Enhancing KubeVirt workload scheduling patterns

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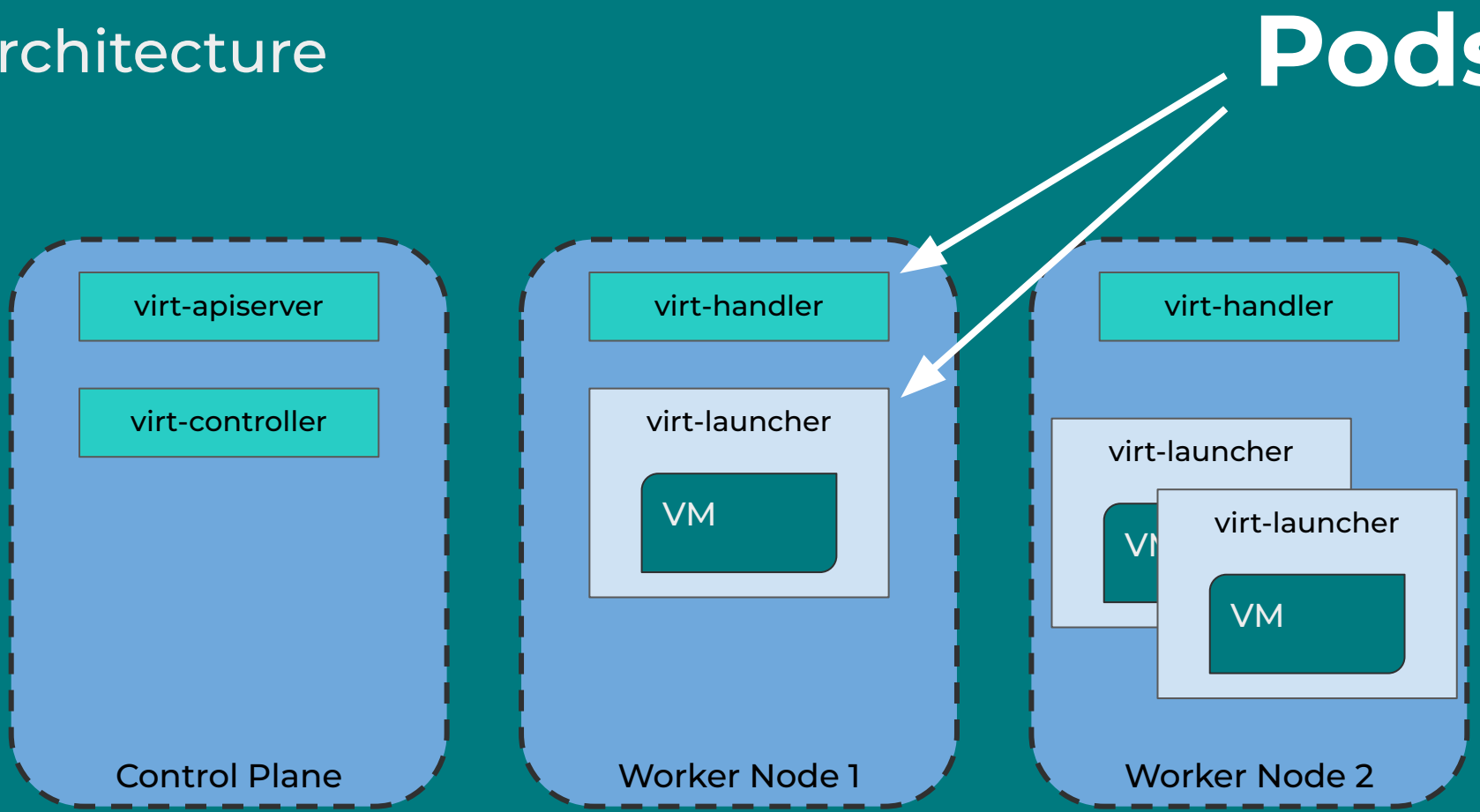
FOSDEM 2025

Scheduling is the process of matching workload to Nodes.

By default, the scheduler used is kube-scheduler.

Architecture

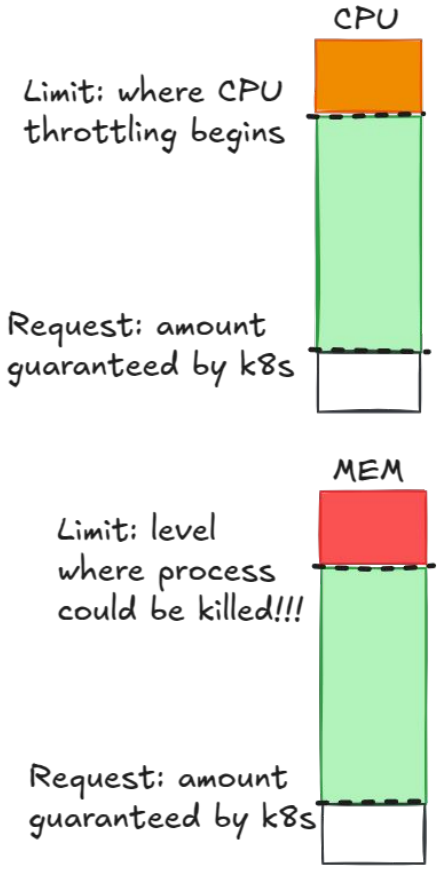


https://kubevirt.io/

K8s workload resources

Request and limit

- **Request**: amount of a resource allowed to be used, with a strong guarantee of availability
  - CPU (seconds/second), RAM (bytes)
  - Scheduler will not overcommit requests
- **Limit**: max amount of a resource that can be used, regardless of guarantees
  - **scheduler ignores limits**
- Implications:
  - request < **usage** <= limit: resources might be available
  - **usage** > limit: throttled (CPU) or killed (memory)



