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Multitenancy and Fairness at Scale with Kueue: A Case Study

Aldo Culquicondor, Google
Rajat Phull, Apple

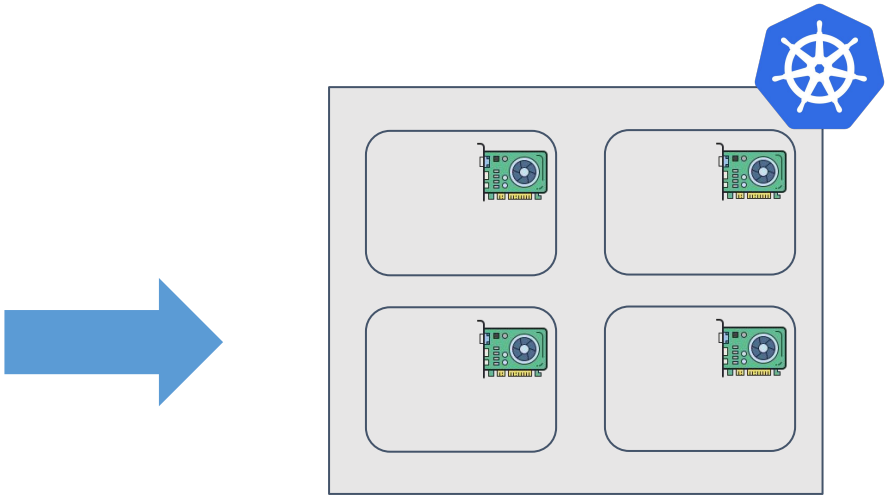
What is Kueue?

- Kueue interacts with kube-scheduler and cluster-autoscaler to provide a full batch /training system in Kubernetes.
- Kueue determines whether workloads should wait for resources or run, based on:
  - Per-tenant quotas
  - Borrowing and lending limits
  - Fair sharing rules New in v0.7
  - The hierarchy of the organization New in v0.9
- Kueue integrates with Pods, Job, JobSet, Kubeflow, KubeRay and has extension mechanisms.

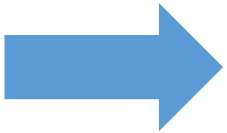
+

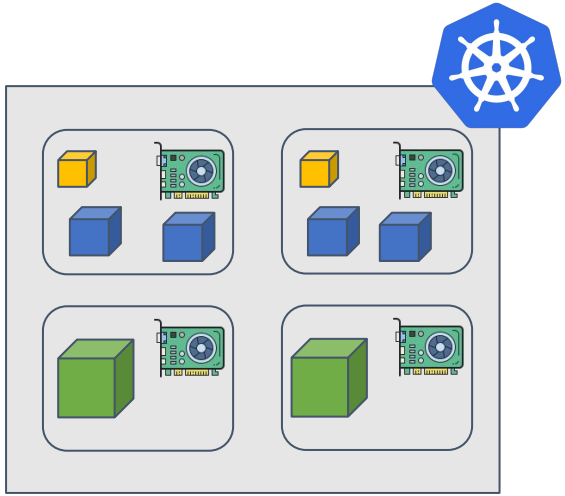
In the beginning…

Bob
AI researcher



In the beginning…





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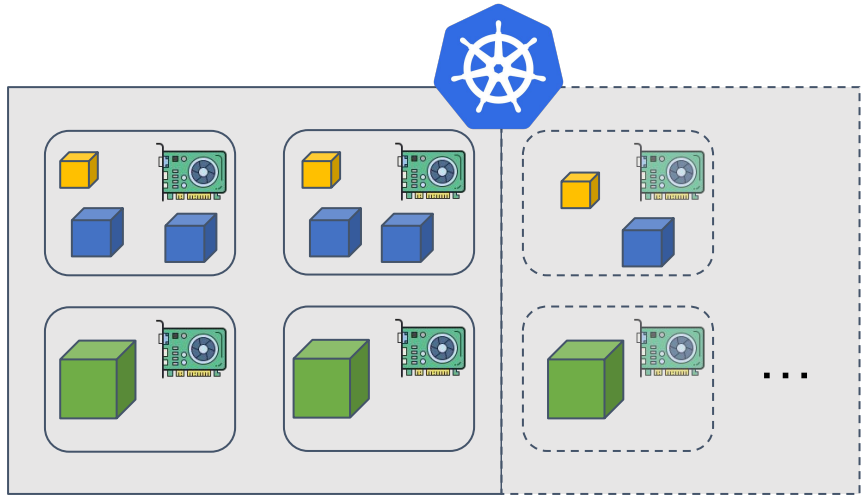
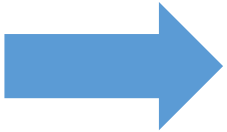
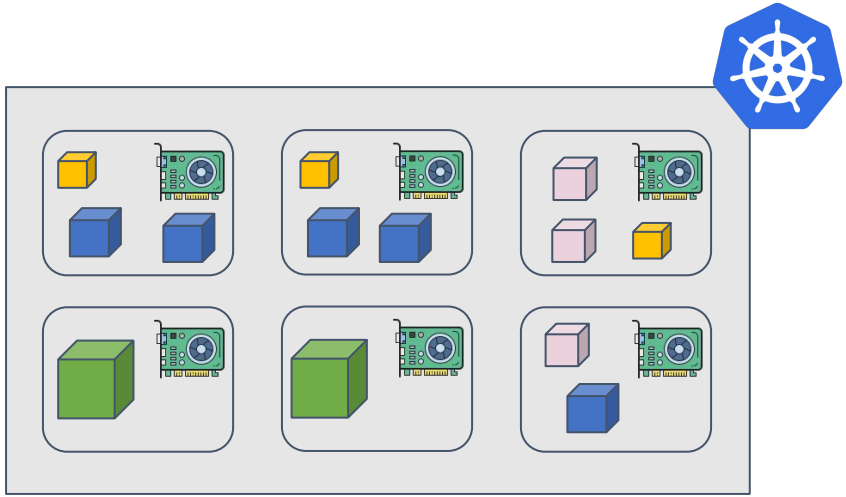


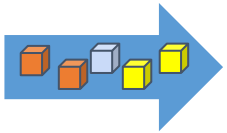
Autoscaled
nodes

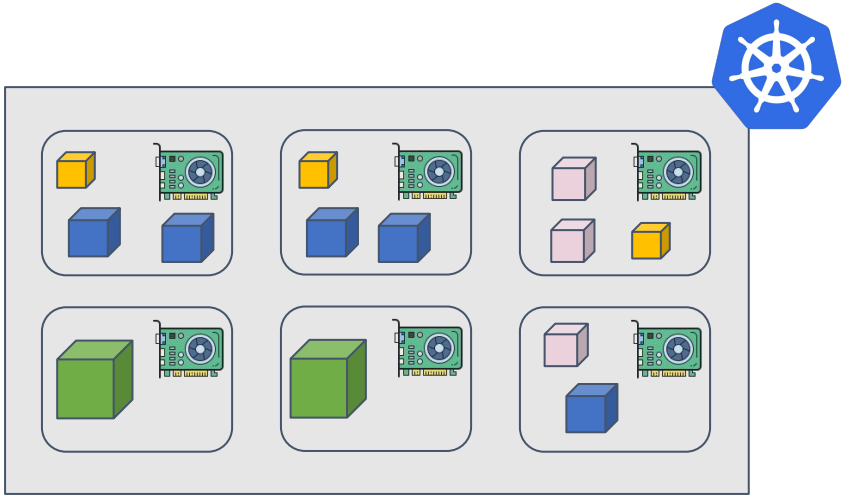
But clusters aren’t infinite



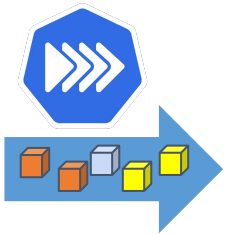


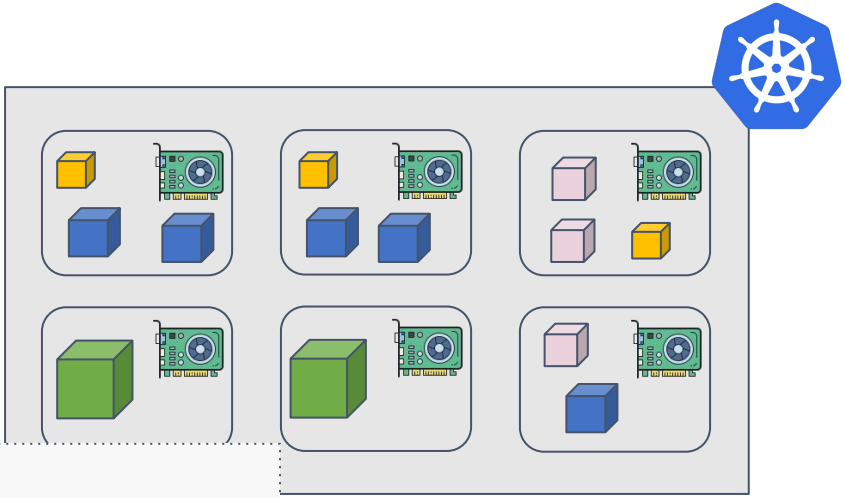
But clusters aren’t infinite





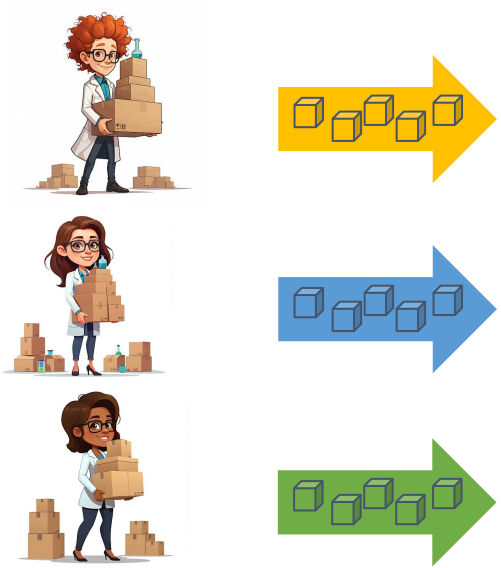
But clusters aren’t infinite

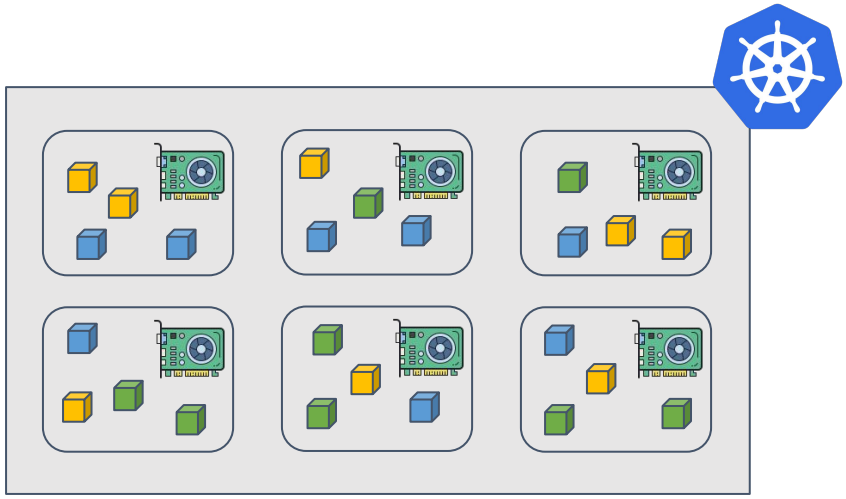




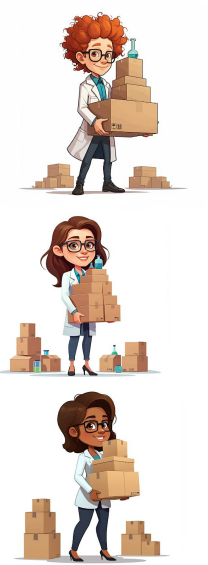
```yaml
kind: ClusterQueue
metadata:
  name: "bob-queue"
spec:
  resourceGroups:
  - coveredResources: ["cpu", "memory", "acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "cpu"
        nominalQuota: 24
      - name: "memory"
        nominalQuota: 48Gi
      - name: "acme.com/gpu"
        nominalQuota: 24
```

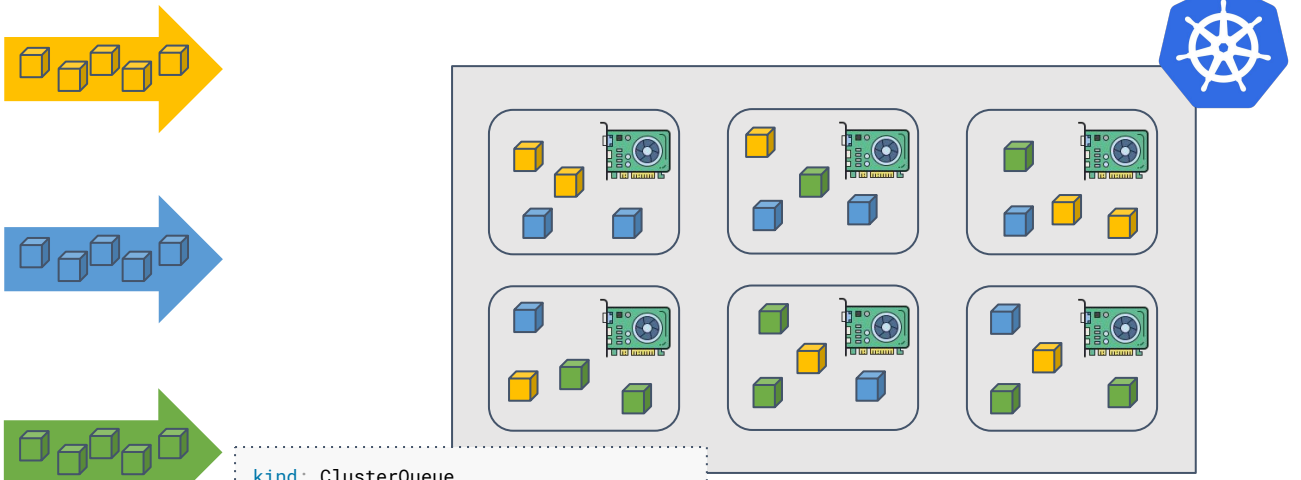
Clusters are often shared





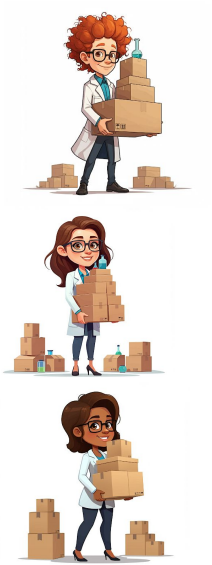
Clusters are often shared

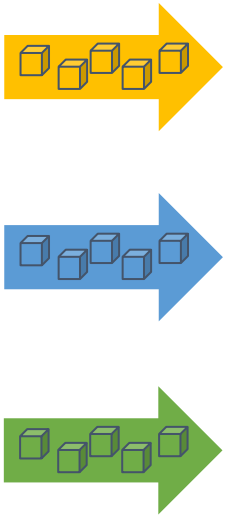


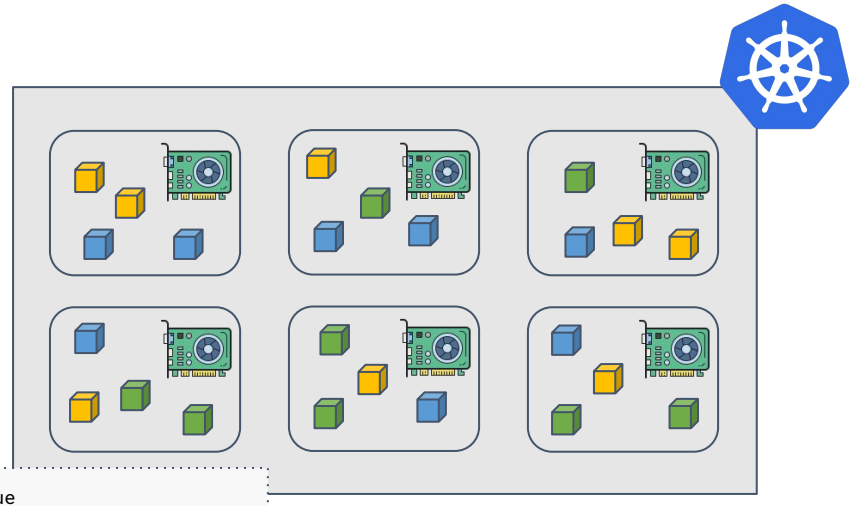


```yaml
kind: ClusterQueue
metadata:
  name: "bob-queue"
spec:
  cohort: "lab"
  resourceGroups:
  - coveredResources: ["acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "acme.com/gpu"
        nominalQuota: 8
  preemption:
    reclaimWithinCohort: "Any"
  fairSharing:
    weight: 1
```

