Cilantro

Performance-Aware Resource Allocation for General Objectives via Online Feedback

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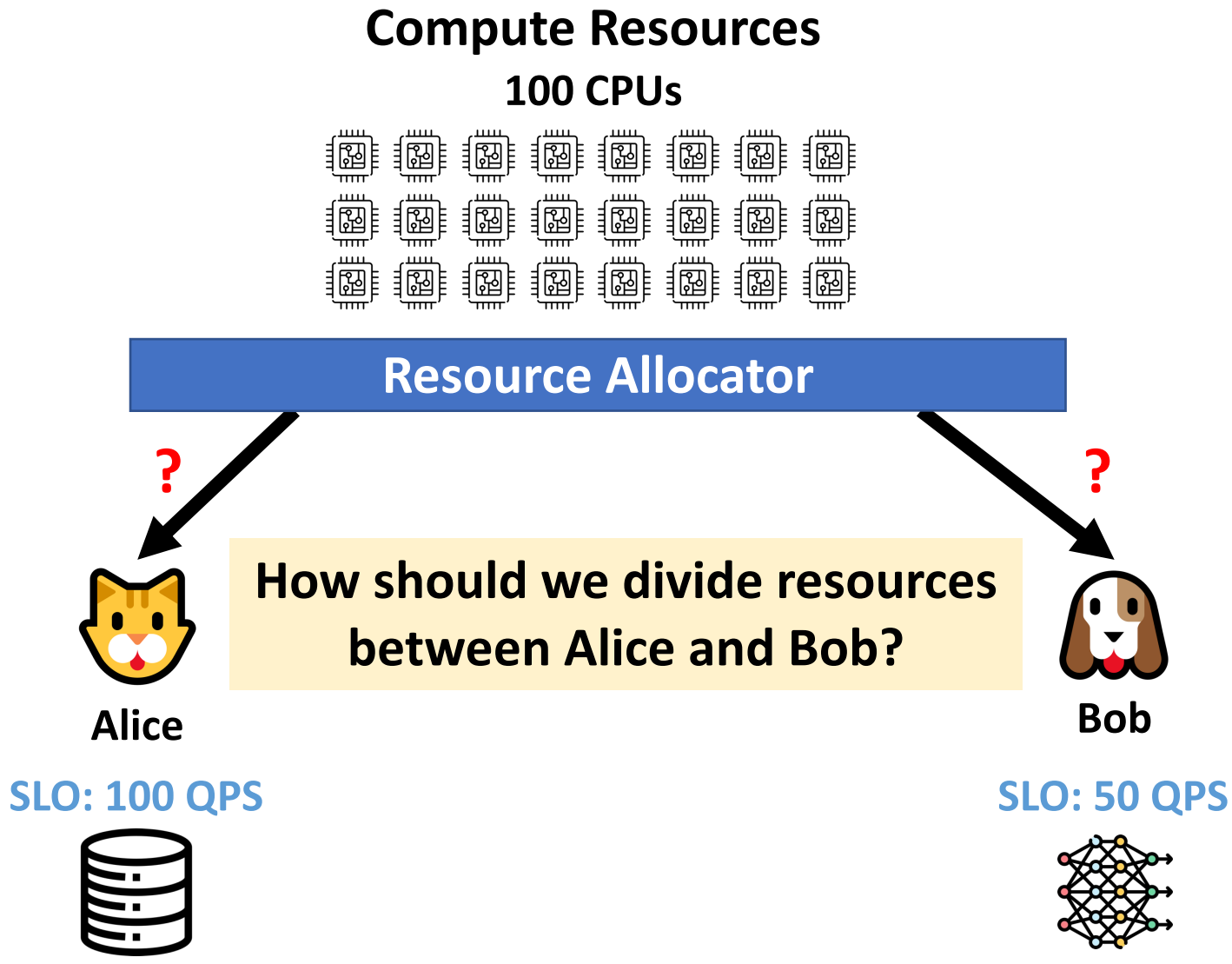
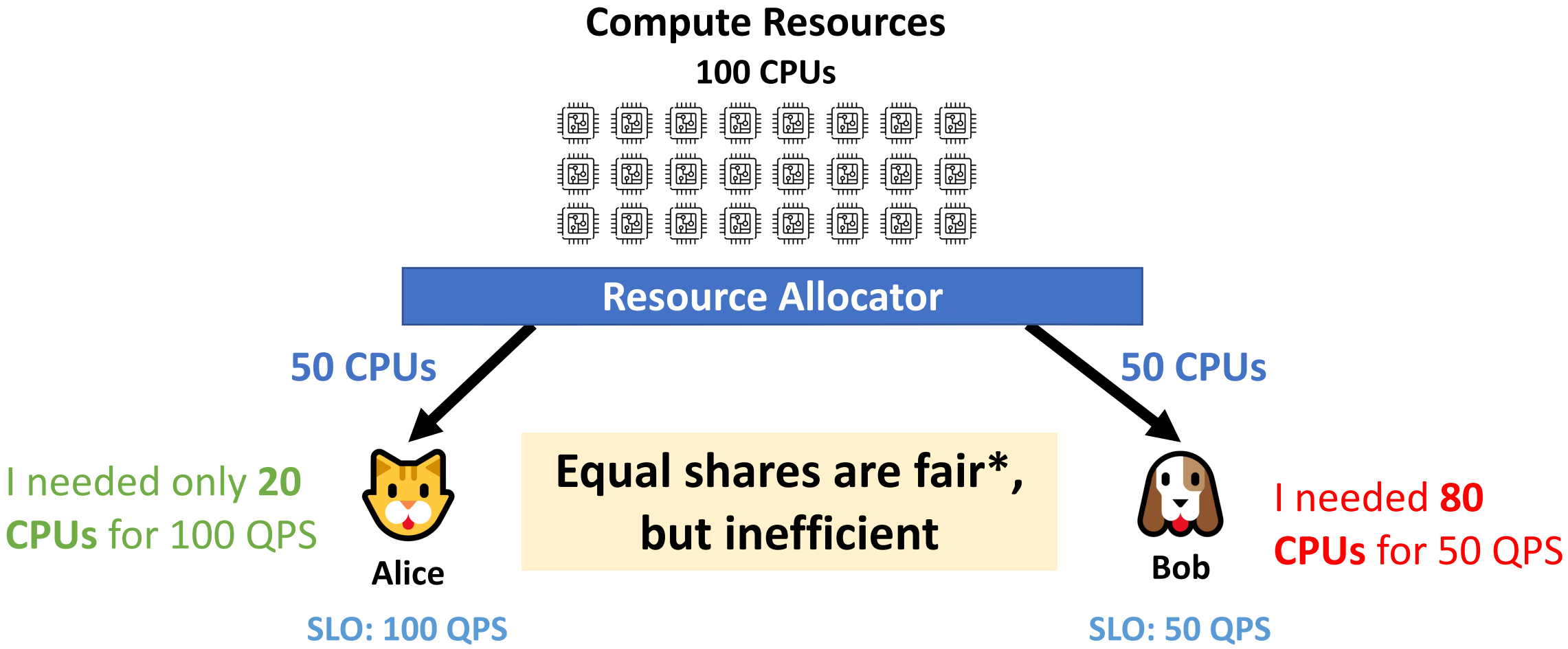
Resource allocation in multi-tenant clusters

