DaoCloud

AI 进阶指南：GPU 故障不求人

主讲人：朱争光

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Part 01

故障排查思路

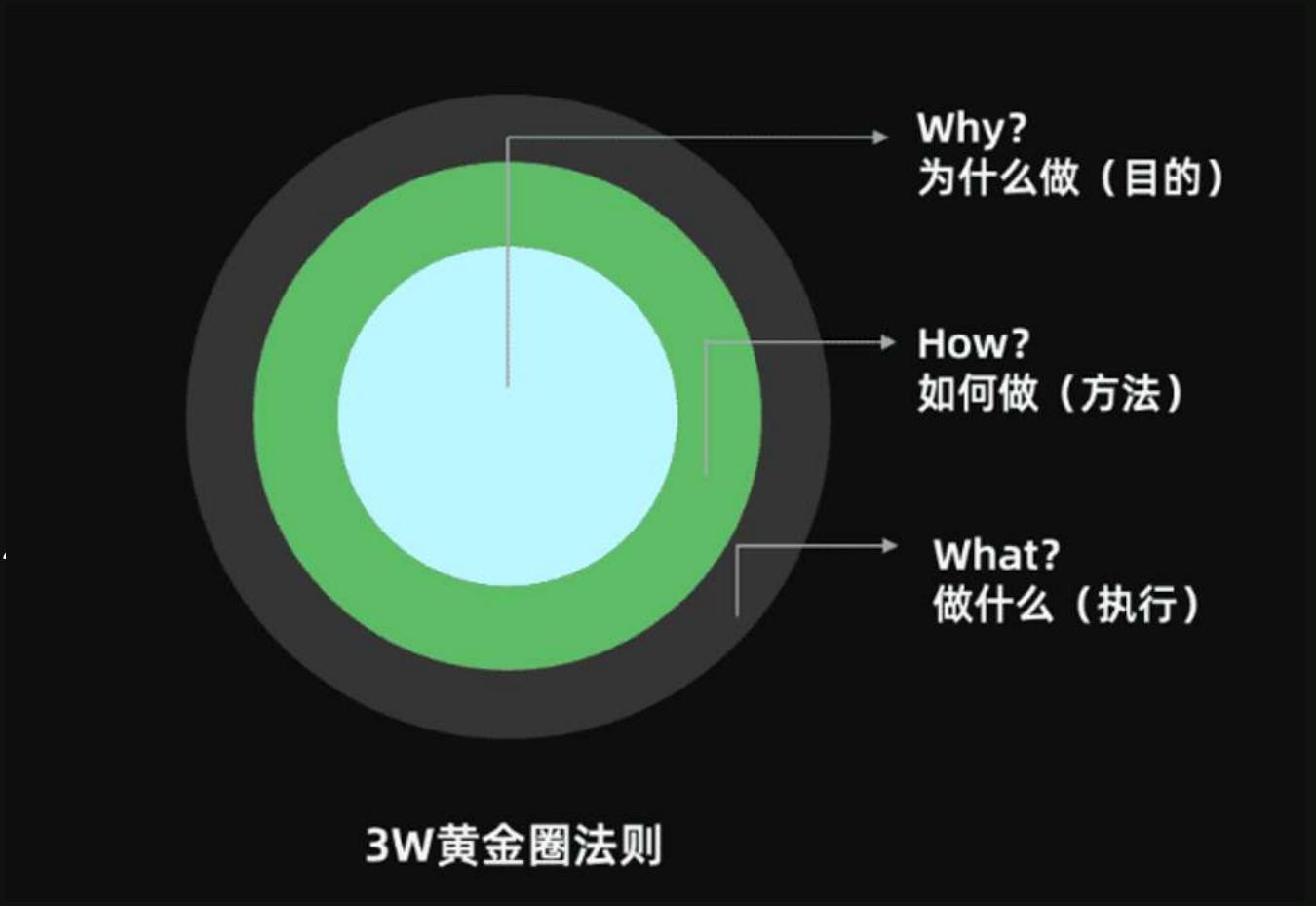
如何维护好一个系统？

个人总结的知识学习方式

WHAT 知道是什么 --- 了解

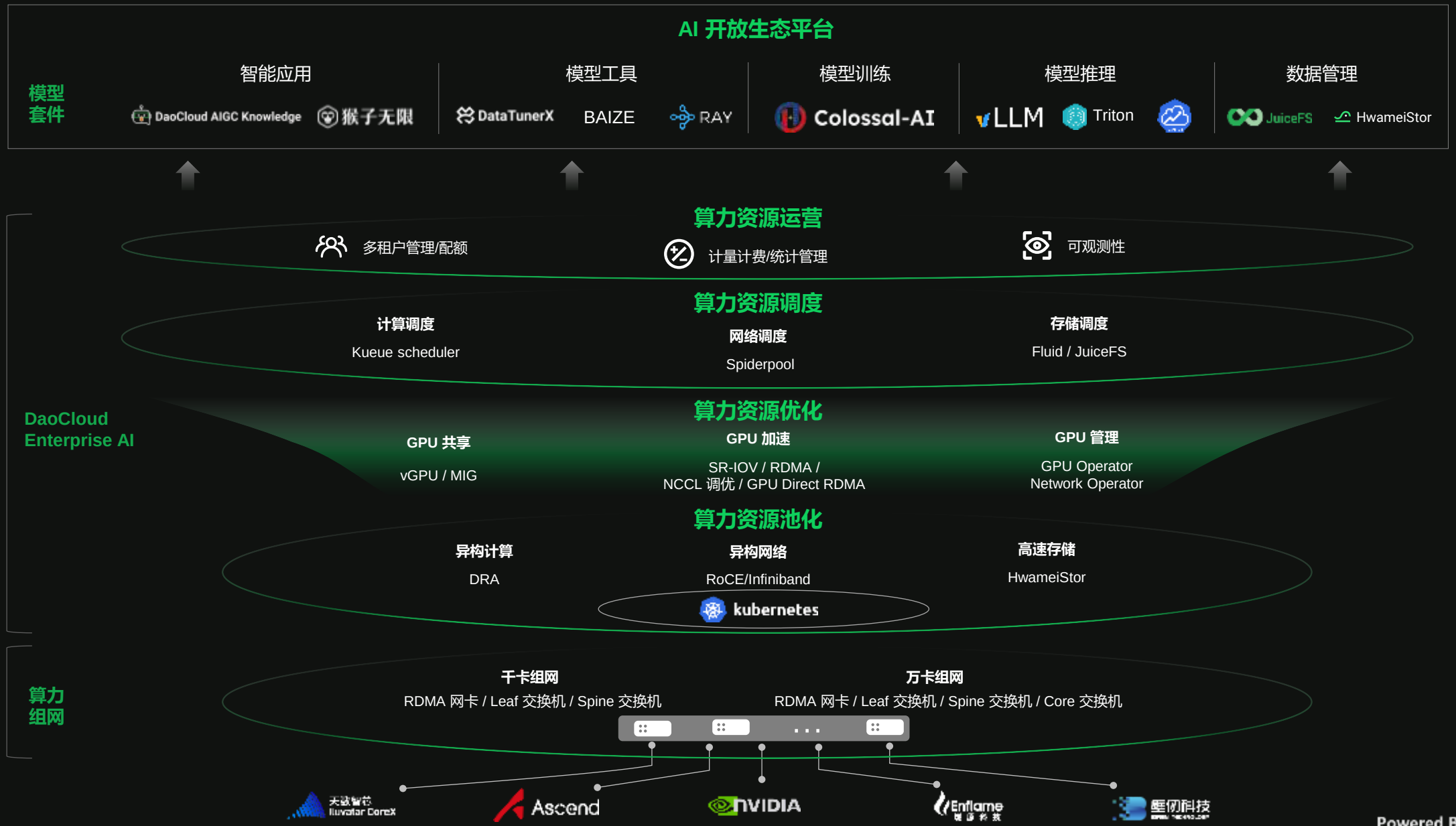
HOW 怎么（安装）使用 --- 熟悉

WHY 底层是如何实现的？ --- 精通



AI 应用通过容器高效使用 GPU 需要啥？

d.run 产品全景图



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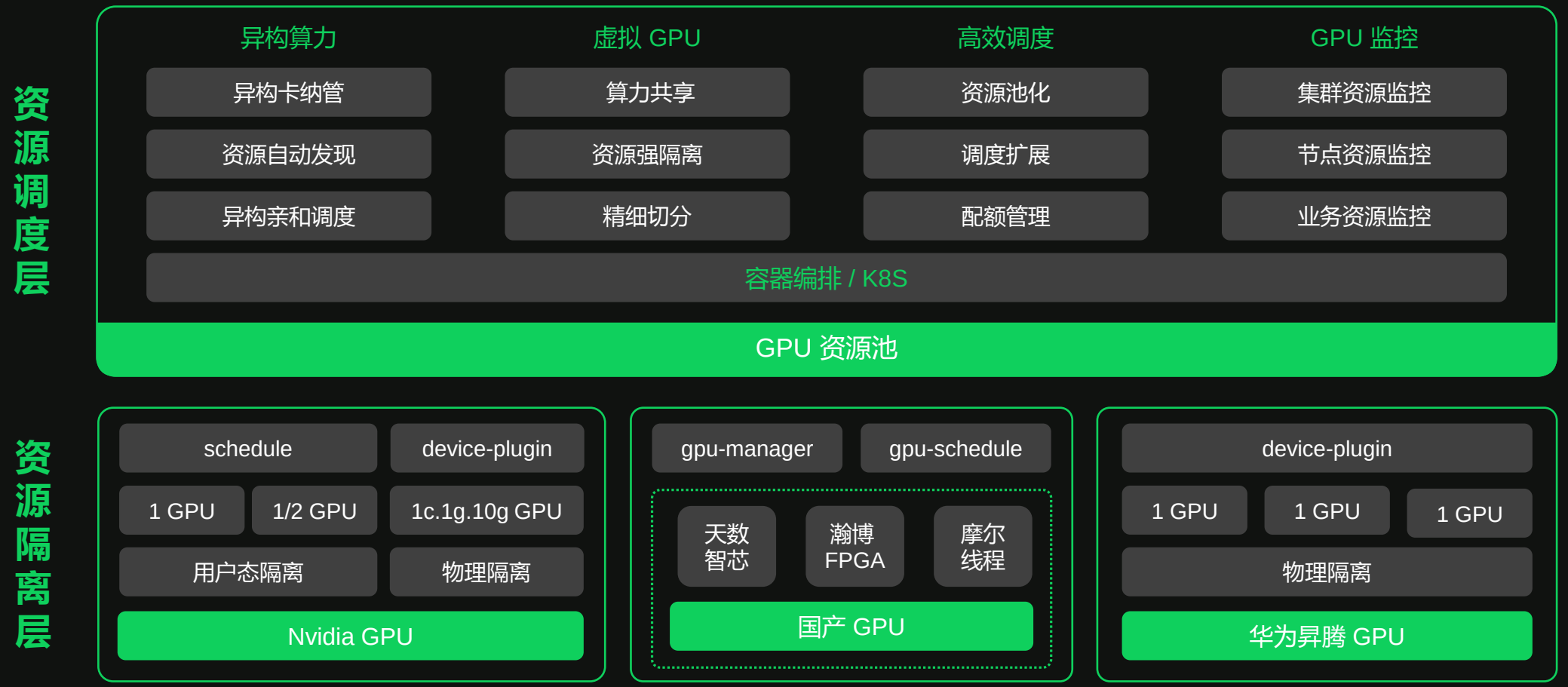
算力资源池化现状