Clusters are often shared

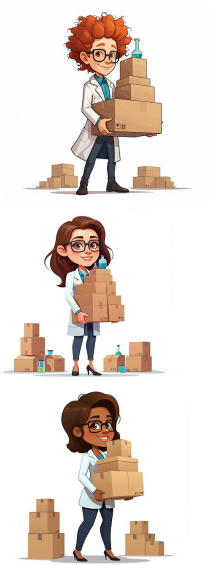


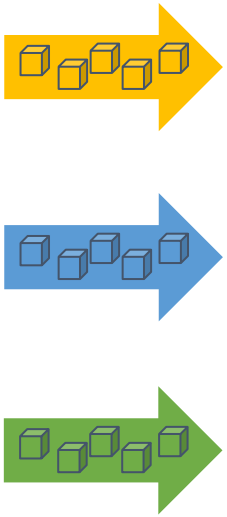


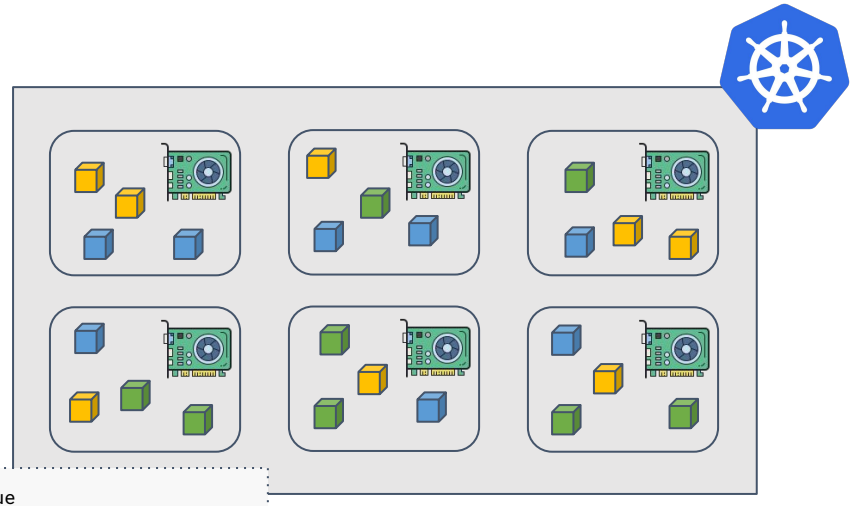


```yaml
kind: ClusterQueue
metadata:
  name: "bob-queue"
spec:
  cohort: "lab"
  resourceGroups:
  - coveredResources: ["acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "acme.com/gpu"
        nominalQuota: 8
  preemption:
    reclaimWithinCohort: "Any"
  fairSharing:
    weight: 1
```

Clusters are often shared







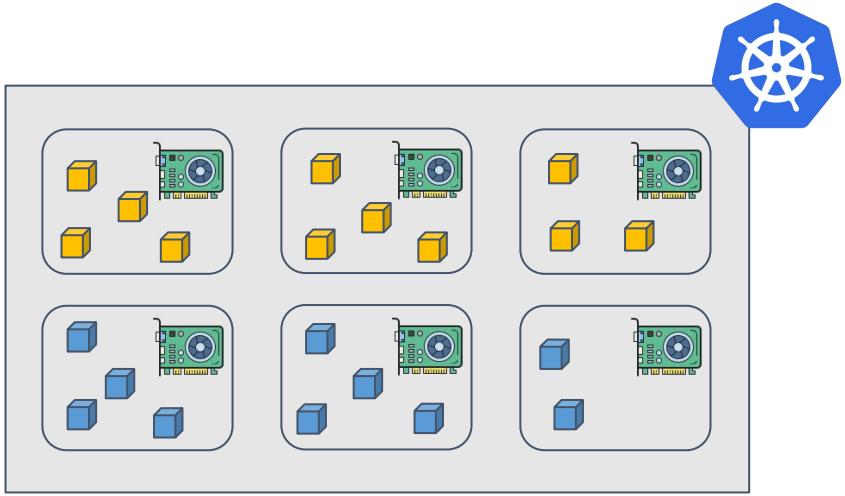
```yaml
kind: ClusterQueue
metadata:
  name: "bob-queue"
spec:
  cohort: "lab"
  resourceGroups:
  - coveredResources: ["acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "acme.com/gpu"
        nominalQuota: 8
  preemption:
    reclaimWithinCohort: "Any"
  fairSharing:
    weight: 1
```

```yaml
kind: ClusterQueue
metadata:
  name: "alice-queue"
spec:
  cohort: "lab"
  resourceGroups:
  - coveredResources: ["acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "acme.com/gpu"
        nominalQuota: 8
  preemption:
    reclaimWithinCohort: "Any"
  fairSharing:
    weight: 2
```

Fair Sharing

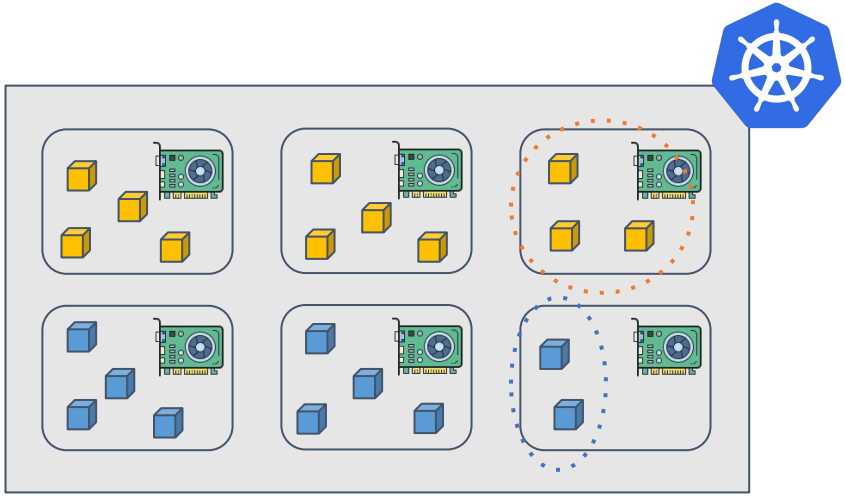
Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	
8	
8	



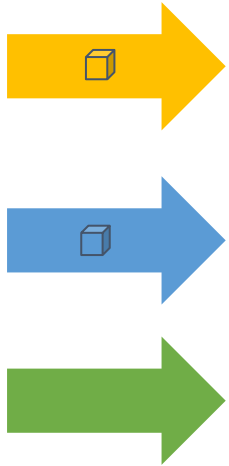
Fair Sharing: Who gets to schedule?

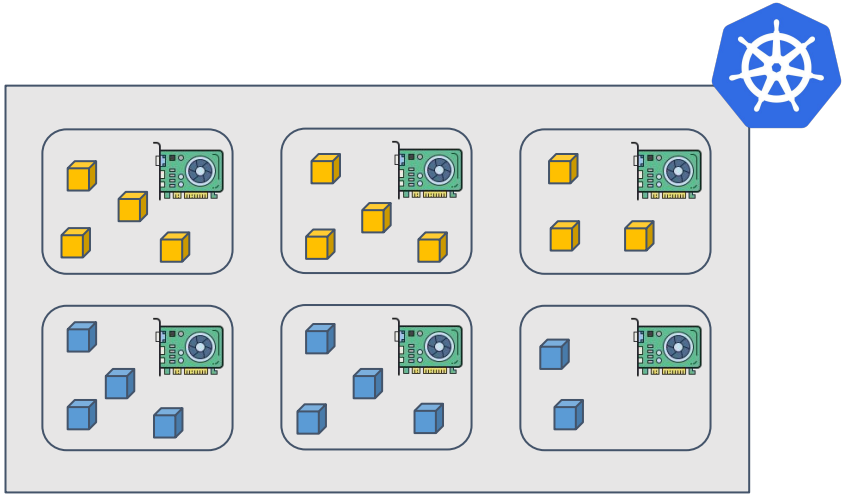
Nominal Quotas	Borrowing
8	3
8	2
8	0



Fair Sharing: Who gets to schedule?

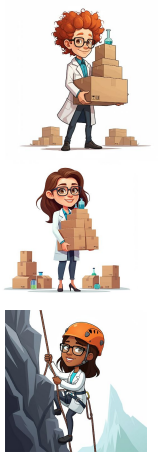
Nominal Quotas	Borrowing
8	3
8	2
8	0

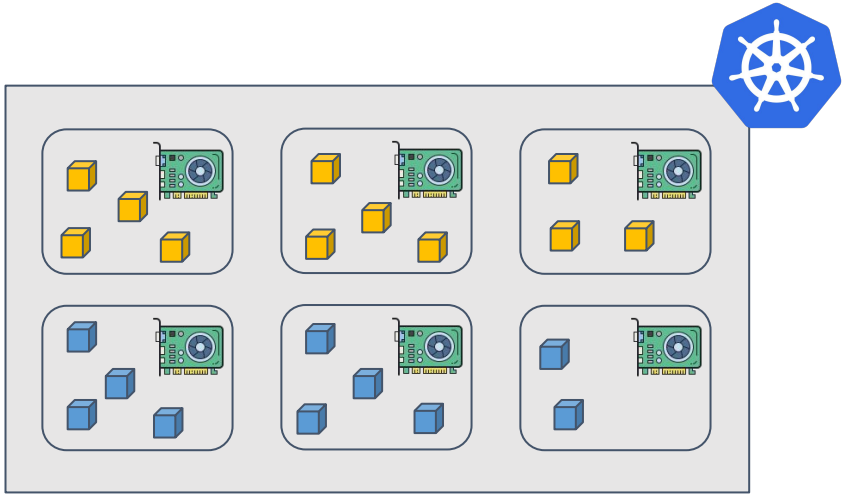




Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	3
8	2
8	0

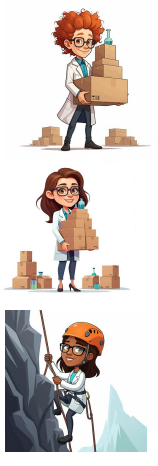


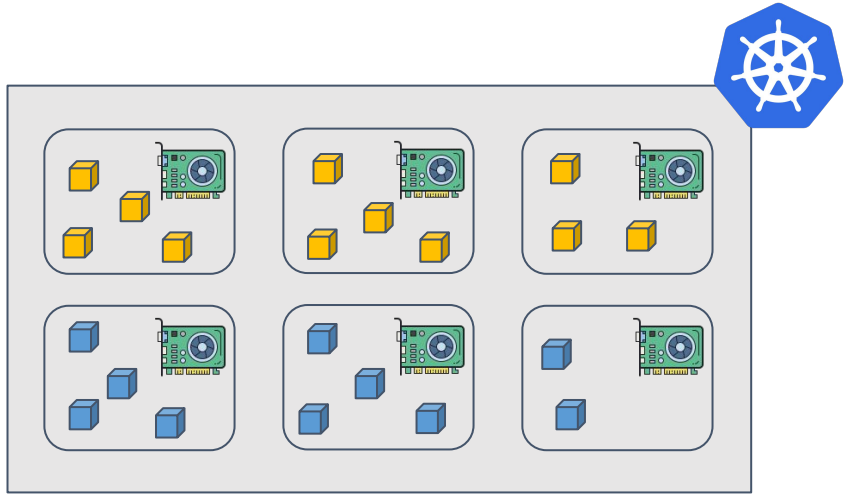


$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	3
8	2
8	0





$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Schedule the ClusterQueue with the **lowest** share value first

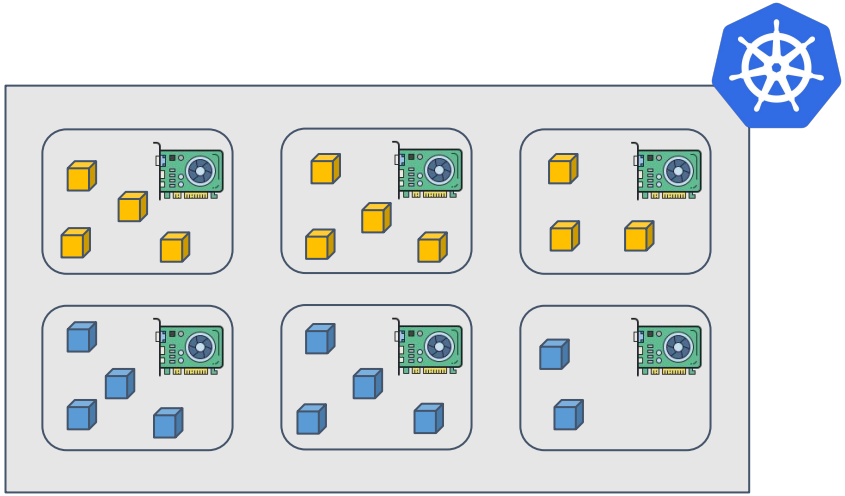
Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	3
8	2
8	0

3/24

2/24

0/24



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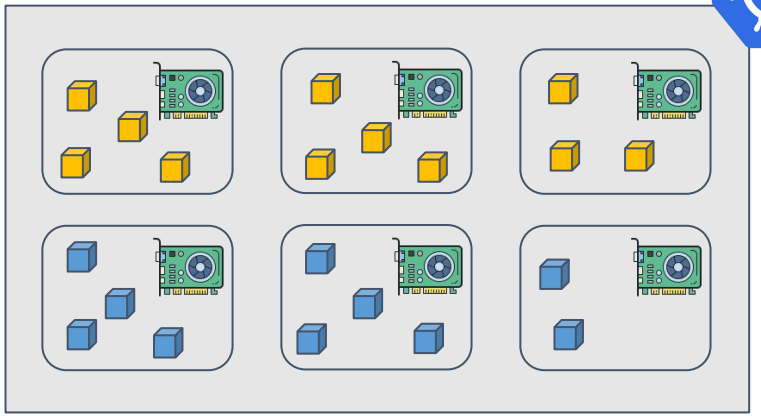
Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	3
8	2
8	0

3/24

2/24

0/24



$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Schedule the ClusterQueue with the **lowest** share value first

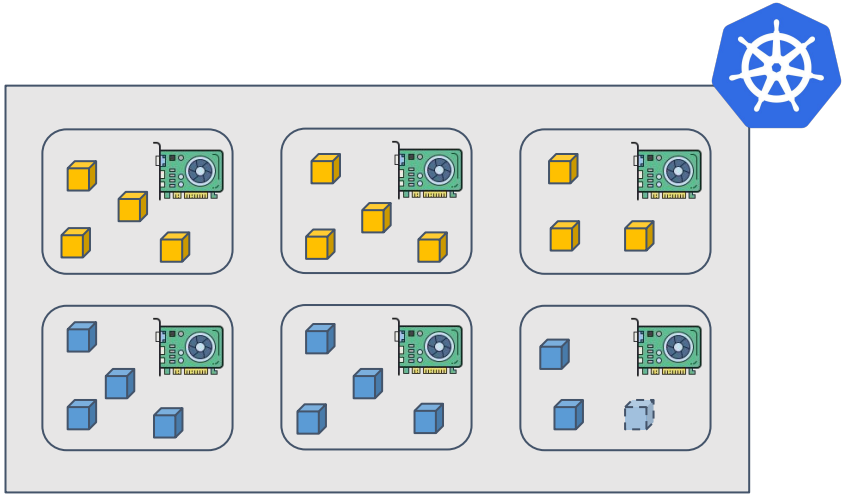
Fair Sharing: Who gets to schedule?

