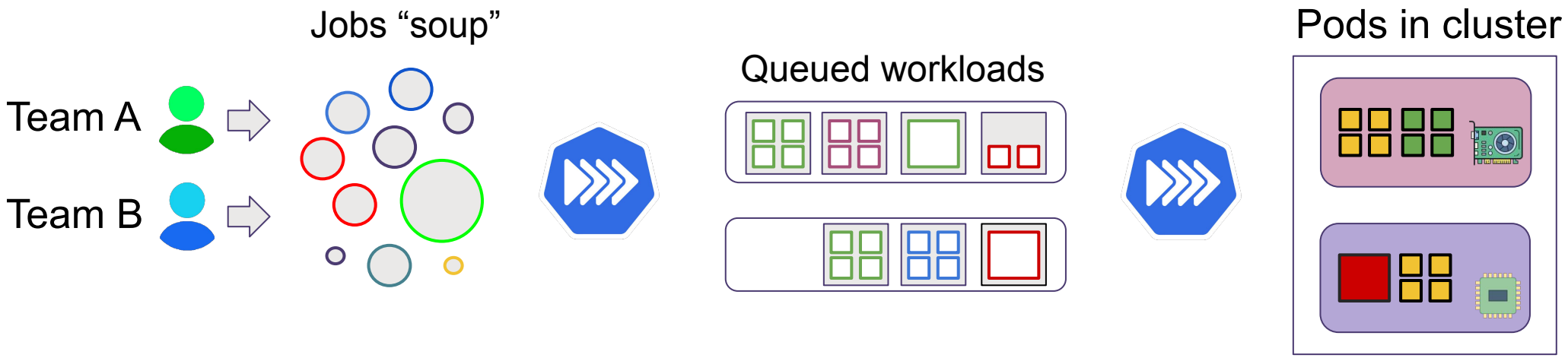
Advanced Resource Management for Running AI/ML Workloads with Kueue

Michał Woźniak (@mimowo), Google
Yuki Iwai (@tenzen-y), CyberAgent, Inc.

What is Kueue?

Job-level scheduler

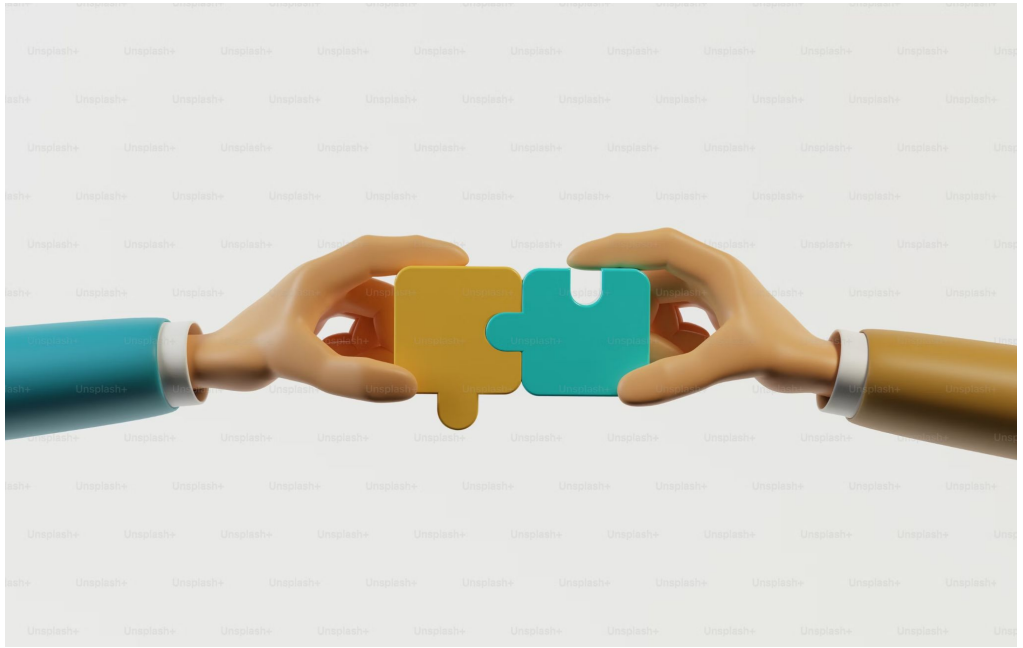
- Determines when to start a job
  - delayed pod creation off-loads api-server and kube-scheduler
- Support all-or-nothing semantics (without it jobs could “deadlock”)
- Resource quota management
  - Multi-tenant quota management
  - Quota management for various types of hardware
  - Control over resource preferences (reservations vs. on-demand vs spot)



Kueue - Design principles

It is “kube-native”:

- There is no external database
- Compatible with kube components:
  - cluster-autoscaler, kube-scheduler, Job controller
  - No kube components are forked or replaced
- Required enhancements are requested upstream



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Kueue - Design principles

- Pods creation is gated by job admission
  - Introduce “suspend” semantics across Job CRDs

- Supported Job-based integrations:
  - k8s: Job, JobSet
  - Kubeflow Jobs
  - Ray: RayJob, RayCluster
  - In-house Jobs via Job framework

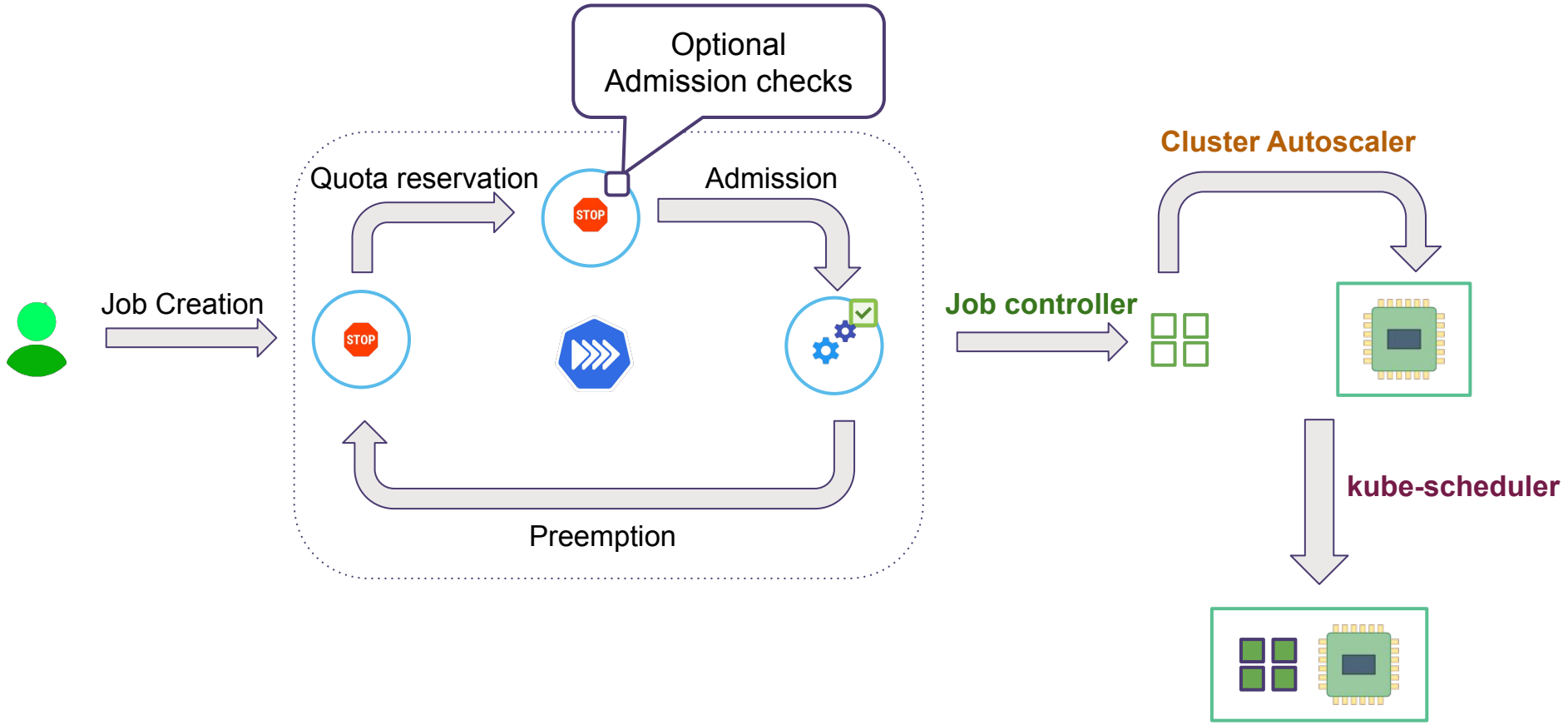
BTW: Plain pod groups are also supported

