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Escra: Event-driven, Sub-second Container Resource Allocation

Greg Cusack, Maziyar Nazari, Sepideh Goodarzy, Erika Hunhoff, Prerit Oberai, Eric Keller, Eric Rozner, Richard Han

ICDCS - July 11, 2022
Bologna, Italy

Containerized Infrastructure

- Light-weight
- Rich orchestration systems
- Development workflow integration
- Strong resource isolation

Developers must make tradeoffs!

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Prioritize Performance

Overallocate compute resources

Prioritize Resource Efficiency

Underallocate compute resources

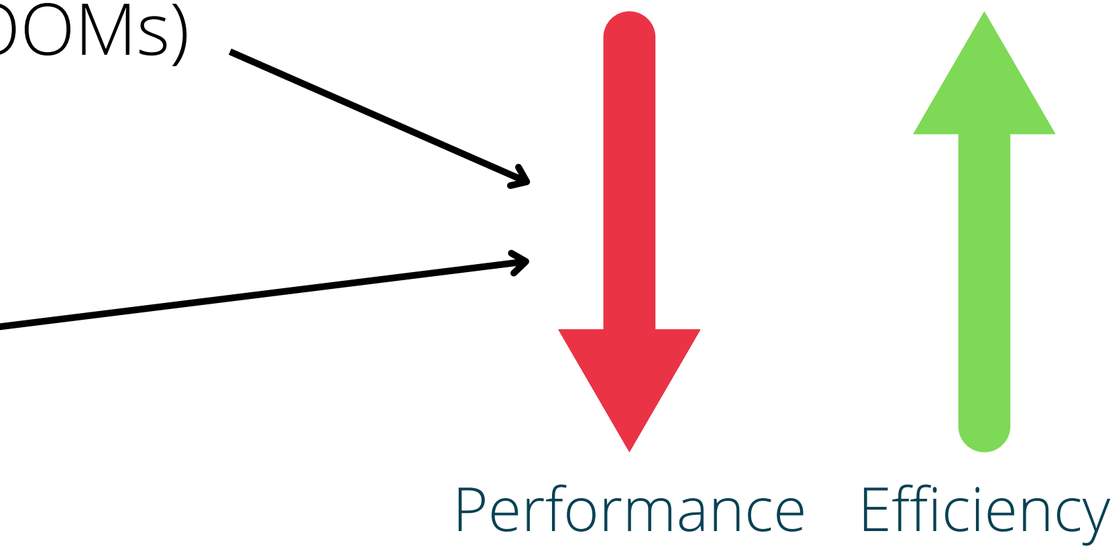
Developers must make tradeoffs

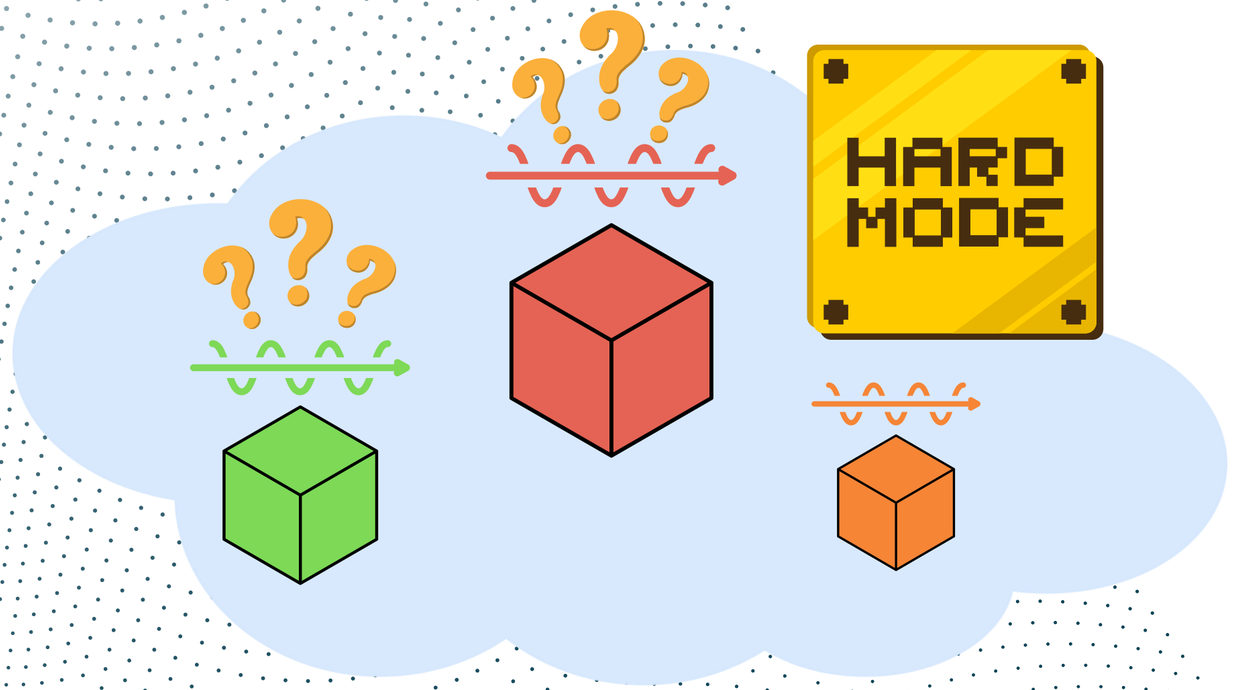
Prioritize Resource Efficiency

Underallocate compute resources

Out of Memory Events (OOMs)

CPU Throttles





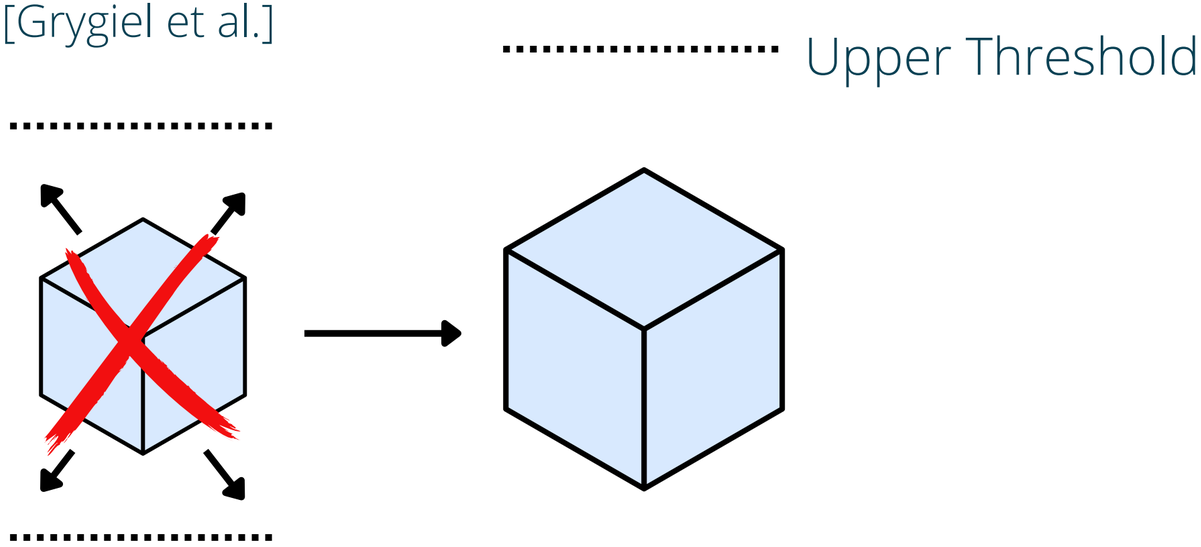
Setting Container Limits is Difficult!

- Requires representative workload
- Resource needs vary over time
- Tools aggregate usage over coarse-grained timescales
- **Result: Over provisioned containers**

Recent Work

Threshold Scaling

VPA
[Grygiel et al.]



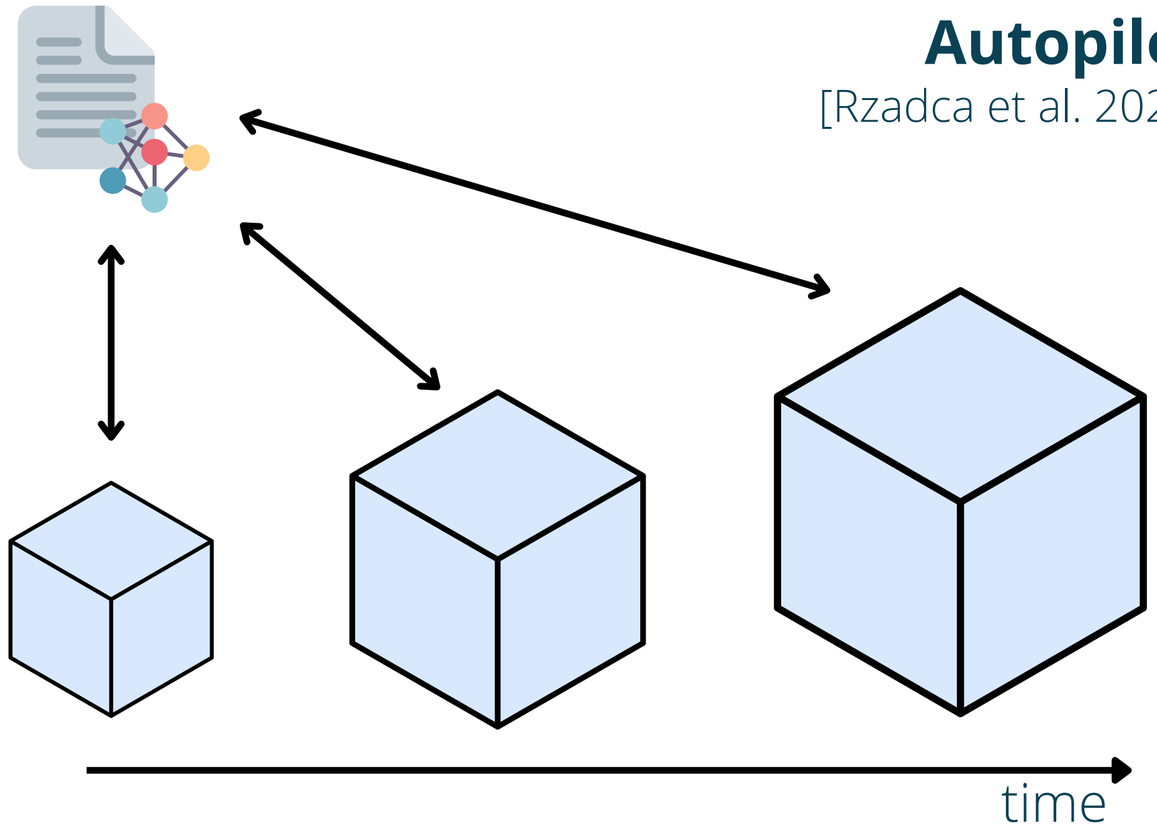
Shortcomings

- Container restart to scale
- Scale once per minute
- High slack

Recent Work

ML-based Scaling

Autopilot
[Rzadca et al. 2020]



Shortcomings

- Cannot respond to quick changes in workload
- Must allocate to maximum prediction over next 5-minute interval
- Unable to correct inaccurate predictions
- Not suitable for short-lived containers (e.g. serverless)

Key Insight

If we can make resource allocation fine grained, we don’t need to predict; we can react to workload changes.

Escra

- Distributed resource allocation
- Sub-second interval scaling within and across hosts
- OOM prevention and scaling
- Immediate CPU throttle response
- No performance penalty

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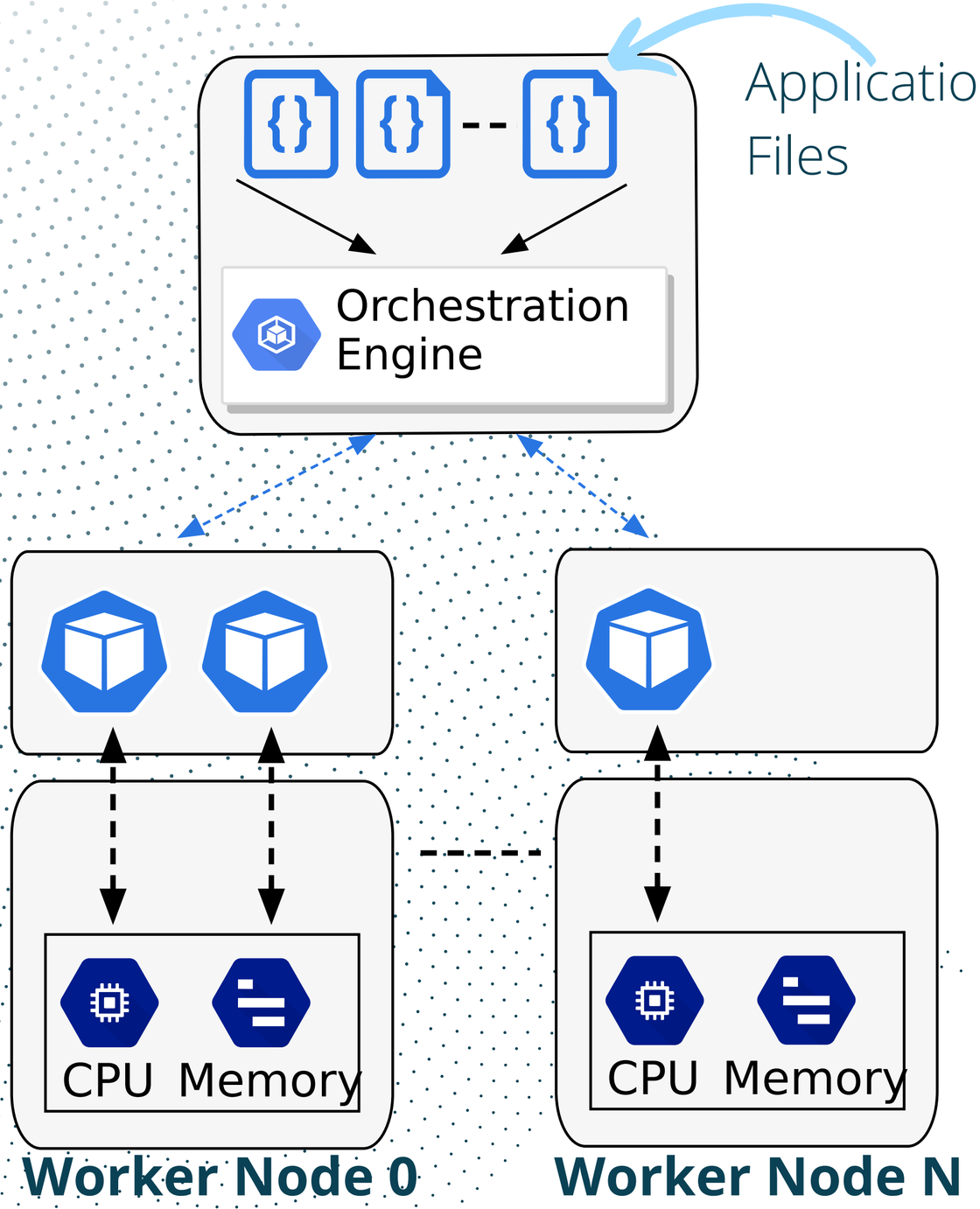
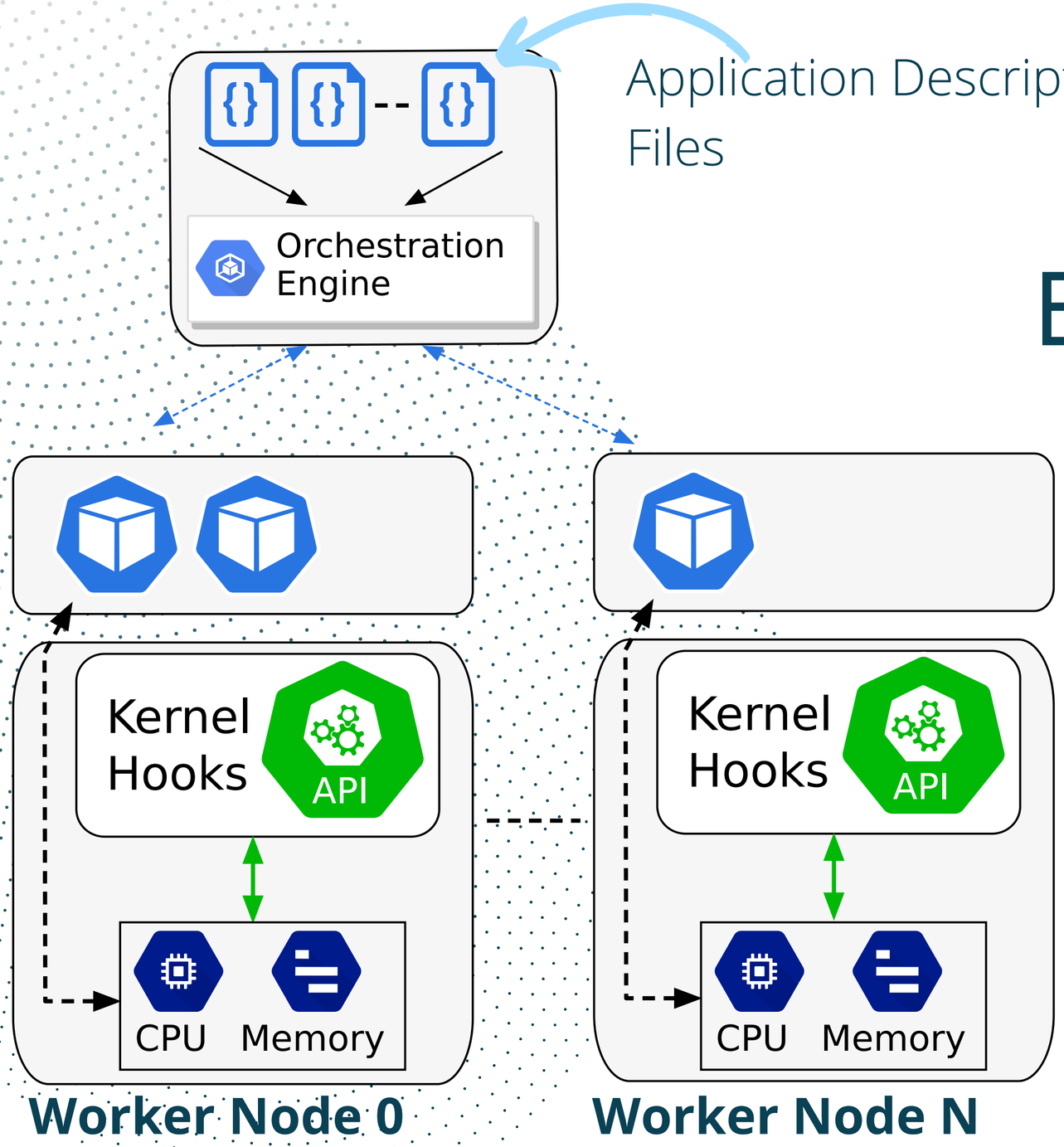
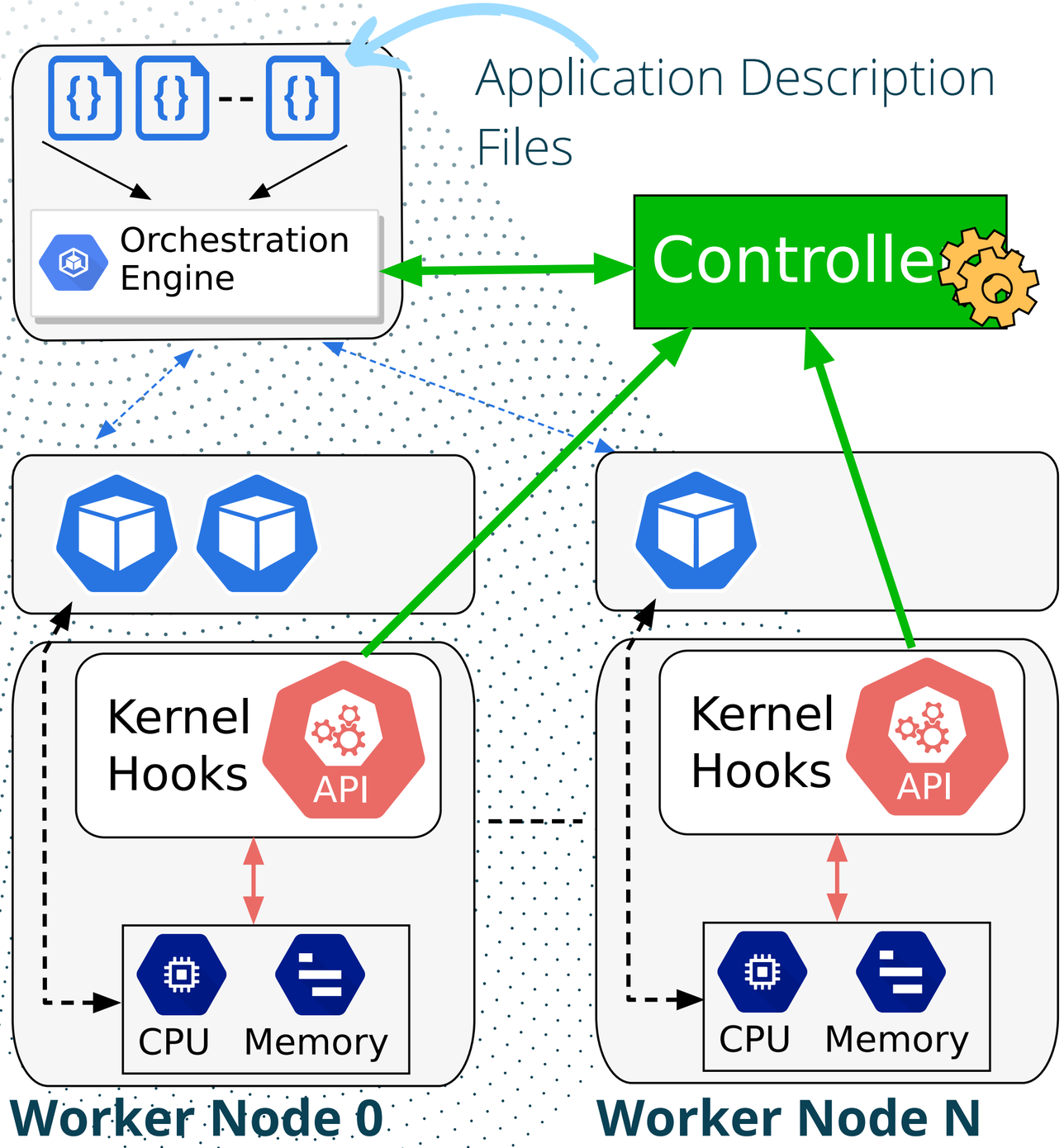
Simplified Cloud Orchestration Architecture