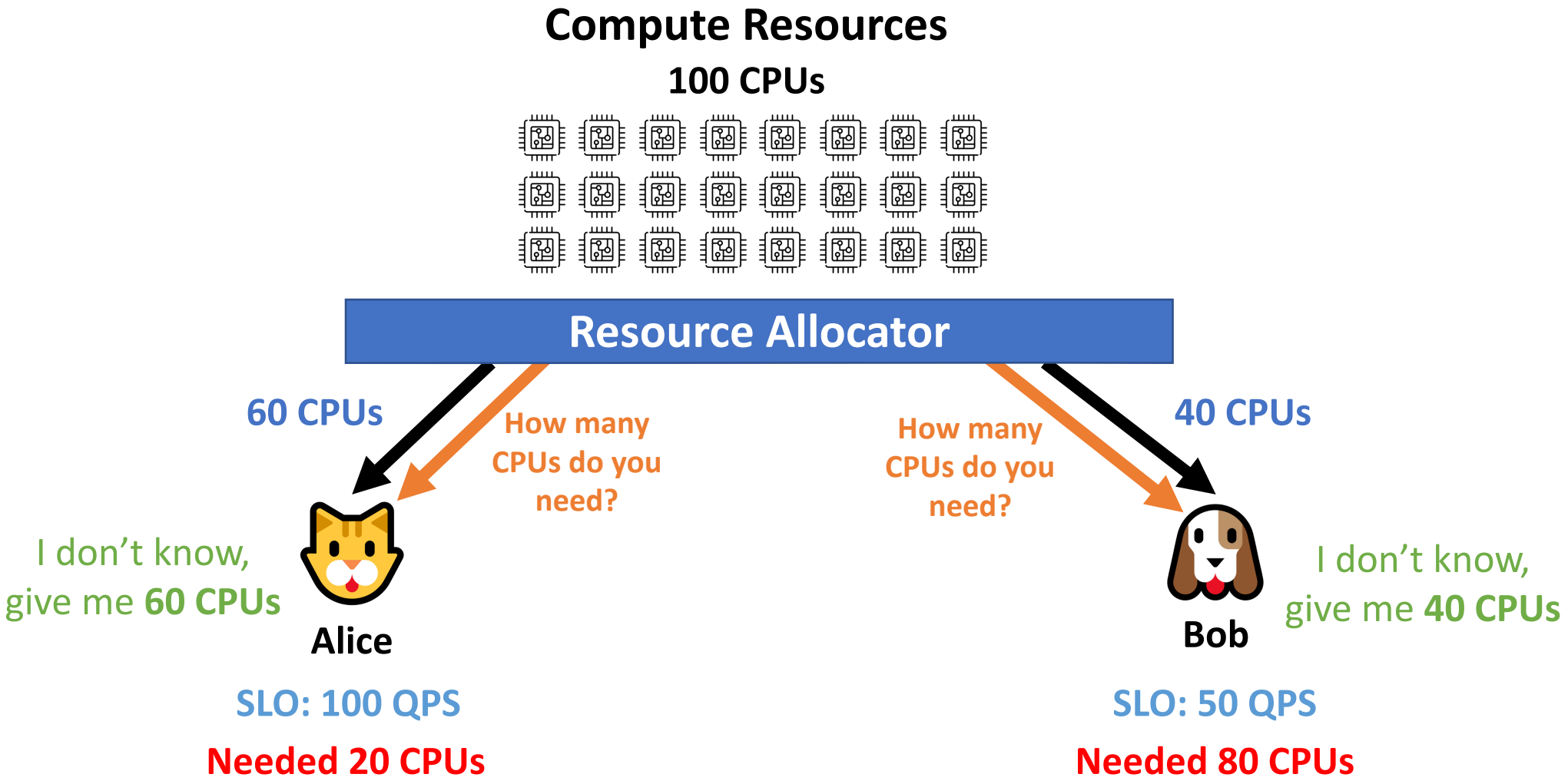


Equal Allocation



*fair = proportional shares

Asking for resource demands

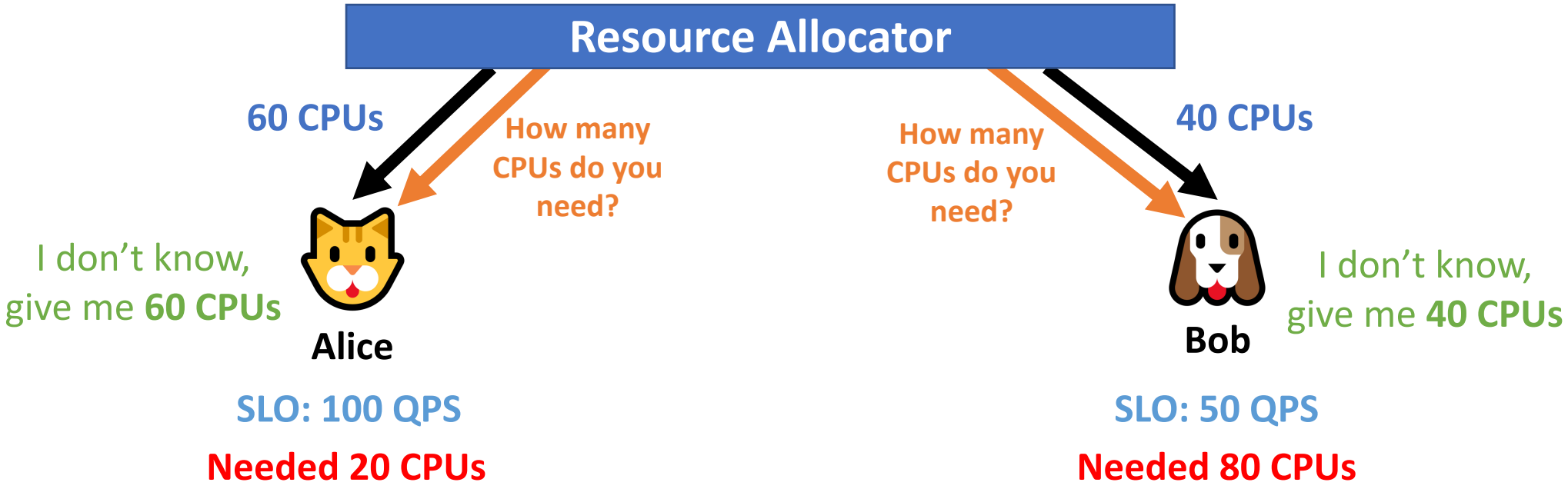


Observed in: Delimitrou & Kozyrakis '14 (PARTIES), Abdu Jyothi et al '16 (Morpheus), Rzadca et al '20 (Google Autopilot)

Asking for resource demands

Compute Resources
100 CPUs

Inaccurate resource demands result in inefficient allocations