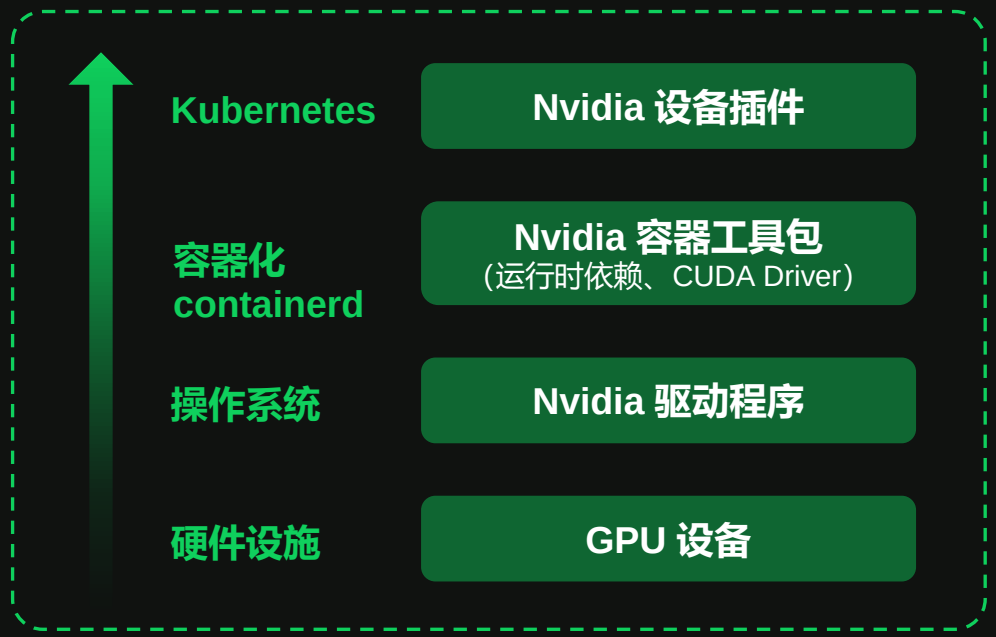


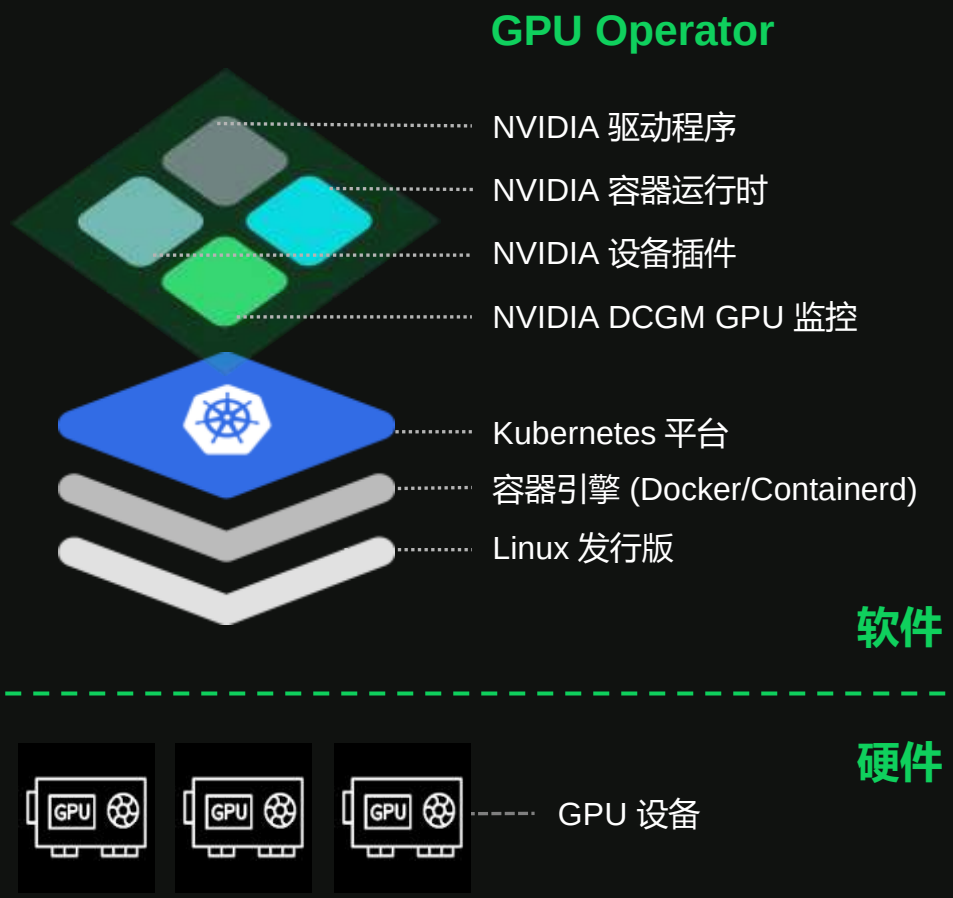
GPU 池化各家做法大致类似，今天我们以目前应用最广泛的 Nvidia Operator 为例来讲解

这次只聊 NVIDIA GPU Operator 😅

GPU Operator - 自动管理并提供 GPU 所需的所有 NVIDIA 软件组件

- **NVIDIA 设备插件** - 通过设备插件机制将 GPU 公开给 Kubelet
- **NVIDIA 容器工具包** ：实现容器化环境中与 GPU 进行交互
- **GPU 驱动程序**：Nvidia 驱动程序组件允许从容器进行驱动安装
- **NVIDIA GPU 功能发现**：检测并标记启用 GPU 的节点
- **NVIDIA DCGM GPU 监控** ： 采集 GPU 指标





Part 02

安装使用

安装GPU Operator

1. Add the NVIDIA Helm repository:

```
$ helm repo add nvidia https://helm.ngc.nvidia.com/nvidia \
    && helm repo update
```

2. Install the GPU Operator.

- Install the Operator with the default configuration:

```
$ helm install --wait --generate-name \
    -n gpu-operator --create-namespace \
    nvidia/gpu-operator
```

推荐：

系统：ubuntu 22.04

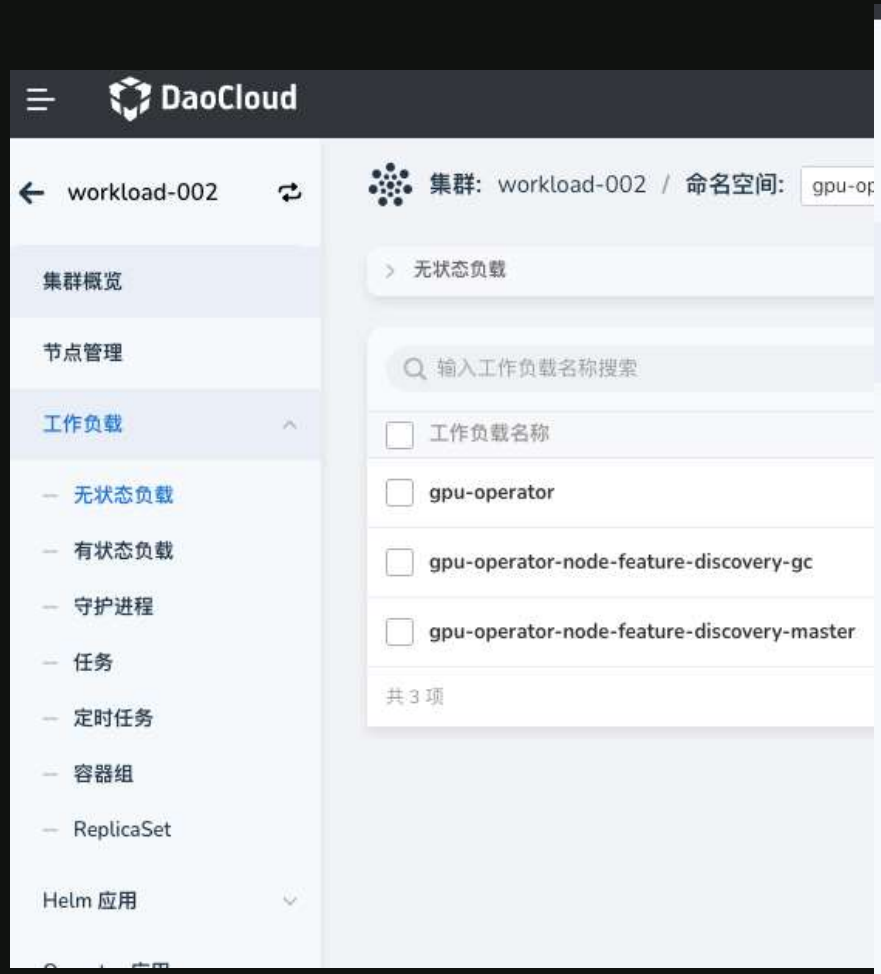
容器: containerD

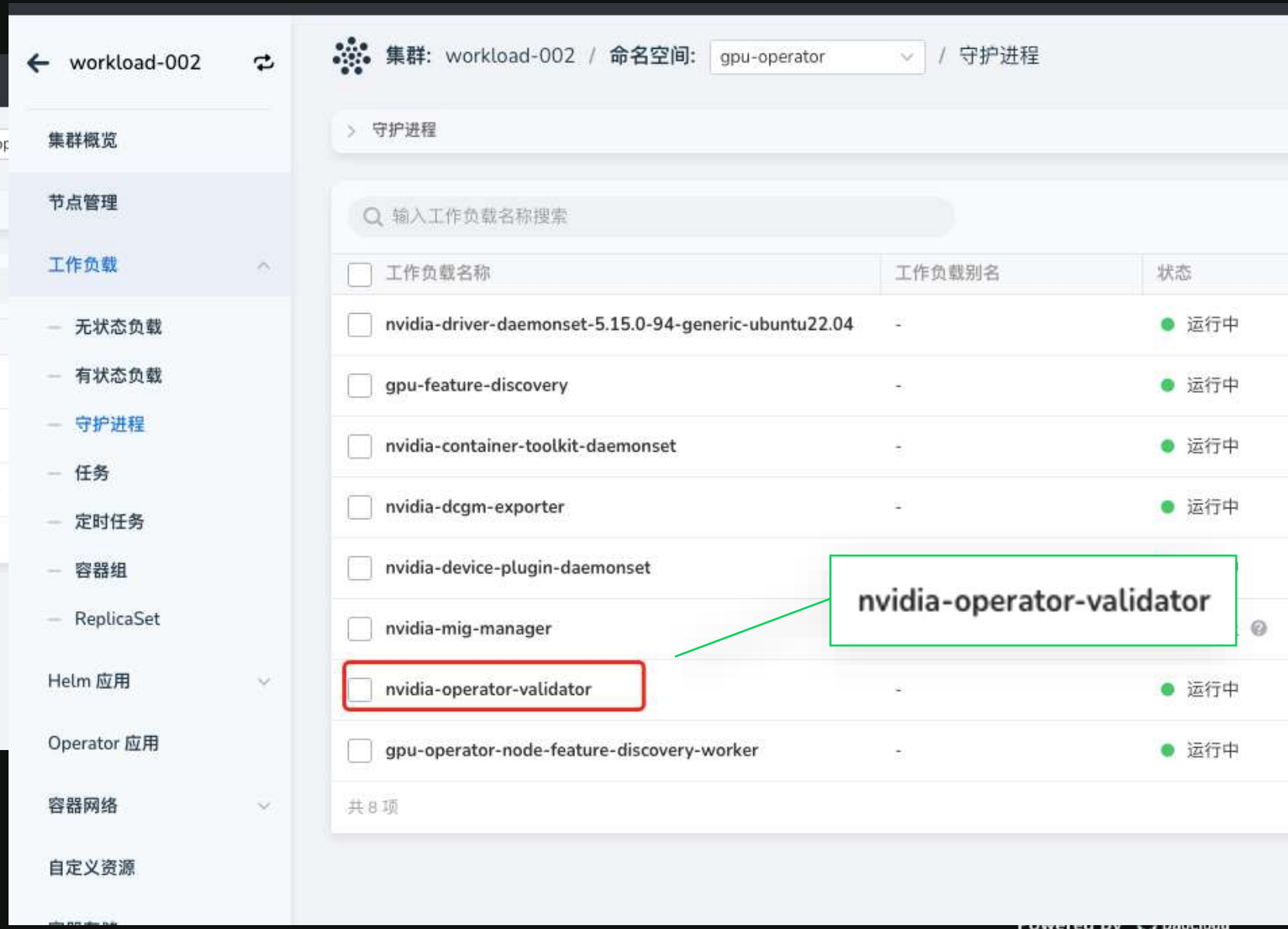
K8s: 1.29+

driver.enabled
driver.usePrecompiled
toolkit.enabled
driver.version
toolkit.version

官网: https://docs.nvidia.com/datacenter/cloud-native/gpu-operator/latest/getting-started.html

安装完成后的效果


DaoCloud
workload-002
集群概览
节点管理
工作负载
无状态负载
有状态负载
守护进程
任务
定时任务
容器组
ReplicaSet
Helm 应用
集群: workload-002 / 命名空间: gpu-op
无状态负载
输入工作负载名称搜索
工作负载名称
gpu-operator
gpu-operator-node-feature-discovery-gc
gpu-operator-node-feature-discovery-master
共 3 项


workload-002
集群概览
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任务
定时任务
容器组
ReplicaSet
Helm 应用
Operator 应用
容器网络
自定义资源
集群: workload-002 / 命名空间: gpu-operator / 守护进程
守护进程
输入工作负载名称搜索
工作负载名称
工作负载别名
状态
nvidia-driver-daemonset-5.15.0-94-generic-ubuntu22.04
gpu-feature-discovery
nvidia-container-toolkit-daemonset
nvidia-dcgm-exporter
nvidia-device-plugin-daemonset
nvidia-mig-manager
nvidia-operator-validator
gpu-operator-node-feature-discovery-worker
运行中
共 8 项
nvidia-operator-validator

