PerfIso: Performance Isolation for Commercial Latency-Sensitive Services

Călin Iorgulescu
EPFL

Reza Azimi
Brown University

Youngjin Kwon
University of Texas

Sameh Elnikety, Manoj Syamala, Vivek Narasayya
Microsoft Research

Herodotus Herodotou
Cyprus University of Technology

Paulo Tomita, Alex Chen, Jack Zhang, Junhua Wang
Microsoft Bing

Interactive services must feel instantaneous

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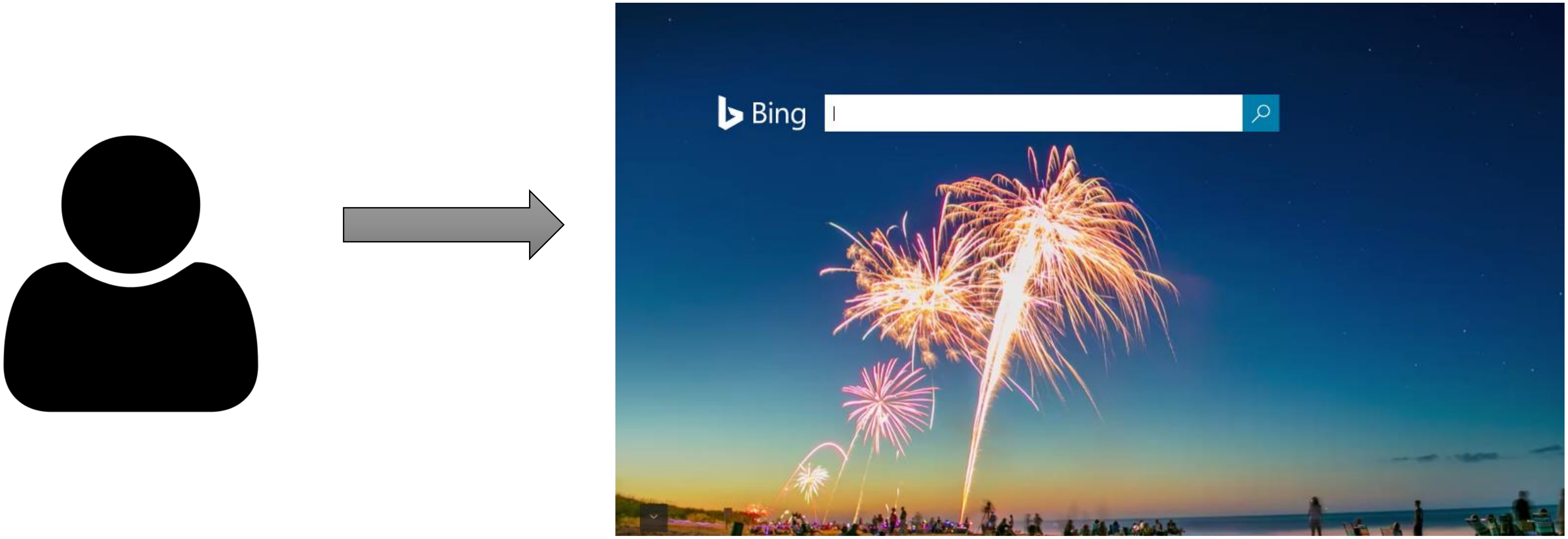

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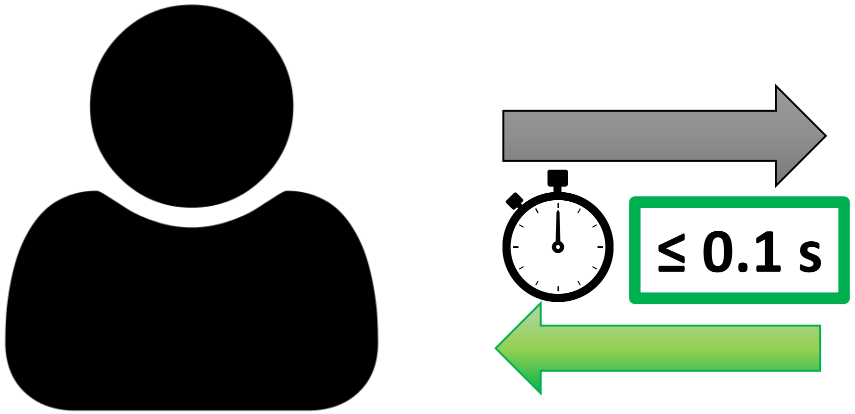

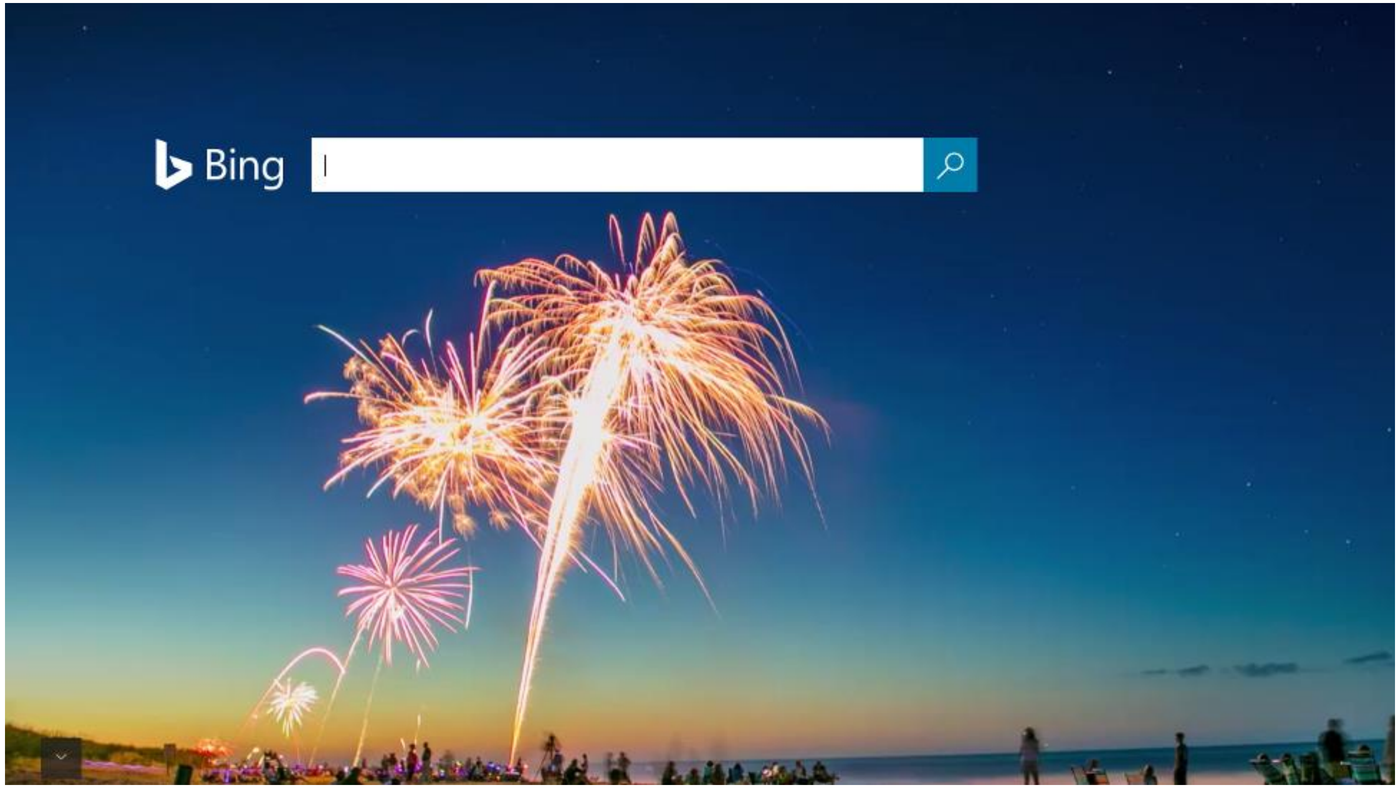

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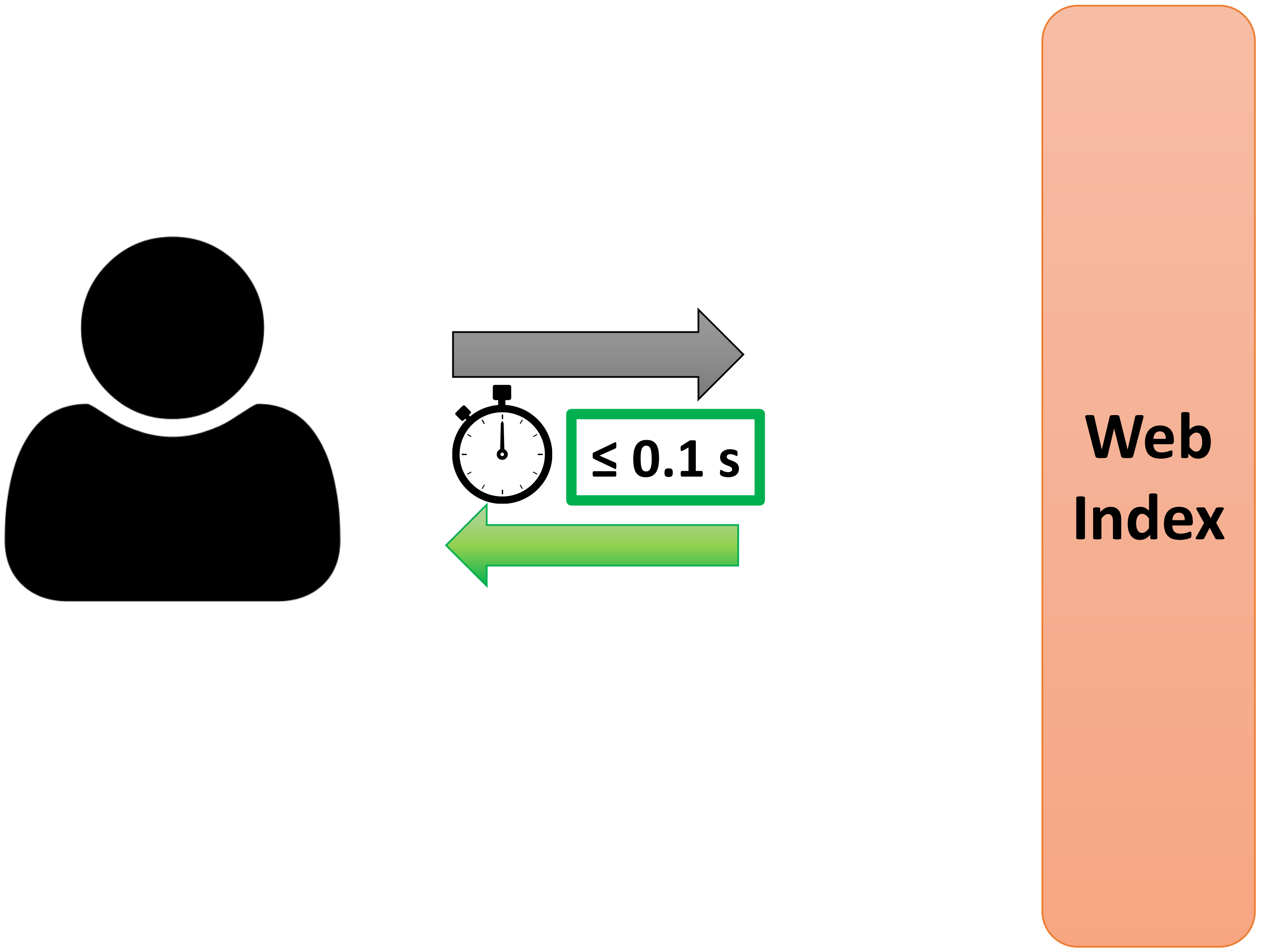

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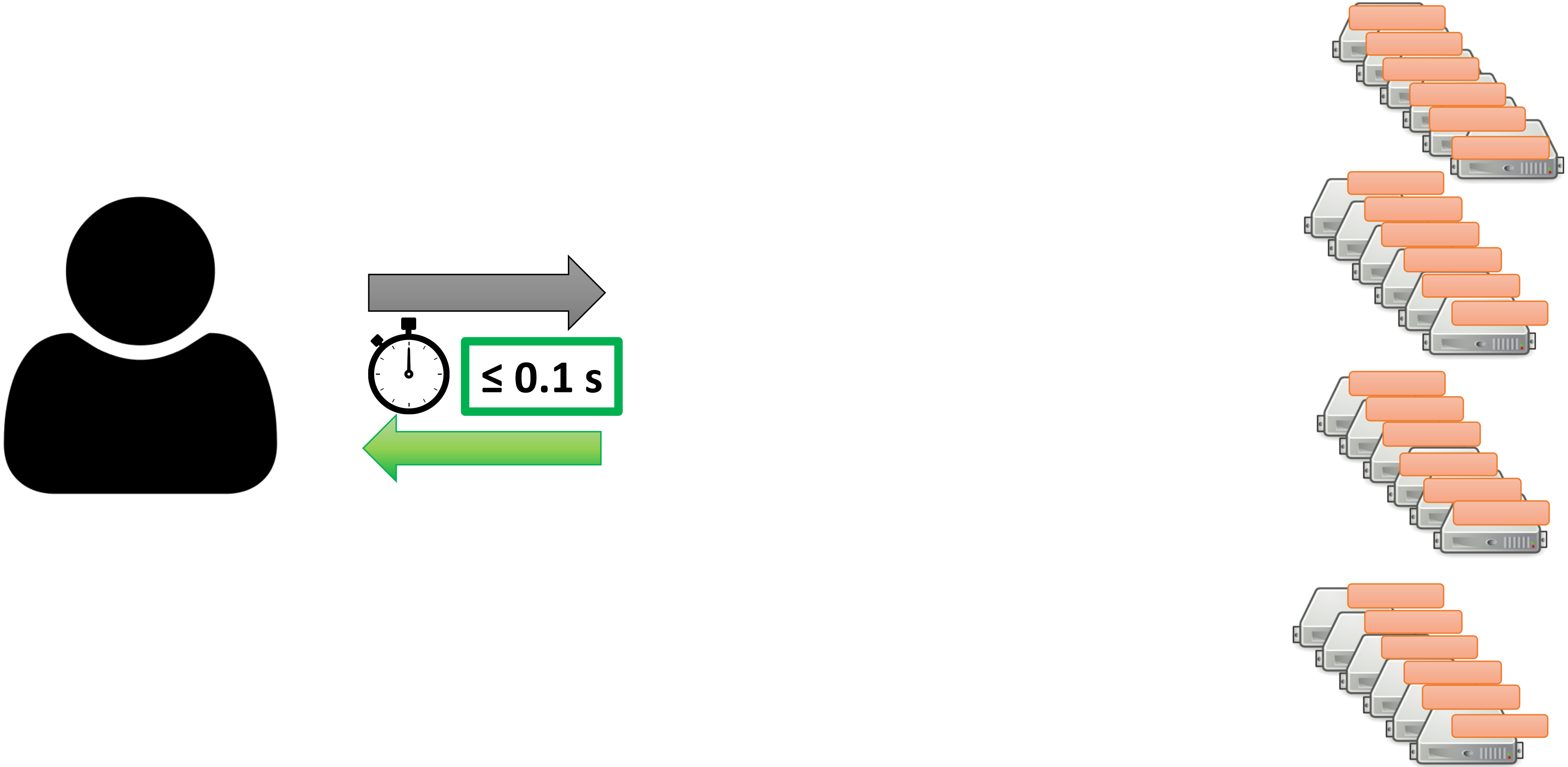

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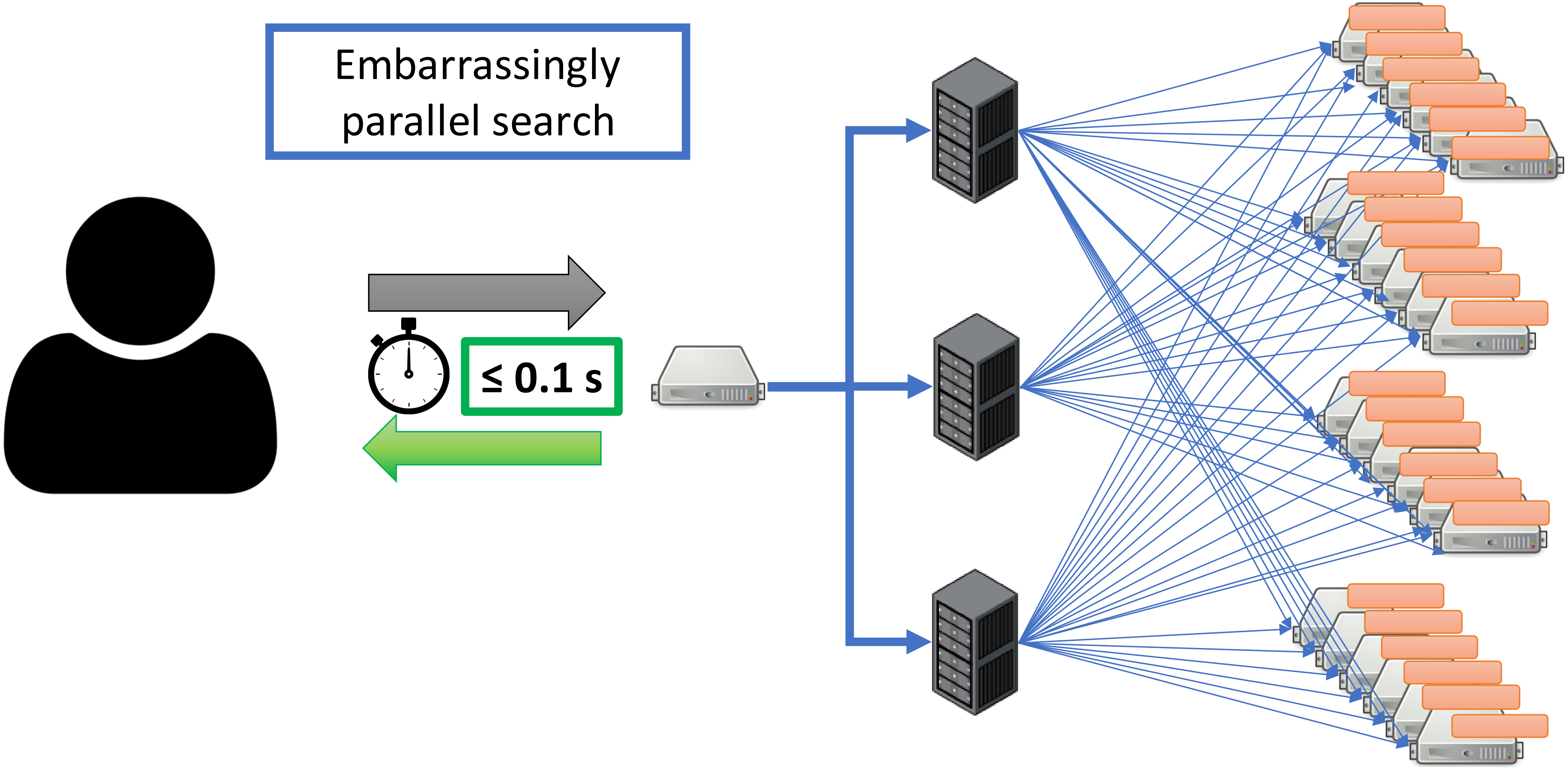