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Asking for resource demands

Users have performance objectives, not resource demands

How can we do performance-aware scheduling?

Alice

SLO: 100 QPS

Bob

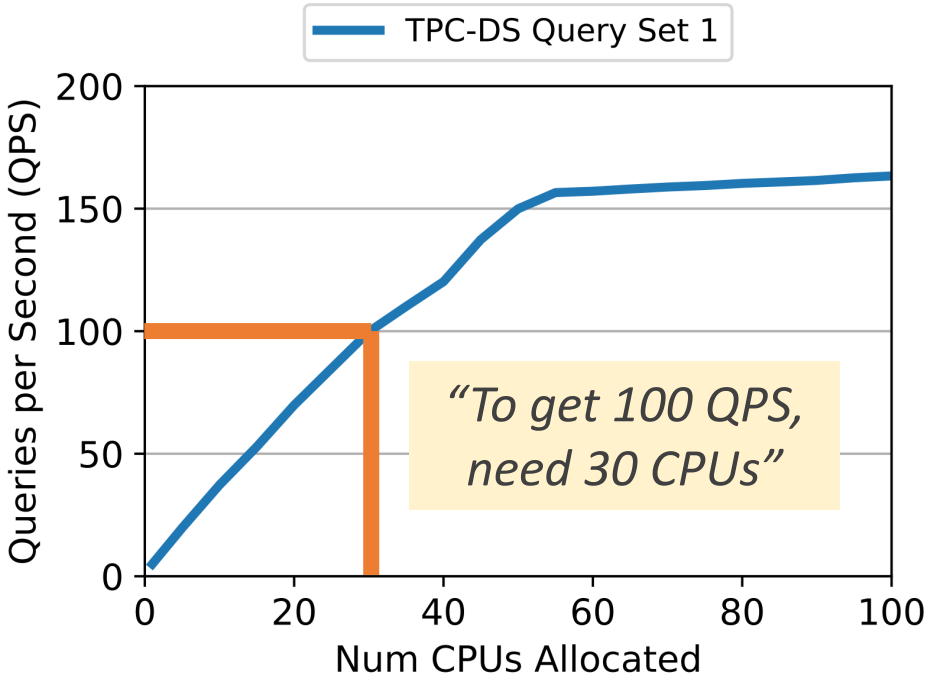
SLO: 50 QPS

Observed in: Delimitrou & Kozyrakis '14 (PARTIES), Abdu Jyothi et al '16 (Morpheus), Rzadca et al '20 (Google Autopilot)