VM Resources

```
apiVersion: kubevirt.io/v1
kind: VirtualMachine
metadata:
  name: testvm
  ...
spec:
  ...
  template:
    spec:
      ...
      domain:
        cpu:
          cores: 1
          sockets: 4
          threads: 1
        memory:
          guest: 2Gi
```

In Kubernetes, one full core is 1000 of CPU time
CPU is REQUESTed according to CPU overcommit ratio
(10 by default):

```
spec:
  configuration:
    developerConfiguration:
      cpuAllocationRatio: 10
```

POD Resources

```
apiVersion: v1
kind: Pod
metadata:
  name: virt-launcher-testvm
spec:
  ...
  containers:
      ...
      name: compute
      resources:
        limits:
          devices.kubevirt.io/kvm: "1"
        requests:
          cpu: 400m
          devices.kubevirt.io/kvm: "1"
          ephemeral-storage: 50M
          memory: 2299Mi
```

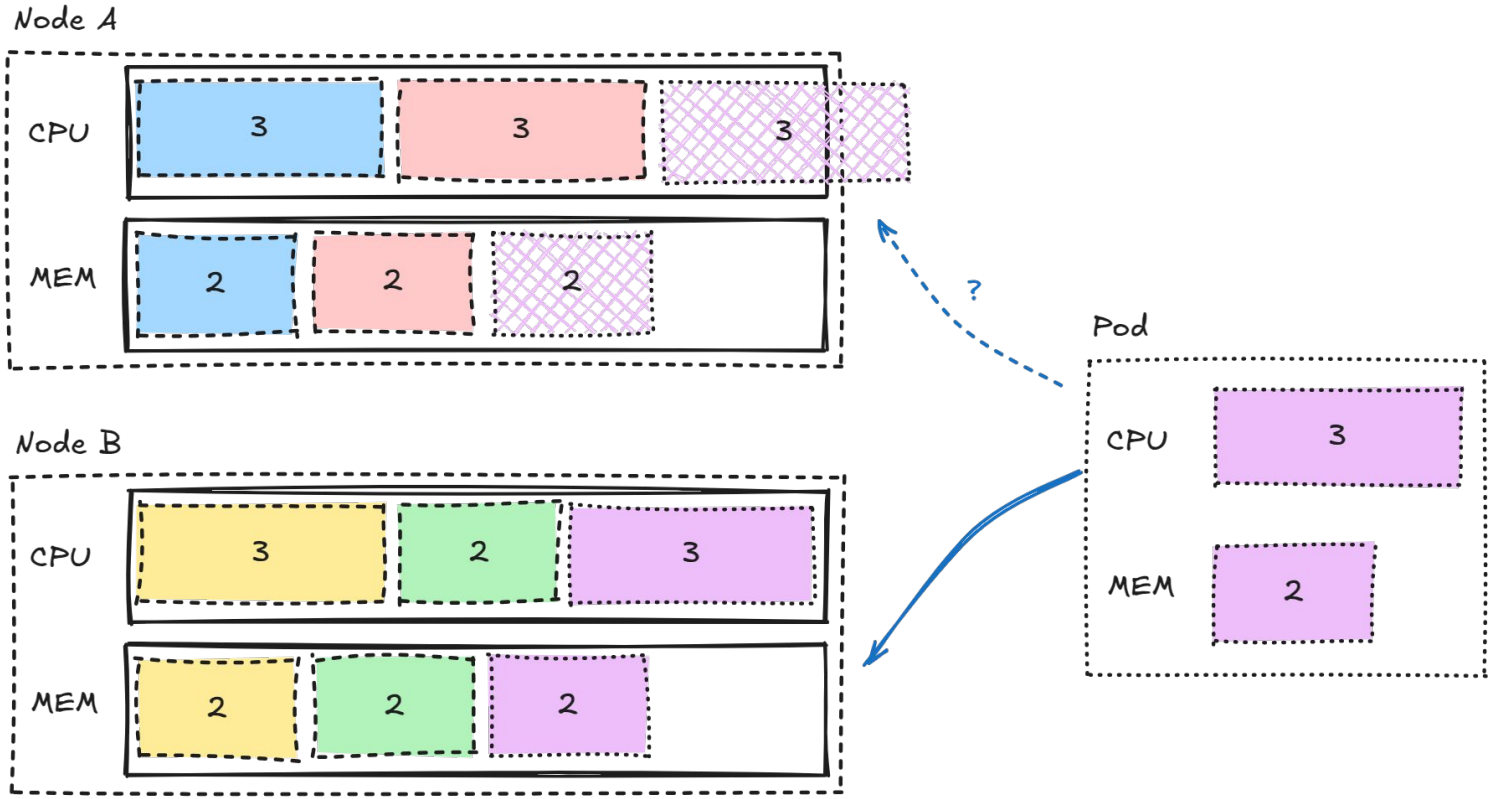
We have also VMs with Guaranteed QoS class:
requests = limits
No overcommit

Memory overcommit is disabled by default (*):
The whole guest OS configured memory plus additional overhead for ancillary components is required to avoid getting killed by OOM