Kubeflow

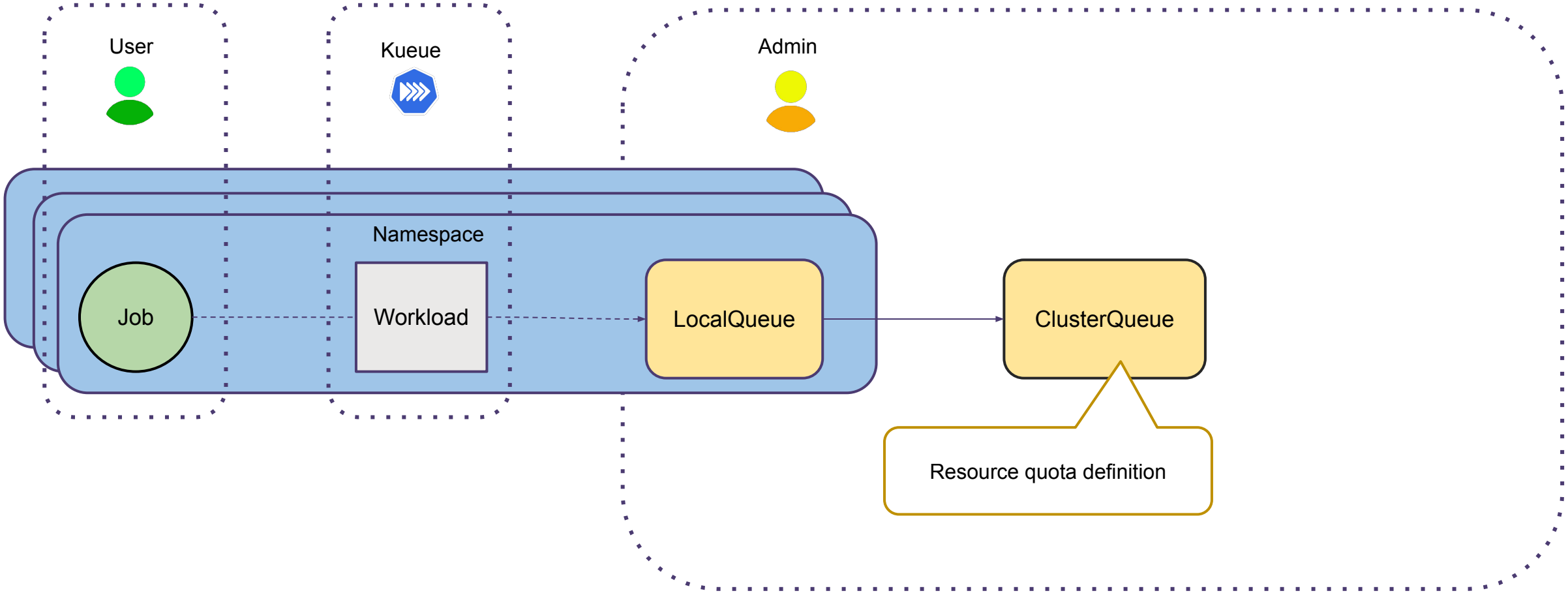
JobSet

TensorFlow

Kueue - Job lifecycle



Kueue - main concepts



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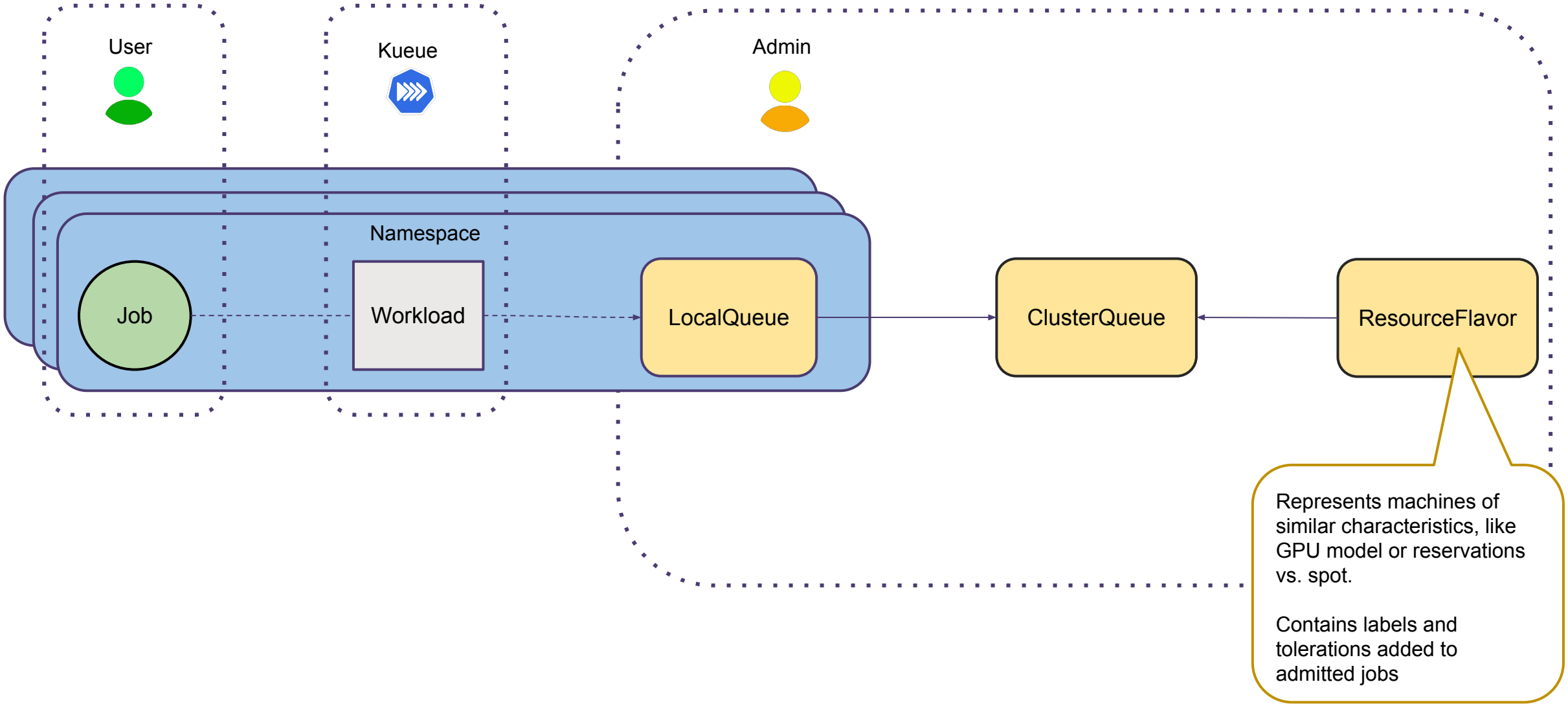

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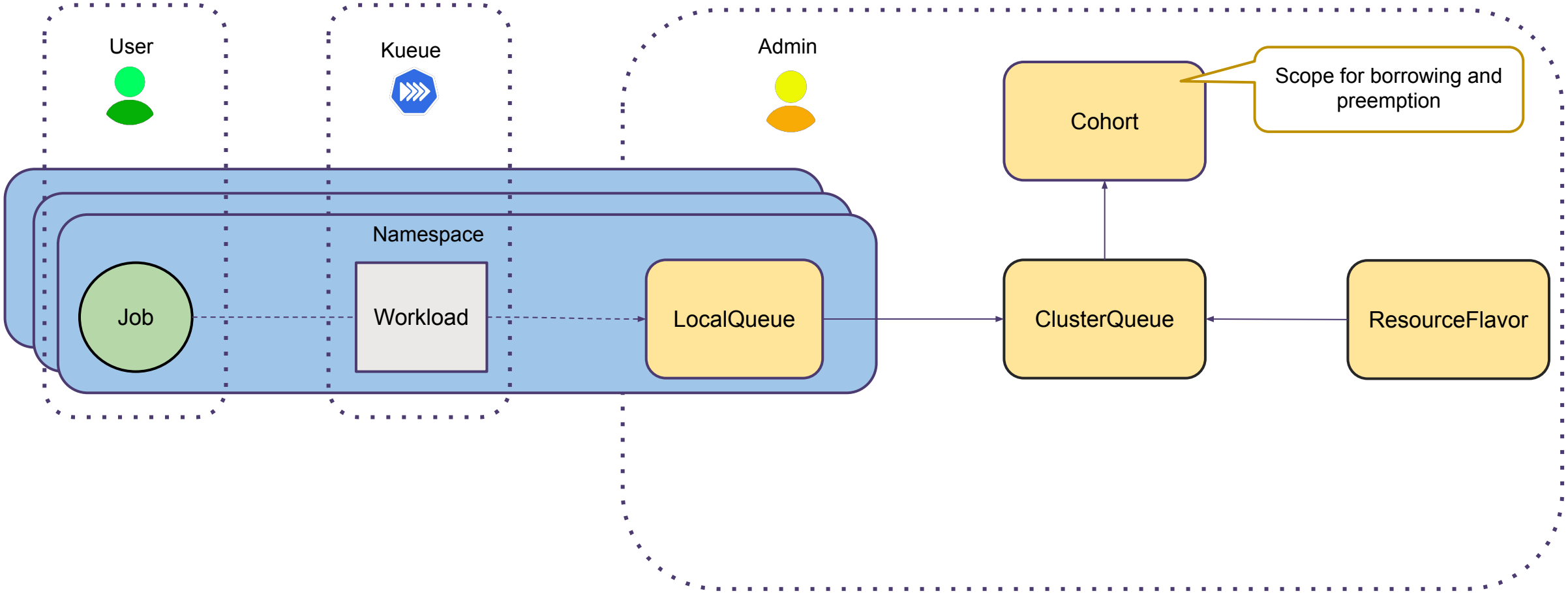

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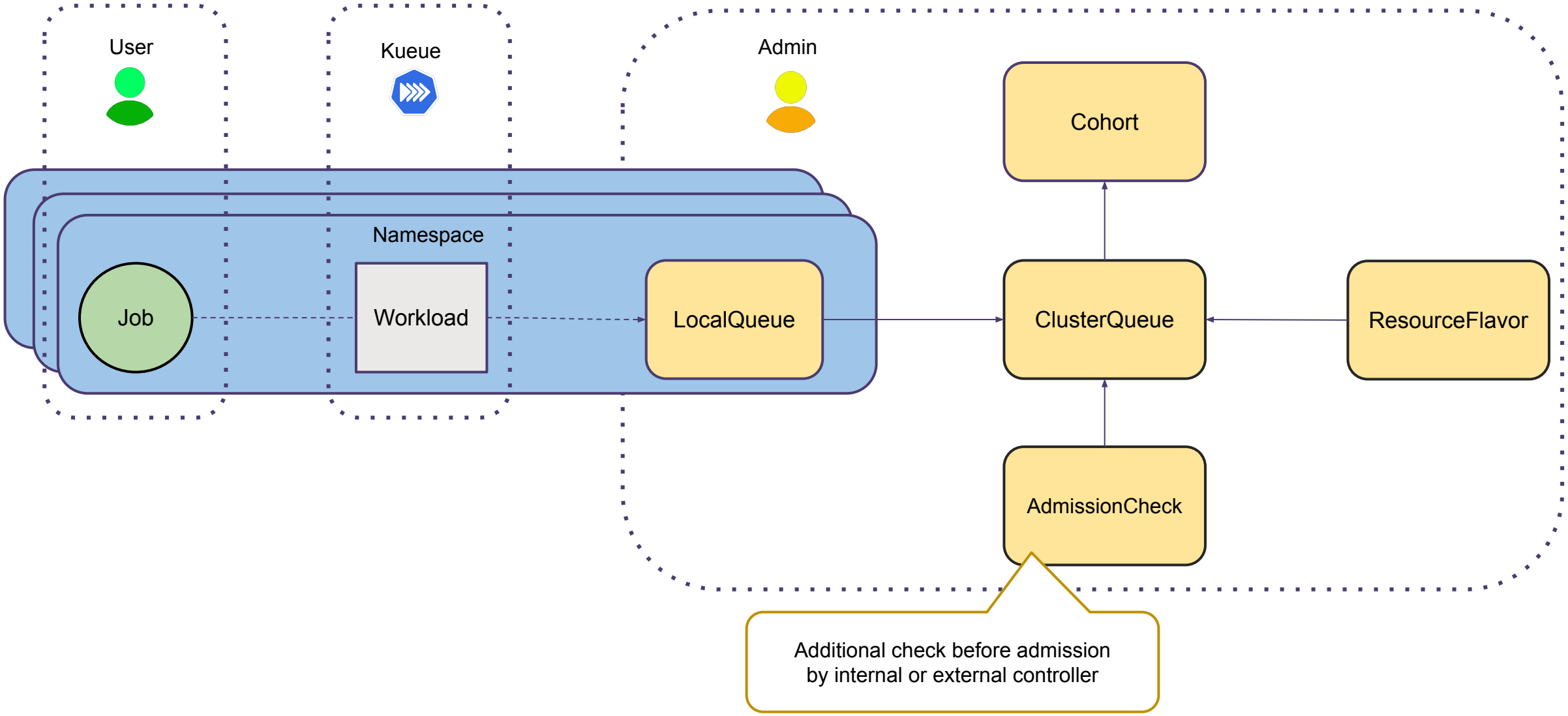


Batch reference architecture

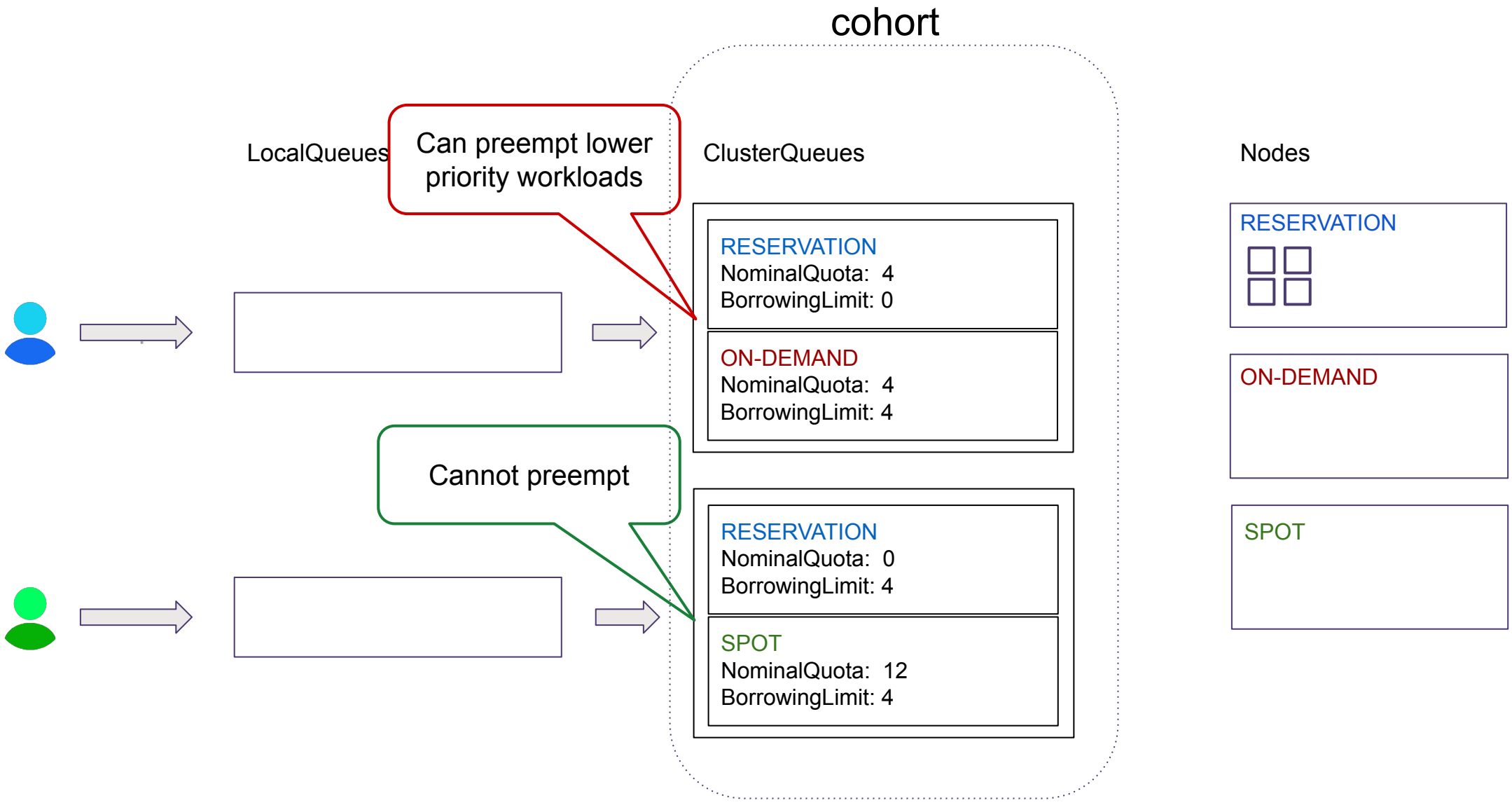
Goals:

- Intended to help platform administrators, cloud architects, and operations professionals deploy a batch processing platform
- Best practices for running batch workloads
- Customizable for user preferences

https://github.com/GoogleCloudPlatform/ai-on-gke/tree/main/gke-batch-refarch

Acknowledgements: Ali Zaidi

Batch reference architecture



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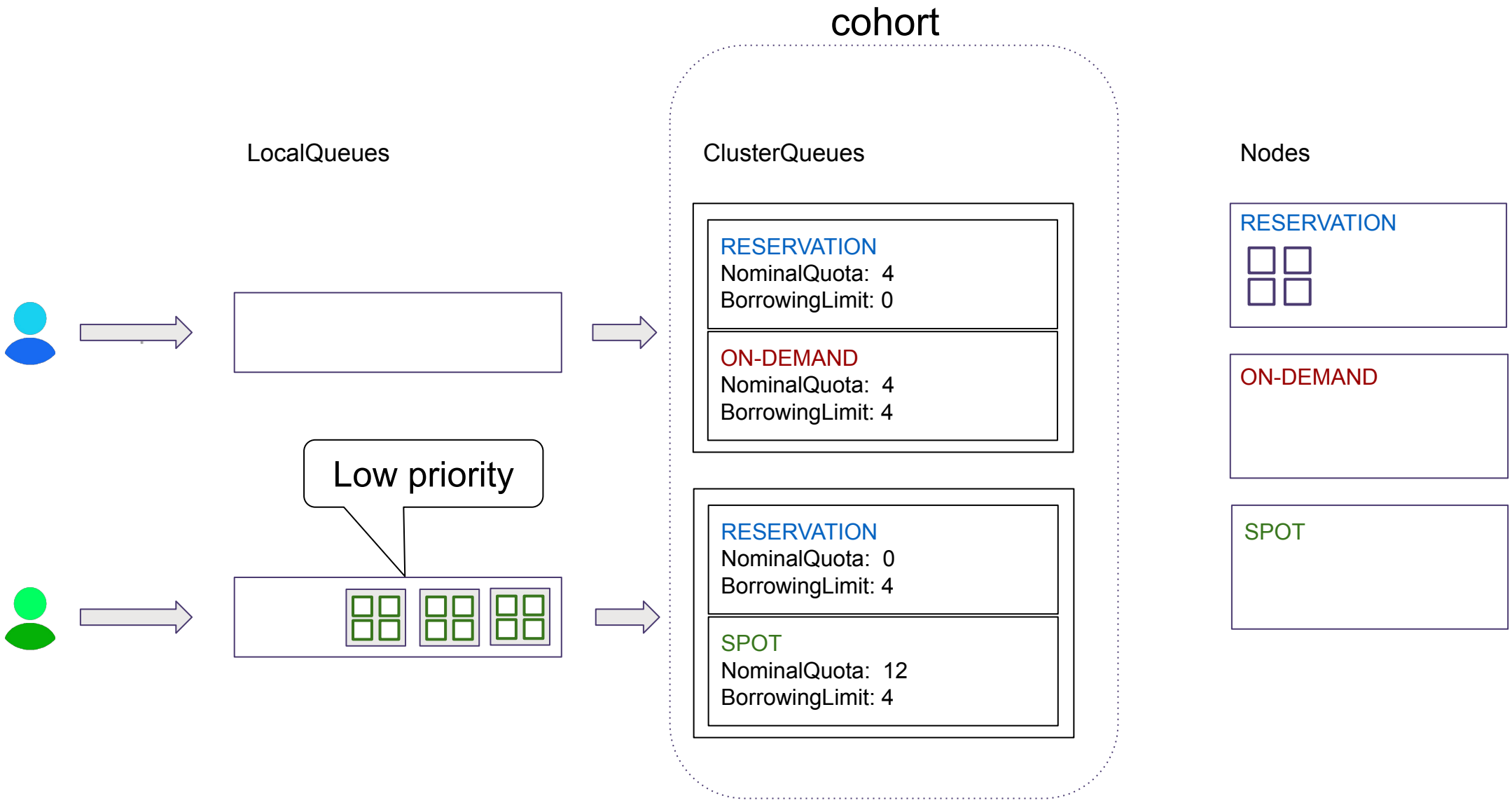

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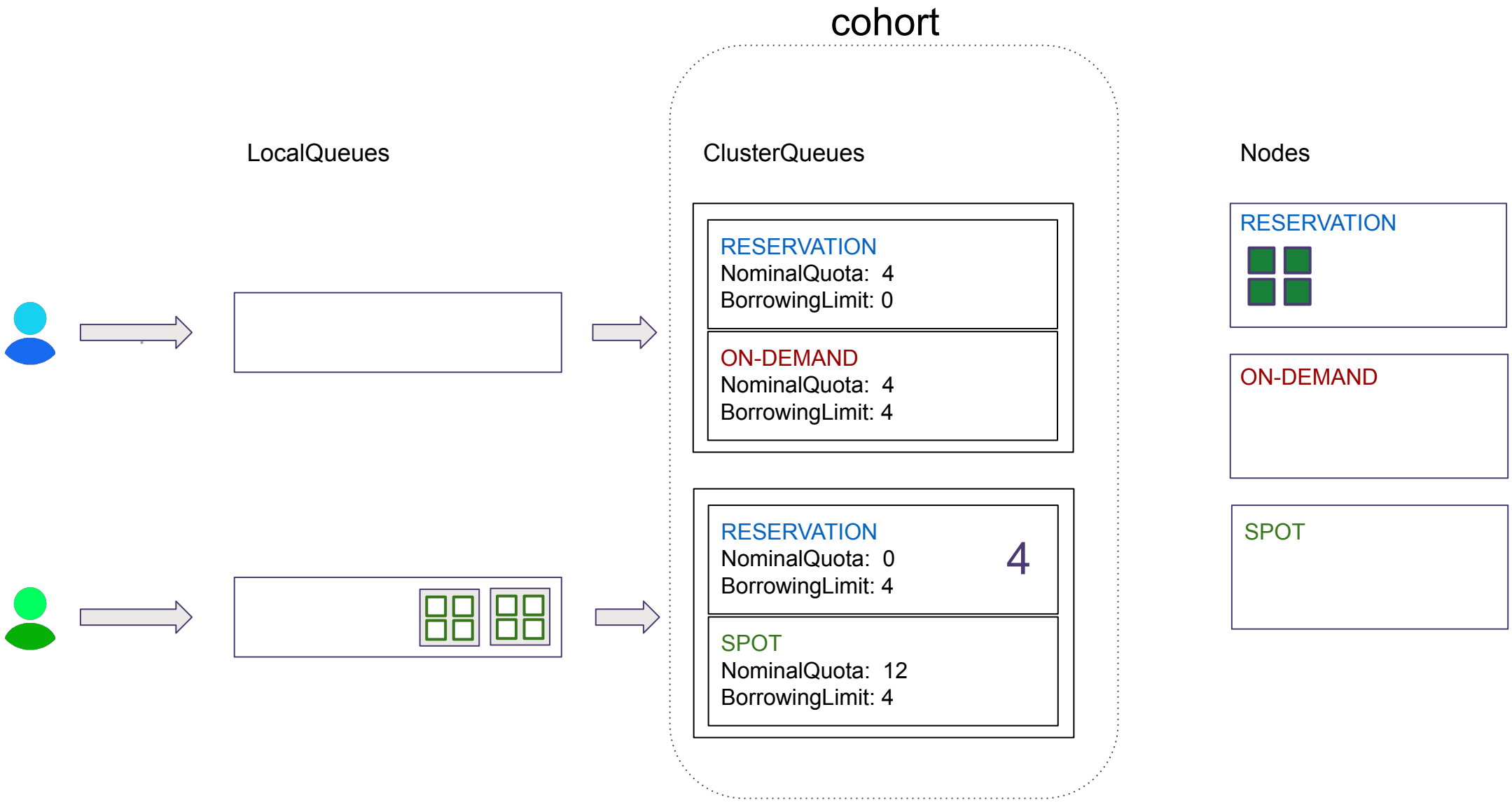

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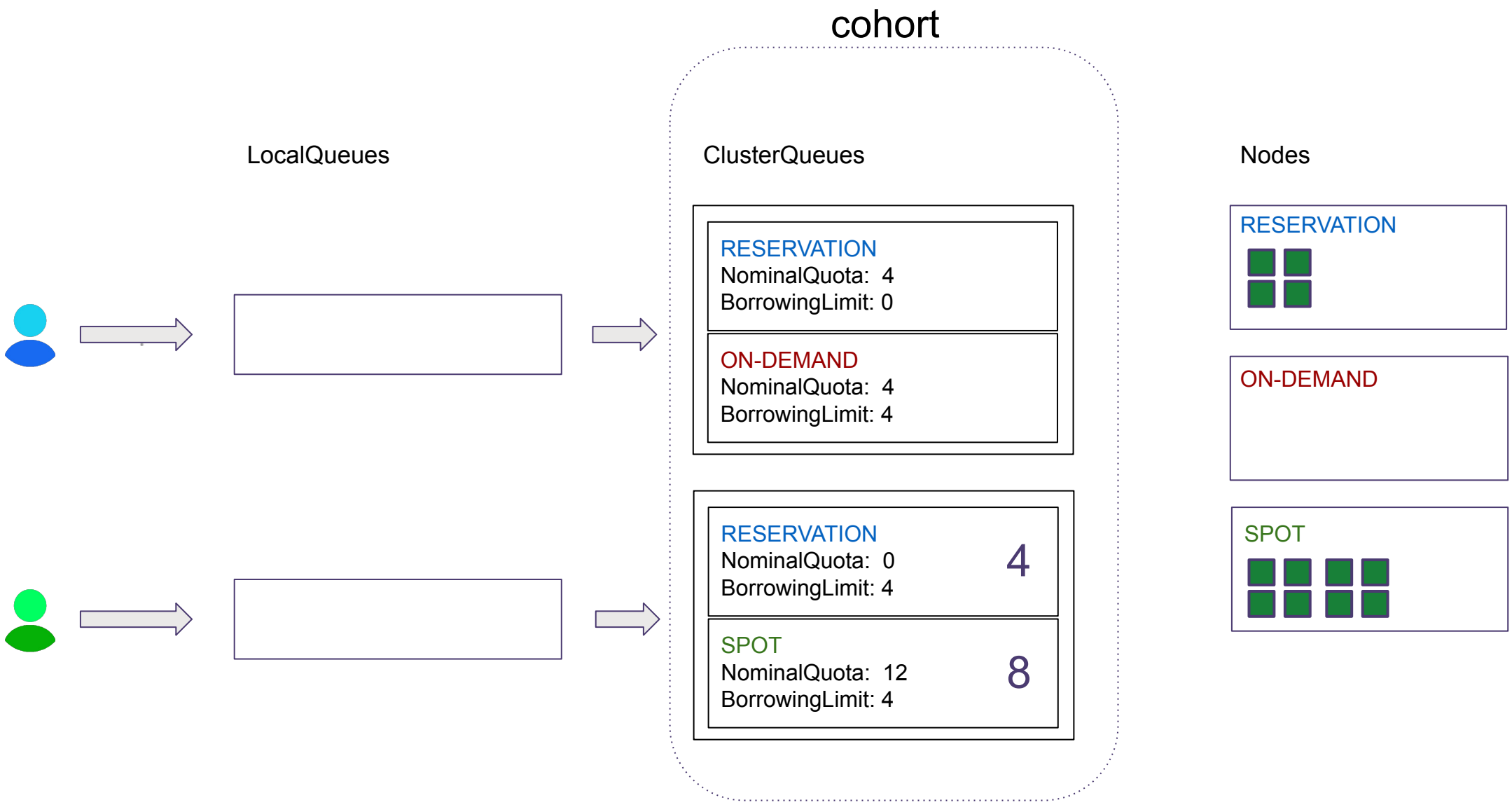

