Provision and manage volumes

Trident

NetApp
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Provision a volume

Create a PersistentVolumeClaim (PVC) that uses the configured Kubernetes StorageClass to request access to the PV. You can then mount the PV to a pod.

Overview

A *PersistentVolumeClaim* (PVC) is a request for access to the PersistentVolume on the cluster.

The PVC can be configured to request storage of a certain size or access mode. Using the associated StorageClass, the cluster administrator can control more than PersistentVolume size and access mode—such as performance or service level.

After you create the PVC you can mount the volume in a pod.

Create the PVC

Steps

1. Create the PVC.

```
kubectl create -f pvc.yaml
```

2. Verify the PVC status.

```
kubectl get pvc
```

```
NAME         STATUS  VOLUME     CAPACITY   ACCESS MODES  STORAGECLASS AGE
pvc-storage Bound   pv-name    1Gi        RWO                   5m
```

1. Mount the volume in a pod.

```
kubectl create -f pv-pod.yaml
```

> You can monitor the progress using `kubectl get pod --watch`.

2. Verify that the volume is mounted on `/my/mount/path`.

```
kubectl exec -it task-pv-pod -- df -h /my/mount/path
```

3. You can now delete the Pod. The Pod application will no longer exist, but the volume will remain.

```
kubectl delete pod pv-pod
```

Sample manifests

PersistentVolumeClaim sample manifests

These examples show basic PVC configuration options.

PVC with RWO access

This example shows a basic PVC with RWO access that is associated with a StorageClass named `basic-csi`.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: pvc-storage
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
  storageClassName: basic-csi
```

PVC with NVMe/TCP

This example shows a basic PVC for NVMe/TCP with RWO access that is associated with a StorageClass named `protection-gold`.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
name: pvc-san-nvme
spec:
accessModes:
  - ReadWriteOnce
resources:
  requests:
    storage: 300Mi
storageClassName: protection-gold
```

Pod manifest samples

These examples show basic configurations to attach the PVC to a pod.

Basic configuration

```
kind: Pod
apiVersion: v1
metadata:
  name: pv-pod
spec:
  volumes:
    - name: storage
      persistentVolumeClaim:
       claimName: pvc-storage
  containers:
    - name: pv-container
      image: nginx
      ports:
        - containerPort: 80
          name: "http-server"
      volumeMounts:
        - mountPath: "/my/mount/path"
          name: storage
```

Basic NVMe/TCP configuration

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-nginx
spec:
  volumes:
    - name: basic-pvc
      persistentVolumeClaim:
        claimName: pvc-san-nvme
  containers:
    - name: task-pv-container
      image: nginx
      volumeMounts:
        - mountPath: "/my/mount/path"
          name: basic-pvc
```

Refer to Kubernetes and Trident objects for details on how storage classes interact with the `PersistentVolumeClaim` and parameters for controlling how Trident provisions volumes.

Expand volumes

Trident provides Kubernetes users the ability to expand their volumes after they are created. Find information about the configurations required to expand iSCSI, NFS, SMB, NVMe/TCP, and FC volumes.

Expand an iSCSI volume

You can expand an iSCSI Persistent Volume (PV) by using the CSI provisioner.

> iSCSI volume expansion is supported by the `ontap-san`, `ontap-san-economy`, `solidfire-san` drivers and requires Kubernetes 1.16 and later.

Step 1: Configure the StorageClass to support volume expansion

Edit the StorageClass definition to set the `allowVolumeExpansion` field to `true`.

```
cat storageclass-ontapsan.yaml
```

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-san
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-san"
allowVolumeExpansion: True
```

For an already existing StorageClass, edit it to include the `allowVolumeExpansion` parameter.

Step 2: Create a PVC with the StorageClass you created

Edit the PVC definition and update the `spec.resources.requests.storage` to reflect the newly desired size, which must be greater than the original size.

```
cat pvc-ontapsan.yaml
```

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: san-pvc
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
  storageClassName: ontap-san
```

Trident creates a Persistent Volume (PV) and associates it with this Persistent Volume Claim (PVC).

```
kubectl get pvc
NAME      STATUS   VOLUME                                     CAPACITY
ACCESS MODES   STORAGECLASS   AGE
san-pvc   Bound    pvc-8a814d62-bd58-4253-b0d1-82f2885db671   1Gi
RWO            ontap-san      8s

kubectl get pv
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM              STORAGECLASS   REASON   AGE
pvc-8a814d62-bd58-4253-b0d1-82f2885db671   1Gi        RWO
Delete           Bound    default/san-pvc    ontap-san               10s
```

Step 3: Define a pod that attaches the PVC

Attach the PV to a pod for it to be resized. There are two scenarios when resizing an iSCSI PV:

- If the PV is attached to a pod, Trident expands the volume on the storage backend, rescans the device, and resizes the filesystem.
- When attempting to resize an unattached PV, Trident expands the volume on the storage backend. After the PVC is bound to a pod, Trident rescans the device and resizes the filesystem. Kubernetes then updates the PVC size after the expand operation has successfully completed.

In this example, a pod is created that uses the `san-pvc`.

```
 kubectl get pod
NAME         READY   STATUS    RESTARTS   AGE
ubuntu-pod   1/1     Running   0          65s

 kubectl describe pvc san-pvc
Name:          san-pvc
Namespace:     default
StorageClass:  ontap-san
Status:        Bound
Volume:        pvc-8a814d62-bd58-4253-b0d1-82f2885db671
Labels:        <none>
Annotations:   pv.kubernetes.io/bind-completed: yes
               pv.kubernetes.io/bound-by-controller: yes
               volume.beta.kubernetes.io/storage-provisioner:
csi.trident.netapp.io
Finalizers:    [kubernetes.io/pvc-protection]
Capacity:      1Gi
Access Modes:  RWO
VolumeMode:    Filesystem
Mounted By:    ubuntu-pod
```

Step 4: Expand the PV

To resize the PV that has been created from 1Gi to 2Gi, edit the PVC definition and update the `spec.resources.requests.storage` to 2Gi.

```
kubectl edit pvc san-pvc
```

```
# Please edit the object below. Lines beginning with a '#' will be
ignored,
# and an empty file will abort the edit. If an error occurs while saving
this file will be
# reopened with the relevant failures.
#
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  annotations:
    pv.kubernetes.io/bind-completed: "yes"
    pv.kubernetes.io/bound-by-controller: "yes"
    volume.beta.kubernetes.io/storage-provisioner: csi.trident.netapp.io
  creationTimestamp: "2019-10-10T17:32:29Z"
  finalizers:
  - kubernetes.io/pvc-protection
  name: san-pvc
  namespace: default
  resourceVersion: "16609"
  selfLink: /api/v1/namespaces/default/persistentvolumeclaims/san-pvc
  uid: 8a814d62-bd58-4253-b0d1-82f2885db671
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 2Gi
 # ...
```

Step 5: Validate the expansion

You can validate the expansion worked correctly by checking the size of the PVC, PV, and the Trident volume:

```
kubectl get pvc san-pvc
NAME      STATUS   VOLUME                                     CAPACITY
ACCESS MODES   STORAGECLASS   AGE
san-pvc   Bound    pvc-8a814d62-bd58-4253-b0d1-82f2885db671   2Gi
RWO            ontap-san      11m
kubectl get pv
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM              STORAGECLASS   REASON   AGE
pvc-8a814d62-bd58-4253-b0d1-82f2885db671   2Gi        RWO
Delete           Bound    default/san-pvc    ontap-san               12m
tridentctl get volumes -n trident
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
| pvc-8a814d62-bd58-4253-b0d1-82f2885db671 | 2.0 GiB | ontap-san     |
block    | a9b7bfff-0505-4e31-b6c5-59f492e02d33 | online | true    |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
```

Expand an FC volume

You can expand an FC Persistent Volume (PV) by using the CSI provisioner.

> FC volume expansion is supported by the `ontap-san` driver and requires Kubernetes 1.16 and later.

Step 1: Configure the StorageClass to support volume expansion

Edit the StorageClass definition to set the `allowVolumeExpansion` field to `true`.

```
cat storageclass-ontapsan.yaml
```

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-san
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-san"
allowVolumeExpansion: True
```

For an already existing StorageClass, edit it to include the `allowVolumeExpansion` parameter.

Step 2: Create a PVC with the StorageClass you created

Edit the PVC definition and update the `spec.resources.requests.storage` to reflect the newly desired size, which must be greater than the original size.

```
cat pvc-ontapsan.yaml
```

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: san-pvc
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
  storageClassName: ontap-san
```

Trident creates a Persistent Volume (PV) and associates it with this Persistent Volume Claim (PVC).

```
kubectl get pvc
NAME      STATUS   VOLUME                                     CAPACITY
ACCESS MODES   STORAGECLASS   AGE
san-pvc   Bound    pvc-8a814d62-bd58-4253-b0d1-82f2885db671   1Gi
RWO            ontap-san      8s

kubectl get pv
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM              STORAGECLASS   REASON   AGE
pvc-8a814d62-bd58-4253-b0d1-82f2885db671   1Gi        RWO
Delete           Bound    default/san-pvc    ontap-san               10s
```

Step 3: Define a pod that attaches the PVC

Attach the PV to a pod for it to be resized. There are two scenarios when resizing an FC PV:

- If the PV is attached to a pod, Trident expands the volume on the storage backend, rescans the device, and resizes the filesystem.
- When attempting to resize an unattached PV, Trident expands the volume on the storage backend. After the PVC is bound to a pod, Trident rescans the device and resizes the filesystem. Kubernetes then updates the PVC size after the expand operation has successfully completed.

In this example, a pod is created that uses the `san-pvc`.

```
 kubectl get pod
NAME         READY   STATUS    RESTARTS   AGE
ubuntu-pod   1/1     Running   0          65s

 kubectl describe pvc san-pvc
Name:          san-pvc
Namespace:     default
StorageClass:  ontap-san
Status:        Bound
Volume:        pvc-8a814d62-bd58-4253-b0d1-82f2885db671
Labels:        <none>
Annotations:   pv.kubernetes.io/bind-completed: yes
               pv.kubernetes.io/bound-by-controller: yes
               volume.beta.kubernetes.io/storage-provisioner:
csi.trident.netapp.io
Finalizers:    [kubernetes.io/pvc-protection]
Capacity:      1Gi
Access Modes:  RWO
VolumeMode:    Filesystem
Mounted By:    ubuntu-pod
```

Step 4: Expand the PV

To resize the PV that has been created from 1Gi to 2Gi, edit the PVC definition and update the `spec.resources.requests.storage` to 2Gi.