Towards performance-aware scheduling

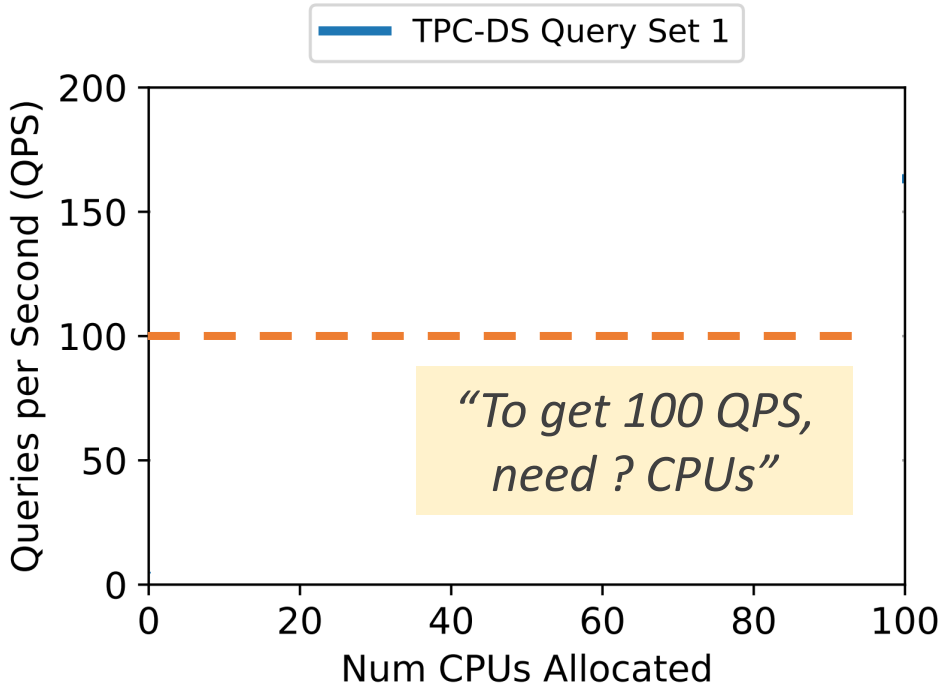
Alice
SLO: 100 QPS

- Users know their **performance objectives (SLOs),** but not the resources required to achieve SLOs
- A **resource-performance mapping** can map SLOs to resource demands

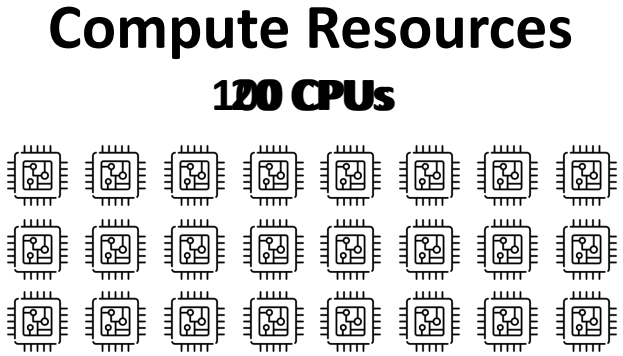


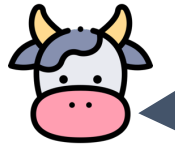
Towards performance-aware scheduling

Challenge 1 - Resource-performance curves are not known



Resource allocation objectives are diverse





Admin

Objective

Maximize the average QPS over all users

Challenge 2 – Scheduling objectives are diverse and require a general resource allocator to satisfy objectives

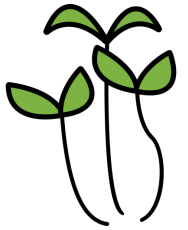
I need **20 CPUs** for 100 QPS

Alice

Bob

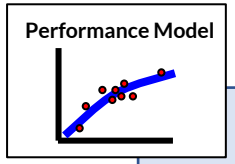
I need **80 CPUs** for 50 QPS

Cilantro



- Cilantro is a **general framework** to enable **performance-aware scheduling** in clusters

Challenge 1 – Resource-performance curves are unknown



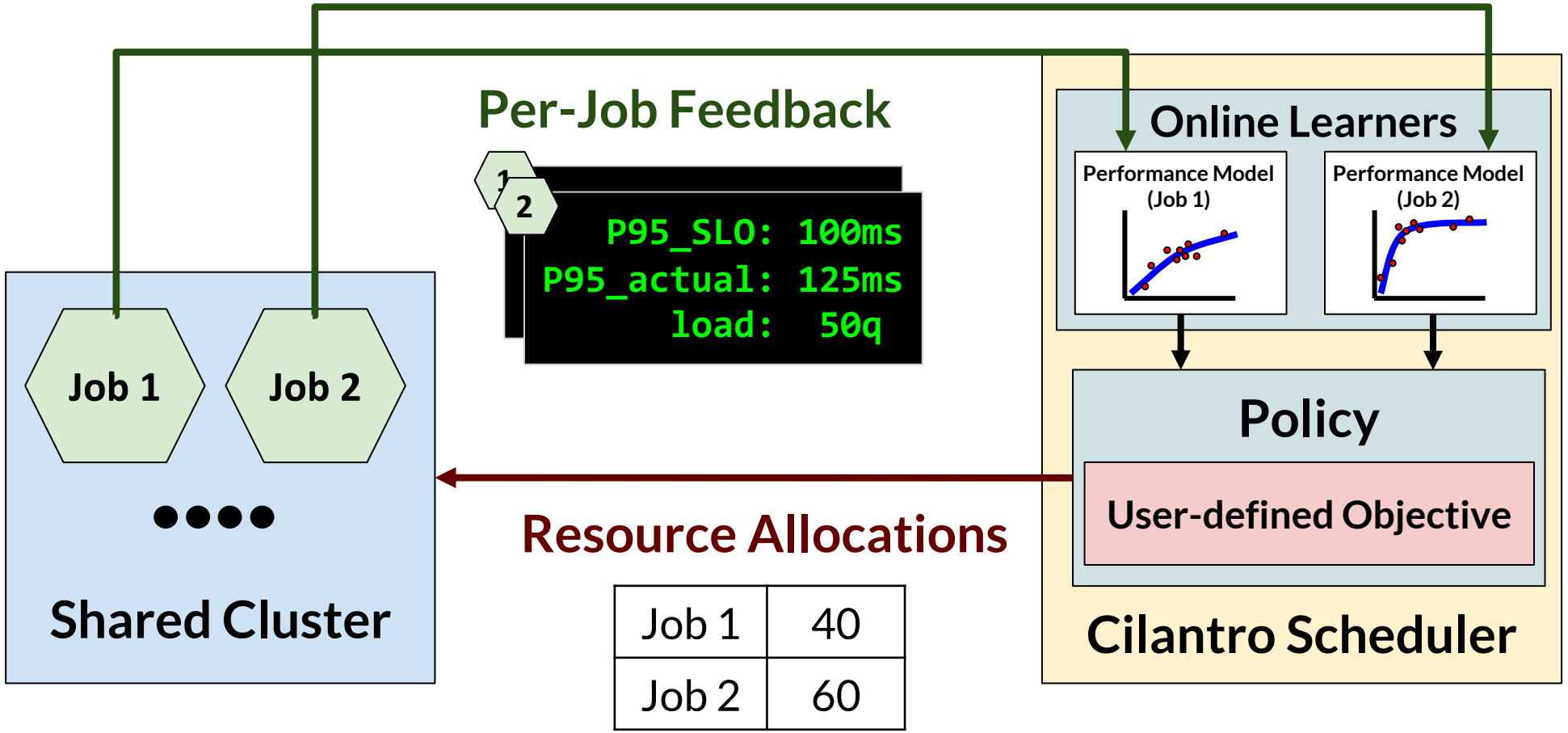
Use **online learning to generate progressively accurate** resource-performance models