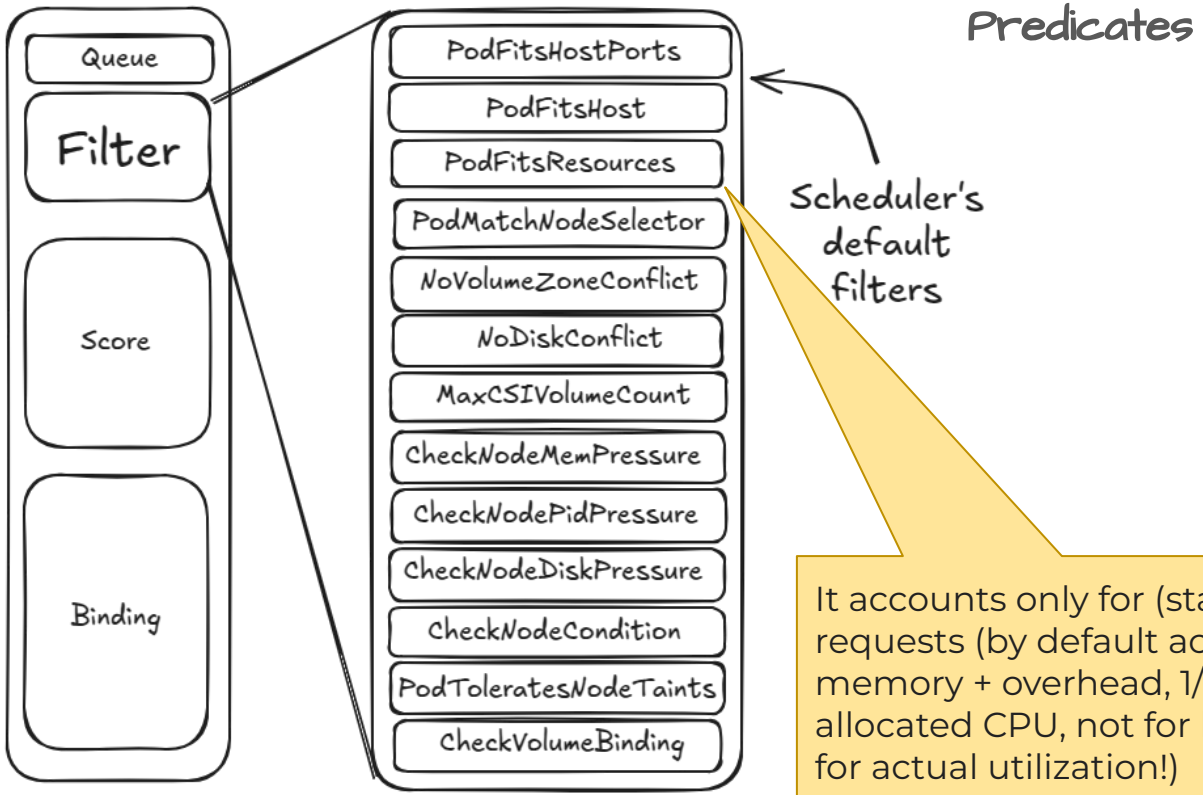
* see: https://kubevirt.io/user-guide/compute/node_overcommit/#overcommit-guest-memory

https://kubevirt.io/

K8s scheduling

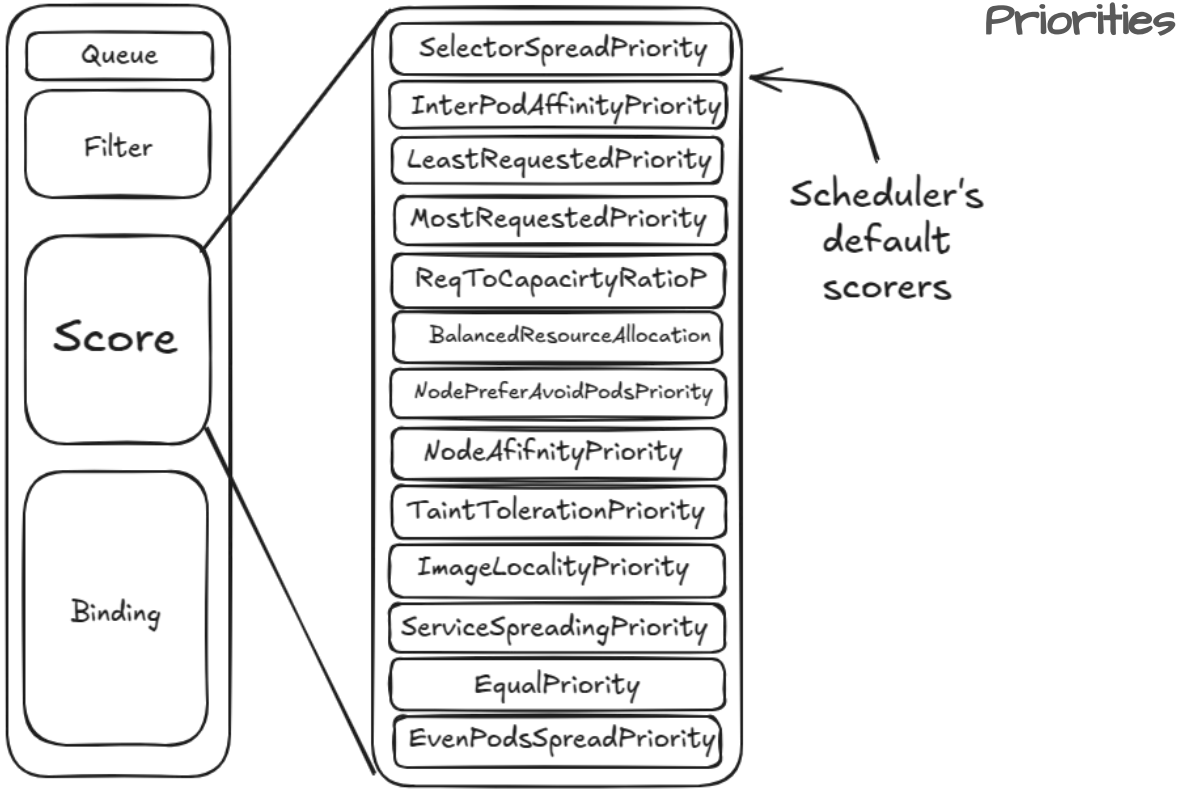


How k8s scheduler works 1/2



It accounts only for (static!) requests (by default actual guest memory + overhead, 1/10 of VM allocated CPU, not for limits nor for actual utilization!)