Nominal Quotas	Borrowing
8	3
8	2
8	0

3/24

2/24

0/24

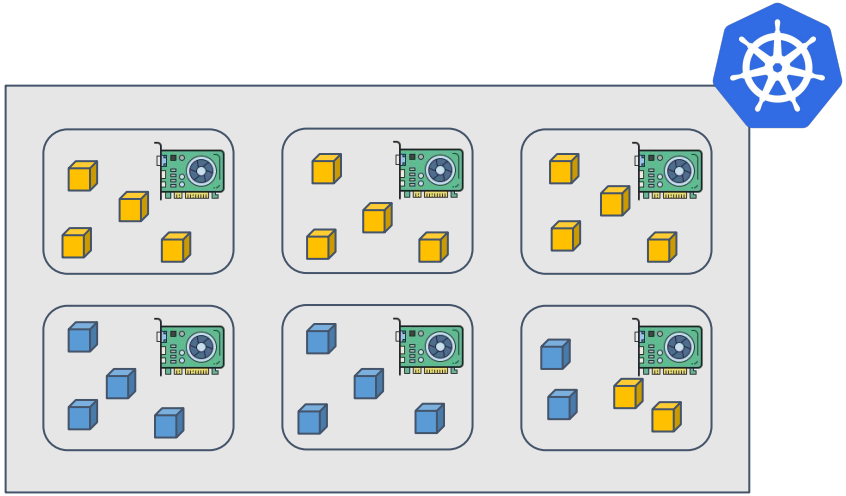


$$\text{ShareValue} = \frac{\text{UsageAboveQuota}}{\text{sum(Quotas)} * \text{Weight}}$$

Schedule the ClusterQueue with the **lowest** share value first

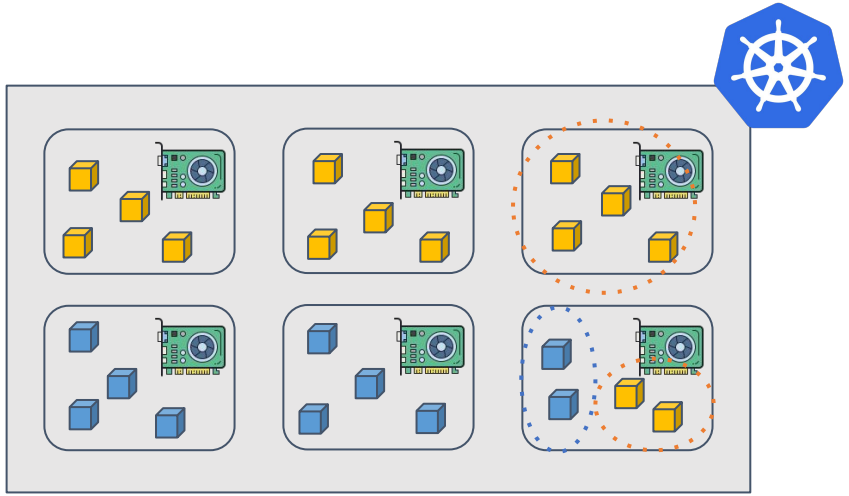
Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	
8	
8	



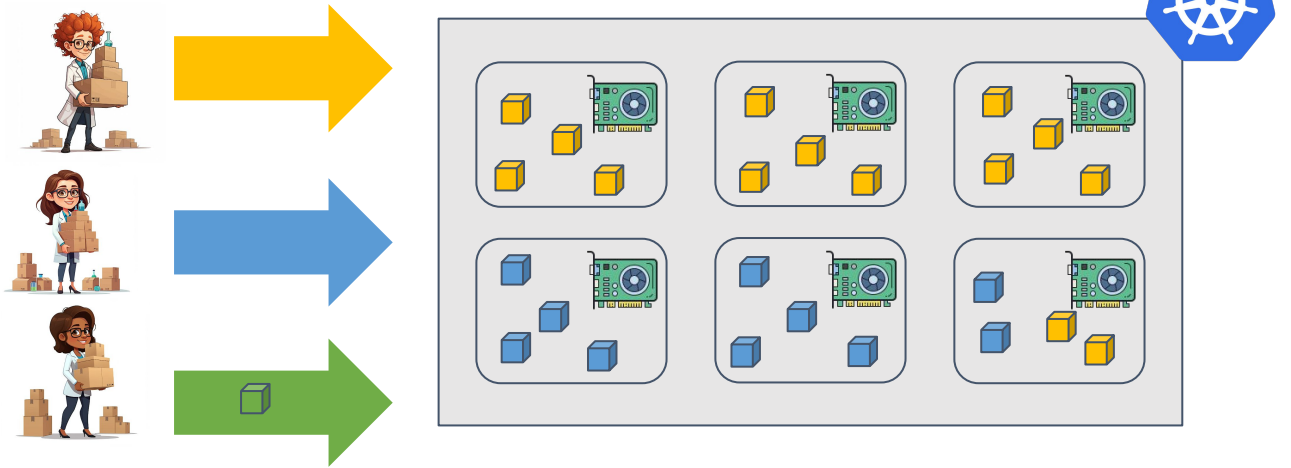
Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0



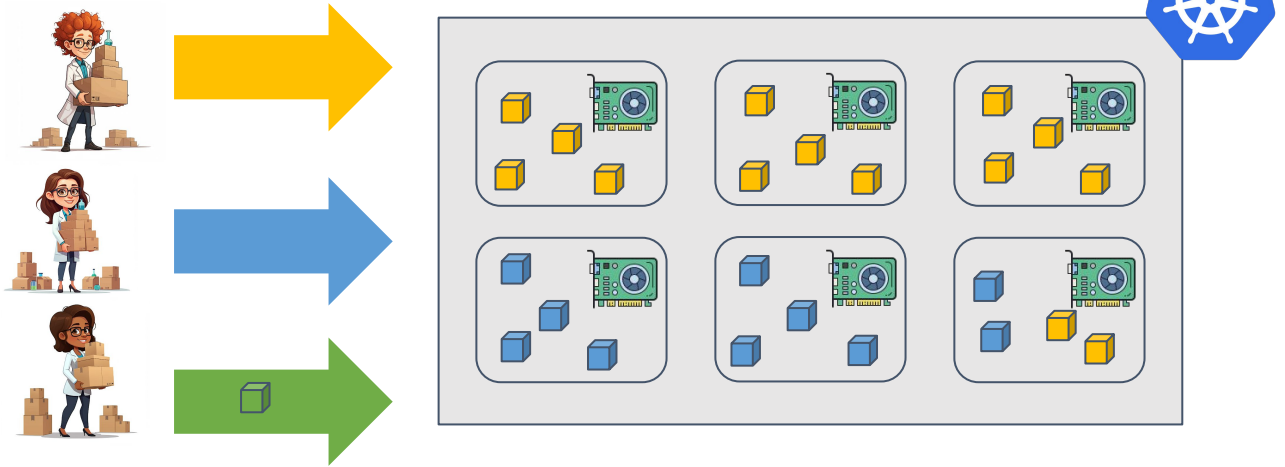
Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0



Fair Sharing: Who gets preempted?

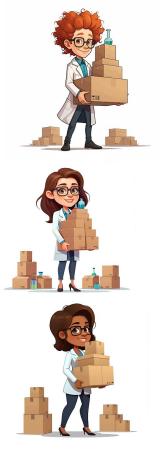
Nominal Quotas	Borrowing
8	6
8	2
8	0

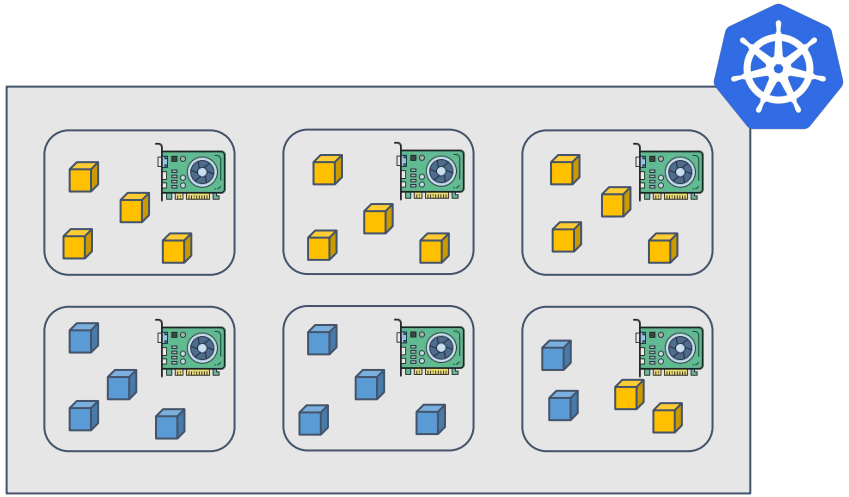


$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0





$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Preempt the ClusterQueue with the **highest** share value first

Fair Sharing: Who gets preempted?

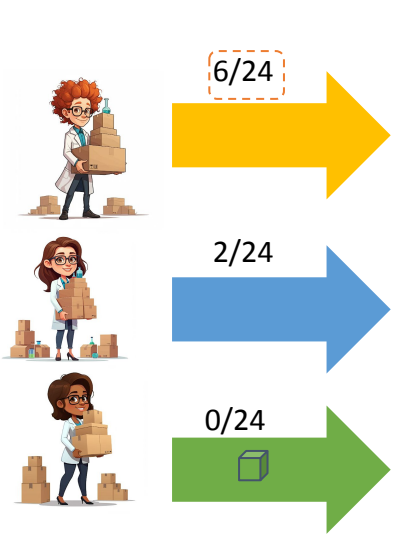
Nominal Quotas	Borrowing
8	6
8	2
8	0

$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Preempt the ClusterQueue with the **highest** share value first

Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0

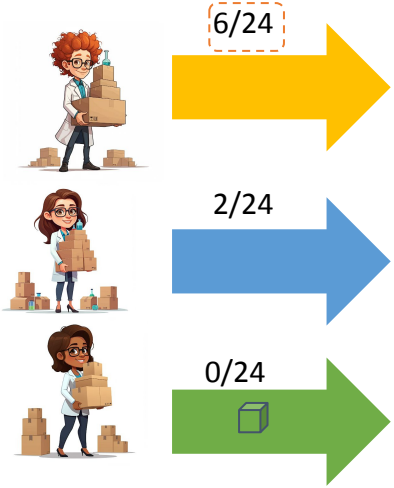


$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Preempt the ClusterQueue with the **highest** share value first

Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0

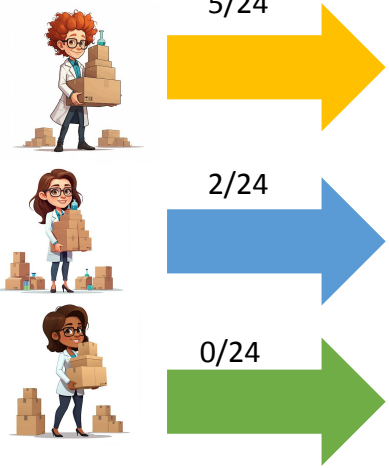


$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Preempt the ClusterQueue with the **highest** share value first

Fair Sharing: Who gets preempted?

Nominal Quotas	Borrowing
8	6
8	2
8	0



$$\text{ShareValue} = \frac{\text{Borrowing}}{\text{sum(Quotas)} * \text{Weight}}$$