Challenge 2 - Support a diverse set of objectives

Decouple allocation policy from learning mechanisms by using resource-performance models

Cilantro workflow

Creating a closed scheduling loop of resource allocations and job feedback



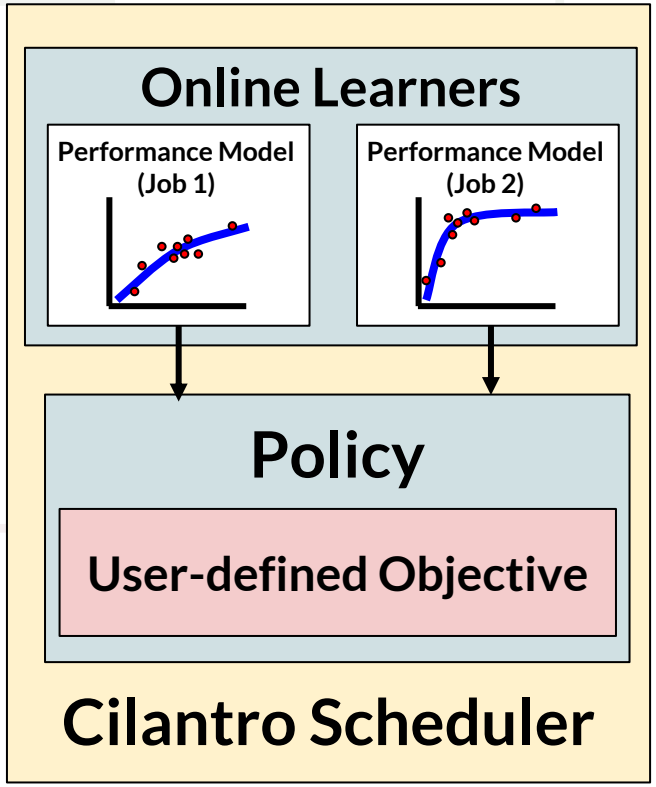
Challenges in Online Learning

Large and expensive search space

Reduce search space by defining a constrained utility model

Model estimates have uncertainty

Make policies uncertainty-aware



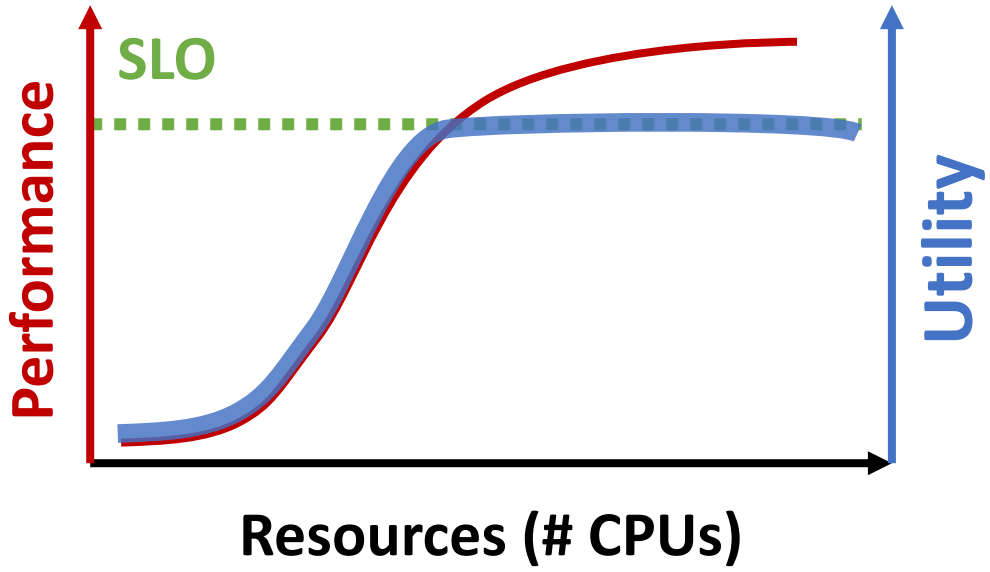
Cilantro utility model

Each job has an unknown resource-performance curve

SLO (Service level objective) is the performance goal specified by the user

Utility is a function of performance. It must be:

1. **Monotonically non-decreasing**
2. **Clipped at SLO**



These properties are desirable because

1. **Makes exploration tractable**
2. **Reflective of real-world "utility"**

Utility u, num jobs n, allocation a, job load l

Common Scheduling Objectives

General Performance objectives

Social Welfare
"Maximize mean utility across all jobs"

$$a = \underset{a_j}{\operatorname{argmax}} \frac{1}{n} \sum_{j=1}^{n} u_j(a_j, l_j)$$

Egalitarian Welfare
"Maximize minimum utility across all jobs"

$$a = \underset{a_j}{\operatorname{argmax}} \left(\min(u_j(a_j, l_j)) \right)$$

Application Performance objectives

Minimize end-to-end latency
of a collection of microservices

$$a^r = \underset{a \in A^r}{\operatorname{argmax}}(u(a, l))$$

Demand-based objectives

No Justified Complaints (NJC) Fairness
"Guarantee at least fair-share"