How k8s scheduler works 2/2



VMs

- Each VM runs a separate OS, providing stronger isolation
- Require more resources (CPU, RAM, storage) due to running full OS per each VM
- Slower startup time due to OS booting
- Usually stateful with data on local disks
- Can be moved between nodes with live-migration with zero-downtime
- Scaling requires rebooting the VM with a different configuration or hotplugging resources: slower and intensive
- Potentially really long uptime

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PODs

- Same kernel OS, isolated user spaces
- (Ideally) lighter
- Fast startup
- Typically stateless, eventually with data on persistent volumes that can be attached
- Cannot be moved between nodes with live-migration but they can be quickly killed and restarted on a different node
- Pods can be "easily scaled" to meet dynamic application requirements
- Supposedly shorter life cycle

VMs Scheduling hints PODs

- nodeSelector

```
nodeSelector:
  performance: high
```

- nodeAffinity

```
affinity:
  nodeAffinity:
    requiredDuringSchedulingIgnoredDuringExecution:
      nodeSelectorTerms:
        - matchExpressions:
            - key: performance
              operator: In
              values:
                - high
```

- podAffinity/podAntiAffinity

```
podAntiAffinity:
  requiredDuringSchedulingIgnoredDuringExecution:
    - labelSelector:
        matchExpressions:
          - key: app
            operator: In
            values:
              - cache
```

- nodeSelector

```
nodeSelector:
  performance: high
```

- nodeAffinity

```
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```
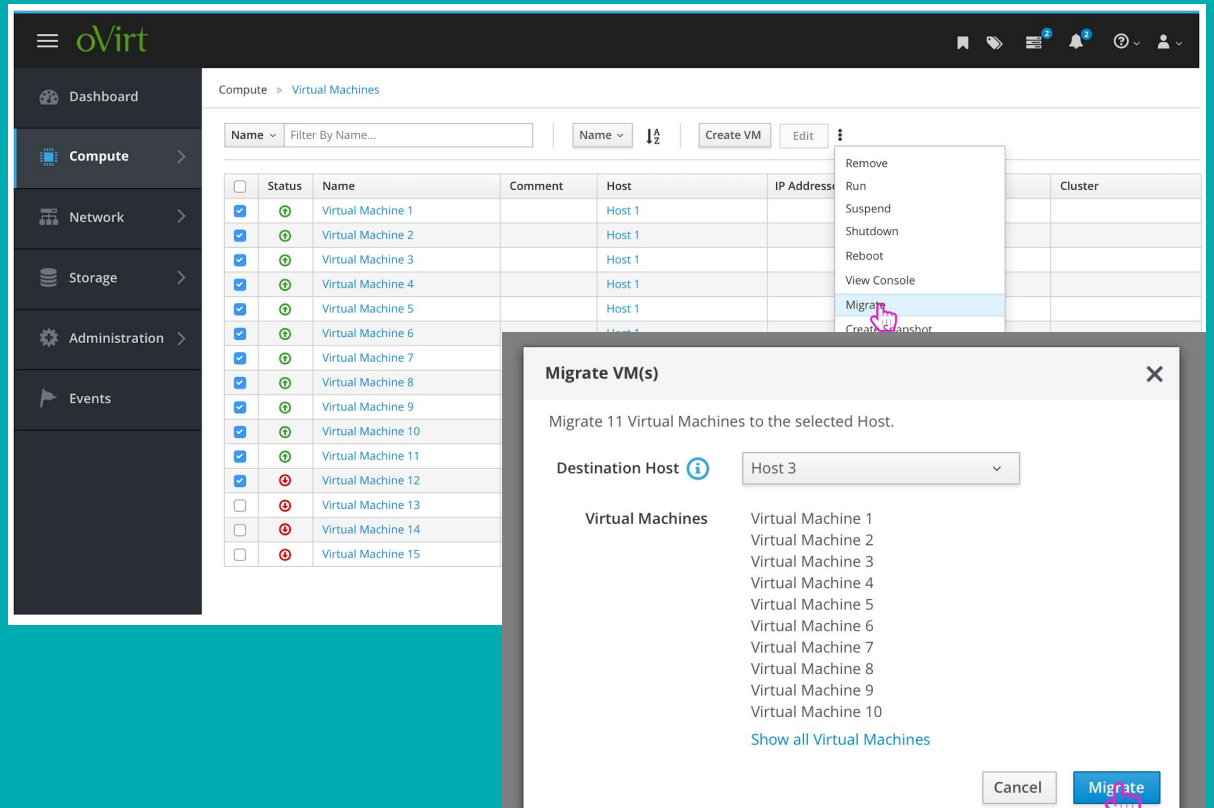
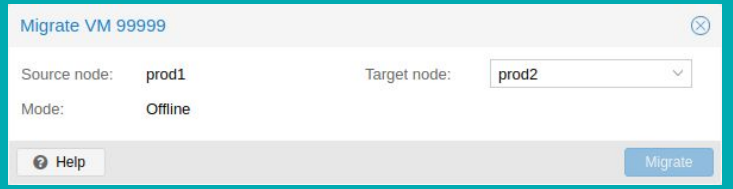

User habits

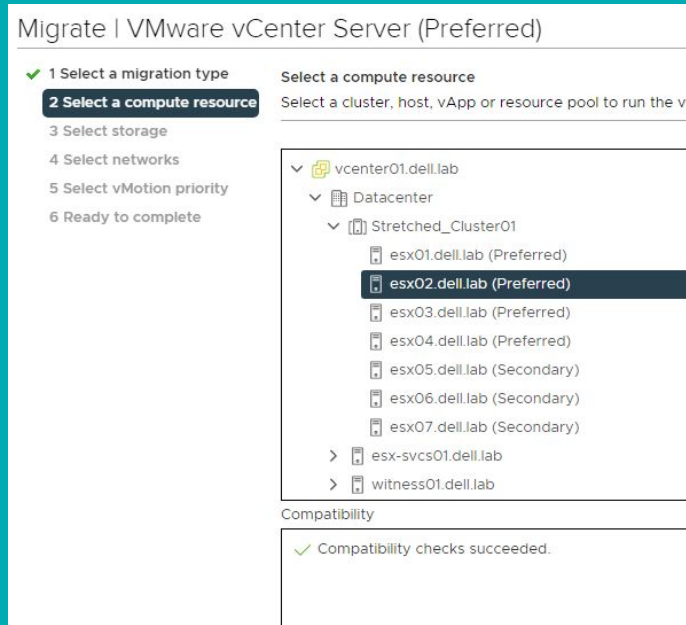
oVirt



Proxmox VE



VMware vCenter



Initiate live migration on KubeVirt

```
apiVersion: kubevirt.io/v1
kind: VirtualMachineInstanceMigration
metadata:
  name: migration-job
  namespace: mynamespace
spec:
  vmiName: testvm
```

It's a namespaced object

You can only specify the name of a VM within the VMIM namespace, everything else will be up to the scheduler...