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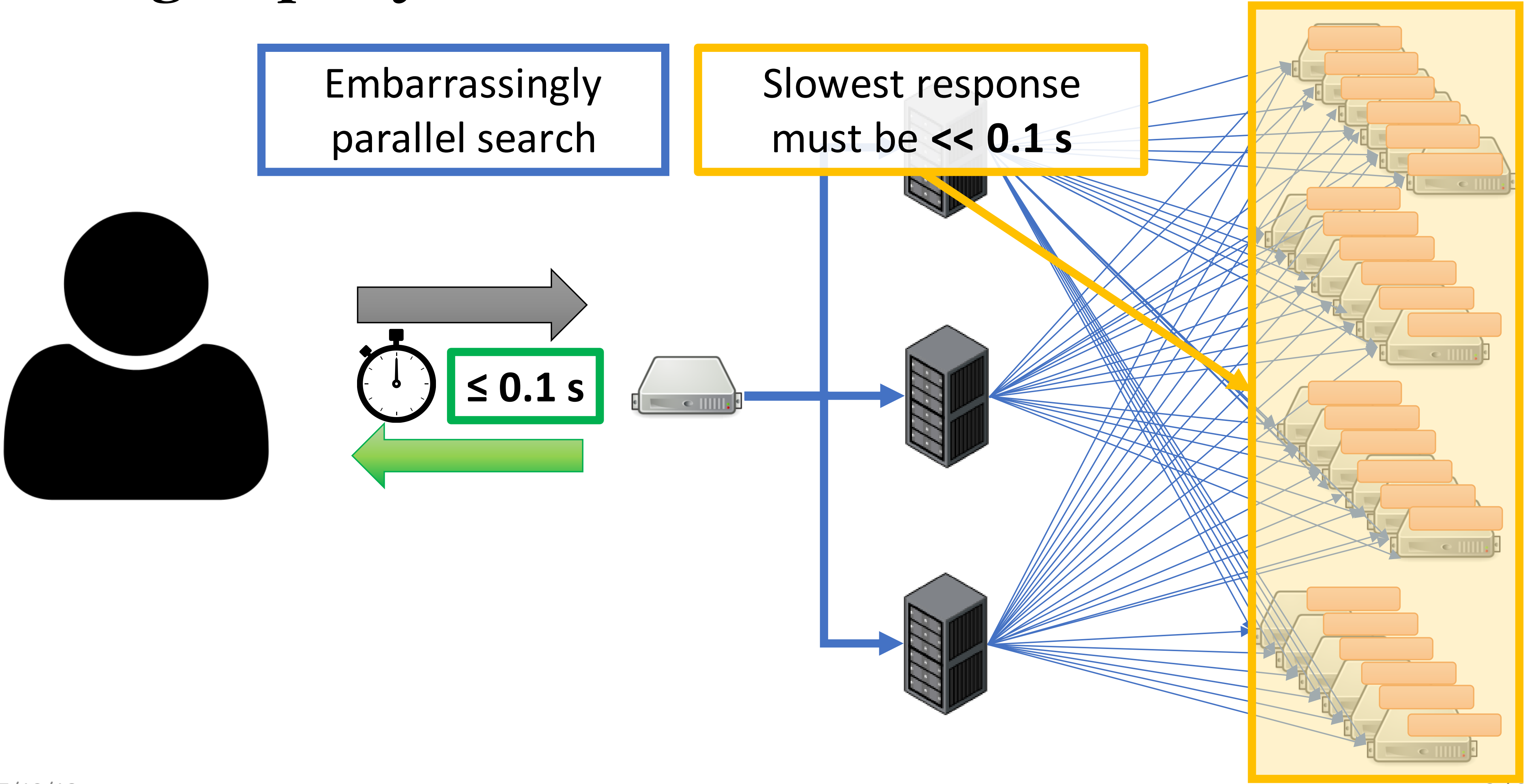

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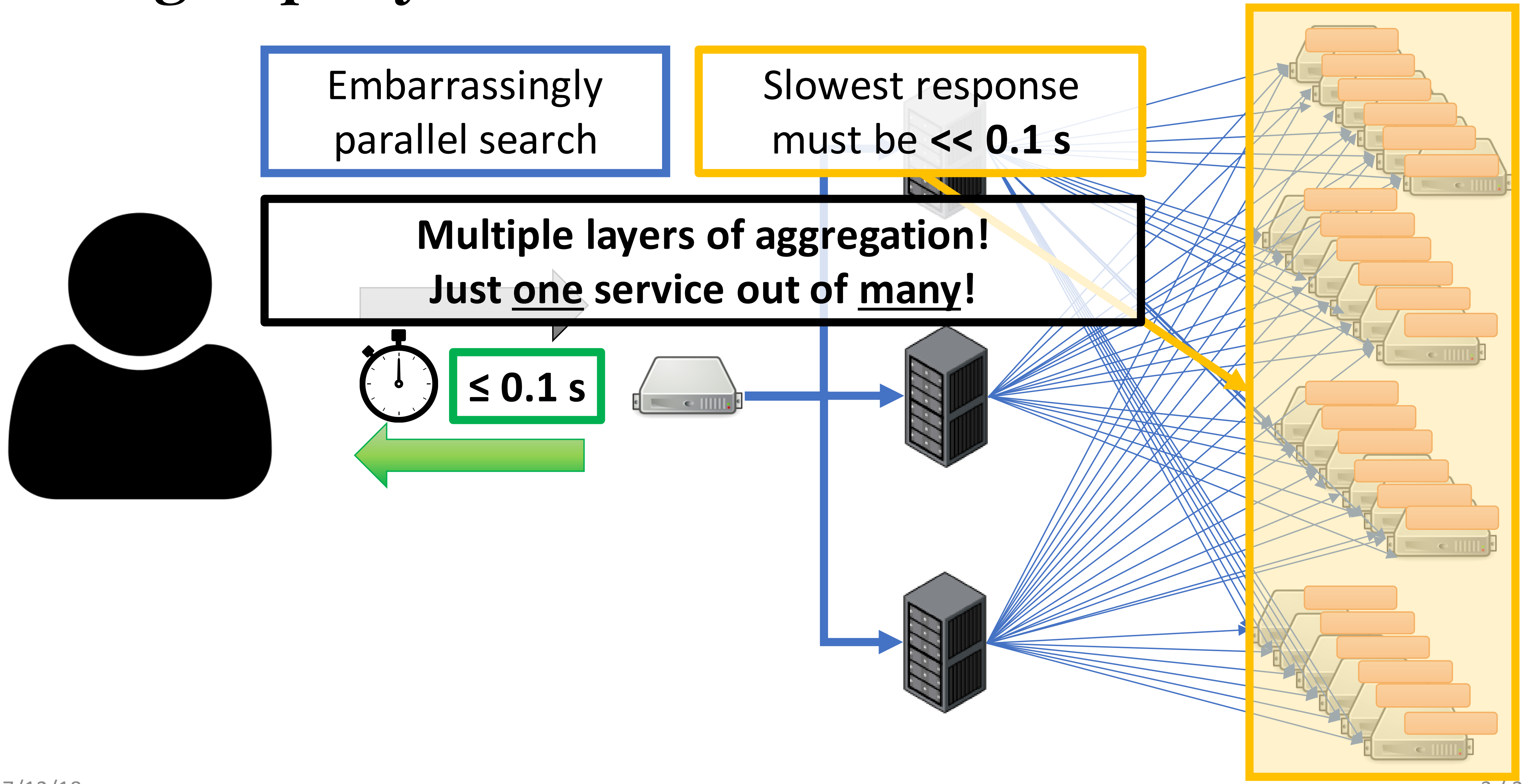
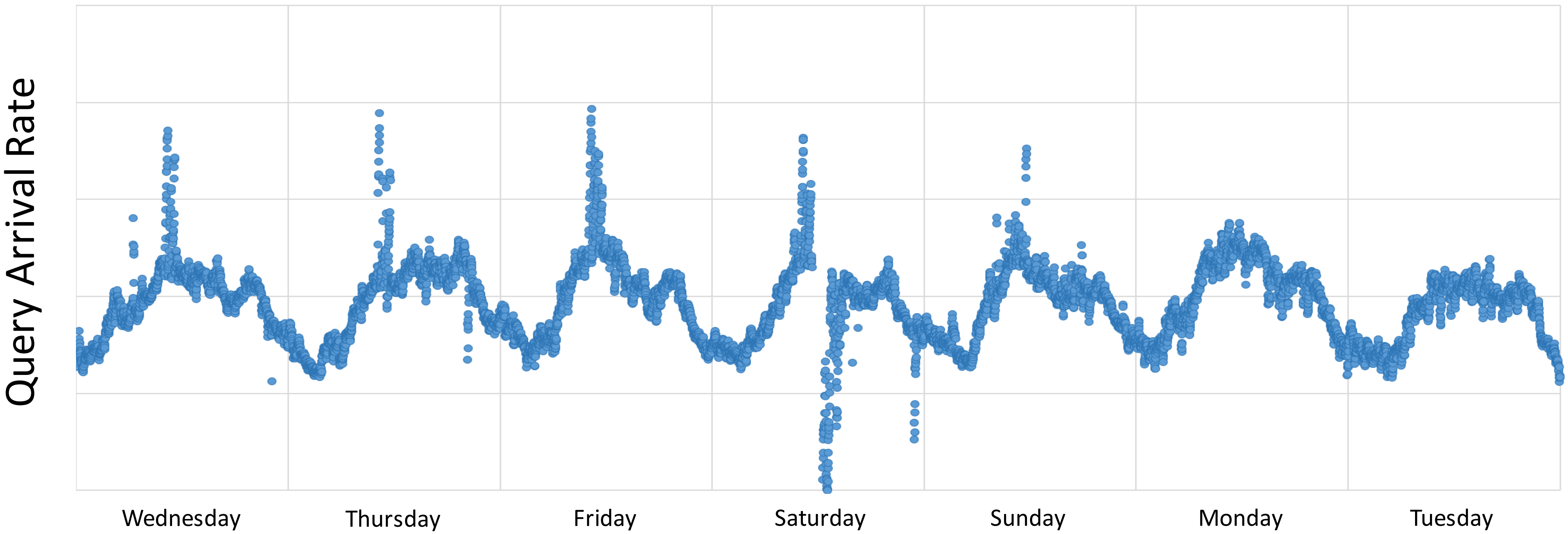


Machines are provisioned for peak load



Request-rate variation for a *Microsoft Bing* sub-cluster over 1 week in 2017

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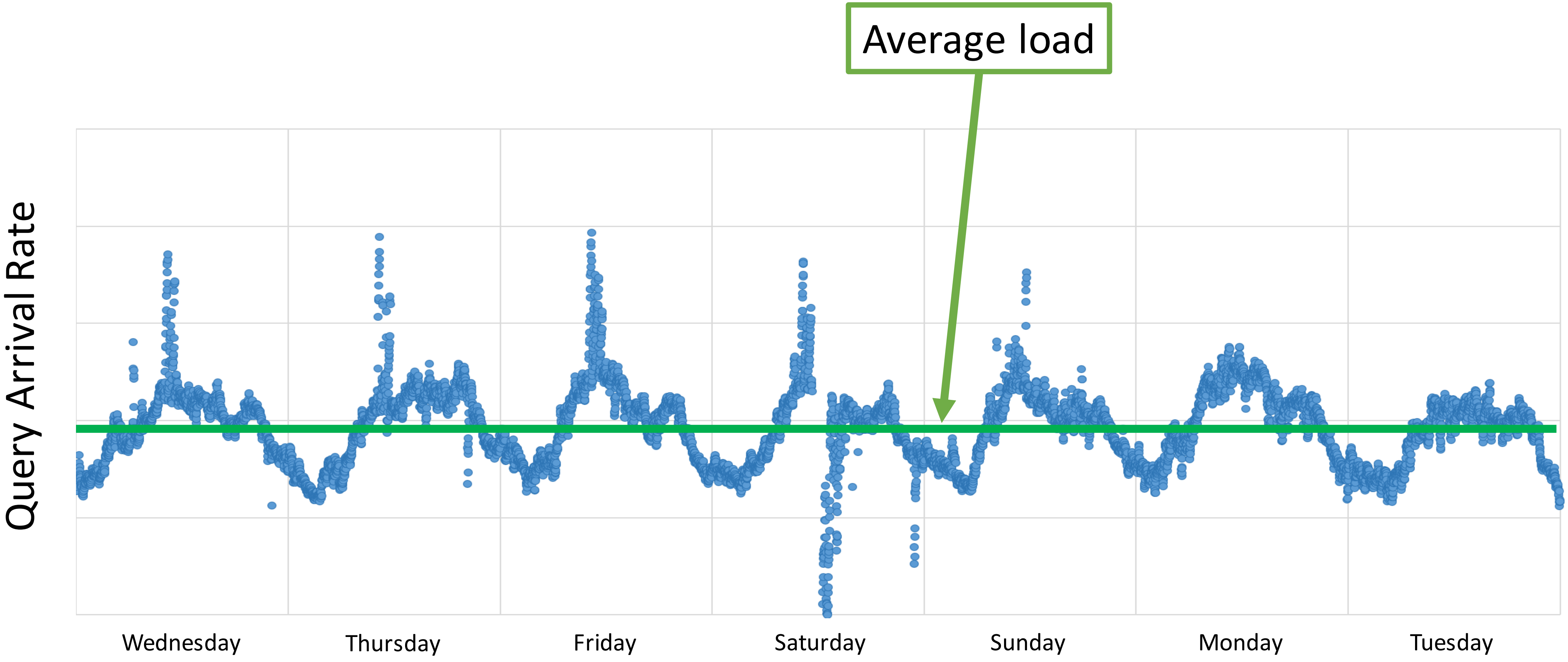

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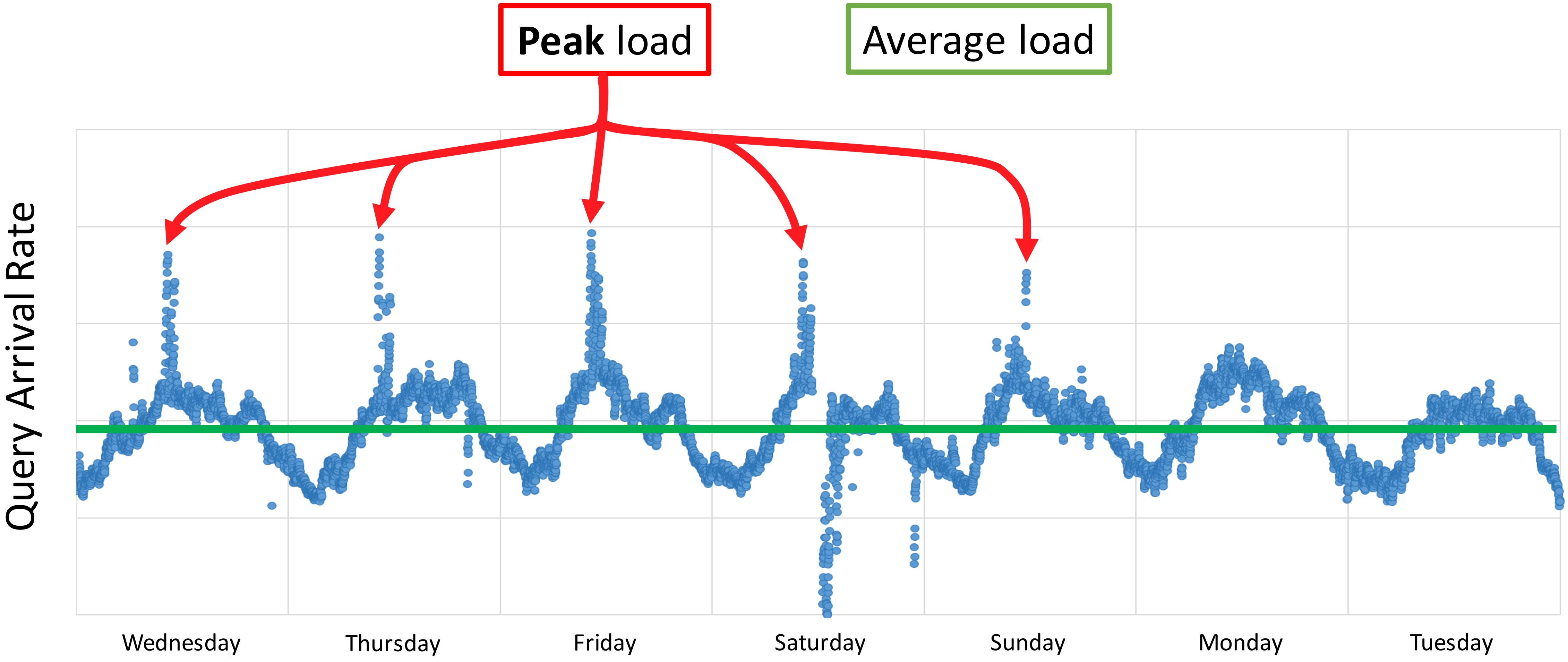