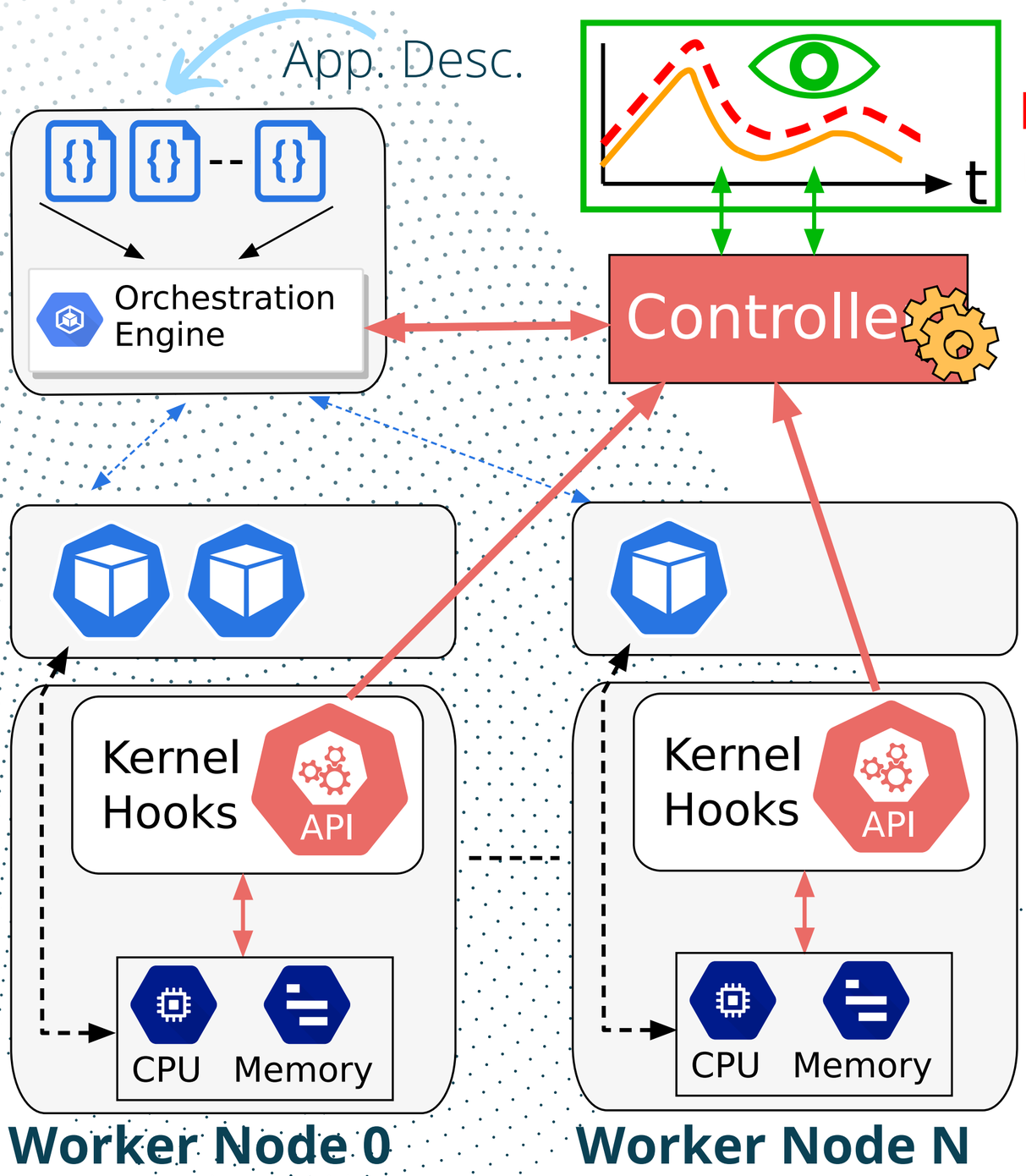
Escra Architecture

- **Kernel Hooks**



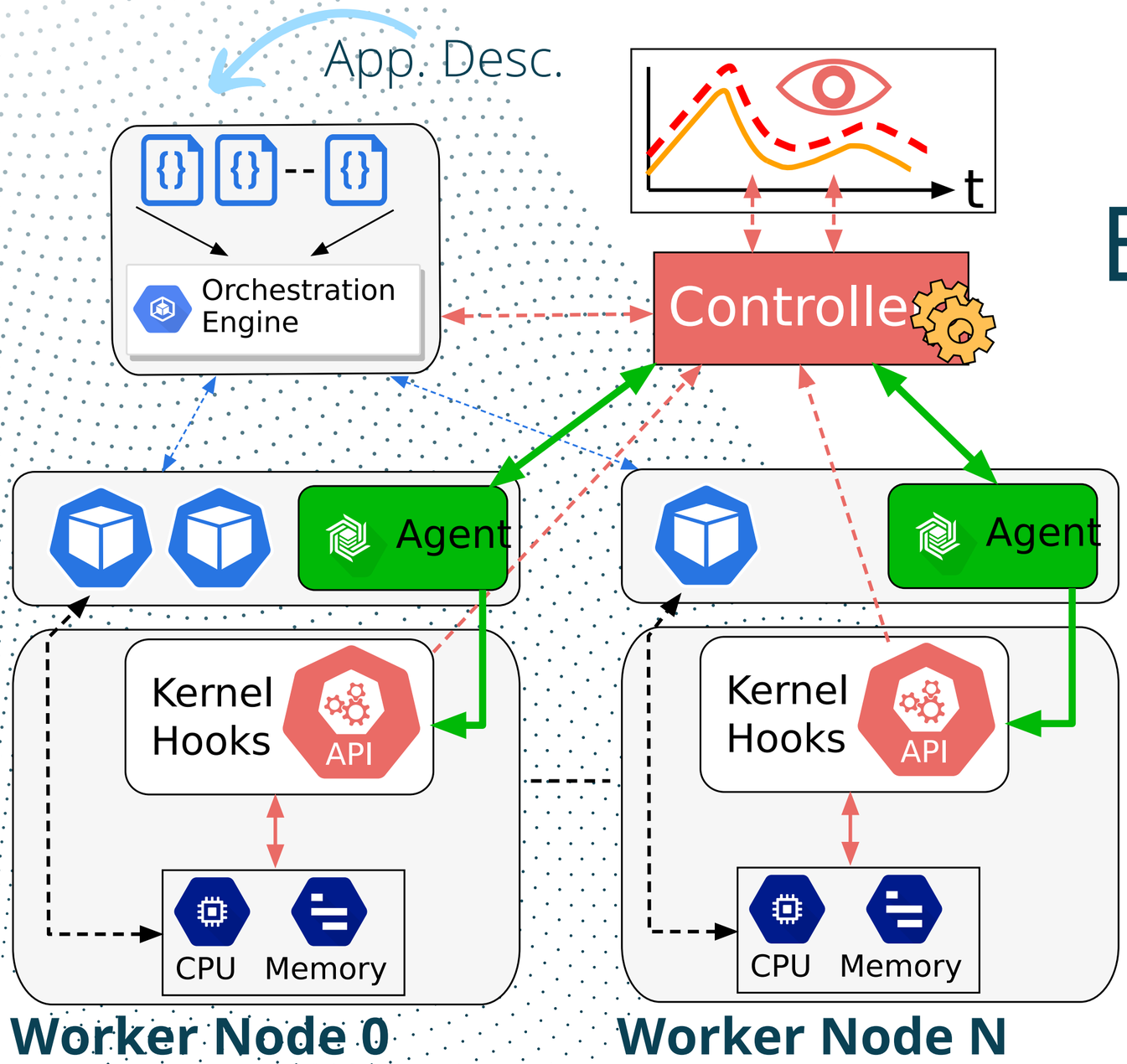
Escra Architecture

- Kernel Hooks
- **Controller**



Escra Architecture

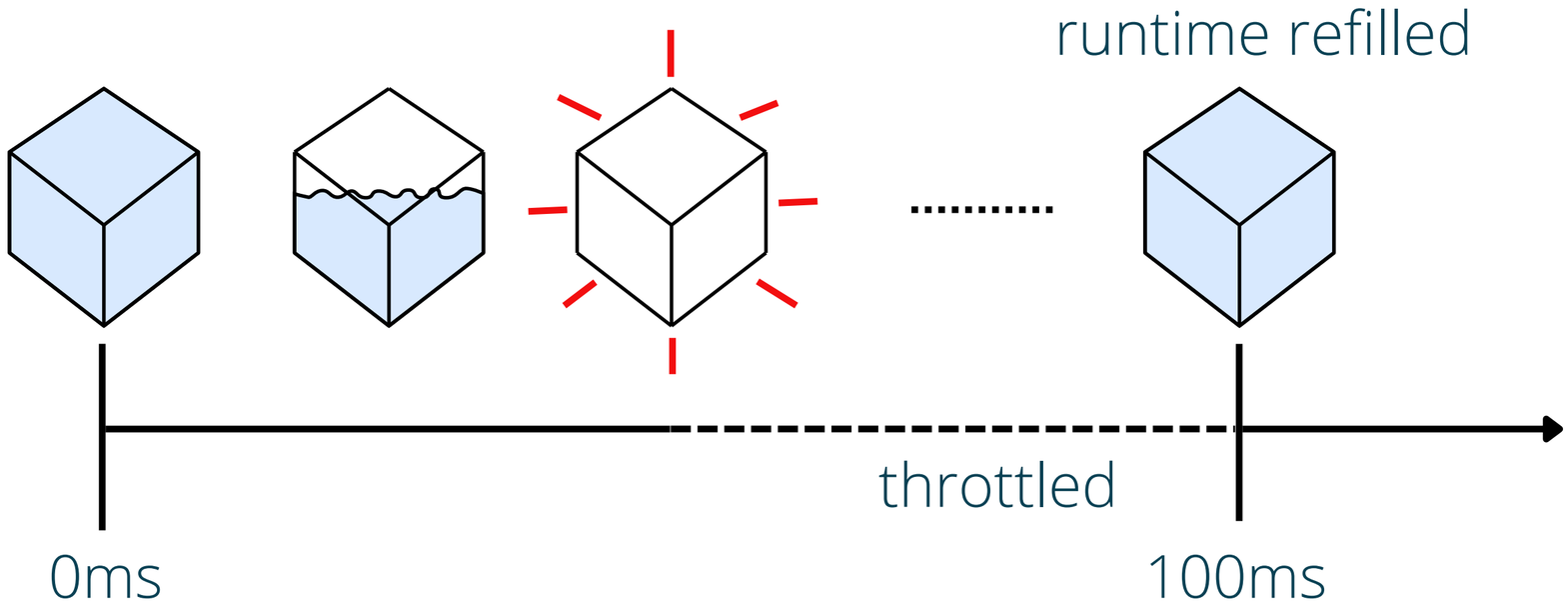
- Kernel Hooks
- Controller
- **Resource Allocator**



Escra Architecture

- Kernel Hooks
- Controller
- Resource Allocator
- **Agent**

CPU Telemetry and Scaling



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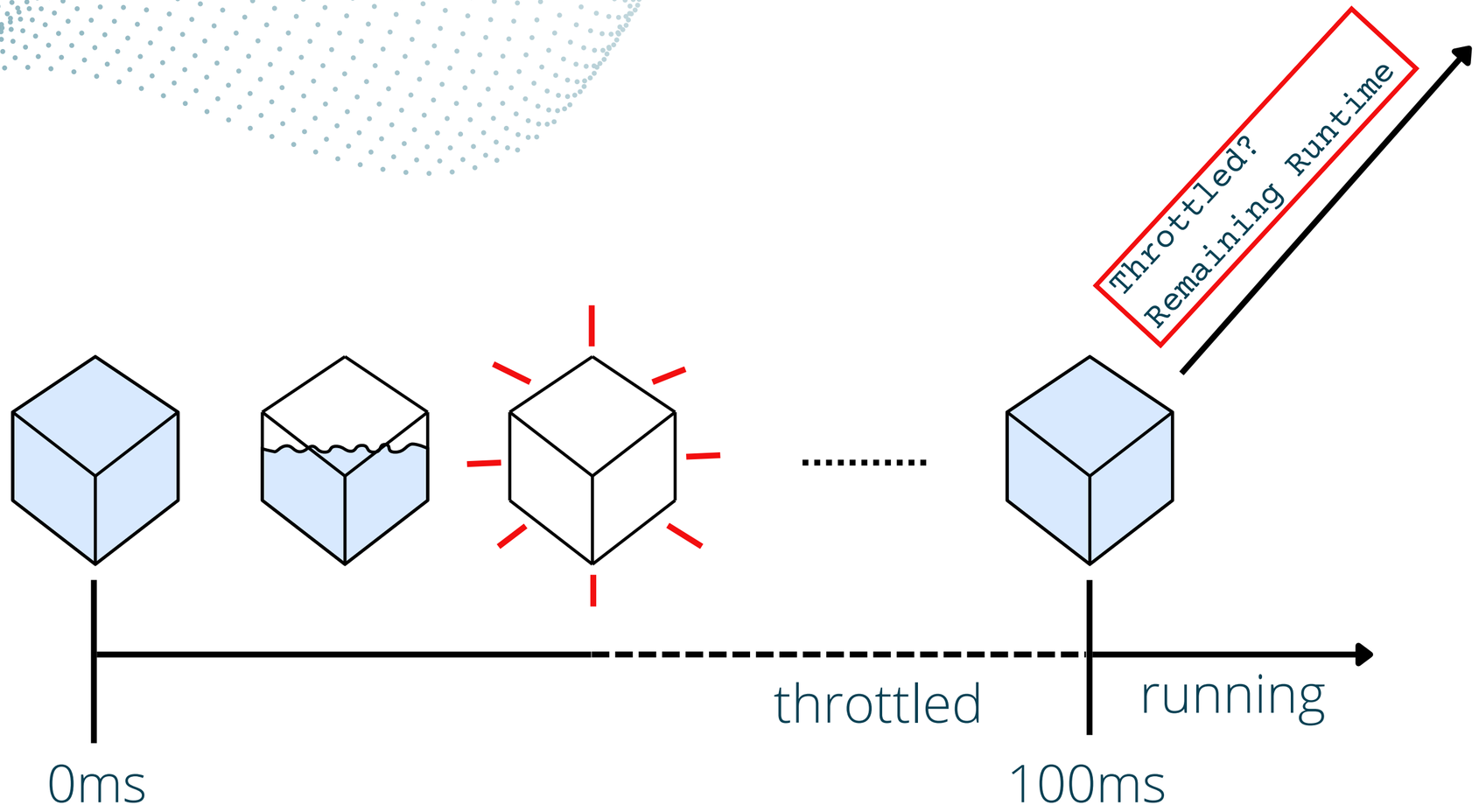

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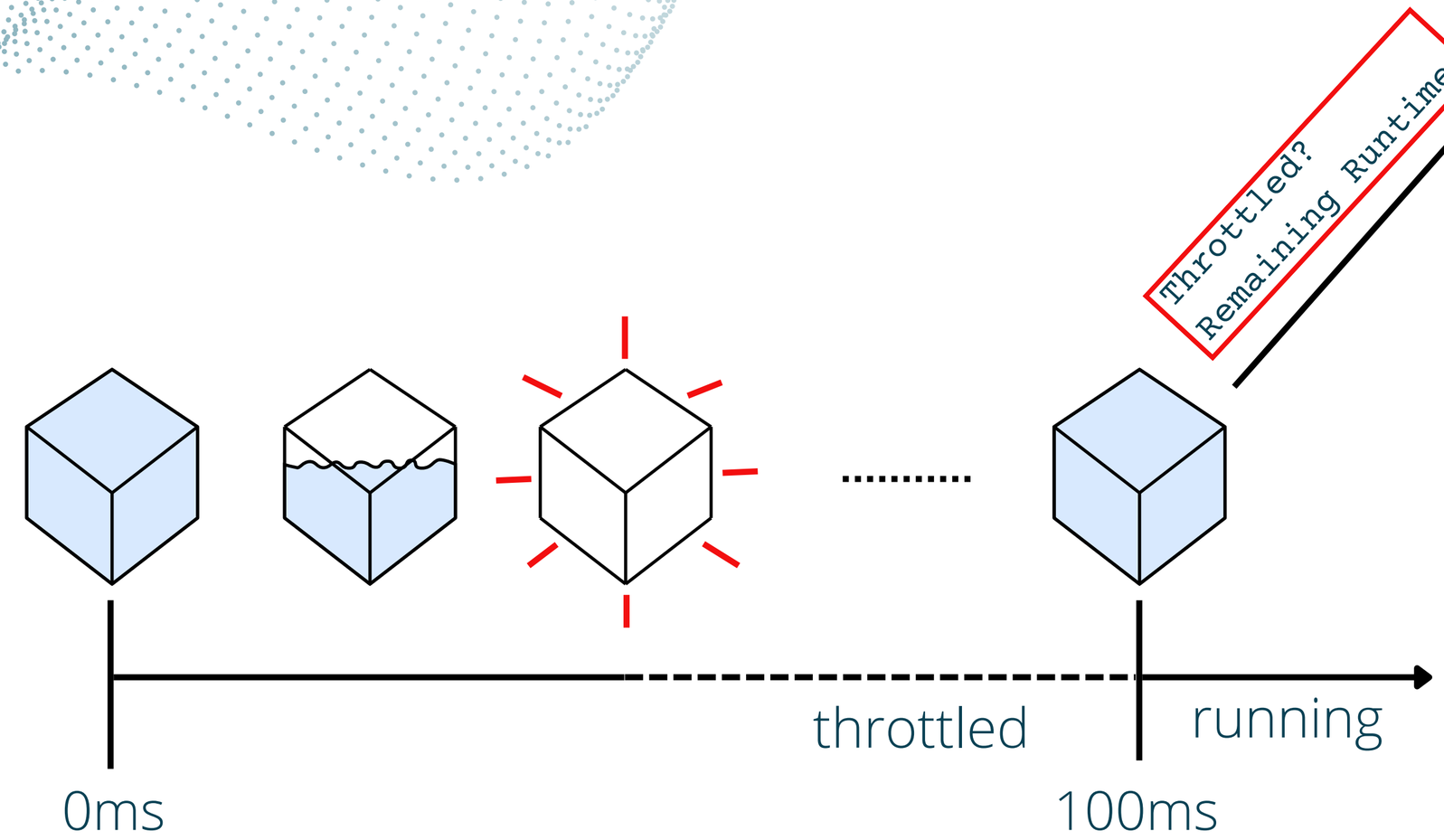
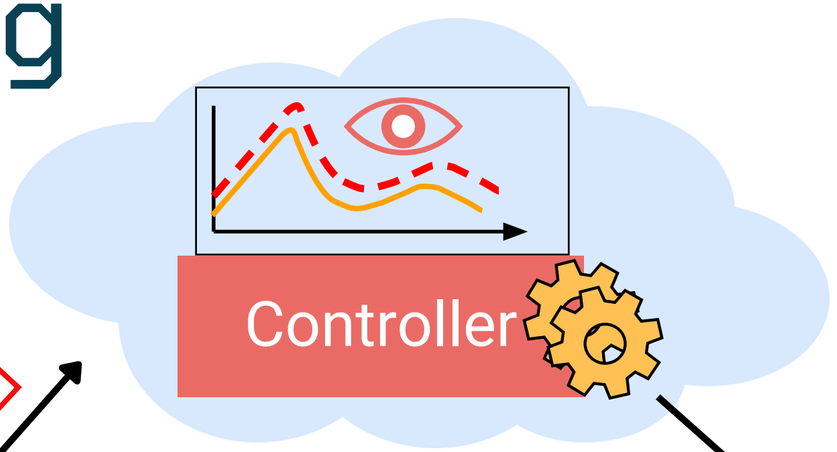
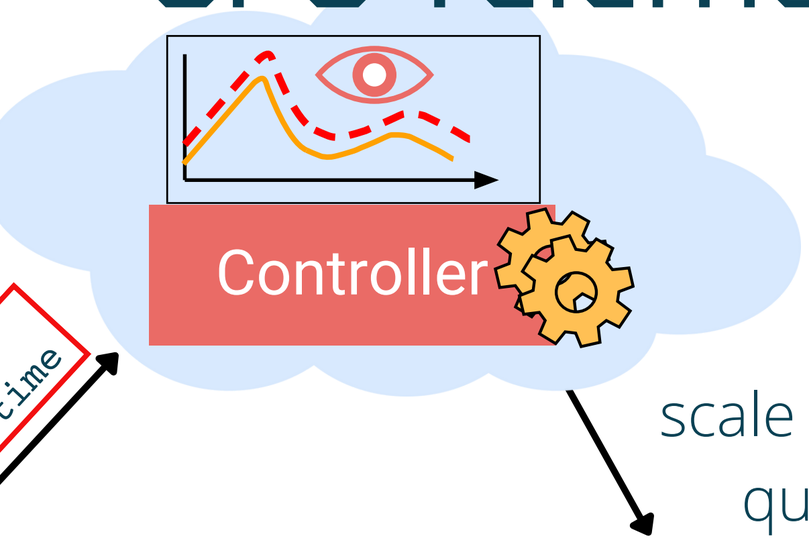
CPU Telemetry and Scaling