Preempt the ClusterQueue with the **highest** share value first

Hierarchical Cohorts

Clusters can be used by large organizations

Data Wizards

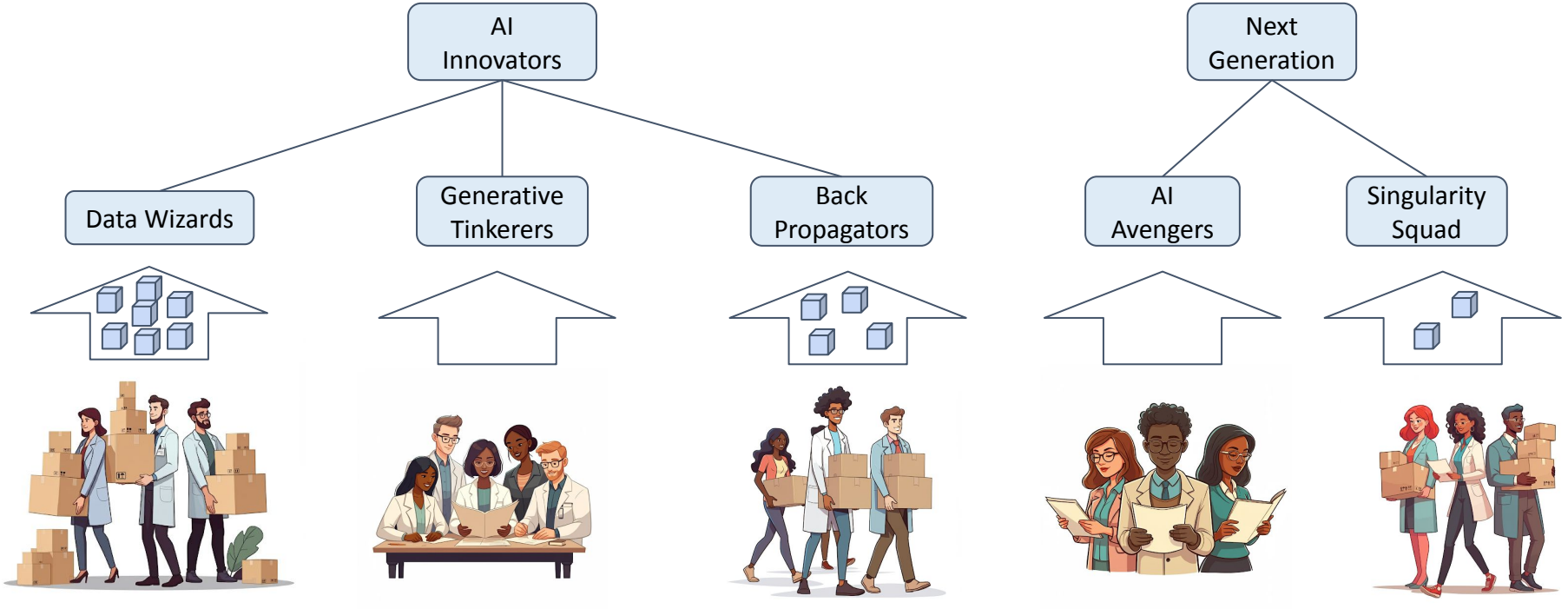
Generative Tinkerers

Back Propagators

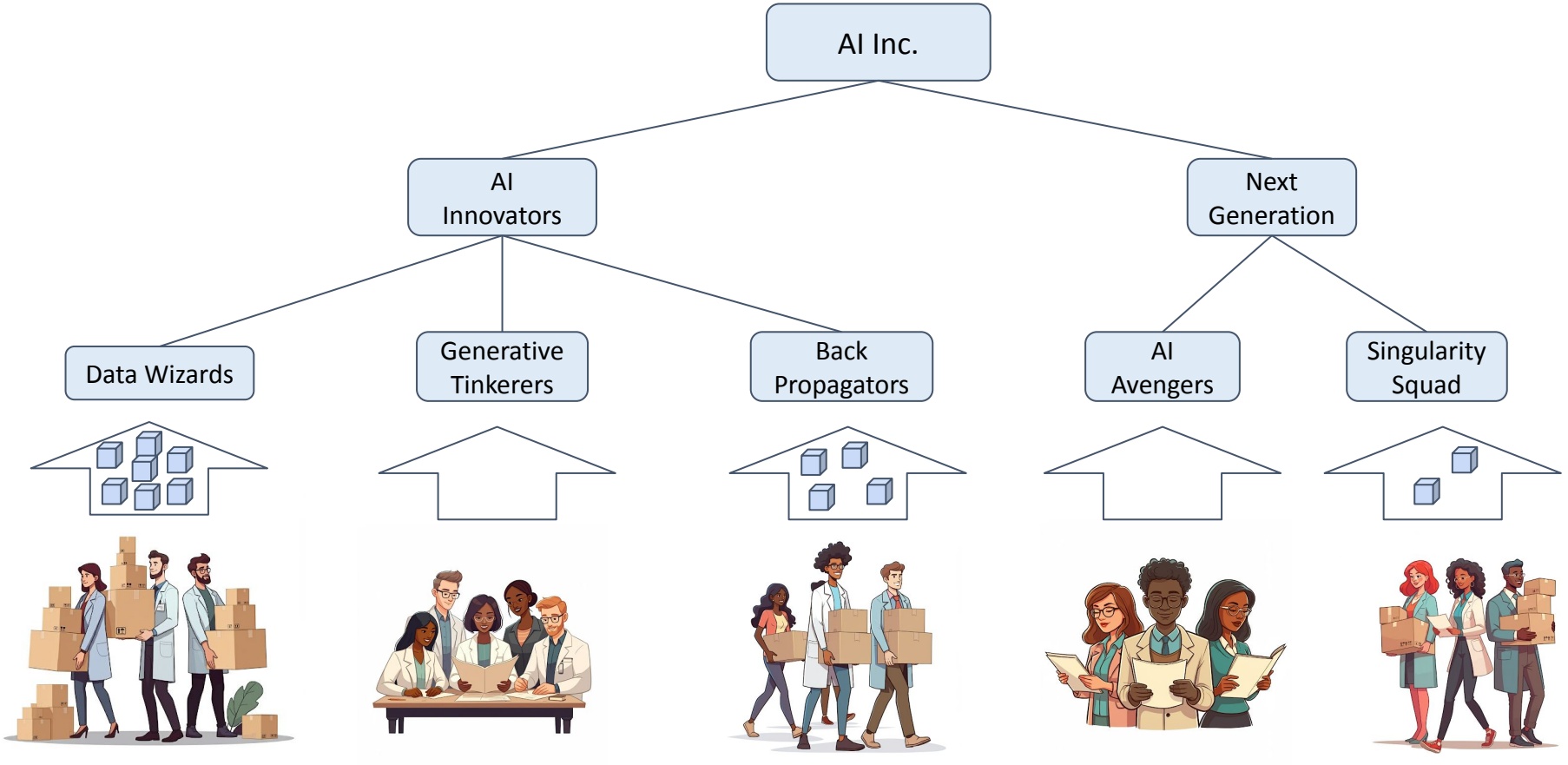
AI Avengers

Singularity Squad

Clusters can be used by large organizations

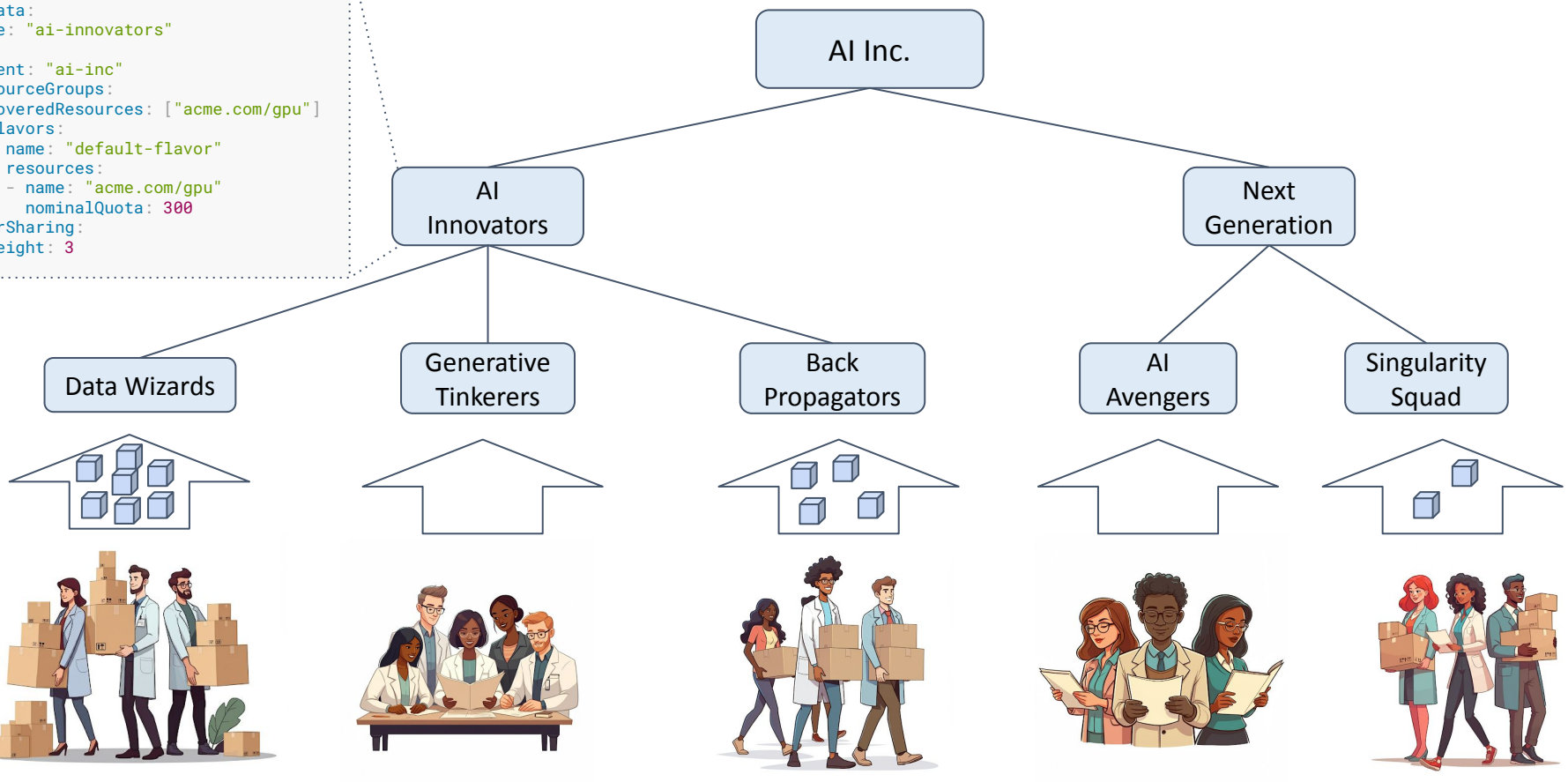


Clusters can be used by large organizations



Clusters can be used by large organizations


```yaml
kind: Cohort
metadata:
  name: "ai-innovators"
spec:
  parent: "ai-inc"
  resourceGroups:
  - coveredResources: ["acme.com/gpu"]
    flavors:
    - name: "default-flavor"
      resources:
      - name: "acme.com/gpu"
        nominalQuota: 300
  fairSharing:
    weight: 3
```