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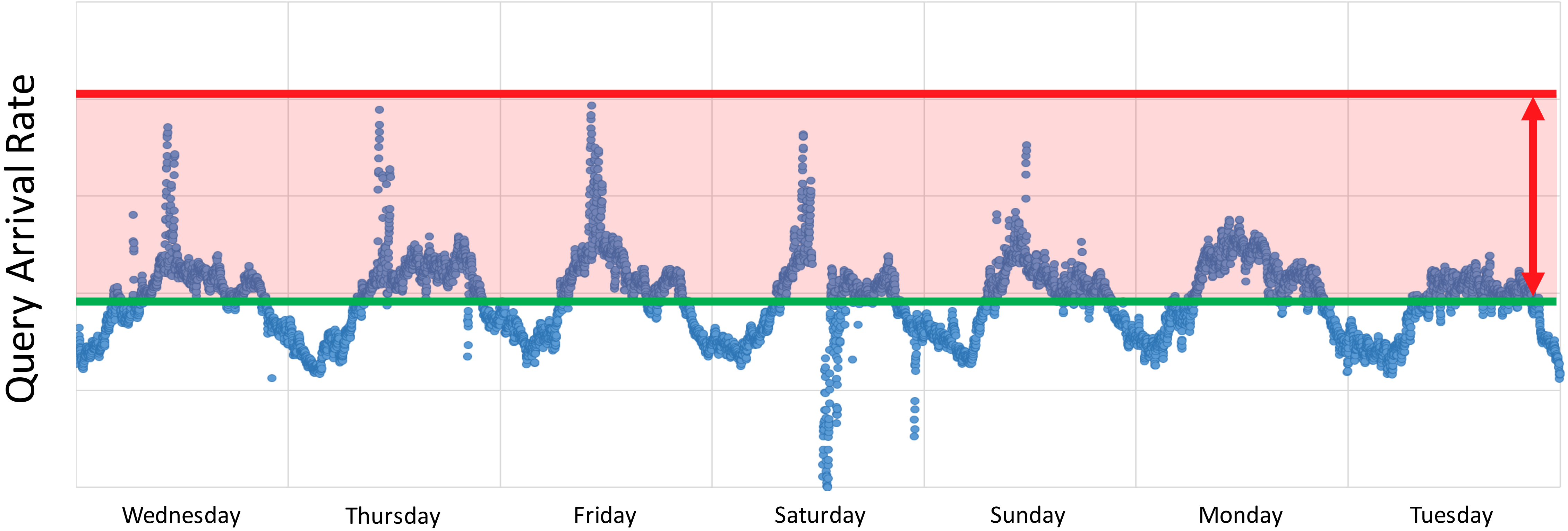

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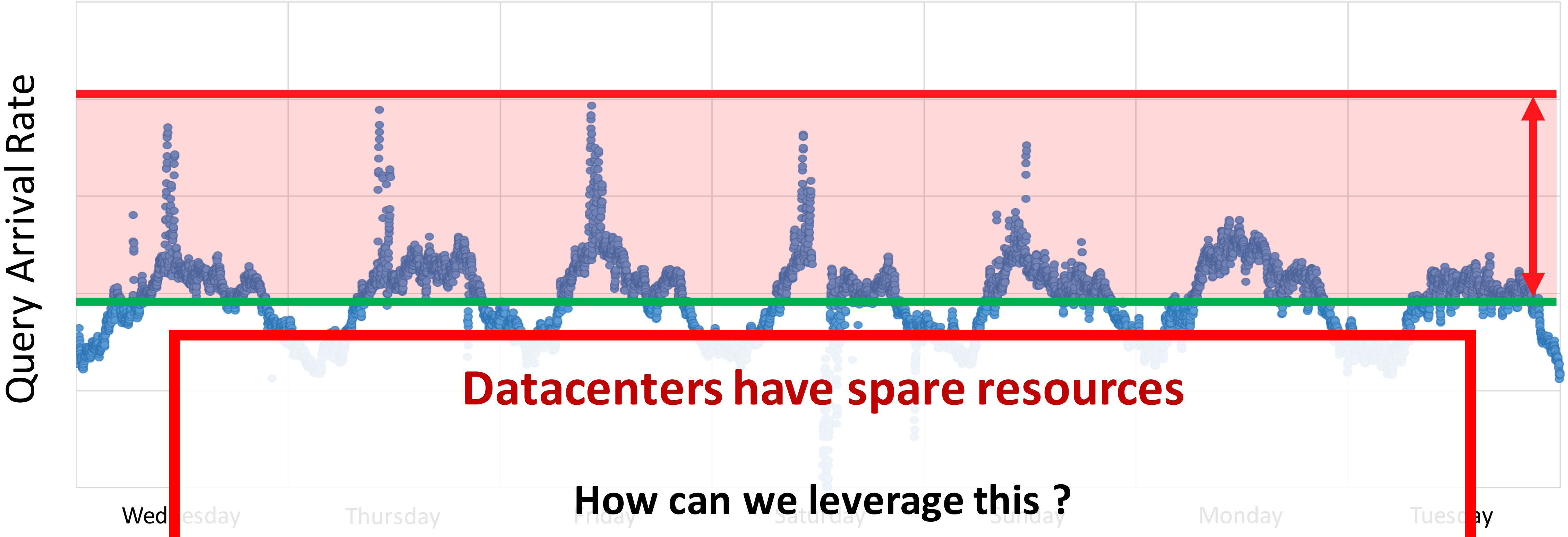


Datacenters have spare resources

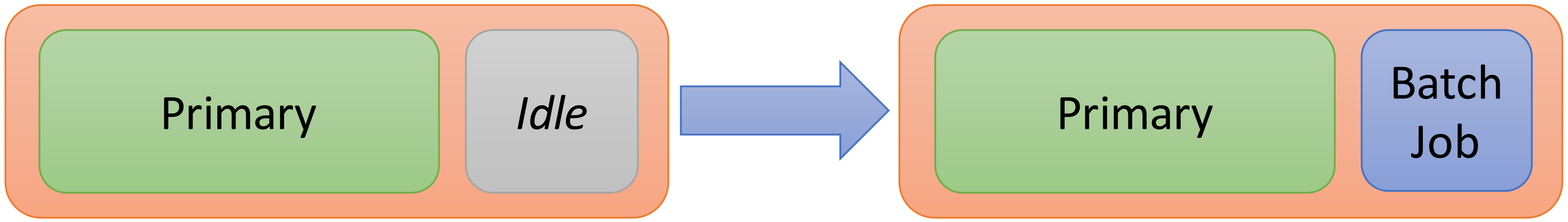
How can we leverage this ?

Request-rate variation for a *Microsoft Bing* sub-cluster over 1 week in 2017

Solution: colocate batch jobs with online services

- Get spare resources to do useful work
- **Primary** tenant – <u>guaranteed</u> performance
  - e.g., Bing IndexServe
- **Secondary** tenant – <u>best-effort</u> performance
  - e.g., Apache Spark

Without colocation *With colocation + **PerfIso***



PerfIso: performance isolation for online services

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Provides **performance isolation** of Primary

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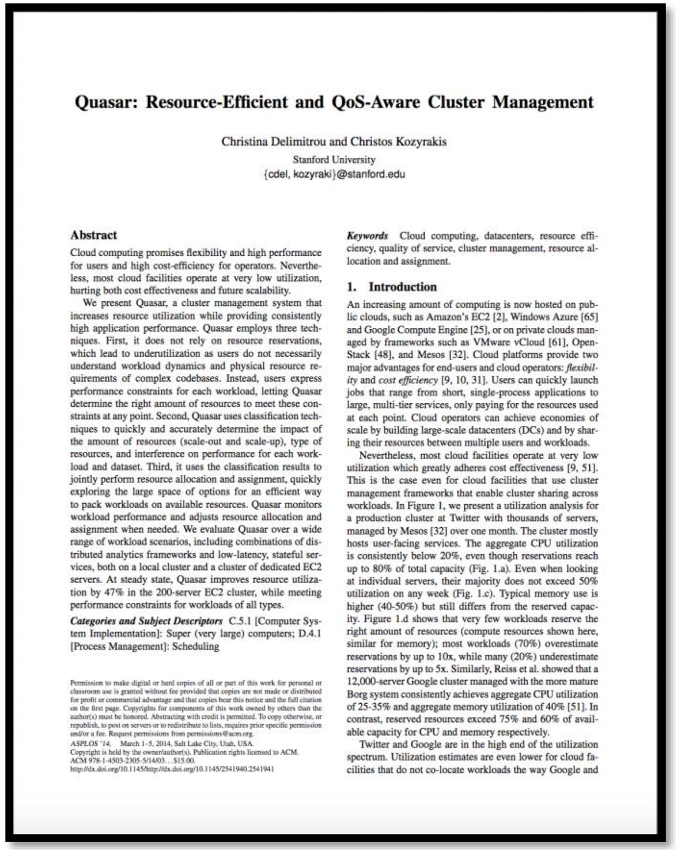
Deployed on over 90,000 servers

- Many different interactive services and hardware setups

Many papers published on performance isolation

Quasar [ASPLOS '14]



Heracles [ISCA '15]

Elfen [USENIX ATC '16]

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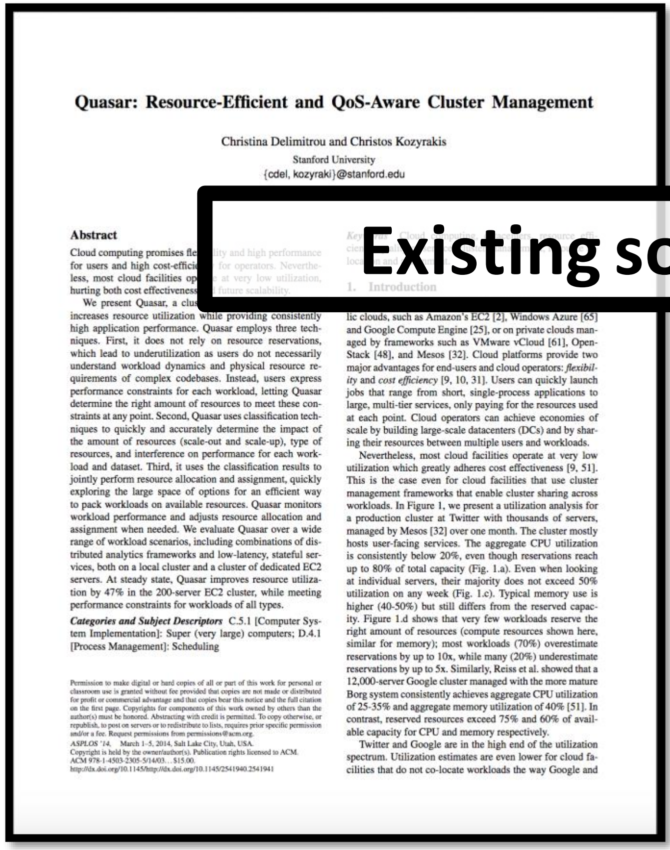
Quasar: Resource-Efficient and QoS-Aware Cluster Management

Christina Delimitrou and Christos Kozyrakis
Stanford University
{cdel, kozyraki}@stanford.edu


Heracles: Improving Resource Efficiency at Scale

David Lo[†], Liqun Cheng[‡], Rama Govindaraju[‡], Parthasarathy Ranganathan[‡] and Christos Kozyrakis[†]
Stanford University[†] Google, Inc.[‡]


Elfen Scheduling: Fine-Grain Principled Borrowing from Latency-Critical Workloads using Simultaneous Multithreading

Xi Yang[†] Stephen M. Blackburn[†] Kathryn S. McKinley[‡]
[†]Australian National University [‡]Microsoft Research

Existing solutions do not fit our requirements

PerfIso: Requirements

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1. **"Black-box": Fewest assumptions about tenants** (wider applicability)

2. **"Standalone": Primary acts like it runs alone** (negligible interference)

3. **"Integrability": Minimize software-stack changes** (easy deployment)

Why is Performance Isolation hard?

Interactive services – highly sensitive to interference!

Leaf-servers keep 99th percentile low

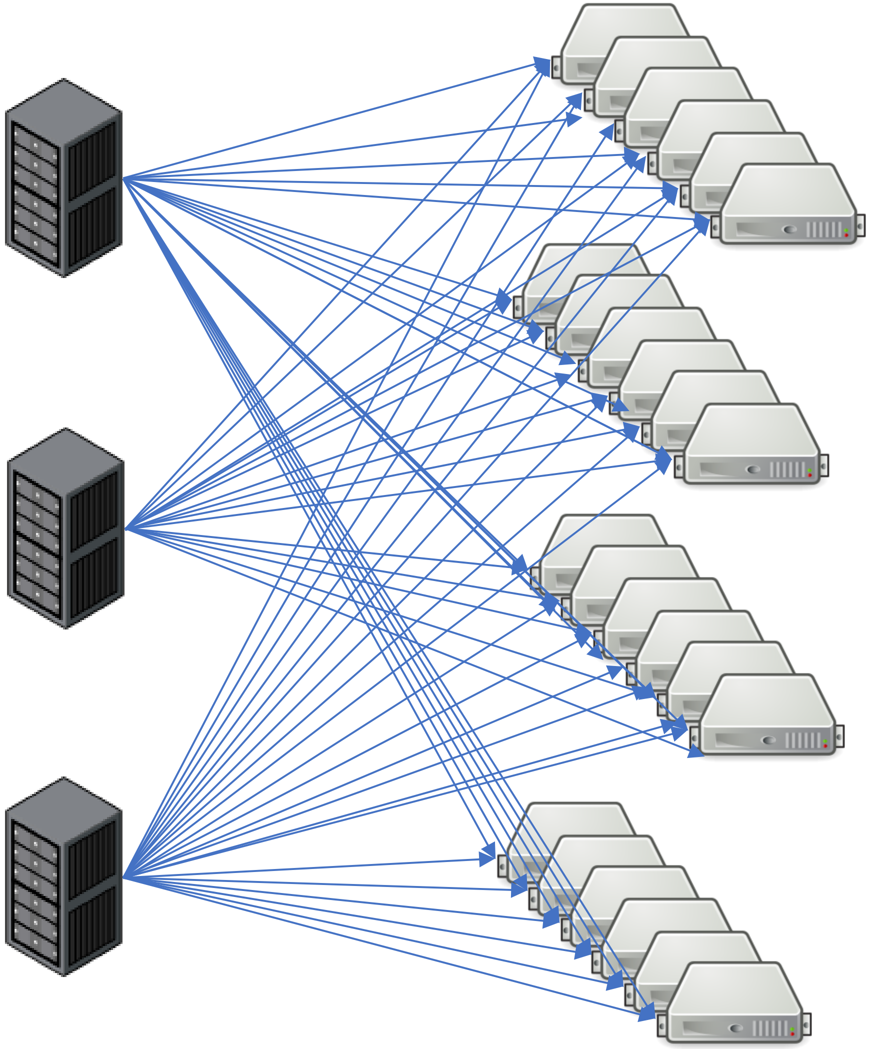
- Over 10 years of optimization work!
  - e.g., compression, adaptive parallelism, etc.

How often does the 99th percentile occur?

- For 10,000 queries / s → 100 times / s

What happens in a 100-node fanout?

- <u>Every query runs at the 99th percentile</u>!



The Primary demands many resources quickly

- **Bing IndexServe**: multi-threaded web-index server

➢ Up to 15 threads wake up in $5\mu s$[1]

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- **Workload arrives in bursts – exacerbates problem**

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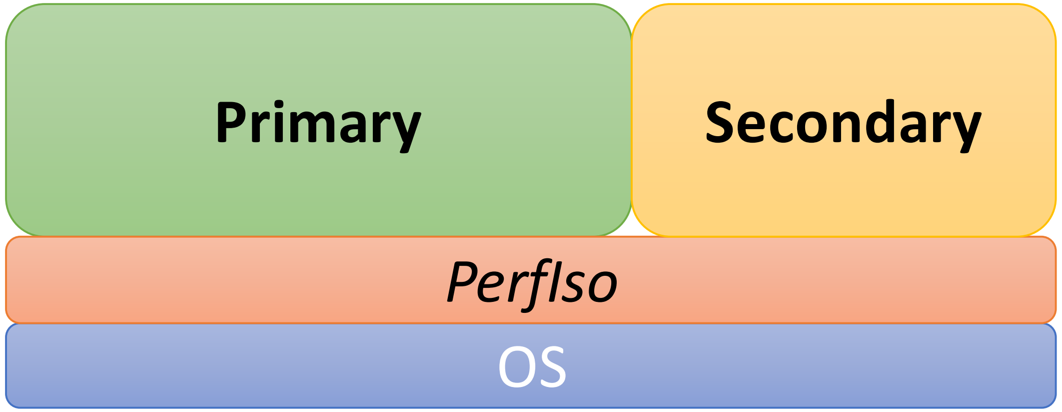
If a query is delayed, it is already too late!