```
$ virtctl migrate <vmname>
```

https://kubevirt.io/

A bit of history...

design-proposal: VirtualMachineInstanceMigration - Live migration to a named node #320

Edit | Code

Open | tiraboschi wants to merge 4 commits into `kubevirt:main` from `tiraboschi:migration_target`

Conversation 178 | Commits 4 | Checks 0 | Files changed 1 | +216 -0

tiraboschi commented on Sep 3, 2024 • edited — Member

What this PR does / why we need it:
Adding a design proposal to extend VirtualMachineInstanceMigration
object with an additional API to let a cluster admin
try to trigger a live migration of a VM injecting
on the fly and additional NodeSelector constraint.
The additional NodeSelector can only restrict the set
of Nodes that are valid target for the migration
(eventually down to a single host).
All the affinity rules defined on the VM spec are still
going to be satisfied.

Which issue(s) this PR fixes *(optional, in `fixes #<issue number>(, fixes #<issue_number>, ...)` format, will close the issue(s) when PR gets merged)*:
Fixes https://issues.redhat.com/browse/CNV-7075

Special notes for your reviewer:
Something like this was directly proposed/implemented with
kubevirt/kubevirt#10712 getting already discussed there.

Reviewers
- iholder101
- enp0s3
- alicefr
- dankenigsberg
- vladikr
- davidvossel
- fabiand
- EdDev
- aburdenthehand
- jobbler

Still in progress? Convert to draft

area/virtctl | dco-signoff: yes | do-not-merge/release-note-label-needed | kind/api-change | lifecycle/rotten | needs-ok-to-test | size/L

Support specify one node to migrate

Closed | zhonglin6666 wants to merge 1 commit into `kubevirt:main` from `zhon`

Conversation 34 | Commits 1 | Checks 0 | Files chang

zhonglin6666 commented on Nov 10, 2023

What this PR does / why we need it:
The current migration of virtual machines involves setting node affinity or n
selectors, but cannot be done by specifying a fixed node. Now there are cur
ways to migrate:

- Migrate to the specified node through the `virtctl migrate vm node` co
- Migrate to the selected node by scheduler through the `virtctl migrate`
  command.

kubectl get vmim

```
NAME                                PHASE       VMI
kubevirt-migrate-vm-2snmc           Succeeded   vm-test
```

CONTROVERSIAL

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It's not a new idea...

Motivation

User stories

- As a cluster administrator:
  - Experienced admins are used to control where their critical workloads are going to be moved to
    - **Habits**
    - **Existing patterns/automation** on/over previous VM management solutions
    - **Planned maintenance** activities on nodes
  - Workload balancing solution doesn't always work as expected
    - I can anticipate load profile changes
  - **Troubleshooting** a node
  - **Validating** a new node migrating there a specific VM
- As a VM owner:
  - I don't want to see my VM object getting amended by another user/admin just for maintenance reasons

Goals

- A user allowed to trigger a live-migration of a VM **limiting** its admitted **target** to a subset of nodes
- The target node that is explicitly required for the actual live migration attempt **should not influence future live migrations** or the placement in case the VM is restarted
- The constraints directly added on the one-off migration can only complement and **limit** constraints already defined on the VM object (**pure AND logic**)
- It's a **one off migration attempt**: it could successfully complete or fail as it can already do today

Proposed design

```
apiVersion: kubevirt.io/v1
kind: VirtualMachineInstanceMigration
metadata:
  name: migration-job
  namespace: mynamespace
spec:
  vmiName: testvm
  addedNodeSelector:
    accelerator: gpuenabled123
    kubernetes.io/hostname: "ip-172-20-114-199.example"
```

A node will be a valid target if it will match all the node selector constraints specified on the VM AND additional node selectors specified here