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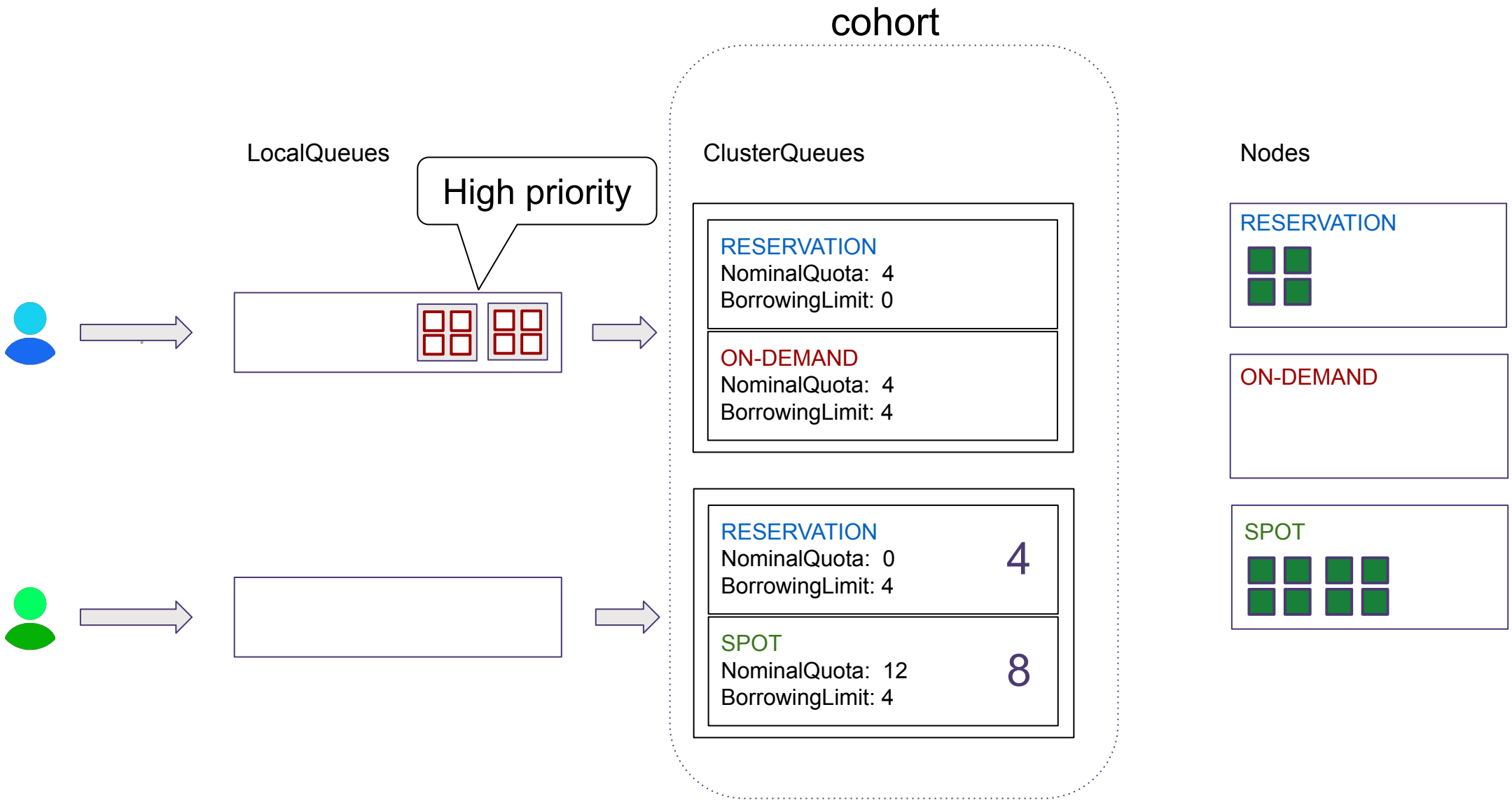

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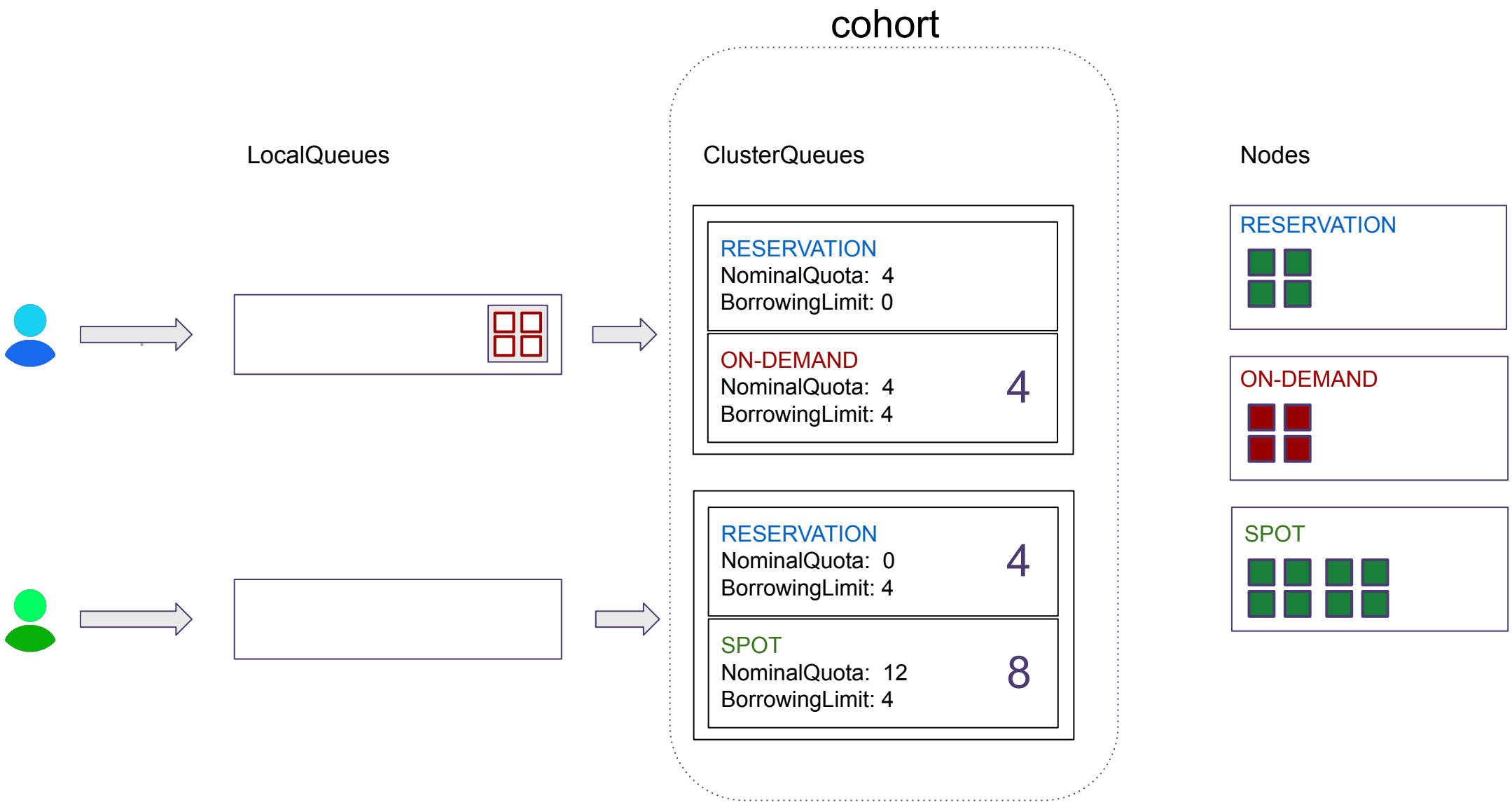

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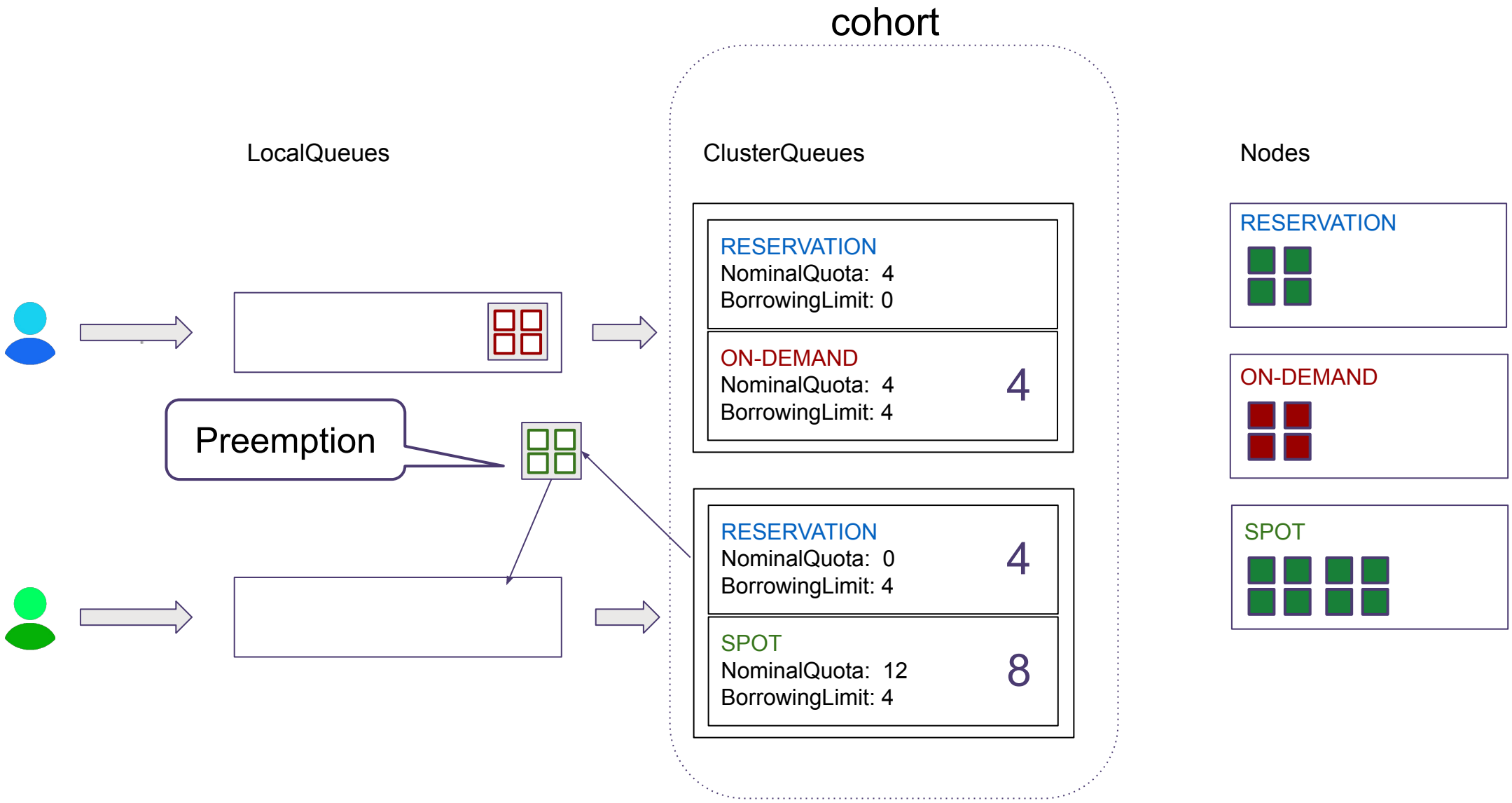

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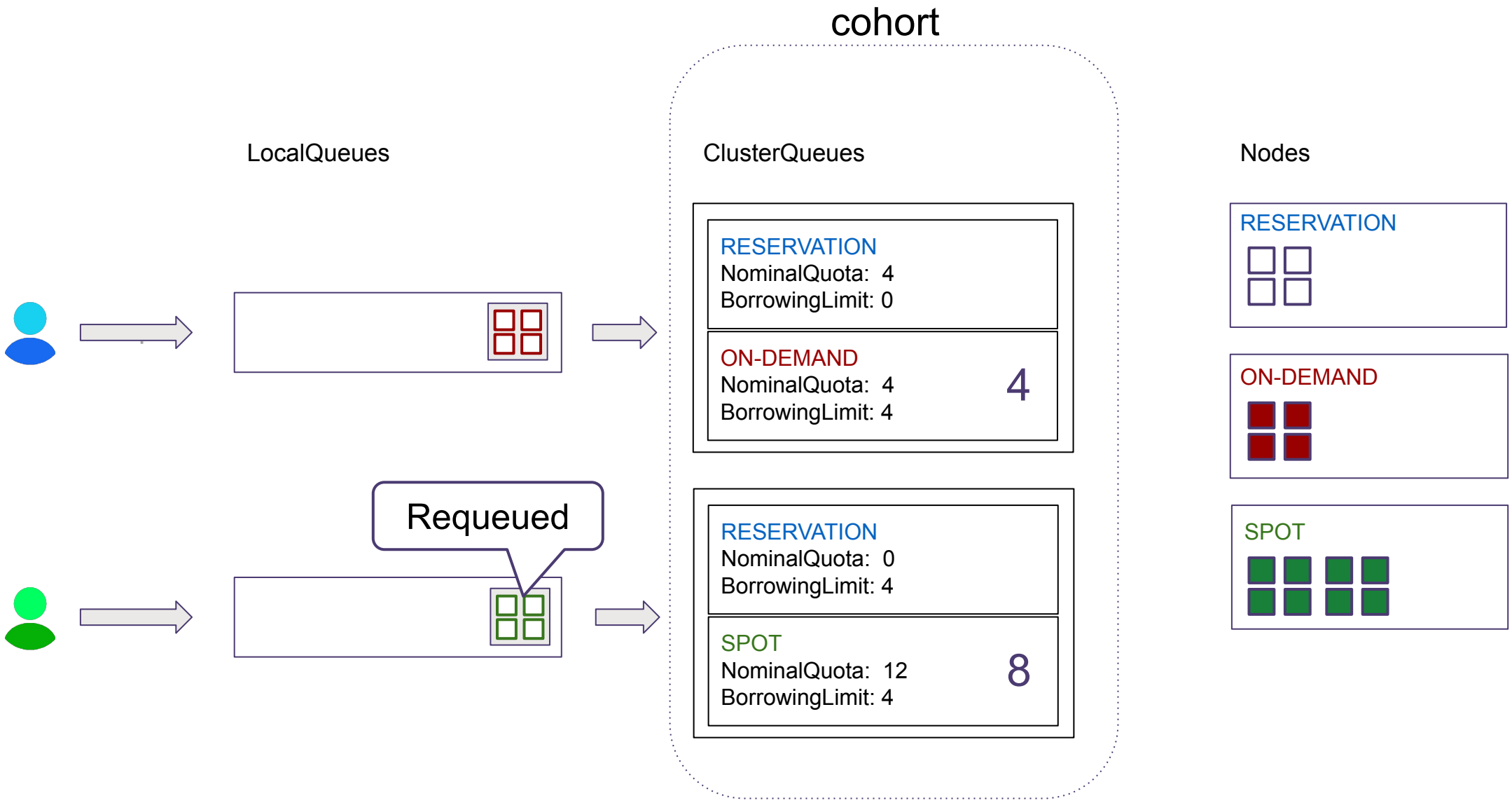