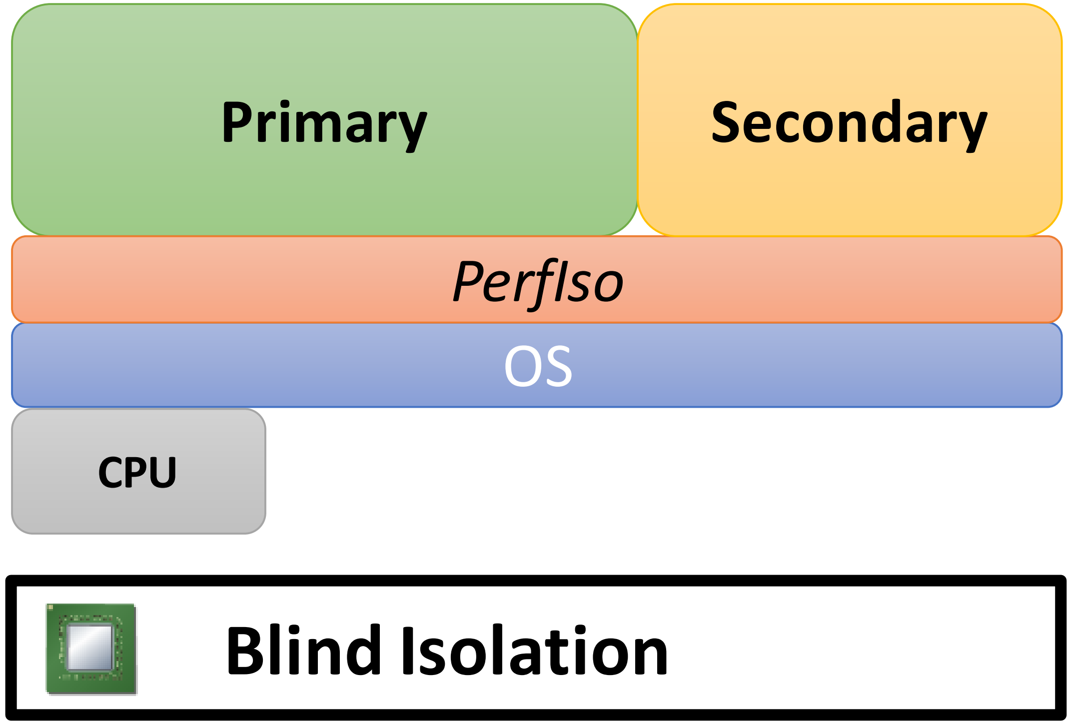
PerfIso

PerfIso: Implemented as a <u>user-mode</u> service

- Only keeps track of **Secondary**'s PID



PerfIso: Managed resources



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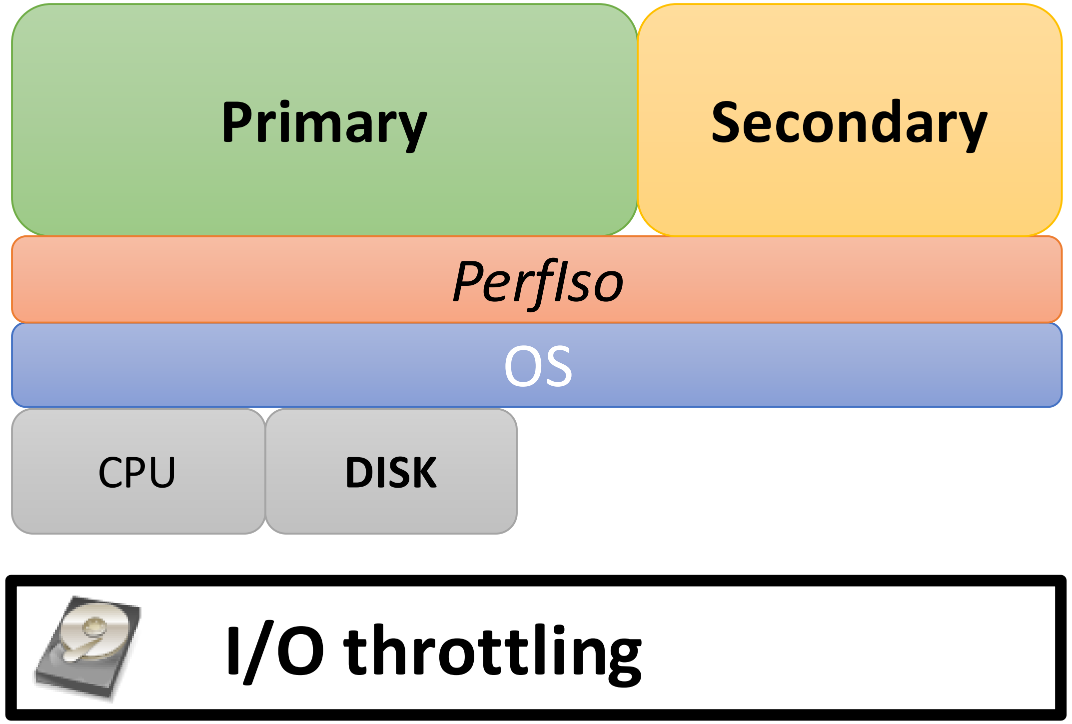

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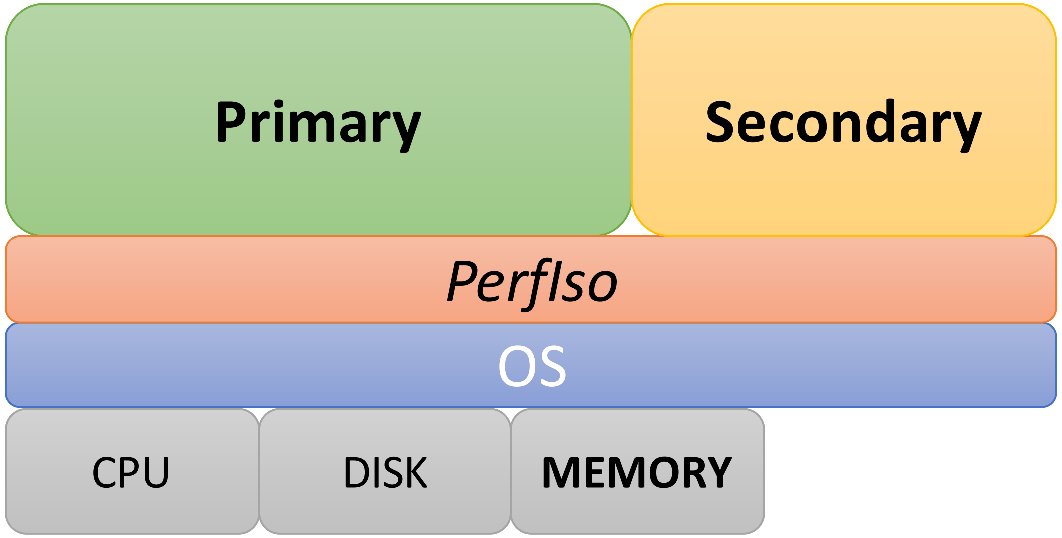

Restrict footprint

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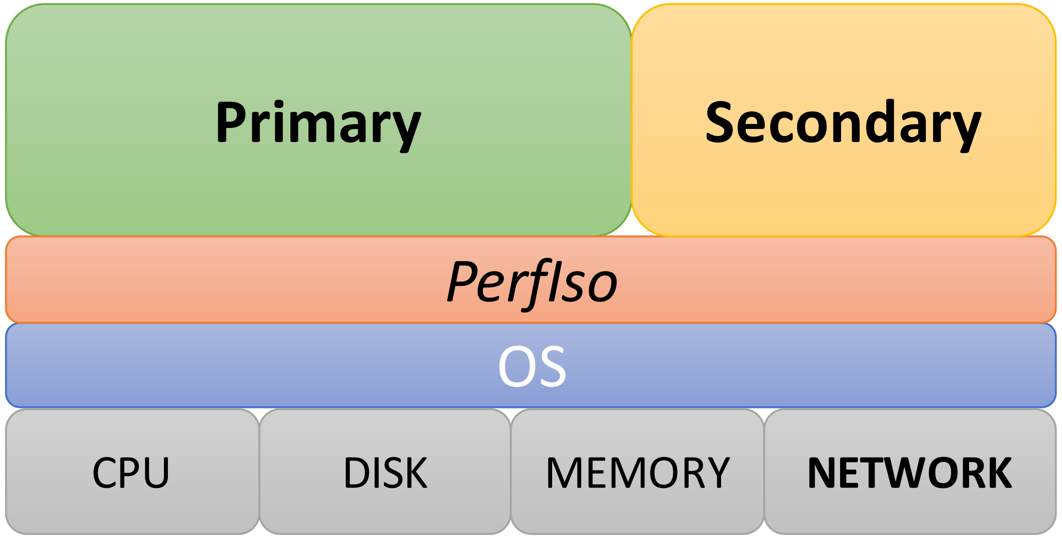
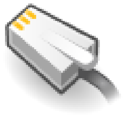
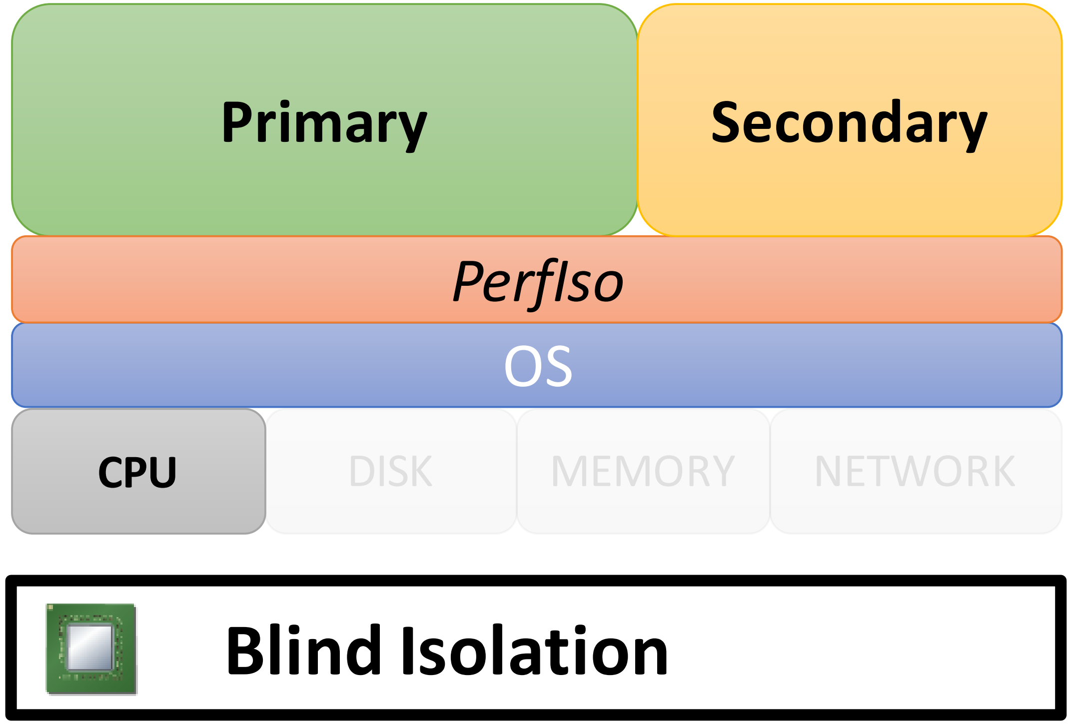




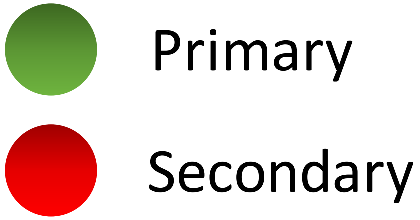
Throttle egress packets

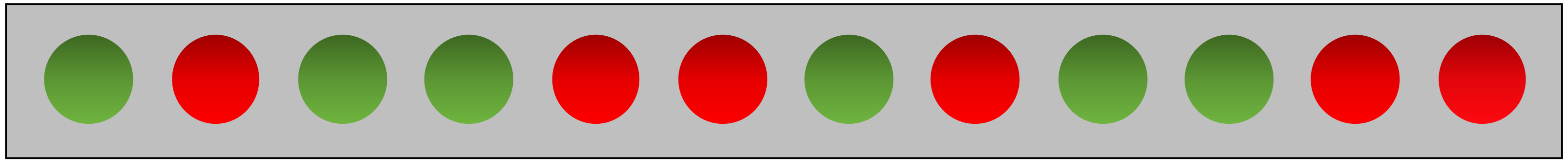
PerfIso: CPU is the most important resource



CPU sharing without *PerfIso*

- **Primary** and **Secondary** compete for cores.
- **Secondary** is aggressive: no idle cores exist.

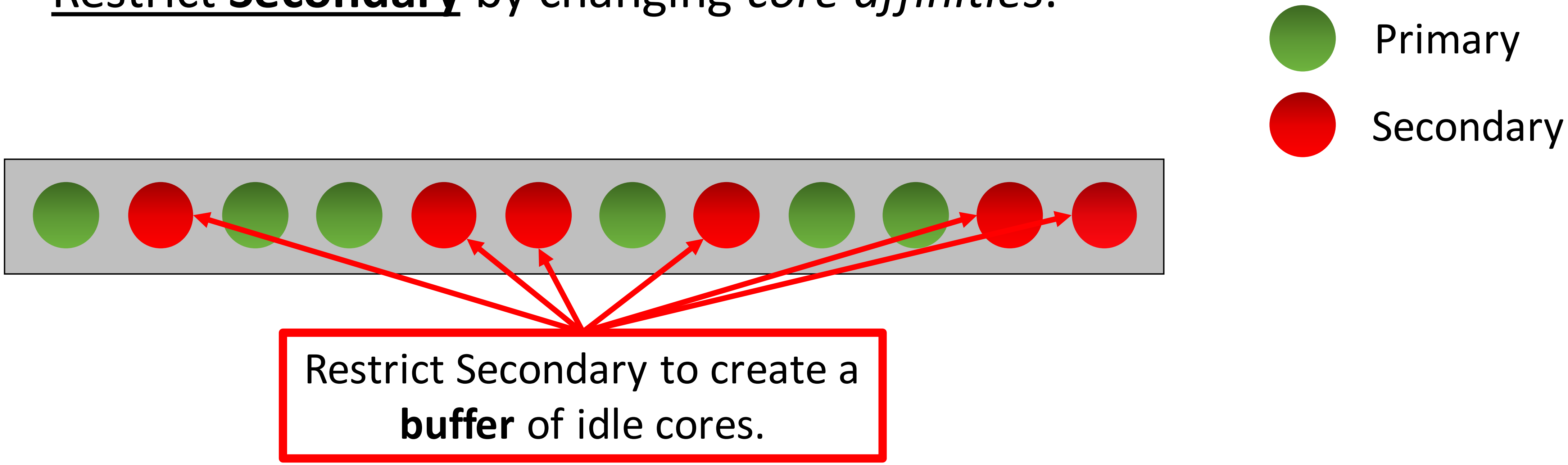




Machine with **12 cores**

CPU Blind Isolation: Keep a "buffer" of idle cores

- *PerfIso* only knows the **Secondary**.
- Restrict **Secondary** by changing *core affinities*.



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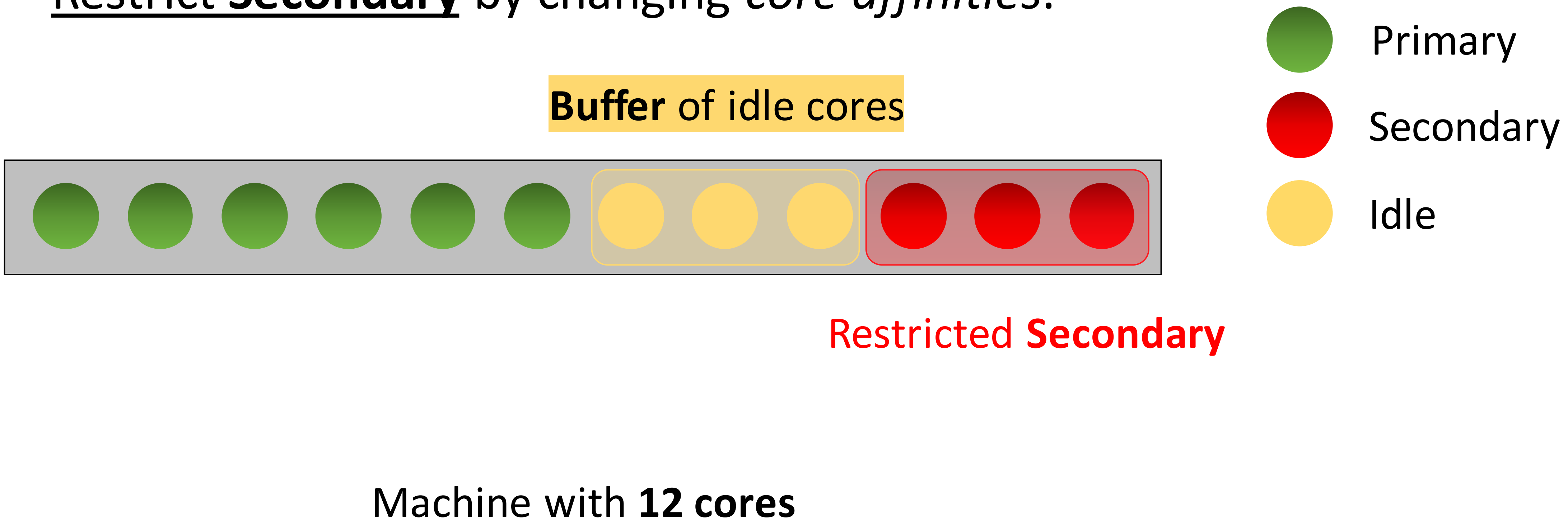

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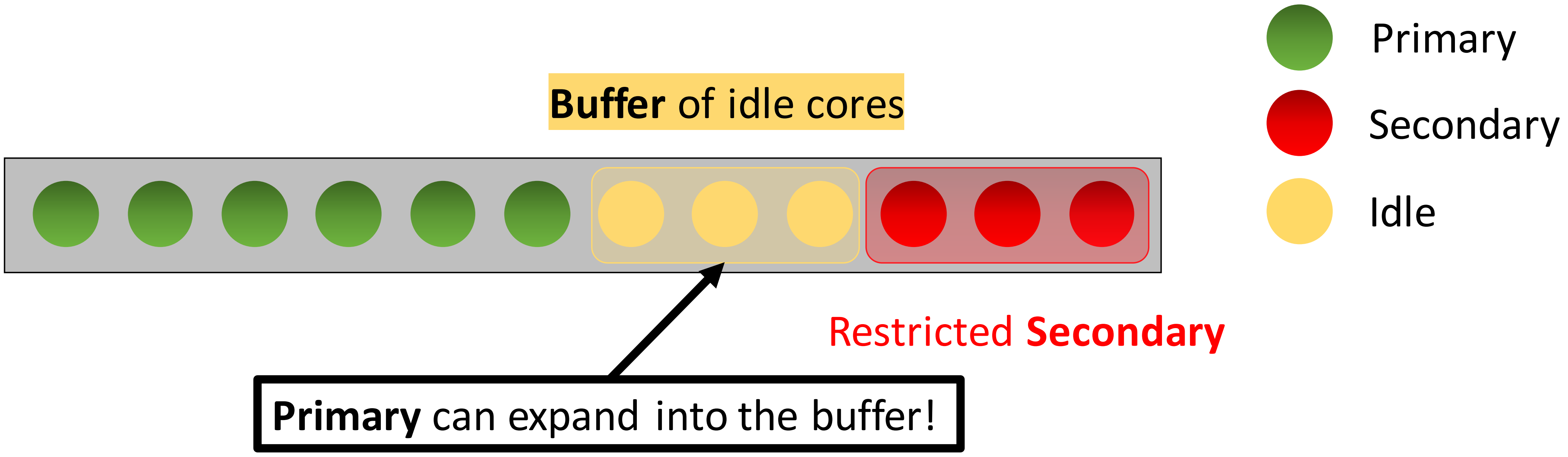