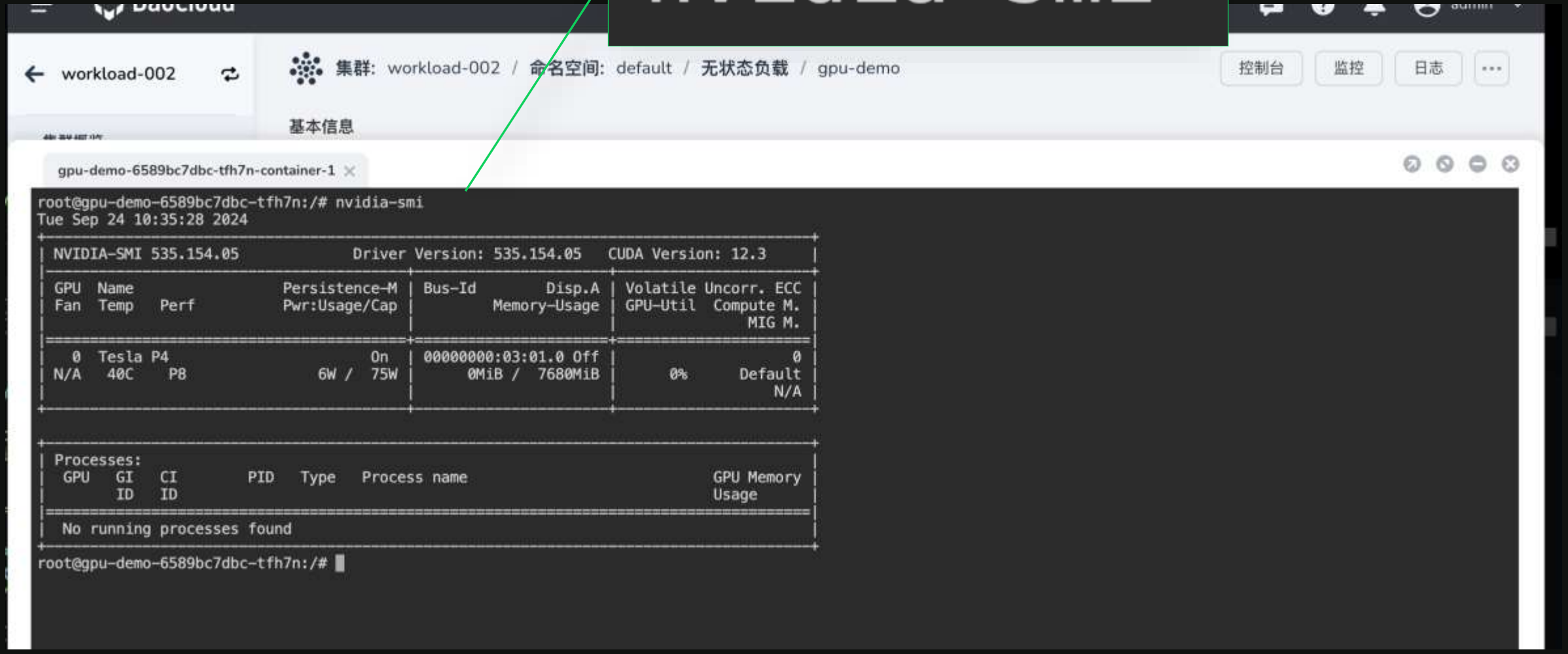
如何使用

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: cuda-vectoradd
spec:
  restartPolicy: OnFailure
  containers:
  - name: cuda-vectoradd
    image: "nvcr.io/nvidia/k8s/cuda-sample:vectoradd-cuda11.7.1-ubuntu2
    resources:
      limits:
        nvidia.com/gpu: 1
```

nvidia.com/gpu: 1

测试

nvidia-smi



Part 03

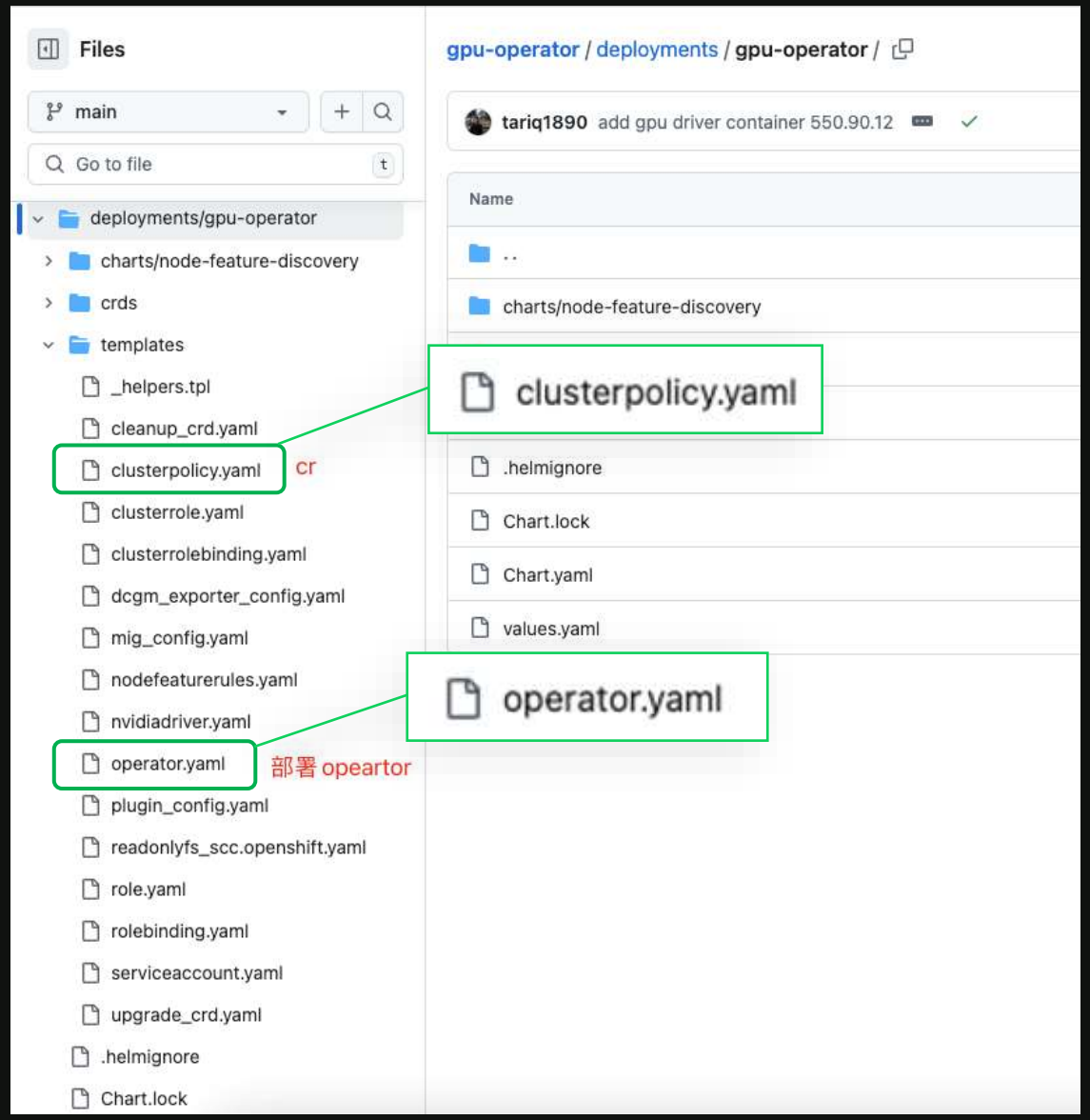
GPU Operator 原理

安装命令底层层执行了啥？

Helm 包大致逻辑：

1. 安装 operator 和 node-feature-discovery 模块
2. 创建 cr 和配置文件

然后 operator 会根据 cr 完成剩余安装

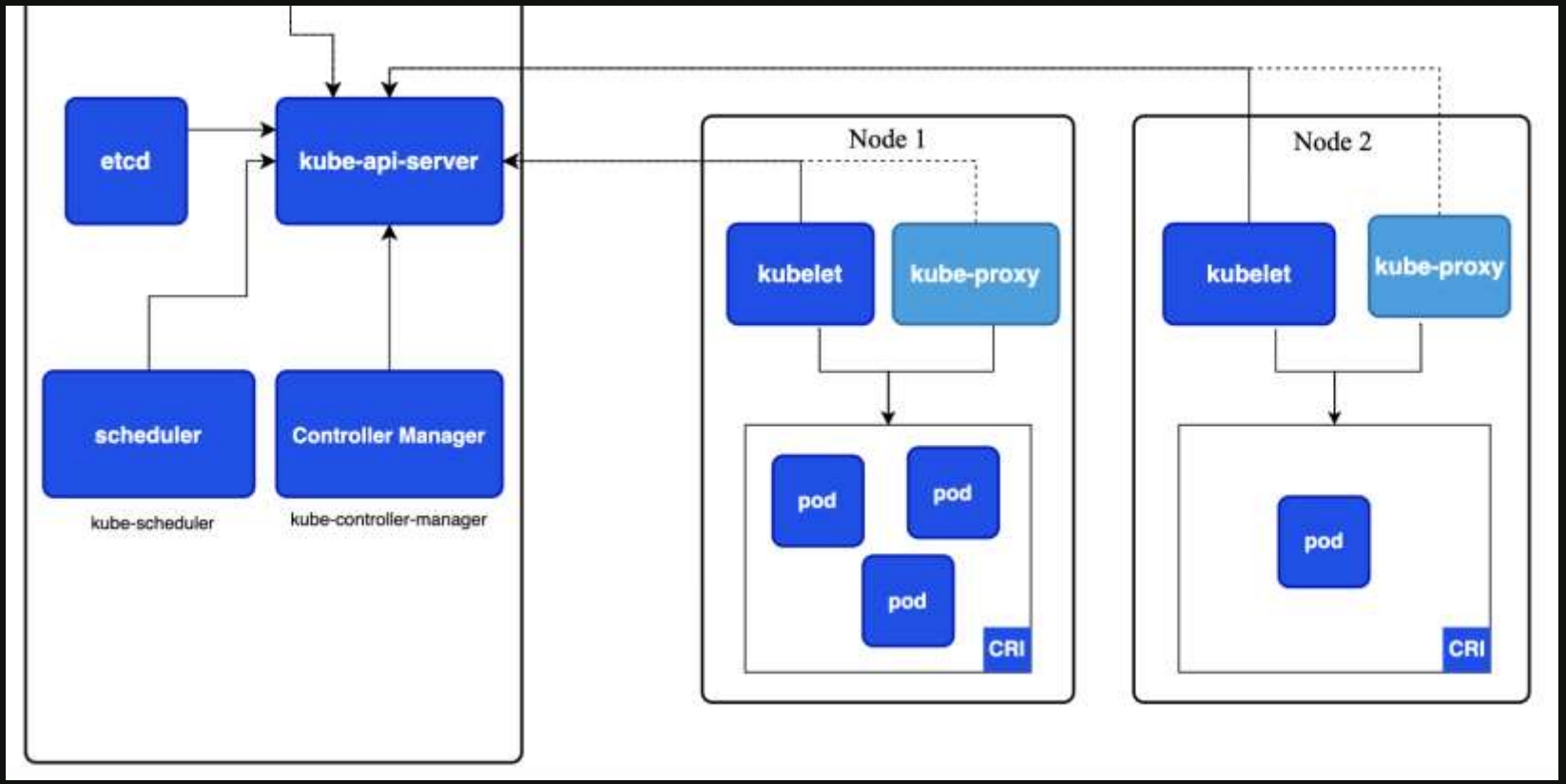


https://github.com/NVIDIA/gpu-operator/tree/main/deployments/gpu-operator

GPU Operator 如何完成剩余任务的？

Gpu operator: 根据 ClusterPolicy 的配置，创建各组件的 ds，一般是：

- Driver
- Container-toolkit
- Device-plugin
- Node-feature discovery
- Dcgm-exporter
- Validator



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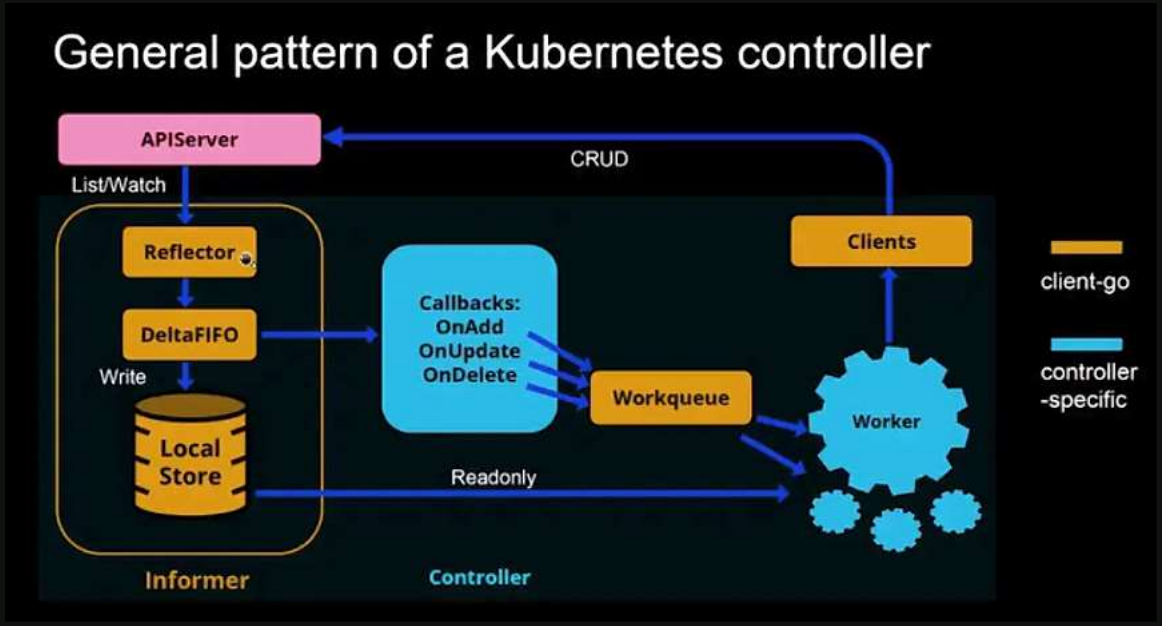