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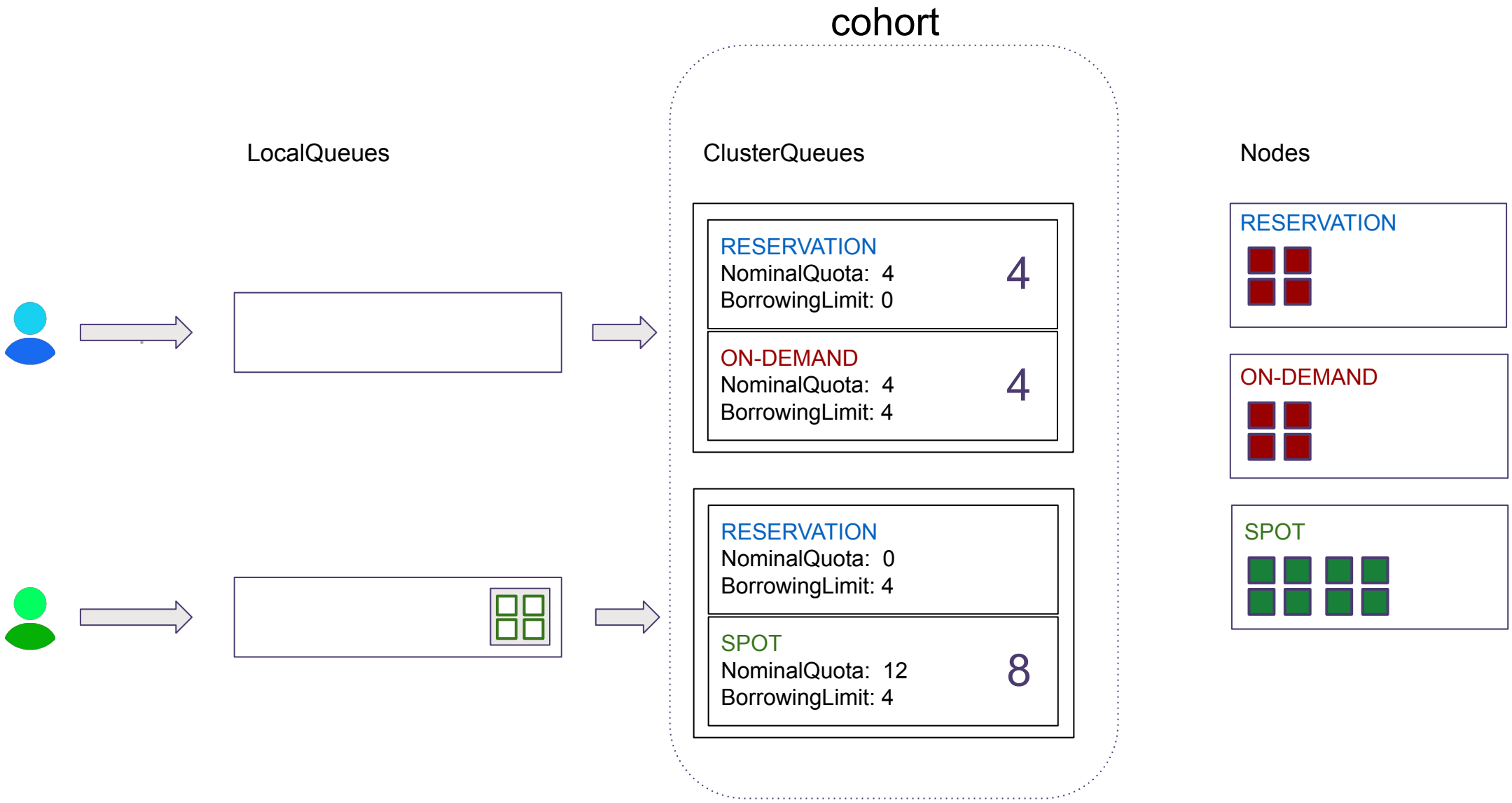

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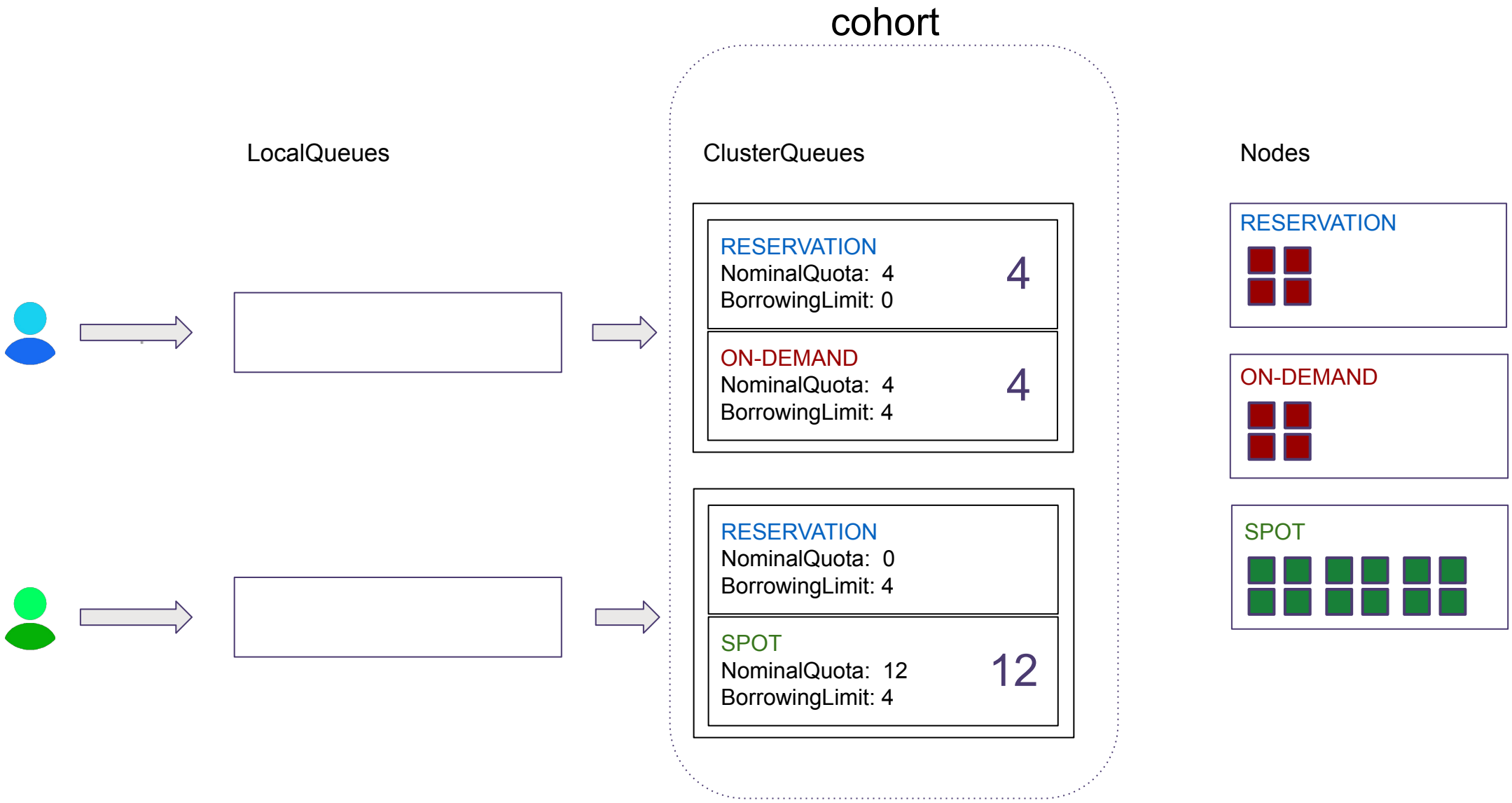

Kueue in CyberAgent

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Kueue in CyberAgent

CyberAgent Internal on-premise ML Platform

Infrastructure

- Bare metal machines for GPU Nodes
- Heterogeneous computing resources with 7 types GPUs
  - NVIDIA H100
  - NVIDIA A100 40GB
  - NVIDIA A100 80GB
  - NVIDIA L4
  - etc …

Kubernetes Cluster

- A Single Vanilla Multi-Tenant Cluster
- The number of tenants is over 300
- Operation Period is over 4 years in the same cluster

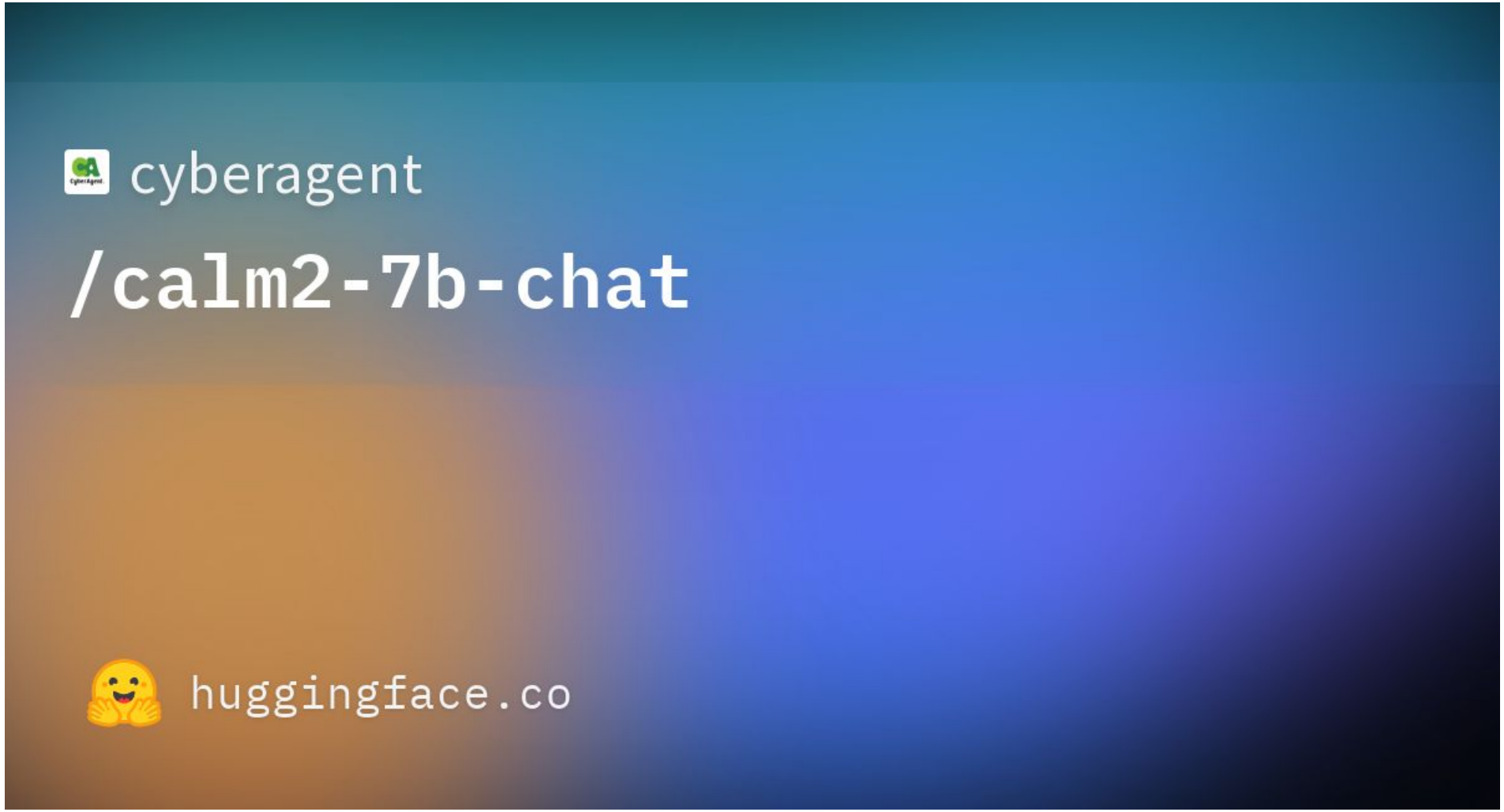
Kueue in CyberAgent

Workloads and Frameworks

- Training Machine Learning Models
  - batch/v1 Job
  - Kubeflow TFJob / PyTorchJob / MPIJob
- Jupyter Notebook
  - Managed by in-house system
    - Managed by in-house kueue-job manager
- Serving Machine Learning Model
  - Kserve (formerly KFServing)
  - Managed by ResourceQuota

Kueue in CyberAgent

Training Machine Learning Models: What do we work on the platform?



