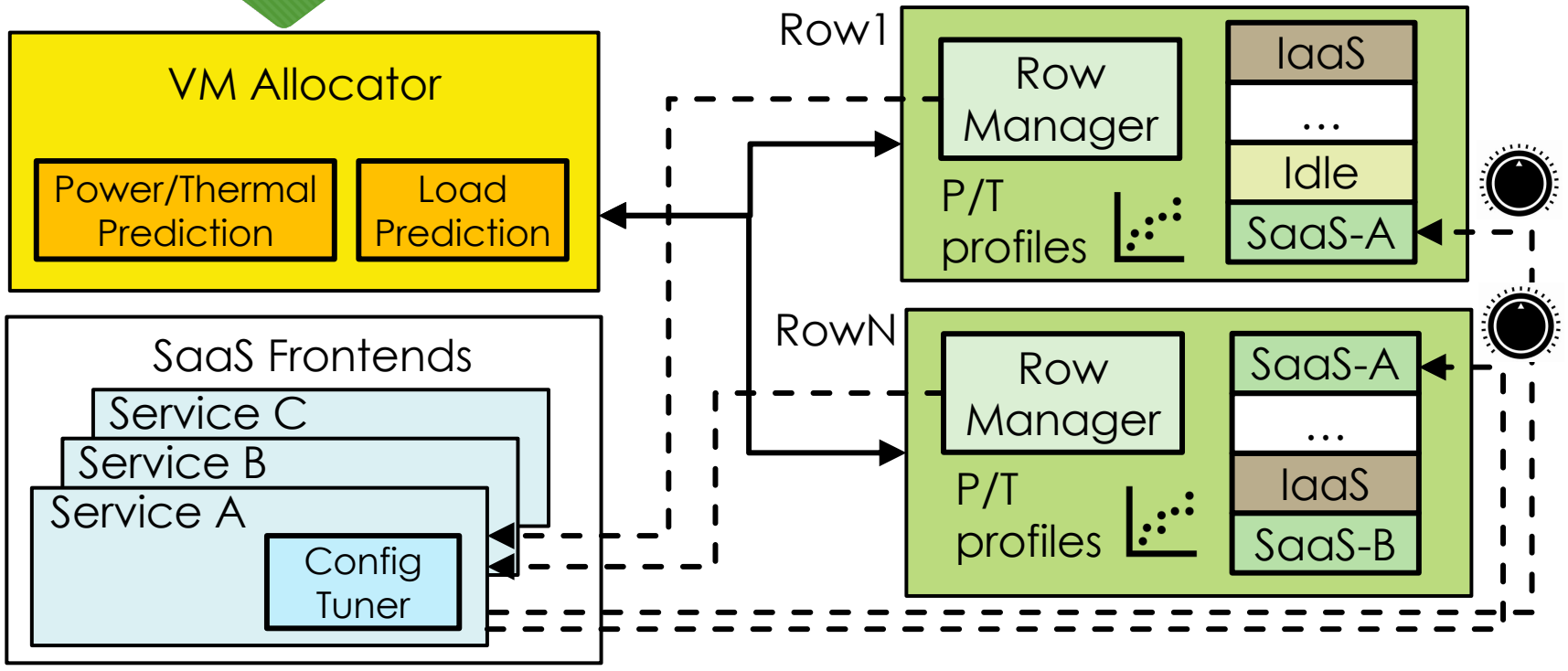
TAPAS: VM Placement



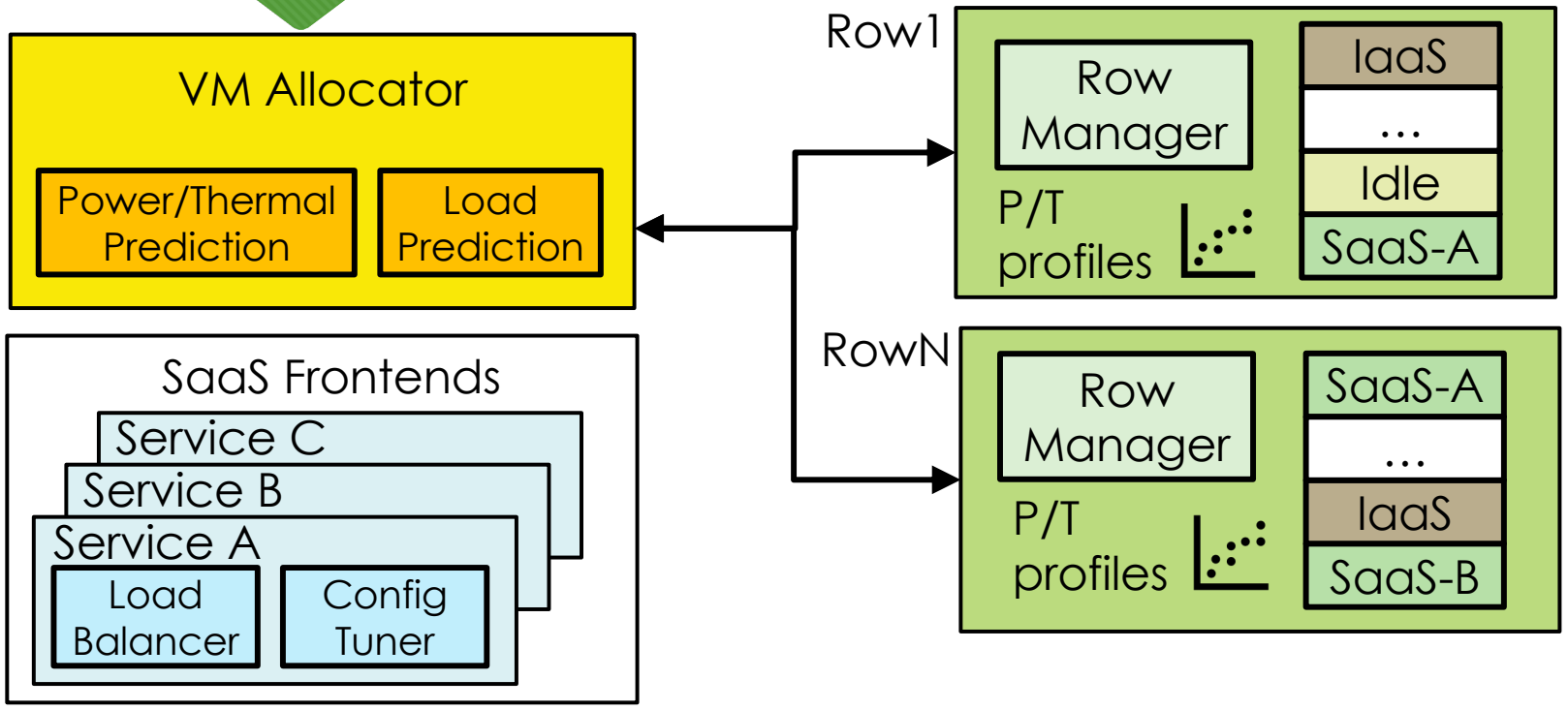
TAPAS: Configuration Tuning