```
root@m-10-17-16-18:~# kubectl get clusterpolicies.nvidia.com/cluster-po
apiVersion: nvidia.com/v1
kind: ClusterPolicy
metadata:
  annotations:
    meta.helm.sh/release-name: gpu-operator
    meta.helm.sh/release-namespace: gpu-operator
  creationTimestamp: "2024-08-30T05:03:24Z"
  generation: 3
  labels:
    app.kubernetes.io/component: gpu-operator
    app.kubernetes.io/instance: gpu-operator
    app.kubernetes.io/managed-by: Helm
    app.kubernetes.io/name: gpu-operator
    app.kubernetes.io/version: v23.9.0
    helm.sh/chart: gpu-operator-v23.9.0
  name: cluster-policy
  resourceVersion: "12931634"
  uid: 68be3737-14d5-43f1-9041-63c4b58606c6
spec:
  ccManager:
    defaultMode: "off"
    enabled: false
    env: []
    image: nvidia/cloud-native/k8s-cc-manager
    imagePullPolicy: IfNotPresent
    repository: 10.17.16.10/nvcr.m.daocloud.io
    version: v0.1.1
  cdi:
    default: true
    enabled: true
  daemonsets:
    labels:
      app.kubernetes.io/managed-by: gpu-operator
      helm.sh/chart: gpu-operator-v23.9.0
    priorityClassName: system-node-critical
    rollingUpdate:
      maxUnavailable: "1"
    tolerations:
    - effect: NoSchedule
      key: nvidia.com/gpu
      operator: Exists
    updateStrategy: RollingUpdate
  dcgm:
    enabled: false
    hostPort: 5555
    image: nvidia/cloud-native/dcgm
    imagePullPolicy: IfNotPresent
    repository: 10.17.16.10/nvcr.m.daocloud.io
    version: 3.2.6-1-ubuntu20.04
```

Driver 是如何装起来的？

目前 driver 有两种安装方式

1. 通过 clusterPolicy 设置：一般场景
2. 通过 NVIDIADriver 设置：针对不同节点 gpu 和系统存在差异等场景

容器做的事情

1. 初始化: 卸载驱动

driver-manager uninstall_driver

2. 启动: 安装驱动

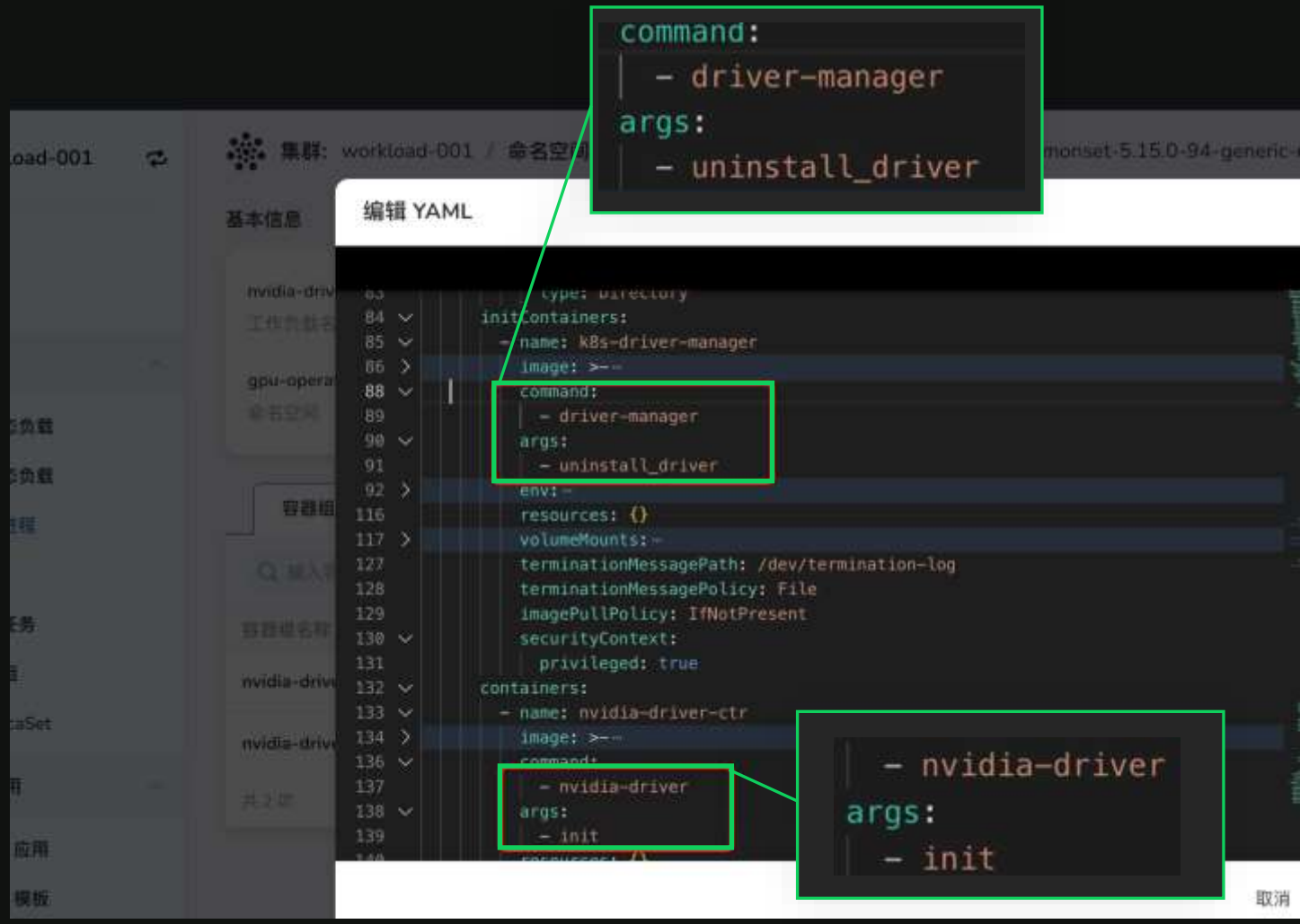
nvidia-driver init

3. 成功后: 创建

/run/nvidia/validations/.driver-ctr-ready

4. 删除 pod 前：

删除/run/nvidia/validations/.driver-ctr-ready



https://docs.nvidia.com/datacenter/cloud-native/gpu-operator/latest/gpu-driver-configuration.html

Driver 预编译安装逻辑-离线安装

容器启动后，执行 nvidia-driver init

安装逻辑：

1. 卸载内核模块：nvidia-drm，nvidia-moneset，nvidia-uvm，nvidia-peermem，nvidia
2. umount /run/nvidia/driver
3. _install_driver: 根据OPEN_KERNEL_MODULES_ENABLED变量安装开源或闭源驱动
   （因为镜像构建时已经执行过，包都缓存了，所以这里不需要联网）
4. _load_driver: 启用内核模块: modprobe nvidia …;启动nvidia-persistenced，nv-fabricmanager
5. **mount /sys 和mount / /run/nvidia/driver**

https://docs.nvidia.com/datacenter/cloud-native/openshift/latest/gpu-operator-with-precompiled-drivers.html
https://github.com/NVIDIA/gpu-driver-container/blob/main/ubuntu22.04/precompiled/nvidia-driver
https://catalog.ngc.nvidia.com/orgs/nvidia/containers/driver/tags

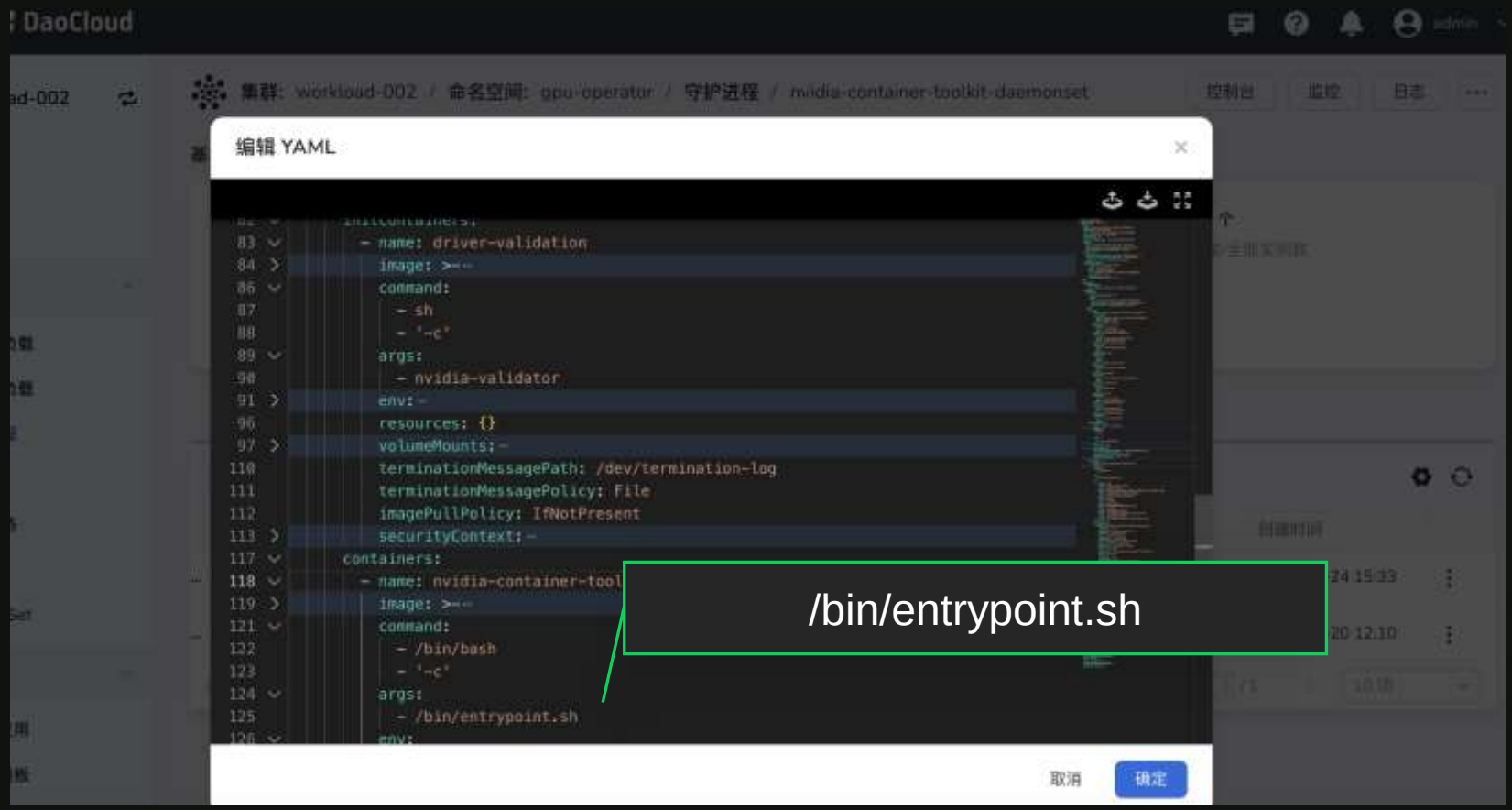
Container toolkit 安装解释

/work/toolkit 执行内容：

1. 安装 runtime
2. 修改 containerd 的配置

增加 runtime 并且设置为默认

3. 触发 contaienrd 重启



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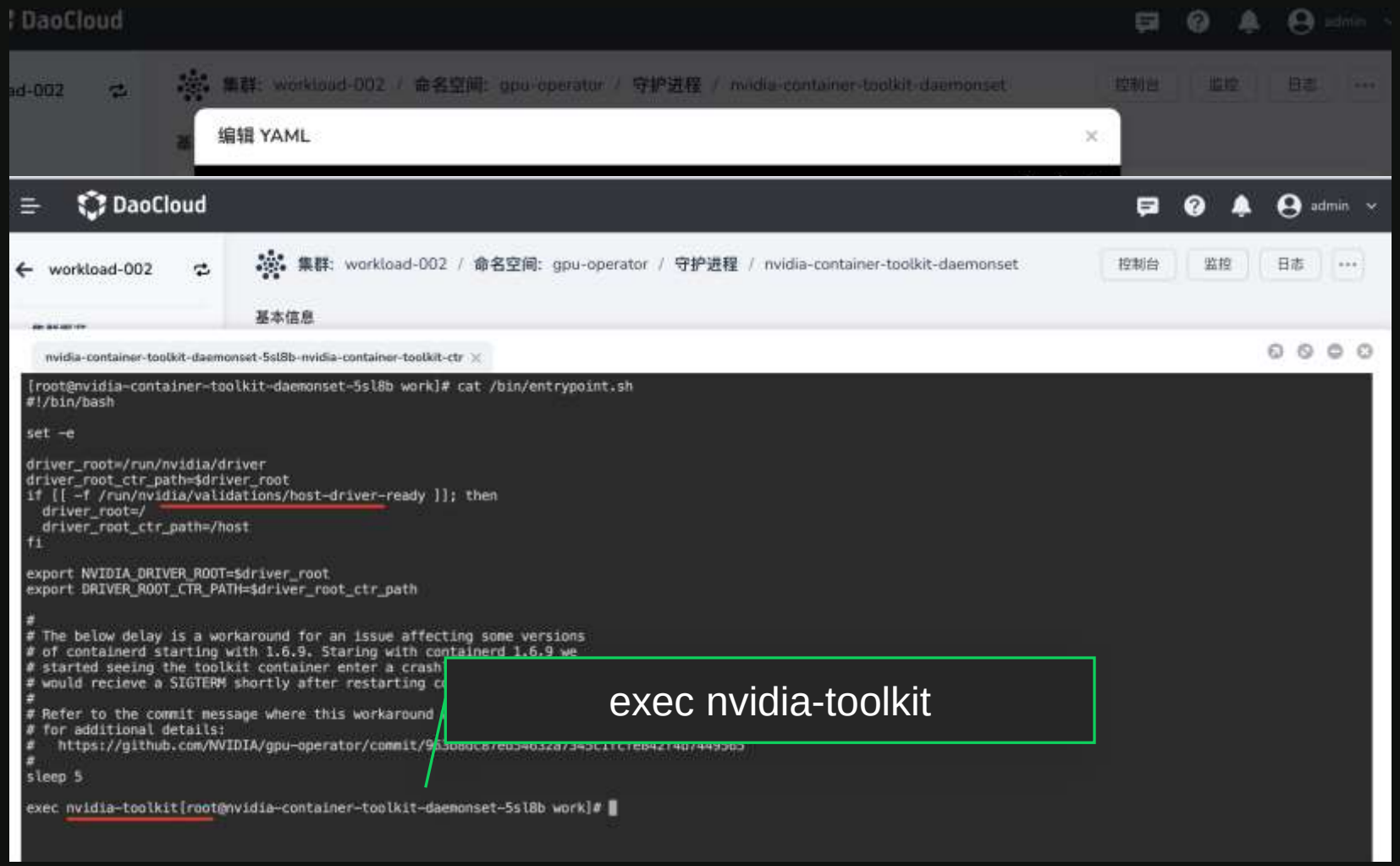

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增加 runtime 并且设置为默认

3. 触发 contaienrd 重启