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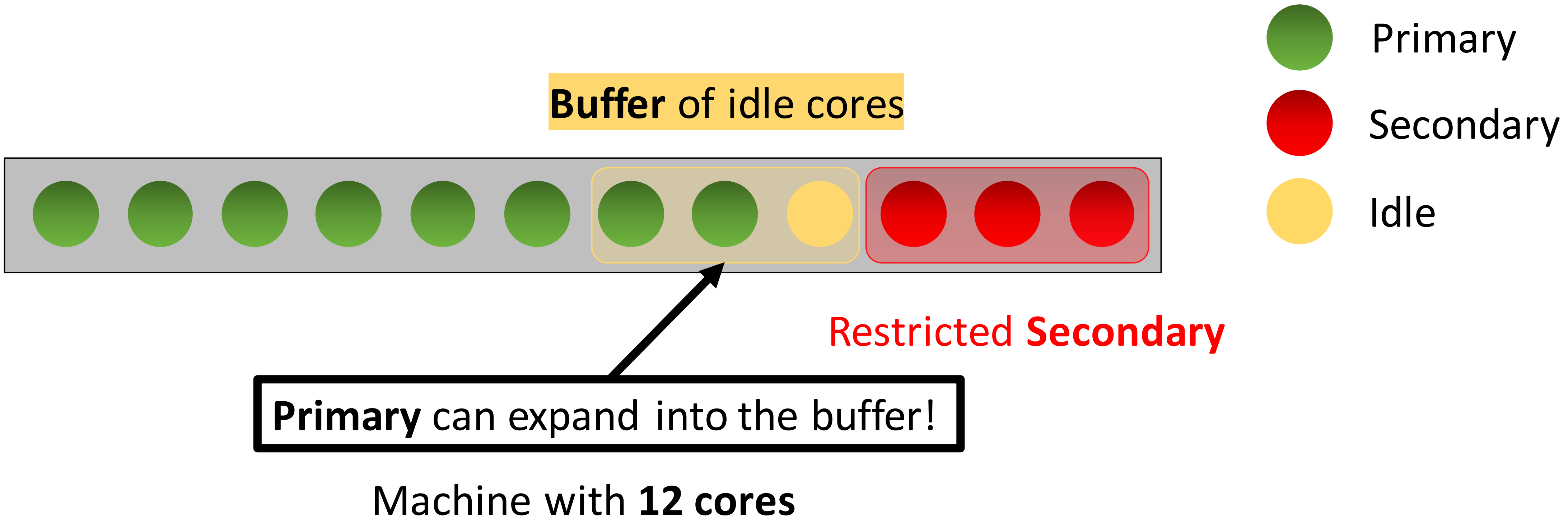

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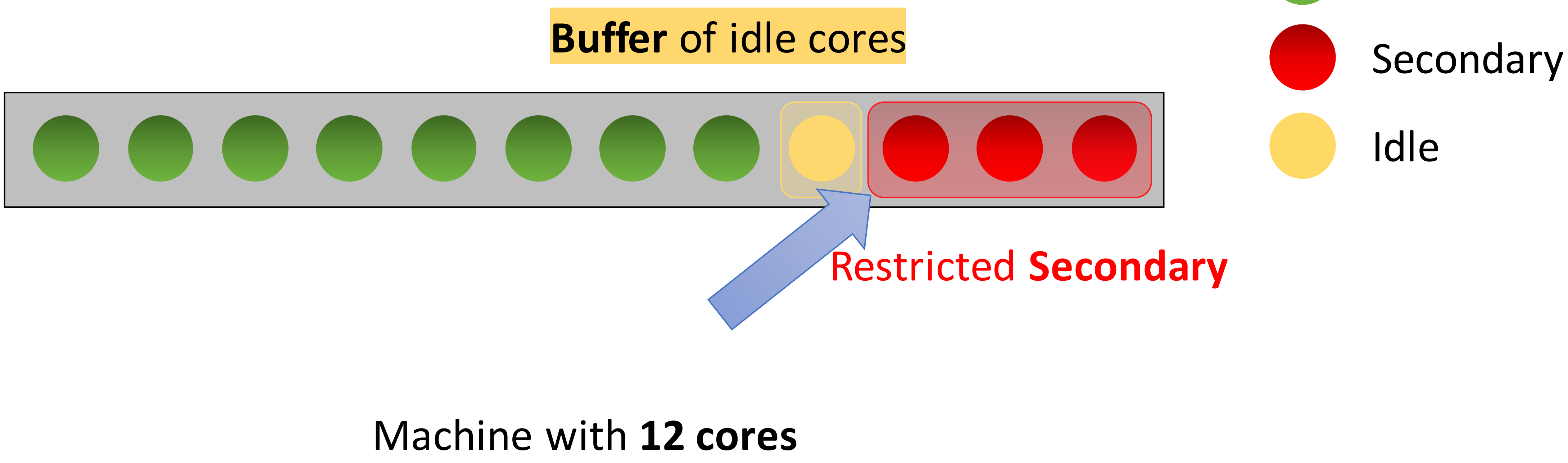

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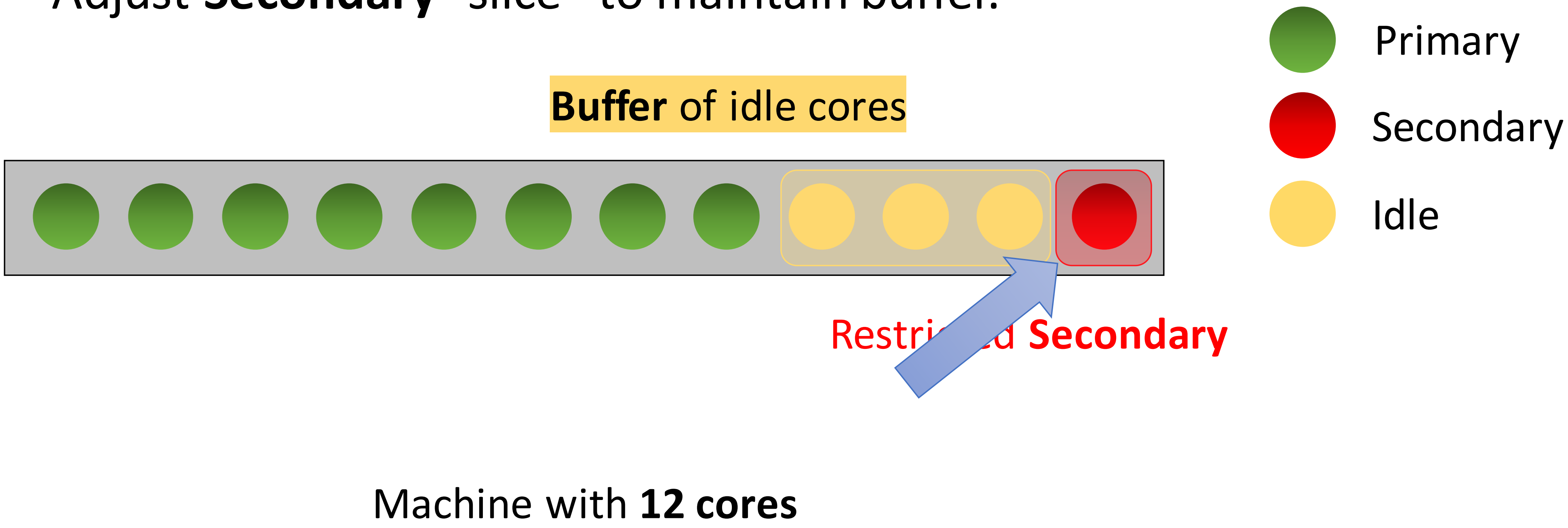

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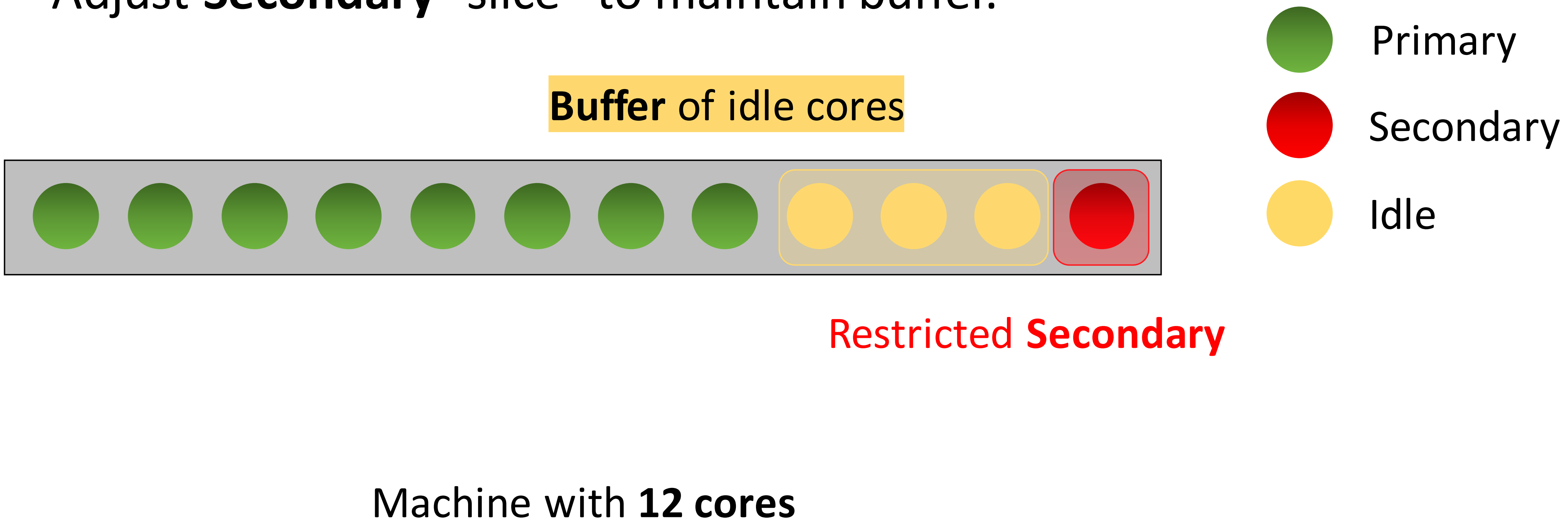

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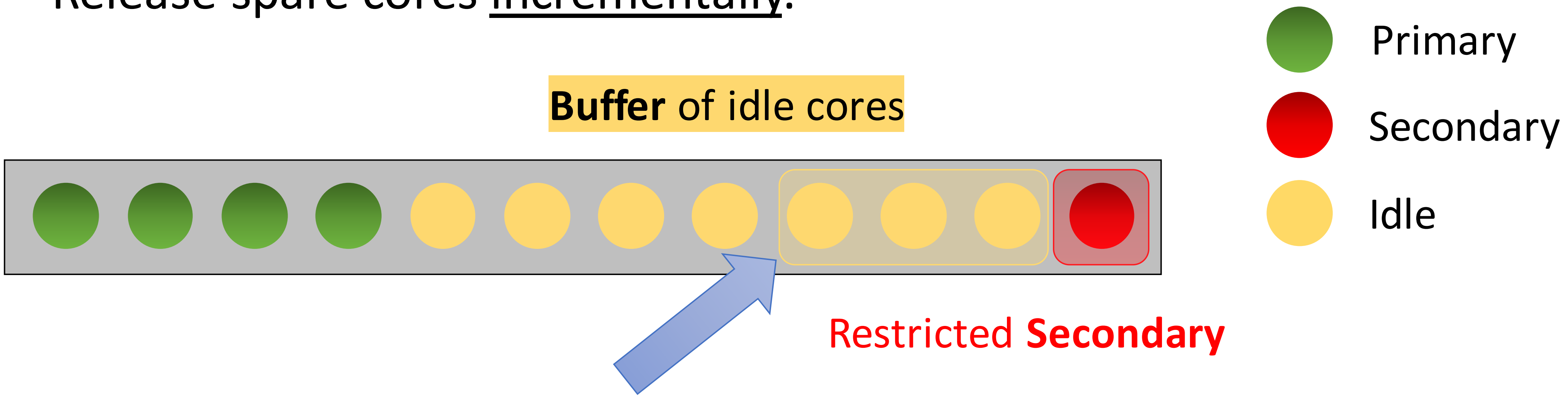

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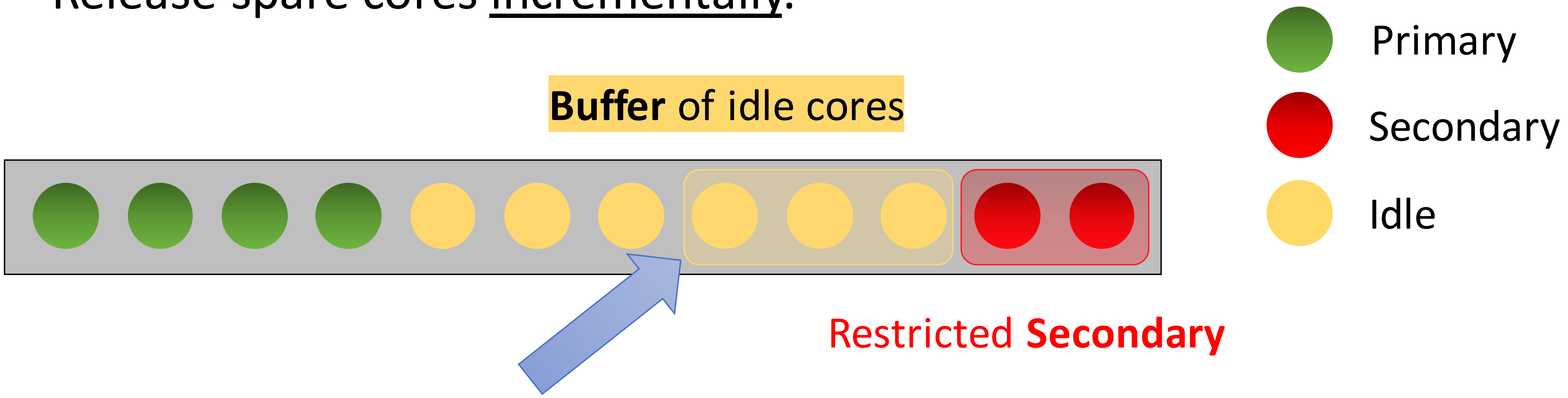

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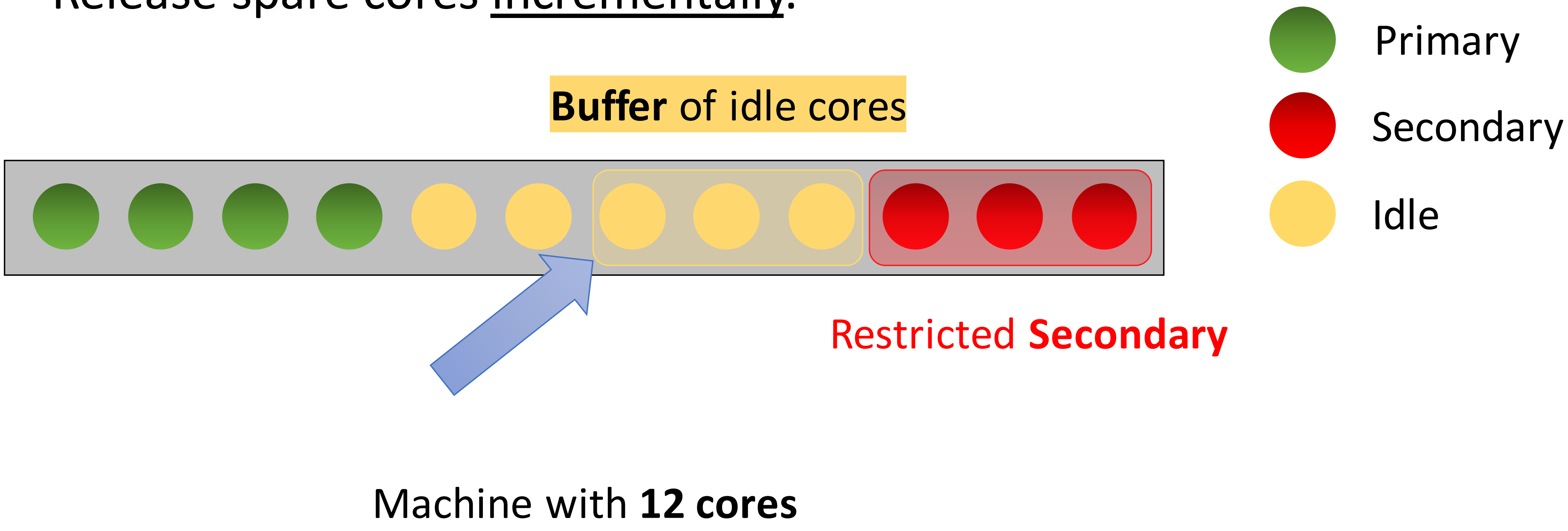