```
kubectl edit pvc san-pvc
```

```
# Please edit the object below. Lines beginning with a '#' will be
ignored,
# and an empty file will abort the edit. If an error occurs while saving
this file will be
# reopened with the relevant failures.
#
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  annotations:
    pv.kubernetes.io/bind-completed: "yes"
    pv.kubernetes.io/bound-by-controller: "yes"
    volume.beta.kubernetes.io/storage-provisioner: csi.trident.netapp.io
  creationTimestamp: "2019-10-10T17:32:29Z"
  finalizers:
  - kubernetes.io/pvc-protection
  name: san-pvc
  namespace: default
  resourceVersion: "16609"
  selfLink: /api/v1/namespaces/default/persistentvolumeclaims/san-pvc
  uid: 8a814d62-bd58-4253-b0d1-82f2885db671
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 2Gi
 # ...
```

Step 5: Validate the expansion

You can validate the expansion worked correctly by checking the size of the PVC, PV, and the Trident volume:

```
kubectl get pvc san-pvc
NAME      STATUS   VOLUME                                     CAPACITY
ACCESS MODES   STORAGECLASS   AGE
san-pvc   Bound    pvc-8a814d62-bd58-4253-b0d1-82f2885db671   2Gi
RWO            ontap-san      11m
kubectl get pv
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM             STORAGECLASS   REASON   AGE
pvc-8a814d62-bd58-4253-b0d1-82f2885db671   2Gi        RWO
Delete           Bound    default/san-pvc   ontap-san               12m
tridentctl get volumes -n trident
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
| pvc-8a814d62-bd58-4253-b0d1-82f2885db671 | 2.0 GiB | ontap-san     |
block    | a9b7bfff-0505-4e31-b6c5-59f492e02d33 | online | true    |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
```

Expand an NFS volume

Trident supports volume expansion for NFS PVs provisioned on `ontap-nas`, `ontap-nas-economy`, `ontap-nas-flexgroup`, and `azure-netapp-files` backends.

Step 1: Configure the StorageClass to support volume expansion

To resize an NFS PV, the admin first needs to configure the storage class to allow volume expansion by setting the `allowVolumeExpansion` field to `true`:

```
cat storageclass-ontapnas.yaml
```

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontapnas
provisioner: csi.trident.netapp.io
parameters:
  backendType: ontap-nas
allowVolumeExpansion: true
```

If you have already created a storage class without this option, you can simply edit the existing storage class

by using `kubectl edit storageclass` to allow volume expansion.

Step 2: Create a PVC with the StorageClass you created

```
cat pvc-ontapnas.yaml
```

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: ontapnas20mb
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 20Mi
  storageClassName: ontapnas
```

Trident should create a 20 MiB NFS PV for this PVC:

```
kubectl get pvc
NAME           STATUS    VOLUME
CAPACITY     ACCESS MODES   STORAGECLASS    AGE
ontapnas20mb   Bound    pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7   20Mi
RWO            ontapnas        9s

kubectl get pv pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM                  STORAGECLASS    REASON
AGE
pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7   20Mi       RWO
Delete           Bound    default/ontapnas20mb   ontapnas
2m42s
```

Step 3: Expand the PV

To resize the newly created 20 MiB PV to 1 GiB, edit the PVC and set `spec.resources.requests.storage` to 1 GiB:

```
kubectl edit pvc ontapnas20mb
```

```
# Please edit the object below. Lines beginning with a '#' will be
ignored,
# and an empty file will abort the edit. If an error occurs while saving
this file will be
# reopened with the relevant failures.
#
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  annotations:
    pv.kubernetes.io/bind-completed: "yes"
    pv.kubernetes.io/bound-by-controller: "yes"
    volume.beta.kubernetes.io/storage-provisioner: csi.trident.netapp.io
  creationTimestamp: 2018-08-21T18:26:44Z
  finalizers:
  - kubernetes.io/pvc-protection
  name: ontapnas20mb
  namespace: default
  resourceVersion: "1958015"
  selfLink: /api/v1/namespaces/default/persistentvolumeclaims/ontapnas20mb
  uid: c1bd7fa5-a56f-11e8-b8d7-fa163e59eaab
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
# ...
```

Step 4: Validate the expansion

You can validate the resize worked correctly by checking the size of the PVC, PV, and the Trident volume:

```
kubectl get pvc ontapnas20mb
NAME           STATUS   VOLUME
CAPACITY   ACCESS MODES   STORAGECLASS    AGE
ontapnas20mb   Bound    pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7   1Gi
RWO            ontapnas        4m44s

kubectl get pv pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7
NAME                                       CAPACITY   ACCESS MODES
RECLAIM POLICY   STATUS   CLAIM                  STORAGECLASS    REASON
AGE
pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7   1Gi        RWO
Delete           Bound    default/ontapnas20mb   ontapnas
5m35s

tridentctl get volume pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7 -n trident
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
| pvc-08f3d561-b199-11e9-8d9f-5254004dfdb7 | 1.0 GiB | ontapnas      |
file     | c5a6f6a4-b052-423b-80d4-8fb491a14a22 | online | true    |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+--------+---------+
```

Understand RWX NVMe subsystem limits

ReadWriteMany (RWX) volumes that use the NVMe protocol have a scalability limit of 64 nodes per volume. The following includes the limitations, explains the NVMe subsystem architecture involved, and outlines the required resolution steps.

Understand the 64-node limit

If you plan to use ReadWriteMany (RWX) volumes with the NVMe protocol, a single RWX NVMe volume cannot be mounted by more than 64 nodes in a Kubernetes cluster.

Do not schedule workloads that mount the same RWX NVMe PersistentVolumeClaim across more than 64 nodes.

This limitation applies only to RWX volumes that use the NVMe protocol.

Understand NVMe subsystem models

Per-volume subsystem model (Trident releases earlier than 26.02)

In Trident releases earlier than 26.02, RWX NVMe volumes are provisioned using a per-volume subsystem model.
Each RWX NVMe volume is mapped to its own dedicated NVMe subsystem on ONTAP.

This model is simple, but it has a lower scalability limit.
In large Kubernetes clusters, subsystem controller limits are reached quickly because each RWX volume consumes a dedicated subsystem.

Super-subsystem model (introduced in Trident 26.02)

Starting with Trident 26.02, RWX NVMe volumes use a shared super-subsystem model.
Multiple RWX NVMe volumes share the same NVMe subsystem.

Each super-subsystem supports up to 1024 namespaces (volumes).
This model significantly improves scalability for RWX workloads and reduces the likelihood of reaching ONTAP subsystem limits.

Each RWX NVMe volume supports up to 64 nodes.

Identify error symptoms

If you create or attach RWX NVMe volumes at scale, you might observe errors similar to the following:

```
Maximum number of controllers reached. No more controllers can be created.
```

This error indicates that the ONTAP NVMe subsystem controller limit has been reached.

Resolve subsystem limit errors

To move beyond per-volume subsystem limitations and take advantage of the super-subsystem model, upgrade to Trident 26.02 or later.

Upgrade Trident to apply the super-subsystem model

To apply the super-subsystem model for RWX NVMe volumes:

1. Upgrade Trident to version 26.02 or later.
2. Scale down all pods that use RWX NVMe volumes to zero replicas.
3. Verify that no workloads are actively using RWX NVMe volumes.
4. Scale the pods back up.

This restart sequence ensures that RWX NVMe volumes are attached using the super-subsystem model.

- This limitation applies only to RWX volumes that use the NVMe protocol.
- The 64-node limit applies per RWX NVMe volume.
- Other access modes and other protocols are not affected.

Controller scalability

Trident introduces controller scalability through improved concurrency across multiple storage drivers. Customers can identify which Trident drivers support controller scalability at general availability and which drivers are available as a technical preview in Trident 26.02. This enables informed deployment decisions and appropriate risk management for scalable Kubernetes environments.

Key concepts and definitions

Controller scalability

Controller scalability refers to the Trident controller's ability to process multiple storage operations in parallel rather than serializing them behind a single lock.
These operations include volume creation, deletion, resizing, snapshot creation and deletion, volume publish and unpublish, and backend management.

When controller scalability is enabled, operations on different volumes and backends proceed concurrently. This increases throughput and reduces end-to-end operation time in environments with high numbers of concurrent PersistentVolumeClaim and VolumeSnapshot operations.

Controller scalability support

Trident supports controller scalability with different maturity levels depending on the storage driver.

General availability

The following drivers support controller scalability at general availability in Trident 26.02:

- `ontap-san`
- `ontap-nas`
- `google-cloud-netapp-volumes`

> The `google-cloud-netapp-volumes` and `google-cloud-netapp-volumes-san` drivers are different.
> Only `google-cloud-netapp-volumes` is supported. Do not use `google-cloud-netapp-volumes-san` in backend configurations or examples.

Enable controller scalability

Controller scalability is controlled by the `enableConcurrency` configuration option. This option must be explicitly enabled during Trident installation or by updating an existing deployment.

Trident operator deployment

To enable controller scalability with the Trident operator, set `enableConcurrency` to `true` in the `TridentOrchestrator` custom resource.

New installation

Create or edit the `TridentOrchestrator` CR with `enableConcurrency` set to `true`:

```
apiVersion: trident.netapp.io/v1
kind: TridentOrchestrator
metadata:
  name: trident
spec:
  namespace: trident
  enableConcurrency: true
```

Apply the CR:

```
kubectl apply -f tridentorchestrator_cr.yaml
```

Existing installation

Patch the existing `TridentOrchestrator` CR to enable controller scalability:

```
kubectl patch torc trident --type=merge -p
'{"spec":{"enableConcurrency":true}}'
```

Verify the setting was applied:

```
kubectl get torc trident -o
jsonpath='{.status.currentInstallationParams.enableConcurrency}'
```

Helm deployment

To enable controller scalability with Helm, set the `enableConcurrency` value to `true`.

New installation

```
helm install trident netapp-trident/trident-operator --namespace trident
--create-namespace --set enableConcurrency=true
```

Existing installation

```
helm upgrade trident netapp-trident/trident-operator --namespace trident
--set enableConcurrency=true
```

Alternatively, set `enableConcurrency` to `true` in a custom `values.yaml` file:

```
# values.yaml
enableConcurrency: true
```

Then install or upgrade using the values file:

```
helm install trident netapp-trident/trident-operator --namespace trident
--create-namespace -f values.yaml
```

tridentctl deployment

To enable controller scalability with `tridentctl`, pass the `--enable-concurrency` flag during installation.

New installation

```
tridentctl install -n trident --enable-concurrency
```

Existing installation

To enable controller scalability on an existing `tridentctl`-based deployment, uninstall and reinstall with the flag:

```
tridentctl uninstall -n trident
tridentctl install -n trident --enable-concurrency
```

Verify controller scalability is enabled

After enabling controller scalability, verify that the Trident controller is running with concurrency enabled by checking the controller pod logs:

```
kubectl logs -n trident deploy/trident-controller | grep -i concurrency
```

You should see a log entry indicating that concurrency is enabled.

Technical preview

The following drivers support controller scalability as a technical preview in Trident 26.02:

- `nas-eco`
- `san-eco`

For these drivers:

- Controller concurrency is available for evaluation and testing
- Behavior may change in future releases
- Use in production environments is not recommended

Concurrency behavior

When controller scalability is enabled:

- Trident replaces the single global lock with fine-grained, per-resource locking
- Operations that modify the same resource are serialized to maintain data consistency
- Operations that only read from a resource can proceed concurrently with other read operations on that resource
- Trident limits concurrent ONTAP API requests to 20 per management LIF to prevent overloading backend storage systems
- If multiple backends share the same management LIF, they share this 20-request limit

Known limitations and considerations

The following considerations apply to controller scalability:

- Concurrency is managed internally by the Trident controller
- There are no user-configurable concurrency limits in this release
- Overall throughput depends on:
  - The storage driver in use
  - Backend responsiveness
  - Kubernetes API server performance
- High concurrency can increase load on backend storage systems

Caveats and limitations

The following limitations apply in Trident 26.02:

- Controller scalability behavior is not identical across all drivers
- Technical preview drivers may exhibit:
  - Inconsistent performance under high load
  - Changes in behavior between releases
- Debugging concurrent operations may be more complex due to parallel execution
- Metrics and logs may show interleaved operation output

Recommendations

- Use general availability (GA) drivers for production environments that require high scalability
- Evaluate technical preview drivers in non-production environments
- Monitor backend and controller performance when operating at scale

- Avoid assuming operation ordering in automation scripts

Automatic volume expansion

Automatic volume expansion enables Persistent Volumes provisioned by Trident to grow automatically when used capacity reaches a defined threshold. This capability reduces operational overhead and helps prevent application disruption caused by capacity exhaustion. Automatic volume expansion is implemented using Autogrow Policies. An Autogrow Policy defines:

- The utilization threshold that triggers expansion
- The amount by which the volume grows
- The maximum size the volume can reach

> Volumes increase in size automatically when the defined utilization threshold is exceeded. Volumes are never automatically reduced.

Requirements

Before configuring automatic volume expansion, ensure that the following requirements are met:

- Trident 26.02 or later
- Role-based access control permissions to create `TridentAutogrowPolicy` custom resources
- StorageClasses configured with `allowVolumeExpansion: true`
- Supported ONTAP protocols:
  - Network File System (NFS)
  - Internet Small Computer Systems Interface (iSCSI)
  - Non-Volatile Memory Express (NVMe)
  - Fibre Channel Protocol (FCP)

Limitations

- ONTAP Non-Volatile Memory Express raw block volumes earlier than ONTAP 9.16.1 do not support automatic expansion.
- For storage area network volumes, if `growthAmount` is less than or equal to 50 mebibytes, Trident automatically increases the value to 51 mebibytes before resizing, provided the resulting size does not exceed `maxSize`.
- In brownfield environments, automatic expansion might not function for certain existing volumes due to volume publication migration behavior.
- When a volume reaches `maxSize`, no further expansion occurs.
- Supported protocols for automatic volume expansion:
  - Network File System (NFS)
  - Internet Small Computer Systems Interface (iSCSI)

- Non-Volatile Memory Express (NVMe)
- Fibre Channel Protocol (FCP)

Provision Volumes with Autogrow Policy

Autogrow Policy can be configured at two levels:

- Storage class level: Sets default for all volumes (using annotation)
- PVC level: Overrides storage class default (using annotation)

Create an Autogrow Policy

Autogrow Policies enable automatic volume expansion when volumes reach a defined capacity threshold.

Ensure you have:

- Trident 26.02 or later installed
- Role-based access control permissions to create `TridentAutogrowPolicy` resources
- Understanding of workload growth requirements

An Autogrow Policy defines how volumes expand automatically when they reach a defined capacity threshold.

You can create Autogrow Policies at any point in your workflow:

- Before StorageClasses and volumes are created
- After StorageClasses exist
- After volumes are provisioned

This flexibility allows you to introduce automatic expansion without recreating existing resources.

Autogrow Policy specifications

Autogrow Policies are Kubernetes custom resources defined as follows:

Field	Description	Format	Required	Example	Default
name	Unique policy identifier	String	Yes	production-db-policy	None
usedThreshold	Capacity percentage that triggers expansion	Percentage string	Yes	"80%"	None
growthAmount	Amount to grow when threshold is reached	Percentage or size	No	"10%" or "5Gi"	"10%"
maxSize	Maximum volume size limit	Kubernetes quantity	No	"500Gi"	Unlimited

Create an Autogrow Policy

Steps

1. Create a YAML file that defines your Autogrow Policy:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: standard-autogrow
spec:
  usedThreshold: "80%"
  growthAmount: "10%"
  maxSize: "500Gi"
```

2. Apply the policy to your cluster:

```
kubectl apply -f autogrow-policy.yaml
```

3. Verify that the policy was created:

```
kubectl get tridentautogrowpolicy standard-autogrow
```

Expected output

```
NAME                USED THRESHOLD   GROWTH AMOUNT   STATE
standard-autogrow   80%              10%             Success
```

Policy states

After you create a policy, Trident validates the specification and assigns one of the following states:

State	Description	Action required
Success	Policy is validated and ready to use.	None.
Failed	Validation errors detected.	Review and fix the specification.
Deleting	Deletion is in progress.	Wait for completion.

Associate a policy with a StorageClass

You can associate an Autogrow Policy with a StorageClass by using the `trident.netapp.io/autogrowPolicy` annotation. All volumes provisioned from that StorageClass inherit the policy.

The StorageClass must have `allowVolumeExpansion: true`.

Steps

1. Create or modify a StorageClass with the Autogrow Policy annotation:

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-gold
  annotations:
    trident.netapp.io/autogrowPolicy: "production-db-policy"
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-san"
  fsType: "ext4"
allowVolumeExpansion: true
```

2. Apply the StorageClass:

```
kubectl apply -f storageclass.yaml
```

3. Verify the annotation:

```
kubectl get storageclass ontap-gold -o
jsonpath='{.metadata.annotations.trident\.netapp\.io/autogrowPolicy}'
```

Expected output

```
production-db-policy
```

Policy precedence

When Autogrow Policy annotations are set on both a StorageClass and a PVC, Trident applies the following precedence rules:

1. **PVC annotation takes priority.** If a PVC sets `trident.netapp.io/autogrowPolicy`, that value is always used.
2. **StorageClass annotation applies only when the PVC has no annotation.**
3. **If neither has the annotation,** no Autogrow Policy is applied.

Table 1. Precedence examples

StorageClass annotation	PVC annotation	Effective behavior
`trident.netapp.io/autogrowPolicy: standard-agp`	Not set	Uses `standard-agp`.

StorageClass annotation	PVC annotation	Effective behavior
`trident.netapp.io/autogrowPolicy: standard-agp`	`trident.netapp.io/autogrowPolicy: logs-policy`	Uses `logs-policy` (PVC overrides StorageClass).
`trident.netapp.io/autogrowPolicy: standard-agp`	`trident.netapp.io/autogrowPolicy: "none"`	No Autogrow Policy (PVC disables autogrow).
Not set	`trident.netapp.io/autogrowPolicy: dev-policy`	Uses `dev-policy`.
Not set	Not set	No Autogrow Policy.

Configuration examples

The following examples show common Autogrow Policy configurations for different use cases.

Conservative policy for production databases

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: production-db-policy
spec:
  usedThreshold: "75%"
  growthAmount: "20%"
  maxSize: "5Ti"
```

Log storage with fixed growth increments

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: log-storage-policy
spec:
  usedThreshold: "90%"
  growthAmount: "10Gi"
  maxSize: "100Gi"
```

Minimal policy with defaults

When you omit `growthAmount` and `maxSize`, Trident uses the defaults (`10%` growth, unlimited size):

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: logs-policy
spec:
  usedThreshold: "85%"
```

Policy with a custom maxSize and default growthAmount

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: default-ga-policy
spec:
  usedThreshold: "70%"
  maxSize: "100Gi"
```

Aggressive growth with unlimited maxSize

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: aggressive-growth-policy
spec:
  usedThreshold: "80%"
  growthAmount: "150%"
```

Policy with fractional percentages

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: precise-policy
spec:
  usedThreshold: "80.28%"
  growthAmount: "10.65%"
  maxSize: "100Gi"
```

Fractional percentages are supported. If you specify more than three decimal places, Trident rounds the value to three decimal places.

NAS StorageClass with Autogrow

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-nas-autogrow
  annotations:
    trident.netapp.io/autogrowPolicy: "standard-autogrow"
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-nas"
  fsType: "ext4"
allowVolumeExpansion: true
```

SAN StorageClass with Autogrow

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: database-storage
  annotations:
    trident.netapp.io/autogrowPolicy: "production-db-policy"
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-san"
  fsType: "ext4"
allowVolumeExpansion: true
```

Manage Autogrow Policies

After you create Autogrow Policies, you can view, update, and delete them as needed. You can also monitor which volumes are using a given policy.

View Autogrow Policies

List all policies

Use `kubectl` to list all Autogrow Policies in your cluster:

```
kubectl get tridentautogrowpolicy
```

Alternatively, use `tridentctl`:

```
tridentctl get autogrowpolicy
```

View policy details

To view the full specification and status of a policy:

```
kubectl describe tridentautogrowpolicy production-db-policy
```

To view a policy with its associated volumes in YAML format:

```
tridentctl get autogrowpolicy production-db-policy -o yaml
```

Update an Autogrow Policy

You can modify an existing policy to change its threshold, growth amount, or maximum size. Changes take effect immediately for all volumes that use the policy.

> Changes affect all volumes currently using the policy. Test changes in a non-production environment first when possible.

Steps

1. Edit the policy:

   ```
   kubectl edit tridentautogrowpolicy production-db-policy
   ```

2. Modify the `spec` fields as needed:

   ```
   spec:
     usedThreshold: "75%"     # Changed from 80%
     growthAmount: "20%"      # Changed from 10%
     maxSize: "1Ti"           # Changed from 500Gi
   ```

3. Save and exit. The changes take effect immediately.

Update considerations

- **Immediate effect:** All volumes using the policy adopt new parameters at the next growth evaluation.
- **No volume restart needed:** Changes apply to the next growth operation.
- **Test first:** Validate changes in a non-production environment when possible.
- **Communicate changes:** Notify teams when you modify shared policies.

Delete an Autogrow Policy

Autogrow Policies use finalizer protection to prevent accidental deletion while volumes are actively using them.

Steps

1. Delete the policy:

```
kubectl delete tridentautogrowpolicy production-db-policy
```

2. If volumes are still using the policy, the deletion enters a `Deleting` state. Check which volumes are affected:

```
tridentctl get autogrowpolicy production-db-policy -o yaml
```

3. Remove the policy from each affected volume. Choose one of the following options:

   - **Option A: Explicitly disable autogrow** by setting the annotation to `"none"`:

```
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy="none" \
  --overwrite
```

   - **Option B: Remove the annotation entirely:**

```
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy-
```

Deletion behavior

Scenario	Behavior
No volumes use the policy	Policy is deleted immediately.
Volumes are using the policy	Policy enters `Deleting` state. A finalizer blocks completion until all volumes are removed.
All volumes are removed from the policy	Finalizers are removed and the policy is deleted.

Monitor Autogrow Policy usage

Check volumes using a policy

```
tridentctl get autogrowpolicy production-db-policy -o json | jq '.volumes'
```

Find which policy a volume uses

```
kubectl get pvc database-pvc -o
jsonpath='{.metadata.annotations.trident\.netapp\.io/autogrowPolicy}'
```

Monitor policy events

```
kubectl get events --field-selector
involvedObject.kind=TridentAutogrowPolicy
```

Supported protocols

Autogrow supports the following storage protocols:

- NFS
- iSCSI
- FCP
- NVMe

> For SAN volumes, if the configured `growthAmount` is 50 MiB or less, Trident automatically increases the growth amount to 51 MB for the resize operation, as long as the resulting size does not exceed `maxSize`.

Known limitations

- **ONTAP NVMe raw block volumes:** Volumes created with ONTAP versions earlier than 9.16.1 do not support autogrow.
- **Existing volumes (brownfield deployments):** Autogrow might not work for existing volumes even if a valid Autogrow Policy is applied. This is due to an ongoing migration of volume publications. To confirm migration has completed, check the Trident controller logs for `"Migration completed"` messages.

Frequently asked questions

When does Trident evaluate the threshold?

Trident continuously monitors volume usage. When the used capacity crosses the `usedThreshold`, Trident creates an internal resize request and expands the volume by the configured `growthAmount`.

For example, this policy triggers expansion at 80% capacity and grows the volume by 10% each time, up to a maximum of 500 GiB:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: standard-autogrow
spec:
  usedThreshold: "80%"
  growthAmount: "10%"
  maxSize: "500Gi"
```

Can I apply a policy after volumes are already provisioned?

Yes. You can create an Autogrow Policy at any time and apply it to existing PVCs by adding or updating the `trident.netapp.io/autogrowPolicy` annotation. You do not need to recreate the PVC or the StorageClass.

To apply a policy to an existing PVC:

```
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy="production-db-policy" \
  --overwrite
```

To apply a policy to an existing StorageClass:

```
kubectl annotate storageclass ontap-gold \
  trident.netapp.io/autogrowPolicy="production-db-policy" \
  --overwrite
```

What happens if I set an Autogrow Policy on both the StorageClass and the PVC?

The PVC annotation always takes precedence. If a PVC has the `trident.netapp.io/autogrowPolicy` annotation, Trident uses that value regardless of what the StorageClass specifies. Refer to Policy precedence for details.

For example, given this StorageClass:

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-gold
  annotations:
    trident.netapp.io/autogrowPolicy: "standard-agp"
provisioner: csi.trident.netapp.io
allowVolumeExpansion: true
```

And this PVC that overrides the StorageClass policy:

```
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: database-pvc
  annotations:
    trident.netapp.io/autogrowPolicy: "logs-policy"
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 50Gi
  storageClassName: ontap-gold
```

Trident uses `logs-policy` for `database-pvc`, not `standard-agp`.

How do I disable autogrow for a specific volume?

Set the PVC annotation to `"none"`. This overrides any StorageClass-level policy for that volume:

```
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy="none" \
  --overwrite
```

You can verify that autogrow is disabled:

```
kubectl get pvc <pvc-name> -o jsonpath
='{.metadata.annotations.trident\.netapp\.io/autogrowPolicy}'
```

Expected output

```
none
```

What happens when a volume reaches maxSize?

Trident stops expanding the volume. No further resize requests are created for that volume, even if usage continues to increase beyond the `usedThreshold`.

For example, with this policy, Trident stops growing the volume once it reaches 100 GiB:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: capped-policy
spec:
  usedThreshold: "90%"
  growthAmount: "10Gi"
  maxSize: "100Gi"
```

To allow unlimited growth, omit `maxSize` or set it to `0`:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: unlimited-policy
spec:
  usedThreshold: "85%"
  growthAmount: "10%"
```

Can I change a policy without restarting volumes?

Yes. When you update a policy, all volumes using that policy adopt the new parameters at the next growth evaluation. No volume restarts are required.

To update a policy in place:

```
kubectl edit tridentautogrowpolicy production-db-policy
```

Modify the fields as needed:

```
spec:
  usedThreshold: "75%"    # Changed from 80%
  growthAmount: "20%"     # Changed from 10%
  maxSize: "1Ti"          # Changed from 500Gi
```

Save and exit. Verify the updated policy:

```
kubectl get tridentautogrowpolicy production-db-policy
```

Expected output

```
NAME                    USED THRESHOLD   GROWTH AMOUNT   STATE
production-db-policy    75%              20%             Success
```

Why is my policy in a Failed state?

A `Failed` state indicates that the policy specification contains validation errors. Run the following command to view the error details:

```
kubectl describe tridentautogrowpolicy <policy-name>
```

Common causes include an invalid `usedThreshold` (must be 1–99%), a `growthAmount` that exceeds `maxSize`, or an invalid Kubernetes quantity format. Correct the specification and reapply:

```
kubectl apply -f autogrow-policy.yaml
```

Why can't I delete a policy?

Policies use finalizer protection. If volumes are still using the policy, deletion enters a `Deleting` state and waits until all volumes are removed from the policy.

Identify the affected volumes:

```
tridentctl get autogrowpolicy production-db-policy -o yaml
```

Then remove the annotation from each PVC:

```
# Option A: Explicitly disable autogrow
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy="none" \
  --overwrite

# Option B: Remove the annotation entirely
kubectl annotate pvc <pvc-name> \
  trident.netapp.io/autogrowPolicy-
```

After all volumes are removed, the finalizer is released and the policy is deleted.

Does autogrow work with all ONTAP backends?

Autogrow supports NFS, iSCSI, FCP, and NVMe protocols. However, NVMe raw block volumes require ONTAP 9.16.1 or later.

Existing volumes in brownfield deployments might require volume publication migration to complete before autogrow takes effect. Verify migration status by checking the Trident controller logs:

```
kubectl logs -l app=trident-controller -n trident | grep "Migration
completed"
```

The following StorageClass examples show autogrow configured for NAS and SAN backends:

NAS backend

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: ontap-nas-autogrow
  annotations:
    trident.netapp.io/autogrowPolicy: "standard-autogrow"
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-nas"
  fsType: "ext4"
allowVolumeExpansion: true
```

SAN backend

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: database-storage
  annotations:
    trident.netapp.io/autogrowPolicy: "production-db-policy"
provisioner: csi.trident.netapp.io
parameters:
  backendType: "ontap-san"
  fsType: "ext4"
allowVolumeExpansion: true
```

What is the minimum growth amount for SAN volumes?

For SAN volumes, the effective minimum growth amount is 51 MB. If you configure a `growthAmount` of 50 MiB or less, Trident automatically increases the growth to 51 MB for the resize operation.

For example, this policy sets a `growthAmount` of `"40Mi"`, but Trident applies a 51 MB growth for any SAN volume that uses it:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: san-minimal-policy
spec:
  usedThreshold: "85%"
  growthAmount: "40Mi"
  maxSize: "100Gi"
```

To avoid this automatic adjustment, set `growthAmount` to a value greater than 50 MiB:

```
apiVersion: trident.netapp.io/v1
kind: TridentAutogrowPolicy
metadata:
  name: san-policy
spec:
  usedThreshold: "85%"
  growthAmount: "100Mi"
  maxSize: "500Gi"
```

Import volumes

You can import existing storage volumes as a Kubernetes PV using `tridentctl import` or by creating a Persistent Volume Claim (PVC) with Trident import annotations.

Overview and considerations

You might import a volume into Trident to:

- Containerize an application and reuse its existing data set
- Use a clone of a data set for an ephemeral application
- Rebuild a failed Kubernetes cluster
- Migrate application data during disaster recovery

Considerations

Before importing a volume, review the following considerations.

- Trident can import RW (read-write) type ONTAP volumes only. DP (data protection) type volumes are SnapMirror destination volumes. You should break the mirror relationship before importing the volume into Trident.
- We suggest importing volumes without active connections. To import an actively-used volume, clone the volume and then perform the import.

This is especially important for block volumes as Kubernetes would be unaware of the previous connection and could easily attach an active volume to a pod. This can result in data corruption.

- Though `StorageClass` must be specified on a PVC, Trident does not use this parameter during import. Storage classes are used during volume creation to select from available pools based on storage characteristics. Because the volume already exists, no pool selection is required during import. Therefore, the import will not fail even if the volume exists on a backend or pool that does not match the storage class specified in the PVC.
- The existing volume size is determined and set in the PVC. After the volume is imported by the storage driver, the PV is created with a ClaimRef to the PVC.
  - The reclaim policy is initially set to `retain` in the PV. After Kubernetes successfully binds the PVC and PV, the reclaim policy is updated to match the reclaim policy of the Storage Class.
  - If the reclaim policy of the Storage Class is `delete`, the storage volume will be deleted when the PV is deleted.
- By default, Trident manages the PVC and renames the FlexVol volume and LUN on the backend. You can pass the `--no-manage` flag to import an unmanaged volume and the `--no-rename` flag to retain the volume name.
  - **`--no-manage`** - If you use the `--no-manage` flag, Trident does not perform any additional operations on the PVC or PV for the lifecycle of the objects. The storage volume is not deleted when the PV is deleted and other operations such as volume clone and volume resize are also ignored.
  - **`--no-rename`** - If you use the `--no-rename` flag, Trident retains the existing volume name while importing volumes, and manages the lifecycle of the volumes. This option is supported only for the `ontap-nas`, `ontap-san` (including ASA r2 systems), and `ontap-san-economy` drivers.