```
/etc/containerd/config.toml
root@m-10-17-16-18:~# cat /etc/containerd/config.toml
oom_score = 0
root = "/var/lib/containerd"
state = "/run/containerd"
version = 2

[debug]
  level = "info"

[grpc]
  max_recv_message_size = 16777216
  max_send_message_size = 16777216

[metrics]
  address = ""
  grpc_histogram = false

[plugins]

  [plugins."io.containerd.grpc.v1.cri"]
    enable_unprivileged_icmp = false
    enable_unprivileged_ports = false
    max_container_log_line_size = -1
    sandbox_image = "10.17.16.10/regist

    [plugins."io.containerd.grpc.v1.cri".containerd]
      default_runtime_name = "nvidia"
      discard_unpacked_layers = true
      snapshotter = "overlayfs"

      [plugins."io.containerd.grpc.v1.cri".containerd.runtimes]

        [plugins."io.containerd.grpc.v1.cri".containerd.runtimes.nvidia]
          base_runtime_spec = "/etc/containerd/cri-base.json"
          container_annotations = ["nvidia.cdi.k8s.io/*"]
          runtime_engine = ""
          runtime_root = ""
          runtime_type = "io.containerd.runc.v2"

          [plugins."io.containerd.grpc.v1.cri".containerd.runtimes.nvidia.options]
            BinaryName = "/usr/local/nvidia/toolkit/nvidia-container-runtime"
```

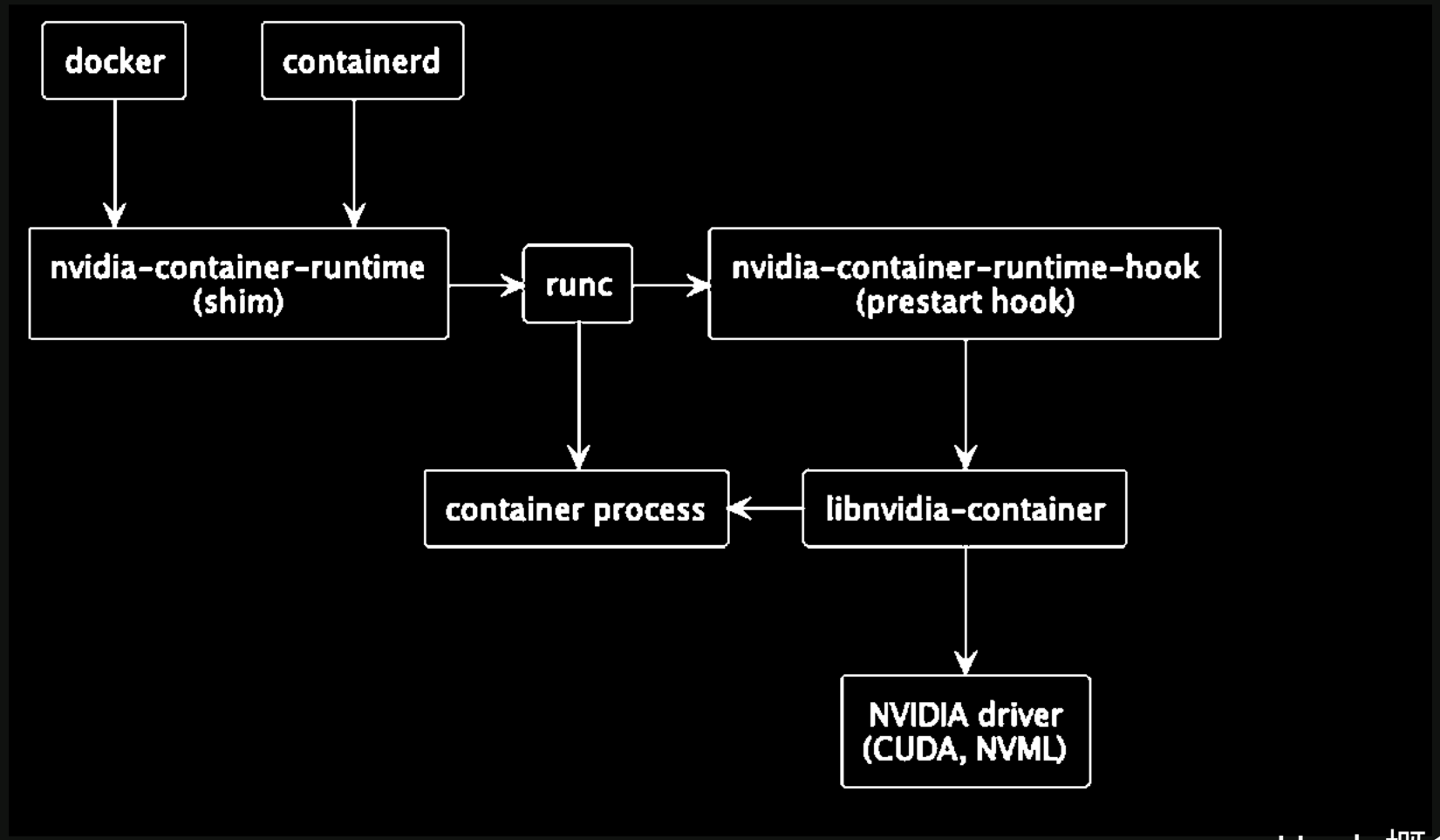
root@m-10-17-16

default_runtime_name = "nvidia"

Container toolkit ：容器如何能运行GPU的？

作用：

让容器内能够使用 gpu



https://github.com/NVIDIA/nvidia-container-toolkit/blob/main/tools/container/README.md
https://docs.nvidia.com/datacenter/cloud-native/container-toolkit/latest/arch-overview.html

Hook 概念?

container toolkit 测试命令

export PATH=$PATH:/usr/local/nvidia/toolkit
echo "/run/nvidia/driver/usr/lib/x86_64-linux-gnu" > /etc/ld.so.conf.d/nvidia.conf
ldconfig
nerdctl run -it --rm --runtime=/usr/local/nvidia/toolkit/nvidia-container-runtime \
--gpus all m.daocloud.io/docker.io/nvidia/cuda:12.3.1-base-ubuntu20.04 nvidia-smi

