Scalable multi-node training for Autonomous Vehicle workloads on Red Hat OpenShift 4.4 with IBM Spectrum Scale and NVIDIA DGX systems

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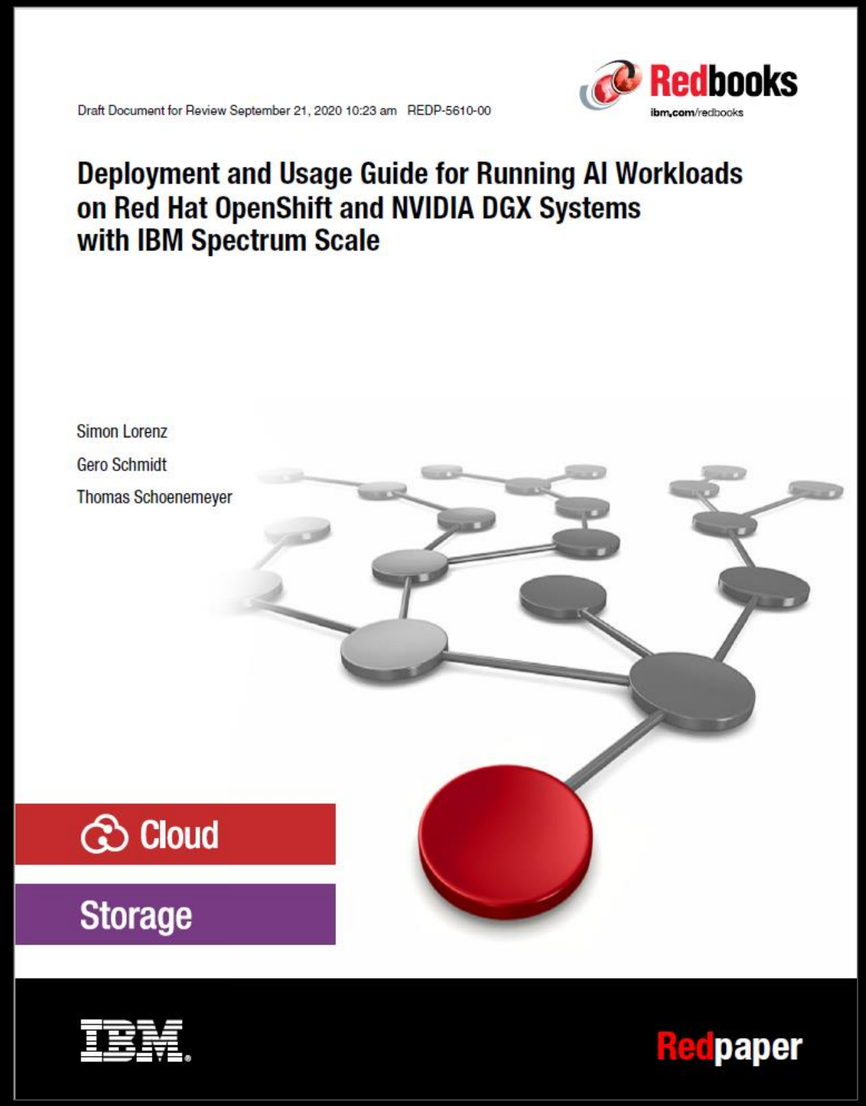
IBM

IBM Redpaper published on the topic:

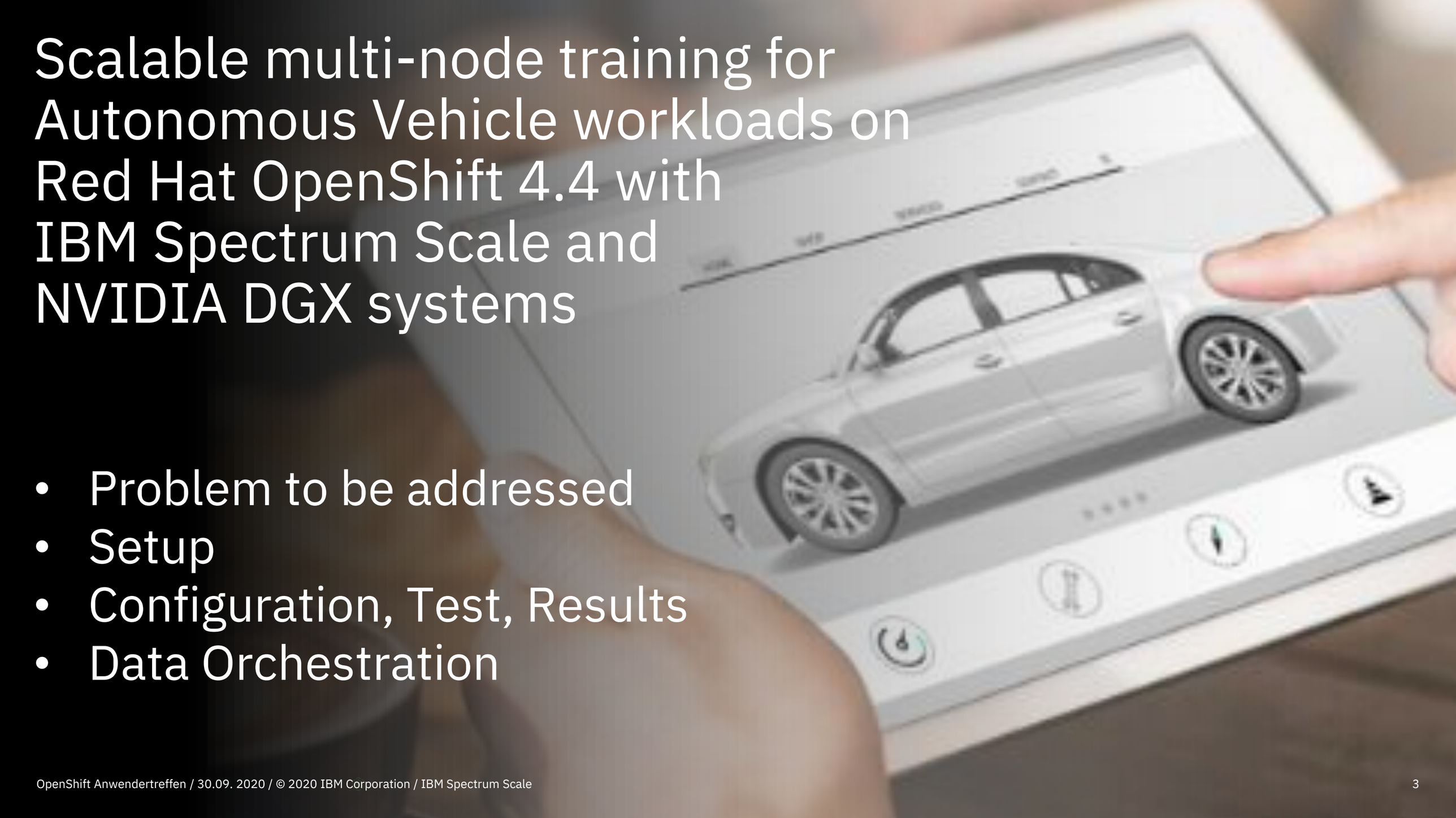
Deployment and Usage Guide for Running AI Workloads on Red Hat OpenShift and NVIDIA DGX Systems with IBM Spectrum Scale

Visit:

http://www.redbooks.ibm.com/redpieces/abstracts/redp5610.html
(published September 21, 2020)



Scalable multi-node training for Autonomous Vehicle workloads on Red Hat OpenShift 4.4 with IBM Spectrum Scale and NVIDIA DGX systems



- Problem to be addressed
- Setup
- Configuration, Test, Results
- Data Orchestration

DEEP LEARNING AT SCALE FOR AV

Safer Driving begins in the DC

Many DNN models are deployed in autonomous vehicles and need to be trained

- Many scenarios: highway, urban, countryside, etc.
- Different conventions: traffic signs, road marks, etc.
- Thousands of unexpected conditions/events

Core Challenge: need **high accuracy** and **robust DNNs**

DEEP LEARNING AT SCALE FOR AV
Common Approach to Improve Accuracy

- **Increase network architecture**
  - Larger networks are slower at training and inference
  - **May need several days on one worker**
- **Increase training data**
  - 100 cars with 5 2MP cameras => 200 PB / year
  - Improvement due to "just" more data saturates fairly quickly
  - Only a tiny fraction of unlabeled data is and can be used for training
  - find the **most informative** unlabeled data

Majority of useful problems are far too complex to run on single GPUs

Setup DL Cluster with GPUs- What could go wrong ?

Storage too slow

Internode HighSpeed Network too slow

Not enough resources at the right time

Privileges for Container

SOLVE LARGE SCALE DL PROBLEMS

NVIDIA GPU Worker Nodes

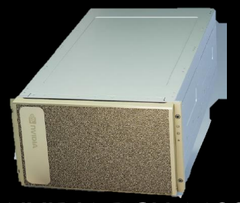
Algorithms for Deep Learning

- Matrix-Matrix Operations well-suited for running on NVIDIA GPU workers
- Integrated AI Systems with DGX OS, NVLINK and NVSwitch

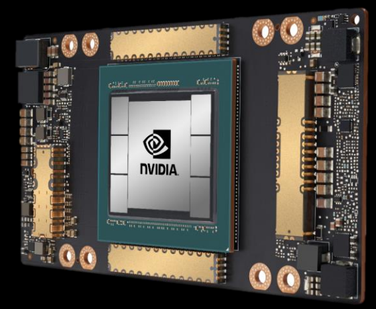
NVIDIA DGX-1

Remove all performance bottlenecks in a cluster

- High-Speed Networking between GPU worker nodes → **NVIDIA NCCL**
- Use Optimized Containers for GPU worker nodes → **NVIDIA NGC**
- Seamless integration of GPU Worker nodes into K8s/OpenShift 4.x
- Deploy Data Parallelism with Kubeflow/MPI/Horovod



NVIDIA DGX A100



A100 GPU

THE POWER OF SCALABILITY

MLPERF 0.7 Standard AI Benchmark

Benchmark	Time to resolution on single node DGX A100	Large Scale Results (DGX SuperPOD Cluster)	Number of nodes/workers (NVIDIA DGX A100)
NLP (BERT) - PyTorch NVIDIA 20.06	49.01 Min	3.36 Min	32
Reinforcement Learning (MiniGo) - TensorFlow NVIDIA 20.06	299.73 Min	29.7 Min	32
Translation (Non-recurrent) - PyTorch NVIDIA 20.06	7.84 Min	1.02 Min	20
Translation (Recurrent) GNMT - PyTorch NVIDIA 20.06	7.81 Min	0.98 Min	32
Object Detection (Heavy Weight) Mask R-CNN GNMT - PyTorch NVIDIA 20.06	82.16 Min	10.46 Min	32
Object Detection (Light Weight) SSD - PyTorch NVIDIA 20.06	10.21 Min	0.89 Min	64
Image Classification (ResNet-50 v1.5) - MXNet NVIDIA 20.06	39.78 Min	1.06 Min	96

NVIDIA ACCELERATED COMPUTING PRODUCT FAMILY

One architecture – CUDA-accelerated computing

FULLY INTEGRATED AI SYSTEMS + DGXPERTS

Deployed for this study

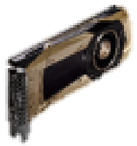
DGX-1

DGX-2

Announced in May 2020

DGX A100

DESKTOP



TITAN/ GeForce

WORKSTATION

DGX Station

VIRTUAL WORKSTATION

vGPU (e.g. V100/Quadro)

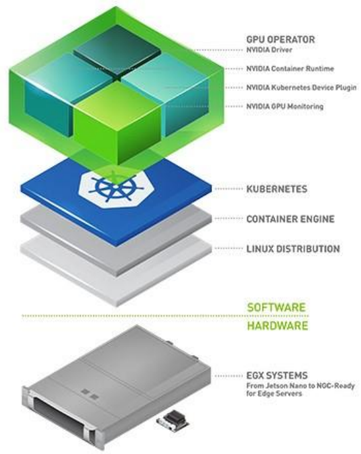
DATA CENTER

T4 / V100 A100

SERVER PLATFORM

HGX-1/ 2 HGX A100

EDGE



EGX A100

From Jetson Nano to Edge Server

NGC

CONTAINERS

150+

TRAINED MODELS

100+

HELM CHARTS

ML, Inference

Monthly Updates

UP TO 4X MORE PERFORMANCE IN 1.5 YEARS

Full Stack Innovation Delivers Continuous Improvements

OPTIMIZED FRAMEWORKS

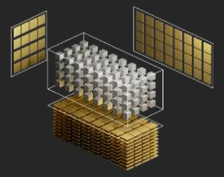
Apex, Horovod, MXNet, PyTorch, TensorFlow
Available through NVIDIA NGC