Clusters can be used by large organizations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        nominalQuota: 300
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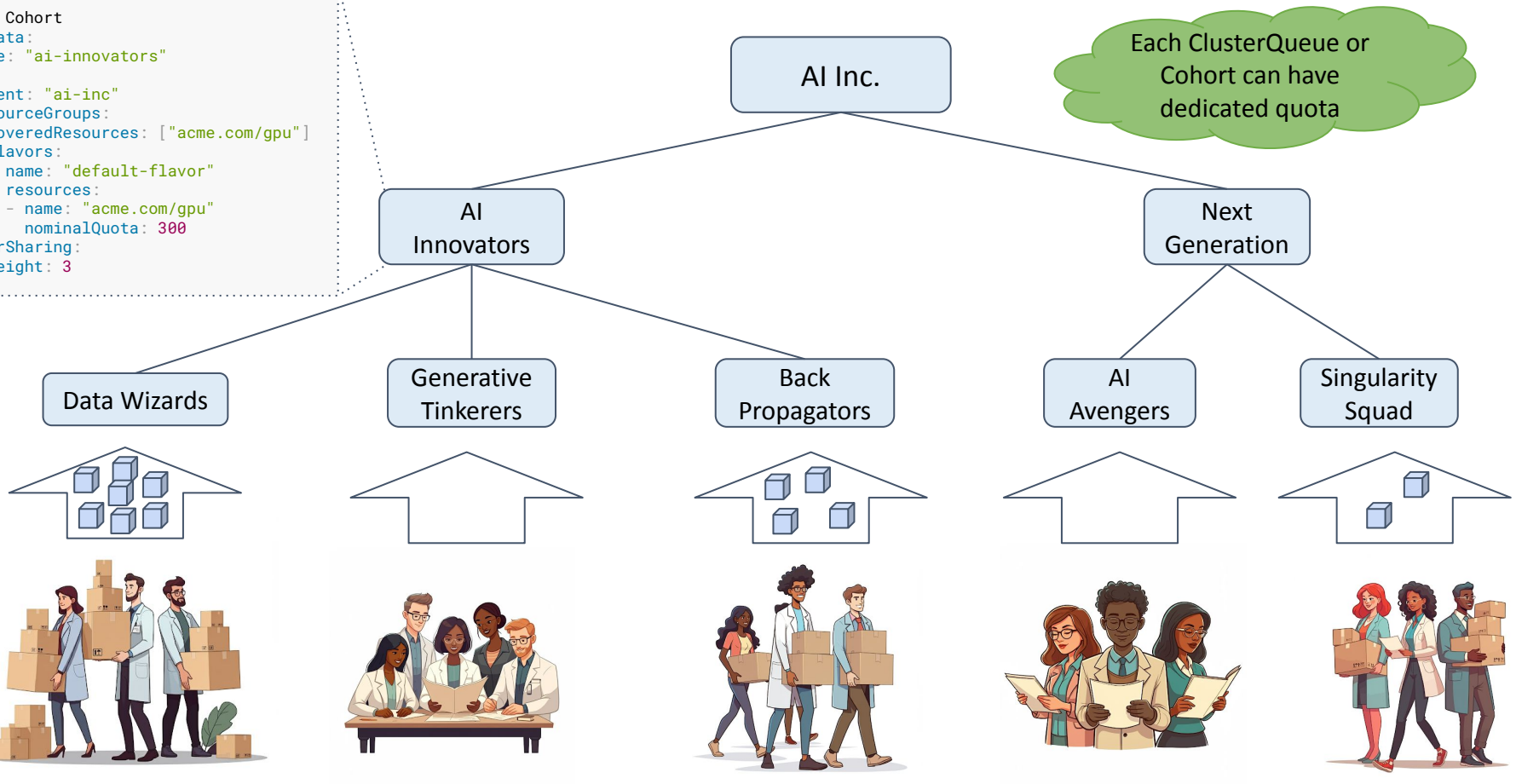
```



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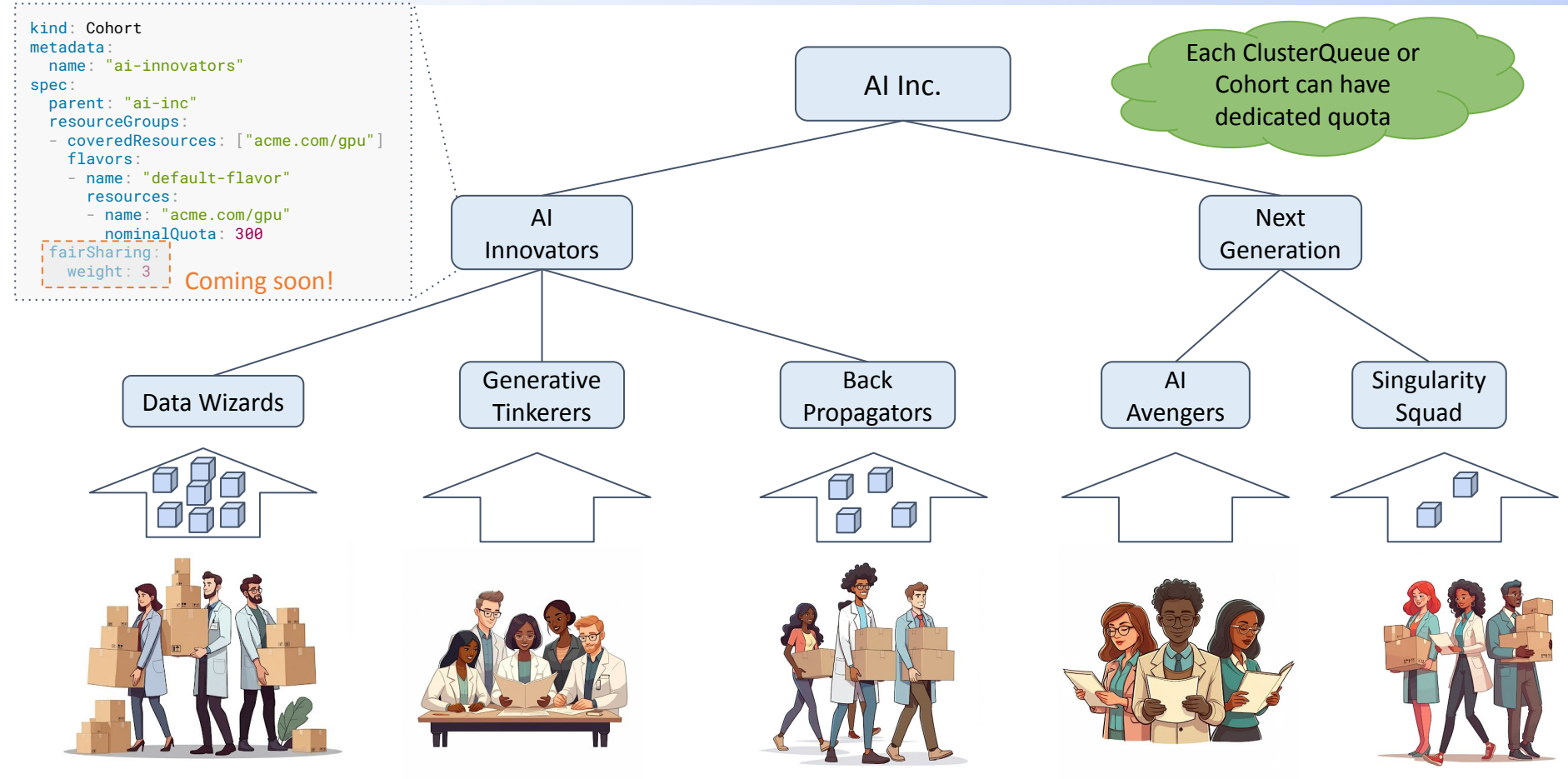
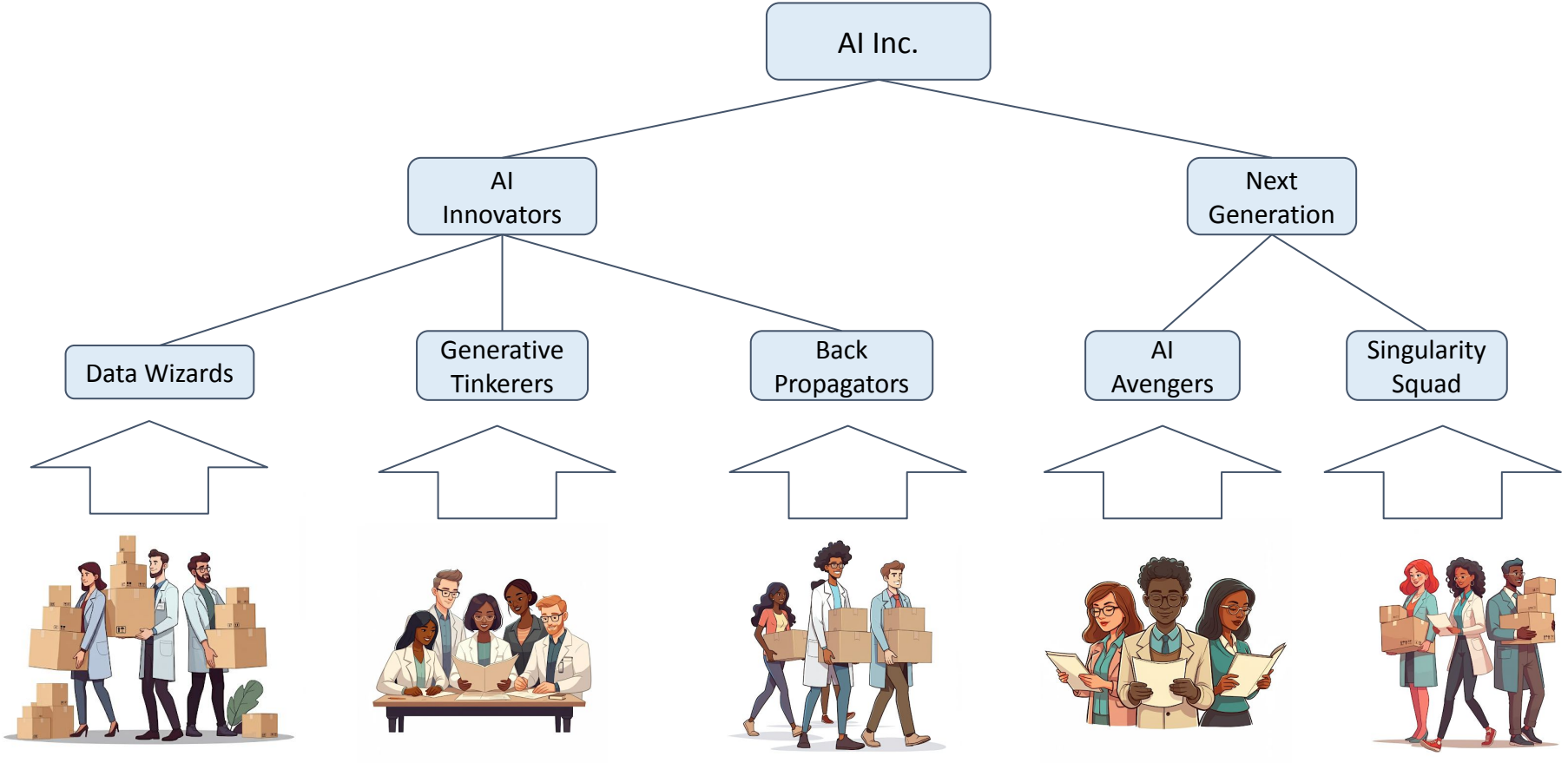
Coming soon!



Which job to run and which job to preempt?



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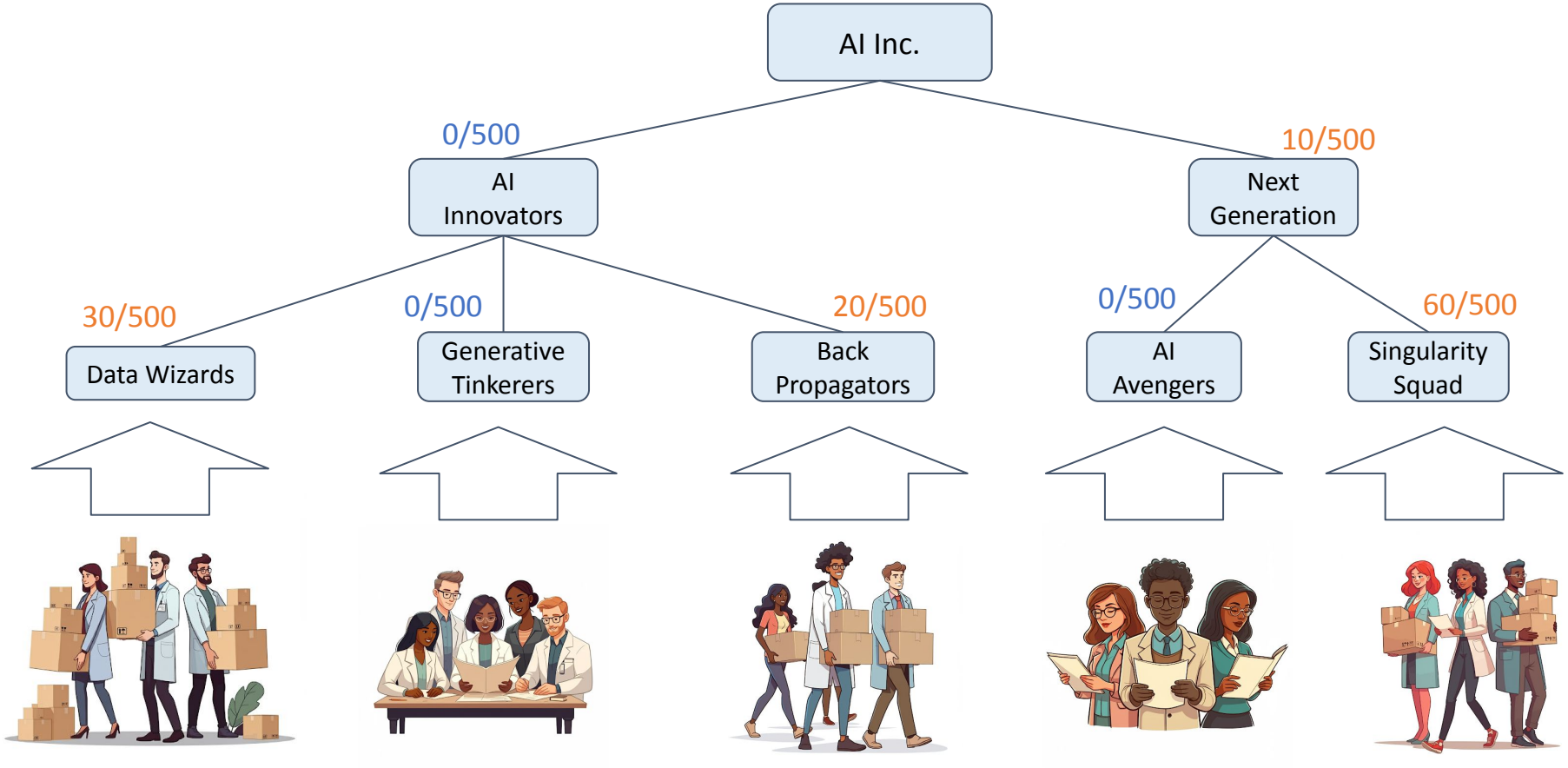

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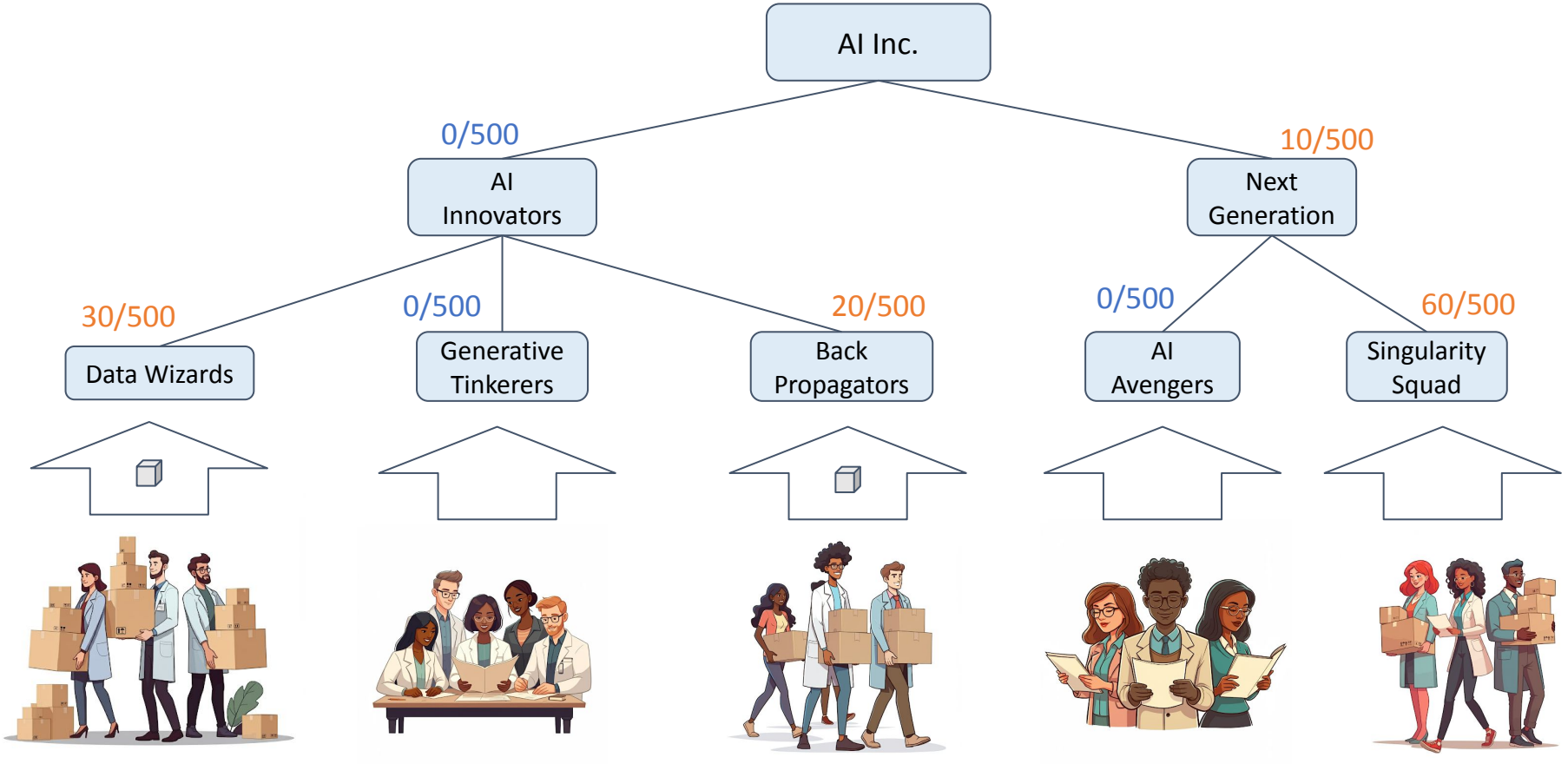

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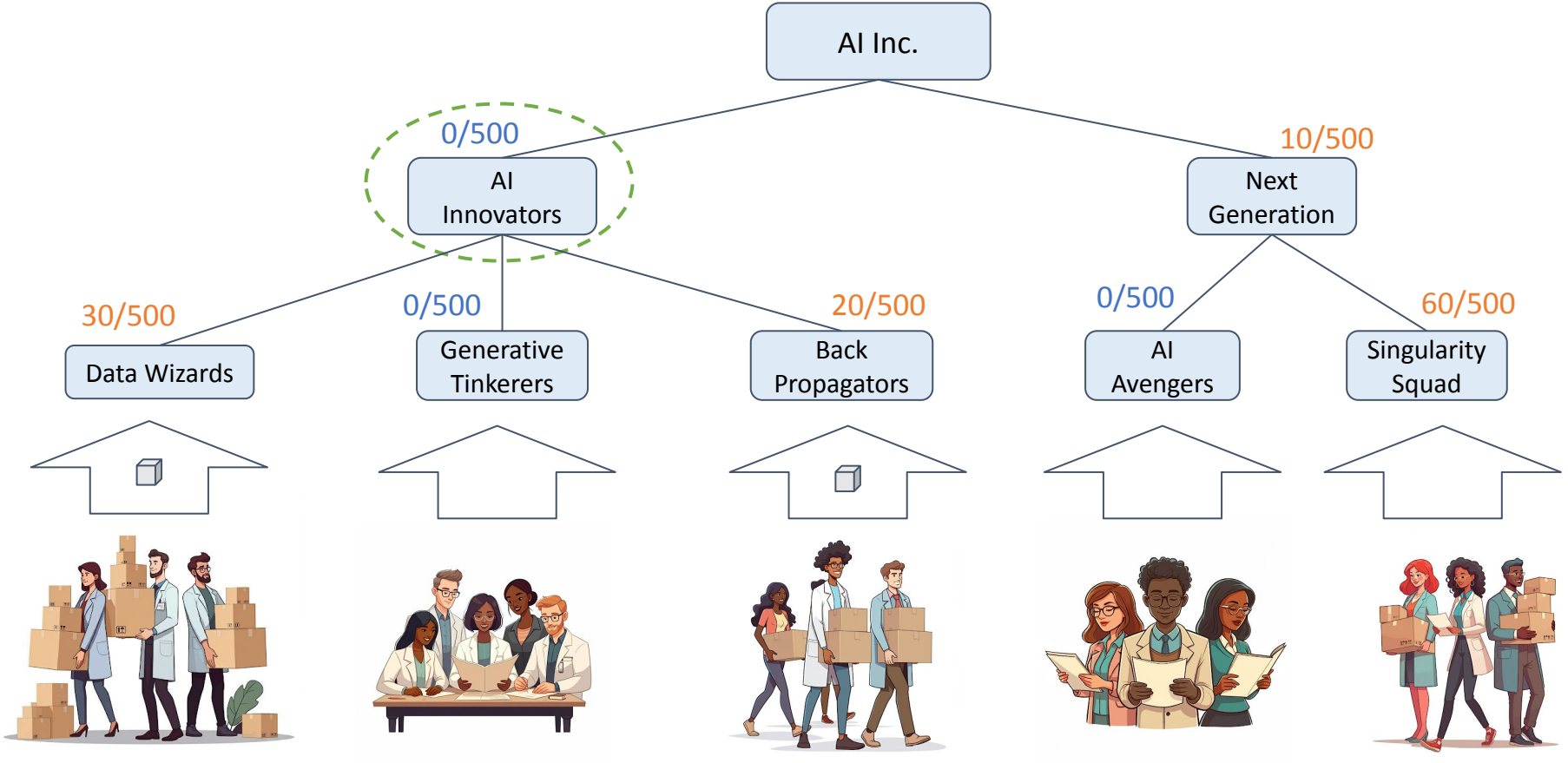

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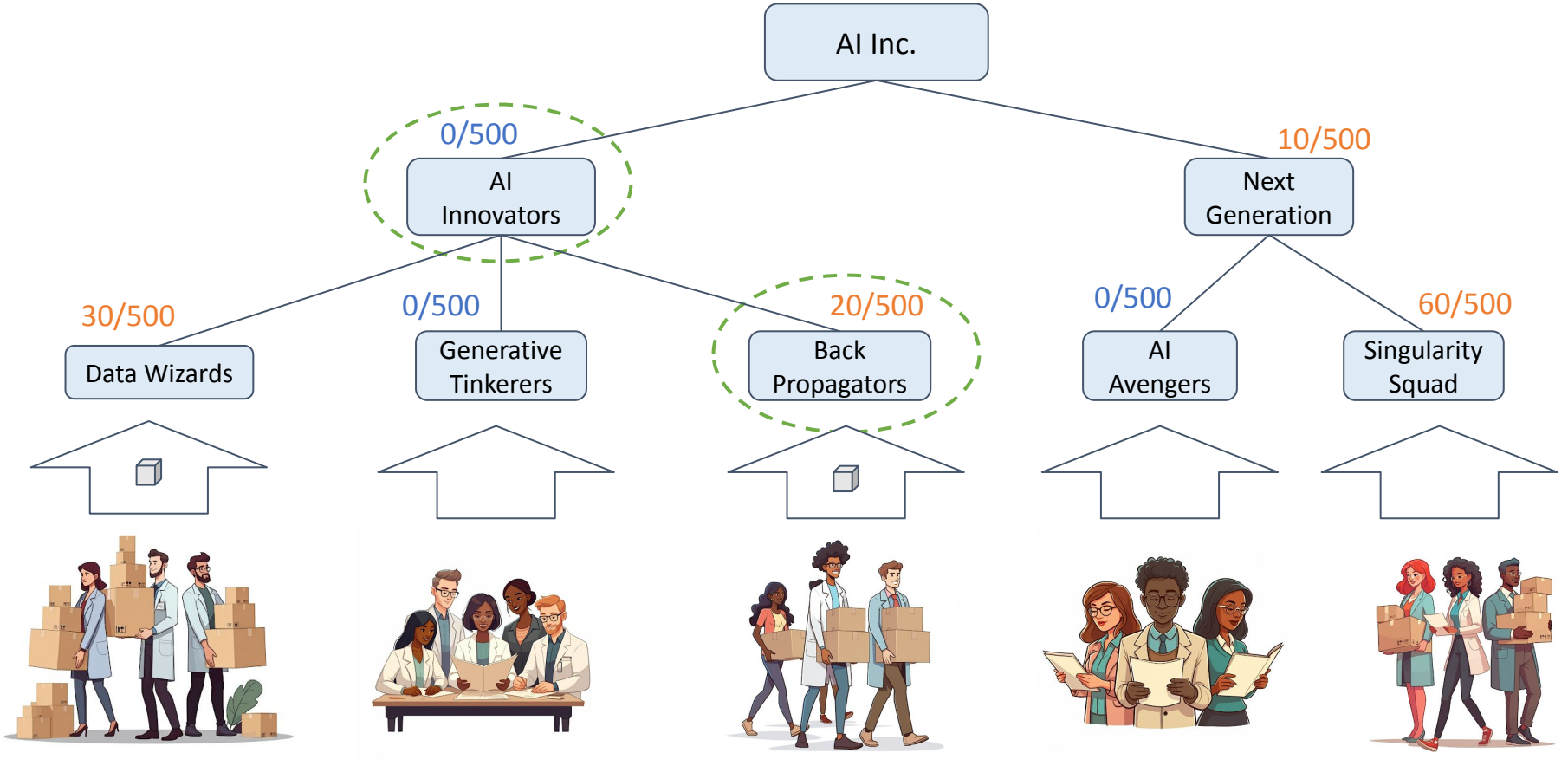

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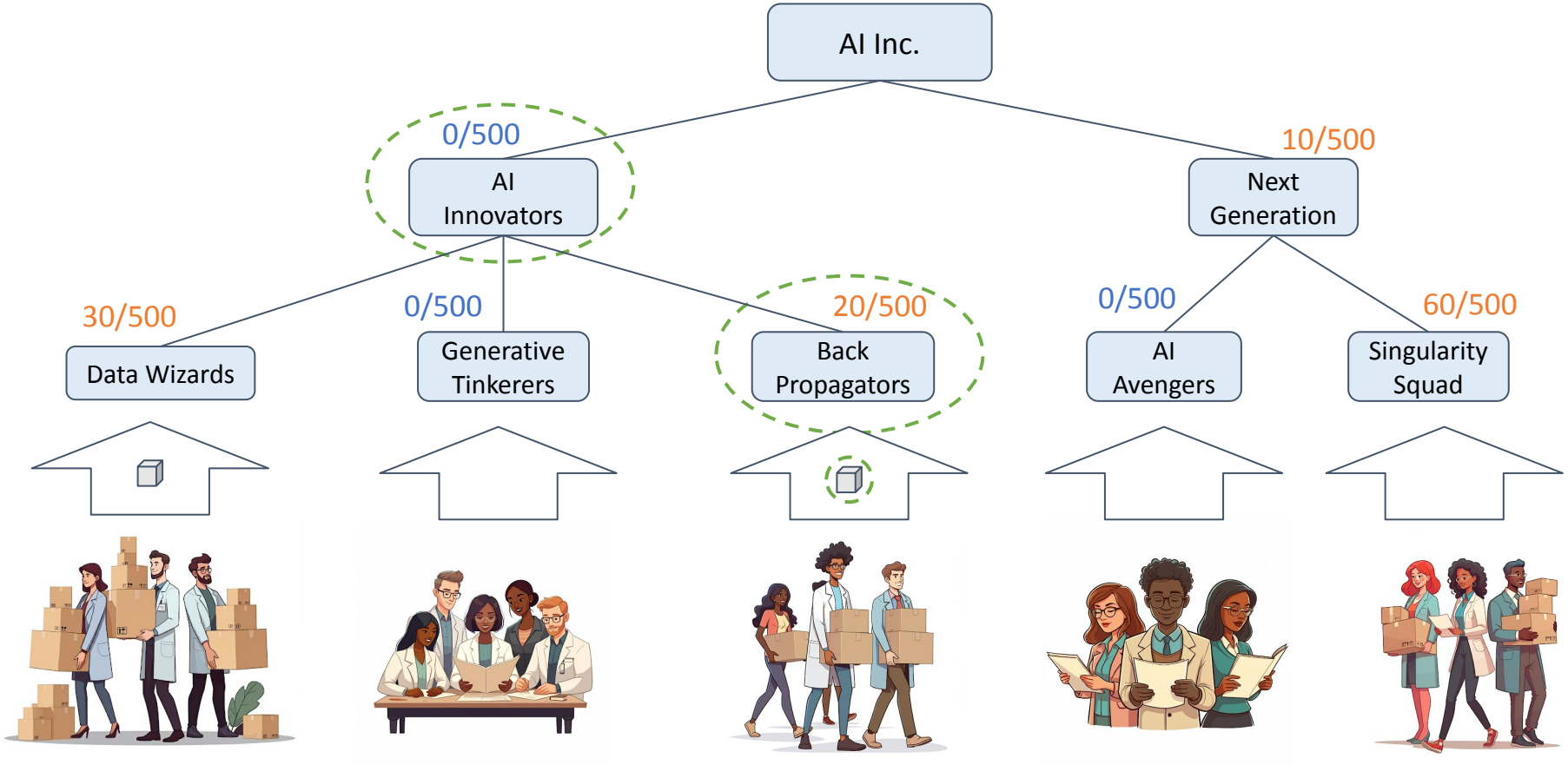

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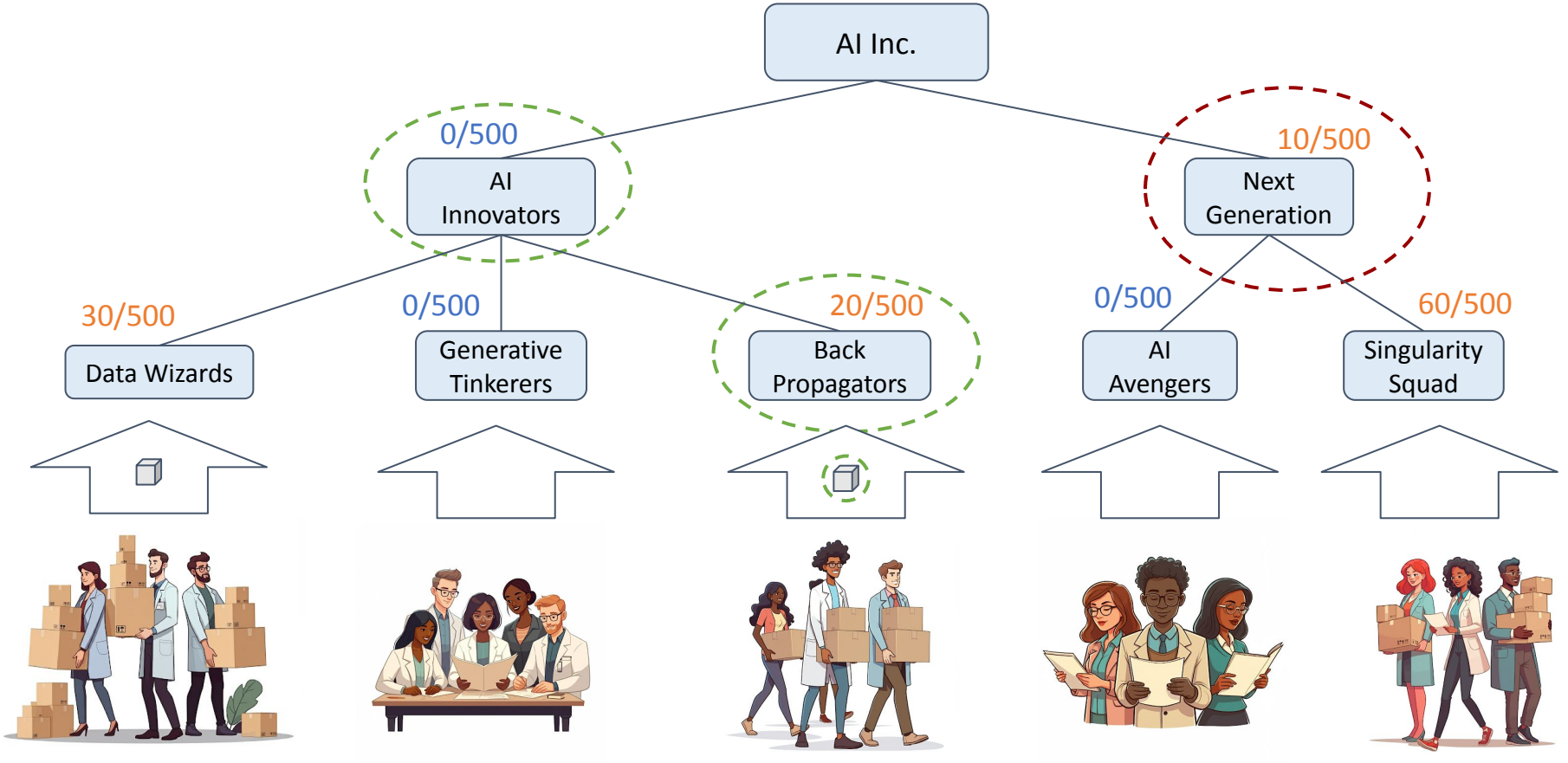