    These options are useful if you want to use Kubernetes for containerized workloads but otherwise want to manage the lifecycle of the storage volume outside of Kubernetes.
- An annotation is added to the PVC and PV that serves a dual purpose of indicating that the volume was imported and if the PVC and PV are managed. This annotation should not be modified or removed.

Import a volume

You can import a volume using either `tridentctl import` or by creating a PVC with Trident import annotations.

If you use PVC annotations, you don't need to download or use `tridentctl` to import the volume.

Using tridentctl

Steps

1. Create a PVC file (for example, `pvc.yaml`) that will be used to create the PVC. The PVC file should include `name`, `namespace`, `accessModes`, and `storageClassName`. Optionally, you can specify `unixPermissions` in your PVC definition.

   The following is an example of a minimum specification:

   ```
   kind: PersistentVolumeClaim
   apiVersion: v1
   metadata:
     name: my_claim
     namespace: my_namespace
   spec:
     accessModes:
       - ReadWriteOnce
     storageClassName: my_storage_class
   ```

   > Include only the required parameters. Additional parameters such as PV name or volume size can cause the import command to fail.

2. Use the `tridentctl import` command to specify the name of the Trident backend containing the volume and the name that uniquely identifies the volume on the storage (for example: ONTAP FlexVol, Element Volume). The `-f` argument is required to specify the path to the PVC file.

   ```
   tridentctl import volume <backendName> <volumeName> -f <path-to-pvc-file>
   ```

Using PVC annotations

Steps

1. Create a PVC YAML file (for example, `pvc.yaml`) with the required Trident import annotations. The PVC file should include:
   - `name` and `namespace` in metadata
   - `accessModes`, `resources.requests.storage`, and `storageClassName` in spec
   - Annotations:
     - `trident.netapp.io/importOriginalName`: Volume name on the backend
     - `trident.netapp.io/importBackendUUID`: Backend UUID where volume exists
     - `trident.netapp.io/notManaged` (*Optional*): Set to `"true"` for unmanaged volumes. Default is `"false"`.

       The following is an example specification for importing a managed volume:

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: <pvc-name>
  namespace: <namespace>
  annotations:
    trident.netapp.io/importOriginalName: "<volume-name>"
    trident.netapp.io/importBackendUUID: "<backend-uuid>"
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: <size>
  storageClassName: <storage-class-name>
```

2. Apply the PVC YAML file to your Kubernetes cluster:

```
kubectl apply -f <pvc-file>.yaml
```

Trident will automatically import the volume and bind it to the PVC.

Examples

Review the following volume import examples for supported drivers.

ONTAP NAS and ONTAP NAS FlexGroup

Trident supports volume import using the `ontap-nas` and `ontap-nas-flexgroup` drivers.

- Trident does not support volume import using the `ontap-nas-economy` driver.
- The `ontap-nas` and `ontap-nas-flexgroup` drivers do not allow duplicate volume names.

Each volume created with the `ontap-nas` driver is a FlexVol volume on the ONTAP cluster. Importing FlexVol volumes with the `ontap-nas` driver works the same. A FlexVol volumes that already exists on an ONTAP cluster can be imported as a `ontap-nas` PVC. Similarly, FlexGroup vols can be imported as `ontap-nas-flexgroup` PVCs.

ONTAP NAS examples using tridentctl

The following examples show how to import managed and unmanaged volumes using `tridentctl`.

Managed volume

The following example imports a volume named `managed_volume` on a backend named `ontap_nas`:

```
tridentctl import volume ontap_nas managed_volume -f <path-to-pvc-file>

+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
| pvc-bf5ad463-afbb-11e9-8d9f-5254004dfdb7 | 1.0 GiB | standard      |
file     | c5a6f6a4-b052-423b-80d4-8fb491a14a22 | online | true    |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
```

Unmanaged volume

When using the `--no-manage` argument, Trident does not rename the volume.

The following example imports `unmanaged_volume` on the `ontap_nas` backend:

```
tridentctl import volume nas_blog unmanaged_volume -f <path-to-pvc-
file> --no-manage

+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
| pvc-df07d542-afbc-11e9-8d9f-5254004dfdb7 | 1.0 GiB | standard      |
file     | c5a6f6a4-b052-423b-80d4-8fb491a14a22 | online | false   |
+-----------------------------------------+---------+---------------
+----------+-----------------------------------------+---------+---------+
```

ONTAP NAS examples using PVC annotations

The following examples show how to import managed and unmanaged volumes using PVC annotations.

Managed volume

The following example imports a 1GiB `ontap-nas` volume named `ontap_volume1` from backend `81abcb27-ea63-49bb-b606-0a5315ac5f21` with RWO access mode set using PVC annotations:

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: <managed-imported-volume>
  namespace: <namespace>
  annotations:
    trident.netapp.io/importOriginalName: "ontap_volume1"
    trident.netapp.io/importBackendUUID: "81abcb27-ea63-49bb-b606-
0a5315ac5f21"
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
  storageClassName: <storage-class-name>
```

Unmanaged volume

The following example imports 1Gi `ontap-nas` volume named `ontap-volume2` from backend `34abcb27-ea63-49bb-b606-0a5315ac5f34` with RWO access mode set using PVC annotations:

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: <umanaged-imported-volume>
  namespace: <namespace>
  annotations:
    trident.netapp.io/importOriginalName: "ontap-volume2"
    trident.netapp.io/importBackendUUID: "34abcb27-ea63-49bb-b606-
0a5315ac5f34"
    trident.netapp.io/notManaged: "true"
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
  storageClassName: <storage-class-name>
```

ONTAP SAN

Trident supports volume import using the `ontap-san` (iSCSI, NVMe/TCP, and FC) and `ontap-san-economy` drivers.

Trident can import ONTAP SAN FlexVol volumes that contain a single LUN. This is consistent with the `ontap-san` driver, which creates a FlexVol volume for each PVC and a LUN within the FlexVol volume. Trident imports the FlexVol volume and associates it with the PVC definition. Trident can import `ontap-san-economy` volumes that contain multiple LUNs.

The following examples show how to import managed and unmanaged volumes:

Managed volume

For managed volumes, Trident renames the FlexVol volume to the `pvc-<uuid>` format and the LUN within the FlexVol volume to `lun0`.

The following example imports the `ontap-san-managed` FlexVol volume that is present on the `ontap_san_default` backend:

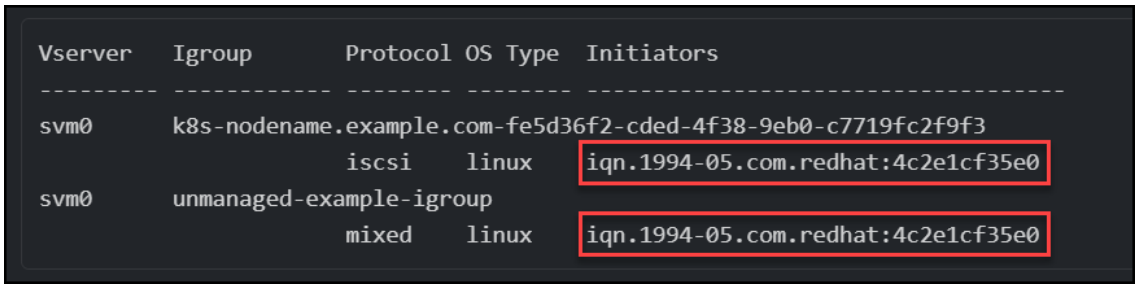
```
tridentctl import volume ontapsan_san_default ontap-san-managed -f pvc-
basic-import.yaml -n trident -d

+-----------------------------------------+--------+--------------
+----------+-----------------------------------------+--------+---------+
|                   NAME                  |  SIZE  | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+--------+--------------
+----------+-----------------------------------------+--------+---------+
| pvc-d6ee4f54-4e40-4454-92fd-d00fc228d74a | 20 MiB | basic         |
block    | cd394786-ddd5-4470-adc3-10c5ce4ca757 | online | true    |
+-----------------------------------------+--------+--------------
+----------+-----------------------------------------+--------+---------+
```

Unmanaged volume

The following example imports `unmanaged_example_volume` on the `ontap_san` backend:

```
tridentctl import volume -n trident san_blog unmanaged_example_volume
-f pvc-import.yaml --no-manage
+-----------------------------------------+---------+--------------
+----------+-----------------------------------------+--------+---------+
|                   NAME                  |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID              | STATE  | MANAGED |
+-----------------------------------------+---------+--------------
+----------+-----------------------------------------+--------+---------+
| pvc-1fc999c9-ce8c-459c-82e4-ed4380a4b228 | 1.0 GiB | san-blog      |
block    | e3275890-7d80-4af6-90cc-c7a0759f555a | online | false   |
+-----------------------------------------+---------+--------------
+----------+-----------------------------------------+--------+---------+
```

If you have LUNS mapped to igroups that share an IQN with a Kubernetes node IQN, as shown in the following example, you will receive the error: `LUN already mapped to initiator(s) in this group`. You will need to remove the initiator or unmap the LUN to import the volume.