CUDA-X LIBRARIES

CUDA & Core Libraries: cuBLAS, cuDNN, CUDA graphs, DALI, NCCL, SHARP

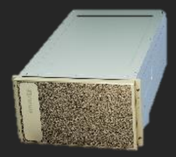
HARDWARE INNOVATIONS

GPU



Tensor Core

NVLink / NVSwitch



DGX

CX-6, HDR IB

DGX SuperPOD

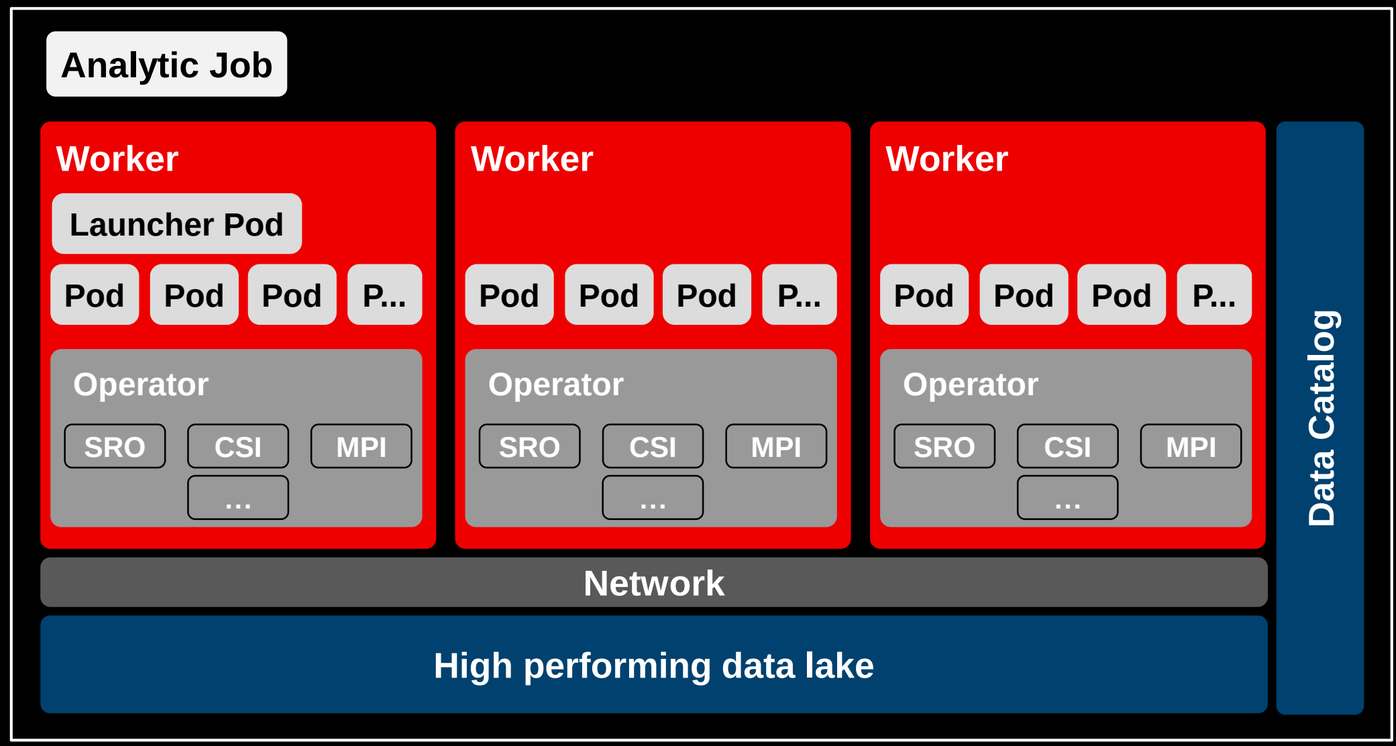
Access NGC in OpenShift – NVIDIA CONTAINER REPO

Scaling large deep learning workloads is challenging

- Horizontal scaling: ensure optimal resource utilization across
  - Nodes, CPU, GPU, Memory, …

- High performing data lake
  - Global namespace
  - Performance
  - No silos
  - No data copies
  - Secure

- Know your data



IBM Spectrum Scale

- Performance: remove data-related bottlenecks
- Ease of management: enable global collaboration
- Economics: optimize cost and performance
- Robust: data availability, integrity and security
- Containerized: Easier access to Kubernetes data

Storage for the world's smartest supercomputers

Summit System

- 4608 nodes each
- 200 petaflops peak performance for modeling and simulation
- 3.3 ExaOps peak performance for data analytics and AI

2.5 TB/sec
throughput to storage architecture

500 PB
HDD storage capacity

NVMe Flash for AI and Big Data Workloads

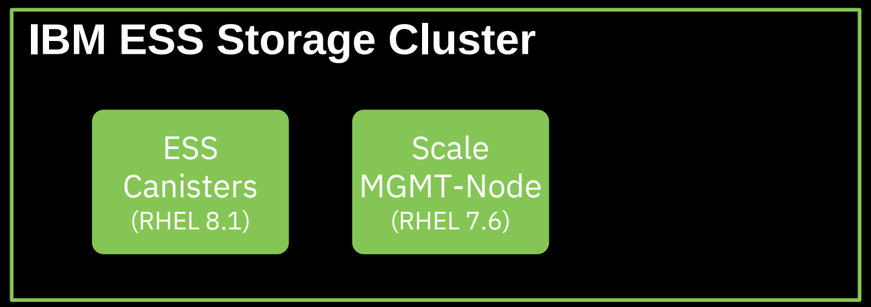
IBM Elastic Storage System 3000

All-new storage solution

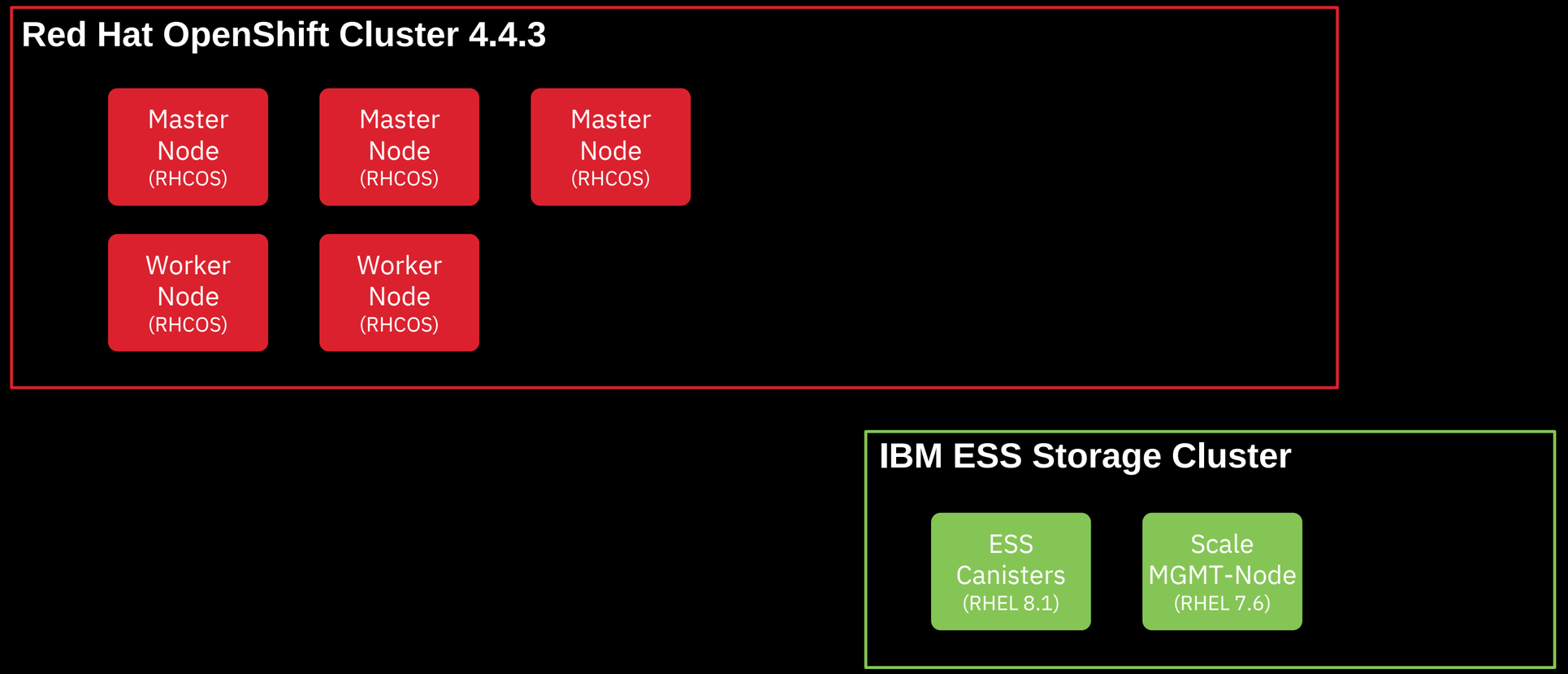
- Leverages proven FS9100 technology
- Integrated scale-out advanced data management with end-to-end NVMe storage
- Containerized software for ease of install and update
- Fast initial configuration, update and scale-out expansion
- Performance, capacity, and ease of integration for AI and Big Data workflows

IBM **Spectrum Scale**

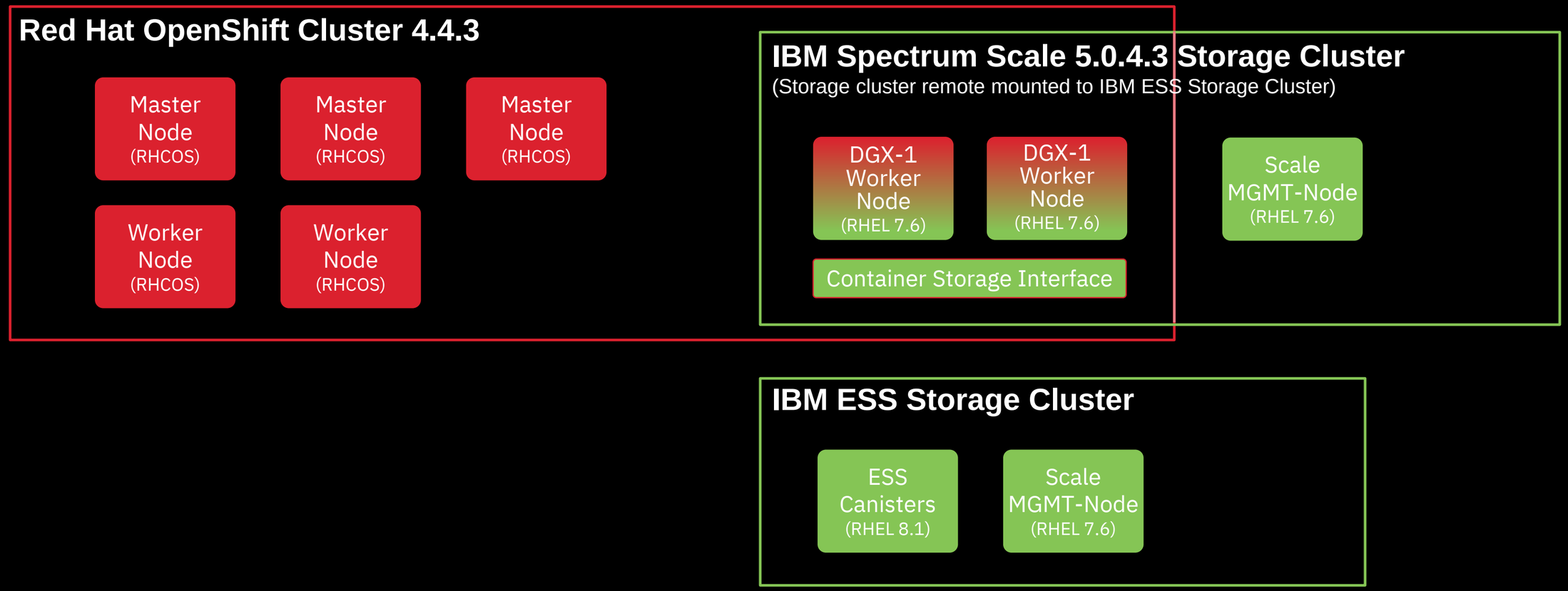
Red Hat OpenShift & IBM Spectrum Scale & CSI



Red Hat OpenShift & IBM Spectrum Scale & CSI



Red Hat OpenShift & IBM Spectrum Scale & CSI



Red Hat OpenShift & IBM Spectrum Scale & CSI

Red Hat OpenShift Cluster 4.4.3

3 Master Nodes
RHCOS

2 Worker Nodes
VM's RHCOS

IBM Spectrum Scale 5.0.4.3 Storage Cluster
(Storage cluster remote mounted to IBM ESS Storage Cluster)

DGX-1
Worker 1

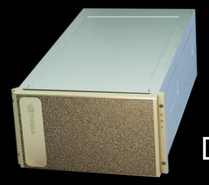
DGX-1
Worker 2

VM

- RH 7.6
  Scale GUI, Quorum, Manager

IBM ESS Storage Cluster

Node, Scale GUI, Quorum
ESS3000



DGX A100 in process of being tested and validated by NVIDIA and IBM

Infiniband Network

Red Hat OpenShift Cluster 4.4.3

3 Master Nodes
RHCOS

2 Worker Nodes
VM's RHCOS

IBM Spectrum Scale 5.0.4.3 Storage Cluster
(Storage cluster remote mounted to IBM ESS Storage Cluster)