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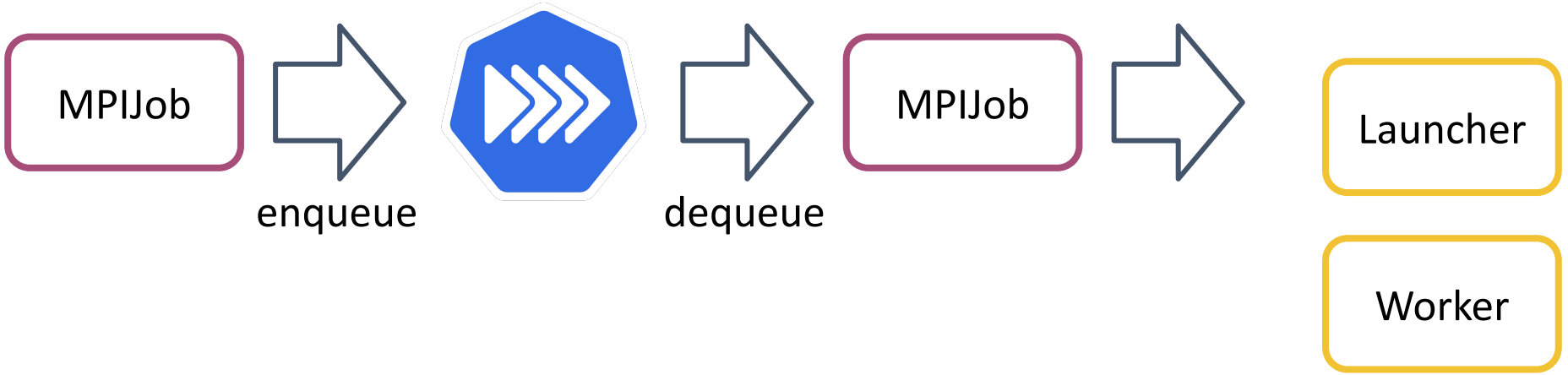
Training Machine Learning Model:

WaitForPodsReady with Configurable RequeueingStrategy

- When admitted Job isn't ready until timeout, Job is pushed back into ***Head*** (selected) or Tail of queue
- Not Ready Reasons:
  - Missing images, credentials and PVC etc.
  - The available quota is fragmented across multiple nodes



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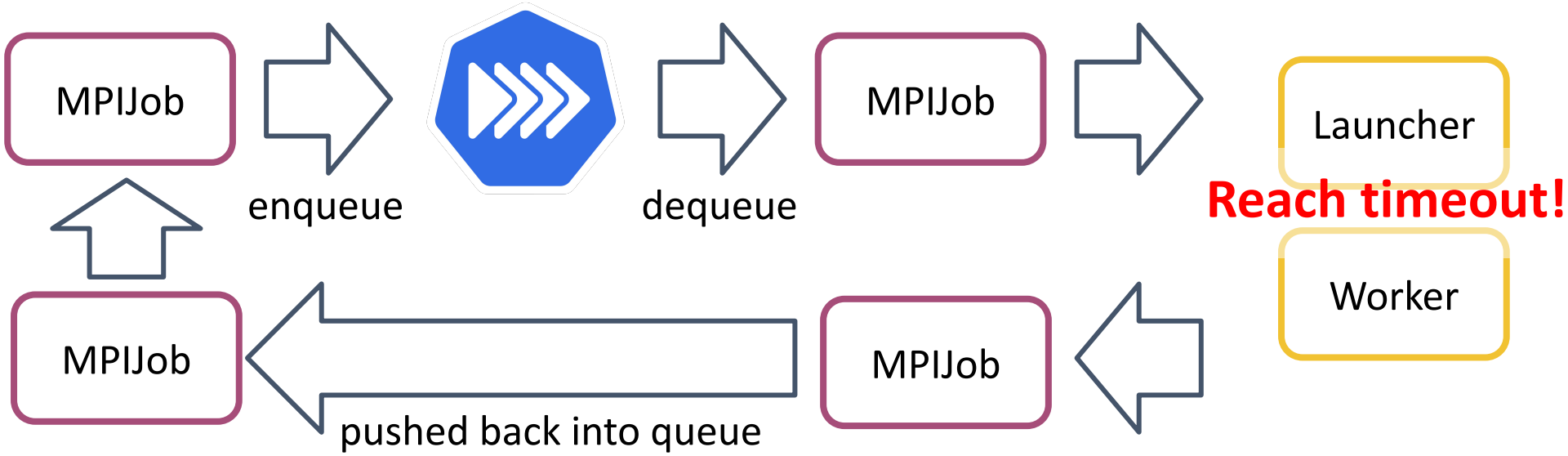

Kueue in CyberAgent

Bridging the Gap between Ideal and Real worlds

- Ideal world
  - All resources and workloads are completely managed by Kueue
- Real world
  - Conflicting between existing quota management system and Kueue
  - Some workloads and frameworks are not yet supported by Kueue
  - Kueue's functions are insufficient
    (e.g. Model Serving Server and Auto Scaling Semantics etc.)

Kueue in CyberAgent

Migrate K8s's ResourceQuota to Kueue's ClusterQueue

- Ideal world: Quota management and Queueing system by Kueue
  - Kueue admits jobs based on quota defined in ClusterQueues
- Real world: Existing quota management system
  - It depends on ResourceQuota
  - It distributes ResourceQuota to namespaces (tenants) to reserve quota

Kueue in CyberAgent

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- Gap
  - Over-assignment could occur
    - Over-assigned Job continues to be rejected by ResourceQuota until resources are free
  - Kueue can not admit jobs based on ResourceQuota

Kueue in CyberAgent

Migrate K8s's ResourceQuota to Kueue's ClusterQueue

- Ide
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  -
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  - It distribute[illegible] to namespaces (tenants) to reserve quota
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Approaches to bridge the gap:

1. WaitForPodsReady with Configurable RequeuingStrategy
2. AdmissionCheck for ResourceQuota

Kueue in CyberAgent

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Approaches to bridge the gap:

1. WaitForPodsReady with Configurable RequeuingStrategy
2. ***AdmissionCheck for ResourceQuota (※1)***

※1 Currently, it is evaluating in NON-production environment

Kueue in CyberAgent

Migrate K8s's ResourceQuota to Kueue's ClusterQueue

- WaitForPodsReady with Configurable RequeuingStrategy
  - Pros:
    - Ready to use by a Kueue's configuration setting
  - Cons:
    - Increased API-server load due to repeated try to create Pods and re-queueing jobs

Kueue in CyberAgent

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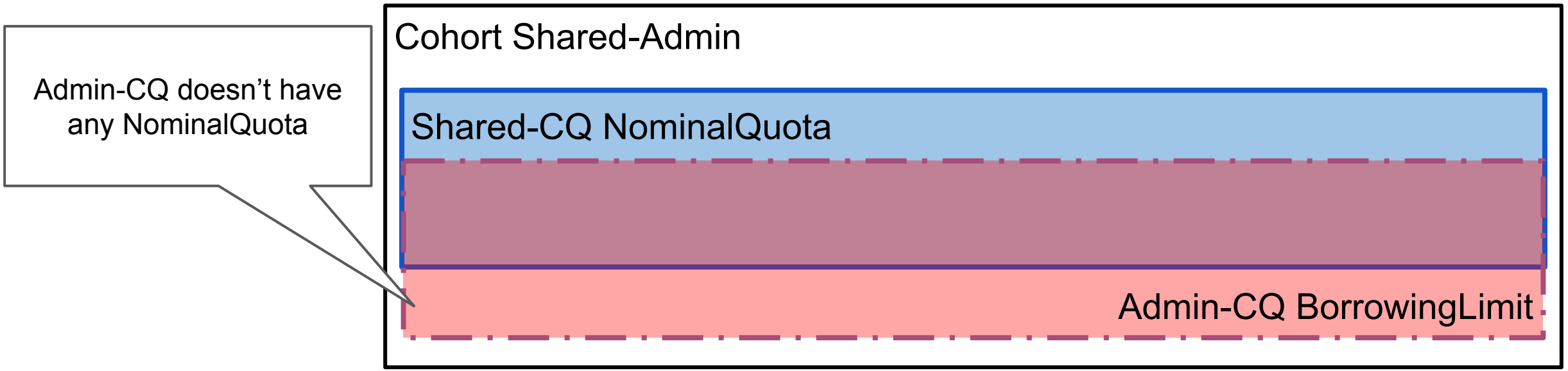
  - Pros:
    - Ready to use by a Kueue's configuration setting
  - Cons:
    - Increased API-server load due to repeated try to create Pods and re-queueing jobs
- AdmissionCheck for ResourceQuota
  - Pros:
    - It could avoid higher kube-api server load
  - Cons:
    - It needs to implement small custom controller

Kueue in CyberAgent

Overlapping Quota Model between User and Admin

- Conflicting Demands against GPUs
  - All GPUs always SHOULD be allocated to user's workloads
  - Cluster Admins WANT to verify platform features using GPUs
- Admins can submit Jobs only when there are some free quota in Shared-CQ

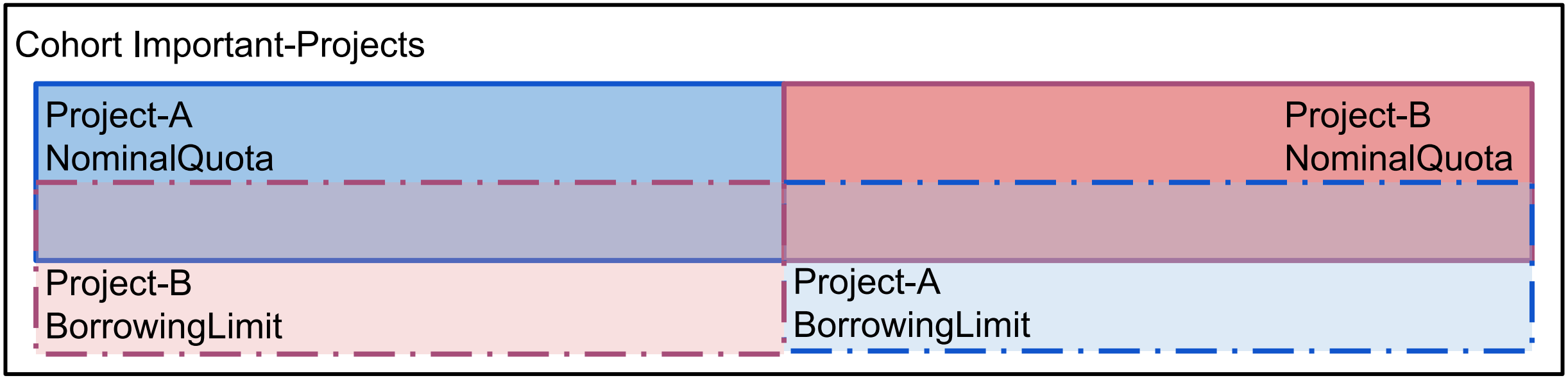


Kueue in CyberAgent

Elastically Reserved Quota Model between the same priority important projects

- Conflicting Demands against GPUs
  - Important projects WANT to reserve GPUs so that they can use GPUs when they want to use it
  - Any GPUs SHOULD NOT be left over for efficient usage
- Any Jobs borrowed by other ClusterQueues always be preempted

```
preemption:
    reclaimWithinCohort: Any
```