```
root@m-10-17-16-18:~# nerdctl run -it --rm --runtime=/usr/local/nvidia/toolkit/nvidia-container-runtime --gpus all m.daocloud.io/docker.io/nvid
ia/cuda:12.3.1-base-ubuntu20.04 bash
root@f15313c40a62:/# df -h
Filesystem             Size  Used Avail Use% Mounted on
overlay                 97G   23G   75G  23% /
tmpfs                   64M     0   64M   0% /dev
shm                     64M     0   64M   0% /dev/shm
/dev/mapper/vg0-lv--0   97G   23G   75G  23% /etc/hosts
tmpfs                  7.9G   12K  7.9G   1% /proc/driver/nvidia
overlay                 97G   23G   75G  23% /usr/bin/nvidia-smi
tmpfs                   64M     0   64M   0% /dev/nvidia0
tmpfs                  7.9G     0  7.9G   0% /proc/acpi
tmpfs                  7.9G     0  7.9G   0% /sys/firmware
tmpfs                  7.9G     0  7.9G   0% /sys/devices/virtual/powercap
tmpfs                  7.9G     0  7.9G   0% /proc/scsi
root@f15313c40a62:/# exit
exit
root@m-10-17-16-18:~# nerdctl run -it --rm  m.daocloud.io/docker.io/nvidia/cuda:12.3.1-base-ubuntu20.04 bash
root@5928cc845a92:/# df -h
Filesystem             Size  Used Avail Use% Mounted on
overlay                 97G   23G   75G  23% /
tmpfs                   64M     0   64M   0% /dev
shm                     64M     0   64M   0% /dev/shm
/dev/mapper/vg0-lv--0   97G   23G   75G  23% /etc/hosts
tmpfs                  7.9G     0  7.9G   0% /proc/acpi
tmpfs                  7.9G     0  7.9G   0% /sys/firmware
tmpfs                  7.9G     0  7.9G   0% /sys/devices/virtual/powercap
tmpfs                  7.9G     0  7.9G   0% /proc/scsi
root@5928cc845a92:/#
```

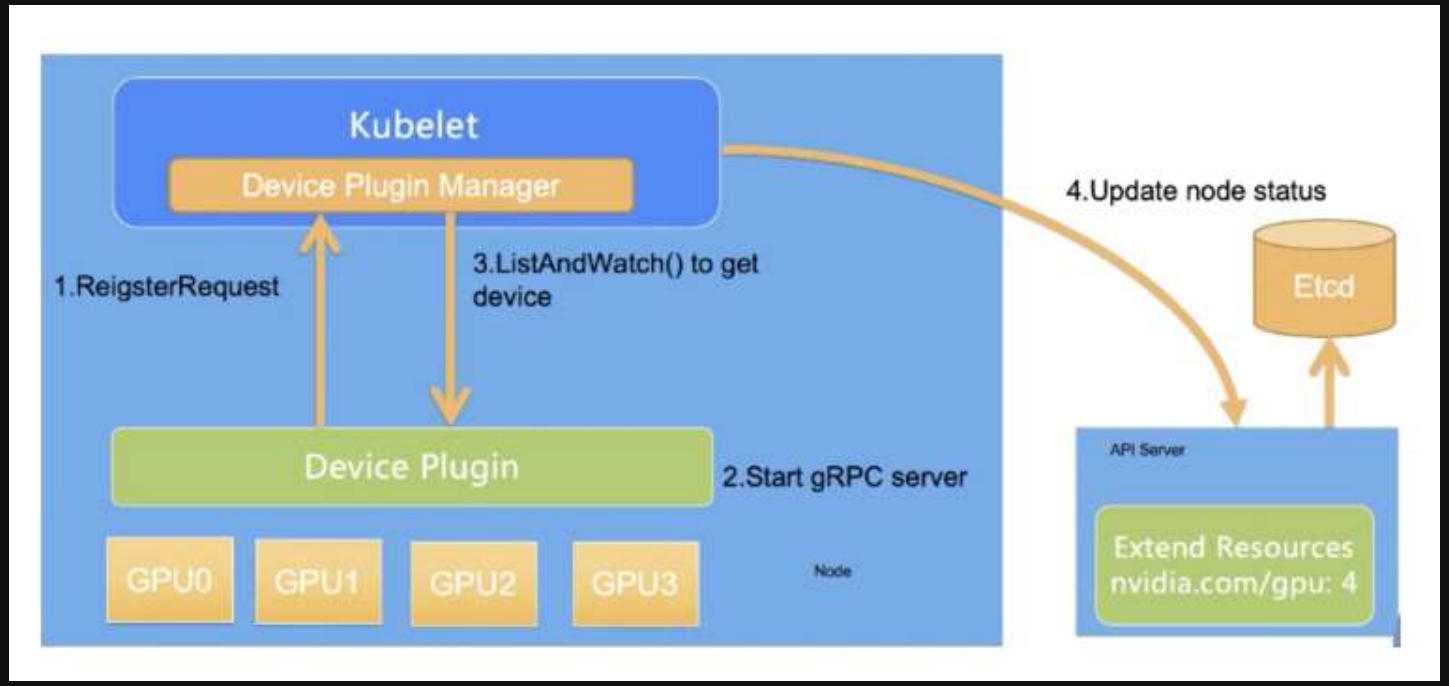
/proc/driver/nvidia
/usr/bin/nvidia-smi
/dev/nvidia0

K8s device plugin: K8s 如何运行GPU的

K8S 提供了device plugin 机制，可以扩展自定义的设备

大概的过程：

1. 插件程序按实现规范启动 grpc 服务
2. 然后插件程序向 kubelet 注册自己
3. kubelet 调用插件获取设备信息，更新到 node
4. 当部署 pod 指定了某个设备时，kubelet 调用插件程序完成容器附加设备的动作



https://kubernetes.io/zh-cn/docs/concepts/extend-kubernetes/compute-storage-net/device-plugins/

K8s device plugin 检查方式

kubectl get node m-10-17-16-18 -oyaml|grep allocatable: -C 10

可以看到对应的设备信息

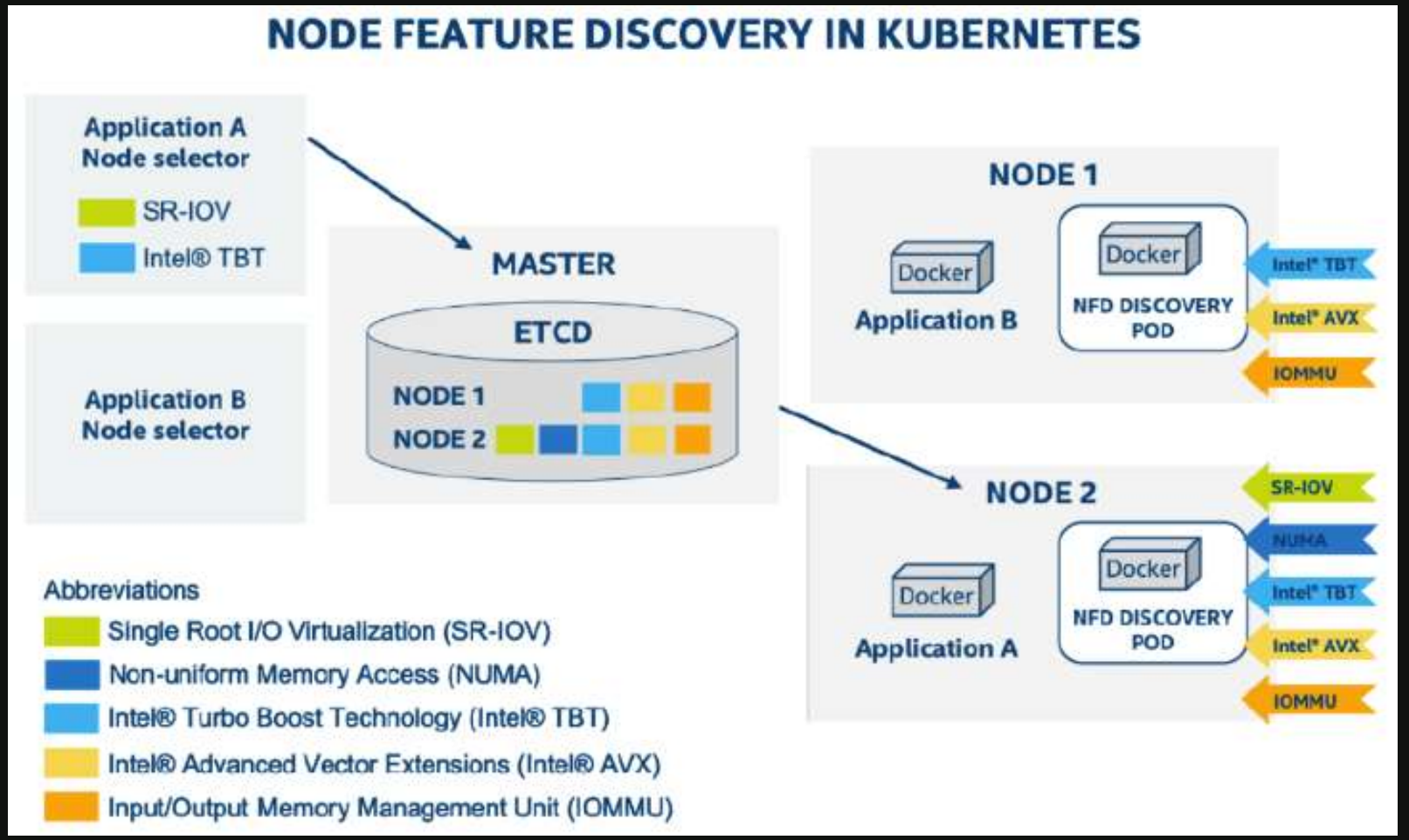
```
root@m-10-17-16-18:~# kubectl get node m-10-17-16-18 -oyaml|grep allocatable: -C 10
  name: m-10-17-16-18
  resourceVersion: "14012050"
  uid: 3d8b2ffd-8479-43b9-a3e4-8fa455a8ecdc
spec: {}
status:
  addresses:
  - address: 10.17.16.18
    type: InternalIP
  - address: m-10-17-16-18
    type: Hostname
  allocatable:
    cpu: 7800m
    ephemeral-storage: "93639068313"
    hugepages-1Gi: "0"
    hugepages-2Mi: "0"
    memory: 15745052Ki
    nvidia.com/gpu: "1"
    pods: "110"
  capacity:
```

Feature discovery： K8s 如何选择特定的GPU卡

NFD-Master：是一个**负责**与 kubernetes API Server 通信的 Deployment Pod，它从 NFD-Worker 接收**节**点特性并相**应**地修改 Node **资**源**对**象（**标签**、注解）。

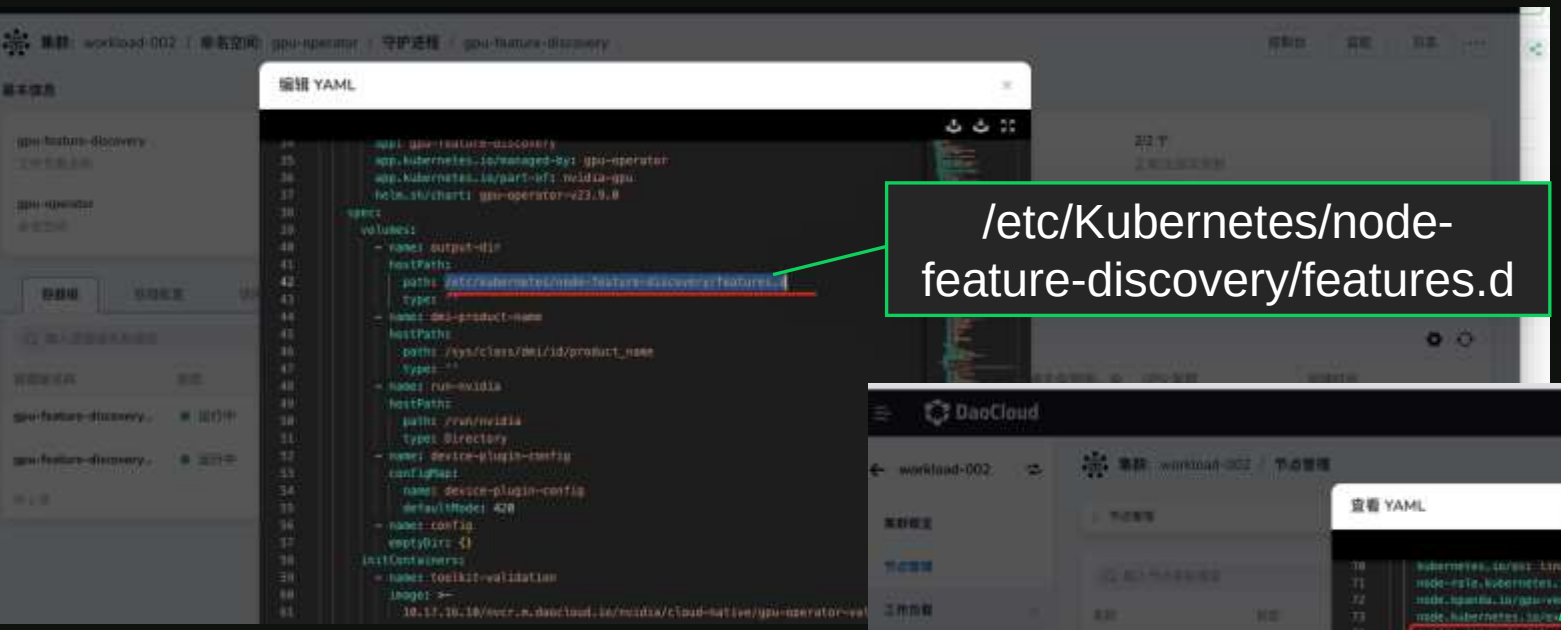
NFD-Worker：是一个**负责对** Node 的特性能力**进**行**检测**的 Daemon Pod，然后它将信息**传递给** NFD-Master，NFD-Worker **应该**在每个 Node 上运行。

NFD 插件: 根据**规**范，把自己的**设备**特性写入到特定目**录**



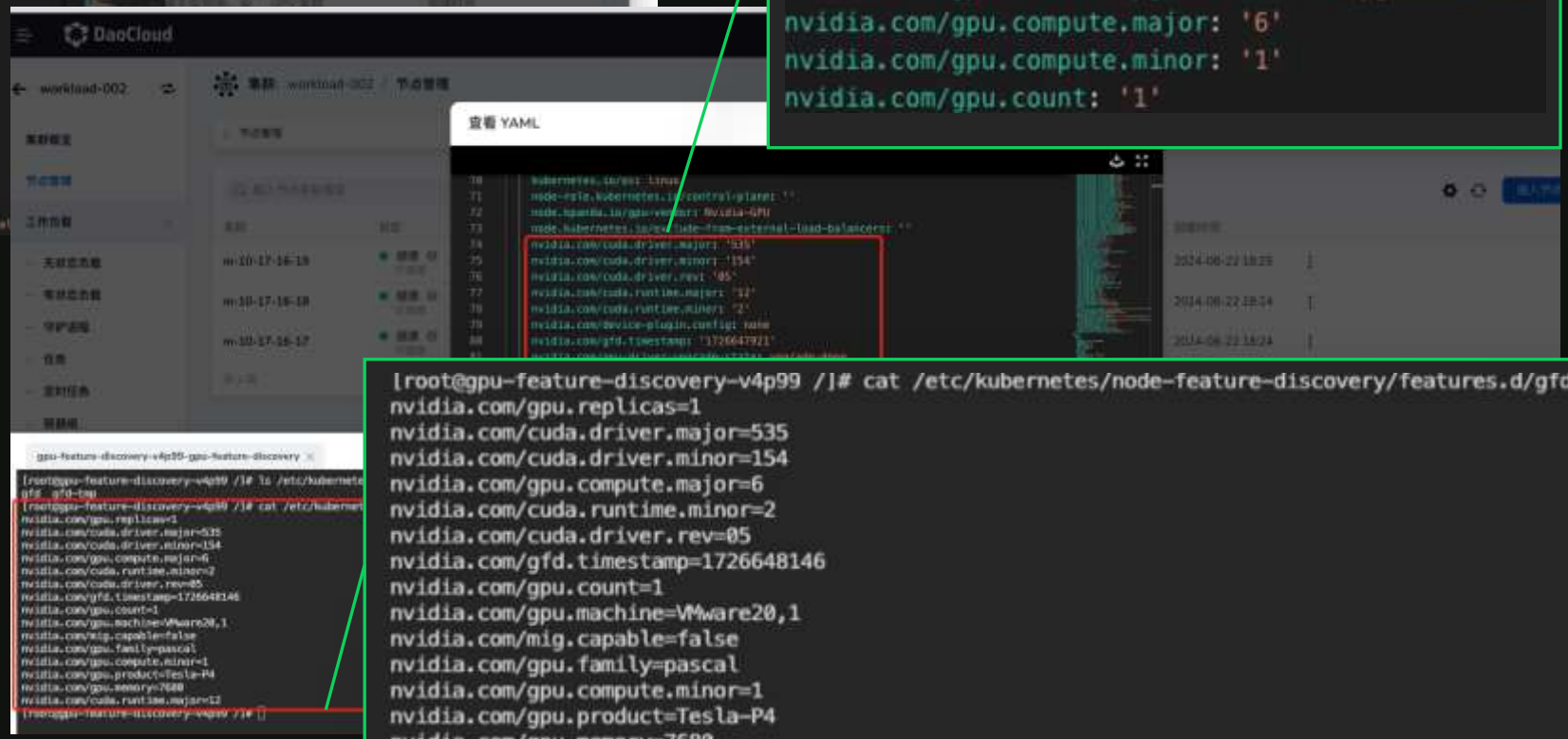
https://www.cnblogs.com/zhangmingcheng/p/18072751

Feature discovery 安装后如何确认和排查



/etc/Kubernetes/node-feature-discovery/features.d