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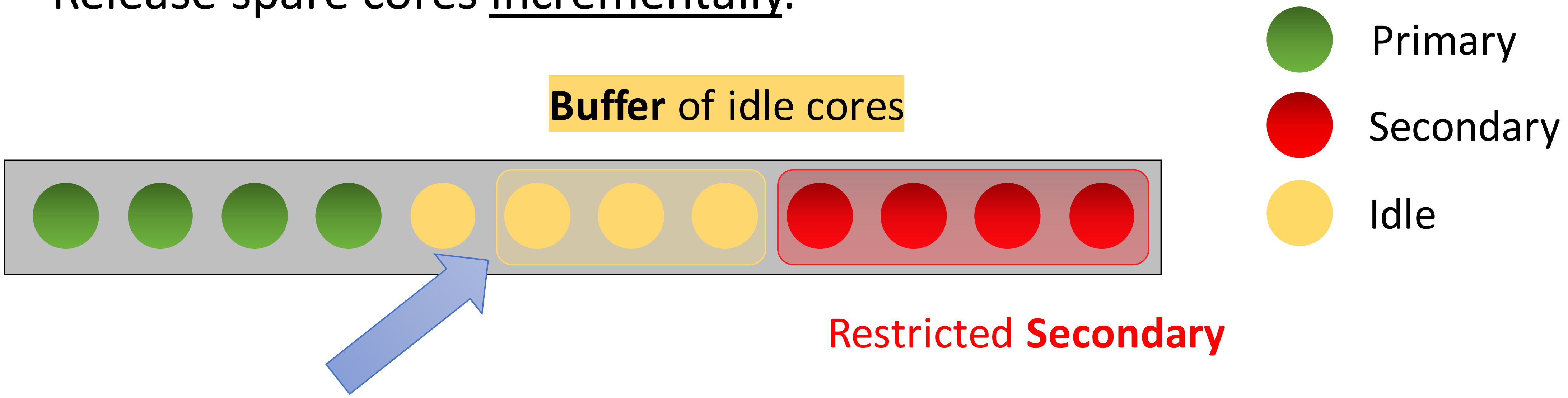

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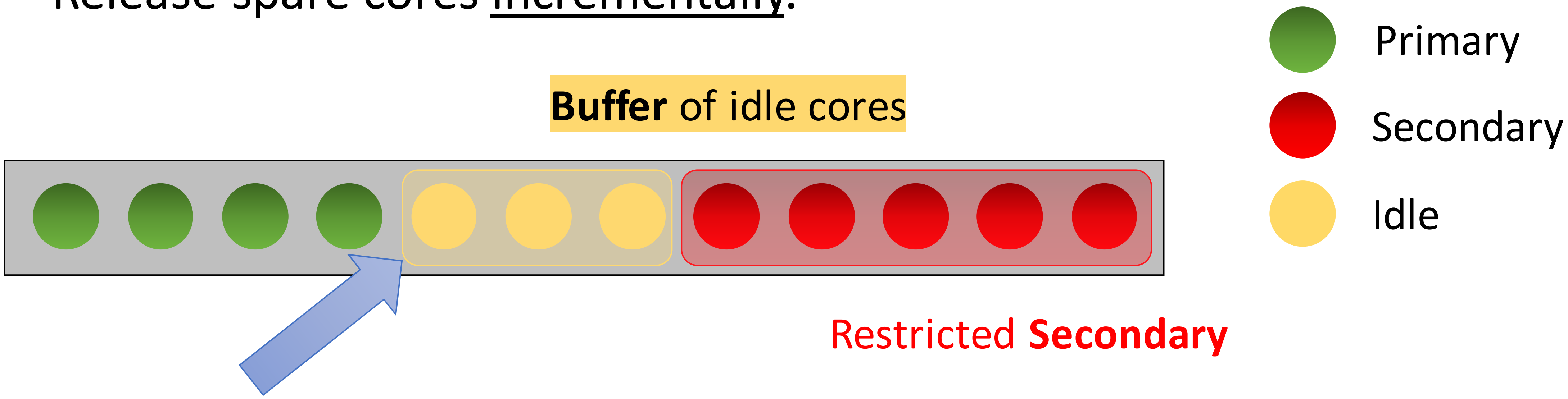

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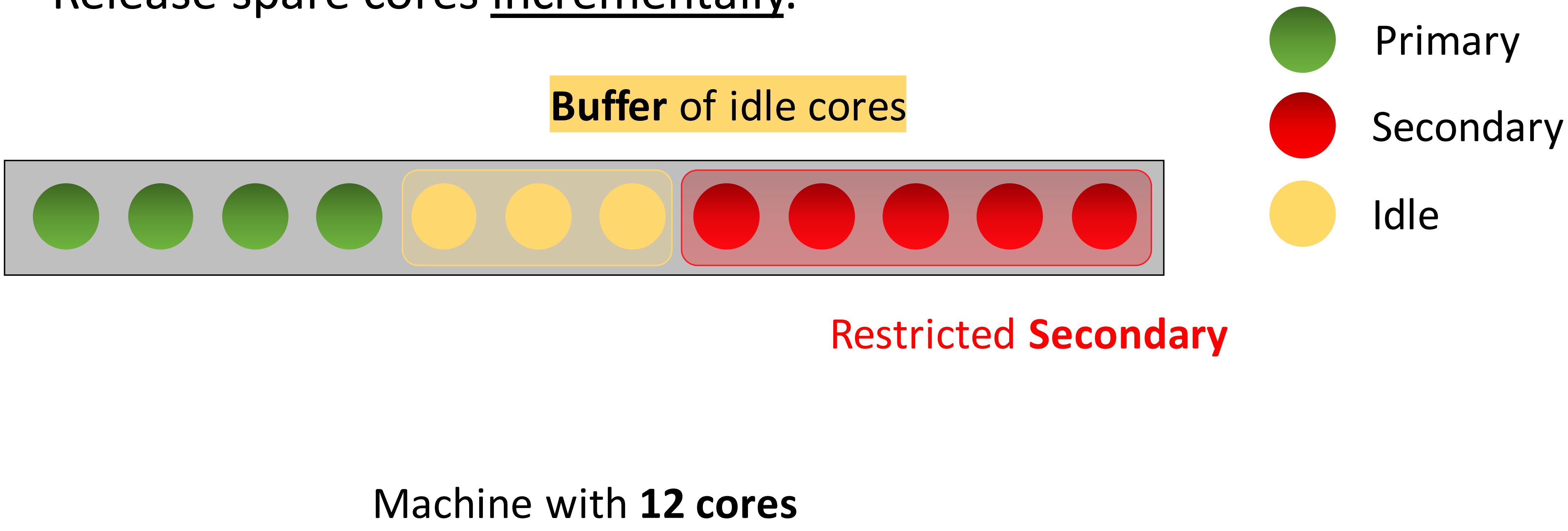
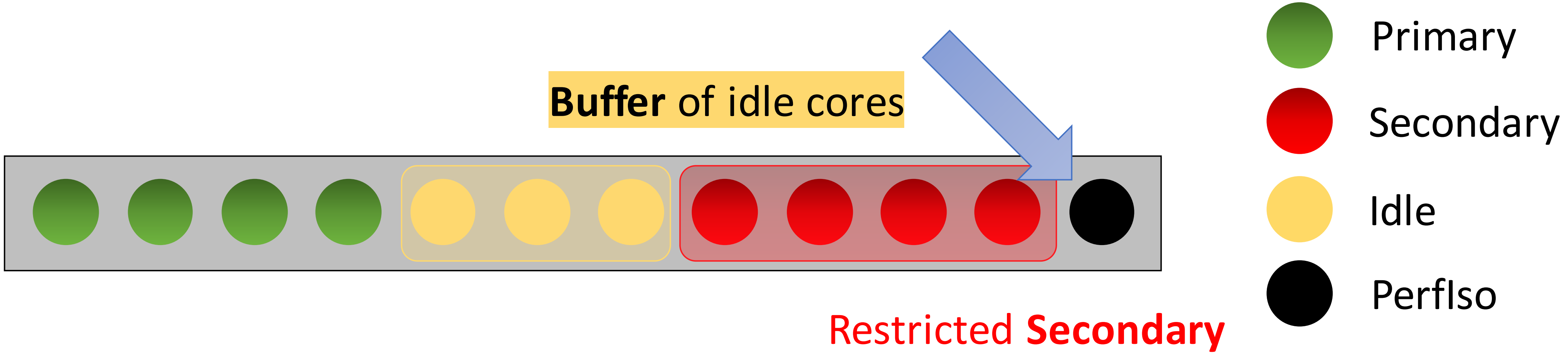


CPU Blind Isolation: We dedicate 1 core to *PerfIso*

- ***PerfIso*** does continuous polling → we affinitize it to 1 core.



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Evaluation

Experiment testbed

Hardware

- Intel Xeon E5 – 24 cores (48 w/ HT)
- 128GB RAM

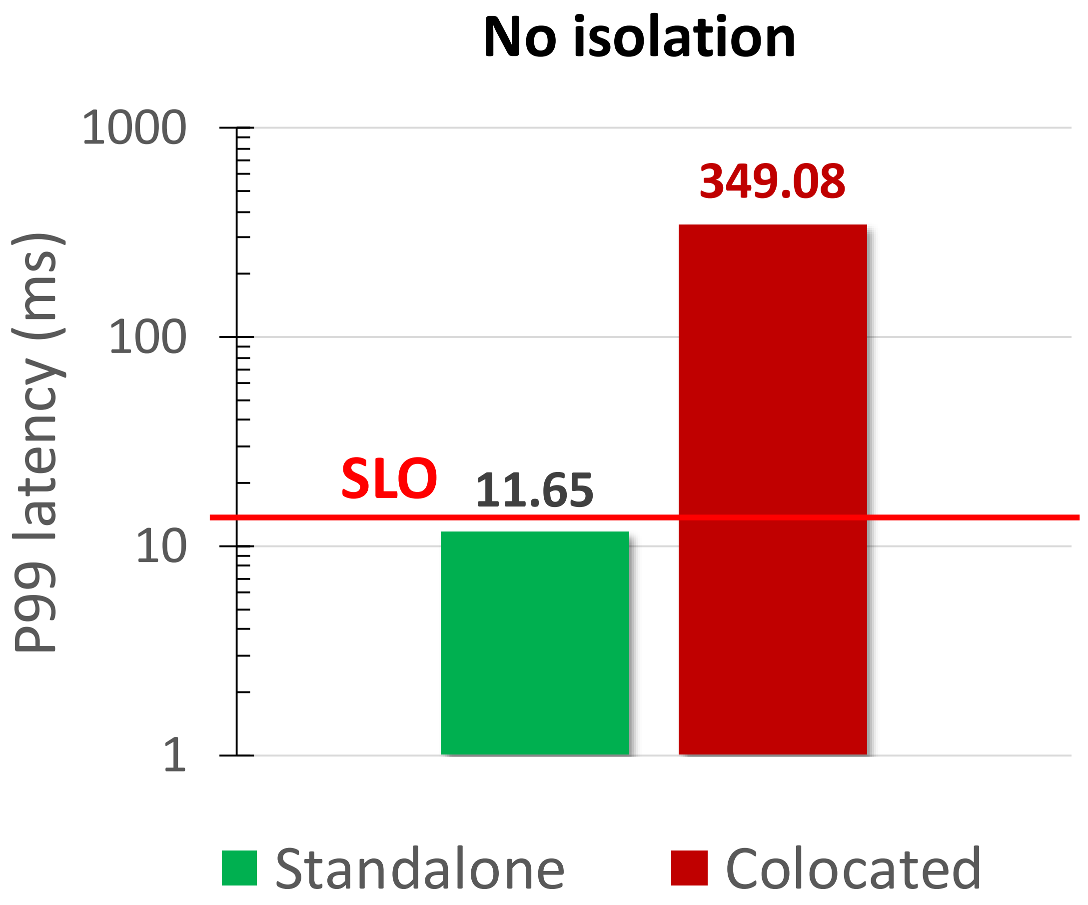
Primary: *Bing IndexServe*

- 569 GB index-slice
- Open-loop client
- 500,000 queries @ 2,000 Q / s

Secondary: CPU micro-benchmark

Single server: *PerfIso* protects tail-latency

Secondary: CPU-intensive micro-benchmark



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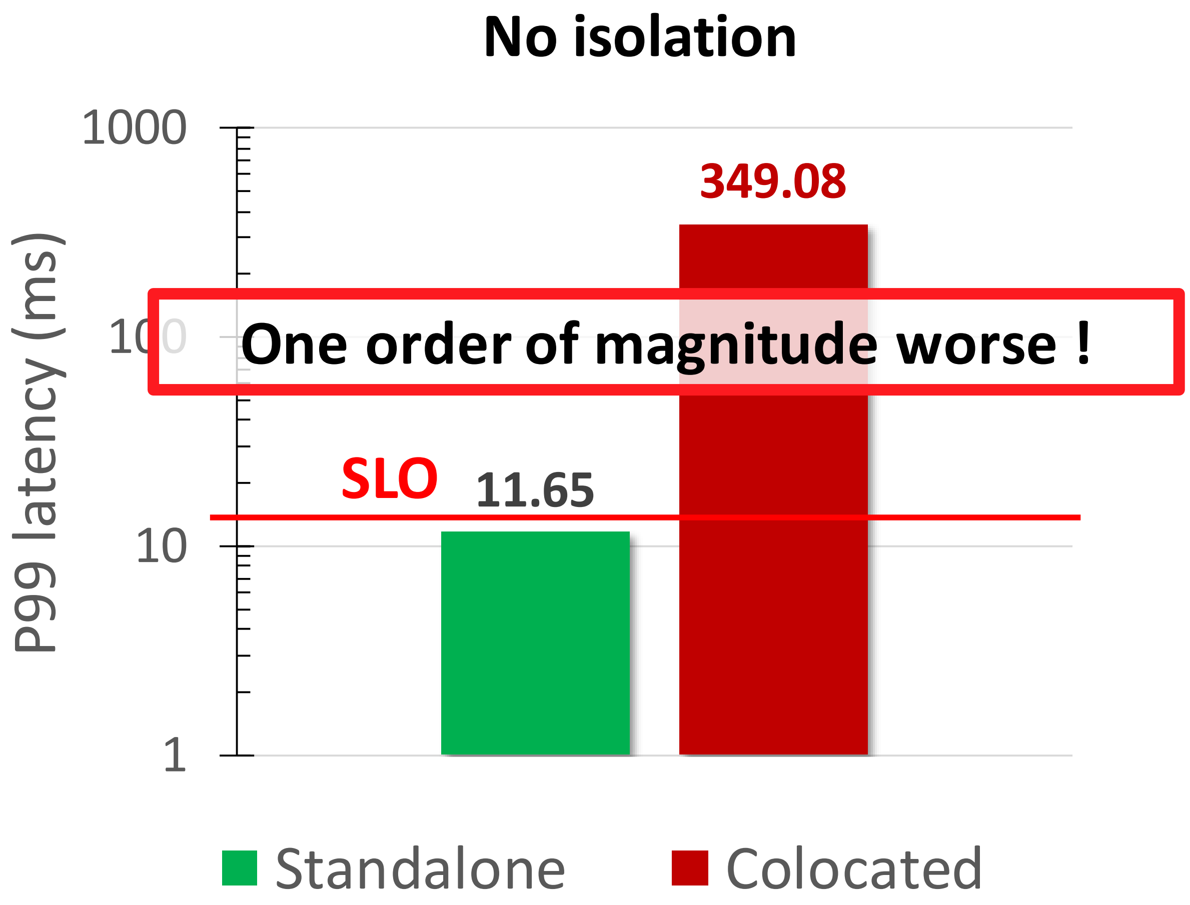

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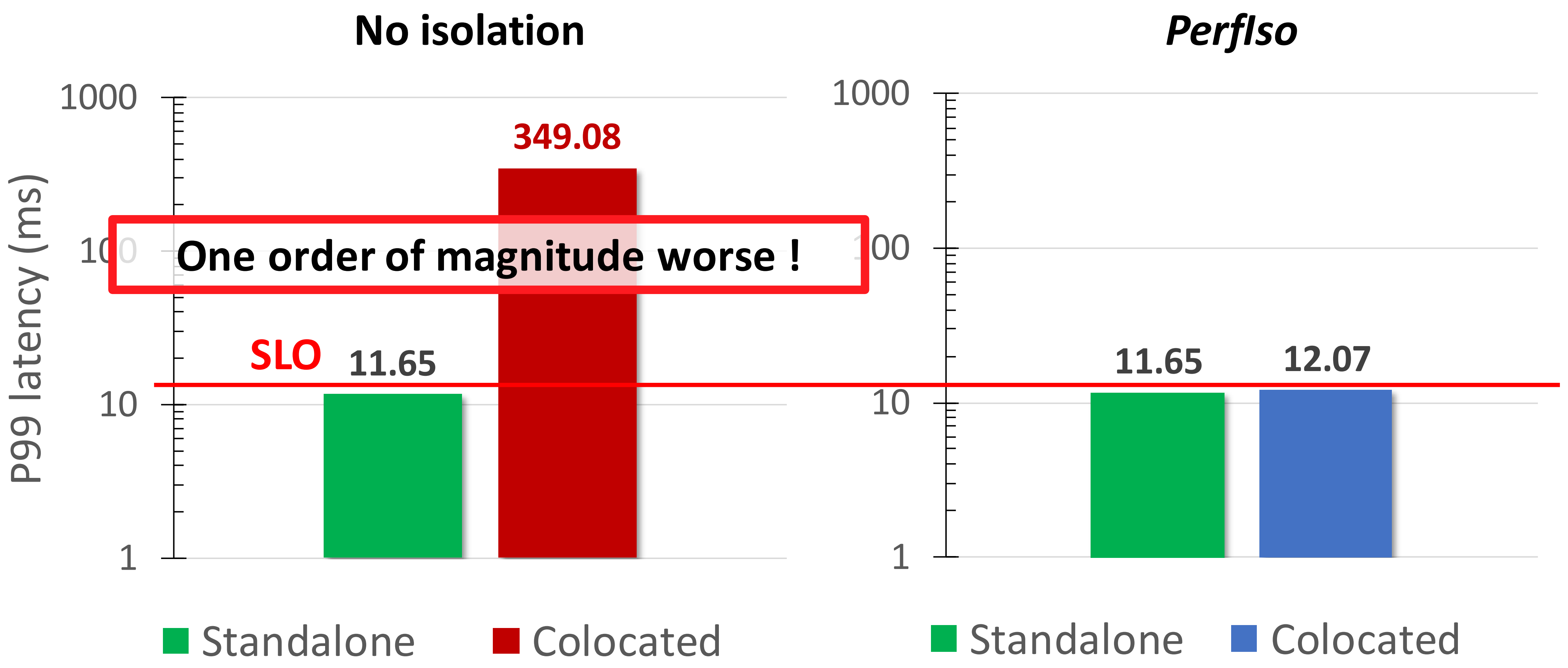

Single server: CPU utilization 3x higher!