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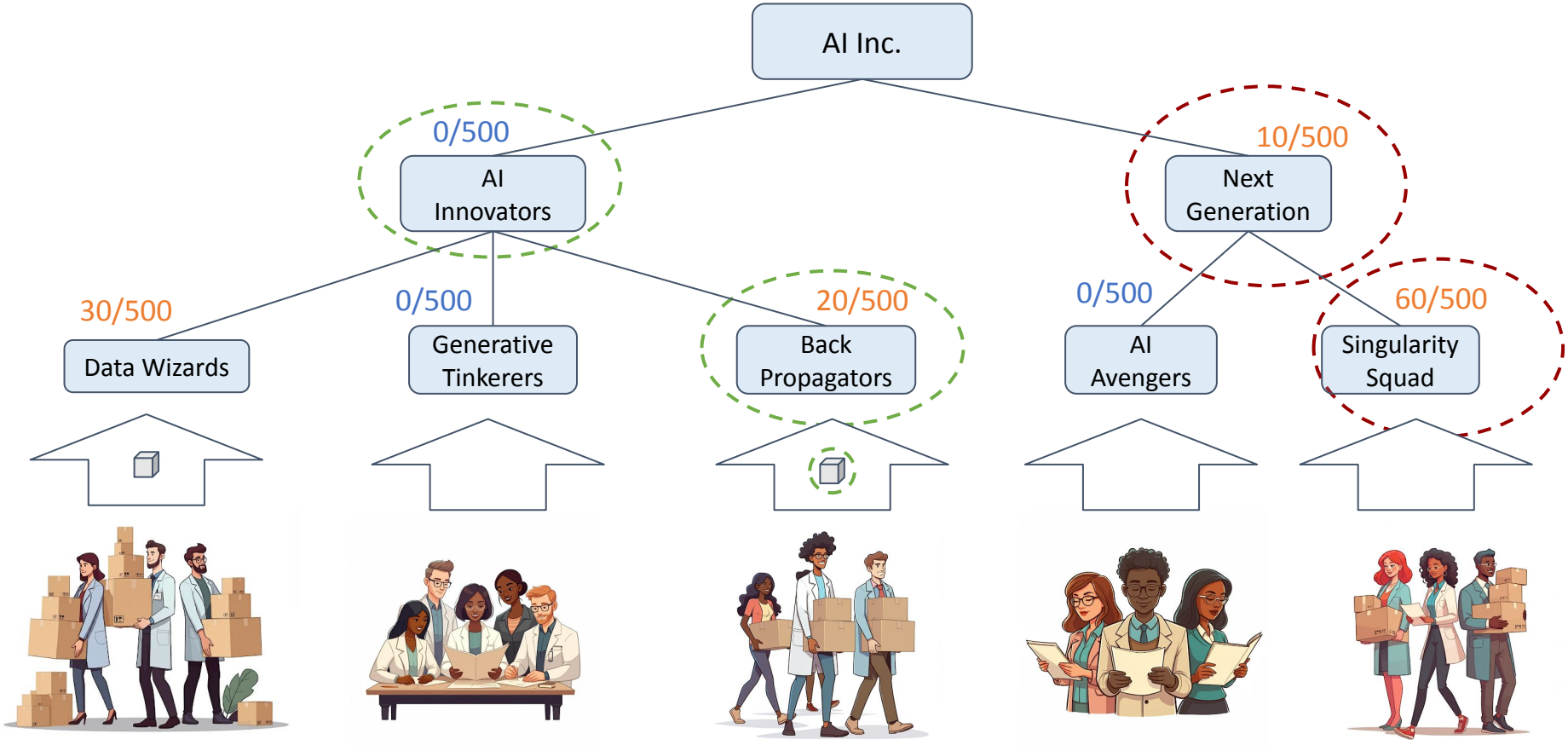

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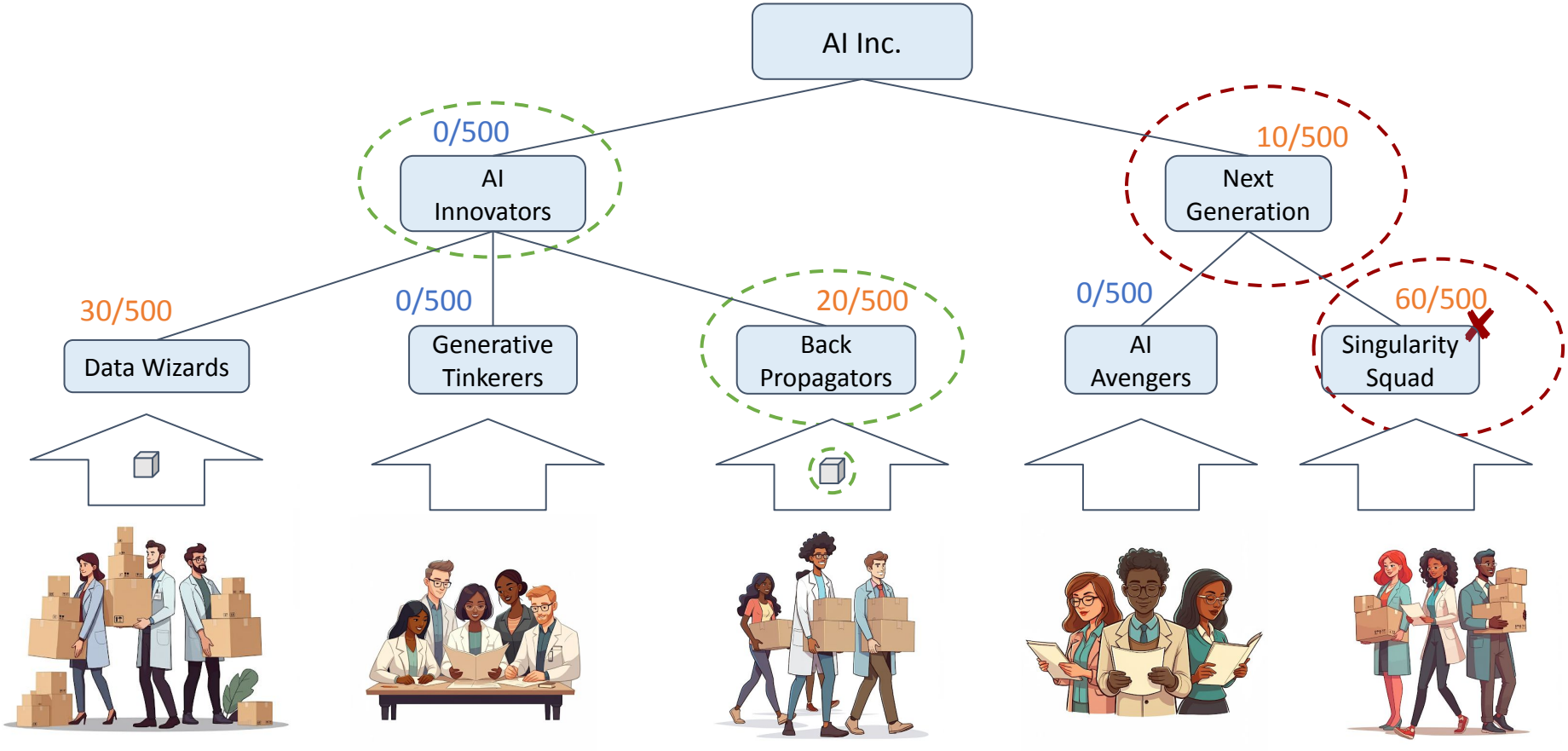

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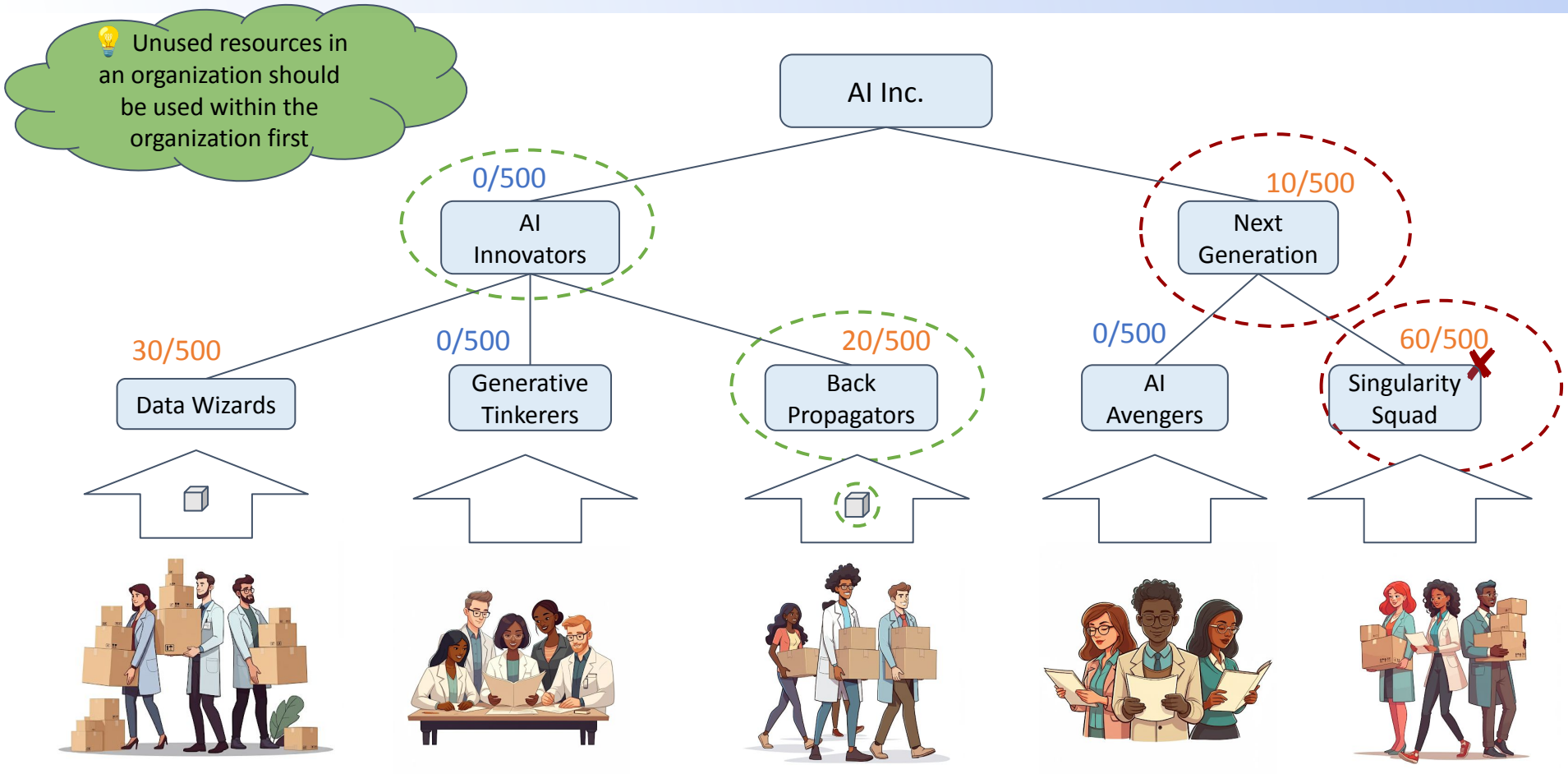
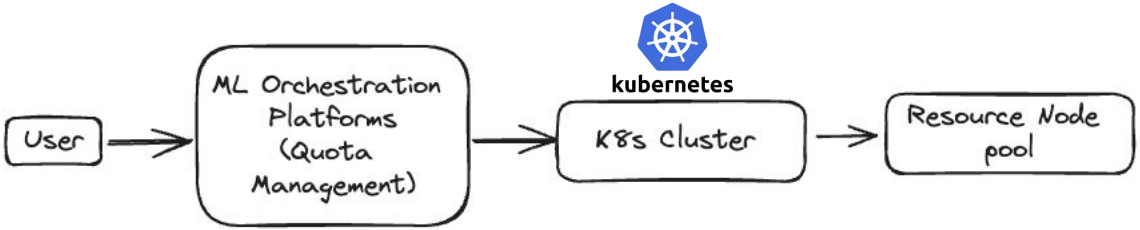


Building an ML Platform

How can Kueue integrate with ML Platforms?

ML Platforms over K8s



How can Kueue integrate with ML Platforms?

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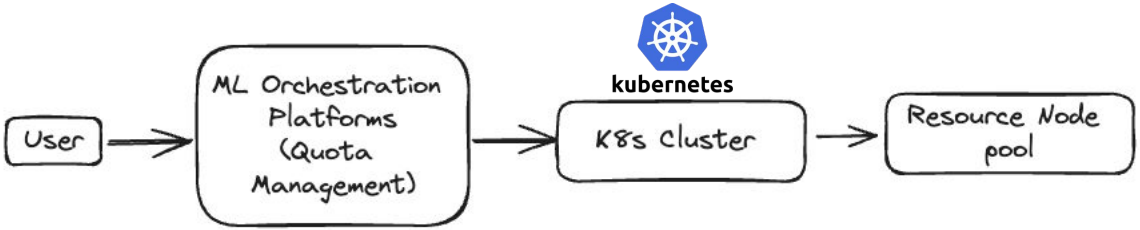
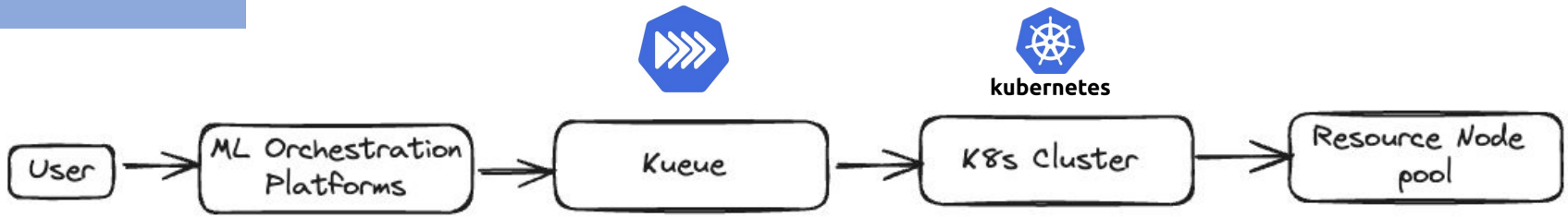
ML Platforms over K8s



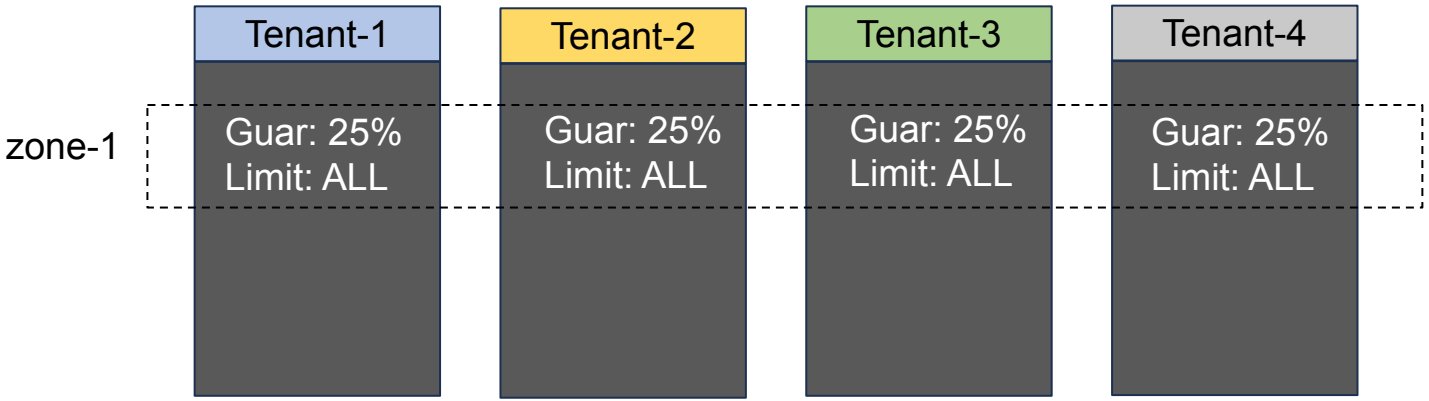
ML Platforms with Kueue + K8s

Simplifies quota management and second level scheduling



Case Study for ML Platforms

- Gang Scheduling and Preemption
- Priority/Reclamation Preemption
- Hierarchy of organizations and teams



Case Study for ML Platforms

- Gang Scheduling and Preemption
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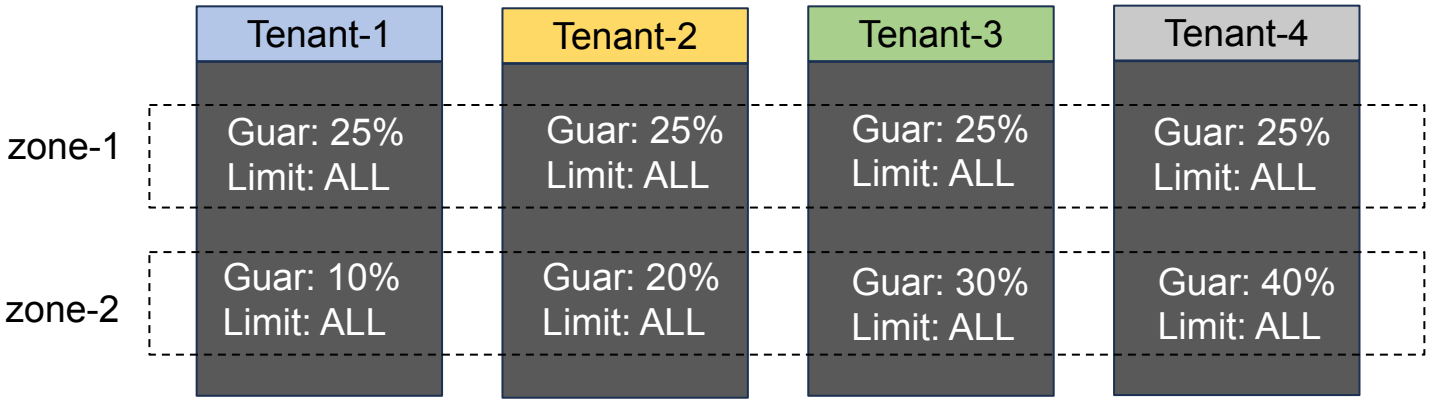