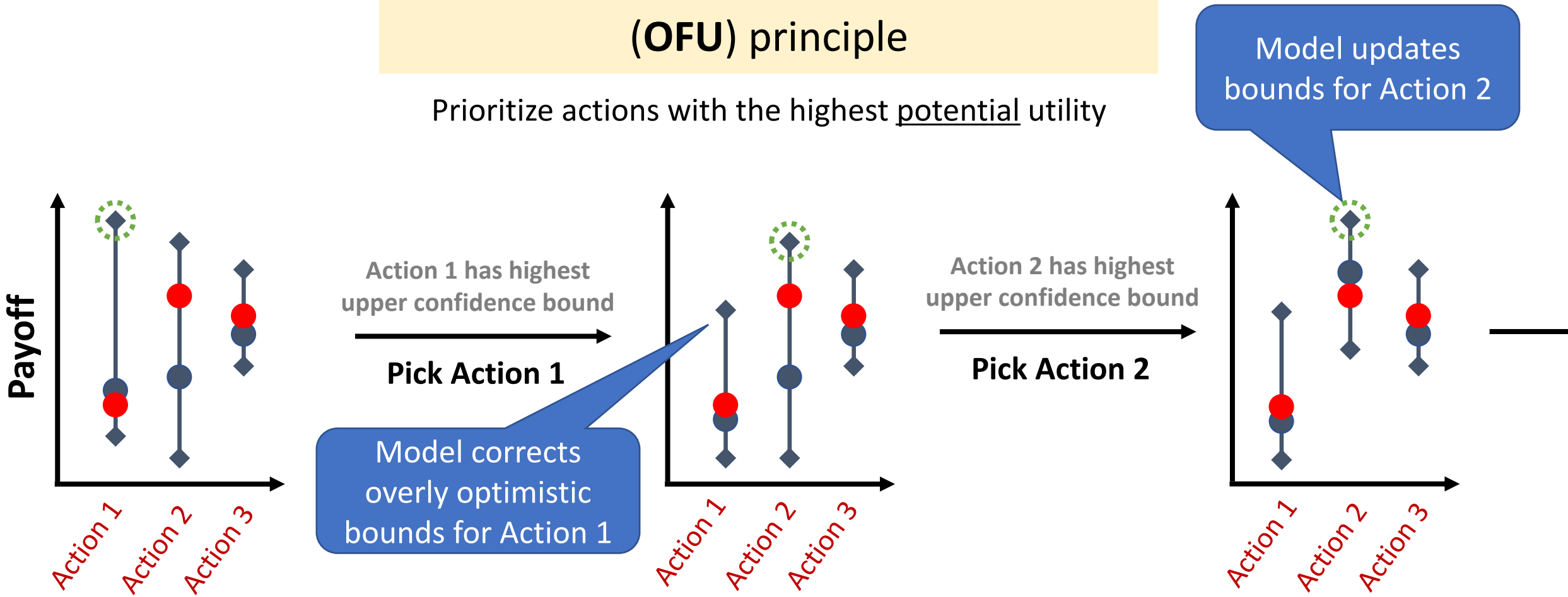
$$a = \underset{a_j}{\operatorname{argmax}} \left(\min_{j \in \{1,\ldots n\}} \left(\frac{u_j(a_j, l_j)}{u_j(R/n, l_j)} \right) \right)$$

Making policies uncertainty-aware

Real payoff
Expected payoff
Confidence bounds

"Optimism in the Face of Uncertainty"[1]
(**OFU**) principle

Prioritize actions with the highest potential utility



[1] "Regret Analysis of Stochastic and Nonstochastic Multi-armed Bandit Problems", Bubek et. al 2012

Making policies uncertainty-aware

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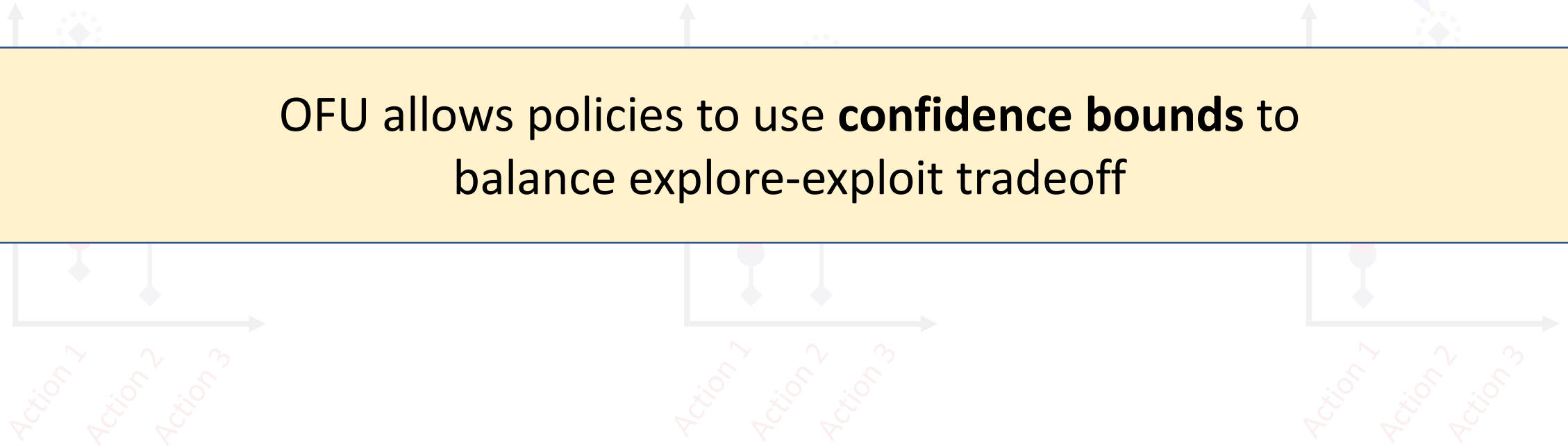

OFU allows policies to use **confidence bounds** to balance explore-exploit tradeoff

[1] "Regret Analysis of Stochastic and Nonstochastic Multi-armed Bandit Problems", Bubek et. al 2012