scale container
quota up

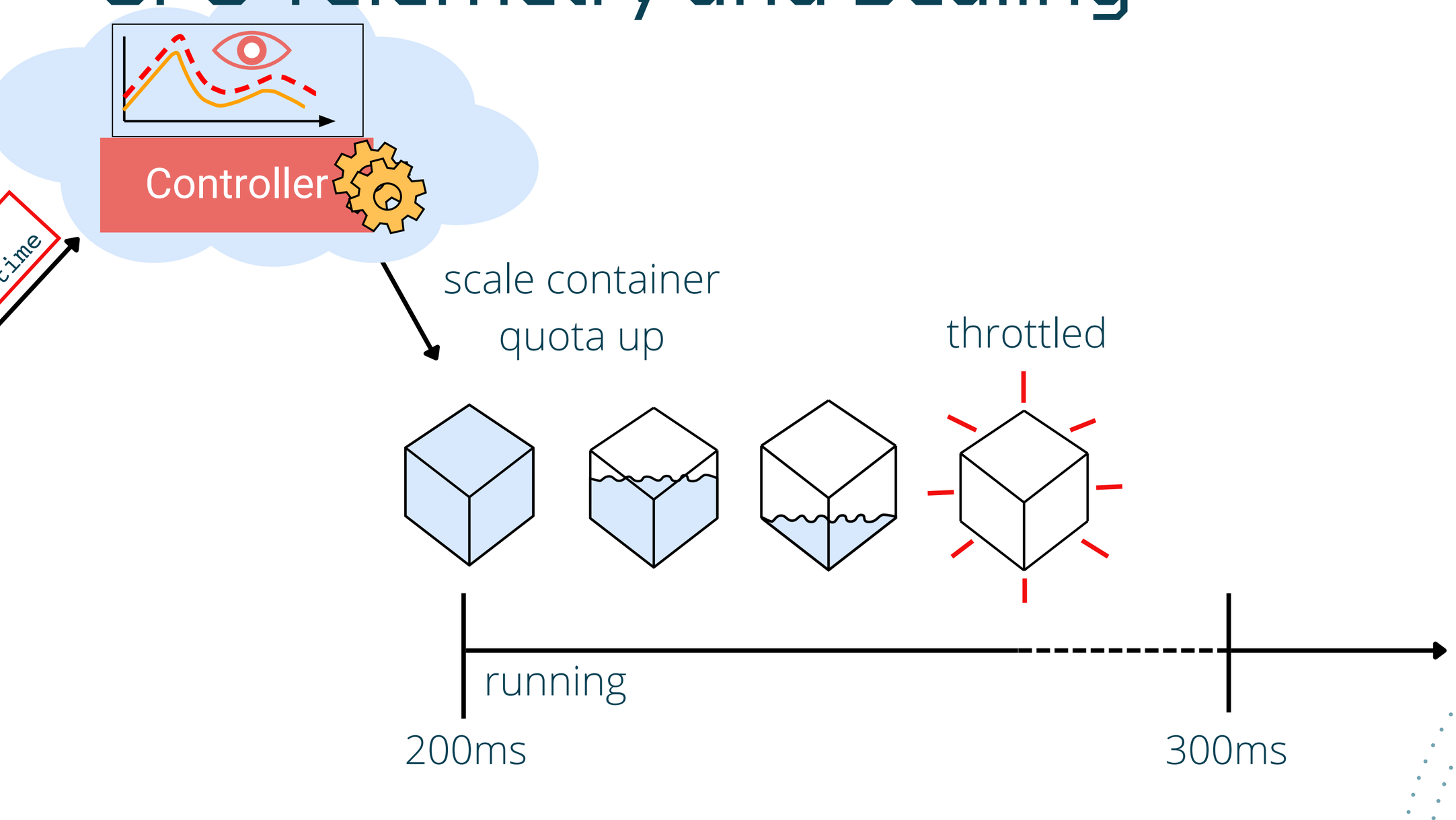
CPU Telemetry and Scaling



scale container
quota up

$$C(i)_q[t+1] = C(i)_q[t] + \frac{\sum_{t=0}^{n} C(i)_{th}[t]}{n} * \Upsilon(\Omega_l - \sum_{i=0}^{\lambda} C(i)_q[t])$$

CPU Telemetry and Scaling



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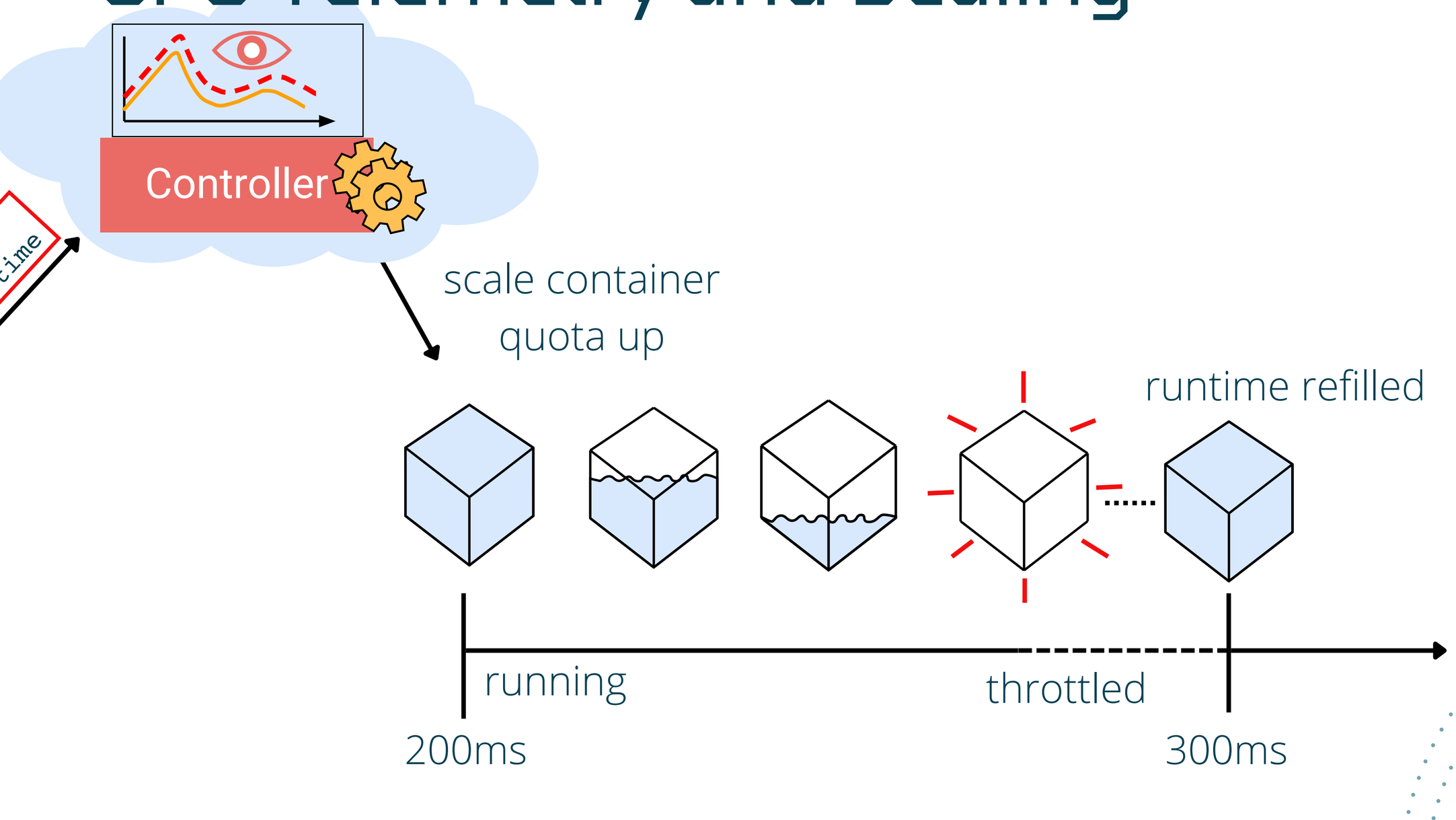

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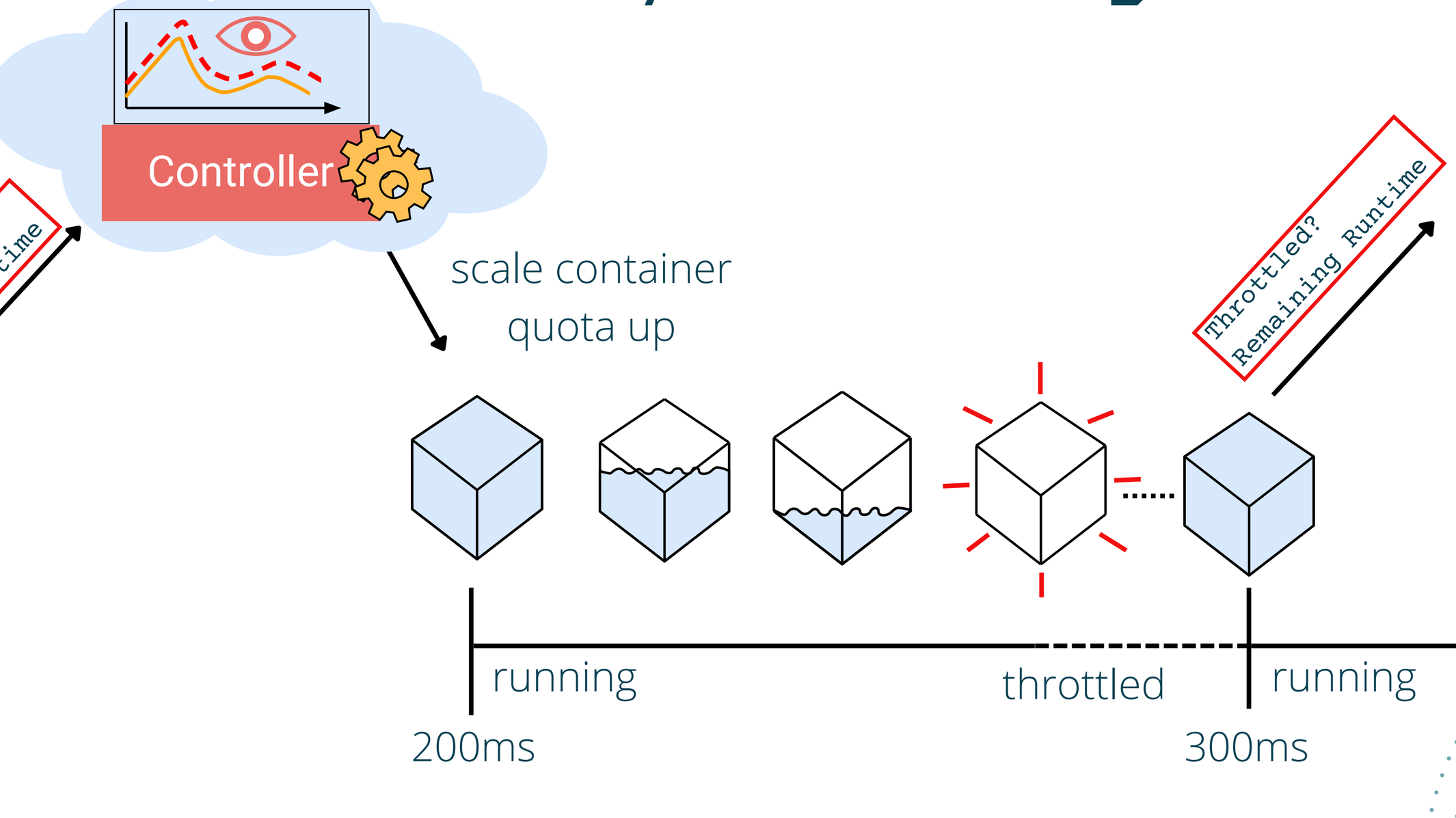
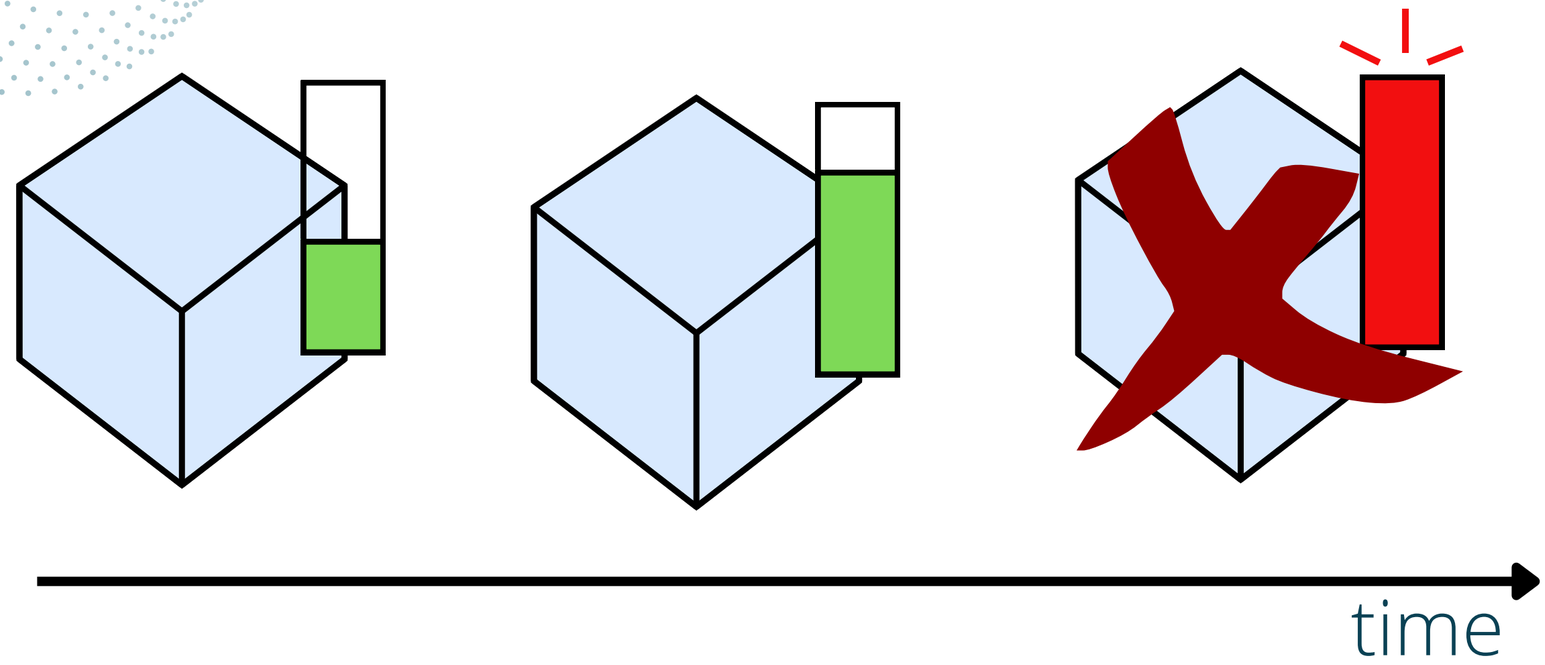


Event-Based Memory Scaling

Typical Scenario



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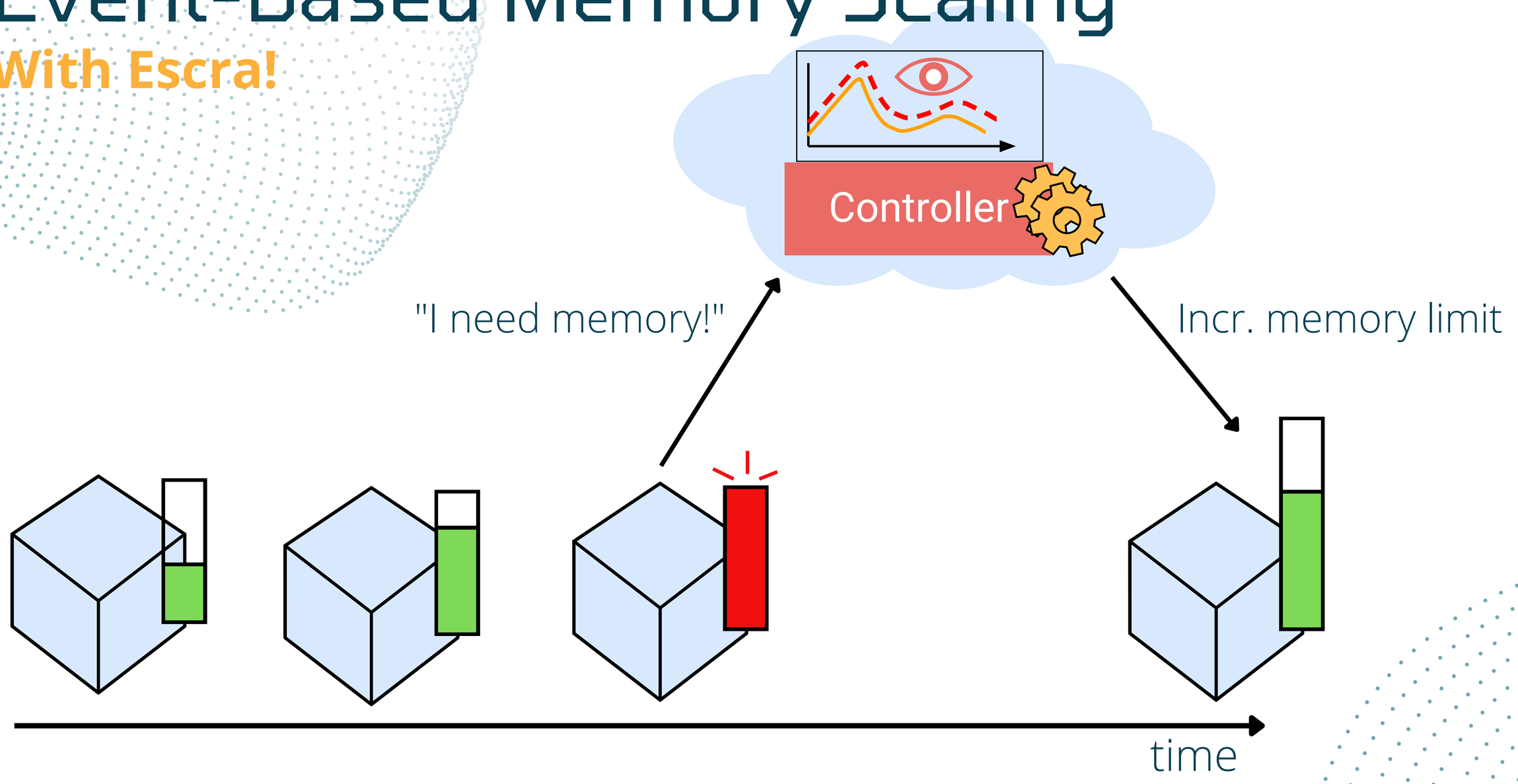
Event-Based Memory Scaling

With Escra!