DGX-1
Worker 1

DGX-1
Worker 2

VM

- RH 7.6
  Scale GUI, Quorum, Manager

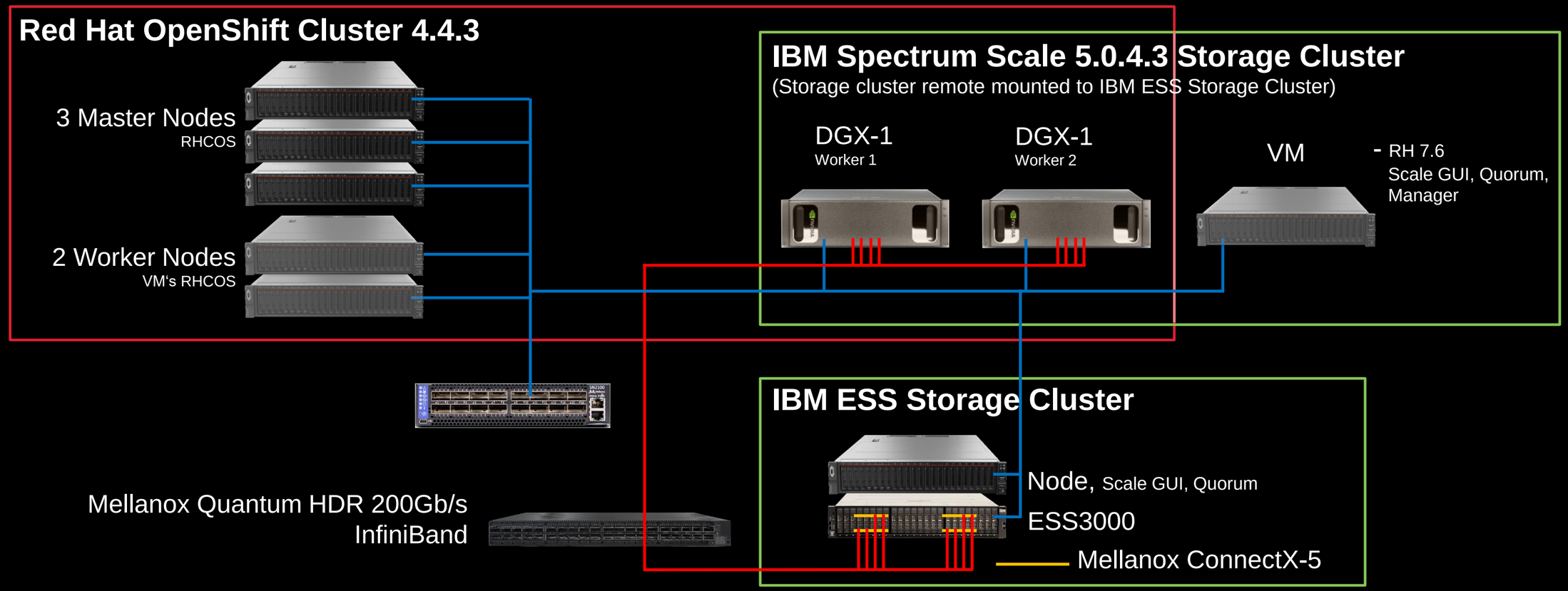
Mellanox Quantum HDR 200Gb/s InfiniBand

IBM ESS Storage Cluster

Node, Scale GUI, Quorum
ESS3000
Mellanox ConnectX-5

100Gb IB EDR Data Network 10.10.10.x/24

Network options, Infiniband



Installation Steps

- Integrating DGX-1 Systems as Worker Nodes into the Red Hat OpenShift Cluster
- Adding DGX-1 Systems as Client Nodes to the IBM Spectrum Scale Cluster
- Configure Red Hat OpenShift Stack: GPU, RDMA, Spectrum Scale CSI, MPI

Installation Steps: Integrate DGX-1 Systems as Worker Nodes

- Installing Red Hat Enterprise Linux 7.6 Base OS and DGX Software
  https://docs.nvidia.com/dgx/dgx-rhel-install-guide/installing-rhel7.html#installing-rhel7https://docs.nvidia.com/dgx/dgx-rhel-install-guide/installing-dgx-sw.html#installing-required-components
  Note: Stop right before step to install the NVIDIA® CUDA® driver.
- Installing NVIDIA Mellanox InfiniBand Drivers (MLNX_OFED)
  https://docs.nvidia.com/dgx/dgx-rhel-install-guide/installing-ib-drivers.html#installing-ib-drivers
  Note: Stop right before step to install the NVIDIA peer memory module (nvidia-peer-memory-dkms).
- Installing GPUDirect RDMA Kernel Module
  Manually build nvidia-peer-memory kernel module from https://github.com/Mellanox/nv_peer_memory
- Installing NVIDIA Mellanox SELinux Module
  Download and apply: `# semodule -i infiniband.pp`
  https://docs.mellanox.com/download/attachments/19804150/infiniband.zip?version=1&modificationDate=1575464686823&api=v2&download=true
- Adding DGX-1 systems as Worker Nodes to the Red Hat OpenShift Cluster
  https://docs.openshift.com/container-platform/4.4/machine_management/user_infra/adding-rhel-compute.html

Installation Steps: Add DGX-1 Nodes to Spectrum Scale Cluster

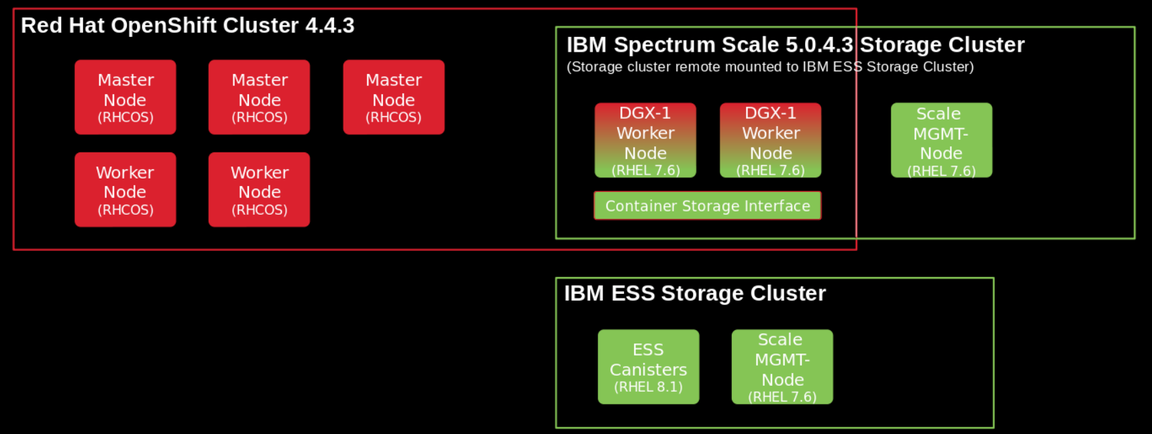
Add DGX-1 worker nodes as IBM Spectrum Scale *Client nodes* to the local Spectrum Scale cluster:

```
# ./spectrumscale node add dgx01.ocp4.scale.ibm.com
# ./spectrumscale node add dgx02.ocp4.scale.ibm.com
# ./spectrumscale install [--precheck]
# ./spectrumscale deploy [--precheck]
```

See: https://www.ibm.com/support/knowledgecenter/en/STXKQY_5.0.4/com.ibm.spectrum.scale.v5r04.doc/bl1ins_addingtoaninstallation.htm

Configure InfiniBand RDMA

```
[dgx]
verbsRdma enable
verbsRdmaSend yes
verbsPorts mlx5_0/1 mlx5_1/1 mlx5_2/1 mlx5_3/1
```



Remote Mount of ESS filesystem

```
# mmremotecluster show
Cluster name:    ess3000.bda.scale.ibm.com
Contact nodes:   fscc-fab3-3-a-priv.bda.scale.com,fscc-fab3-3-b-priv.bda.scale.com
File systems:    ess3000_4M (ess3000_4M)
```

See: https://www.ibm.com/support/knowledgecenter/STXKQY_5.0.4/com.ibm.spectrum.scale.v5r04.doc/bl1adv_admrmsec.htm

Installation Steps: Configure Red Hat OpenShift Stack

Add-Ons:

- Special Resource Operator (SRO)
- NVIDIA Mellanox RDMA Shared Device Plugin
- MPI Operator
- IBM Spectrum Scale CSI Driver

Additional Steps:

- Enabling `IPC_LOCK` in User Namespace for RDMA Shared Device Plugin

OpenShift: *Special Resource Operator* (GPU support)

https://github.com/openshift-psap/special-resource-operator

- Provides driver support (e.g. CUDA for NVIDIA GPUs)
- Adds **`nvidia.com/gpu`** as a new resource for K8s scheduler

(1) Install from OperatorHub in OpenShift Web Console:

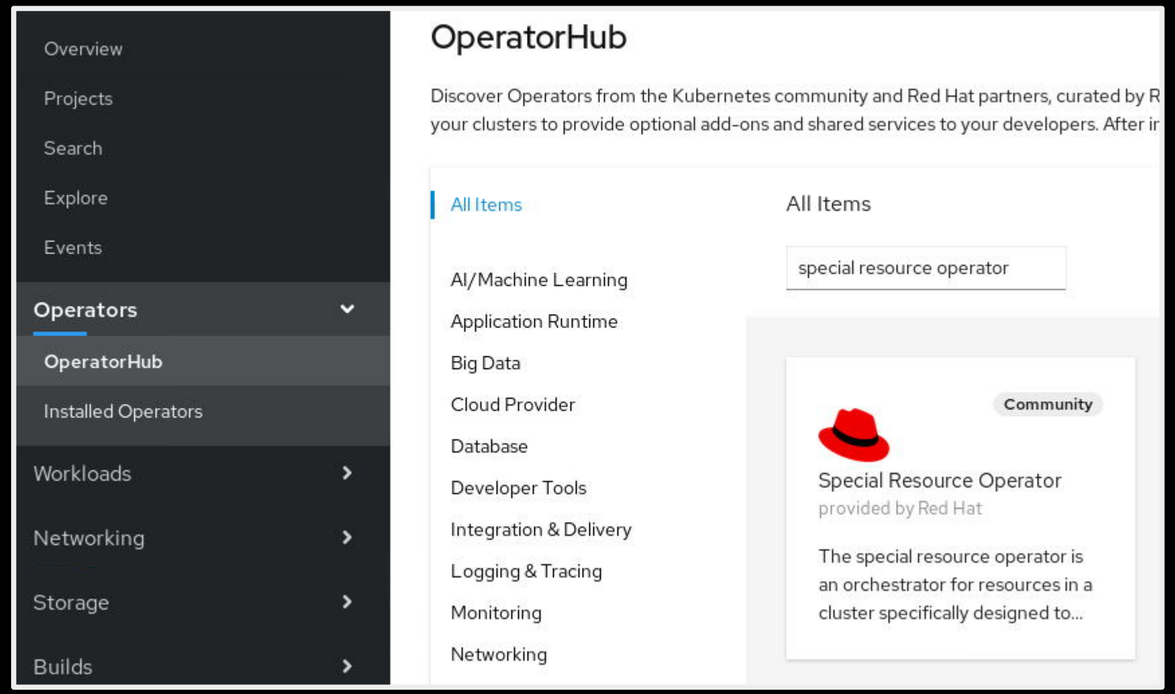
(2) Install manually:

1. Installation of the *Node Feature Discovery* (NFD) operator

```
# git clone https://github.com/openshift/cluster-nfd-operator
# cd cluster-nfd-operator
# make deploy
```

2. Installation of SRO (requires NFD operator as dependency)

```
# git clone https://github.com/openshift-psap/special-resource-operator
# cd special-resource-operator
# PULLPOLICY=Always make deploy
```




```
# oc describe node dgx01.ocp4.scale.com
Allocatable:
  nvidia.com/gpu:     8
```

OpenShift: *NVIDIA Mellanox RDMA Shared Device Plugin*

https://github.com/Mellanox/k8s-rdma-shared-dev-plugin

- Provides shared access to InfiniBand (IB) ports for non-privileged pods
- Adds **`rdma/[my-name-ibX]`** as a new resource for K8s scheduler

IB enables high performance communication between GPUs with NVIDIA Collective Communications Library (NCCL) via RDMA so that multi-node workloads can scale out seamlessly across worker nodes.