```
$ virtctl migrate <vmname> --addedNodeSelector key1=value1,key2=value2
```

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Criticisms and concerns

- **K8s** is **the scheduler**, the user should not have the control
  - OK, but...
- On K8s we cannot live migrate a pod to a named node
  - OK, but we cannot live migrate a pod at all
  - And without **KubeVirt** we neither have VMs: this is a **VM** specific problem so it should be solved in KubeVirt
- We have other **k8s native paradigms** to "**individually**" address many if not all of the user stories there (e.g. combinations of taints and tolerations, draining and/or cordoning/uncordoning nodes in a specific sequence)
  - Correct but different tasks requires different strategies and they could be **less obvious** for less trained user. We don't have a simply solution to rule them all
- Live migrations are **resource expensive operations**
  - The number of parallel live migrations is capped (by default 5) and we have a single migration queue
  - Migrations are also used for critical infra operations (node drains, upgrades, hotplugging...)
  - "Namespace owners" are currently able to trigger live migrations, we fear that enhancing migration capabilities we could end with users "abusing" that capability
  - But we can make this better...

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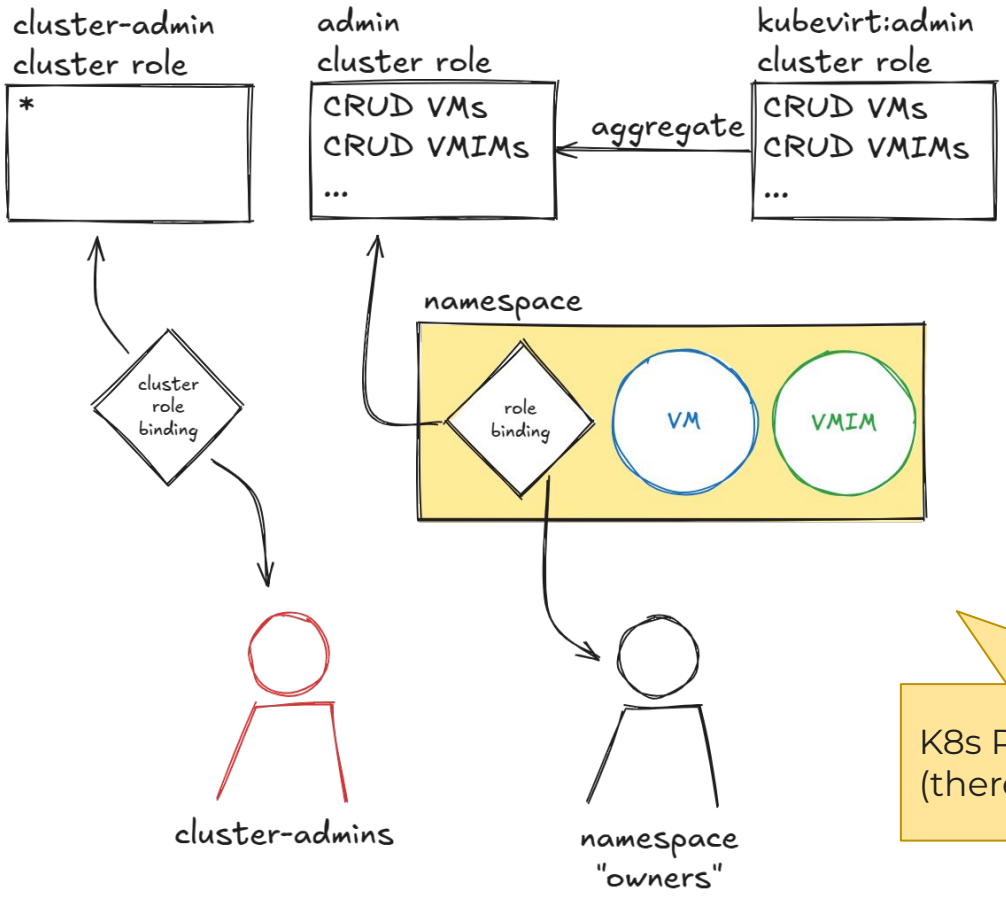
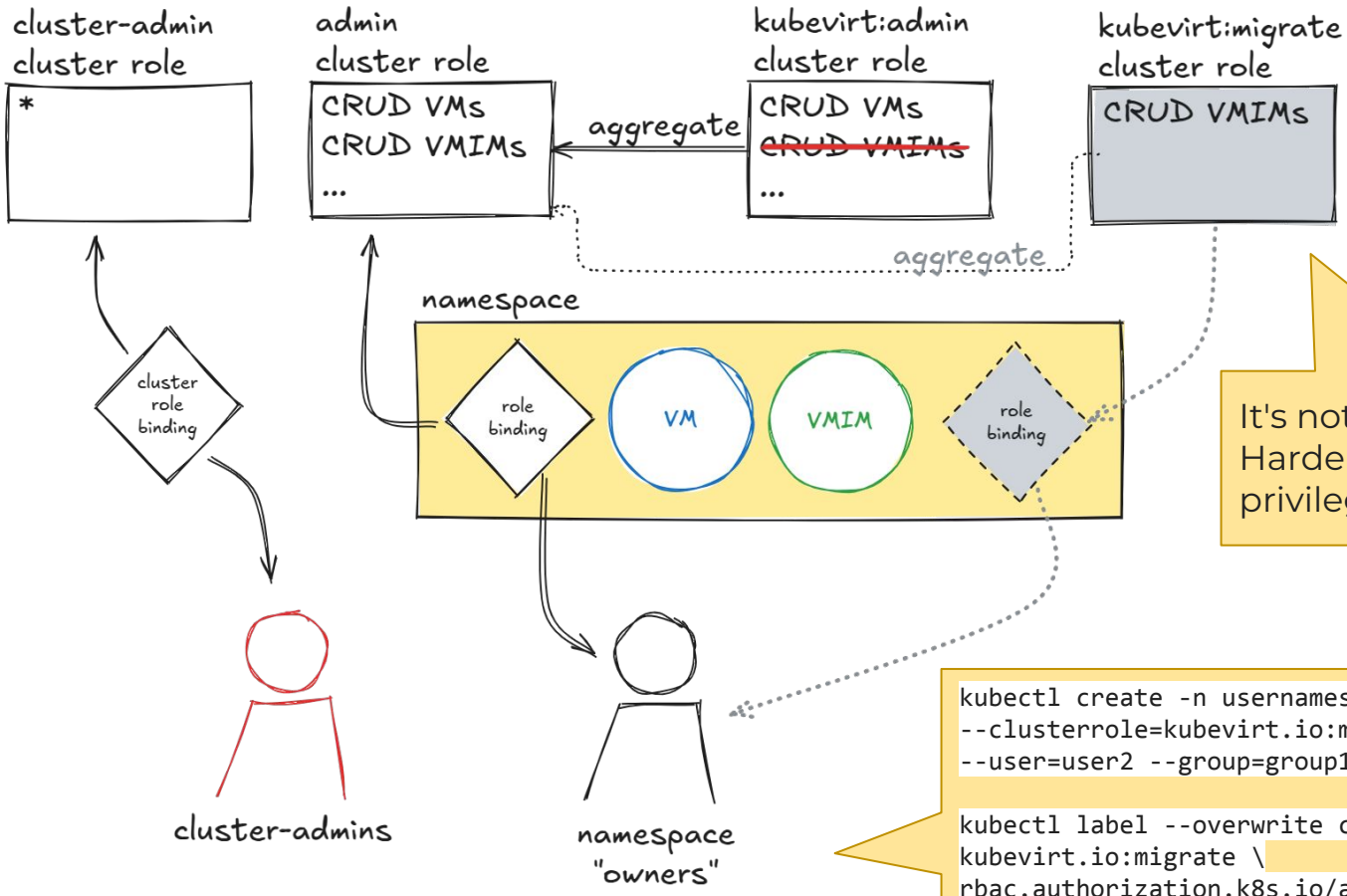
KubeVirt RBAC model



K8s RBAC model is purely additive (there are no "deny" rules).

KubeVirt RBAC model (KubeVirt 1.6)



It's not an API change.
Hardening: principle of least privilege