New features

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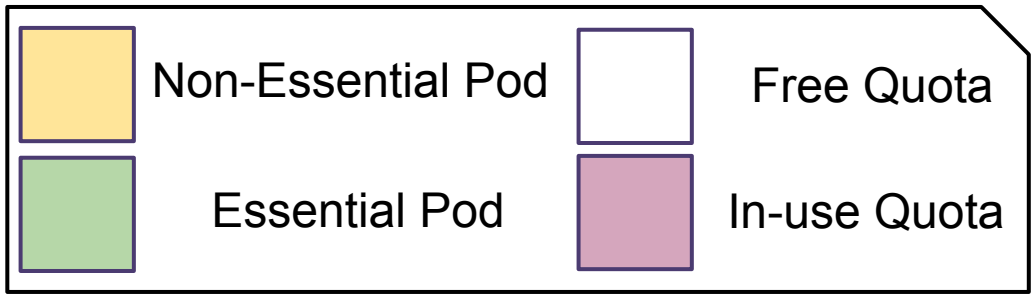
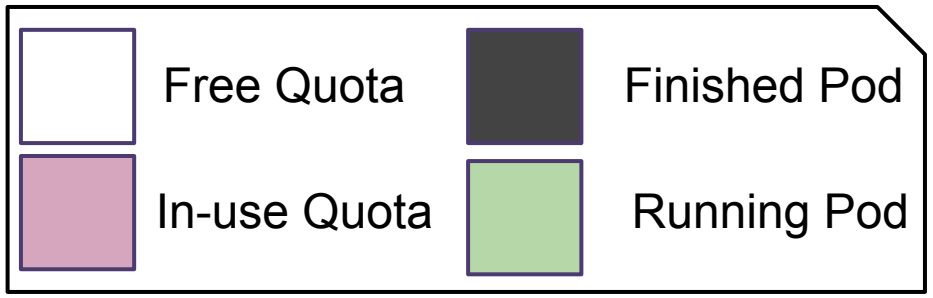
LendingLimit

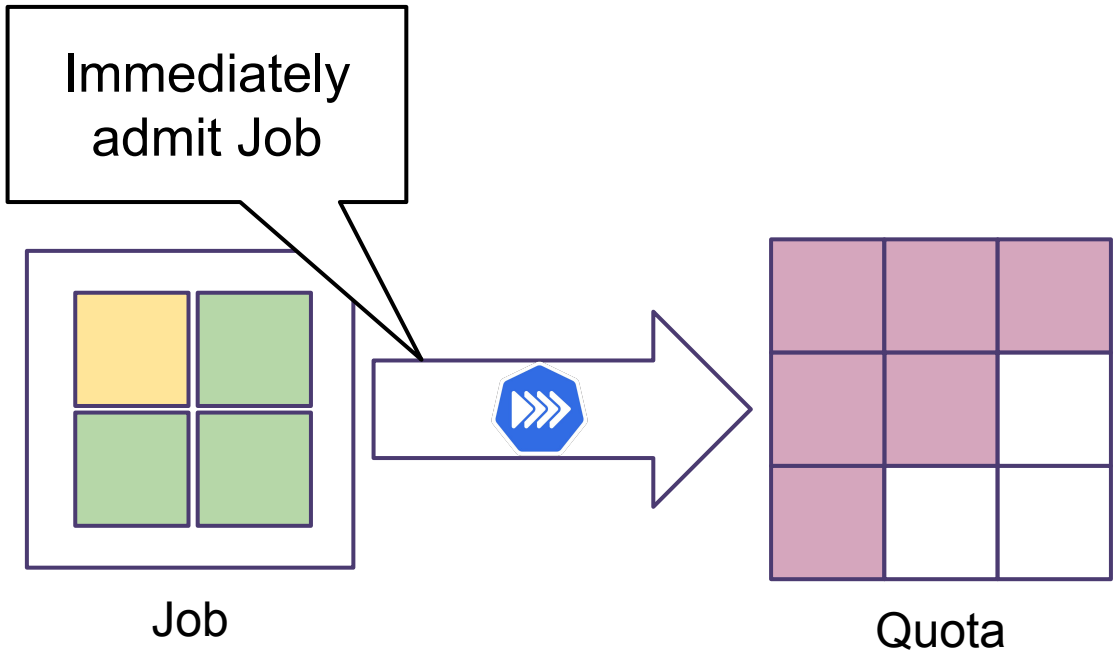
- **LendingLimit** indicates *how much resources can this ClusterQueue lend to other ClusterQueues within the same Cohort.*

- Use cases
  - Control the size of the guaranteed quota for a ClusterQueue in a Cohort
  - Reserve quota for latency sensitive workloads such as ML Model Serving
    - In the future, it is possible to integrate with Kserve (formerly KFServing)

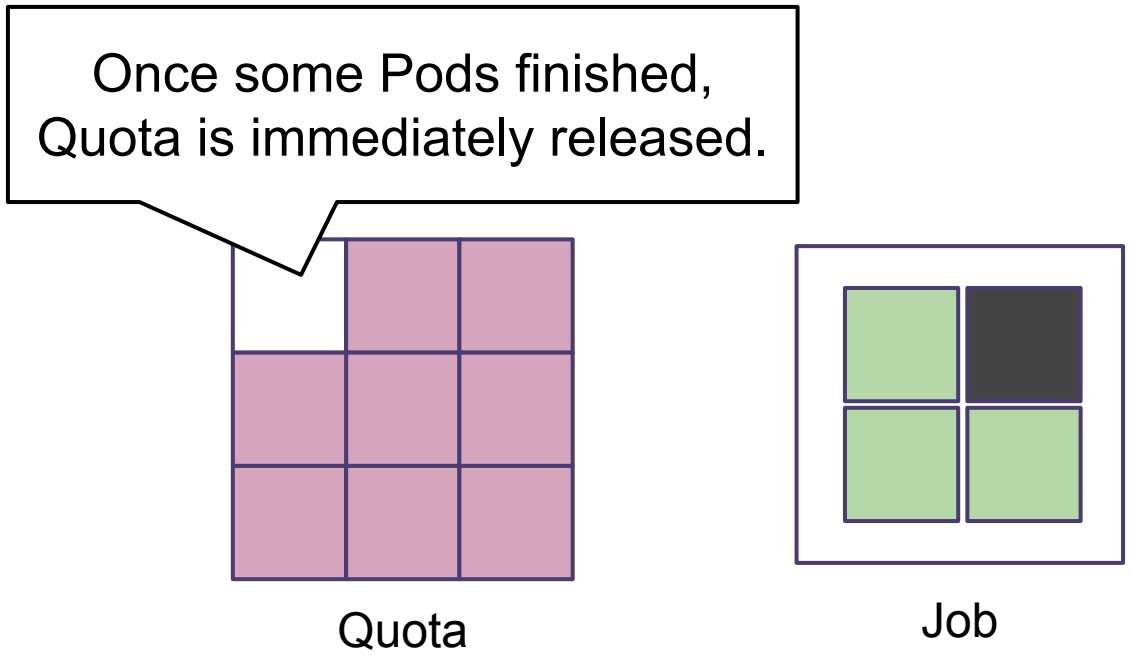
Dynamically Admission and Reclaiming







Partial Admission



Dynamically Reclaiming Resources

Provisioning Request integration

Motivation:

- All-or-nothing semantics
  - Currently Cluster-Autoscaler does not create new nodes until pods are created
  - Scale ups for large jobs may fail due to GPU stockouts and having 99% of nodes is not enough

Provisioning Request integration

Motivation:

- All-or-nothing semantics
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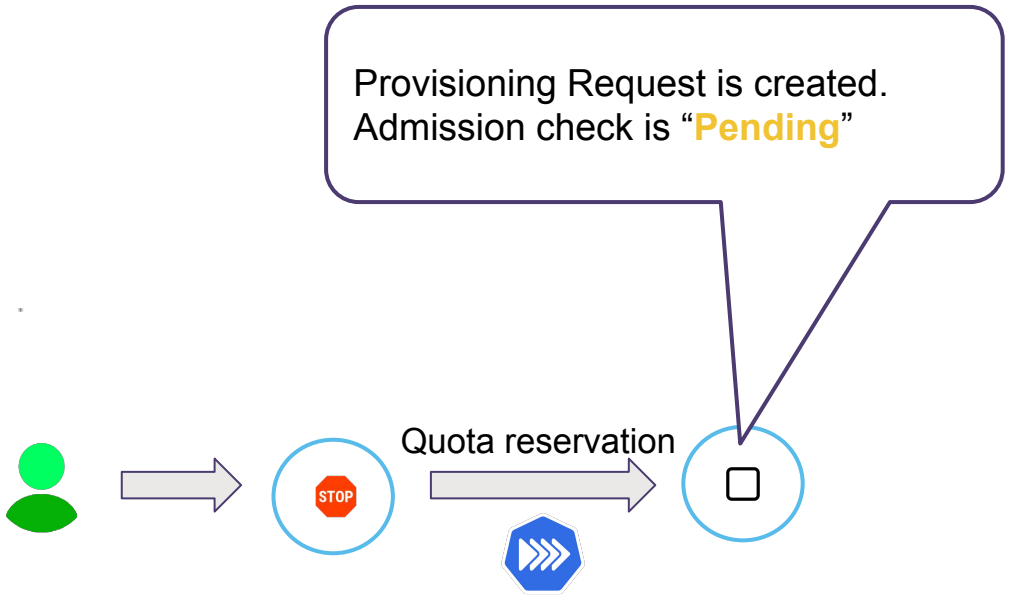
ProvisioningRequest Spec:

- PodSets - represent group of pods needing nodes
- ProvisioningClassName - describes the mode of provisioning
- Parameters - Parameters contains all other parameters classes may require

Provisioning Request integration



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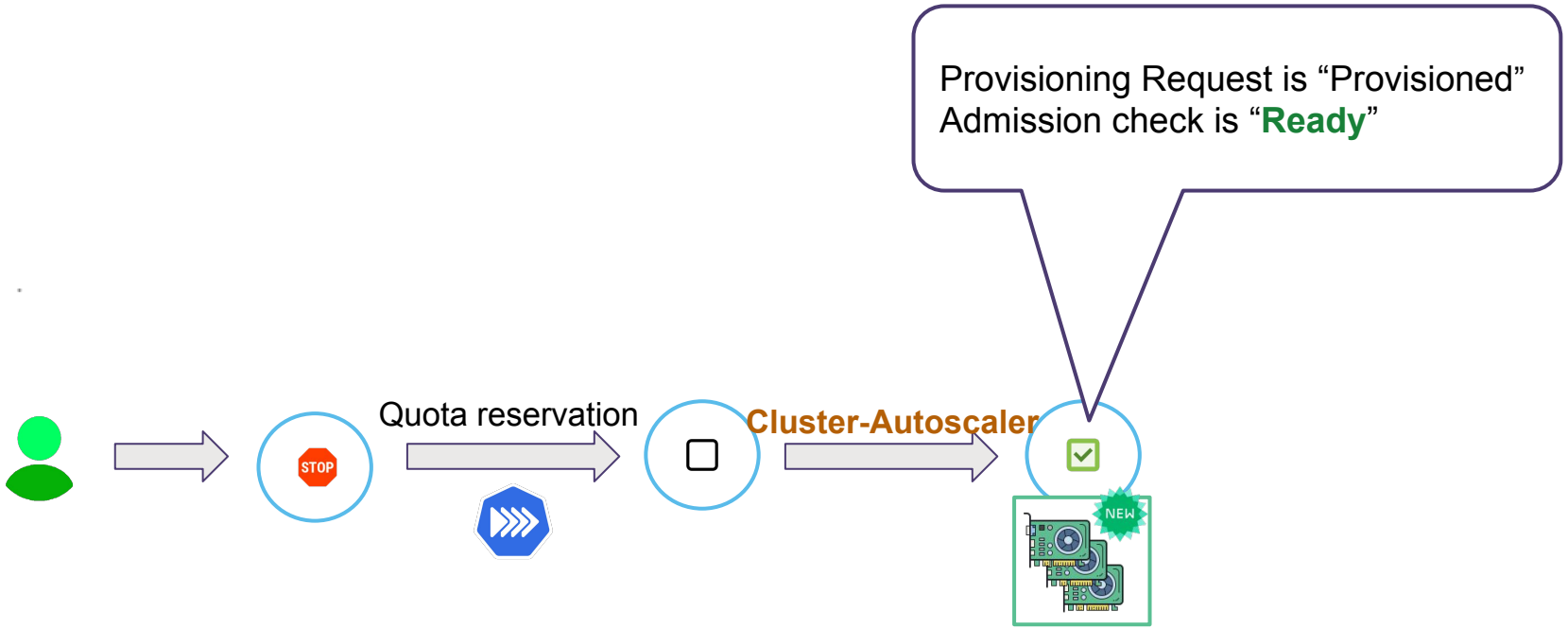