Install manually:

```
# git clone https://github.com/Mellanox/k8s-rdma-shared-dev-plugin.git
# oc apply -f images/k8s-rdma-shared-dev-plugin-config-map.yaml
# oc apply -f images/k8s-rdma-shared-dev-plugin-ds.yaml
```

```
# oc describe node dgx01.ocp4.scale.com
Allocatable:
  rdma/shared_ib0:    100
  rdma/shared_ib1:    100
  rdma/shared_ib2:    100
  rdma/shared_ib3:    100
```

Configured via *ConfigMap*:

```
apiVersion: v1
kind: ConfigMap
metadata:
 name: rdma-devices
data:
 config.json: |
  {
    "configList": [{
      "resourceName": "shared_ib0",
      "rdmaHcaMax": 100,
      "devices": ["ib0"]
     }, ...
    ]
  }
```

OpenShift: *NVIDIA Mellanox RDMA Shared Device Plugin*

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# oc apply -f images/k8s-rdma-shared-dev-plugin-ds.yaml
```

```
# oc describe node dgx01.ocp4.scale.com
Allocatable:
  rdma/shared_ib0:    100
  rdma/shared_ib1:    100
  rdma/shared_ib2:    100
  rdma/shared_ib3:    100
```

```
# cat test-hca-pod.yaml
apiVersion: v1
kind: Pod
metadata:
  name: mofed-test-pod
spec:
  restartPolicy: OnFailure
  containers:
  - image: mellanox/centos_7_4_mofed_4_[...]
    name: mofed-test-ctr
    securityContext:
      capabilities:
        add: [ "IPC_LOCK" ]
    resources:
      limits:
        rdma/shared_ib0: 1
        rdma/shared_ib1: 1
        rdma/shared_ib2: 1
        rdma/shared_ib3: 1
    command:
    - sh
    - -c
    - |
      ls -l /dev/infiniband /sys/class/net
      sleep 1000000
```

OpenShift: *MPI Operator*

https://github.com/kubeflow/mpi-operator

- Provides custom resource definition **kind: MPIJob**
- Allows to conveniently schedule distributed multi-GPU and multi-node training jobs using *Message Passing Interface* (MPI)

Install manually:

```
# git clone https://github.com/kubeflow/mpi-operator.git
# cd mpi-operator/
# oc apply -f deploy/v1alpha2/mpi-operator.yaml
```

```
apiVersion: kubeflow.org/v1alpha2
kind: MPIJob
metadata:
  name: my-mpi-job
spec:
  slotsPerWorker: 1
  mpiReplicaSpecs:
    Launcher:
      replicas: 1
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            command:
            - mpirun
            - -np
            - "16"
            [...]
    Worker:
      replicas: 16
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            resources:
              limits:
                nvidia.com/gpu: 1
            [...]
```

OpenShift: *IBM Spectrum Scale CSI* (storage driver)

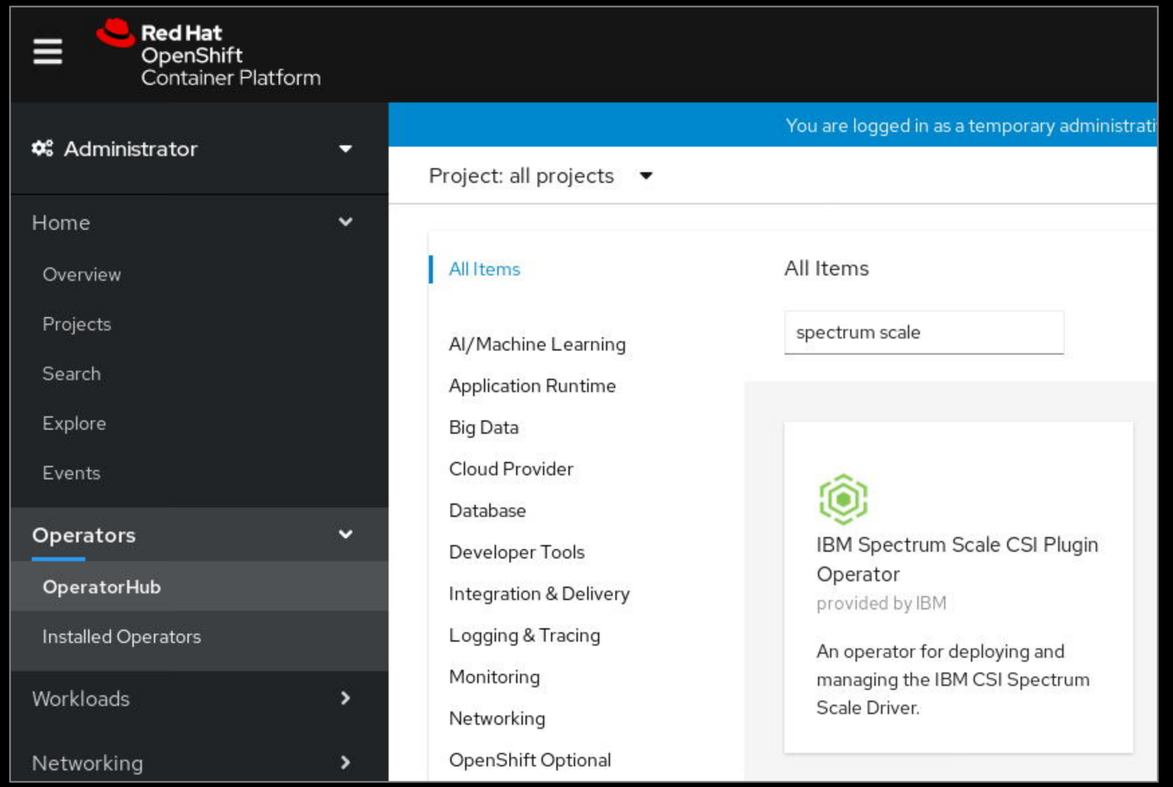
https://github.com/IBM/ibm-spectrum-scale-csi
https://www.ibm.com/support/knowledgecenter/STXKQY_CSI_SHR/ibmspectrumscalecsi_welcome.html

- Operator deploys and manages CSI (Container Storage Interface) plugin for IBM Spectrum Scale
- Provides *Persistent Volume (PV)* provisioning with IBM Spectrum Scale as storage backend

Persistent Volumes (PVs):

- *Dynamically provisioned* on user request (via *storage class*)
- *Statically provisioned* by system admin, allows access to specific paths and existing data in IBM Spectrum Scale

http://www.redbooks.ibm.com/redpieces/abstracts/redp5589.html



OpenShift: Static Provisioning with *IBM Spectrum Scale CSI*

OpenShift: System admin

```
# oc apply -f nv-pv01.yaml
# cat nv-pv01.yaml
apiVersion: v1
kind: PersistentVolume
metadata:
  name: "adas-data-pv01"
  labels:
    type: data
    dept: adas
spec:
  storageClassName: static
  capacity:
    storage: 100Gi
  accessModes:
    - ReadWriteMany
  csi:
    driver: spectrumscale.csi.ibm.com
    volumeHandle: "16217308676014575381;099B6A7A:5EB99743;
                   path=/gpfs/ess3000_4M/adas"
```

OpenShift: User namespace

```
# oc apply -f nv-data-pvc.yaml
# cat nv-data-pvc.yaml
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: "adas-data-pvc"
spec:
  storageClassName: static
  accessModes:
  - ReadWriteMany
  resources:
    requests:
      storage: 100Gi
  selector:
    matchLabels:
      type: data
      dept: adas
```

```
spec:
  containers:
  - name: a2d2-train
    image: tf2:20.03
    [...]
    volumeMounts:
    - name: a2d2-data
      mountPath: /workspace
  volumes:
  - name: a2d2-data
    persistentVolumeClaim:
      claimName: adas-data-pvc
      readOnly: false
```

OpenShift: Dynamic Provisioning with *IBM Spectrum Scale CSI*

OpenShift: System admin

```
# oc apply -f scale-stgclass.yaml
# cat scale-stgclass.yaml
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: remotefs-m4
provisioner: spectrumscale.csi.ibm.com
parameters:
  volBackendFs: ess3000_4M
  clusterId: "21505721748717715"
reclaimPolicy: Delete
```

OpenShift: User namespace

```
# oc apply -f nv-priv-pvc.yaml
# cat nv-priv-pvc.yaml
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: "adas-priv-pvc"
spec:
  storageClassName: remotefs-m4
  accessModes:
  - ReadWriteMany
  resources:
    requests:
      storage: 100Gi
```

```
spec:
  containers:
  - name: a2d2-prep
    image: tf2:20.03
    [...]
    volumeMounts:
    - name: a2d2-priv
      mountPath: /workspace
  volumes:
  - name: a2d2-priv
    persistentVolumeClaim:
      claimName: adas-priv-pvc
      readOnly: false
```

OpenShift: Enabling **IPC_LOCK** in User Namespace

- **NVIDIA Mellanox RDMA device plugin** requires **IPC_LOCK** capability in OpenShift 4 security context.

- A ***regular user*** normally runs under the **restricted** ***Security Context Constraints (SCC)*** in OpenShift 4 so **IPC_LOCK** is not generally available to regular users.

- *A **system admin*** has access to the **privileged** ***Security Context Constraints (SCC)*** and can request the **IPC_LOCK** capability when running pods anytime.

Allowing a regular user to run MPI jobs with RDMA resources for multi-GPU training across nodes requires to grant a user access to the **IPC_LOCK** capability in the user's namespace.
The *system admin* can create a new *SCC* derived from the **restricted** SCC, extend it by the **IPC_LOCK** capability and make the new SCC available to the user namespace by creating a *service account* , a *role binding* and a *role* referencing this new SCC.

```
spec:
  serviceAccount: mpi
  serviceAccountName: mpi
  containers:
  - name: your-container-name
    image: your-container-image:tag
    securityContext:
      capabilities:
        add: [ "IPC_LOCK" ]
```

OpenShift: Enabling `IPC_LOCK` in User Namespace

(1) Derive a new *SCC* from `restricted` SCC and add `IPC_LOCK` capability

(2) Create a new *service account* in the user namespace

(3) Create a new *role* in the user namespace

(4) Create a new *role binding* in the user namespace

```
# oc get scc restricted -o yaml > mpi-scc.yaml
# vi mpi-scc.yaml
[...]
defaultAddCapabilities:
- IPC_LOCK
metadata:
  name: scc-for-mpi
users:
- system:serviceaccount:[user-namespace]:mpi
[...]
# oc apply -f mpi-scc
```

```
# oc apply -f mpi-sa.ya
# cat mpi-sa.yaml
apiVersion: v1
kind: ServiceAccount
metadata:
  name: mpi
  namespace: [user-name
```

```
# oc apply -f mpi-role.yaml
# cat mpi-role.yaml
apiVersion: rbac.authorization.k8s.
kind: Role
metadata:
  name: mpi
  namespace: [user-namespace]
rules:
- apiGroups:
  - security.openshift.io
  resources:
  - securitycontextconstraints
  verbs:
  - use
  resourceNames:
  - scc-for-mpi
```

```
# oc apply -f mpi-rolebinding.yaml
# cat mpi-rolebinding.yaml
apiVersion: rbac.authorization.k8s.io/v1
kind: RoleBinding
metadata:
  name: mpi
  namespace: [user-namespace]
roleRef:
  apiGroup: rbac.authorization.k8s.io
  kind: Role
  name: mpi
  namespace: [user-namespace]
subjects:
- kind: ServiceAccount
  name: mpi
  namespace: [user-namespace]
userNames:
- system:serviceaccount:[user-namespace]:mpi
```

OpenShift: Connectivity Tests with NCCL

https://github.com/NVIDIA/nccl-tests

Connectivity Tests with

- NVIDIA Collective Communications Library (NCCL)
  https://github.com/NVIDIA/nccl
- NGC TensorFlow v2 Container Image
  https://ngc.nvidia.com/catalog/containers/nvidia:tensorflow

NCCL is a stand-alone library of standard collective communication routines for GPUs.

The NCCL tests check both the performance and the correctness of NCCL operations.

The NGC (NVIDIA GPU Cloud) container registry provides access to a comprehensive catalog of GPU-accelerated software for AI, machine learning optimized for NVIDIA GPU platforms.

```
apiVersion: batch/v1
kind: Job
metadata:
  name: nv-nccl
spec:
  template:
    spec:
      nodeName: dgx01.ocp4.scale.ibm.com
      containers:
      - name: nv-nccl
        image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
        imagePullPolicy: IfNotPresent
        command: ["/bin/sh","-c"]
        args: ["nvidia-smi && nvidia-smi topo -m &&
git clone https://github.com/NVIDIA/nccl-tests.git &&
cd nccl-tests && make &&
./build/all_reduce_perf -b 8 -e 256M -f 2 -g 8"]
        resources:
          limits:
            nvidia.com/gpu: 8
      restartPolicy: Never
```

OpenShift: Connectivity Tests with NCCL

```
[root@fscc-sr650-6 nccl]# oc logs job.batch/nv-nccl
Mon Jul  6 12:00:05 2020
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 440.33.01    Driver Version: 440.33.01    CUDA Version: 10.2     |
|-------------------------------
| GPU  Name        Persisten
| Fan  Temp  Perf  Pwr:Usage
|=============================
|   0  Tesla V100-SXM2...  O
| N/A   32C    P0    58W / 3
+-------------------------------
|   1  Tesla V100-SXM2...  O
| N/A   34C    P0    44W / 3
+-------------------------------
|   2  Tesla V100-SXM2...  O
| N/A   34C    P0    42W / 3
+-------------------------------
|   3  Tesla V100-SXM2...  O
| N/A   34C    P0    43W / 3
+-------------------------------
|   4  Tesla V100-SXM2...  O
| N/A   33C    P0    42W / 3
+-------------------------------
|   5  Tesla V100-SXM2...  O
| N/A   36C    P0    41W / 3
+-------------------------------
|   6  Tesla V100-SXM2...  O
| N/A   36C    P0    42W / 3
+-------------------------------
|   7  Tesla V100-SXM2...  O
| N/A   34C    P0    42W / 300W |      0MiB / 16130
+-------------------------------+----------------