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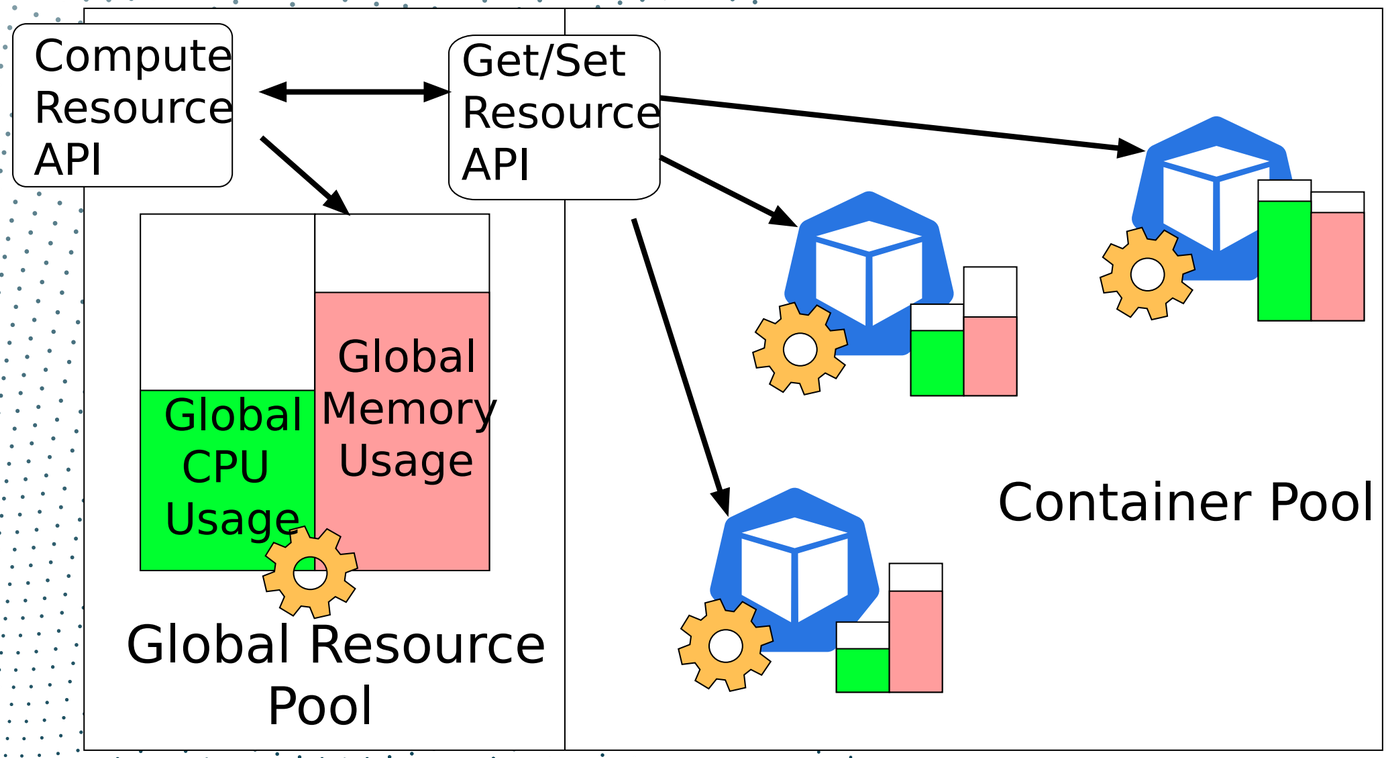
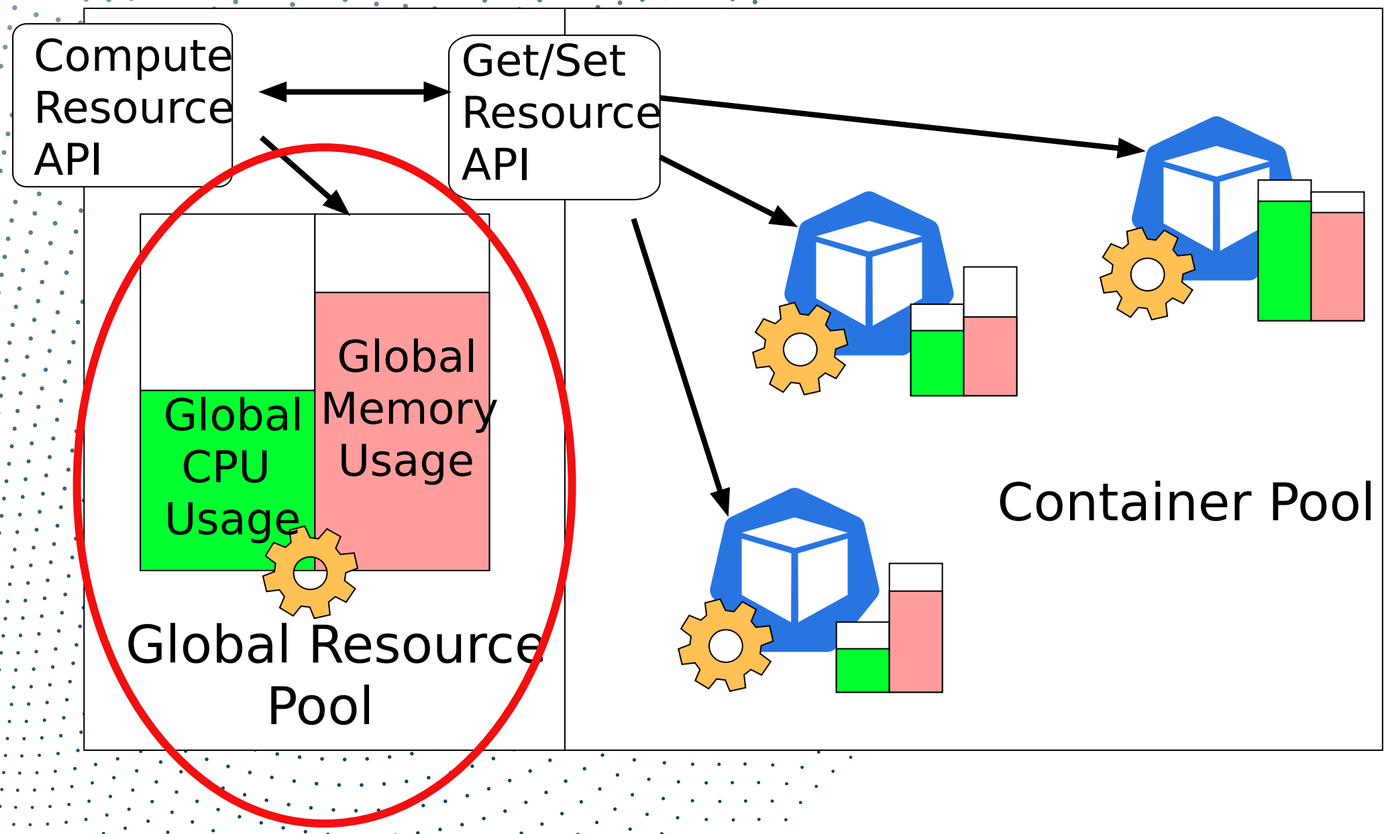
Distributed Container

Distributed Container

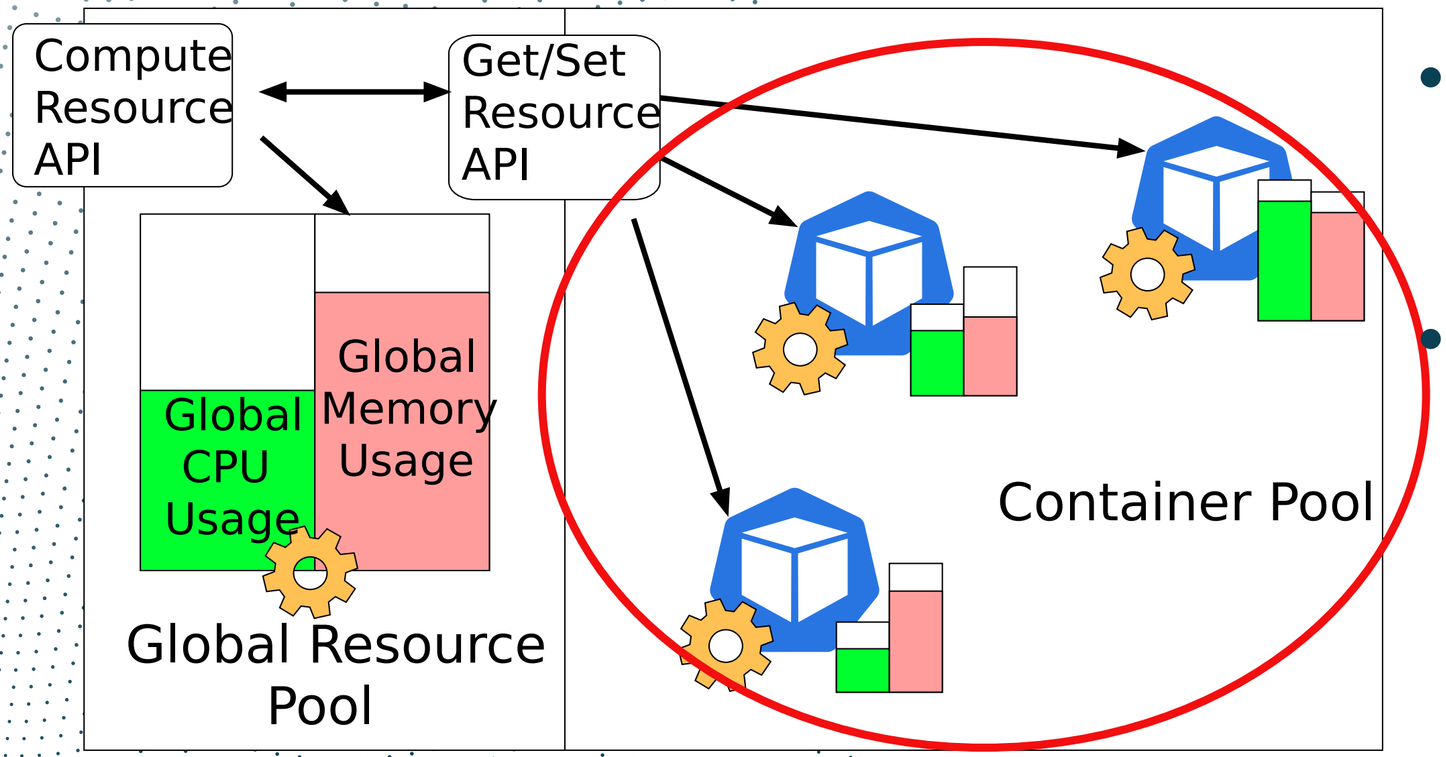


Distributed Container



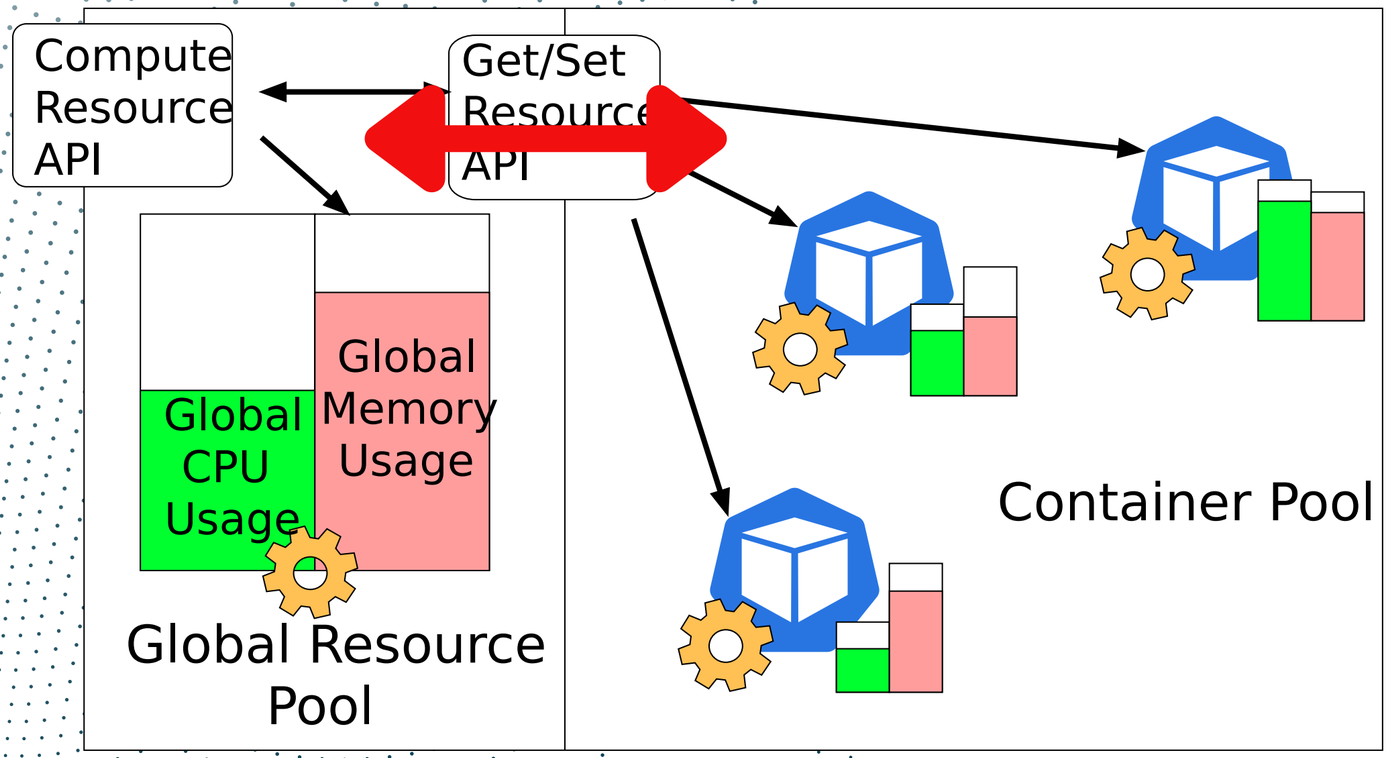
- Enforces per-application resources limits

Distributed Container



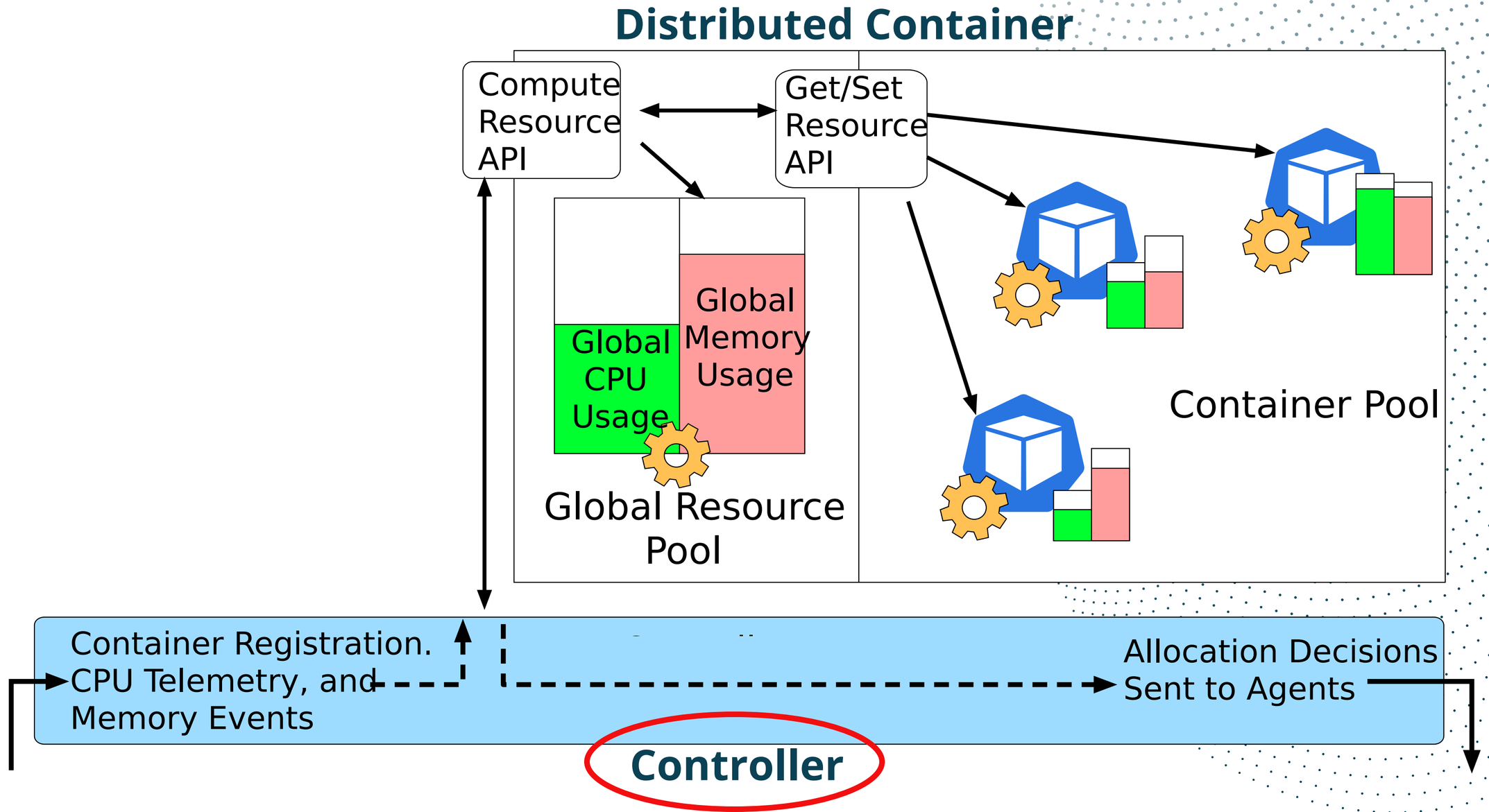
- Enforces per-application resources limits
- Per-container resource usage and limit tracking

Distributed Container



- Enforces per-application resources limits
- Per-container resource usage and limit tracking
- Containers dynamically share compute resources at runtime

Escra Controller



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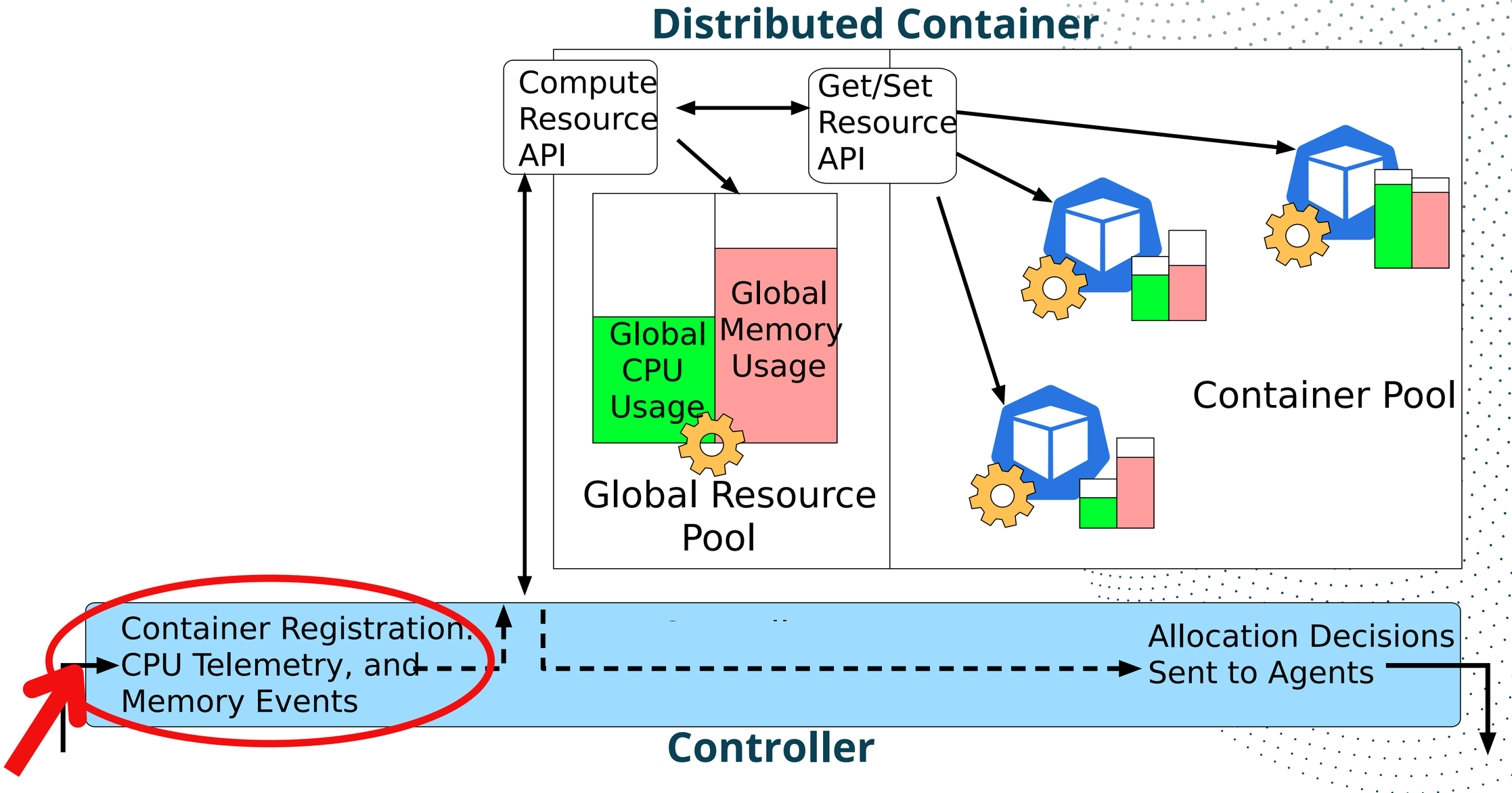