```
nvidia.com/cuda.driver.major: '535'
nvidia.com/cuda.driver.minor: '154'
nvidia.com/cuda.driver.rev: '05'
nvidia.com/cuda.runtime.major: '12'
nvidia.com/cuda.runtime.minor: '2'
nvidia.com/device-plugin.config: none
nvidia.com/gfd.timestamp: '1726647921'
nvidia.com/gpu-driver-upgrade-state: upgrade-done
nvidia.com/gpu.compute.major: '6'
nvidia.com/gpu.compute.minor: '1'
nvidia.com/gpu.count: '1'
```



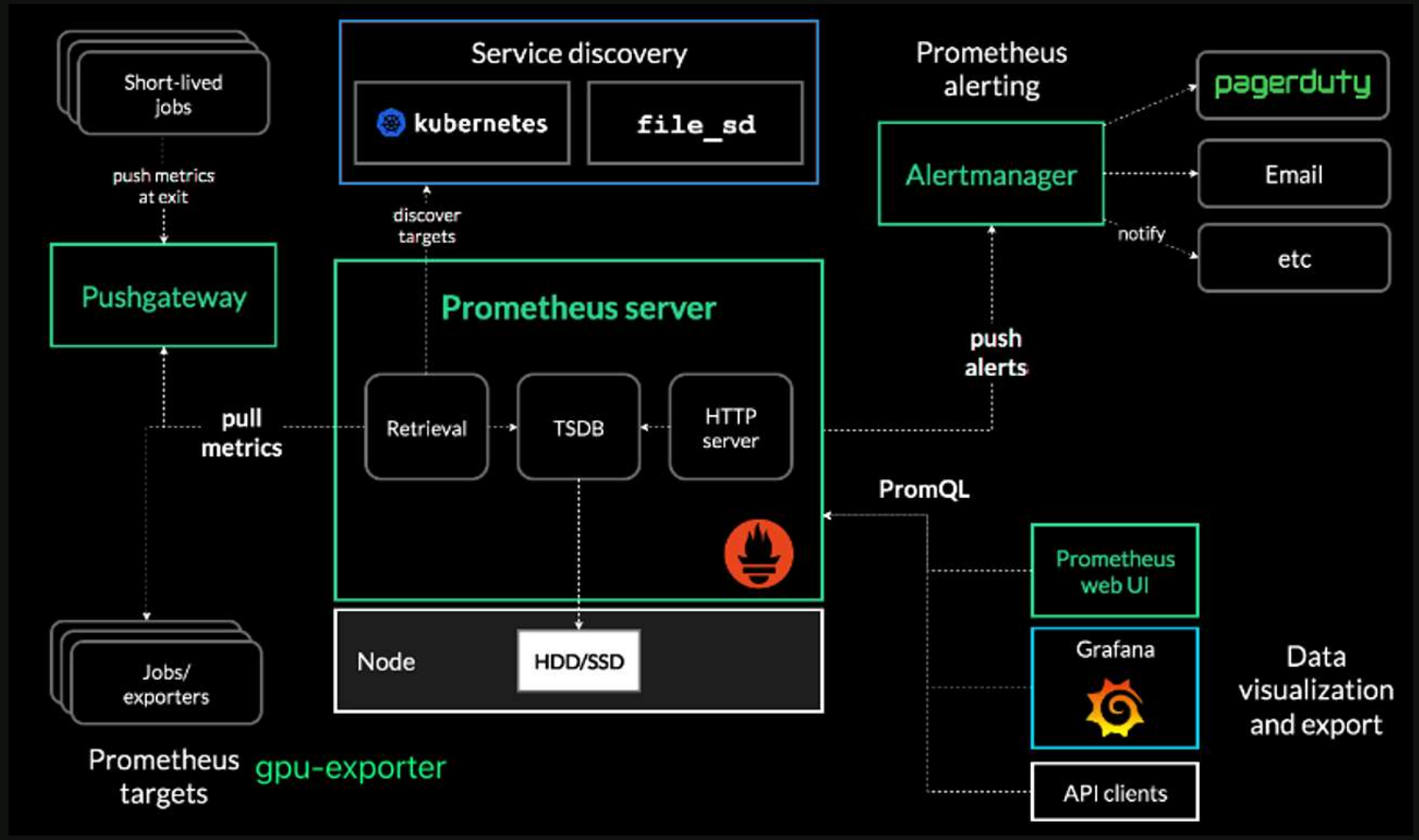
查看gpu-feature-discovery pod 的配置目录

1. 检查配置目录是否有文件
2. 节点是否能够看到对应标签