        GPU0    GPU1    GPU2    GPU3    GPU4    GPU5    GPU6    GPU7    mlx5_0  mlx5_1  mlx5_2  mlx5_3  CPU Affinity
GPU0     X      NV1     NV1     NV2     NV2     SYS     SYS     SYS     PIX     PHB     SYS     SYS     0-19,40-59
GPU1    NV1      X      NV2     NV1     SYS     NV2     SYS     SYS     PIX     PHB     SYS     SYS     0-19,40-59
GPU2    NV1     NV2      X      NV2     SYS     SYS     NV1     SYS     PHB     PIX     SYS     SYS     0-19,40-59
GPU3    NV2     NV1     NV2      X      SYS     SYS     SYS     NV1     PHB     PIX     SYS     SYS     0-19,40-59
GPU4    NV2     SYS     SYS     SYS      X      NV1     NV2     NV2     SYS     SYS     PIX     PHB     20-39,60-79
GPU5    SYS     NV2     SYS     SYS     NV1      X      NV2     NV2     SYS     SYS     PIX     PHB     20-39,60-79
GPU6    SYS     SYS     NV1     SYS     NV2     NV2      X      NV1     PHB     PIX     SYS     SYS     20-39,60-79
GPU7    SYS     SYS     SYS     NV1     NV2     NV2     NV1      X      PHB     PIX     SYS     SYS     20-39,60-79
mlx5_0  PIX     PIX     PHB     PHB     SYS     SYS     PHB     PHB      X      PHB     SYS     SYS
mlx5_1  PHB     PHB     PIX     PIX     PHB     PHB     PIX     PIX     PHB      X      SYS     SYS
mlx5_2  SYS     SYS     SYS     SYS     PIX     PIX     SYS     SYS     SYS     SYS      X      PHB
mlx5_3  SYS     SYS     SYS     SYS     PHB     PHB     SYS     SYS     SYS     SYS     PHB      X

Legend:

  X    = Self
  SYS  = Connection tr
  NODE = Connection tr
  PHB  = Connection tr
  PXB  = Connection tr
  PIX  = Connection tr
  NV#  = Connection tr

# nThread 1 nGpus 8 minBytes 8 maxBytes 268435456 step: 2(factor) warmup iters: 5 iters: 20 validation: 1
#
# Using devices
#   Rank  0 Pid      1 on nv-nccl-7f9ns device  0 [0x06] Tesla V100-SXM2-16GB
#   Rank  1 Pid      1 on nv-nccl-7f9ns device  1 [0x07] Tesla V100-SXM2-16GB
#   Rank  2 Pid      1 on nv-nccl-7f9ns device  2 [0x0a] Tesla V100-SXM2-16GB
#   Rank  3 Pid      1 on nv-nccl-7f9ns device  3 [0x0b] Tesla V100-SXM2-16GB
#   Rank  4 Pid      1 on nv-nccl-7f9ns device  4 [0x85] Tesla V100-SXM2-16GB
#   Rank  5 Pid      1 on nv-nccl-7f9ns device  5 [0x86] Tesla V100-SXM2-16GB
#   Rank  6 Pid      1 on nv-nccl-7f9ns device  6 [0x89] Tesla V100-SXM2-16GB
#   Rank  7 Pid      1 on nv-nccl-7f9ns device  7 [0x8a] Tesla V100-SXM2-16GB
#
#                                                     out-of-place                       in-place
#       size         count    type   redop    time   algbw   busbw  error    time   algbw   busbw  error
#        (B)    (elements)                    (us)  (GB/s)  (GB/s)         (us)  (GB/s)  (GB/s)
           8             2   float     sum   40.92    0.00    0.00  2e-07   44.50    0.00    0.00  1e-07
          16             4   float     sum   38.08    0.00    0.00  6e-08   40.94    0.00    0.00  6e-08
          32             8   float     sum   41.30    0.00    0.00  6e-08   39.27    0.00    0.00  6e-08
          64            16   float     sum   43.86    0.00    0.00  6e-08   38.48    0.00    0.00  6e-08
         128            32   float     sum   42.10    0.00    0.01  6e-08   43.15    0.00    0.01  6e-08
         256            64   float     sum   41.70    0.01    0.01  6e-08   43.80    0.01    0.01  6e-08
         512           128   float     sum   38.83    0.01    0.02  6e-08   44.29    0.01    0.02  6e-08
        1024           256   float     sum   44.58    0.02    0.04  2e-07   45.88    0.02    0.04  2e-07
      [...]
   134217728      33554432   float     sum  1862.1   72.08  126.14  5e-07  1863.6   72.02  126.03  5e-07
   268435456      67108864   float     sum  3671.2   73.12  127.96  5e-07  3637.3   73.80  129.15  5e-07
```

Multi-GPU, multi-Node MPI Jobs with TensorFlow

```
apiVersion: kubeflow.org/v1alpha2
kind: MPIJob
metadata:
  name: tf2-a2d2-16x01x02-gpu
spec:
  slotsPerWorker: 1
  mpiReplicaSpecs:
    Launcher:
      replicas: 1
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            command:
            - mpirun
            - -np
            - "16"
            [...]
    Worker:
      replicas: 16
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            resources:
              limits:
                nvidia.com/gpu: 1
            [...]
```

```
Launcher:
  replicas: 1
  template:
    spec:
      containers:
      - name: tf2-a2d2-16x01x02-gpu
        image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
        command:
        - mpirun
        - -np
        - "16"
        - -wdir
        - "/workspace/scripts/tf2_comparison/hvd"
        [...]
        - -x
        - NCCL_DEBUG=INFO
        - -x
        - NCCL_IB_DISABLE=0
        - -x
        - NCCL_NET_GDR_LEVEL=1
        [...]
        - python
        - main.py
        - --model_dir=checkpt
        - --batch_size=16
        - --exec_mode=train
        - --max_steps=16000
```

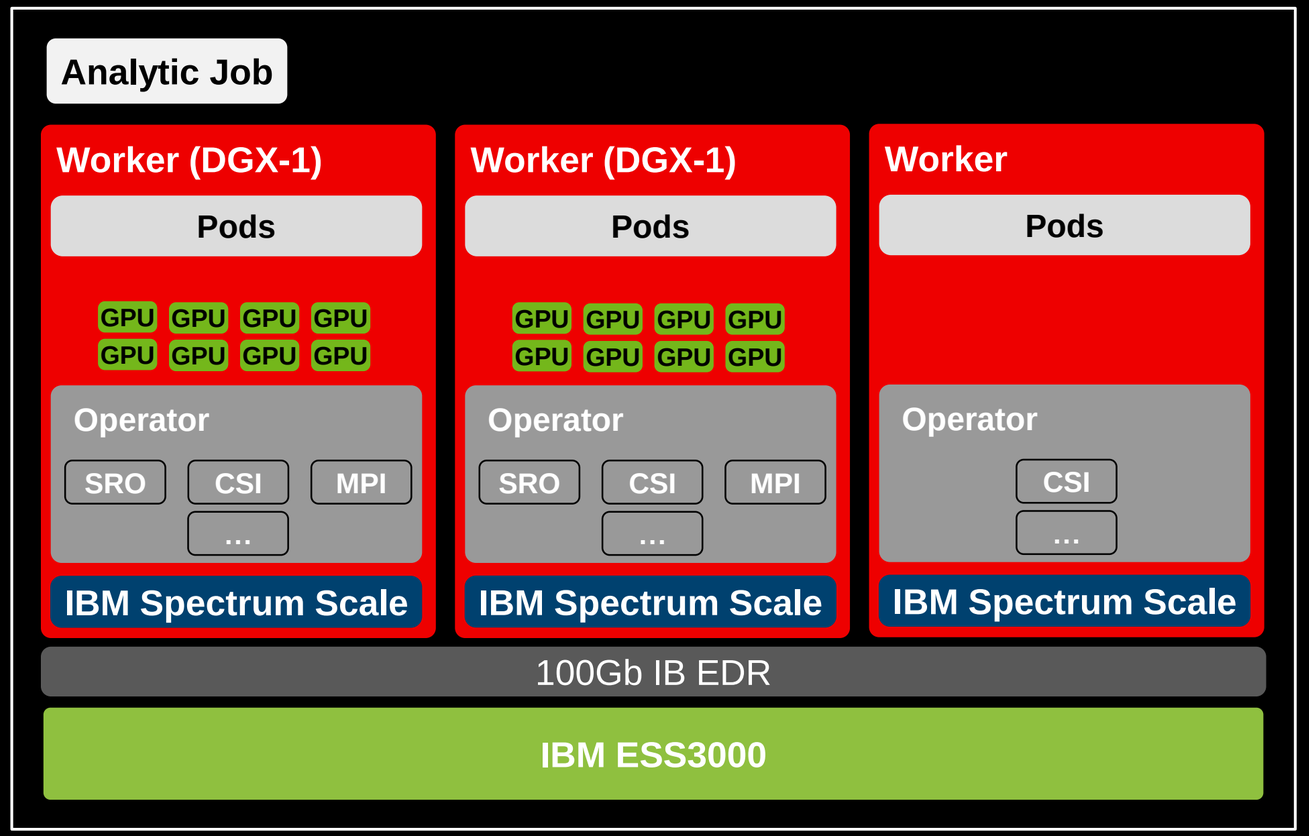
Multi-GPU, multi-Node MPI Jobs with TensorFlow

```
apiVersion: kubeflow.org/v1alpha2
kind: MPIJob
metadata:
  name: tf2-a2d2-16x01x02-gpu
spec:
  slotsPerWorker: 1
  mpiReplicaSpecs:
    Launcher:
      replicas: 1
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            command:
            - mpirun
            - -np
            - "16"
            [...]
    Worker:
      replicas: 16
      template:
        spec:
          containers:
          - image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
            resources:
              limits:
                nvidia.com/gpu: 1
            [...]
```