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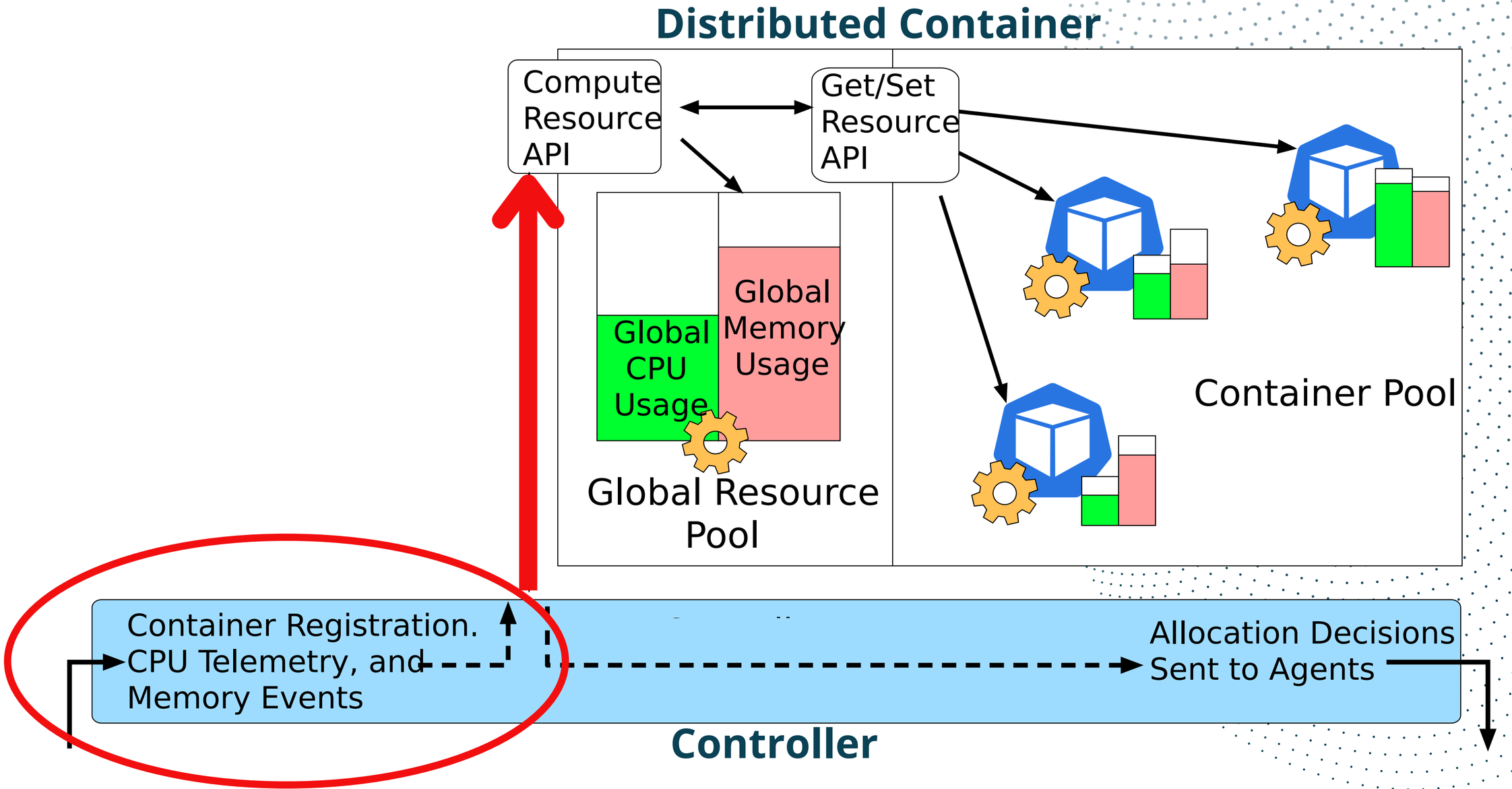

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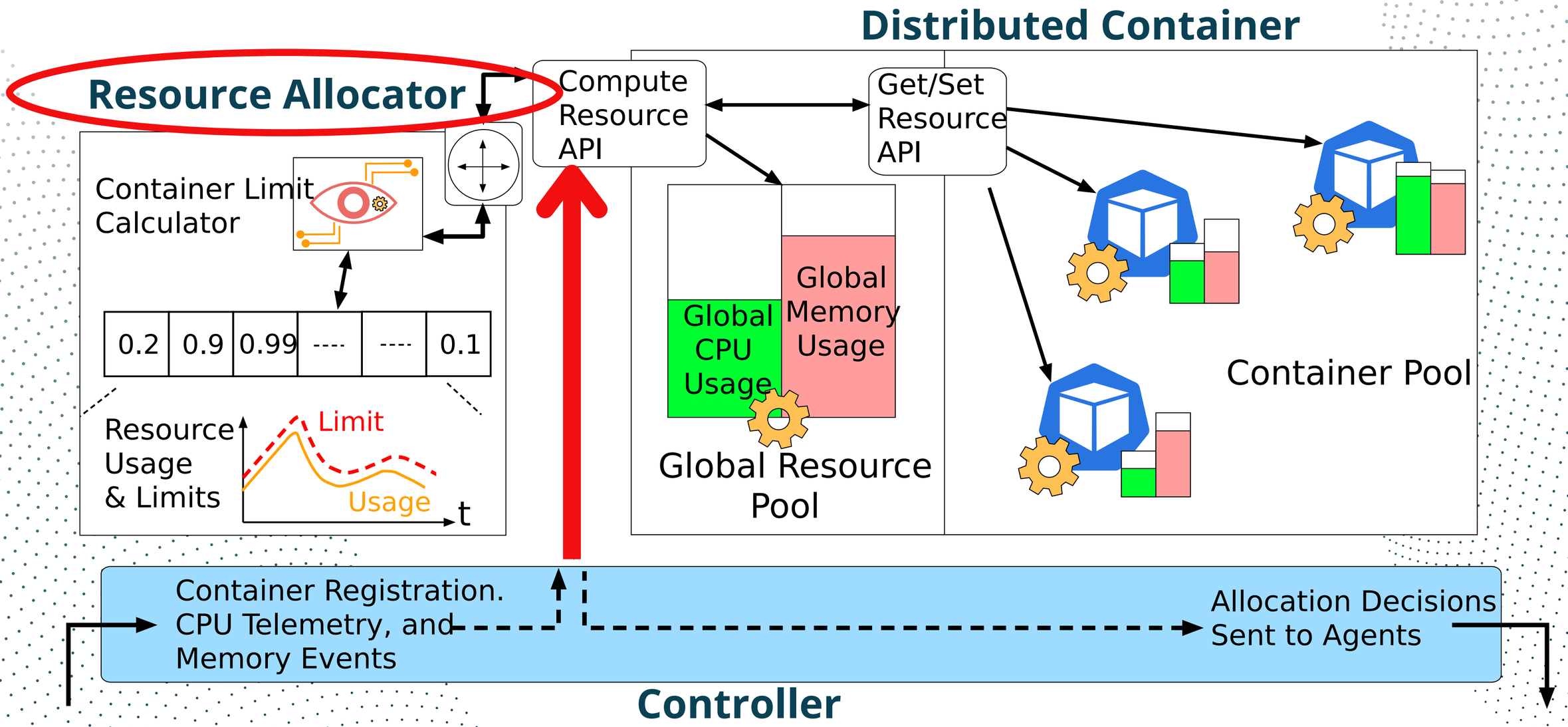
Escra - Control Node



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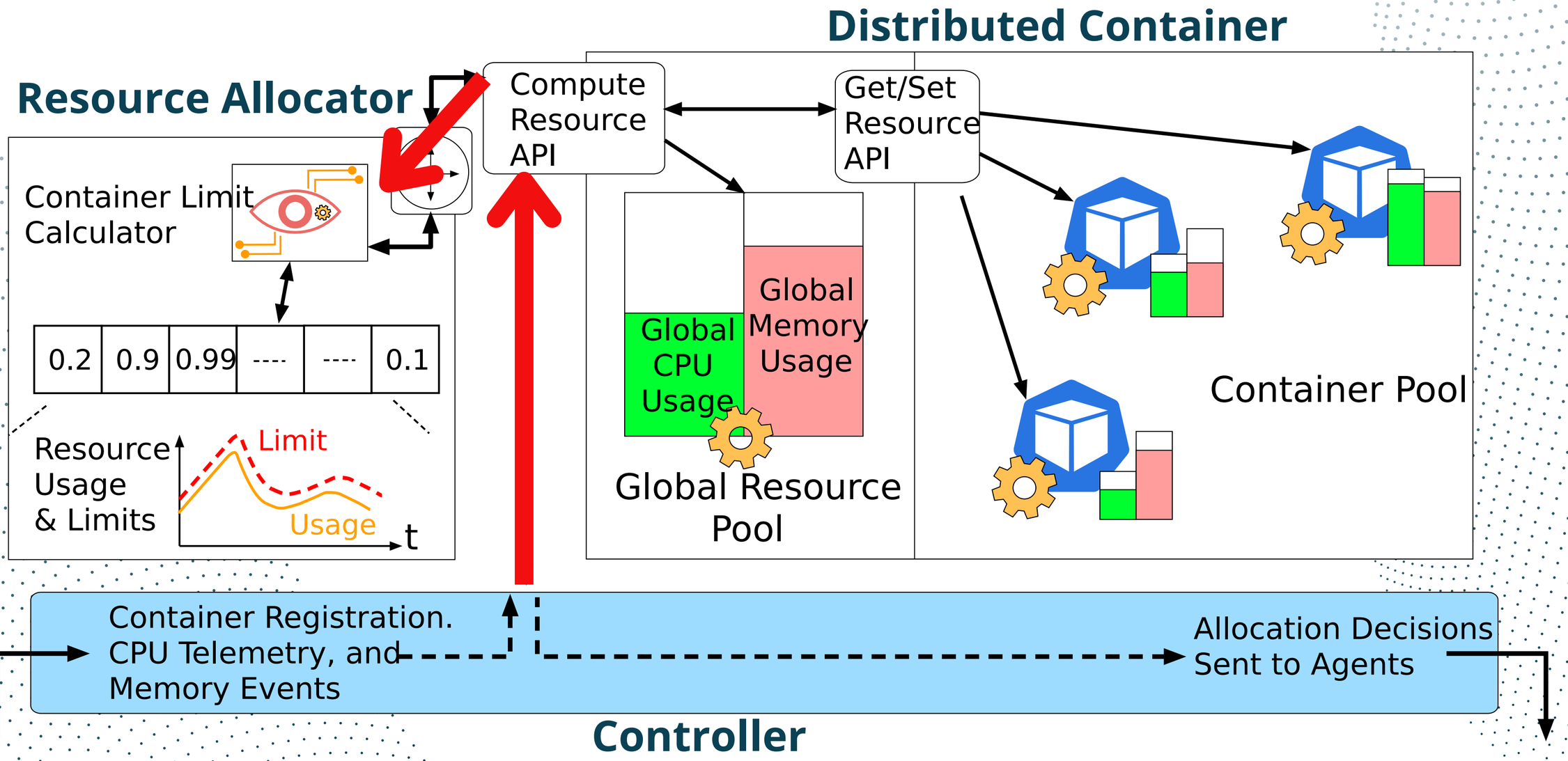

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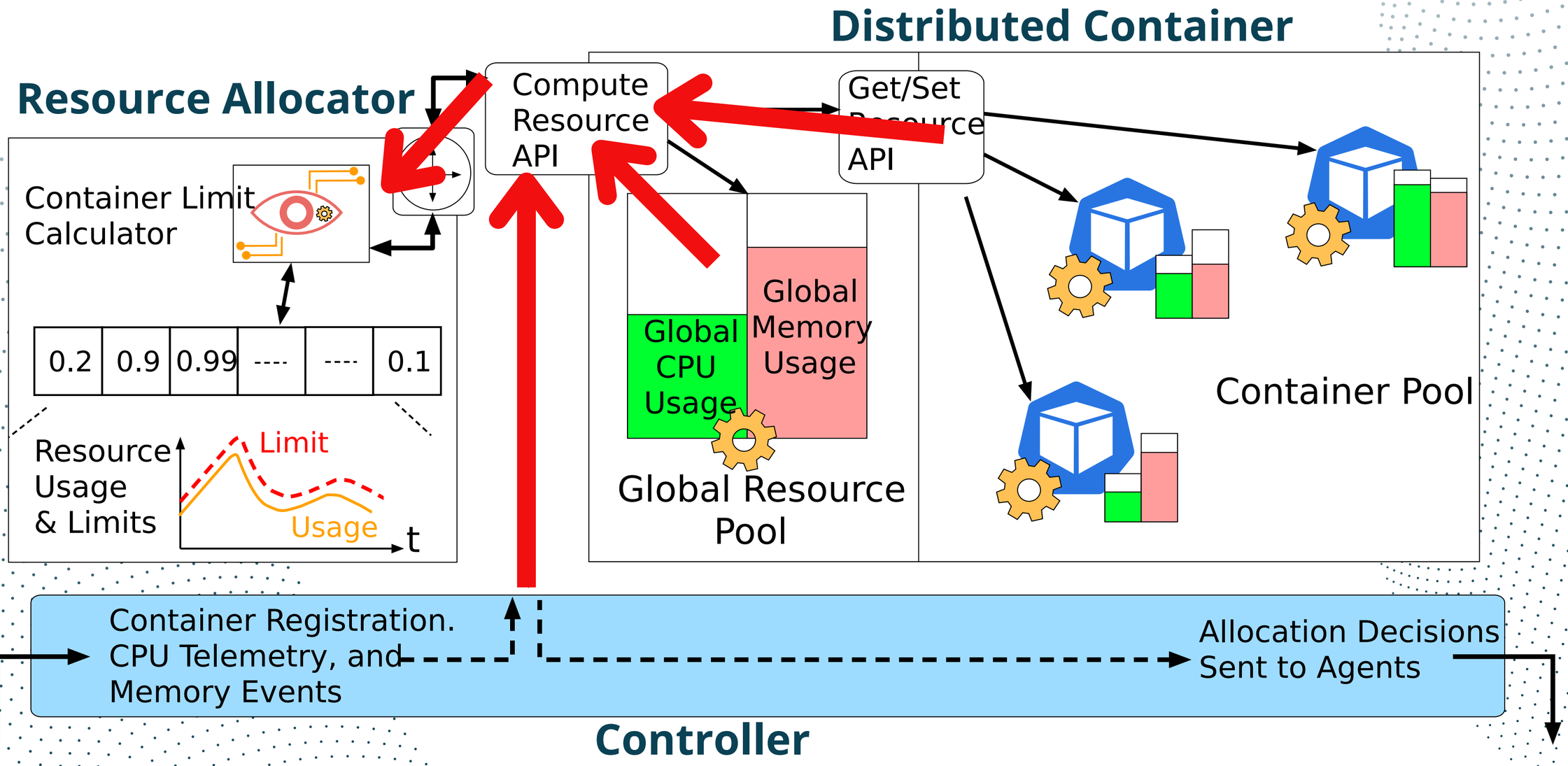

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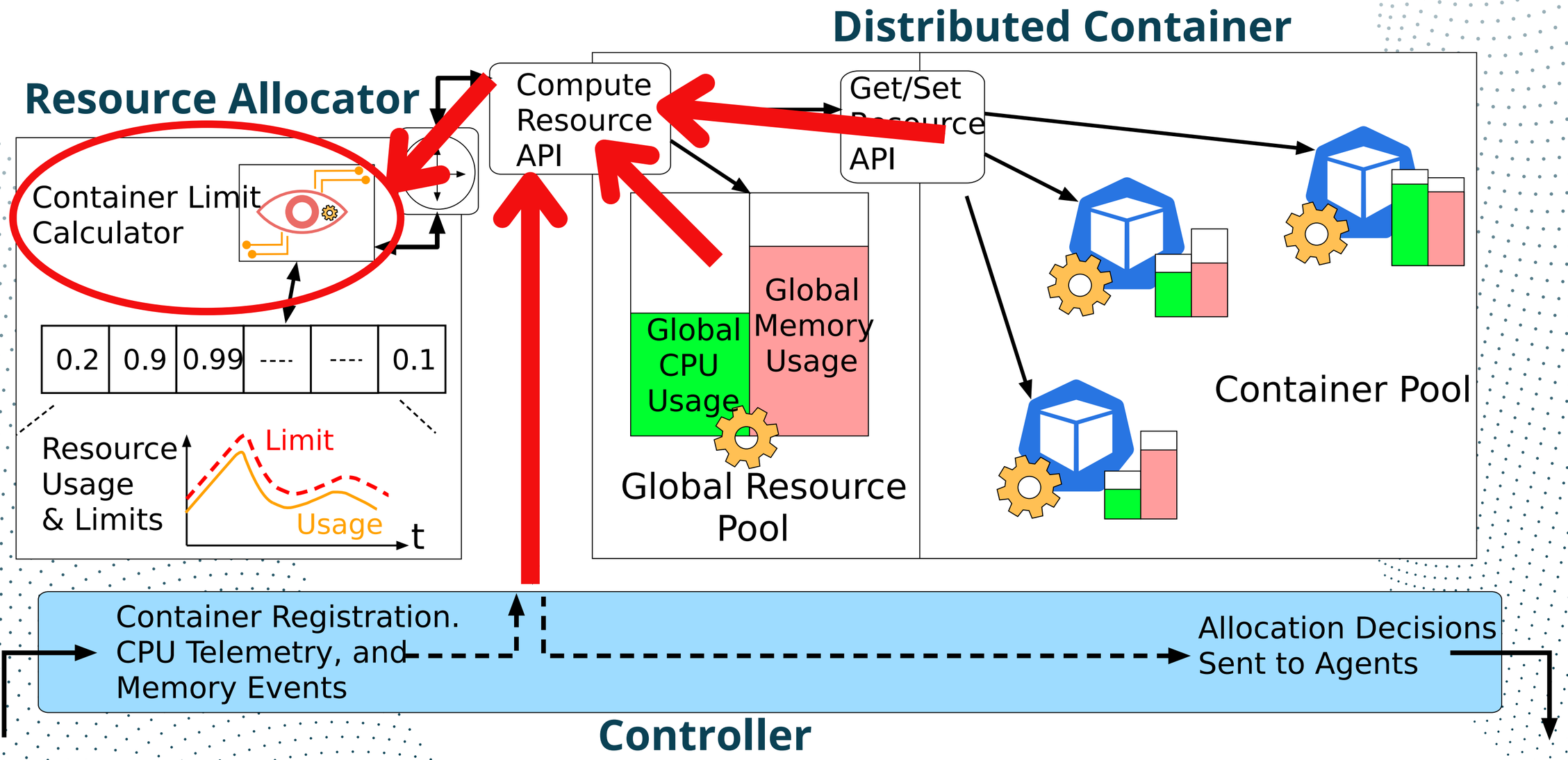

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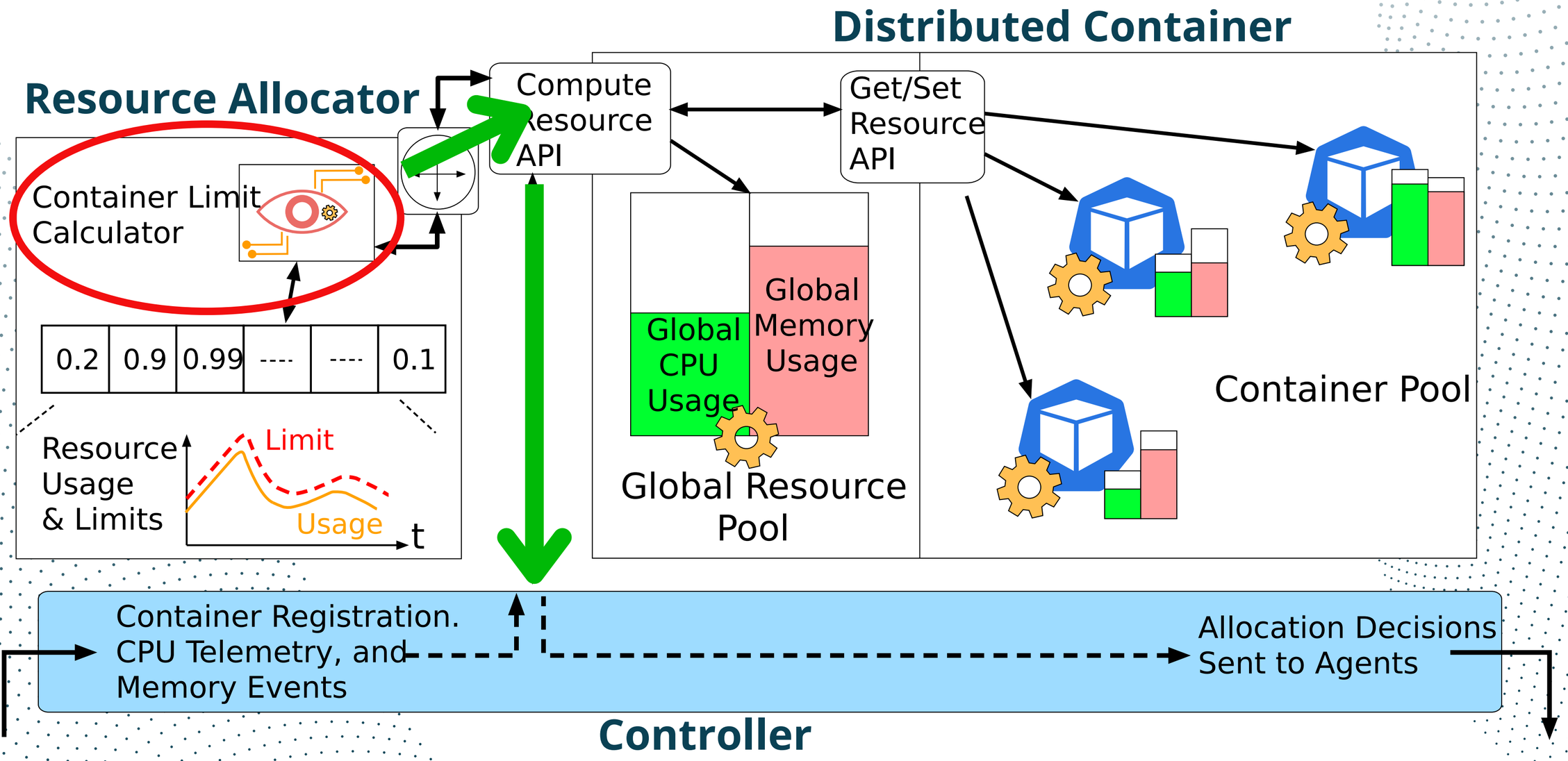