Utility u, num jobs n, allocation a, job load l

OFU-Adapted Objectives

Performance-based objectives

Social Welfare
"Maximize mean utility across all jobs"

$$a = \underset{a_j}{\operatorname{argmax}} \frac{1}{n} \sum_{j=1}^{n} \widehat{u_j}(a_j, \widehat{l_j})$$

Egalitarian Welfare
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Application-specific objectives

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Demand-based objectives

NJC Fairness
"Guarantee at least fair-share"

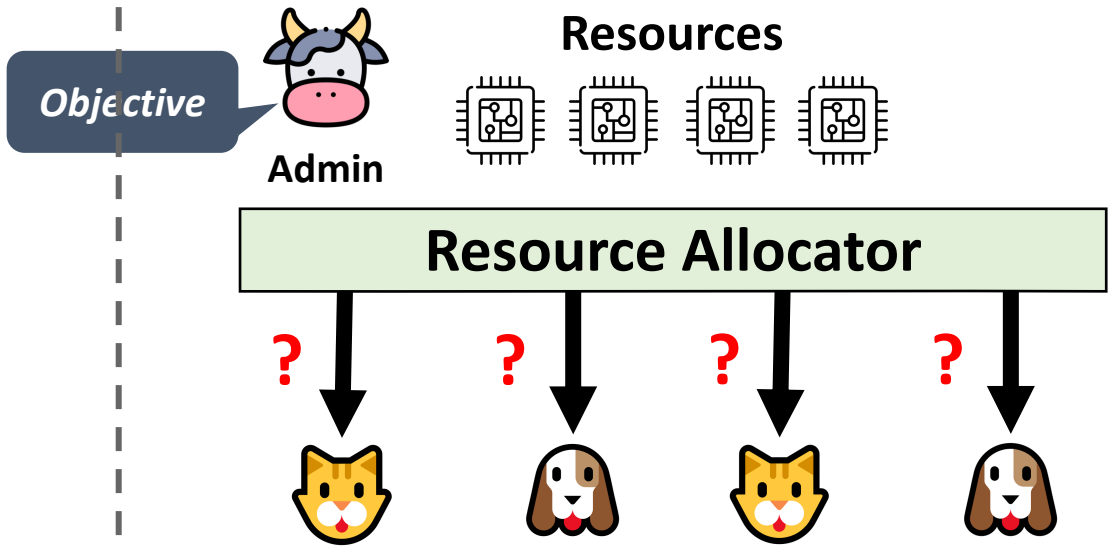
Details in the paper!

Applications of Cilantro

This Talk

Multi-tenant Cluster Sharing

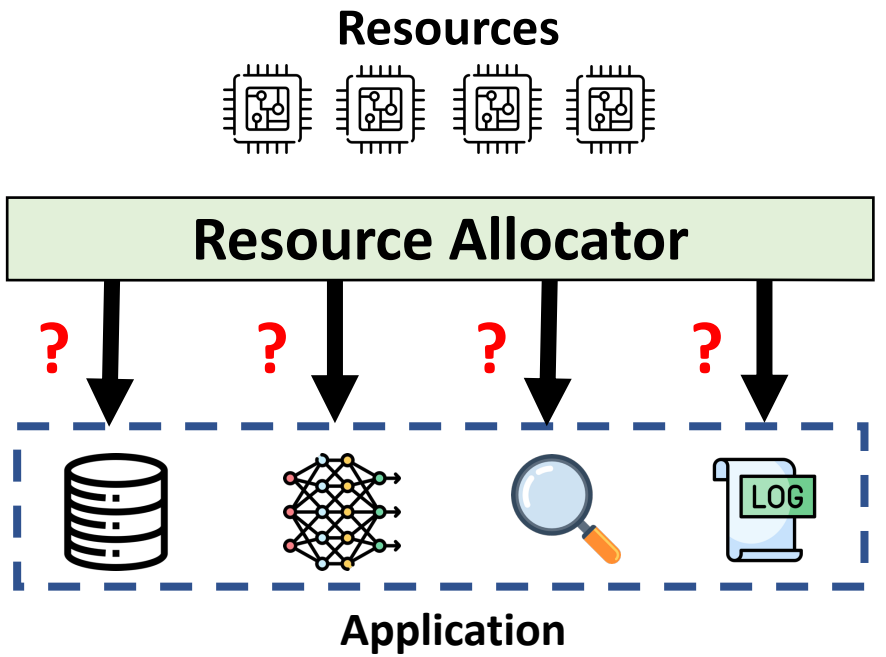
Allocating resources to independent jobs to maximize stated objective