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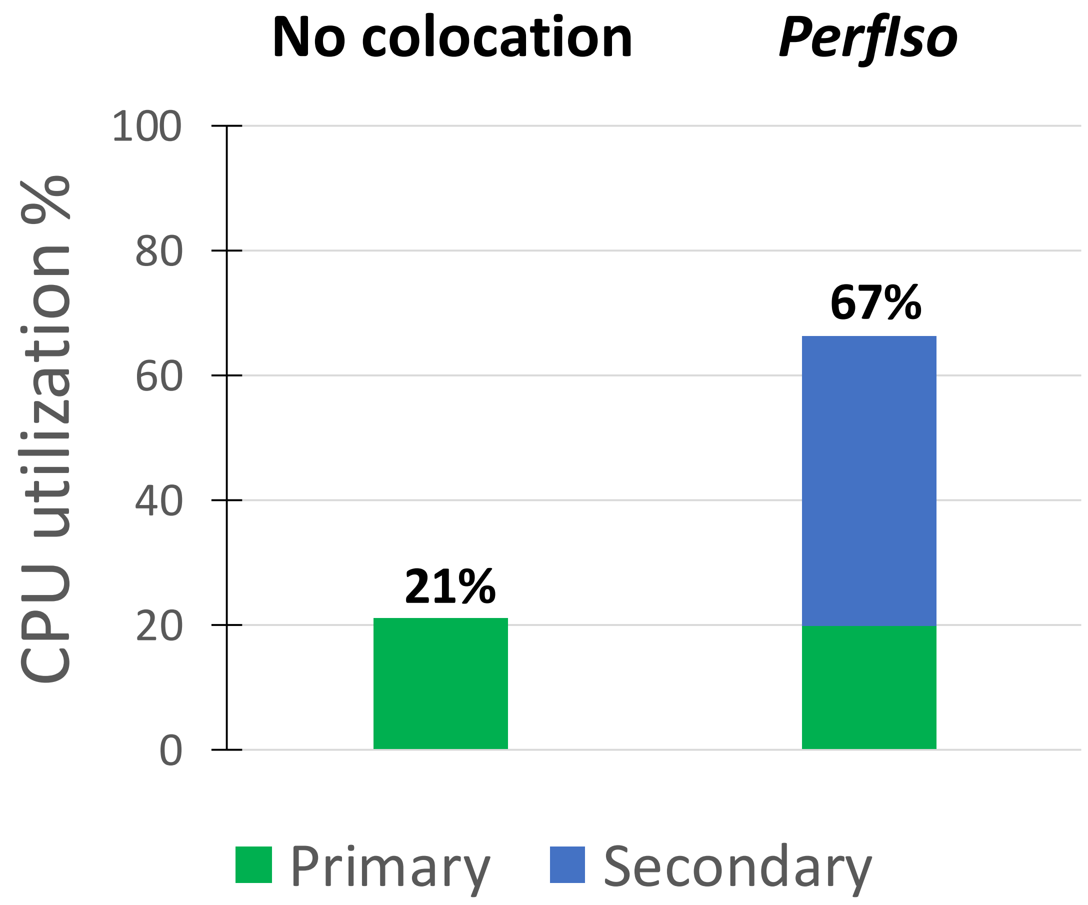

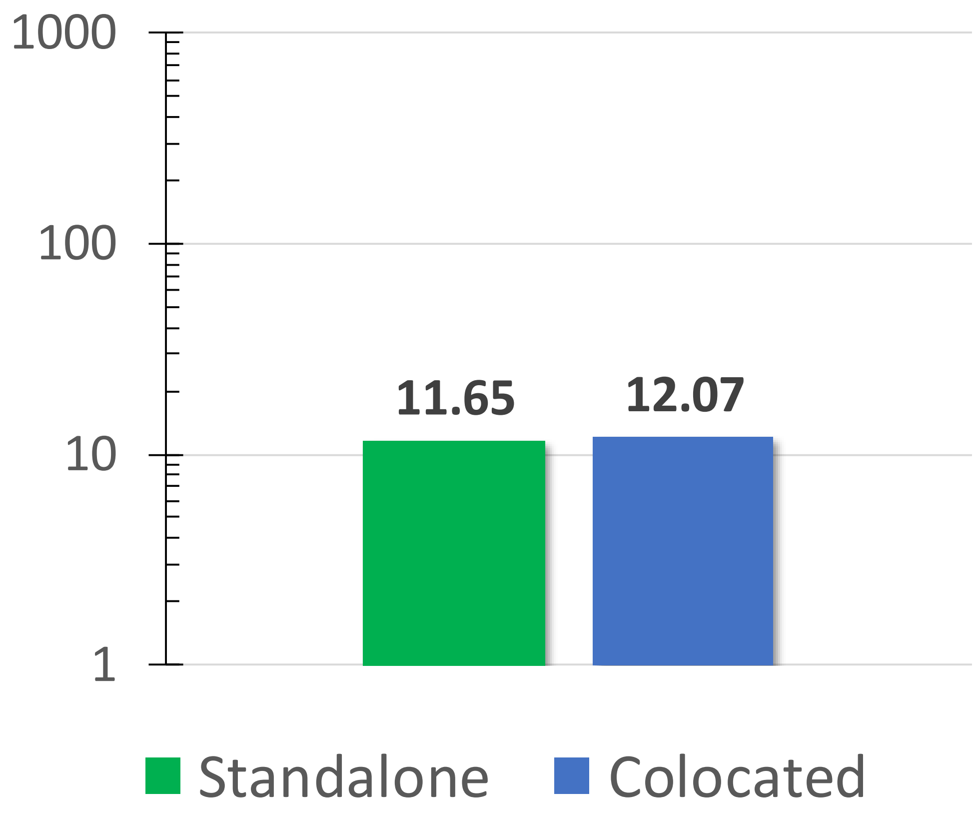

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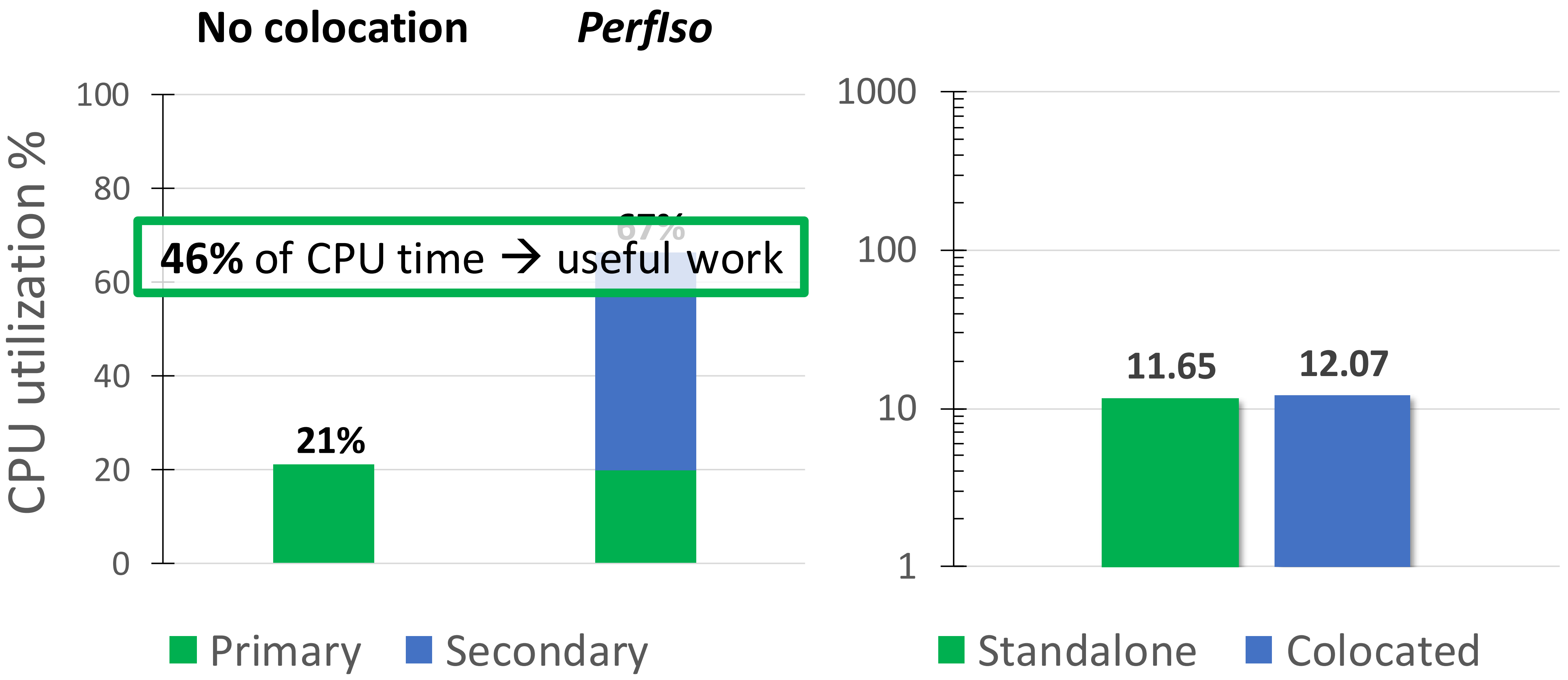
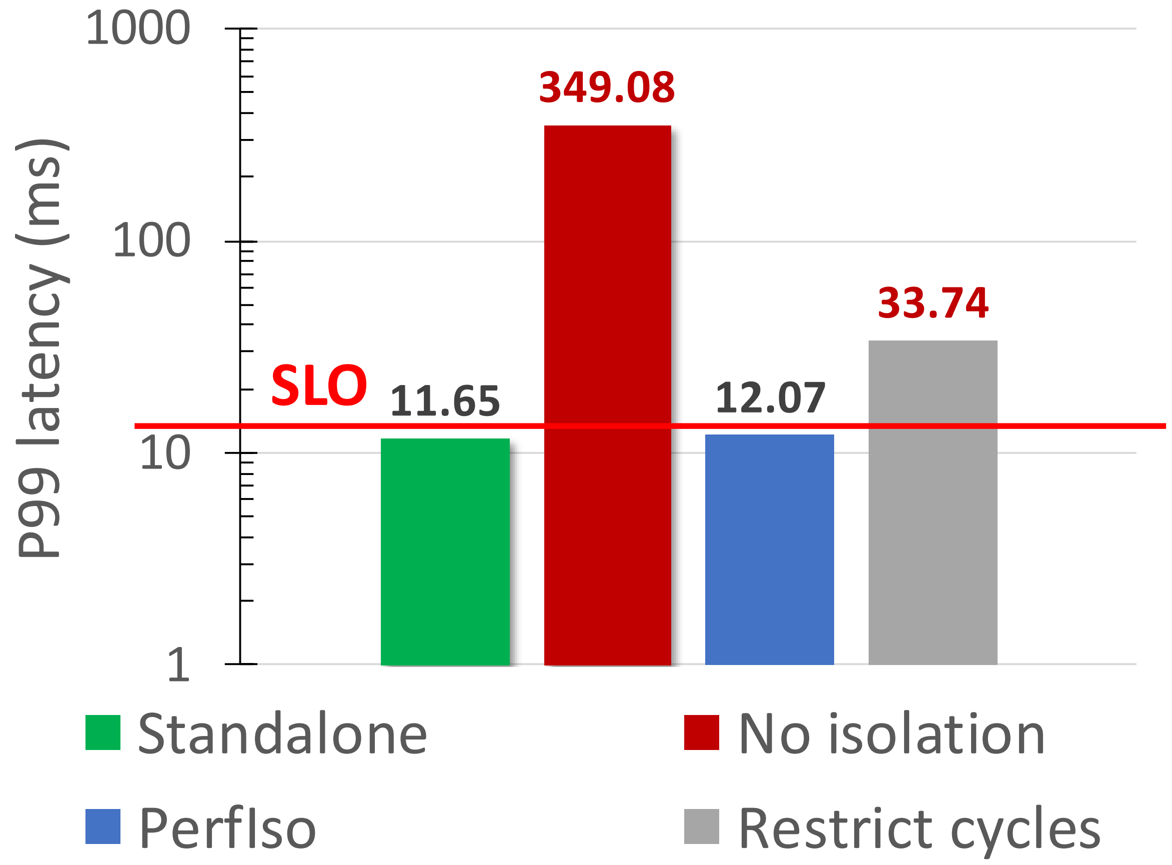


Restricting CPU cycles does not work

Secondary: CPU-intensive micro-benchmark



Secondary → 5% of CPU cycles

P99 latency – **3x higher than SLO!**

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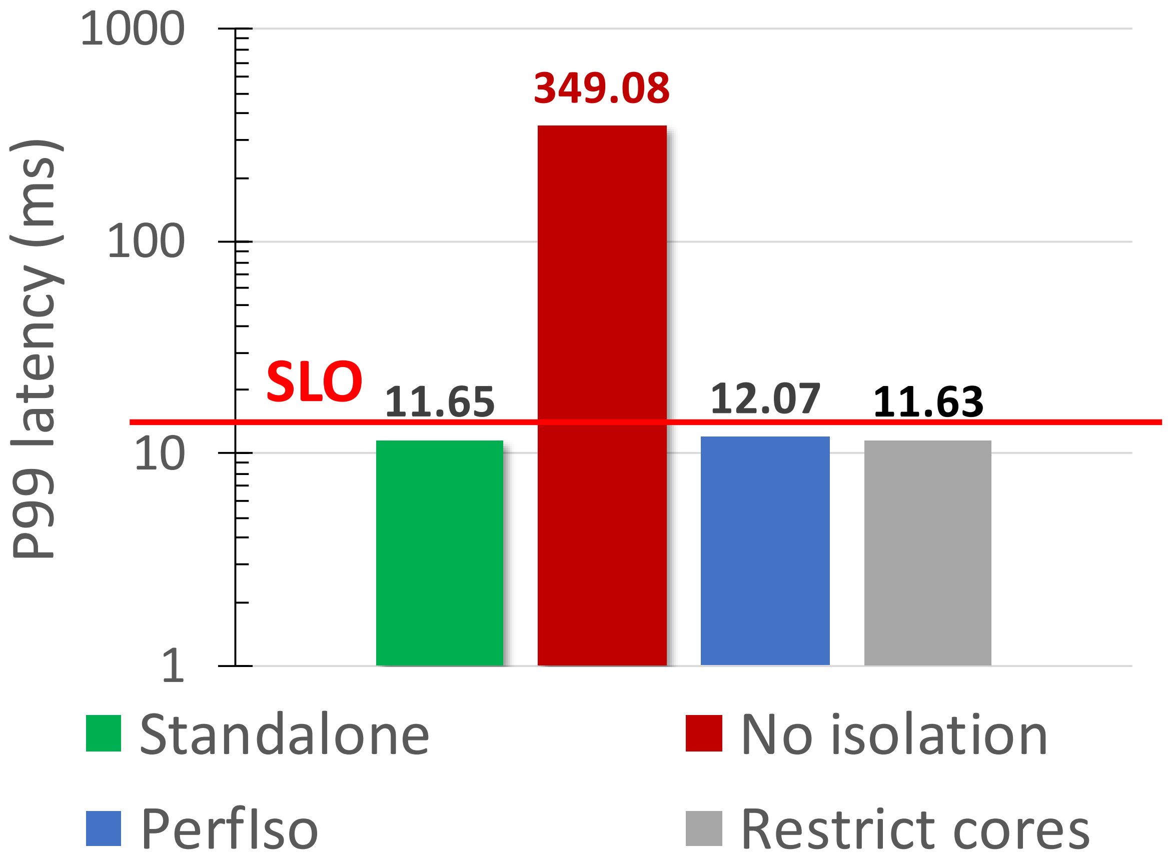