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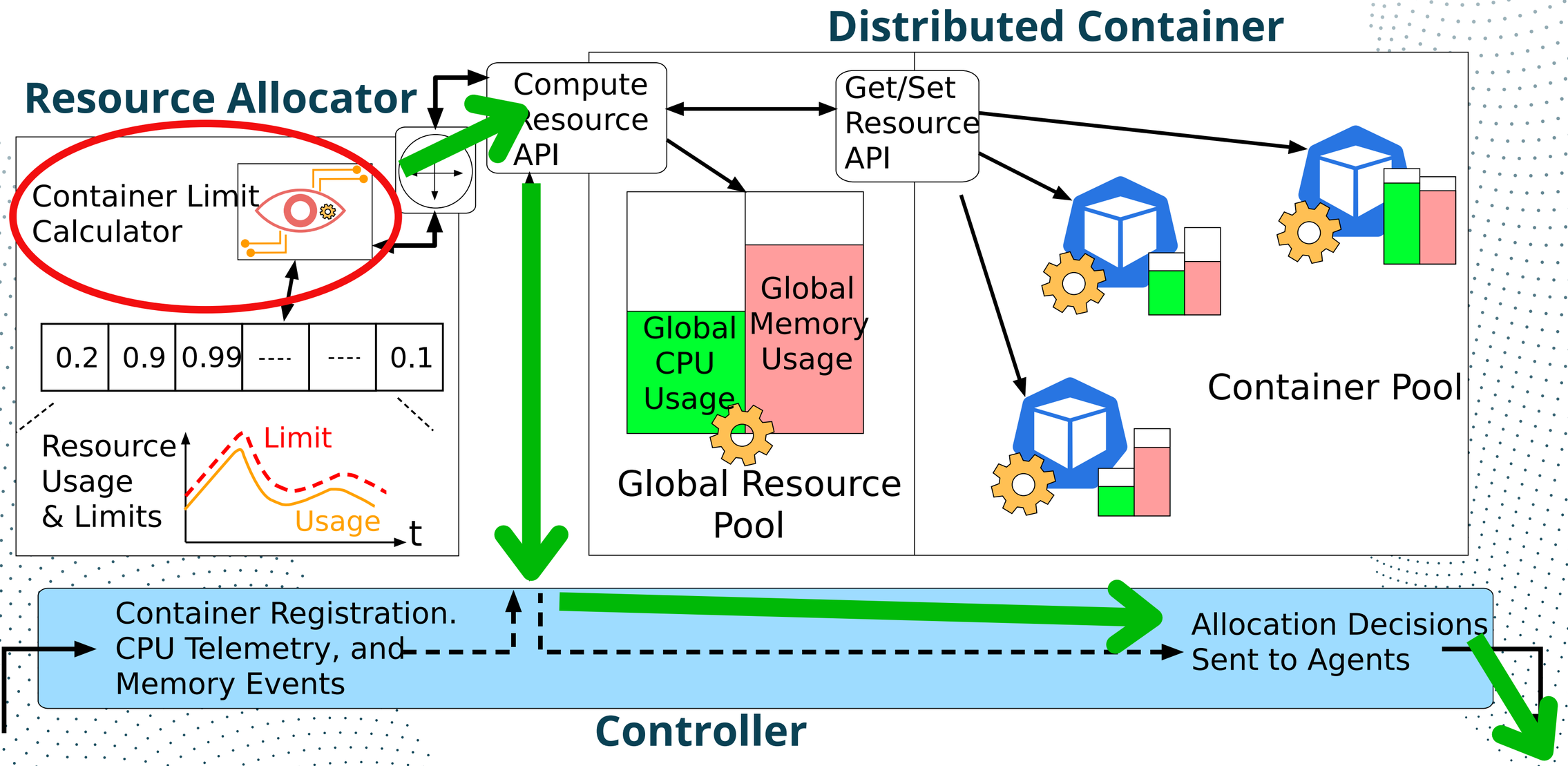


Evaluation - Microservices

Evaluation - Microservices

Metrics

Absolute Slack

Container Limit - Container Usage

Application Throughput

Successful requests/second

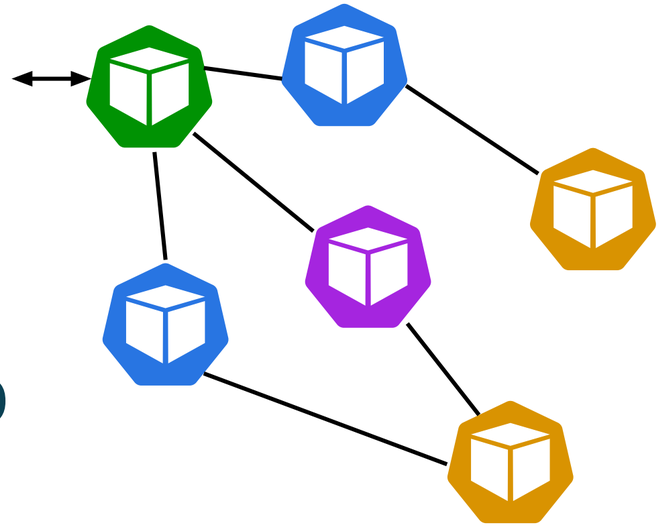
Application 99.9%ile Latency

99.9%ile end-to-end latency

Applications & Workloads

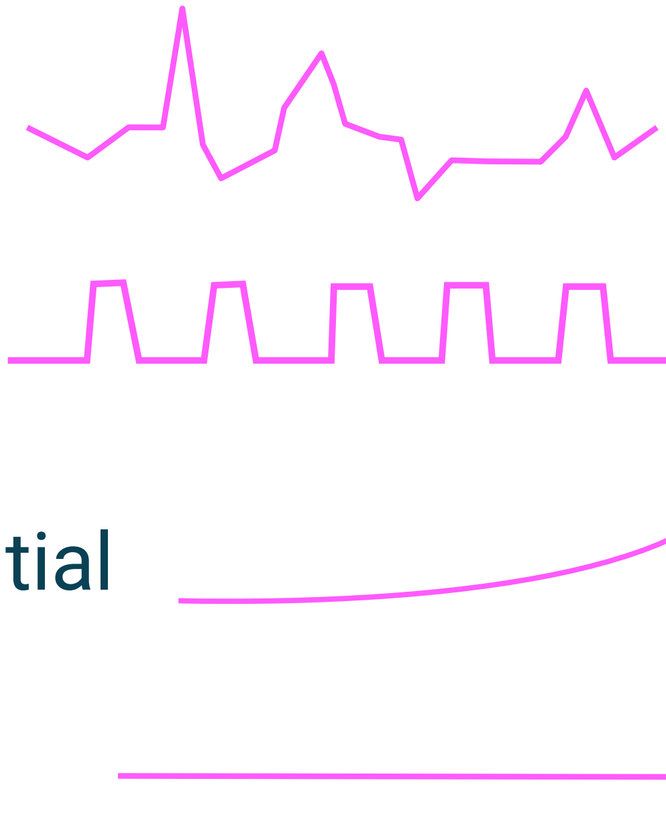
Applications

- TrainTicket
- TeaStore
- HipsterShop
- MediaMicroservice



Workloads

- Alibaba
- Burst
- Exponential
- Fixed



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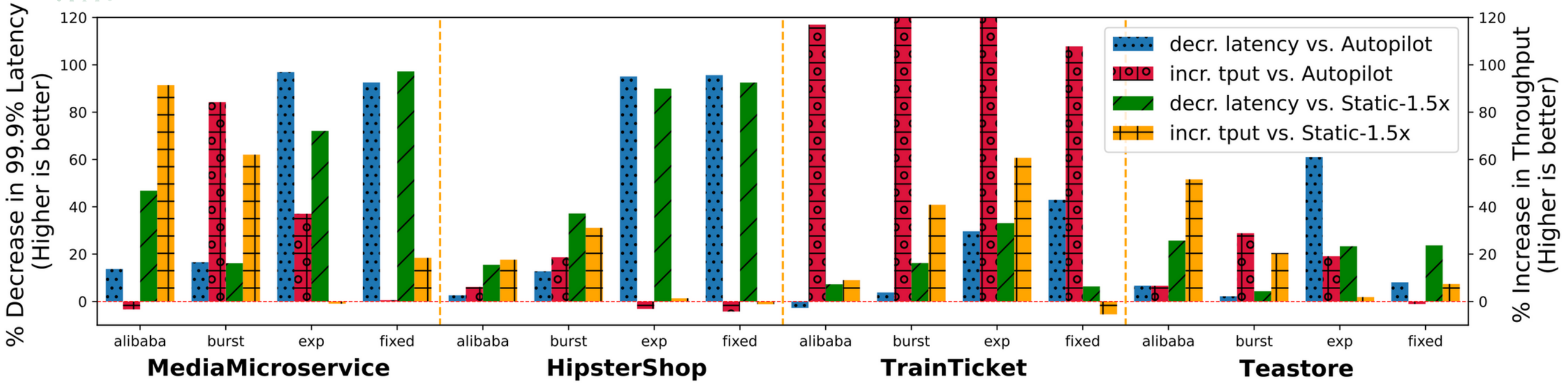
Change in Latency and Throughput

Microservices



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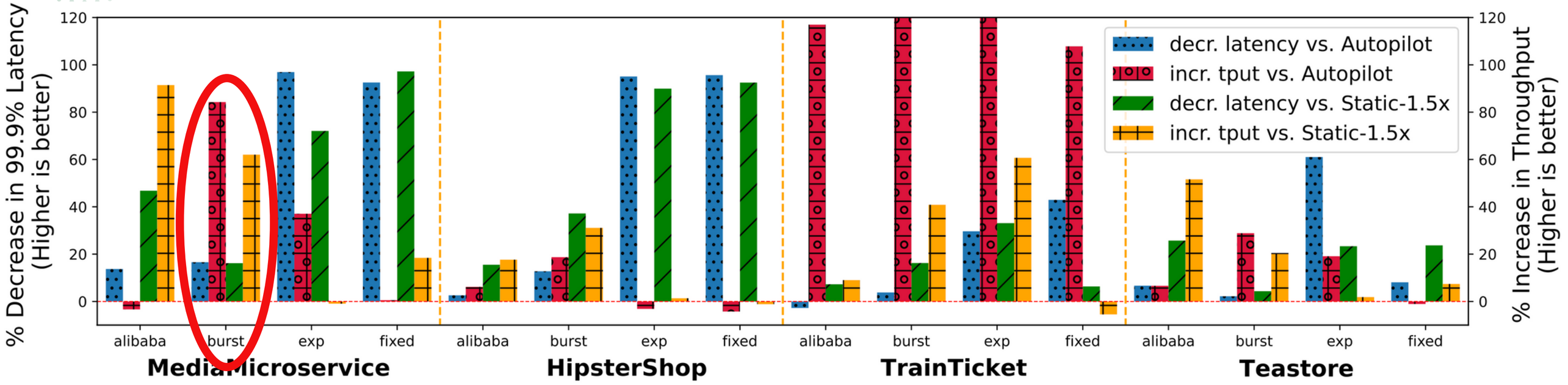
Change in Latency and Throughput

Microservices



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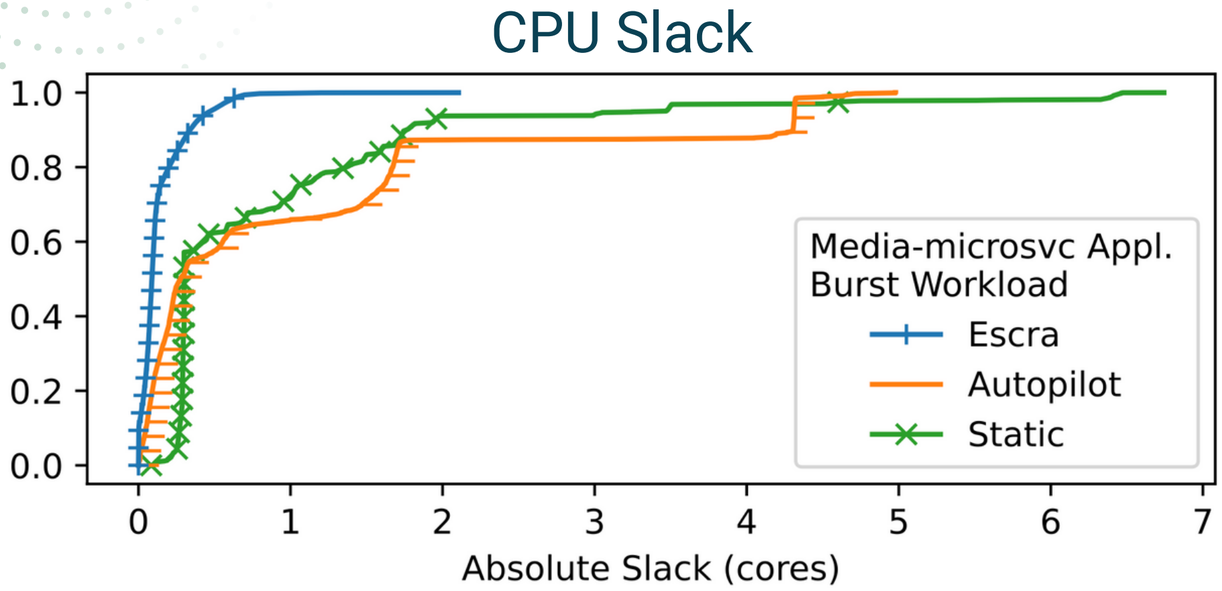
Escra vs. Autopilot

Microservices - MediaMicroservice/Burst Workload



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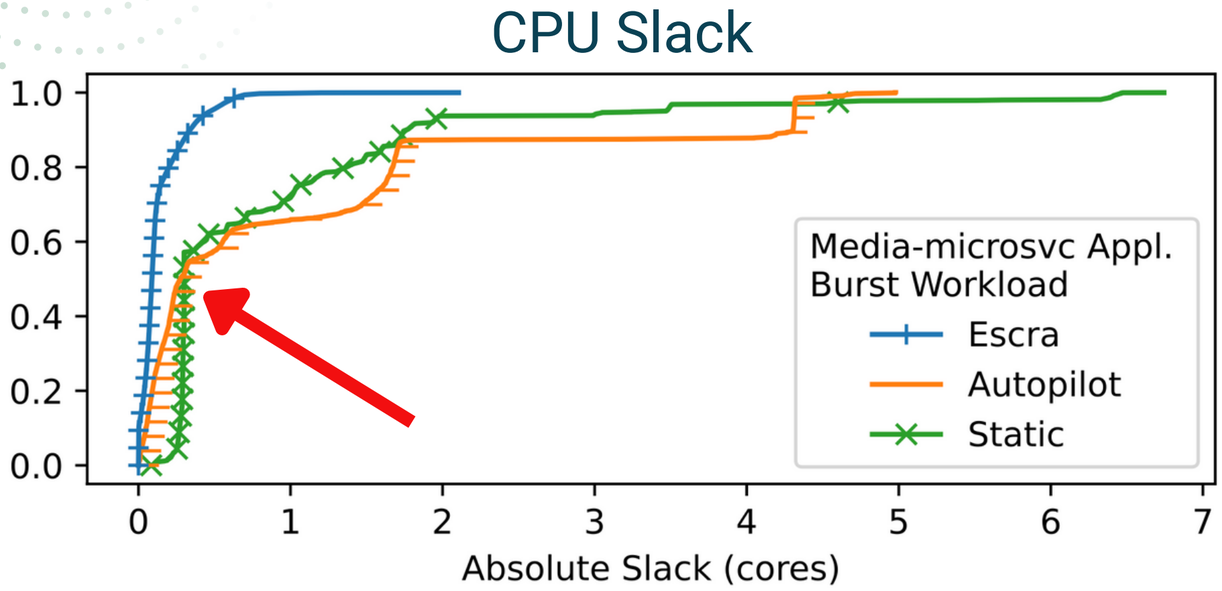

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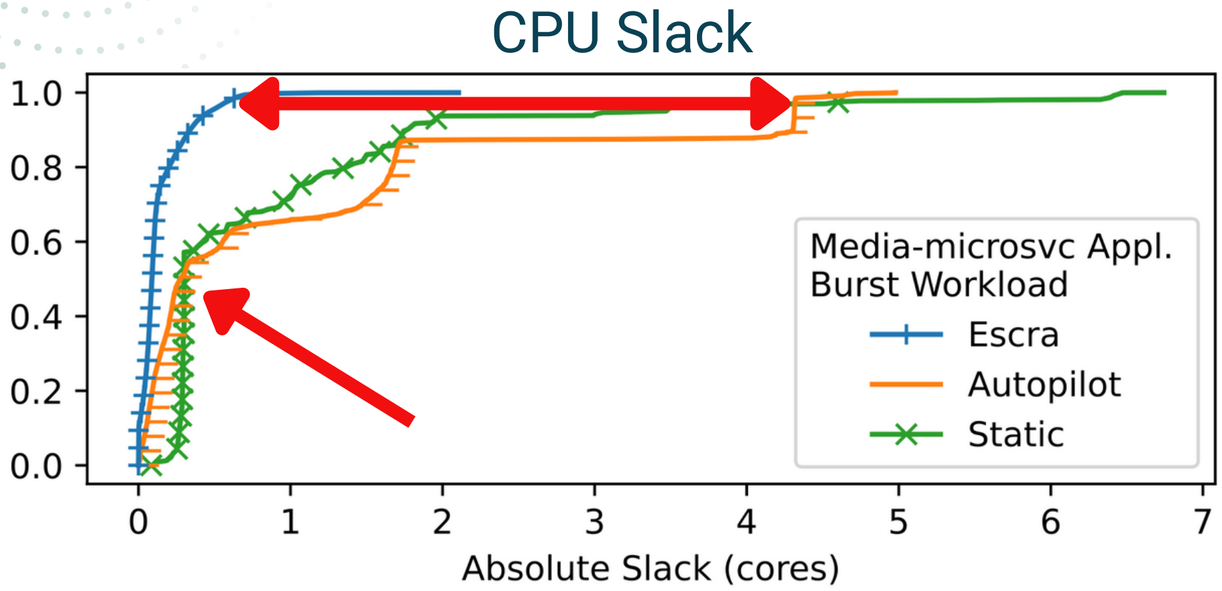

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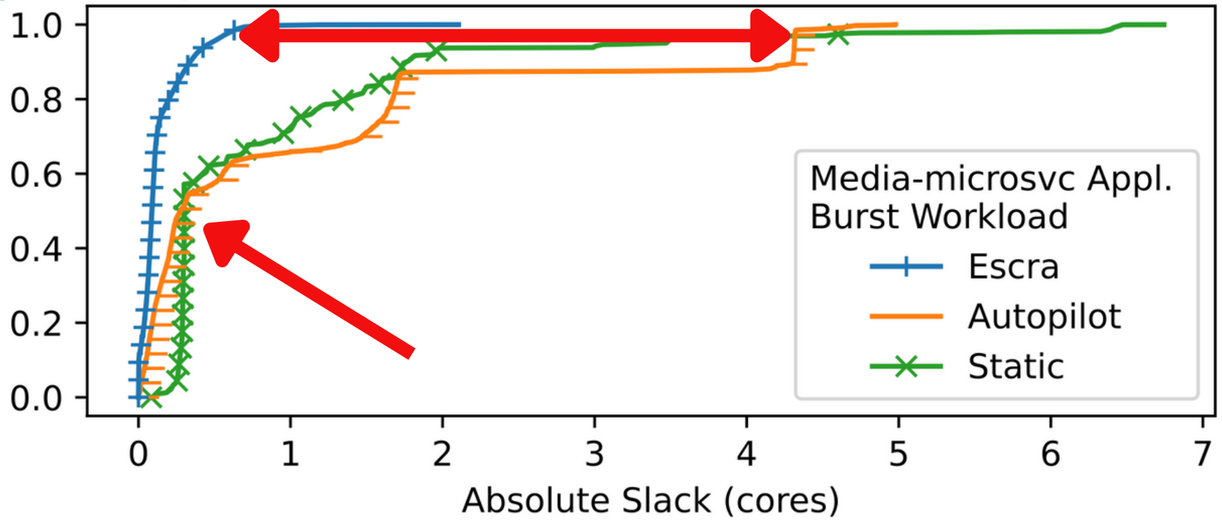
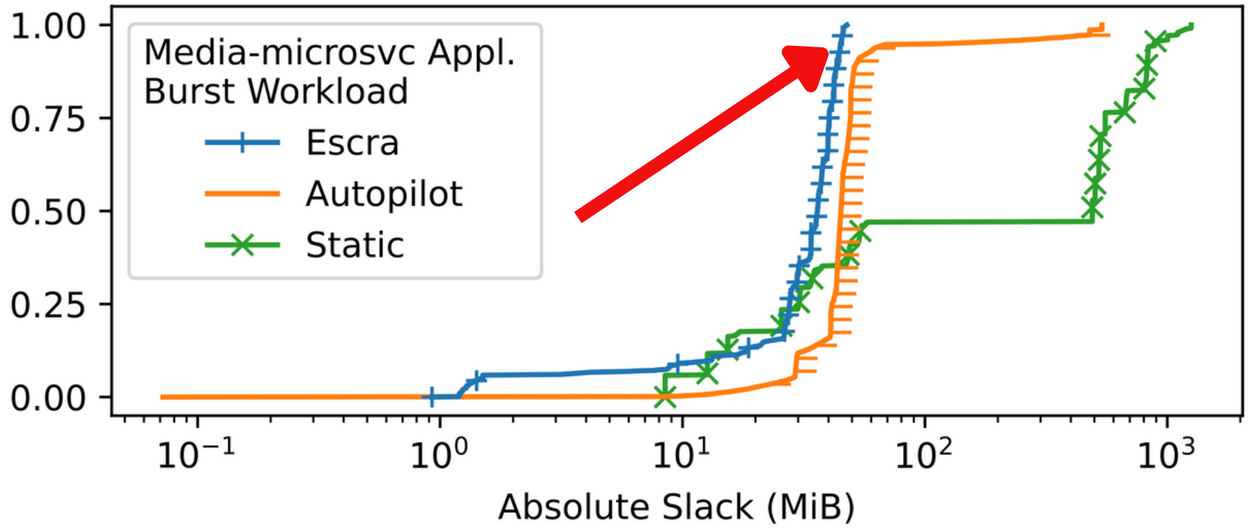
Escra vs. Autopilot