```
Vserver   Igroup       Protocol OS Type  Initiators
--------- ------------ -------- -------- ------------------------------------
svm0      k8s-nodename.example.com-fe5d36f2-cded-4f38-9eb0-c7719fc2f9f3
                       iscsi    linux    iqn.1994-05.com.redhat:4c2e1cf35e0
svm0      unmanaged-example-igroup
                       mixed    linux    iqn.1994-05.com.redhat:4c2e1cf35e0
```

ONTAP SAN-economy examples

The following examples show how to import managed and unmanaged volumes for the `ontap-san-economy` backend.

Managed volume

When you import a managed volume, Trident takes ownership of the FlexVol and renames it. You must account for this renaming when you import multiple LUNs from the same FlexVol.

The following example imports `lun1` from the FlexVol `toimport` as a managed volume named `vol-managed-saneco`:

```
tridentctl import volume vol-managed-saneco toimport/lun1 -f
import1.yaml
```

After importing `lun1`, Trident renames the FlexVol (for example, to `trident_lun_pool_xyz`). To import additional LUNs from the same FlexVol, use the new FlexVol name:

```
tridentctl import volume vol-managed-saneco trident_lun_pool_xyz/lun2
-f import2.yaml
```

The `ontap-san-economy` backend imports one LUN at a time. You can automate multiple imports using a script.

Unmanaged volume

When you import an unmanaged volume, Trident does not take ownership of the FlexVol. However, the FlexVol and LUN must follow Trident naming conventions.

FlexVol naming format

```
trident_lun_pool_STORAGEPREFIX_RANDOMSTRING
```

- `STORAGEPREFIX` is the value of `storagePrefix` in your backend configuration. The default is `trident`.
- `RANDOMSTRING` is any string you choose.

LUN naming requirement

The LUN must be named `lun0`.

Example

If your `storagePrefix` is `xyz`, the full path to the LUN is:

```
trident_lun_pool_xyz_randomstring/lun0
```

Element

Trident supports NetApp Element software and NetApp HCI volume import using the `solidfire-san` driver.

The Element driver supports duplicate volume names. However, Trident returns an error if there are duplicate volume names. As a workaround, clone the volume, provide a unique volume name, and import the cloned volume.

The following example imports an `element-managed` volume on backend `element_default`.

```
tridentctl import volume element_default element-managed -f pvc-basic-
import.yaml -n trident -d

+----------------------------------------+--------+--------------
+----------+----------------------------------------+--------+---------+
|                   NAME                 |  SIZE  | STORAGE CLASS |
PROTOCOL |             BACKEND UUID             | STATE  | MANAGED |
+----------------------------------------+--------+--------------
+----------+----------------------------------------+--------+---------+
| pvc-970ce1ca-2096-4ecd-8545-ac7edc24a8fe | 10 GiB | basic-element |
block    | d3ba047a-ea0b-43f9-9c42-e38e58301c49 | online | true    |
+----------------------------------------+--------+--------------
+----------+----------------------------------------+--------+---------+
```

Azure NetApp Files

Trident supports volume import using the `azure-netapp-files` driver.

To import an Azure NetApp Files volume, identify the volume by its volume path. The volume path is the portion of the volume's export path after the `:/`. For example, if the mount path is `10.0.0.2:/importvol1`, the volume path is `importvol1`.

The following example imports an `azure-netapp-files` volume on backend `azurenetappfiles_40517` with the volume path `importvol1`.

```
tridentctl import volume azurenetappfiles_40517 importvol1 -f <path-to-
pvc-file> -n trident

+----------------------------------------+---------+--------------
+----------+----------------------------------------+--------+---------+
|                   NAME                 |  SIZE   | STORAGE CLASS |
PROTOCOL |             BACKEND UUID             | STATE  | MANAGED |
+----------------------------------------+---------+--------------
+----------+----------------------------------------+--------+---------+
| pvc-0ee95d60-fd5c-448d-b505-b72901b3a4ab | 100 GiB | anf-storage   |
file     | 1c01274f-d94b-44a3-98a3-04c953c9a51e | online | true    |
+----------------------------------------+---------+--------------
+----------+----------------------------------------+--------+---------+
```

Google Cloud NetApp Volumes

Trident supports volume import using the `google-cloud-netapp-volumes` driver.

The following example imports a volume on backend `backend-tbc-gcnv1` with the volume `testvoleasiaeast1`.

```
tridentctl import volume backend-tbc-gcnv1 "testvoleasiaeast1" -f < path-
to-pvc> -n trident

+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
|                   NAME                   |  SIZE   | STORAGE CLASS
| PROTOCOL |             BACKEND UUID             | STATE  | MANAGED |
+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
| pvc-a69cda19-218c-4ca9-a941-aea05dd13dc0 |  10 GiB | gcnv-nfs-sc-
identity | file     | 8c18cdf1-0770-4bc0-bcc5-c6295fe6d837 | online | true
|
+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
```

The following example imports a `google-cloud-netapp-volumes` volume when two volumes are present in the same region:

```
tridentctl import volume backend-tbc-gcnv1
"projects/123456789100/locations/asia-east1-a/volumes/testvoleasiaeast1"
-f <path-to-pvc> -n trident

+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
|                   NAME                   |  SIZE   | STORAGE CLASS
| PROTOCOL |             BACKEND UUID             | STATE  | MANAGED |
+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
| pvc-a69cda19-218c-4ca9-a941-aea05dd13dc0 |  10 GiB | gcnv-nfs-sc-
identity | file     | 8c18cdf1-0770-4bc0-bcc5-c6295fe6d837 | online | true
|
+------------------------------------------+---------
+----------------------+----------+--------------------------------------
+--------+---------+
```

Customize volume names and labels

With Trident, you can assign meaningful names and labels to volumes you create. This helps you identify and easily map volumes to their respective Kubernetes resources (PVCs). You can also define templates at the backend level for creating custom volume names and custom labels; any volumes that you create, import, or clone will adhere to the templates.

Before you begin

Customizable volume names and labels support:

- Volume create, import, and clone operations.
- In the case of the `ontap-nas-economy` driver, only the name of the Qtree volume complies with the name template.
- In the case of the `ontap-san-economy` driver, only the LUN name complies with the name template.

Limitations

- Custom volume names are compatible with ONTAP on-premises drivers only.
- Custom labels are supported only for the `ontap-san`, `ontap-nas`, and `ontap-nas-flexgroup` drivers.
- Custom volume names do not apply to existing volumes.

Key behaviors of customizable volume names

- If a failure occurs due to invalid syntax in a name template, the backend creation fails. However, if the template application fails, the volume will be named according to existing naming convention.
- Storage prefix is not applicable when a volume is named using a name template from the backend configuration. Any desired prefix value may be directly added to the template.

Backend configuration examples with name template and labels

Custom name templates can be defined at the root and/or pool level.

Root level example

```
{
  "version": 1,
  "storageDriverName": "ontap-nas",
  "backendName": "ontap-nfs-backend",
  "managementLIF": "<ip address>",
  "svm": "svm0",
  "username": "<admin>",
  "password": "<password>",
  "defaults": {
    "nameTemplate":
"{{.volume.Name}}_{{.labels.cluster}}_{{.volume.Namespace}}_{{.volume.Requ
estName}}"
  },
  "labels": {
    "cluster": "ClusterA",
    "PVC": "{{.volume.Namespace}}_{{.volume.RequestName}}"
  }
}
```

Pool level example

```
{
  "version": 1,
  "storageDriverName": "ontap-nas",
  "backendName": "ontap-nfs-backend",
  "managementLIF": "<ip address>",
  "svm": "svm0",
  "username": "<admin>",
  "password": "<password>",
  "useREST": true,
  "storage": [
    {
      "labels": {
        "labelname": "label1",
        "name": "{{ .volume.Name }}"
      },
      "defaults": {
        "nameTemplate": "pool01_{{ .volume.Name }}_{{ .labels.cluster
}}_{{ .volume.Namespace }}_{{ .volume.RequestName }}"
      }
    },
    {
      "labels": {
        "cluster": "label2",
        "name": "{{ .volume.Name }}"
      },
      "defaults": {
        "nameTemplate": "pool02_{{ .volume.Name }}_{{ .labels.cluster
}}_{{ .volume.Namespace }}_{{ .volume.RequestName }}"
      }
    }
  ]
}
```

Name template examples

Example 1:

```
"nameTemplate": "{{ .config.StoragePrefix }}_{{ .volume.Name }}_{{
.config.BackendName }}"
```

Example 2:

```
"nameTemplate": "pool_{{ .config.StoragePrefix }}_{{ .volume.Name }}_{{
slice .volume.RequestName 1 5 }}""
```

Points to consider

1. In the case of volume imports, the labels are updated only if the existing volume has labels in a specific format. For example: `{"provisioning":{"Cluster":"ClusterA", "PVC": "pvcname"}}`.
2. In the case of managed volume imports, the volume name follows the name template defined at the root level in the backend definition.
3. Trident does not support the use of a slice operator with the storage prefix.
4. If the templates do not result in unique volume names, Trident will append a few random characters to create unique volume names.
5. If the custom name for a NAS economy volume exceeds 64 characters in length, Trident will name the volumes according to the existing naming convention. For all other ONTAP drivers, if the volume name exceeds the name limit, the volume creation process fails.

Share an NFS volume across namespaces

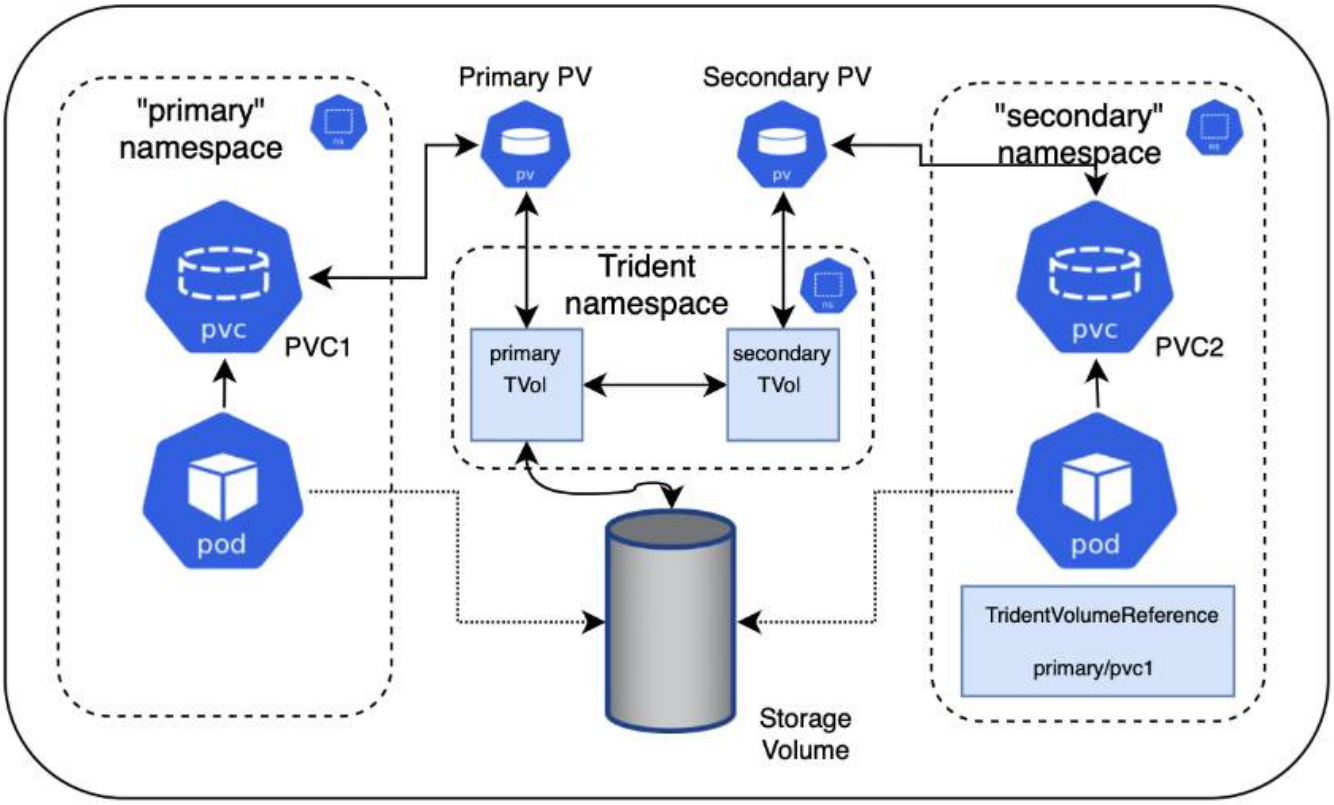
Using Trident, you can create a volume in a primary namespace and share it in one or more secondary namespaces.

Features

The TridentVolumeReference CR allows you to securely share ReadWriteMany (RWX) NFS volumes across one or more Kubernetes namespaces. This Kubernetes-native solution has the following benefits:

- Multiple levels of access control to ensure security
- Works with all Trident NFS volume drivers
- No reliance on tridentctl or any other non-native Kubernetes feature

This diagram illustrates NFS volume sharing across two Kubernetes namespaces.



Quick start

You can set up NFS volume sharing in just a few steps.

1 Configure source PVC to share the volume

The source namespace owner grants permission to access the data in the source PVC.

2 Grant permission to create a CR in the destination namespace

The cluster administrator grants permission to the owner of the destination namespace to create the TridentVolumeReference CR.

3 Create TridentVolumeReference in the destination namespace

The owner of the destination namespace creates the TridentVolumeReference CR to refer to the source PVC.

4 Create the subordinate PVC in the destination namespace

The owner of the destination namespace creates the subordinate PVC to use the data source from the source PVC.

Configure the source and destination namespaces

To ensure security, cross namespace sharing requires collaboration and action by the source namespace owner, cluster administrator, and destination namespace owner. The user role is designated in each step.

Steps

1. **Source namespace owner:** Create the PVC (`pvc1`) in the source namespace that grants permission to share with the destination namespace (`namespace2`) using the `shareToNamespace` annotation.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: pvc1
  namespace: namespace1
  annotations:
    trident.netapp.io/shareToNamespace: namespace2
spec:
  accessModes:
    - ReadWriteMany
  storageClassName: trident-csi
  resources:
    requests:
      storage: 100Gi
```

   Trident creates the PV and its backend NFS storage volume.

   - You can share the PVC to multiple namespaces using a comma-delimited list. For example, `trident.netapp.io/shareToNamespace: namespace2,namespace3,namespace4`.
   - You can share to all namespaces using `*`. For example, `trident.netapp.io/shareToNamespace: *`
   - You can update the PVC to include the `shareToNamespace` annotation at any time.

2. **Cluster admin:** Ensure that proper RBAC is in place to grant permission to the destination namespace owner to create the TridentVolumeReference CR in the destination namespace.
3. **Destination namespace owner:** Create a TridentVolumeReference CR in the destination namespace that refers to the source namespace `pvc1`.

```
apiVersion: trident.netapp.io/v1
kind: TridentVolumeReference
metadata:
  name: my-first-tvr
  namespace: namespace2
spec:
  pvcName: pvc1
  pvcNamespace: namespace1
```

4. **Destination namespace owner:** Create a PVC (`pvc2`) in destination namespace (`namespace2`) using the `shareFromPVC` annotation to designate the source PVC.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  annotations:
    trident.netapp.io/shareFromPVC: namespace1/pvc1
  name: pvc2
  namespace: namespace2
spec:
  accessModes:
    - ReadWriteMany
  storageClassName: trident-csi
  resources:
    requests:
      storage: 100Gi
```

The size of the destination PVC must be less than or equal than the source PVC.

Results

Trident reads the `shareFromPVC` annotation on the destination PVC and creates the destination PV as a subordinate volume with no storage resource of its own that points to the source PV and shares the source PV storage resource. The destination PVC and PV appear bound as normal.

Delete a shared volume

You can delete a volume that is shared across multiple namespaces. Trident will remove access to the volume on the source namespace and maintain access for other namespaces that share the volume. When all namespaces that reference the volume are removed, Trident deletes the volume.

Use `tridentctl get` to query subordinate volumes

Using the `tridentctl` utility, you can run the `get` command to get subordinate volumes. For more information, refer to `tridentctl` commands and options.

```
Usage:
  tridentctl get [option]
```

Flags:

- `-h, --help`: Help for volumes.
- `--parentOfSubordinate string`: Limit query to subordinate source volume.
- `--subordinateOf string`: Limit query to subordinates of volume.

Limitations

- Trident cannot prevent destination namespaces from writing to the shared volume. You should use file locking or other processes to prevent overwriting shared volume data.
- You cannot revoke access to the source PVC by removing the `shareToNamespace` or `shareFromNamespace` annotations or deleting the `TridentVolumeReference` CR. To revoke access, you must delete the subordinate PVC.
- Snapshots, clones, and mirroring are not possible on subordinate volumes.

For more information

To learn more about cross-namespace volume access:

- Watch the demo on NetAppTV.

Clone volumes across namespaces

Using Trident, you can create new volumes using existing volumes or volumesnapshots from a different namespace inside the same Kubernetes cluster.

Prerequisites

Before cloning volumes, ensure that the source and destination backends are of the same type and have the same storage class.

> Cloning across namespaces is supported only for the `ontap-san` and `ontap-nas` storage drivers. Read-only clones are not supported.

Quick start

You can set up volume cloning in just a few steps.

1 **Configure source PVC to clone the volume**

The source namespace owner grants permission to access the data in the source PVC.

2 Grant permission to create a CR in the destination namespace

The cluster administrator grants permission to the owner of the destination namespace to create the TridentVolumeReference CR.

3 Create TridentVolumeReference in the destination namespace

The owner of the destination namespace creates the TridentVolumeReference CR to refer to the source PVC.

4 Create the clone PVC in the destination namespace

The owner of the destination namespace creates PVC to clone the PVC from the source namespace.

Configure the source and destination namespaces

To ensure security, cloning volumes across namespaces requires collaboration and action by the source namespace owner, cluster administrator, and destination namespace owner. The user role is designated in each step.

Steps

1. **Source namespace owner:** Create the PVC (`pvc1`) in the source namespace (`namespace1`) that grants permission to share with the destination namespace (`namespace2`) using the `cloneToNamespace` annotation.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: pvc1
  namespace: namespace1
  annotations:
    trident.netapp.io/cloneToNamespace: namespace2
spec:
  accessModes:
    - ReadWriteMany
  storageClassName: trident-csi
  resources:
    requests:
      storage: 100Gi
```

   Trident creates the PV and its backend storage volume.

- You can share the PVC to multiple namespaces using a comma-delimited list. For example, `trident.netapp.io/cloneToNamespace: namespace2,namespace3,namespace4`.
- You can share to all namespaces using `*`. For example, `trident.netapp.io/cloneToNamespace: *`
- You can update the PVC to include the `cloneToNamespace` annotation at any time.

2. **Cluster admin:** Ensure that proper RBAC is in place to grant permission to the destination namespace owner to create the TridentVolumeReference CR in the destination namespace (`namespace2`).
3. **Destination namespace owner:** Create a TridentVolumeReference CR in the destination namespace that refers to the source namespace `pvc1`.

```
apiVersion: trident.netapp.io/v1
kind: TridentVolumeReference
metadata:
  name: my-first-tvr
  namespace: namespace2
spec:
  pvcName: pvc1
  pvcNamespace: namespace1
```

4. **Destination namespace owner:** Create a PVC (`pvc2`) in destination namespace (`namespace2`) using the `cloneFromPVC` or `cloneFromSnapshot`, and `cloneFromNamespace` annotations to designate the source PVC.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  annotations:
    trident.netapp.io/cloneFromPVC: pvc1
    trident.netapp.io/cloneFromNamespace: namespace1
  name: pvc2
  namespace: namespace2
spec:
  accessModes:
    - ReadWriteMany
  storageClassName: trident-csi
  resources:
    requests:
      storage: 100Gi
```

Limitations

- For PVCs provisioned using ontap-nas-economy drivers, read-only clones are not supported.

Replicate volumes using SnapMirror

Trident supports mirror relationships between a source volume on one cluster and the destination volume on the peered cluster for replicating data for disaster recovery. You can use a namespaced Custom Resource Definition (CRD), called Trident Mirror Relationship (TMR) to perform the following operations:

- Create mirror relationships between volumes (PVCs)
- Remove mirror relationships between volumes
- Break the mirror relationships
- Promote the secondary volume during disaster conditions (failovers)
- Perform lossless transition of applications from cluster to cluster (during planned failovers or migrations)

Replication prerequisites

Ensure that the following prerequisites are met before you begin:

ONTAP clusters

- **Trident**: Trident version 22.10 or later must exist on both the source and destination Kubernetes clusters that utilize ONTAP as a backend.
- **Licenses**: ONTAP SnapMirror asynchronous licenses using the Data Protection bundle must be enabled on both the source and destination ONTAP clusters. Refer to SnapMirror licensing overview in ONTAP for more information.

  Beginning with ONTAP 9.10.1, all licenses are delivered as a NetApp license file (NLF), which is a single file that enables multiple features. Refer to Licenses included with ONTAP One for more information.

  > Only SnapMirror asynchronous protection is supported.

Peering

- **Cluster and SVM**: The ONTAP storage backends must be peered. Refer to Cluster and SVM peering overview for more information.

  > Ensure that the SVM names used in the replication relationship between two ONTAP clusters are unique.

- **Trident and SVM**: The peered remote SVMs must be available to Trident on the destination cluster.

Supported drivers

NetApp Trident supports volume replication with NetApp SnapMirror technology using storage classes backed by the following drivers:
`ontap-nas`: NFS
`ontap-san`: iSCSI
`ontap-san`: FC

`ontap-san`: NVMe/TCP (requires minimum ONTAP version 9.15.1)

> Volume replication using SnapMirror is not supported for ASA r2 systems. For information about ASA r2 systems, see Learn about ASA r2 storage systems.

Create a mirrored PVC

Follow these steps and use the CRD examples to create mirror relationship between primary and secondary volumes.

Steps

1. Perform the following steps on the primary Kubernetes cluster:
   a. Create a StorageClass object with the `trident.netapp.io/replication: true` parameter.

      Example

      ```
      apiVersion: storage.k8s.io/v1
      kind: StorageClass
      metadata:
        name: csi-nas
      provisioner: csi.trident.netapp.io
      parameters:
        backendType: "ontap-nas"
        fsType: "nfs"
        trident.netapp.io/replication: "true"
      ```

   b. Create a PVC with previously created StorageClass.

      Example

      ```
      kind: PersistentVolumeClaim
      apiVersion: v1
      metadata:
        name: csi-nas
      spec:
        accessModes:
        - ReadWriteMany
        resources:
          requests:
            storage: 1Gi
        storageClassName: csi-nas
      ```

   c. Create a MirrorRelationship CR with local information.

Example