```
Worker:
  replicas: 16
  template:
    spec:
      serviceAccount: mpi
      serviceAccountName: mpi
      containers:
      - name: tf2-a2d2-16x01x02-gpu
        image: nvcr.io/nvidia/tensorflow:20.03-tf2-py3
        securityContext:
          capabilities:
            add: [ "IPC_LOCK" ]
        resources:
          limits:
            nvidia.com/gpu: 1
            rdma/shared_ib0: 1
            rdma/shared_ib1: 1
            rdma/shared_ib2: 1
            rdma/shared_ib3: 1
        volumeMounts:
        - name: a2d2-data
          mountPath: /workspace
      volumes:
      - name: a2d2-data
        persistentVolumeClaim:
          claimName: adas-data-pvc
          readOnly: false
```

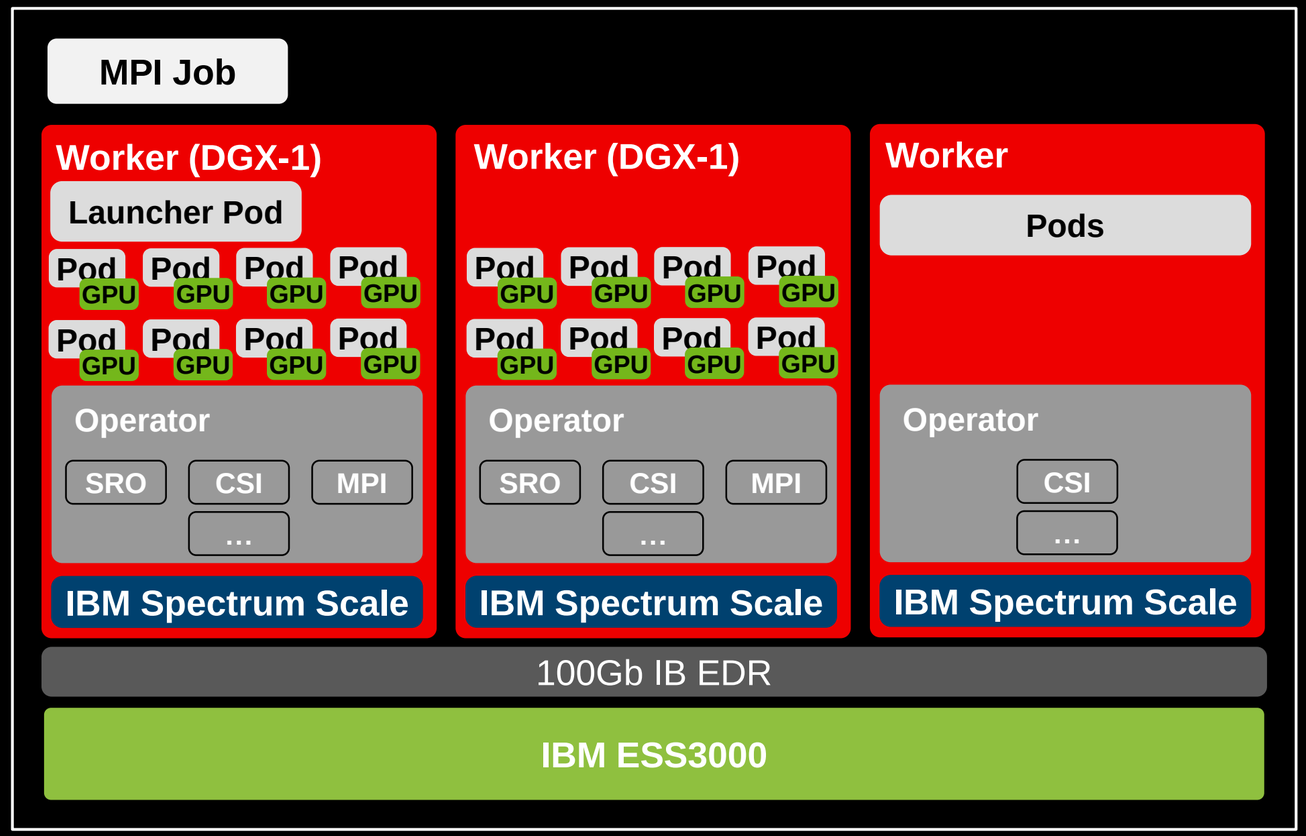
Multi-GPU, Multi-Node GPU Scaling with Tensorflow ResNet50

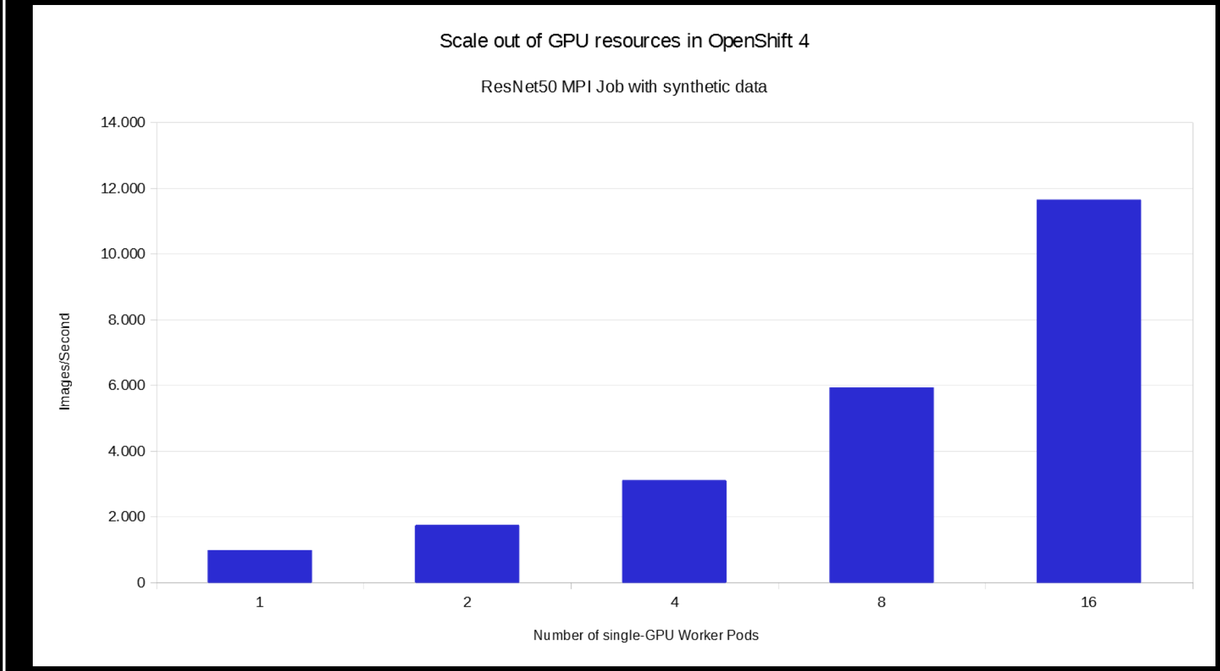
- Used 2x DGX-1 as Worker nodes
- IBM Spectrum Scale clients accessing data via remote mount to IBM ESS Storage Cluster
- 100GB IB EDR Data Network
- Tensorflow ResNet50 benchmark with synthetic data typically scales well with the number of GPUs
- DNN training workload and Data provided to the Pods via CSI provisioned persistent volume (PV)



Multi-GPU, multi-Node GPU Scaling with Tensorflow ResNet50

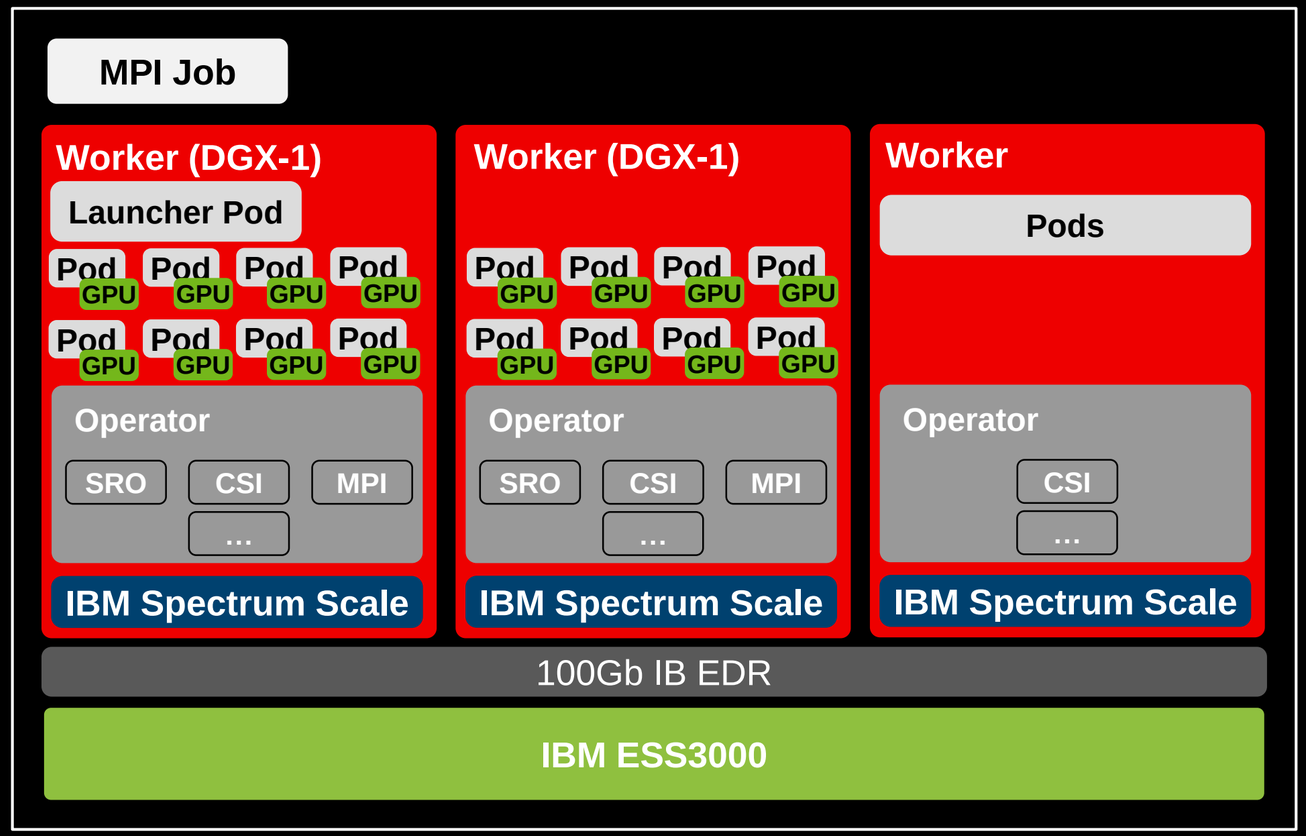
1x Launcher Pod,
starting 16x Worker Pods
each accessing 1 GPU, scale across all nodes

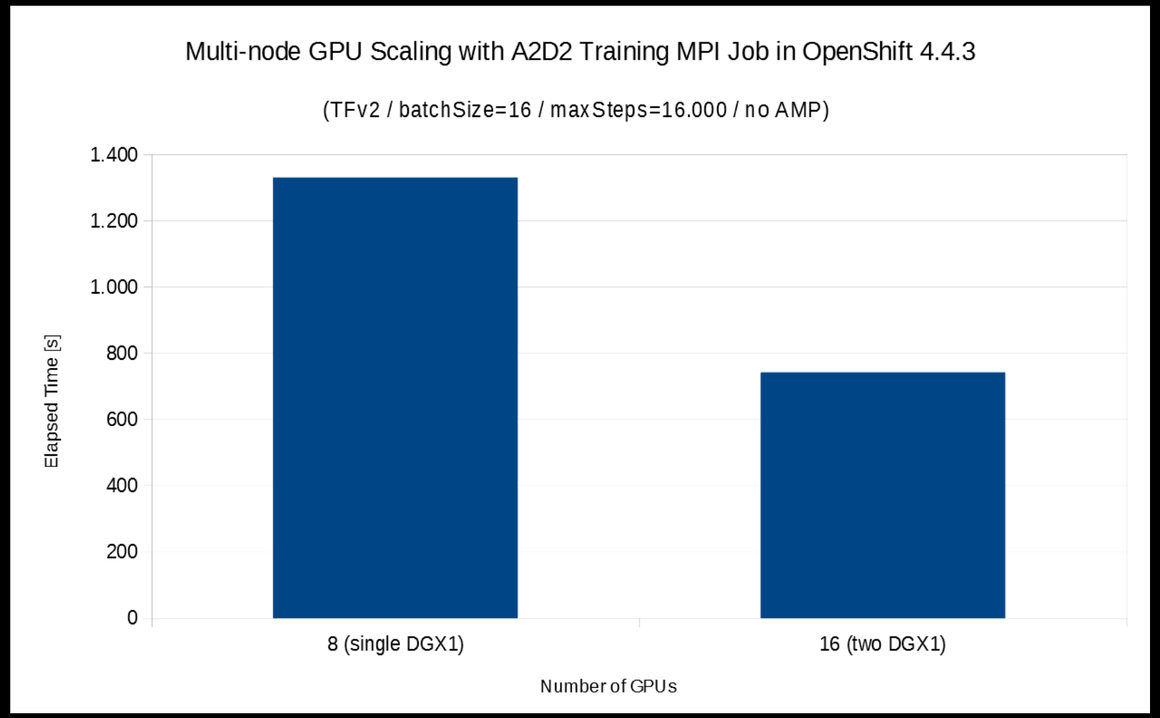




Multi-Node GPU Scaling with A2D2 Training

1x Launcher Pod,
starting 16x Worker Pods
each accessing 1 GPU, scale across all nodes





There is no AI without IA
(information architecture)

Know your data

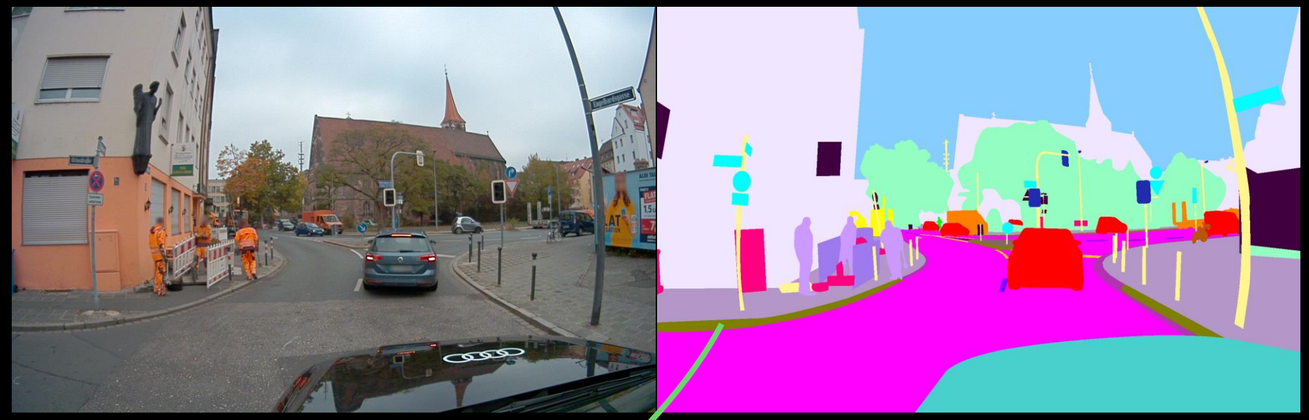
What?
Where?
When?
…

Use your data

at the right time

Autonomous Driving Dataset used

- Audi Autonomous Driving Dataset (A2D2) published by Audi https://www.a2d2.audi
- Six cameras and five Li-DAR units, providing full 360° coverage
- Data is time synchronized and mutually registered
- 41,277 frames with semantic segmentation image and point cloud labels
- Semantic segmentation dataset features 38 categories

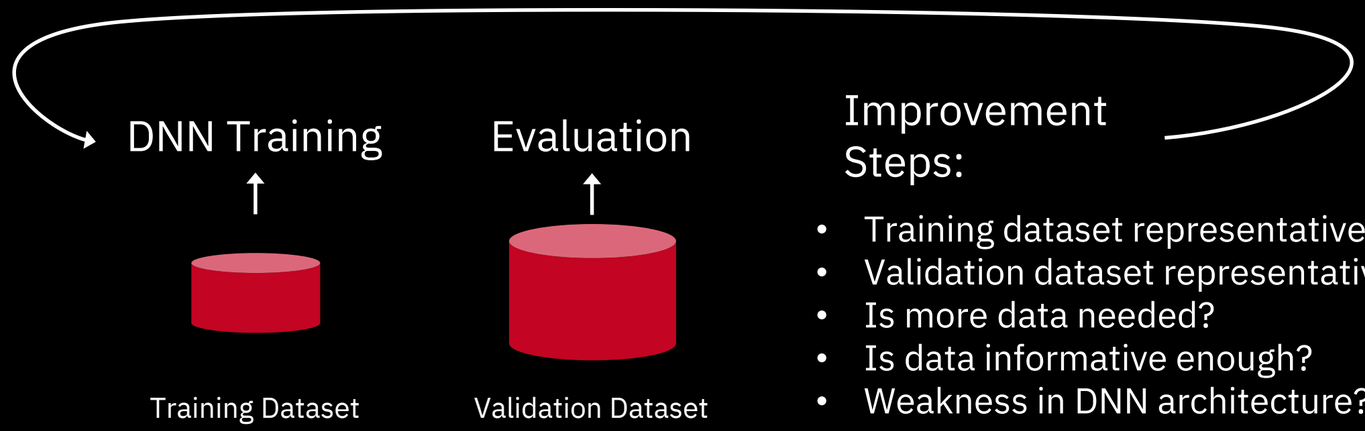


(A2D2- Jacob Geyer et al, 2020, https://arxiv.org/abs/2004.06320)