```
kubectl create -n usernamespace rolebinding kvmigrate \
--clusterrole=kubevirt.io:migrate --user=user1 \
--user=user2 --group=group1

kubectl label --overwrite clusterrole \
kubevirt.io:migrate \
rbac.authorization.k8s.io/aggregate-to-admin=true
```

KubeVirt Razor: "If something is useful for Pods, we should not implement it only for VMs".

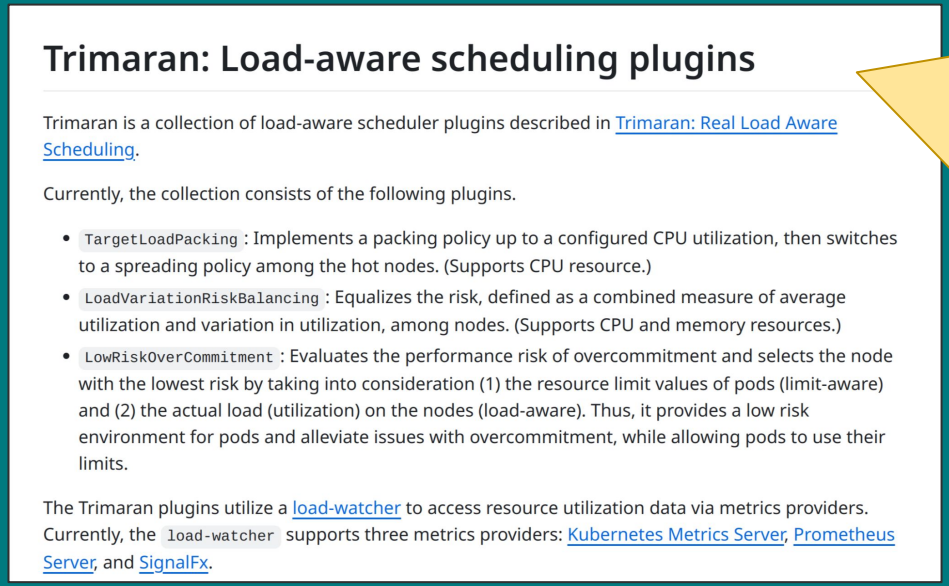
But this is a VM specific topic...

Alternatives: 1 - amend VM node affinity

1. set a (temporary?) nodeSelector/nodeAffinity on the VM
2. wait for it to be propagated to the VMI due to LiveUpdate rollout strategy
3. trigger a live migration with existing APIs (no need for any code change)
4. wait for the migration to complete
5. (eventually) remove the (temporary?) nodeSelector to let the VM be freely migrate to any node in the future

- Imperative flow
- Error prone
- It has still to be somehow "orchestrated"
- It can mess with devops/IaC approaches

Alternatives: 2 - configure a secondary scheduler for VMs



Trimaran: Load-aware scheduling plugins

Trimaran is a collection of load-aware scheduler plugins described in Trimaran: Real Load Aware Scheduling.

Currently, the collection consists of the following plugins.

- `TargetLoadPacking`: Implements a packing policy up to a configured CPU utilization, then switches to a spreading policy among the hot nodes. (Supports CPU resource.)
- `LoadVariationRiskBalancing`: Equalizes the risk, defined as a combined measure of average utilization and variation in utilization, among nodes. (Supports CPU and memory resources.)
- `LowRiskOverCommitment`: Evaluates the performance risk of overcommitment and selects the node with the lowest risk by taking into consideration (1) the resource limit values of pods (limit-aware) and (2) the actual load (utilization) on the nodes (load-aware). Thus, it provides a low risk environment for pods and alleviate issues with overcommitment, while allowing pods to use their limits.