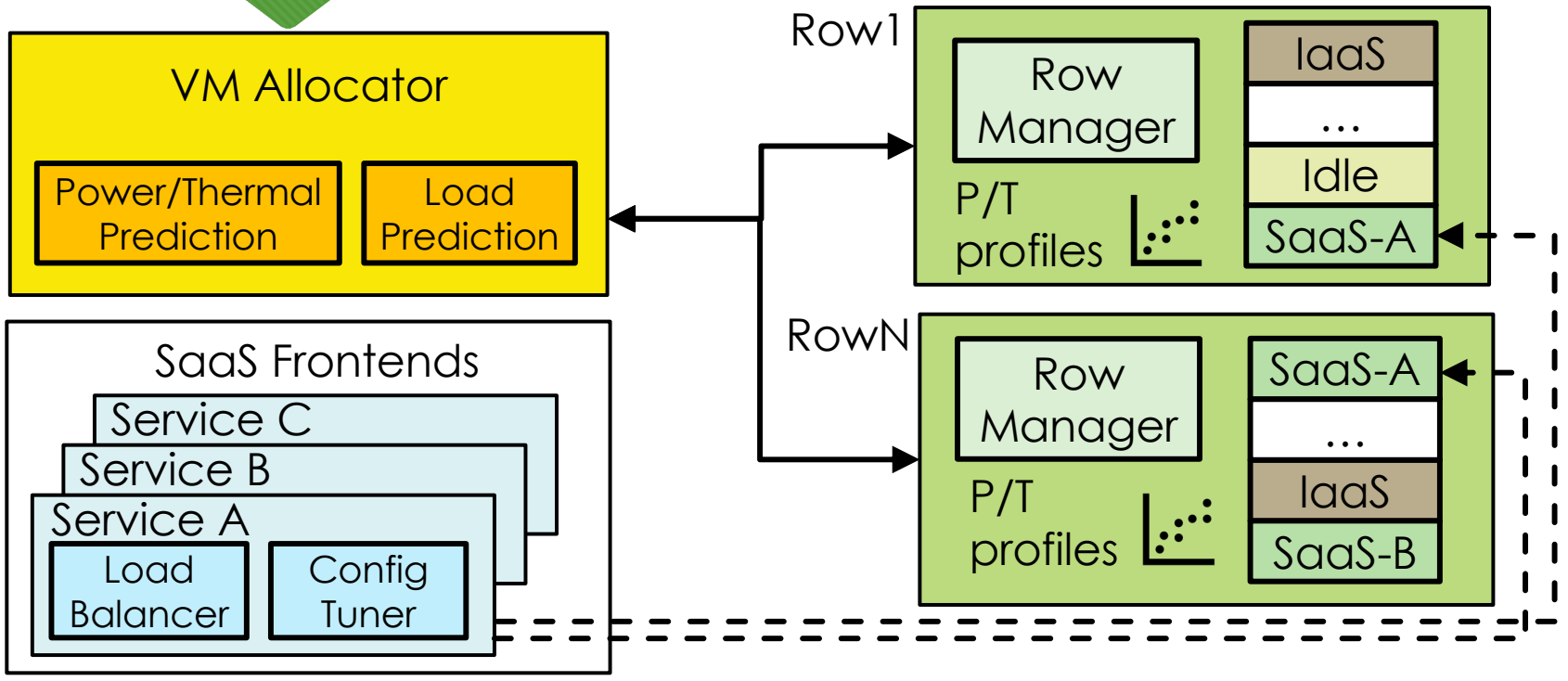
TAPAS: Configuration Tuning



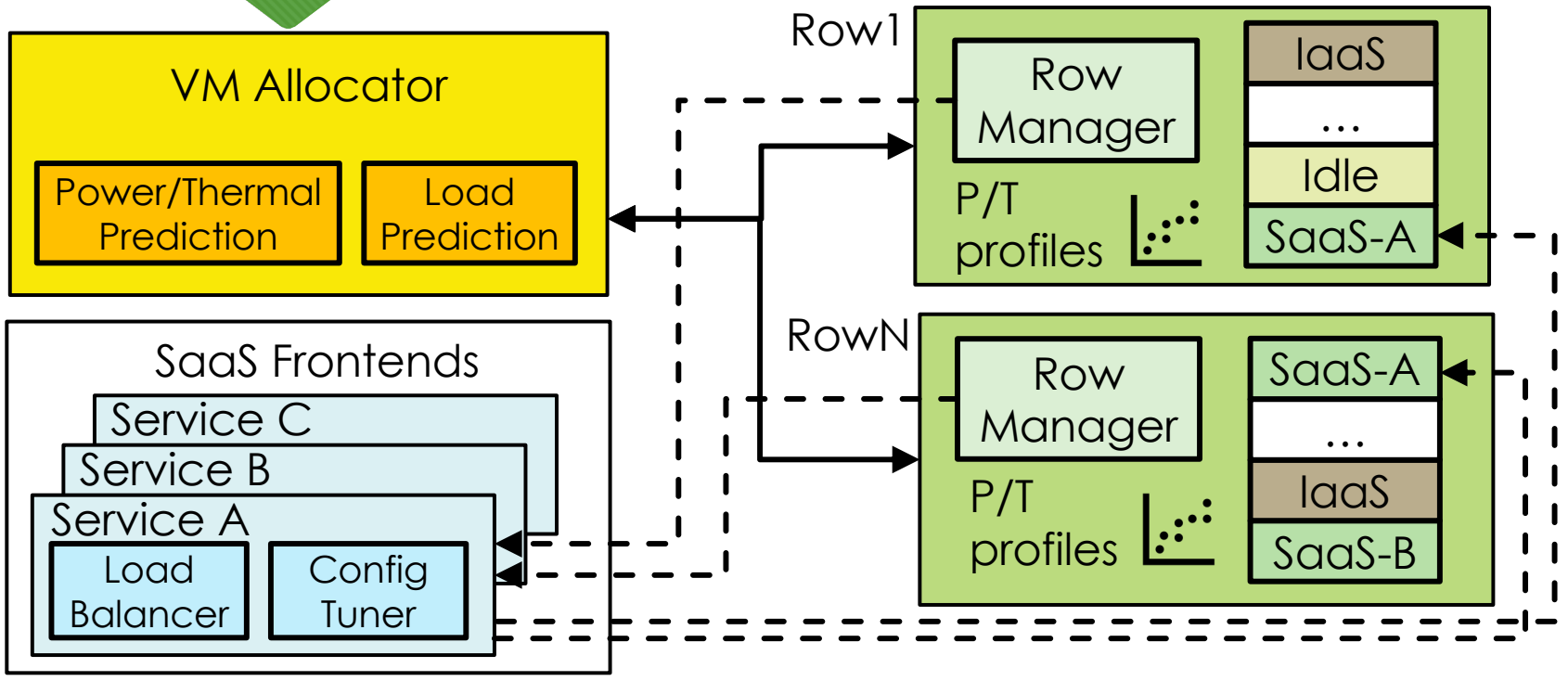
TAPAS: Request Routing



TAPAS: Request Routing