```
26      "#ffffc8": "Utility vehicle 2",
27      "#e96400": "Sidebars",
28      "#6e6e00": "Speed bumper",
29      "#808000": "Curbstone",
30      "#ff[illegible]125": "Solid line",
31      "#40[illegible]040": "Irrelevant signs",
32      "#b9[illegible]a57": "Road blocks",
33      "#000[illegible]64": "Tractor",
34      "#8b636[illegible]": "Non-drivable street",
35      "#d23273": "Zebra crossing",
36      "#ff0080": "Obstacles / trash",
37      "#fff68f": "Poles",
38      "#960096": "RD restricted area",
39      "#ccff99": "Animals",
```

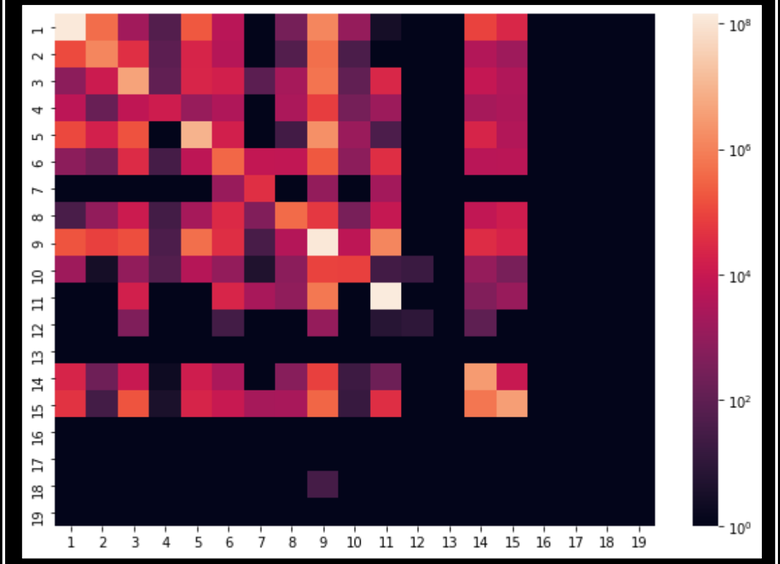
	A	H	I	J	K	L	M	N	O	P
1	Filename	Car	Bicycle	Pedestrian	Truck	Small vehicles	Traffic signal	Traffic sign	Utility vehicle	Sidebars
50	62316.png	39564	3155	2302	0	0	0	7626	0	0
51	78793.png	48538	0	0	7671	0	113	465	0	0
52	12593.png	238144	1511	0	0	1342	0	8956	0	0
53	20783.png	31558	1525	4213	0	0	3337	20014	3917	0
54	27813.png	10728	14712	585	3514	0	5184	3814	1762	0
55	70939.png	31037	1889	187	0	0	0	18397	0	0
56	00488.png	11482	0	0	0	0	130	180	0	0
57	42035.png	299263	4371	0	0	0	4149	3565	0	0
58	73496.png	15546	0	0	0	0	0	7331	0	1955
59	07232.png	25964	4476	5941	0	0	0	17881	0	0
60	74320.png	80	0	0	0	0	0	233	0	4041
61	75272.png	2796	0	0	0	0	0	835	0	137
62	21604.png	172247	3282	0	0	0	180	1413	0	0
63	41344.png	32295	14794	243	13485	0	2348	2346	0	0
64	73456.png	43828	0	0	0	0	0	6814	0	5598
65	68156.png	108909	2071	0	498	0	0	3995	0	0
66	46816.png	213287	0	103	197	0	332	5287	0	0
67	56672.png	102111	0	0	1794	0	0	25615	34367	0
68	22033.png	3783	169	16855	0	585	688	1846	0	0
69	06963.png	28567	0	210	9933	0	0	3346	0	0
70	50297.png	232642	0	8496	0	0	0	7660	0	0
71	62375.png	39551	3061	3878	0	0	0	7880	0	0
72	71954.png	156984	0	26788	41861	0	0	80	0	0

Building the right training and validation dataset



- Training dataset representative?
- Validation dataset representative?
- Is more data needed?