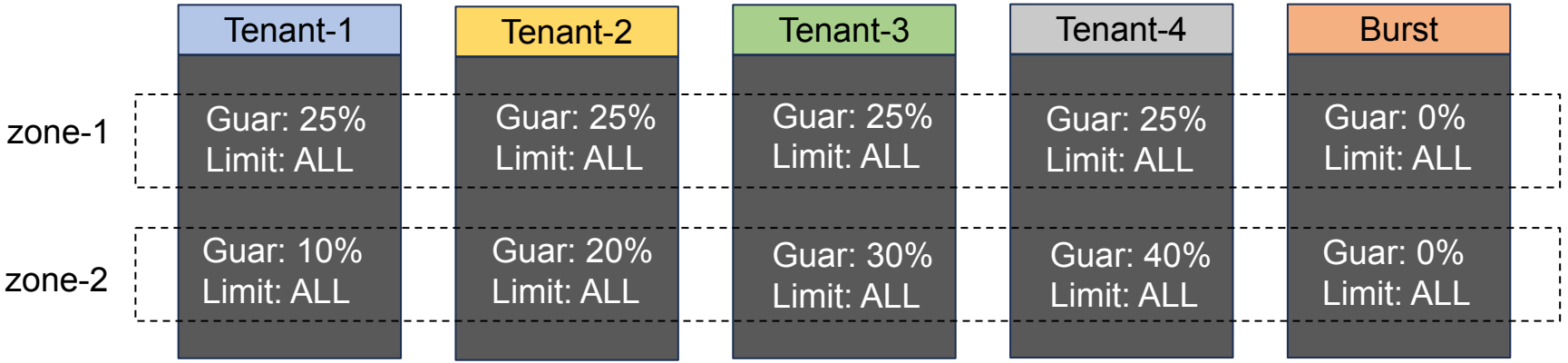
- Hierarchy of organizations and teams
- Model resource flavors for co-located nodes (zone/spine aware scheduling)
- Support for dynamic change of nominal and borrow limits



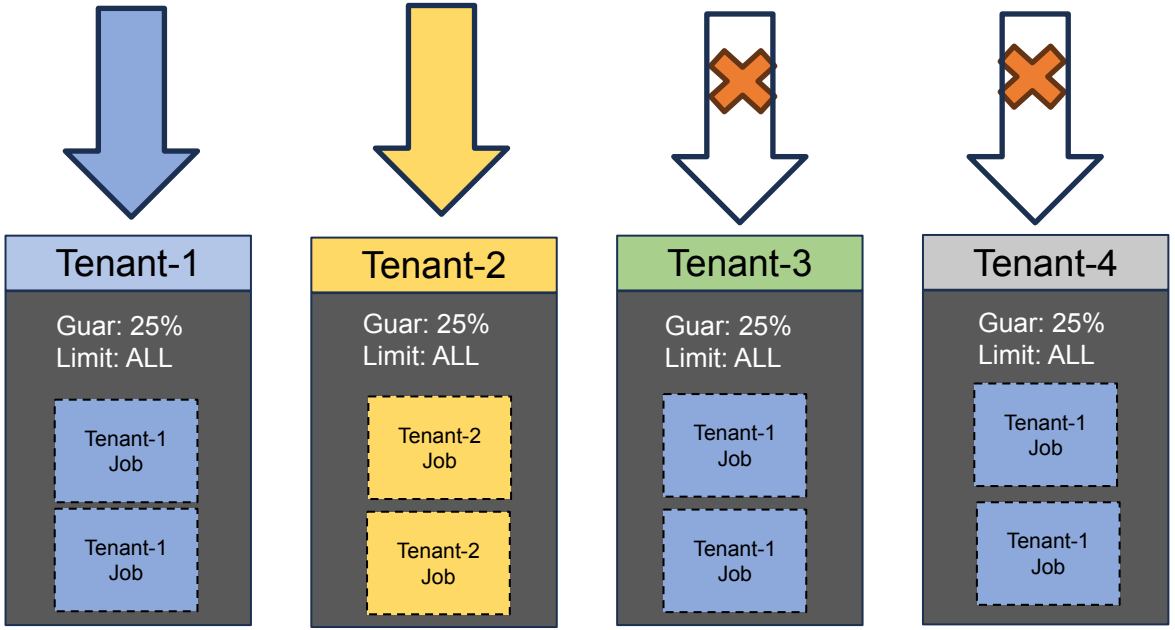
Case Study for ML Platforms

- Gang Scheduling and Preemption
- Priority/Reclamation Preemption
- Hierarchy of organizations and teams
- Model resource flavors for co-located nodes (zone/spine aware scheduling)
- Support for dynamic change of nominal and borrow limits
- Burst capacity sharing



How to prevent capacity usage abuse?

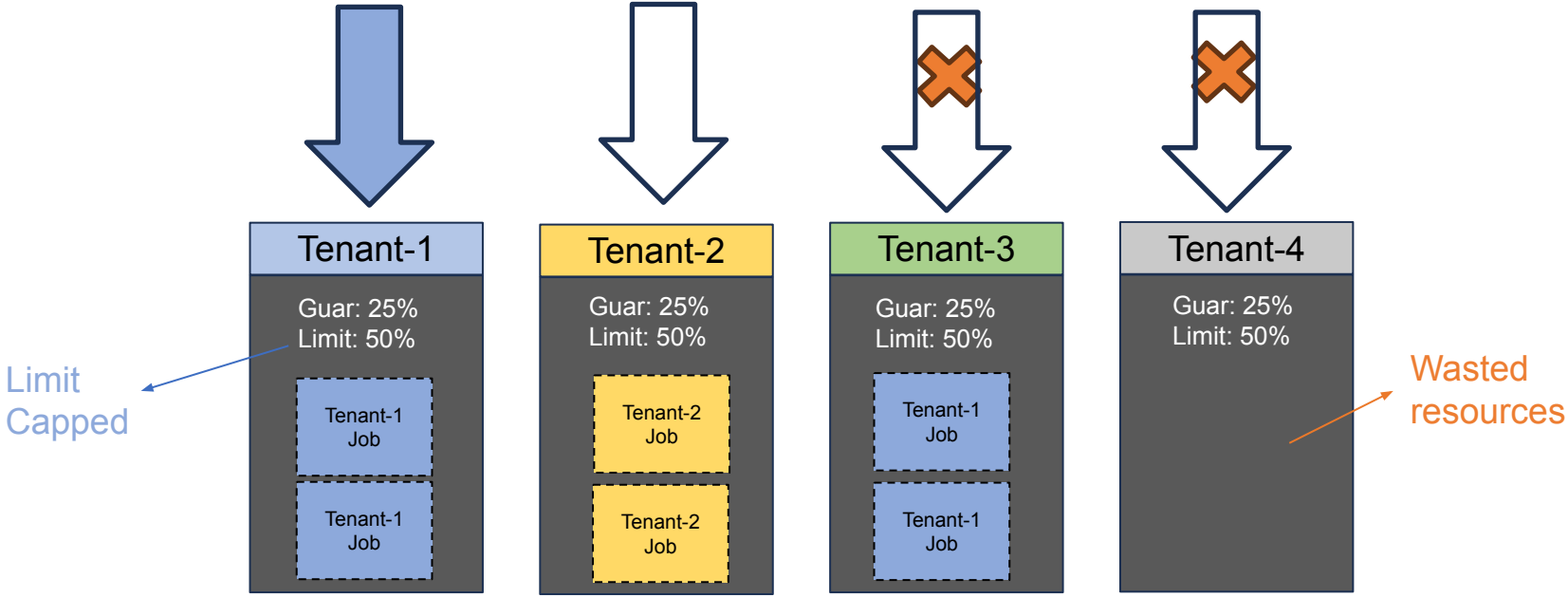
Single Tenant can use all the idle capacity



How to prevent capacity usage abuse?

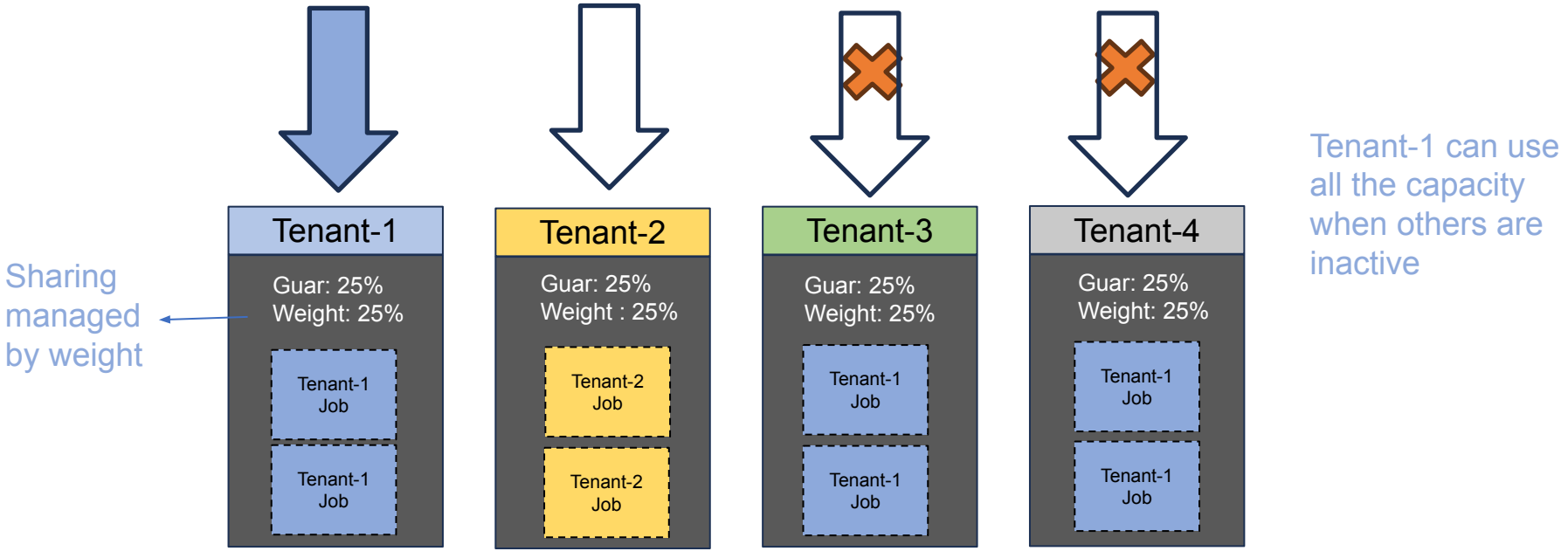
Option 1: Enforce limit per tenant

- Requires frequent adjustments
- May impact utilization



How to prevent capacity usage abuse?

Option 2: Weighted Fair Sharing for idle capacity (No Limits)