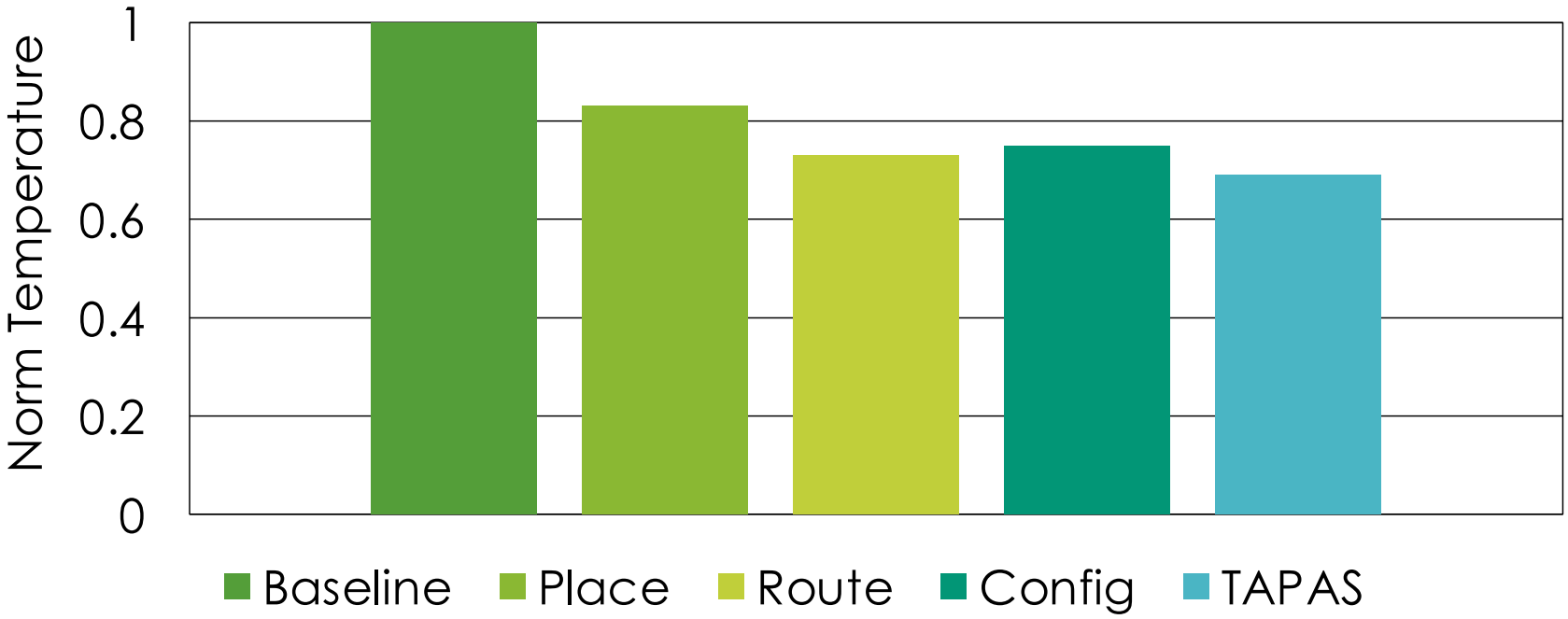
TAPAS: Request Routing



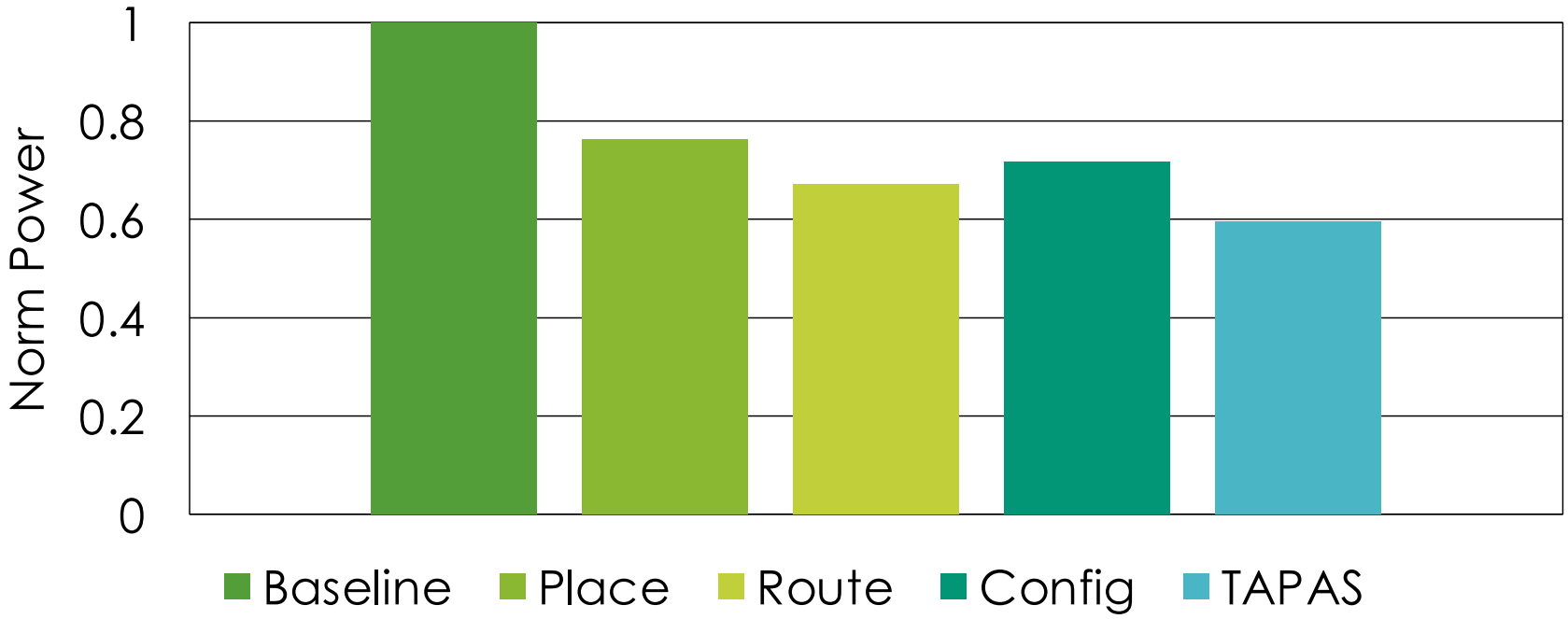
TAPAS Evaluation

- Real cluster experiments
  - Two rows of 80 A100 servers for 1 hour
  - IaaS: direct power and thermal readings
  - SaaS: reply production traces with Llama2 models
- Simulations
  - Week production trace from one of the A100 datacenters
  - Thermal and power modeling using our derived equations