The Trimaran plugins utilize a load-watcher to access resource utilization data via metrics providers. Currently, the `load-watcher` supports three metrics providers: Kubernetes Metrics Server, Prometheus Server, and SignalFx.

- Yes, but...
  - The cluster admin should deploy the **custom scheduler**
  - **Each individual VM** should be configured to be scheduled by the secondary scheduler and VM owners or devops flows could revert it
- Still only about scheduling according to static **reservation** (by default 1/10 of allocated cores), not actual utilization
- It's **not going to continuous rebalance the cluster** according to changes in the usage patterns

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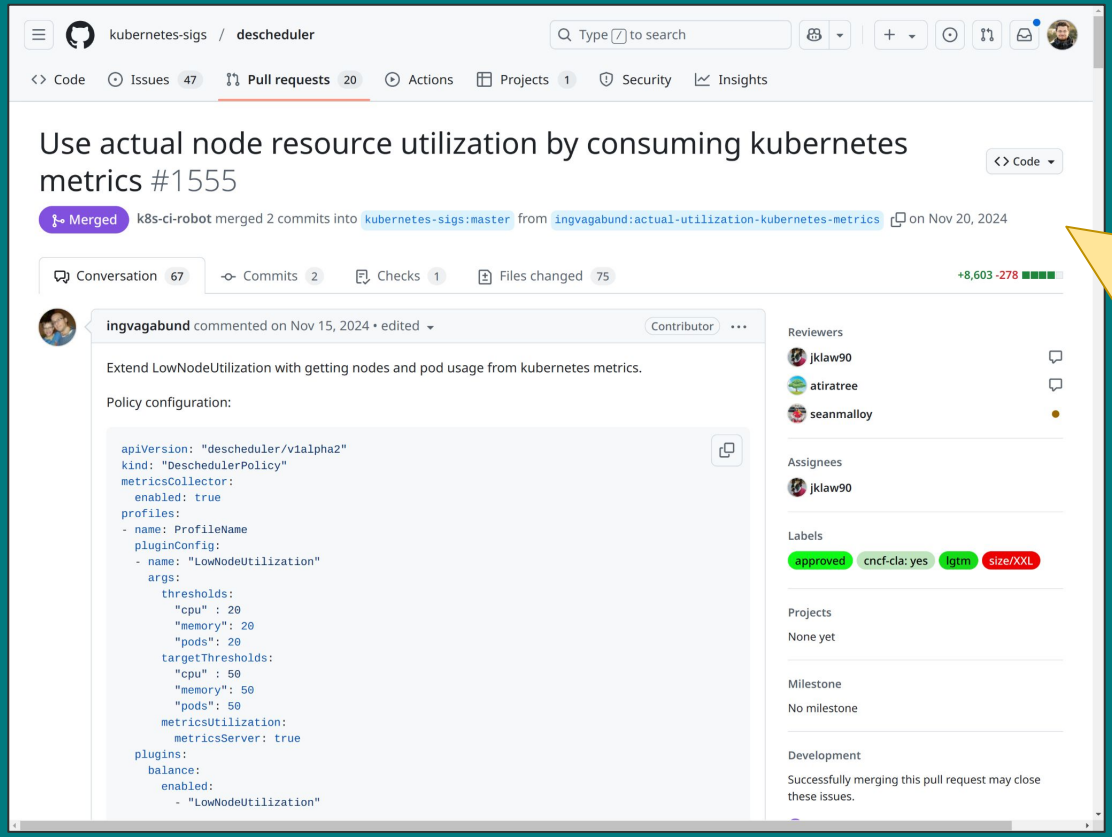
Alternatives: 3 - use Kube Descheduler for automatic workload rebalancing

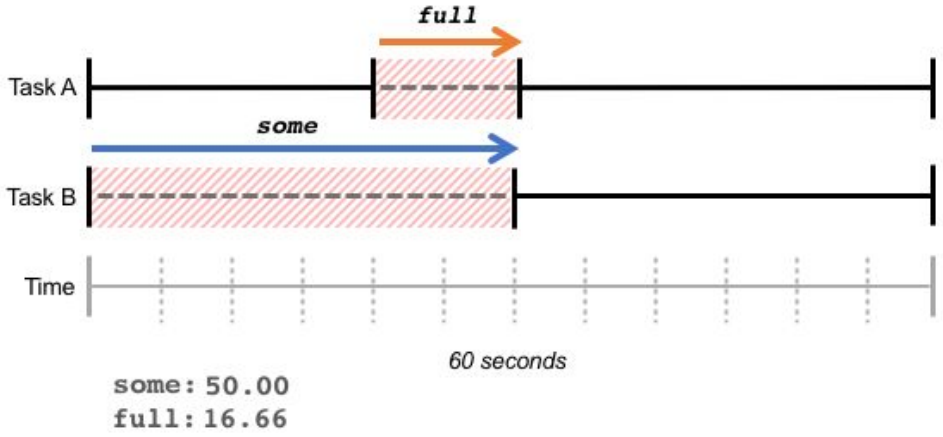


- Now (nov '24) also **load-aware**, before only based on reservation
- Only about **descheduling**: it will not influence the scheduling of the migration target pod
- Likely the smartest option on large clusters, overkilling on small environments (currently it's only an **optional** component)?

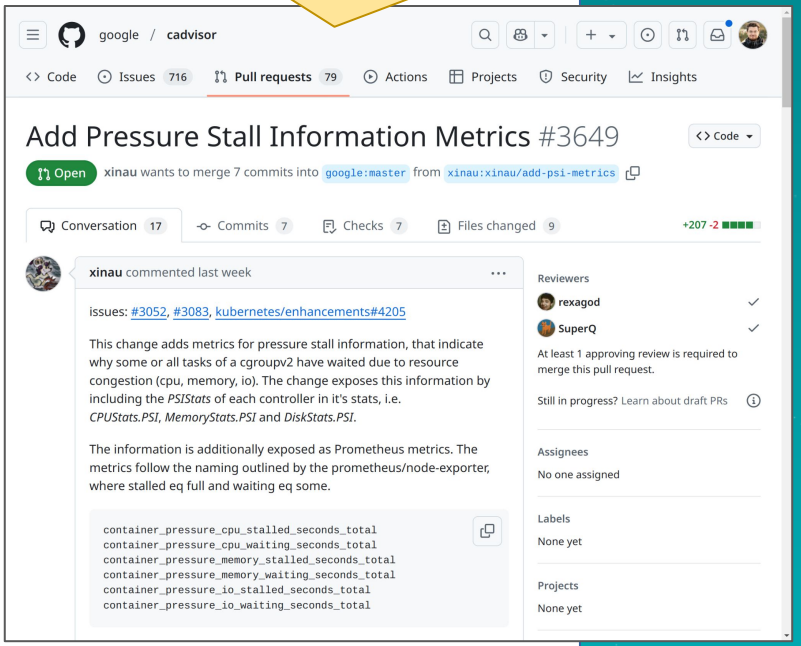
Load aware descheduling: One more thing...

Consume Pressure Stall Information (PSI) metrics

- Novel (>= Kernel 4.20) canonical pressure metrics for three major resources: memory, CPU, and IO.
- Reported at node and cgroup slice level
- It's not measuring usage but the actual productivity losses caused by resource scarcity



cAdvisor integration is still in progress...



Questions?
Comments?

As users,
make your voice heard!!!