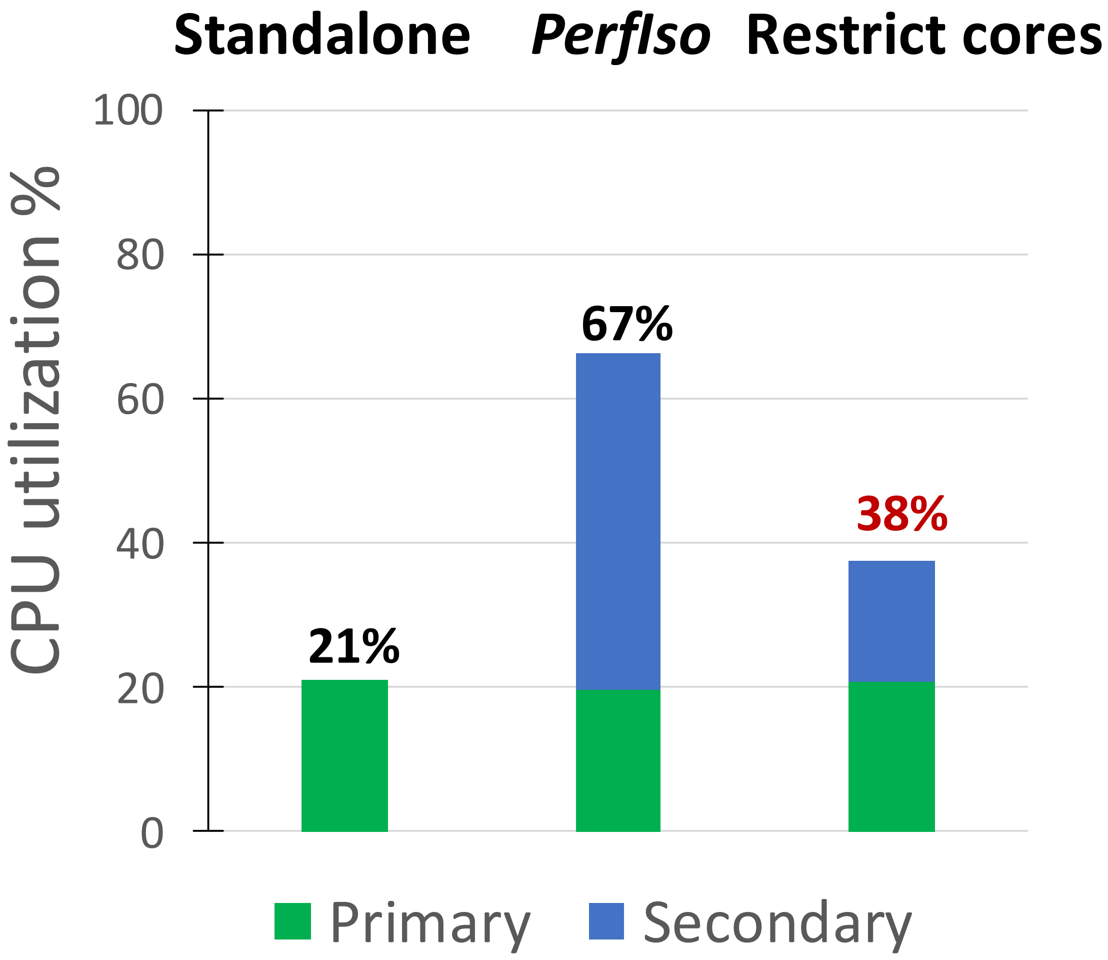

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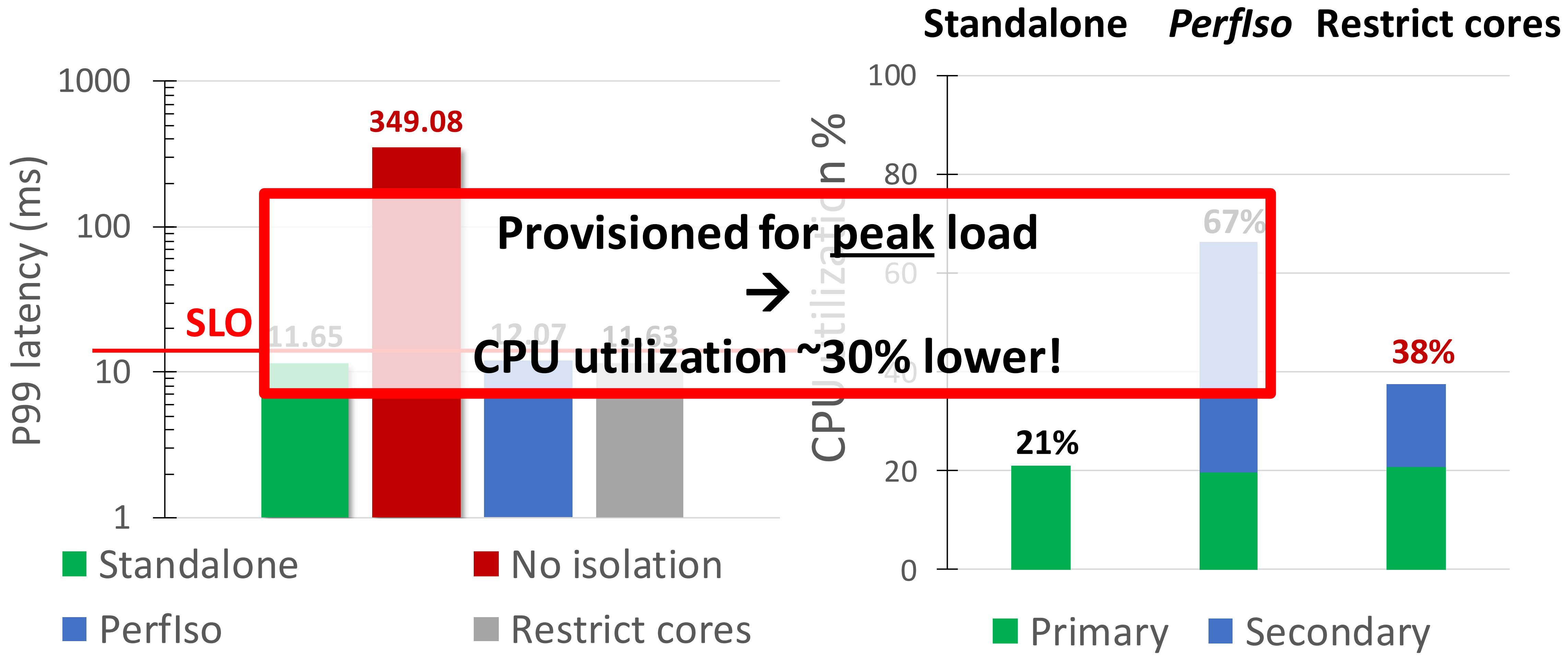
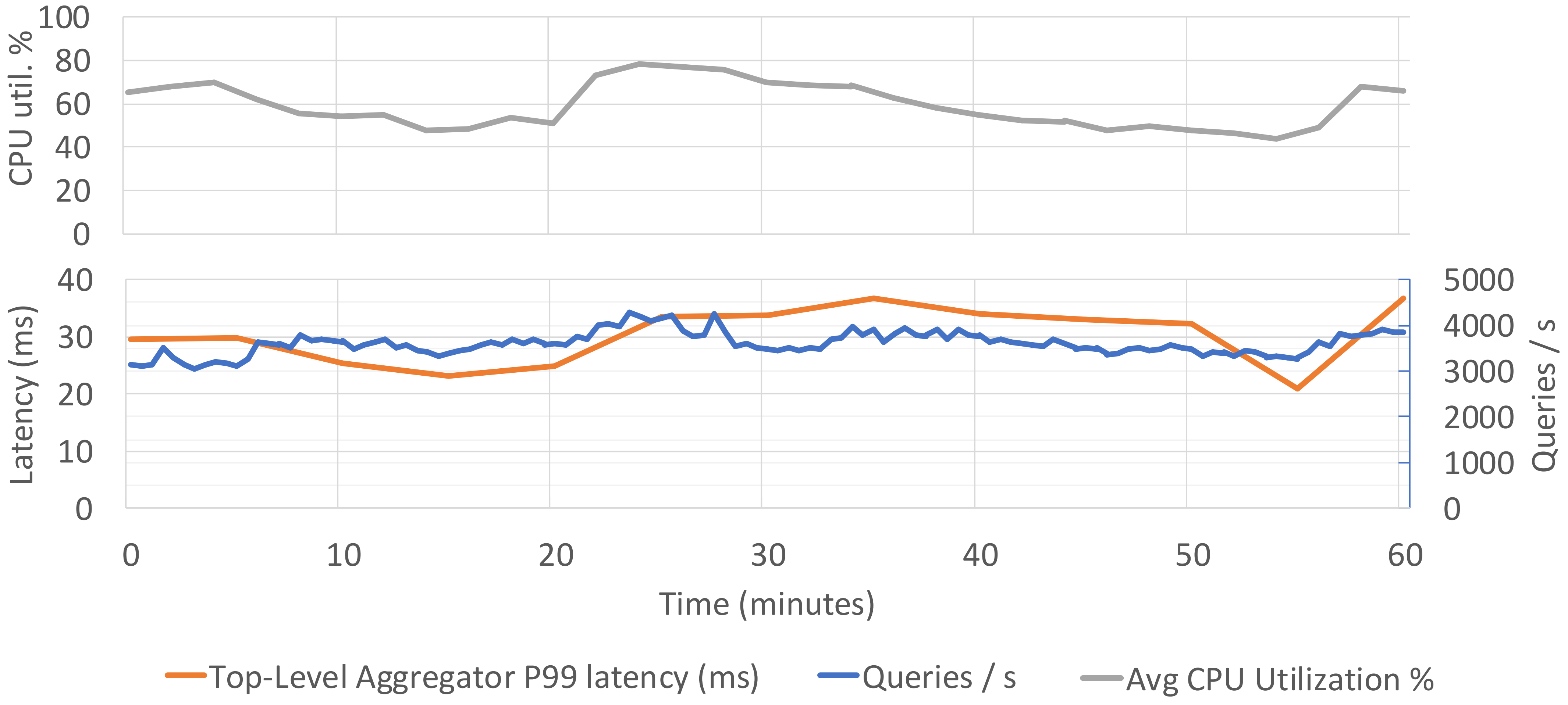


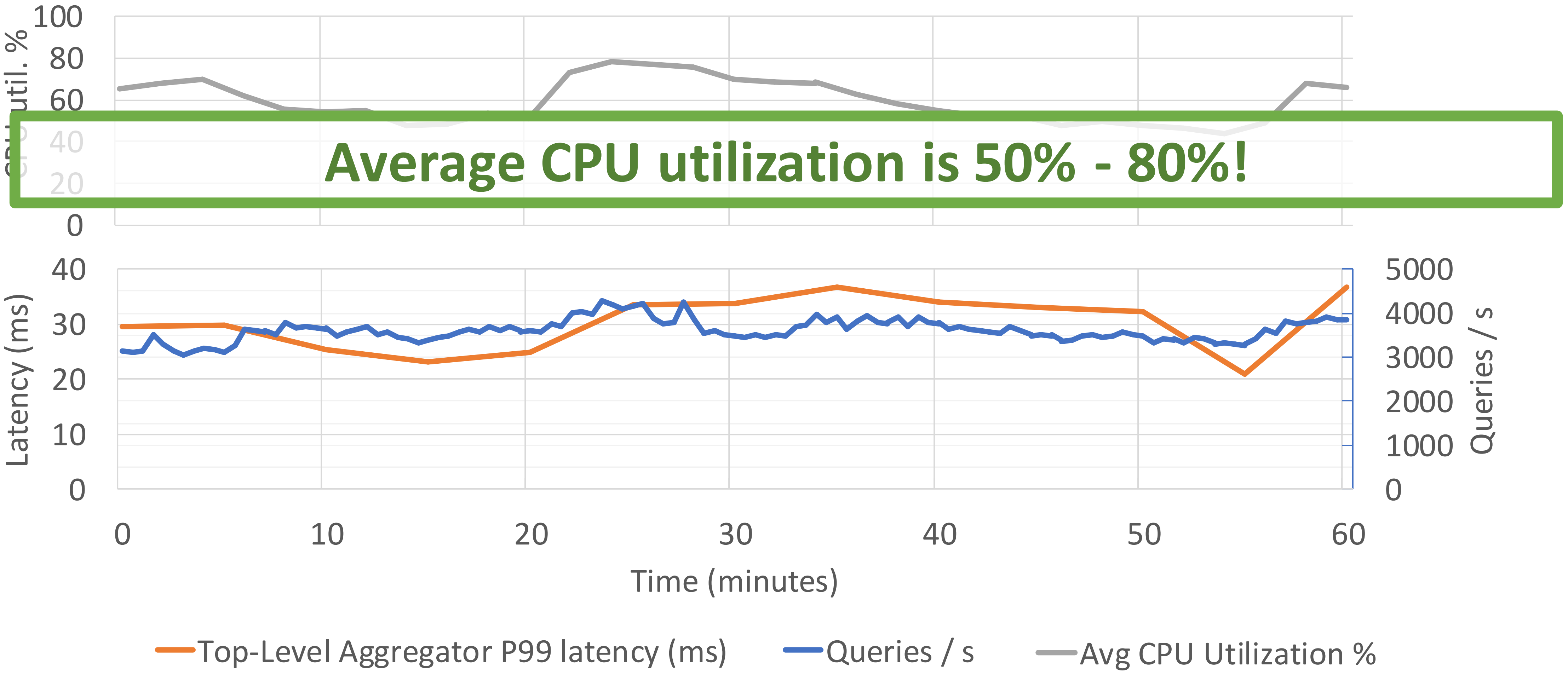
1-hour run of 650 machine cluster

Secondary: Machine-Learning computation



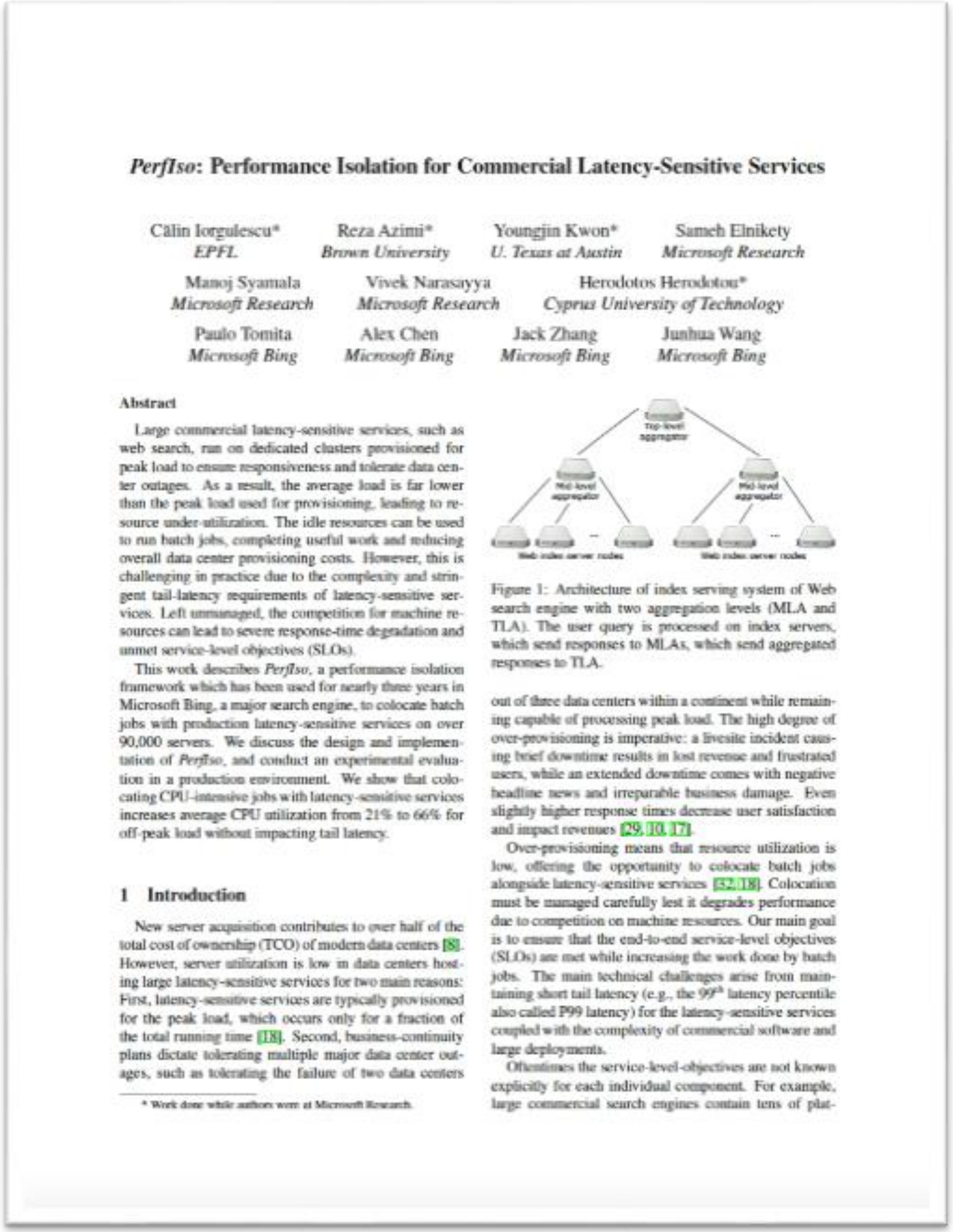
1-hour run of 650 machine cluster

Secondary: Machine-Learning computation



Interesting details in the paper

- Effectiveness of static CPU isolation methods
  - Restricting CPU cycles
  - Restricting CPU cores
- Comparison of state-of-the-art techniques
- Managing disk, memory, and network



PerfIso: Performance Isolation for Commercial Latency-Sensitive Services

Călin Iorgulescu* (EPFL), Reza Azimi* (Brown University), Youngjin Kwon* (U. Texas at Austin), Sameh Elnikety (Microsoft Research), Manoj Syamala (Microsoft Research), Vivek Narasayya (Microsoft Research), Herodotos Herodotou* (Cyprus University of Technology), Paulo Tomita (Microsoft Bing), Alex Chen (Microsoft Bing), Jack Zhang (Microsoft Bing), Junhua Wang (Microsoft Bing)

Abstract

Large commercial latency-sensitive services, such as web search, run on dedicated clusters provisioned for peak load to ensure responsiveness and tolerate data center outages. As a result, the average load is far lower than the peak load used for provisioning, leading to resource under-utilization. The idle resources can be used to run batch jobs, completing useful work and reducing overall data center provisioning costs. However, this is challenging in practice due to the complexity and stringent tail-latency requirements of latency-sensitive services. Left unmanaged, the competition for machine resources can lead to severe response-time degradation and unmet service-level objectives (SLOs).

This work describes *PerfIso*, a performance isolation framework which has been used for nearly three years in Microsoft Bing, a major search engine, to colocate batch jobs with production latency-sensitive services on over 90,000 servers. We discuss the design and implementation of *PerfIso*, and conduct an experimental evaluation in a production environment. We show that colocating CPU-intensive jobs with latency-sensitive services increases average CPU utilization from 21% to 66% for off-peak load without impacting tail latency.

1 Introduction

New server acquisition contributes to over half of the total cost of ownership (TCO) of modern data centers [8]. However, server utilization is low in data centers hosting large latency-sensitive services for two main reasons: First, latency-sensitive services are typically provisioned for the peak load, which occurs only for a fraction of the total running time [18]. Second, business-continuity plans dictate tolerating multiple major data center outages, such as tolerating the failure of two data centers out of three data centers within a continent while remaining capable of processing peak load. The high degree of over-provisioning is imperative: a livesite incident causing brief downtime results in lost revenue and frustrated users, while an extended downtime comes with negative headline news and irreparable business damage. Even slightly higher response times decrease user satisfaction and impact revenues [29, 10, 17].

Over-provisioning means that resource utilization is low, offering the opportunity to colocate batch jobs alongside latency-sensitive services [32, 18]. Colocation must be managed carefully lest it degrades performance due to competition on machine resources. Our main goal is to ensure that the end-to-end service-level objectives (SLOs) are met while increasing the work done by batch jobs. The main technical challenges arise from maintaining short tail latency (e.g., the 99^{th} latency percentile also called P99 latency) for the latency-sensitive services coupled with the complexity of commercial software and large deployments.

Oftentimes the service-level-objectives are not known explicitly for each individual component. For example, large commercial search engines contain tens of plat-

Figure 1: Architecture of index serving system of Web search engine with two aggregation levels (MLA and TLA). The user query is processed on index servers, which send responses to MLAs, which send aggregated responses to TLA.

* Work done while authors were at Microsoft Research.

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- <u>CPU Blind Isolation → colocation without impacting service performance</u>