```
[root@gpu-feature-discovery-v4p99 /]# cat /etc/kubernetes/node-feature-discovery/features.d/gfd
nvidia.com/gpu.replicas=1
nvidia.com/cuda.driver.major=535
nvidia.com/cuda.driver.minor=154
nvidia.com/gpu.compute.major=6
nvidia.com/cuda.runtime.minor=2
nvidia.com/cuda.driver.rev=05
nvidia.com/gfd.timestamp=1726648146
nvidia.com/gpu.count=1
nvidia.com/gpu.machine=VMware20,1
nvidia.com/mig.capable=false
nvidia.com/gpu.family=pascal
nvidia.com/gpu.compute.minor=1
nvidia.com/gpu.product=Tesla-P4
nvidia.com/gpu.memory=7680
nvidia.com/cuda.runtime.major=12
```

dcgm-exporter: gpu 监控数据如何采集的

dcgm-exporter 暴露监控指标, 并通过 ServiceMonitor 发现自己



https://github.com/NVIDIA/dcgm-exporter
https://github.com/NVIDIA/go-dcgm
https://juejin.cn/post/6942457366482780191

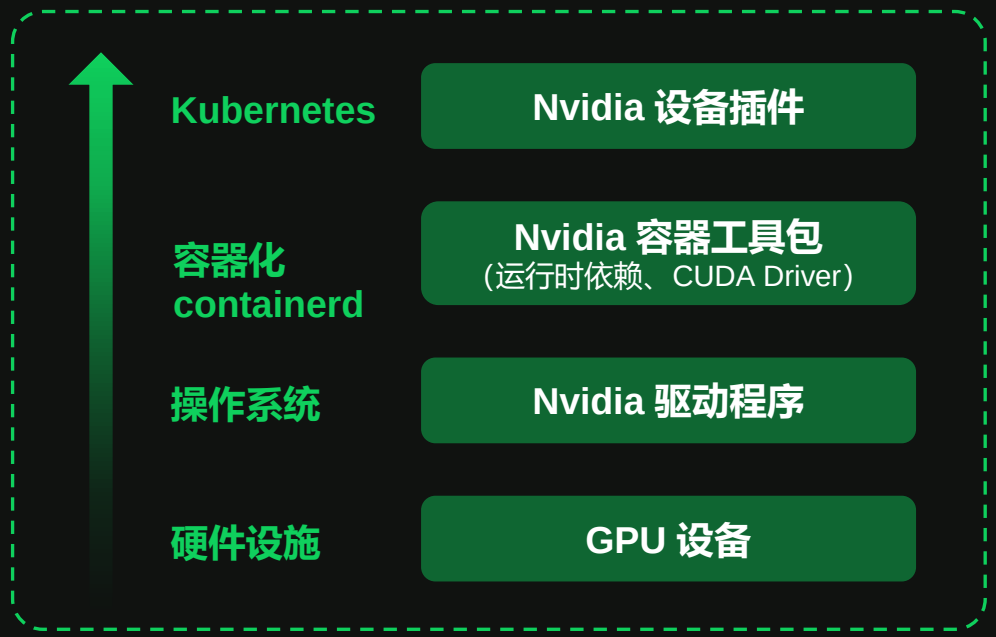
Validator: GPU operator 安装自检功能

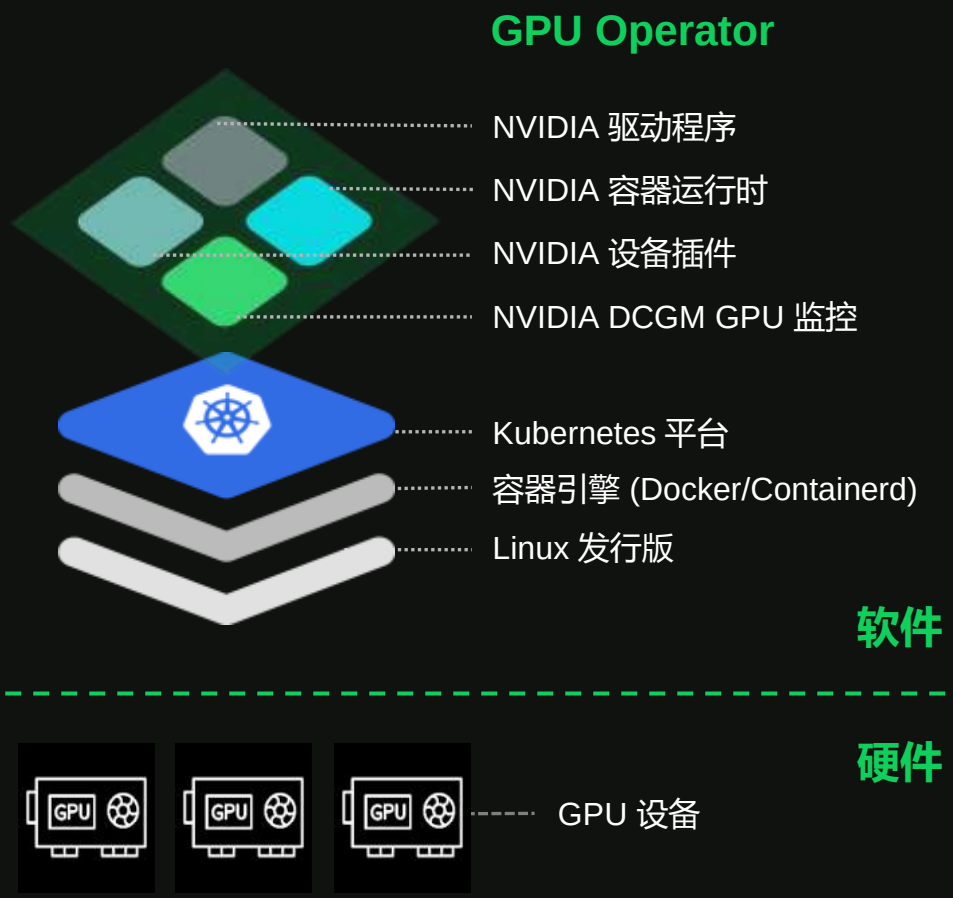
检查安装是否成功

这次只聊 NVIDIA GPU Operator 😅

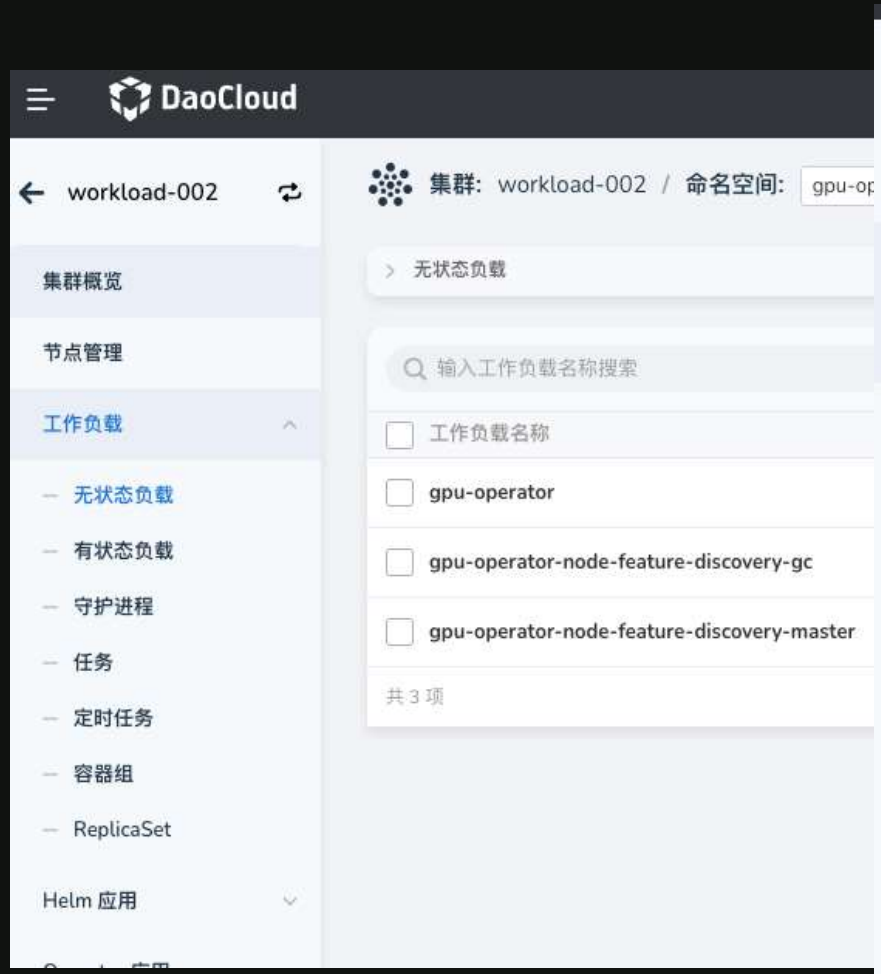
GPU Operator - 自动管理并提供 GPU 所需的所有 NVIDIA 软件组件

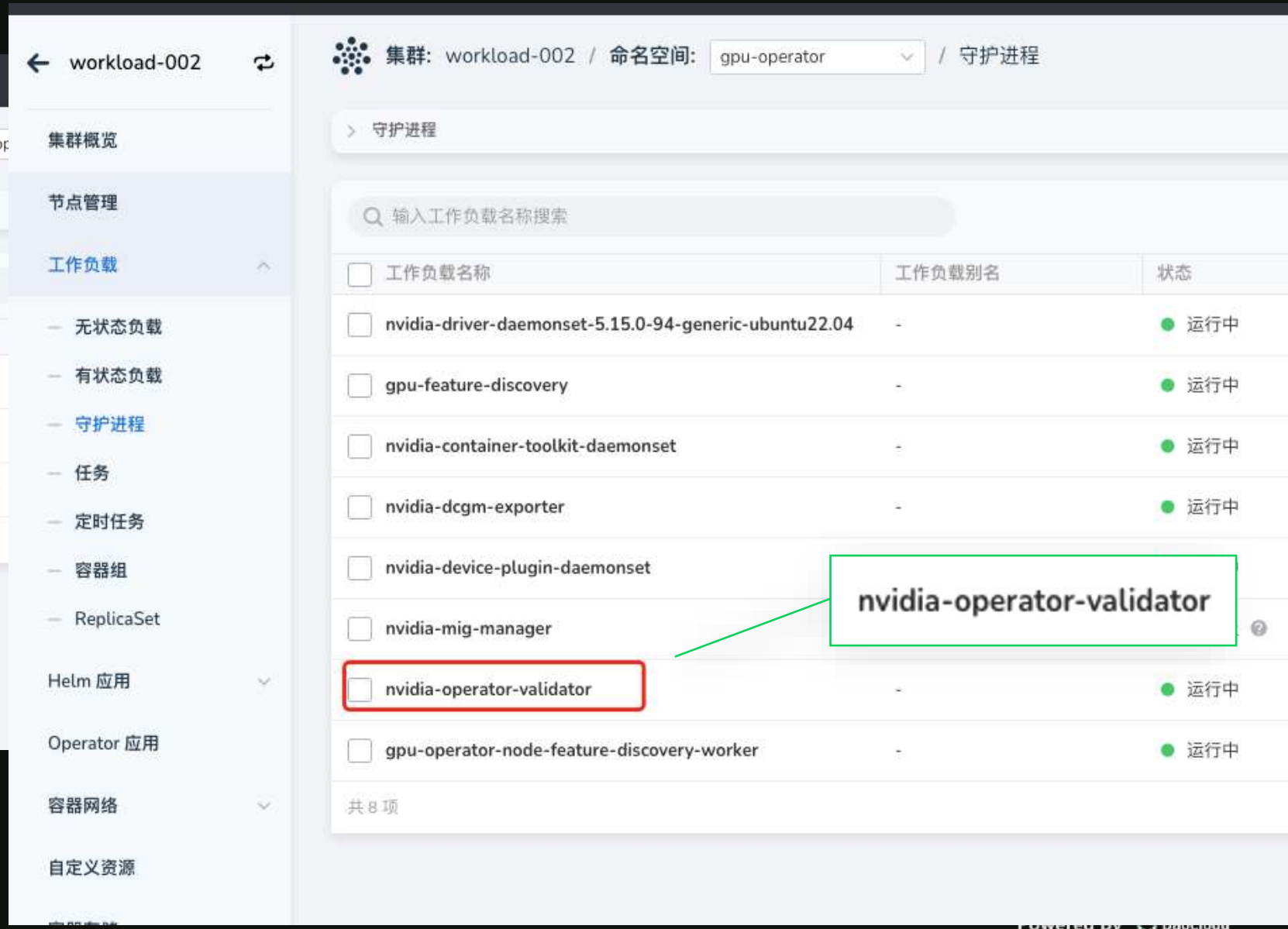
- **NVIDIA 设备插件** - 通过设备插件机制将 GPU 公开给 Kubelet
- **NVIDIA 容器工具包** ：实现容器化环境中与 GPU 进行交互
- **GPU 驱动程序**：Nvidia 驱动程序组件允许从容器进行驱动安装
- **NVIDIA GPU 功能发现**：检测并标记启用 GPU 的节点
- **NVIDIA DCGM GPU 监控** ： 采集 GPU 指标





安装完成后的效果

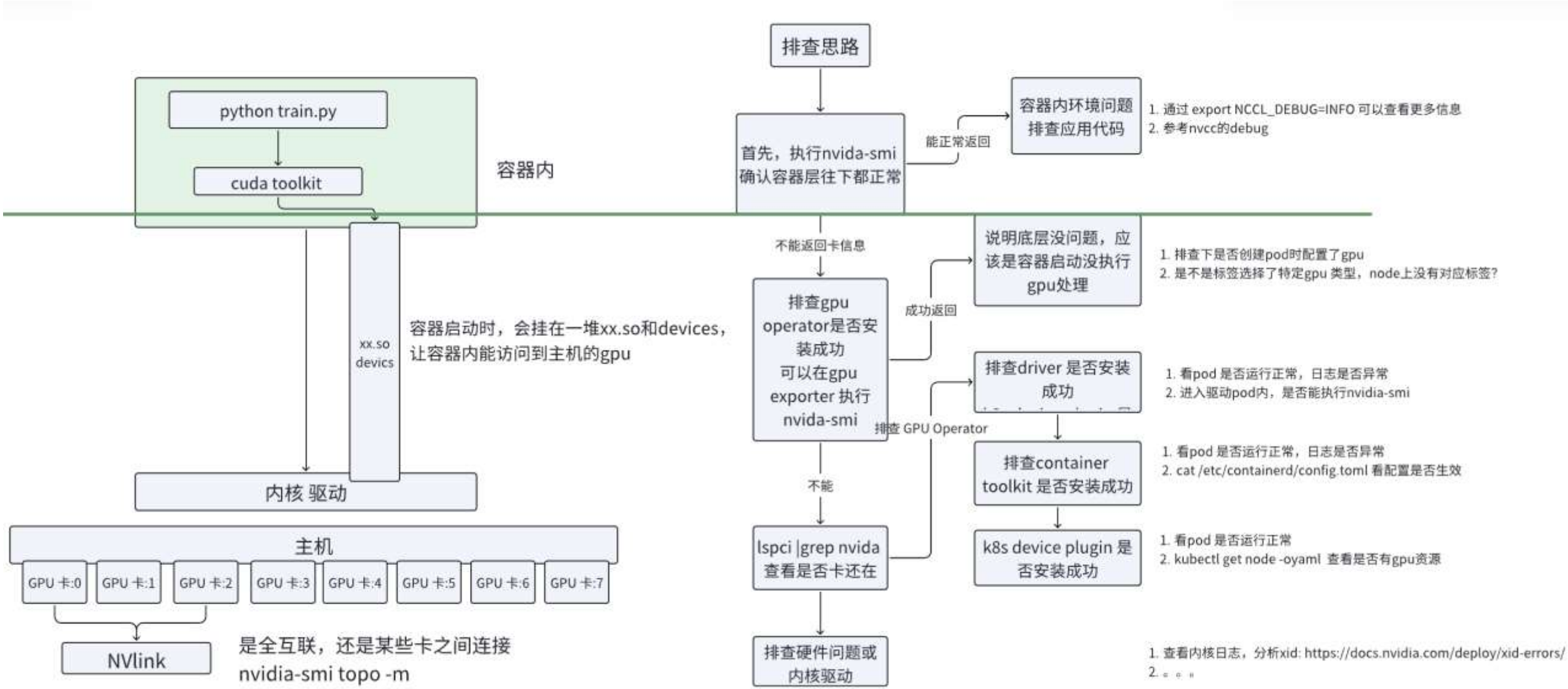

DaoCloud
workload-002
集群概览
节点管理
工作负载
无状态负载
有状态负载
守护进程
任务
定时任务
容器组
ReplicaSet
Helm 应用
集群: workload-002 / 命名空间: gpu-op
无状态负载
输入工作负载名称搜索
工作负载名称
gpu-operator
gpu-operator-node-feature-discovery-gc
gpu-operator-node-feature-discovery-master
共 3 项


workload-002
集群概览
节点管理
工作负载
无状态负载
有状态负载
守护进程
任务
定时任务
容器组
ReplicaSet
Helm 应用
Operator 应用
容器网络
自定义资源
集群: workload-002 / 命名空间: gpu-operator / 守护进程
守护进程
输入工作负载名称搜索
工作负载名称
工作负载别名
状态
nvidia-driver-daemonset-5.15.0-94-generic-ubuntu22.04
gpu-feature-discovery
nvidia-container-toolkit-daemonset
nvidia-dcgm-exporter
nvidia-device-plugin-daemonset
nvidia-mig-manager
nvidia-operator-validator
gpu-operator-node-feature-discovery-worker
运行中
共 8 项
nvidia-operator-validator

Part 04

故障排查指南&常见故障

故障排查 基本思路



常见故障

问题描述	原因	解决
GPU pod 无法启动	原因比较多，要排查对应的报错原因，但一般报错信息都比较明确	根据pod的事件报错信息，进行对应的排查分析，常见： 1.gpu卡所在节点cpu，内存不足 2.驱动安装有问题或重启后异常

运行提示/dev/shm 满或太小
[WARNING] /dev/shm size might be too small, if running in docker increase to at least --shm-size='1gb'
	gpu 在进场通讯时会使用/dev/shm，默认容器配置的空间比较小	可以挂在内存类型的emptyDir 解决
		`spec:`
		`  volumes:`
		`  - name: dshm`
		`  emptyDir:`
		`  medium: Memory`
		`  containers:`
		`  - image: gcr.io/project/image`
		`  volumeMounts:`
		`  - mountPath: /dev/shm`
		`  name: dshm`

Driver 安装需要 yum 或 apt 下载包	如果不是预编译模式，驱动安装过程中会进行联网进行内核模块编译	新版本支持预编译模式
驱动pod 重启后，会重新卸载安装gpu驱动，导致节点 gpu 很长时间不可用	社区一致问题，主要原因是驱动安装是通过把容器内/ 挂在到主机目录实现的，pod重启后挂载文件不完整，只能重新安装再挂载 https://github.com/NVIDIA/gpu-operator/issues/705	如果确实需要优化，可以临时通过在主机上安装驱动方式绕行

Thanks.