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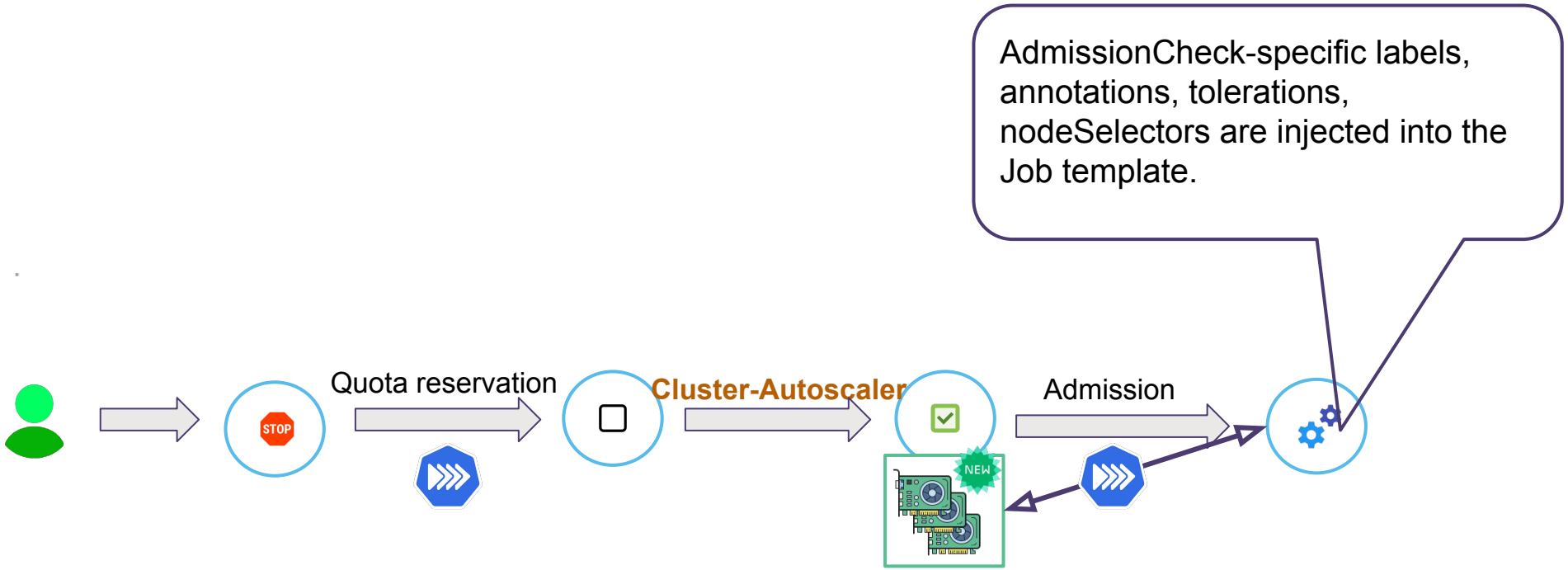
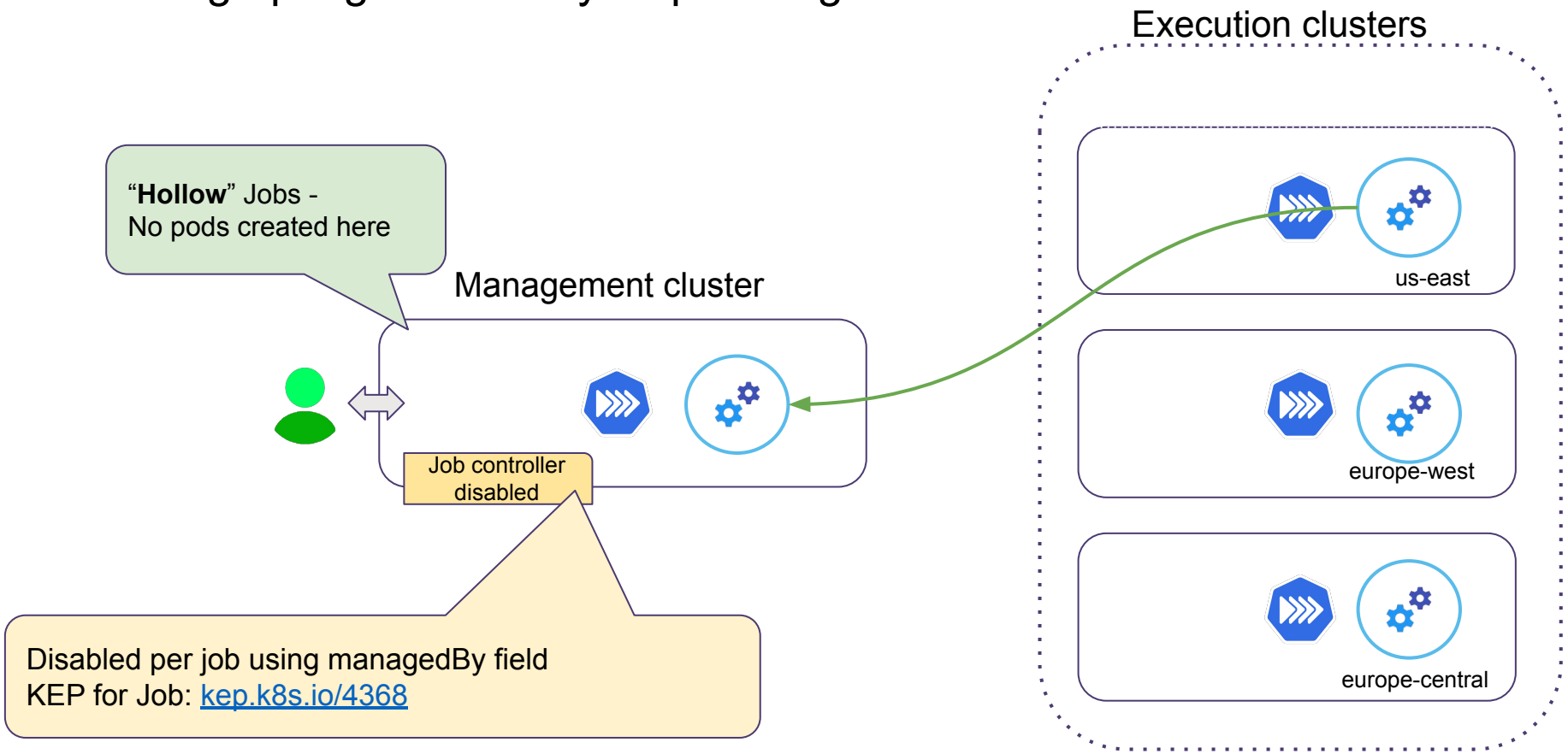


Multi-cluster Job dispatching

A.k.a.: **MultiKueue**

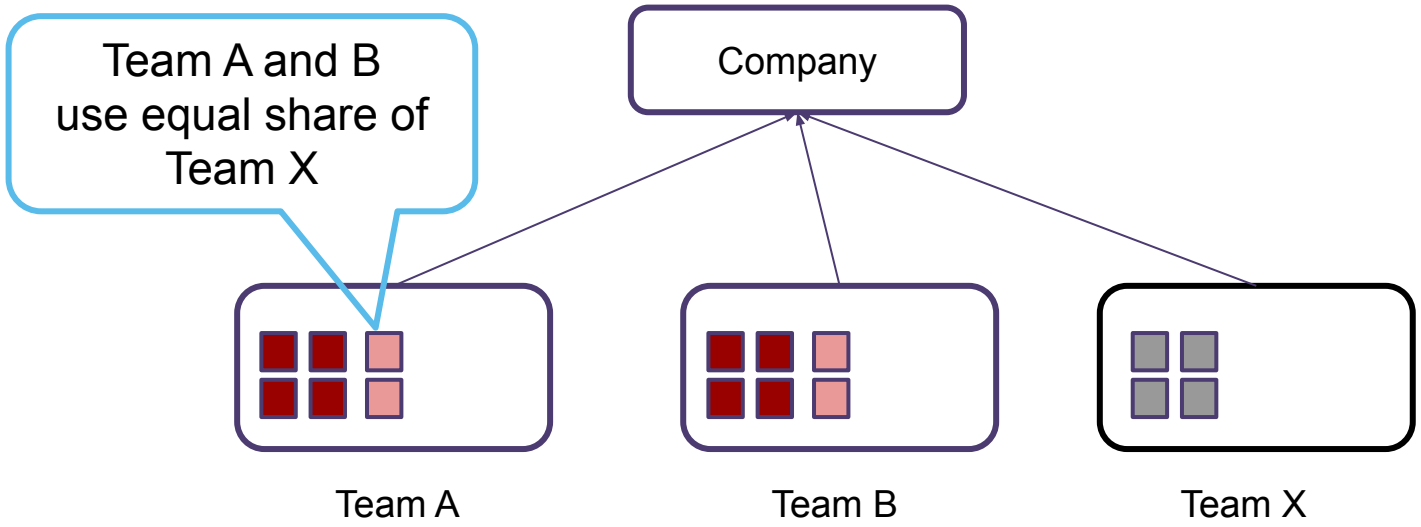
Motivation:

- Obtainability of GPUs across regions (or cloud providers)
- Scaling up big clusters by dispatching execution



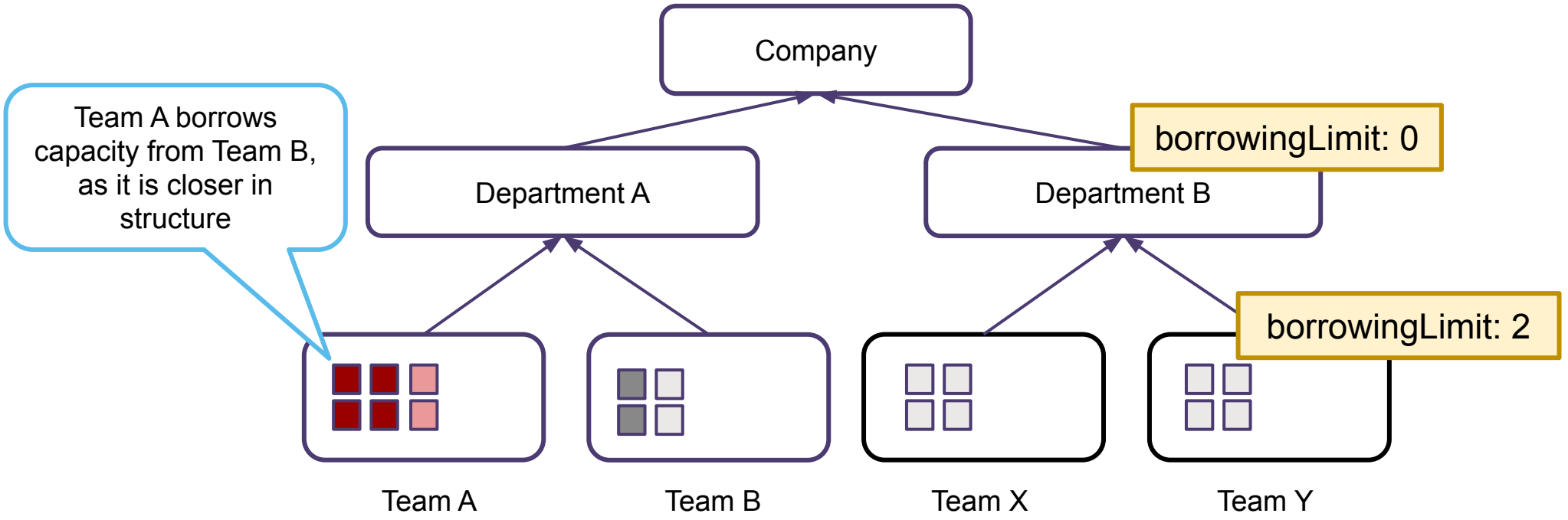
Fair sharing

- Gives fair access to unused resources to different teams
  - Without Fair sharing FIFO-scheme is used
- Resolve quota imbalances within structure by preemption



Hierarchical cohorts

- More levels of hierarchy to reflect the structure for large organizations
- Allows to specify `borrowingLimit` and `lendingLimit` at different levels
- Borrowing closely in the structure is prioritized



Try it yourself

Try yourself: https://kueue.sigs.k8s.io/ !

Getting involved

How to find us?

- slack.k8s.io #wg-batch
- 2 Biweekly meetings:
  - Thursdays 3pm CET
  - Thursdays 3pm PT
- git.k8s.io/community/wg-batch

WG-Batch Updates: What's New and What Is Next? - Yuki Iwai & Michał Woźniak

Questions

Michał Woźniak
- Email: michalwozniak@google.com
- GitHub: mimowo
- Slack: mimowo

Yuki Iwai
- Email: yuki.iwai.tz@gmail.com
- GitHub: tenzen-y
- Slack: tenzen-y

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