In the paper

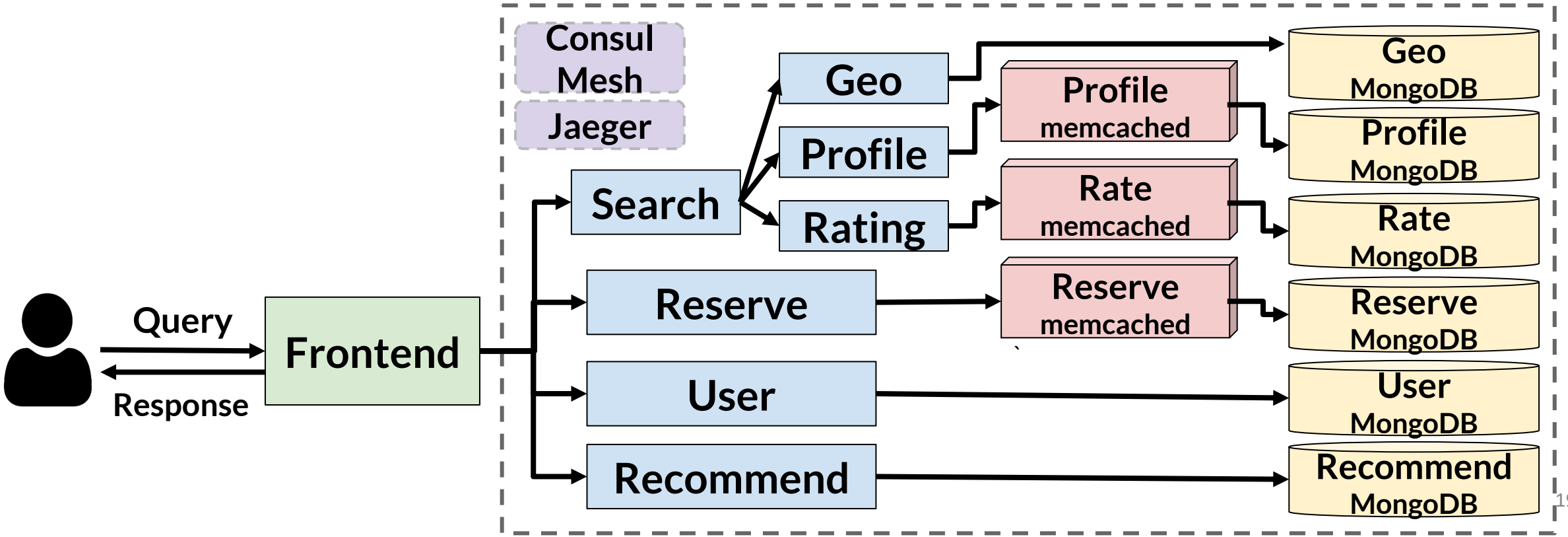
Microservices Resource Allocation

Allocating resources to microservices to minimize end-to-end application latency



Evaluation – Microservices

- Hotel Reservation benchmark from DeathStarBench
- Contains 19 microservices serving one endpoint



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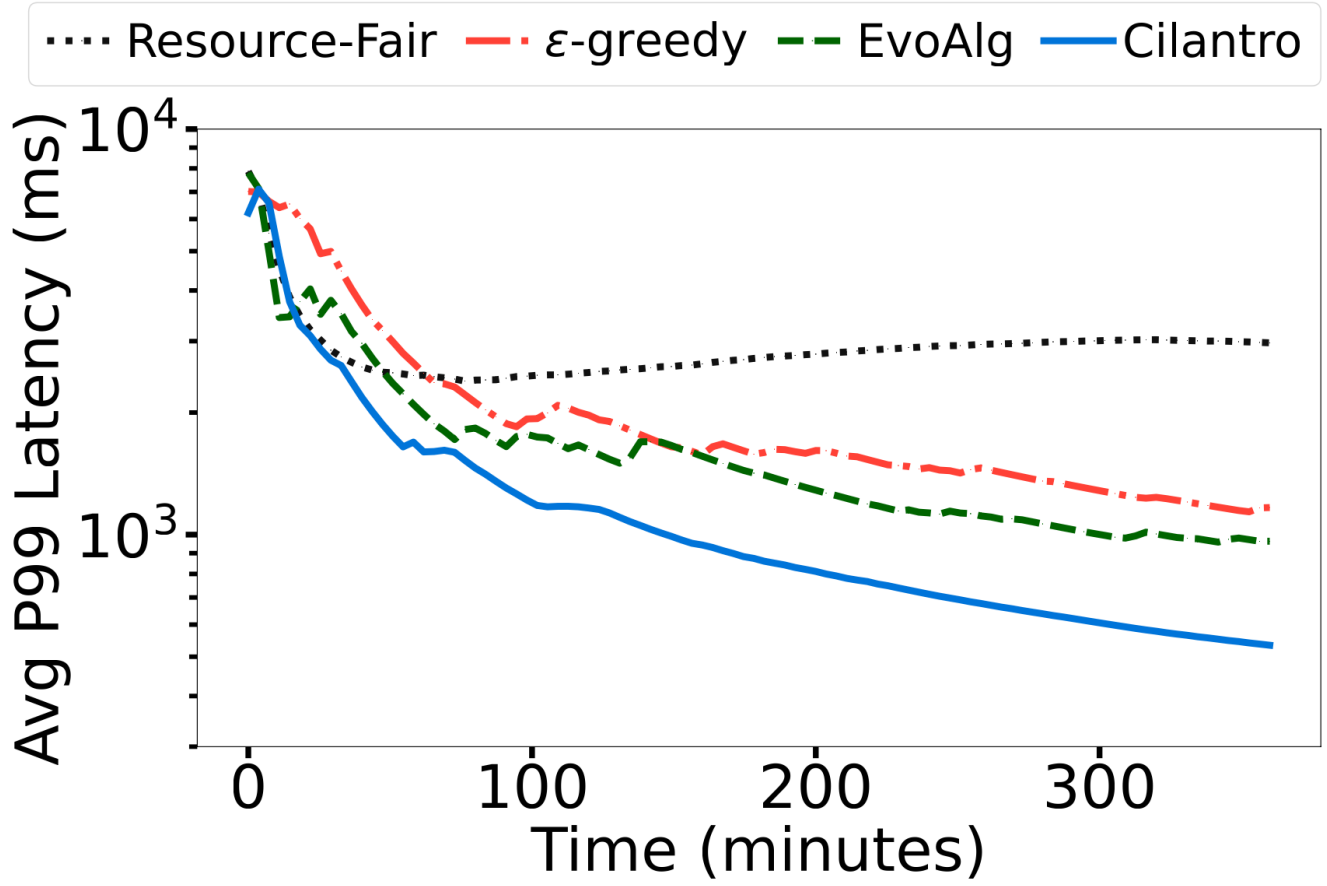

Cilantro reduces P99 latency to 0.57x of the best baseline
without any visibility into the performance or structure of component microservices

Cilantro Summary

github.com/romilbhardwaj/cilantro

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- Cilantro is a **general, performance-aware** cluster scheduling framework
- Users do not state their resource demands - they provide **SLOs and feedback**.
- Online learning estimates **resource-performance curves** and **policies adapt to uncertainty in estimates**
- Improves utilities up to 1.2 – 3.7× in cluster sharing and reduces latencies by 43% for microservices