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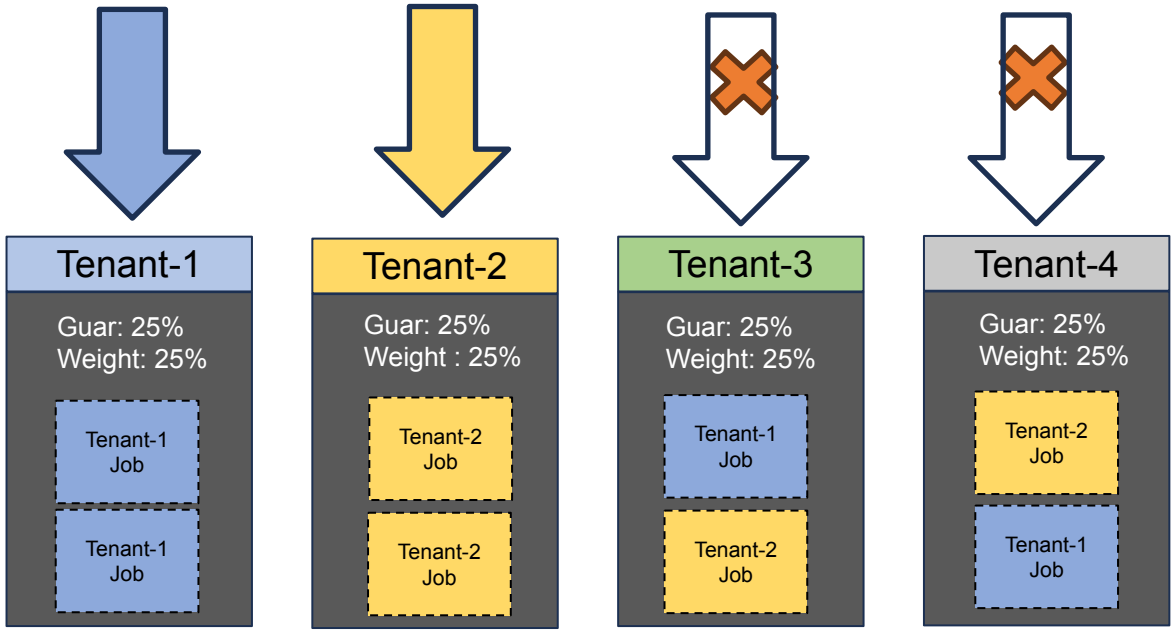
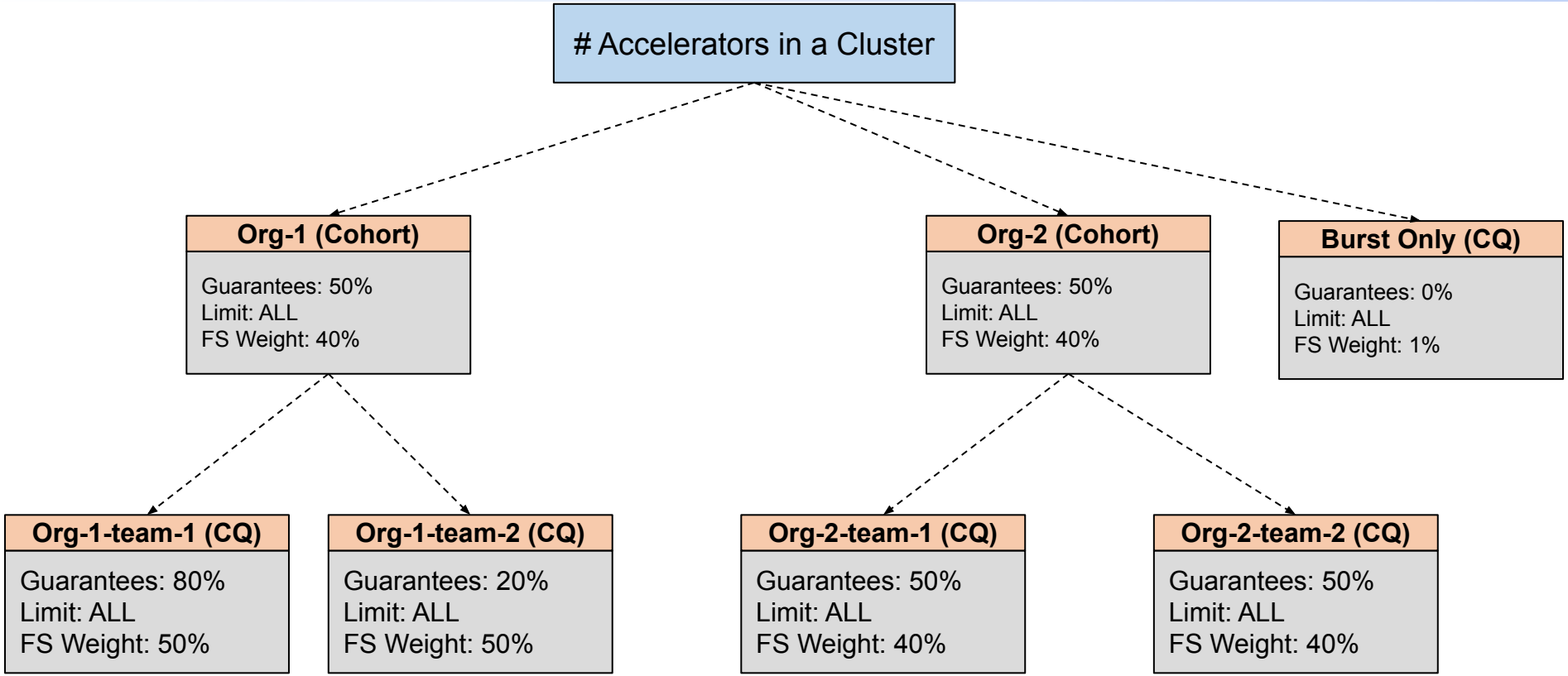


Tenant-1 gets preempted for fair sharing when Tenant-2 submits

Org sharing with Hierarchies



Kueue v0.7 to v0.9 Highlights

- Fair Sharing in a cohort v0.7
- More robust and scalable Pod integration v0.7
- ProvisioningRequest graduated to beta v0.7
- kueuectl: CLI for cluster admins v0.8
- Improved preemption throughput and observability v0.8
- Topology Aware Scheduling v0.9
- Hierarchical Cohorts v0.9
- MultiKueue graduated to beta v0.9
- Support for serving (Deployment and StatefulSet) v0.9
- Resource Transformations v0.9

Multitenancy and Fairness at Scale with Kueue: A Case Study

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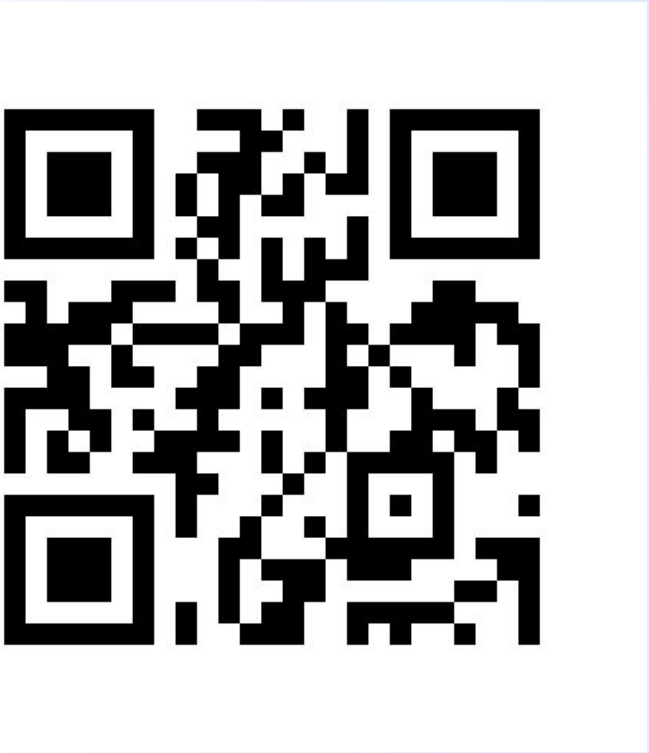
November 12, 2024
Salt Lake City

Aldo Culquicondor
Sr Software Engineer
Google

Rajat Phull
Engineering Manager
Apple

Feedback



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