Microservices - MediaMicroservice/Burst Workload

CPU Slack



Memory Slack



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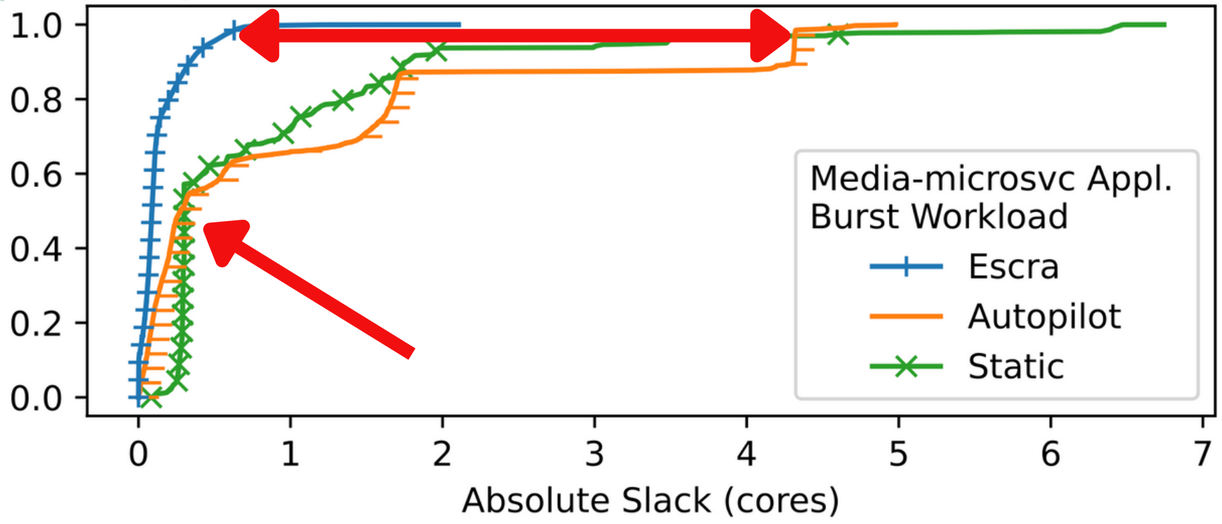
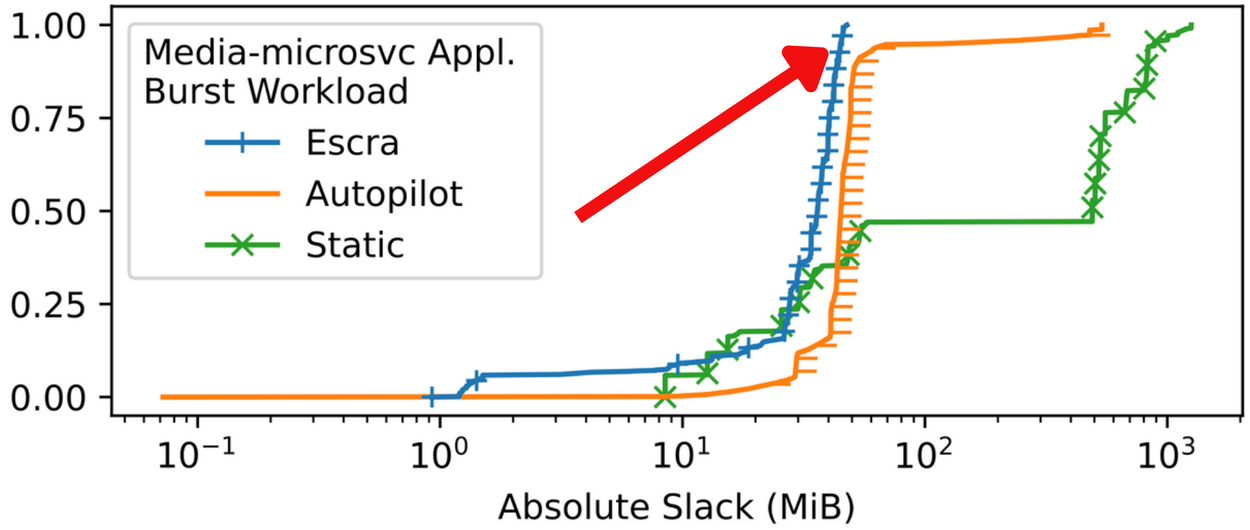
Escra vs. Autopilot

Microservices - MediaMicroservice/Burst Workload

CPU Slack



Memory Slack



- **Latency Decrease: 16.6%**
- **Throughput Increase: 84.3%**

Evaluation - Serverless

Evaluation - Serverless

Metrics

Aggregate Limits

Σcontainer limits - Σcontainer usages

Application Latency

End-to-end latency per request or job

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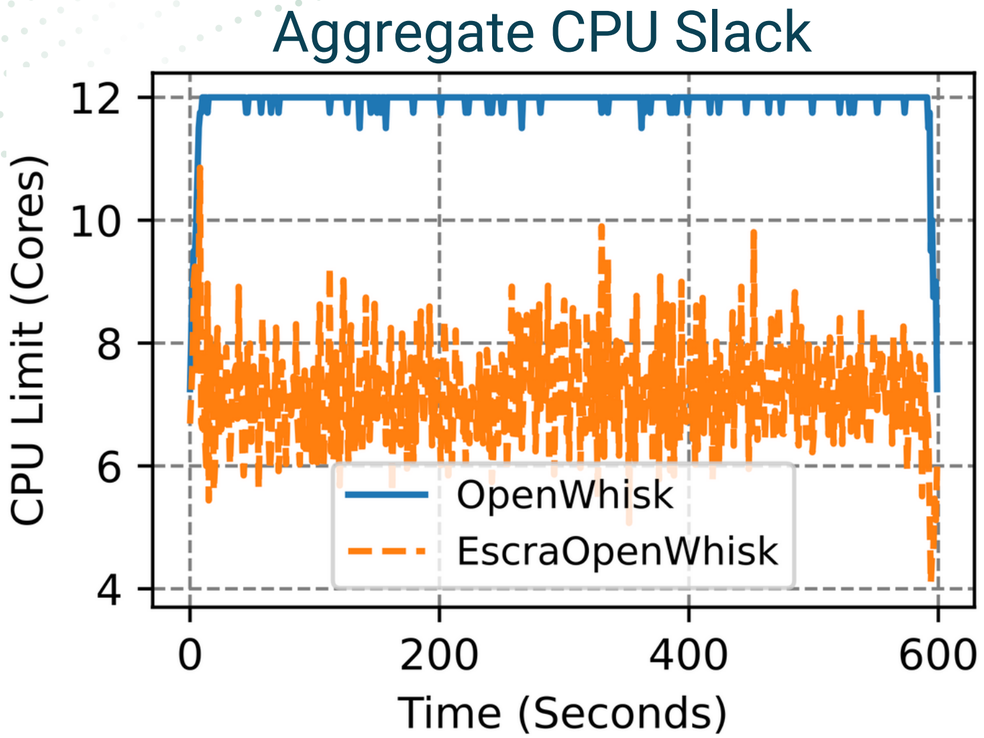
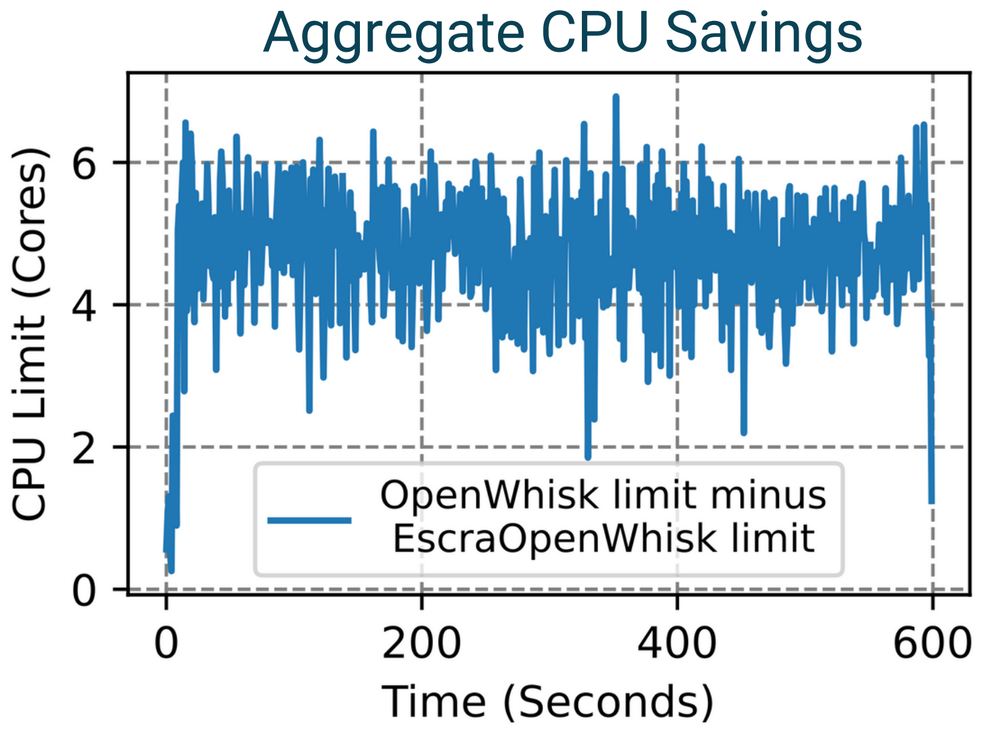
ImageProcess

Serverless





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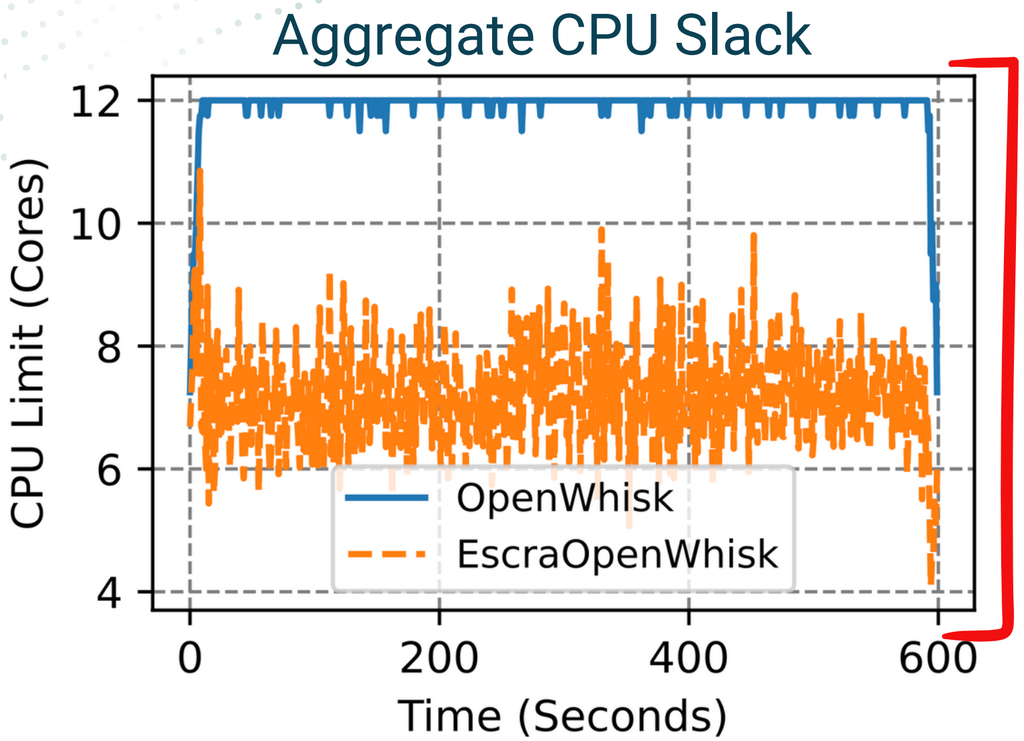
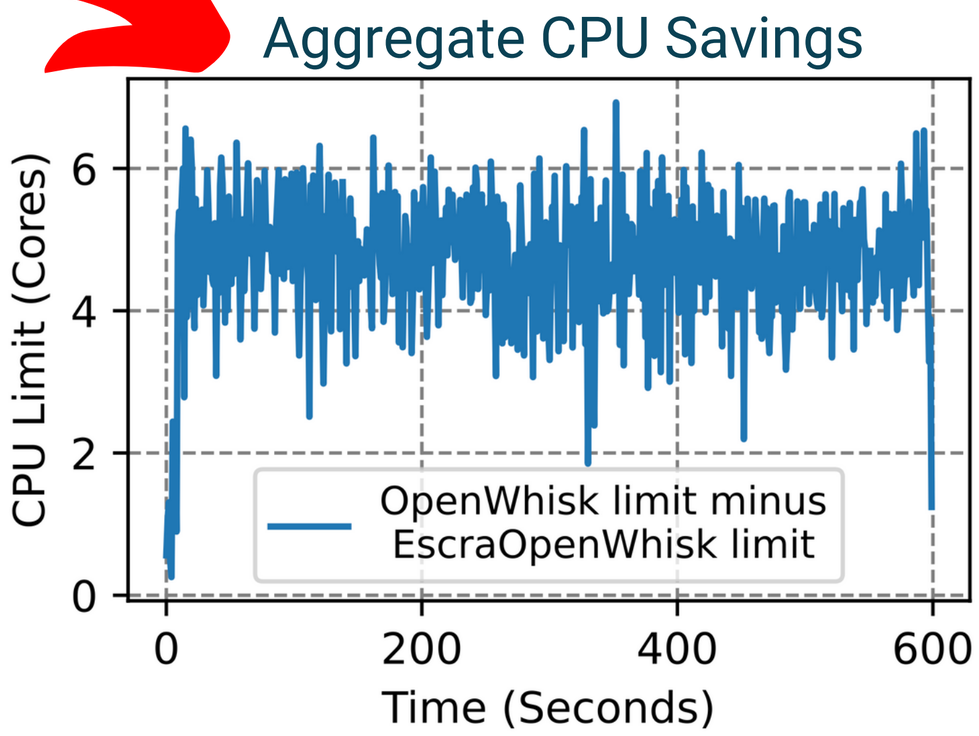
ImageProcess

Serverless

Difference!





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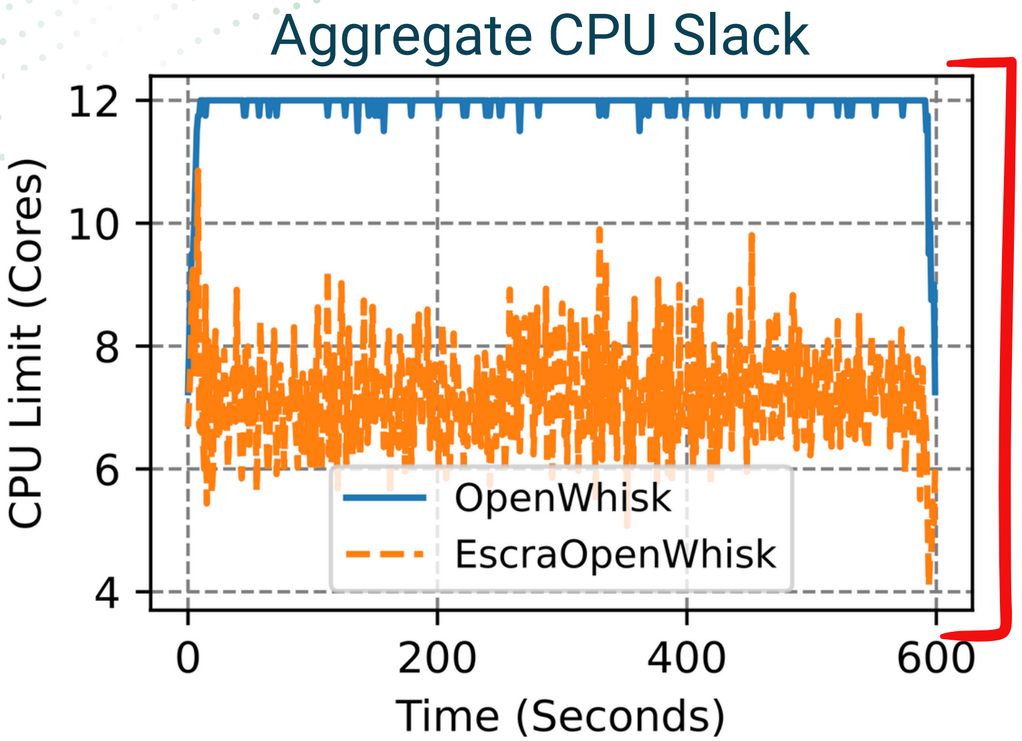
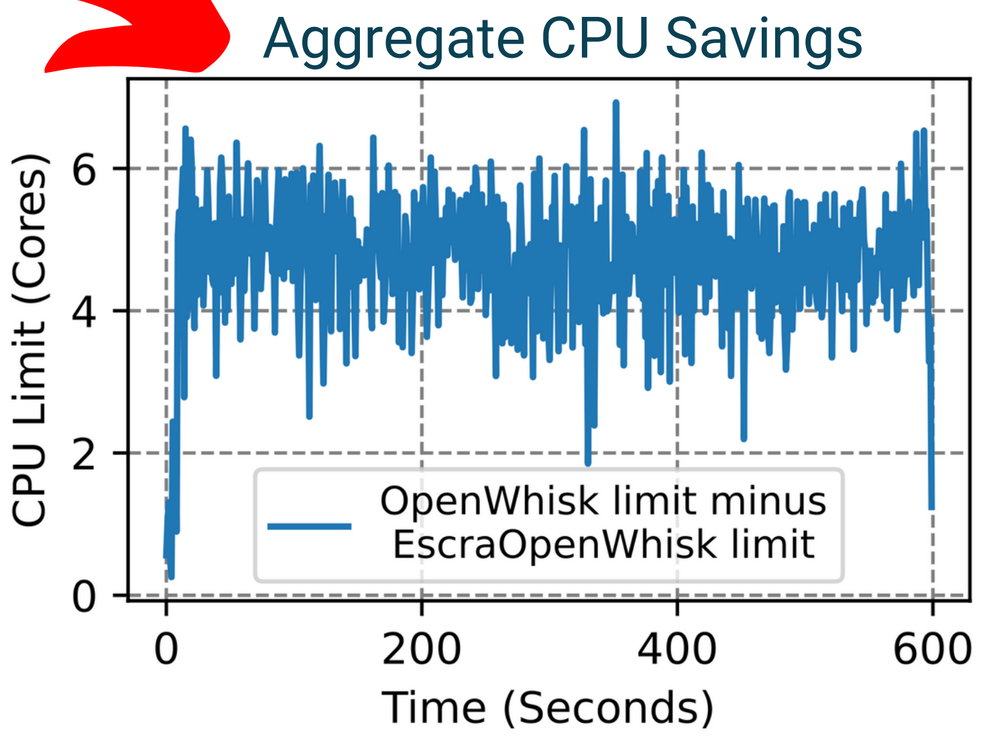
ImageProcess

Serverless

Difference!