- Is data informative enough?
- Weakness in DNN architecture?

- Building a representative validation dataset is challenging
- Validation dataset is significantly larger than the training dataset
- Validating the trained DNN against a large validation dataset is critical to understand its weaknesses



Confusion matrix presenting the training evaluation

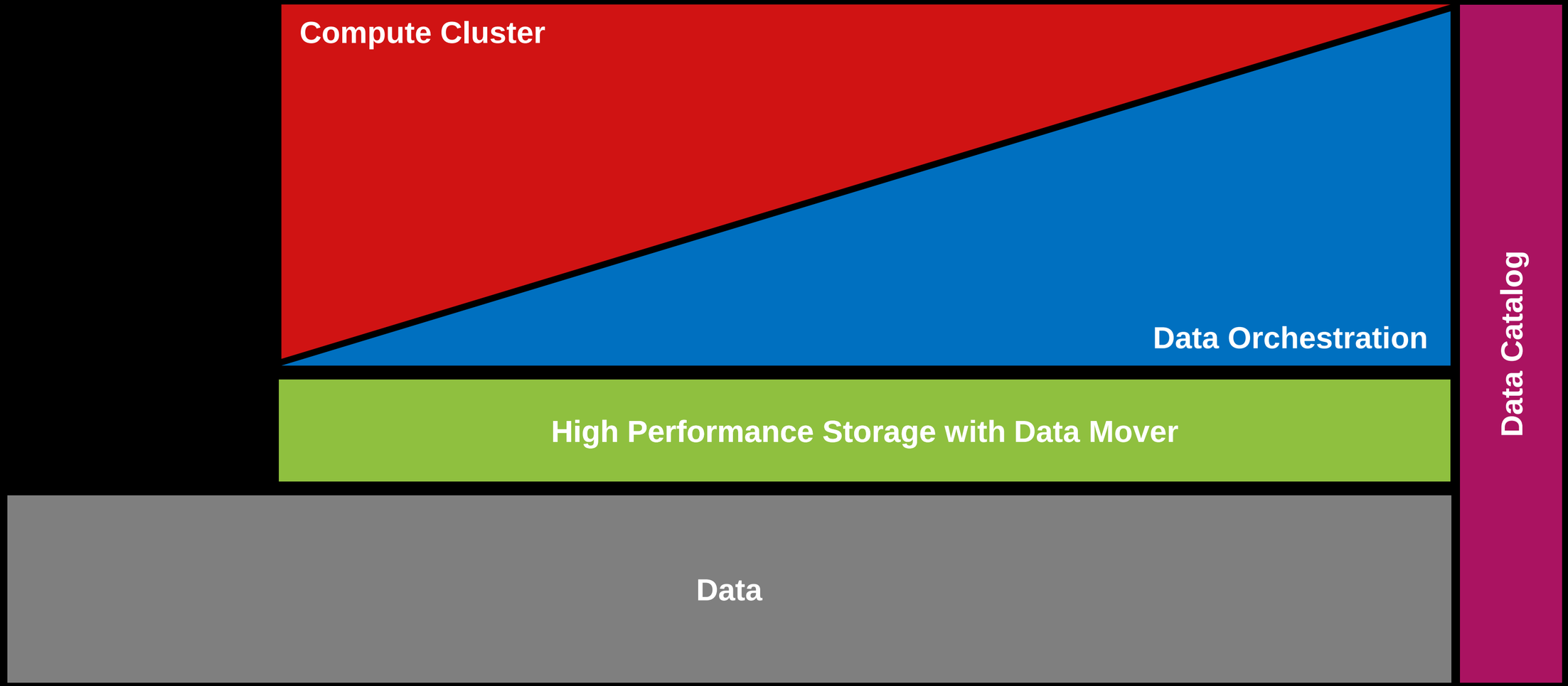
For a perfect predictor:

Diagram would only have a diagonal line from top left to bottom right.

That would read as the network would have classified all pixels of a certain class right.

Data Orchestration

- Abstract data access across storage systems
- Present data with a global namespace
- Train with the right data
- Ensure data is available at the right time



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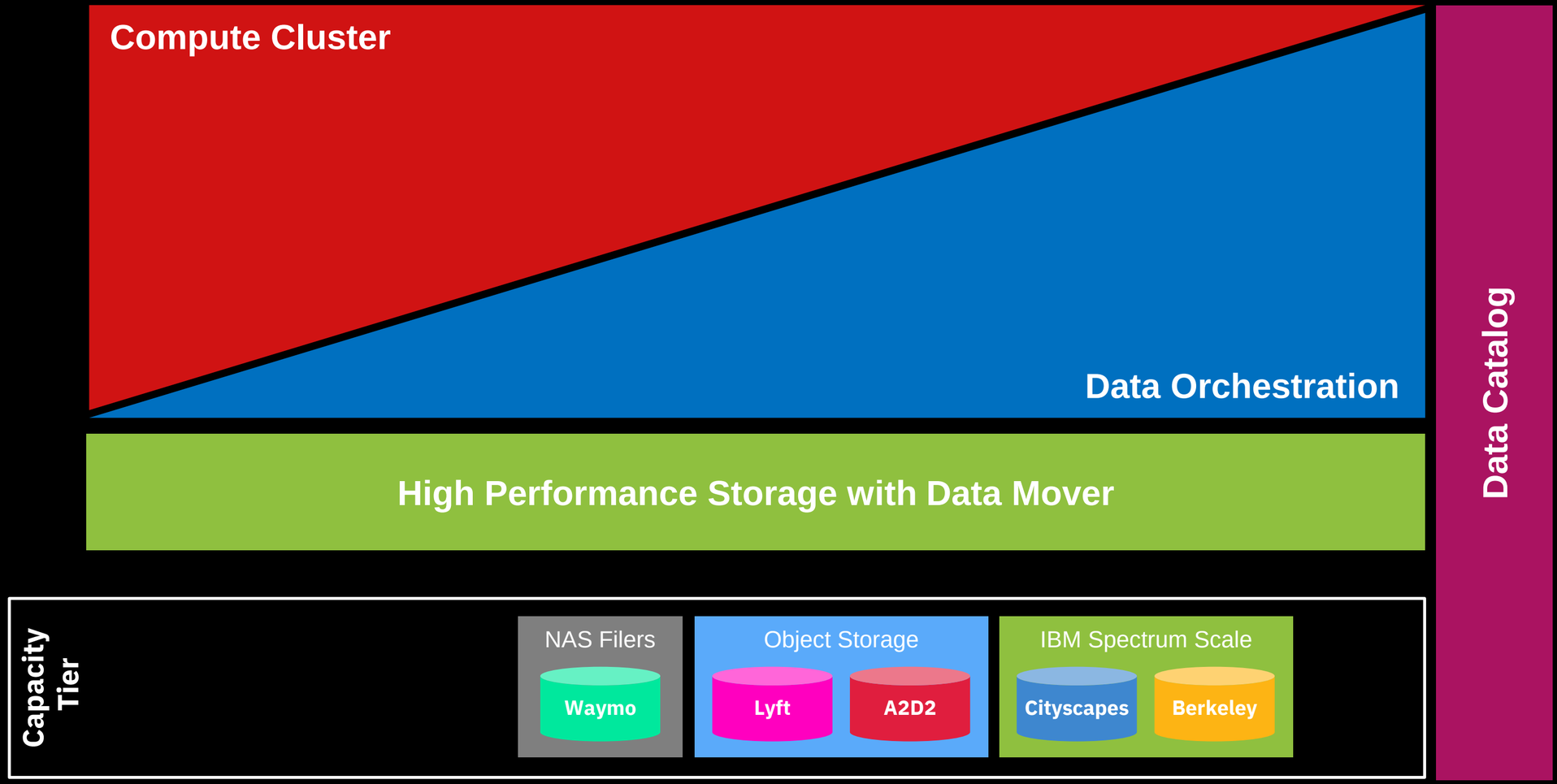

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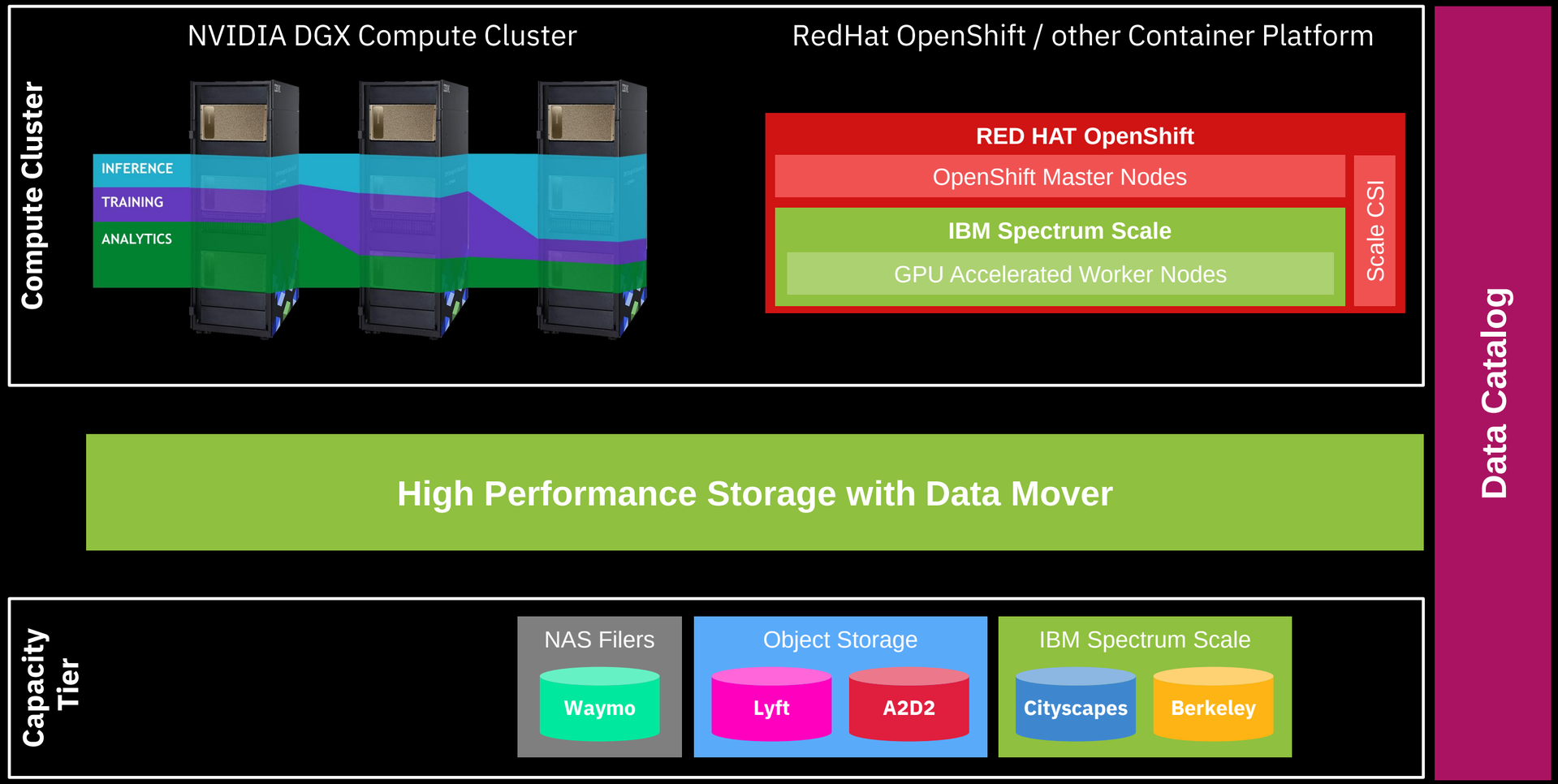

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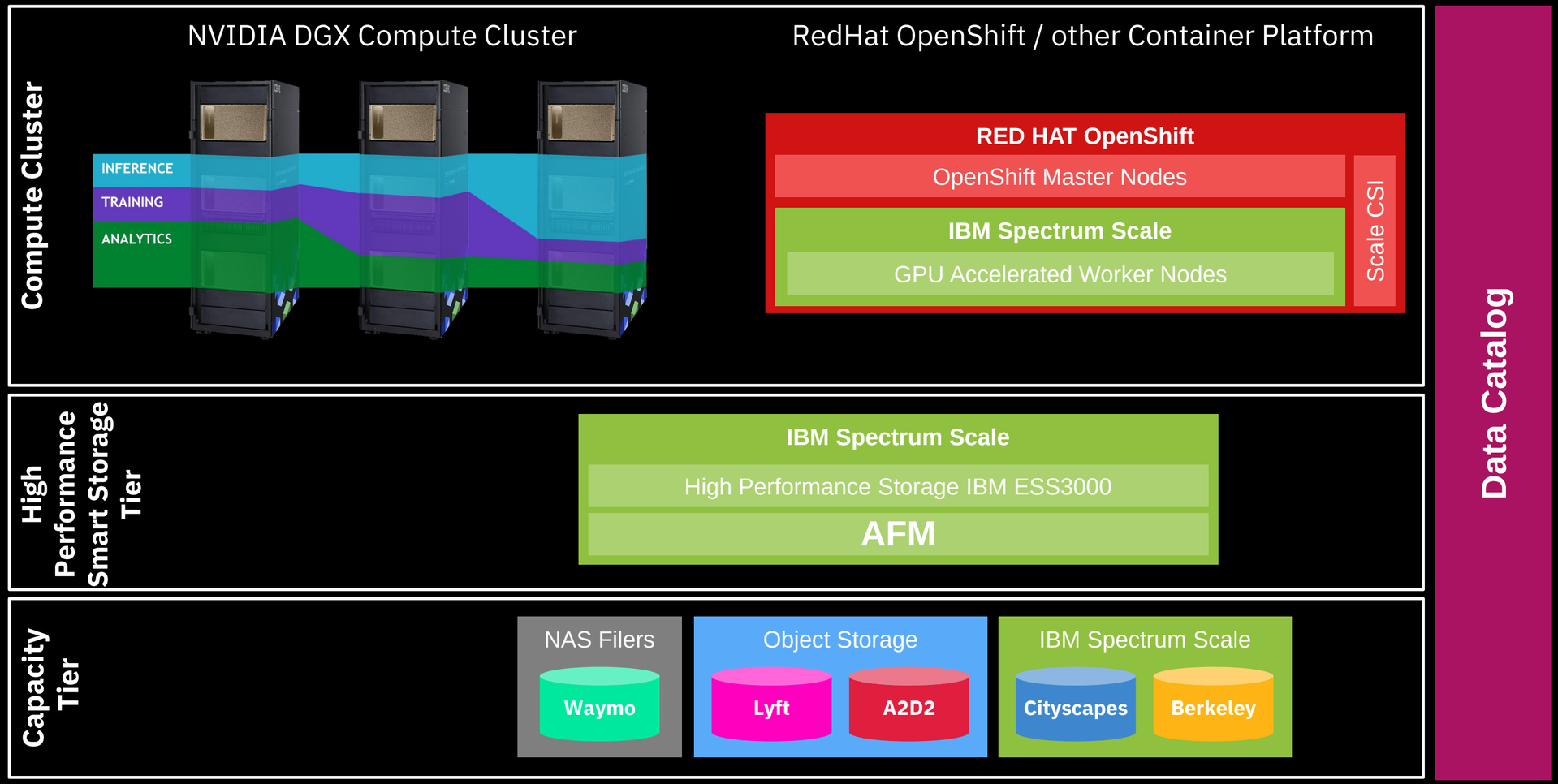
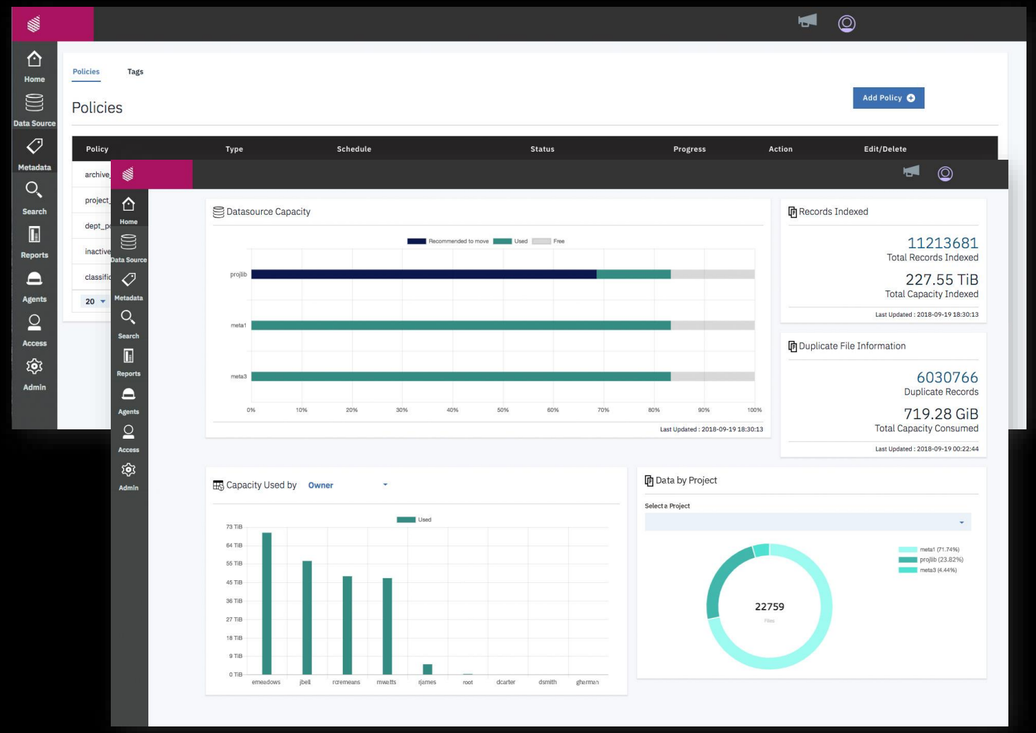


IBM Spectrum Discover

- Automate cataloging/indexing
- Locate and identify for data users or IT Admin
- Manage data governance or analyze for security
- Enable comprehensive insight
- Create custom action agents
- Enable security analysis and data governance



Search billions of files/objects in 0.5 sec and manage AI workflows, data security analysis and data governance

Data Orchestration

- Abstract data access across storage systems
- Present data with a global namespace
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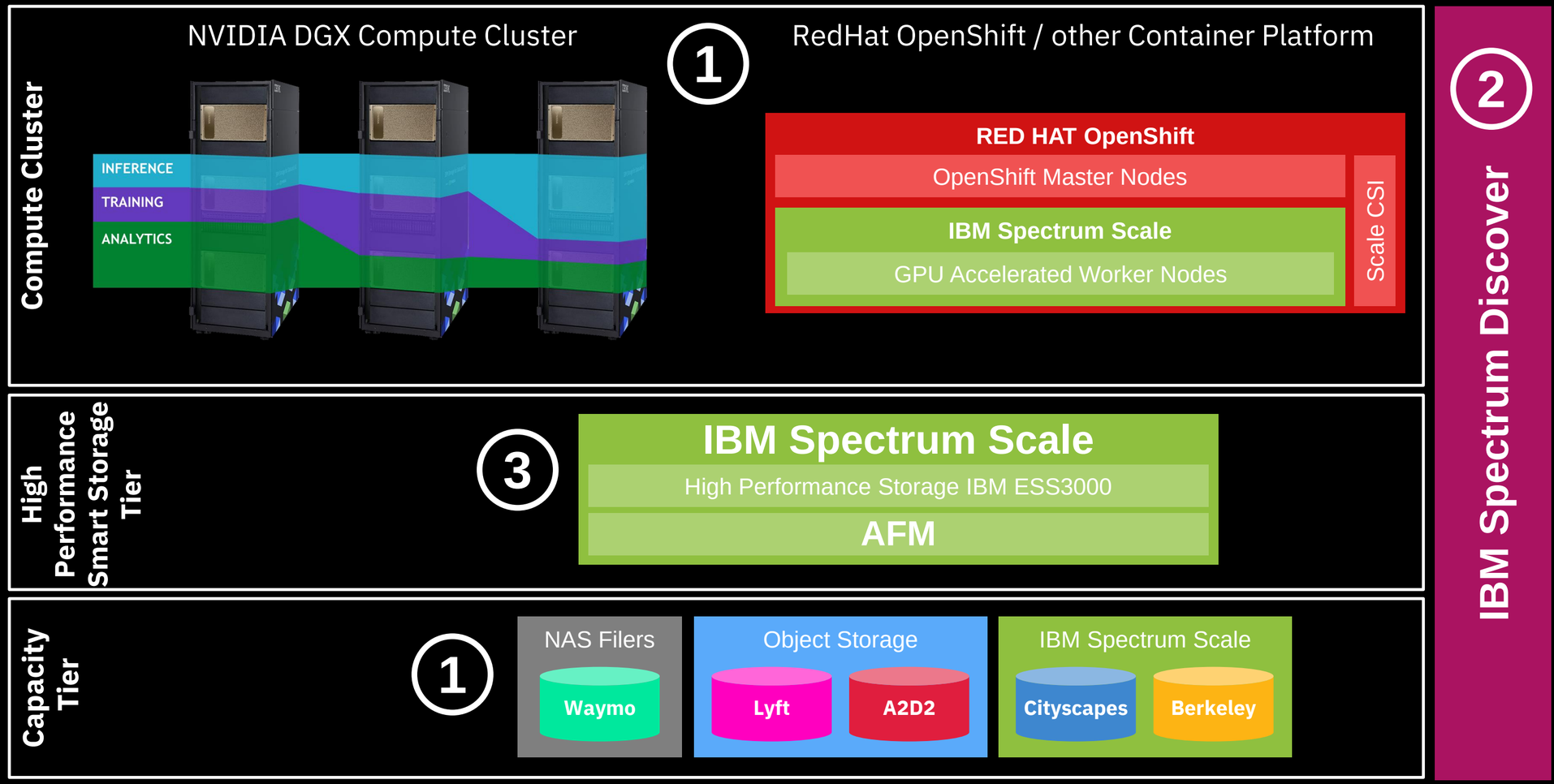
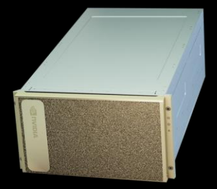


LEARN MORE

www.ibm.com/it-infrastructure/storage/spectrum

www.openshift.com/

www.nvidia.com/dgx-pod



NVIDIA DGX A100

IBM Spectrum Scale

IBM Spectrum Discover

Red Hat OpenShift