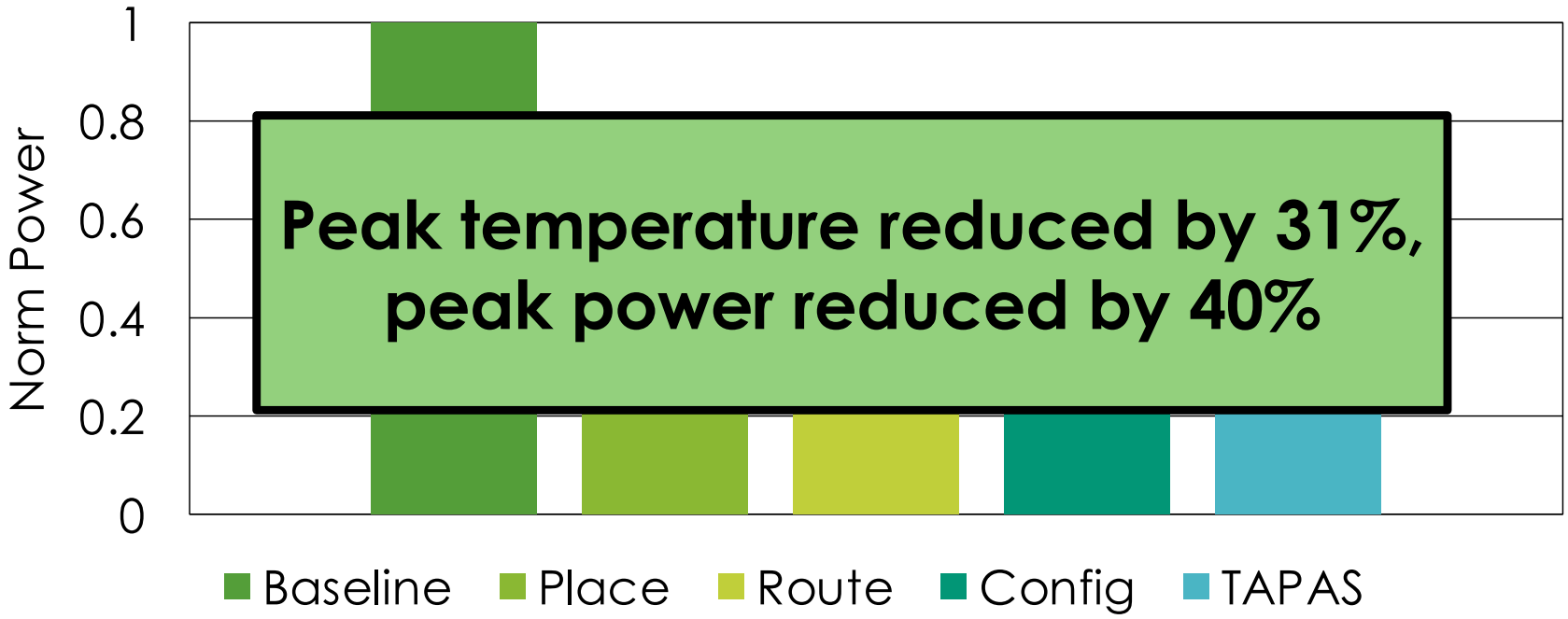
TAPAS Reduces Peak Temperature and Power!



TAPAS Reduces Peak Temperature and Power!



TAPAS Reduces Peak Temperature and Power!



Conclusion

- LLM inference emerging workload in the cloud
  - Its execution thermal- and power-inefficient
- Address these challenges for cost-effective datacenters
- ***TAPAS*** as a step towards our goals!

TAPAS: Thermal- and Power-Aware Scheduling for LLM Inference in Cloud Platforms

ASPLOS 2025

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