- **Escra + Openwhisk avg vCPU limit: 7 vCPU**
- **Openwhisk avg vCPU limit: 12v CPU**

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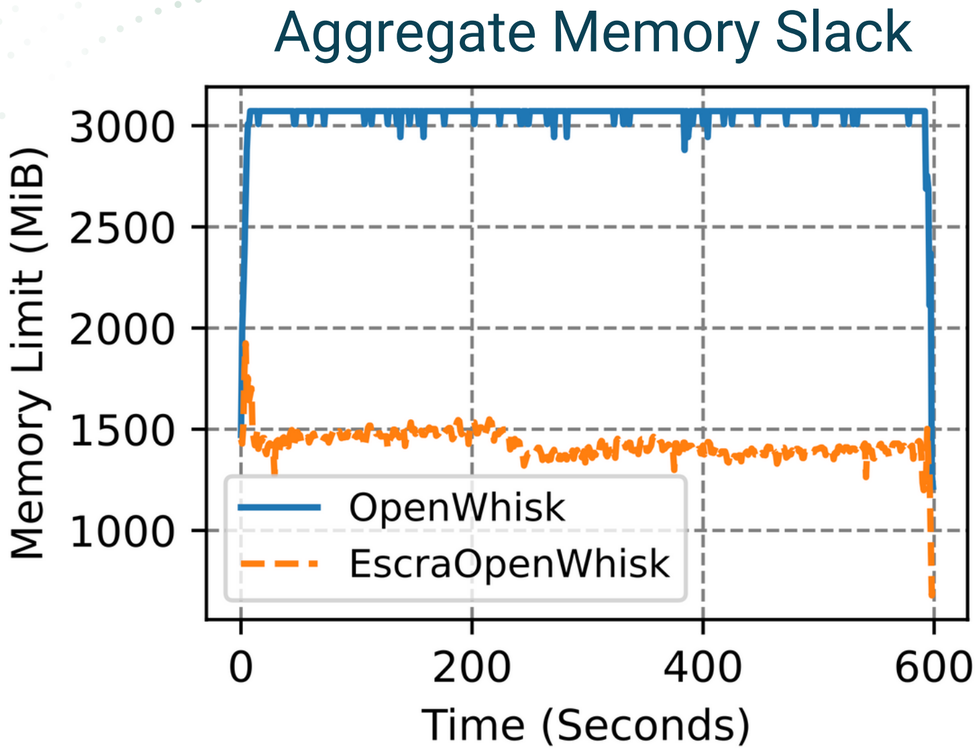
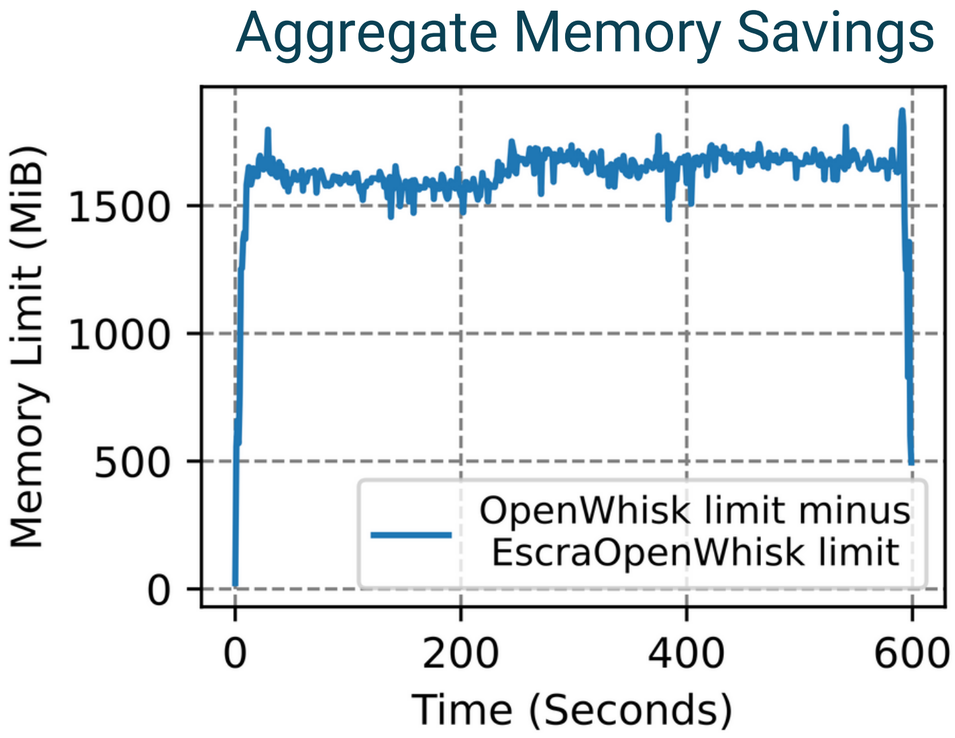
ImageProcess

Serverless





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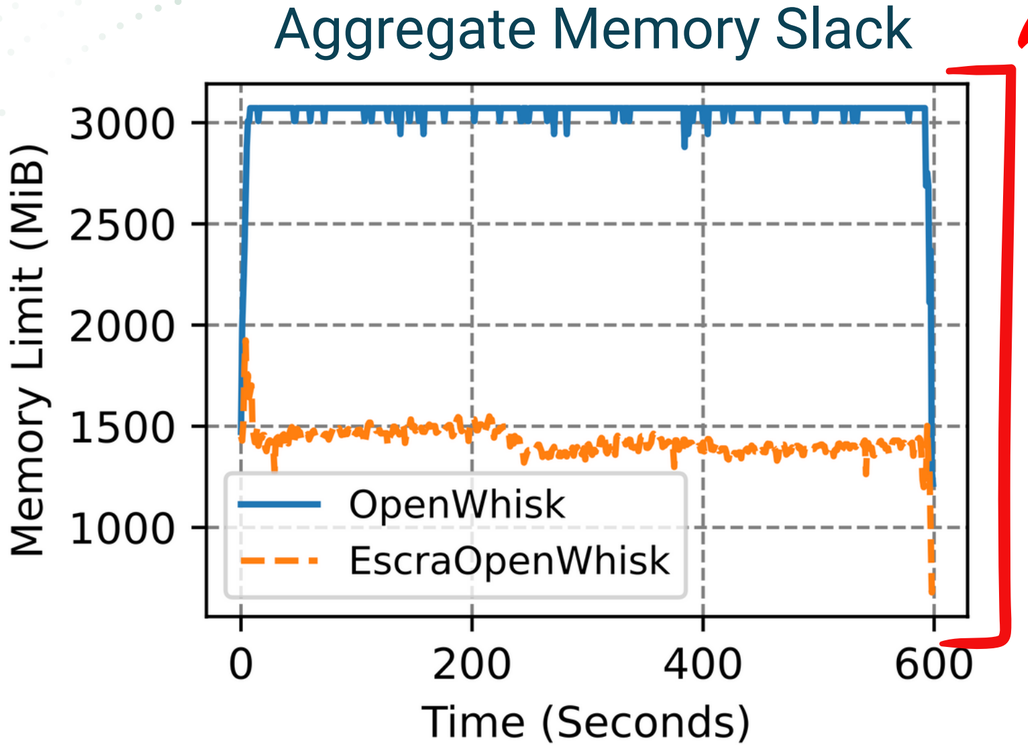
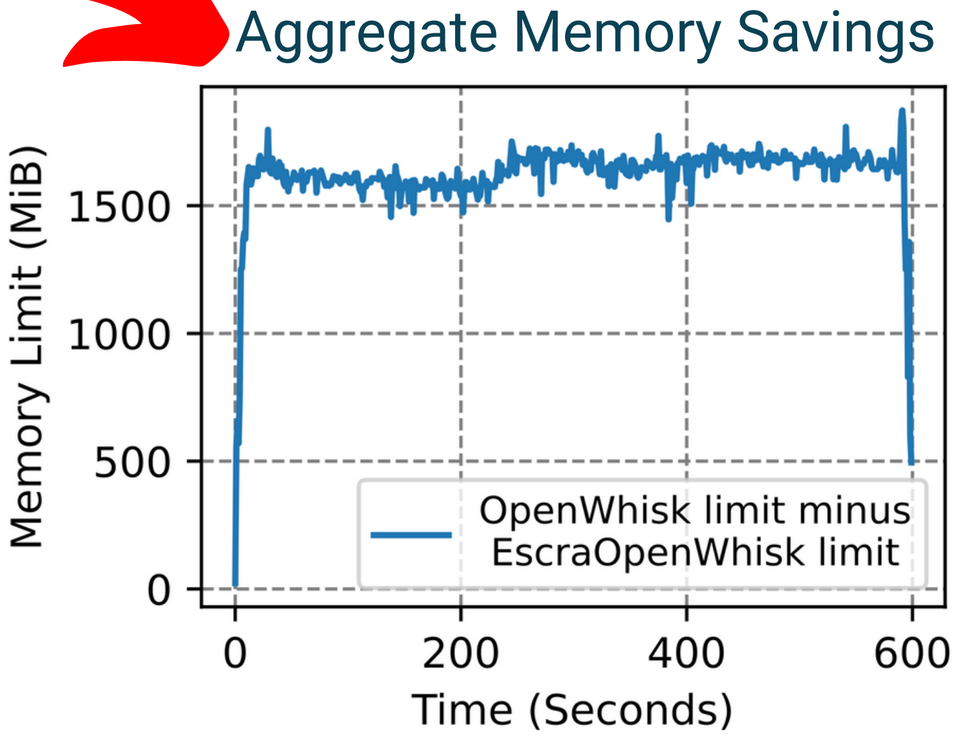
ImageProcess

Serverless

Difference!





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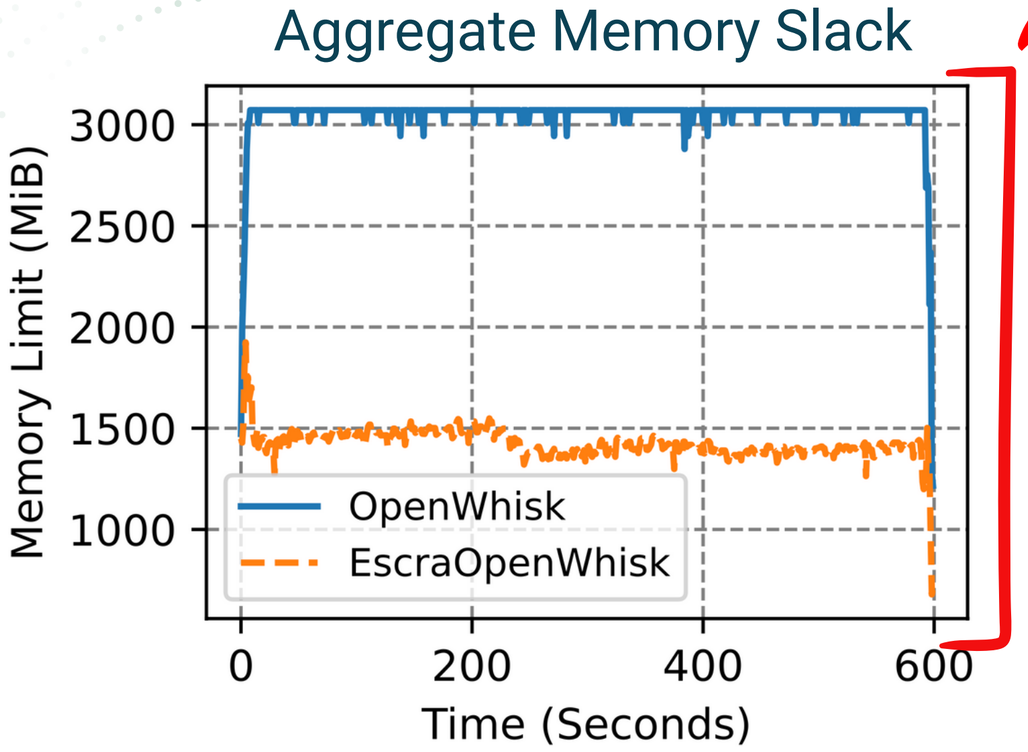
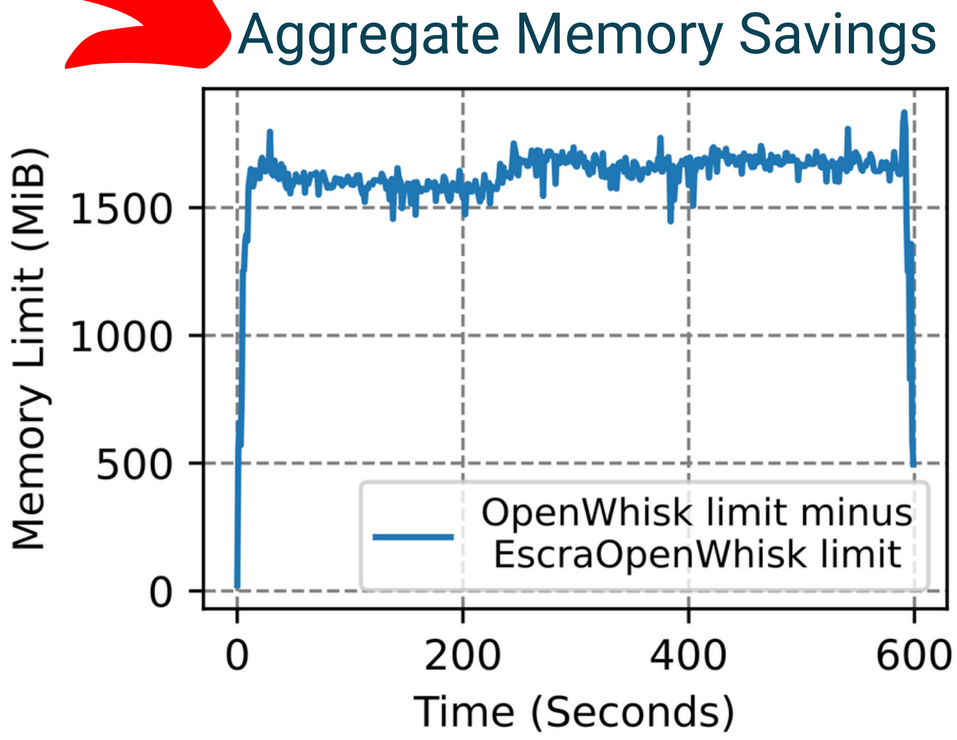
ImageProcess

Serverless

Difference!





Avg. memory savings: 1550 MiB

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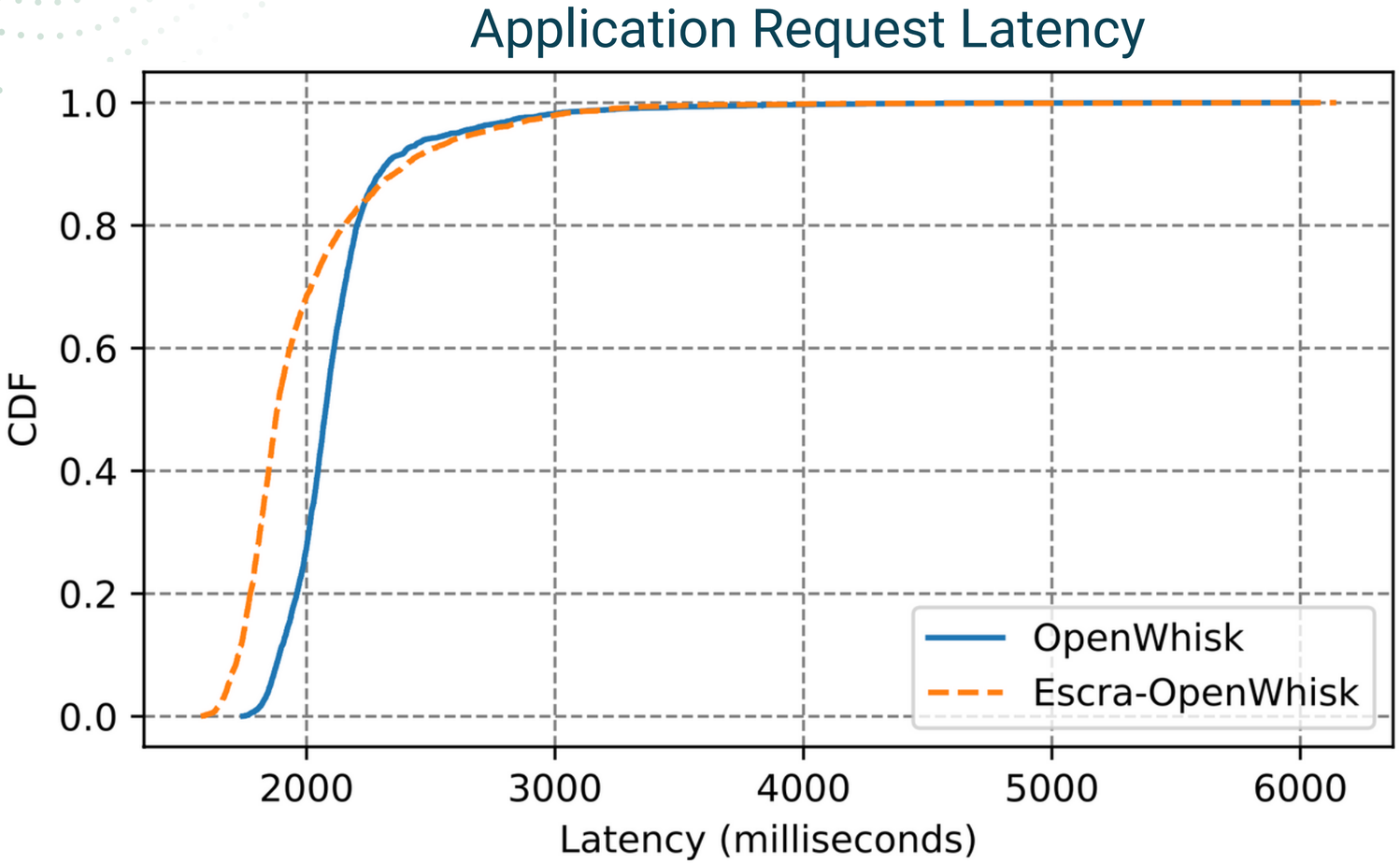
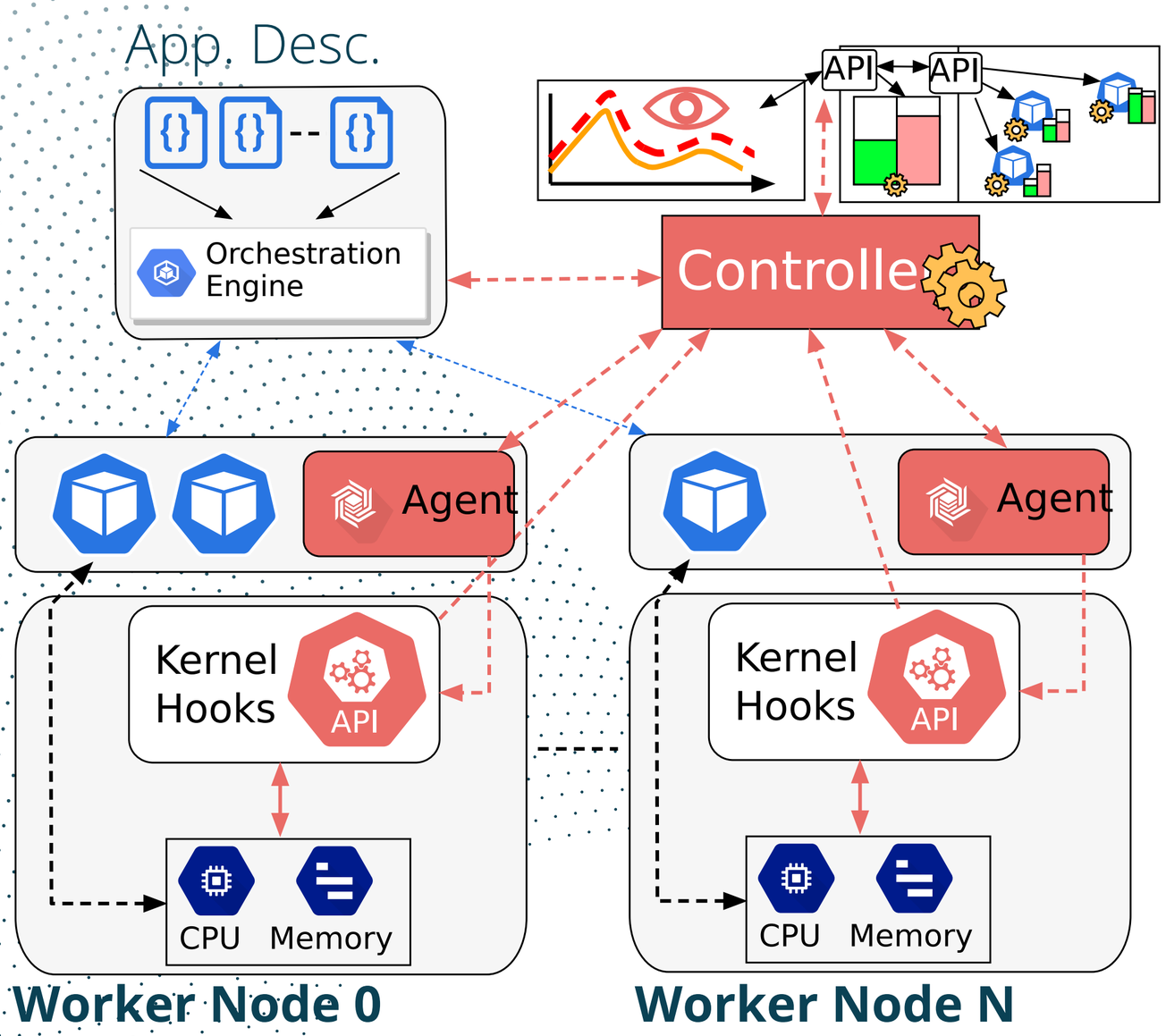
ImageProcess

Serverless



- 80% of the time, Escra + Openwhisk sees a strong performance gain
- 99th%-ile latency remains similar for both



In Conclusion...

- Fine-grained allocations allows us to react to, not predict, workload changes
- High efficiency and high performance!
- Outperforms state of the art!
- Significant resource saving in serverless deployments

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Questions?


github.com/gregcusack/Escra


@GregoryCusack


gregory.cusack@colorado.edu


linkedin.com/in/gregorycusack

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