```
kind: TridentMirrorRelationship
apiVersion: trident.netapp.io/v1
metadata:
  name: csi-nas
spec:
  state: promoted
  volumeMappings:
  - localPVCName: csi-nas
```

Trident fetches the internal information for the volume and the volume's current data protection (DP) state, then populates the status field of the MirrorRelationship.

d. Get the TridentMirrorRelationship CR to obtain the internal name and SVM of the PVC.

```
kubectl get tmr csi-nas
```

```
kind: TridentMirrorRelationship
apiVersion: trident.netapp.io/v1
metadata:
  name: csi-nas
  generation: 1
spec:
  state: promoted
  volumeMappings:
  - localPVCName: csi-nas
status:
  conditions:
  - state: promoted
    localVolumeHandle:
"datavserver:trident_pvc_3bedd23c_46a8_4384_b12b_3c38b313c1e1"
    localPVCName: csi-nas
    observedGeneration: 1
```

2. Perform the following steps on the secondary Kubernetes cluster:

   a. Create a StorageClass with the trident.netapp.io/replication: true parameter.

Example

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: csi-nas
provisioner: csi.trident.netapp.io
parameters:
  trident.netapp.io/replication: true
```

b. Create a MirrorRelationship CR with destination and source information.

Example

```
kind: TridentMirrorRelationship
apiVersion: trident.netapp.io/v1
metadata:
  name: csi-nas
spec:
  state: established
  volumeMappings:
  - localPVCName: csi-nas
    remoteVolumeHandle:
"datavserver:trident_pvc_3bedd23c_46a8_4384_b12b_3c38b313c1e1"
```

Trident will create a SnapMirror relationship with the configured relationship policy name (or default for ONTAP) and initialize it.

c. Create a PVC with previously created StorageClass to act as the secondary (SnapMirror destination).

Example

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: csi-nas
  annotations:
    trident.netapp.io/mirrorRelationship: csi-nas
spec:
  accessModes:
  - ReadWriteMany
resources:
  requests:
    storage: 1Gi
storageClassName: csi-nas
```

Trident will check for the TridentMirrorRelationship CRD and fail to create the volume if the relationship

does not exist. If the relationship exists, Trident will ensure the new FlexVol volume is placed onto an SVM that is peered with the remote SVM defined in the MirrorRelationship.

Volume Replication States

A Trident Mirror Relationship (TMR) is a CRD that represents one end of a replication relationship between PVCs. The destination TMR has a state, which tells Trident what the desired state is. The destination TMR has the following states:

- **Established**: the local PVC is the destination volume of a mirror relationship, and this is a new relationship.
- **Promoted**: the local PVC is ReadWrite and mountable, with no mirror relationship currently in effect.
- **Reestablished**: the local PVC is the destination volume of a mirror relationship and was also previously in that mirror relationship.
  - The reestablished state must be used if the destination volume was ever in a relationship with the source volume because it overwrites the destination volume contents.
  - The reestablished state will fail if the volume was not previously in a relationship with the source.

Promote secondary PVC during an unplanned failover

Perform the following step on the secondary Kubernetes cluster:

- Update the *spec.state* field of TridentMirrorRelationship to `promoted`.

Promote secondary PVC during a planned failover

During a planned failover (migration), perform the following steps to promote the secondary PVC:

Steps

1. On the primary Kubernetes cluster, create a snapshot of the PVC and wait until the snapshot is created.
2. On the primary Kubernetes cluster, create the SnapshotInfo CR to obtain internal details.

   Example

   ```
   kind: SnapshotInfo
   apiVersion: trident.netapp.io/v1
   metadata:
     name: csi-nas
   spec:
     snapshot-name: csi-nas-snapshot
   ```

3. On secondary Kubernetes cluster, update the *spec.state* field of the *TridentMirrorRelationship* CR to *promoted* and *spec.promotedSnapshotHandle* to be the internalName of the snapshot.
4. On secondary Kubernetes cluster, confirm the status (status.state field) of TridentMirrorRelationship to promoted.

Restore a mirror relationship after a failover

Before restoring a mirror relationship, choose the side that you want to make as the new primary.

Steps

1. On the secondary Kubernetes cluster, ensure that the values for the *spec.remoteVolumeHandle* field on the TridentMirrorRelationship is updated.
2. On secondary Kubernetes cluster, update the *spec.mirror* field of TridentMirrorRelationship to `reestablished`.

Additional operations

Trident supports the following operations on the primary and secondary volumes:

Replicate primary PVC to a new secondary PVC

Ensure that you already have a primary PVC and a secondary PVC.

Steps

1. Delete the PersistentVolumeClaim and TridentMirrorRelationship CRDs from the established secondary (destination) cluster.
2. Delete the TridentMirrorRelationship CRD from the primary (source) cluster.
3. Create a new TridentMirrorRelationship CRD on the primary (source) cluster for the new secondary (destination) PVC you want to establish.

Resize a mirrored, primary or secondary PVC

The PVC can be resized as normal, ONTAP will automatically expand any destination flevxols if the amount of data exceeds the current size.

Remove replication from a PVC

To remove replication, perform one of the following operations on the current secondary volume:

- Delete the MirrorRelationship on the secondary PVC. This breaks the replication relationship.
- Or, update the spec.state field to *promoted*.

Delete a PVC (that was previously mirrored)

Trident checks for replicated PVCs, and releases the replication relationship before attempting to delete the volume.

Delete a TMR

Deleting a TMR on one side of a mirrored relationship causes the remaining TMR to transition to *promoted* state before Trident completes the deletion. If the TMR selected for deletion is already in *promoted* state, there is no existing mirror relationship and the TMR will be removed and Trident will promote the local PVC to *ReadWrite*. This deletion releases SnapMirror metadata for the local volume in ONTAP. If this volume is used in a mirror relationship in the future, it must use a new TMR with an *established* volume replication state when creating the new mirror relationship.

Update mirror relationships when ONTAP is online

Mirror relationships can be updated any time after they are established. You can use the `state: promoted` or `state: reestablished` fields to update the relationships.

When promoting a destination volume to a regular ReadWrite volume, you can use *promotedSnapshotHandle* to specify a specific snapshot to restore the current volume to.

Update mirror relationships when ONTAP is offline

You can use a CRD to perform a SnapMirror update without Trident having direct connectivity to the ONTAP cluster. Refer to the following example format of the TridentActionMirrorUpdate:

Example

```
apiVersion: trident.netapp.io/v1
kind: TridentActionMirrorUpdate
metadata:
  name: update-mirror-b
spec:
  snapshotHandle: "pvc-1234/snapshot-1234"
  tridentMirrorRelationshipName: mirror-b
```

`status.state` reflects the state of the TridentActionMirrorUpdate CRD. It can take a value from *Succeeded*, *In Progress*, or *Failed*.

Use CSI Topology

Trident can selectively create and attach volumes to nodes present in a Kubernetes cluster by making use of the CSI Topology feature.

Overview

Using the CSI Topology feature, access to volumes can be limited to a subset of nodes, based on regions and availability zones. Cloud providers today enable Kubernetes administrators to spawn nodes that are zone based. Nodes can be located in different availability zones within a region, or across various regions. To facilitate the provisioning of volumes for workloads in a multi-zone architecture, Trident uses CSI Topology.

Learn more about the CSI Topology feature here.

Kubernetes provides two unique volume binding modes:

- With `VolumeBindingMode` set to `Immediate`, Trident creates the volume without any topology awareness. Volume binding and dynamic provisioning are handled when the PVC is created. This is the default `VolumeBindingMode` and is suited for clusters that do not enforce topology constraints. Persistent Volumes are created without having any dependency on the requesting pod's scheduling requirements.
- With `VolumeBindingMode` set to `WaitForFirstConsumer`, the creation and binding of a Persistent Volume for a PVC is delayed until a pod that uses the PVC is scheduled and created. This way, volumes are created to meet the scheduling constraints that are enforced by topology requirements.

The `WaitForFirstConsumer` binding mode does not require topology labels. This can be used independent of the CSI Topology feature.

What you'll need

To make use of CSI Topology, you need the following:

- A Kubernetes cluster running a supported Kubernetes version

```
kubectl version
Client Version: version.Info{Major:"1", Minor:"19",
GitVersion:"v1.19.3",
GitCommit:"1e11e4a2108024935ecfcb2912226cedeafd99df",
GitTreeState:"clean", BuildDate:"2020-10-14T12:50:19Z",
GoVersion:"go1.15.2", Compiler:"gc", Platform:"linux/amd64"}
Server Version: version.Info{Major:"1", Minor:"19",
GitVersion:"v1.19.3",
GitCommit:"1e11e4a2108024935ecfcb2912226cedeafd99df",
GitTreeState:"clean", BuildDate:"2020-10-14T12:41:49Z",
GoVersion:"go1.15.2", Compiler:"gc", Platform:"linux/amd64"}
```

- Nodes in the cluster should have labels that introduce topology awareness (`topology.kubernetes.io/region` and `topology.kubernetes.io/zone`). These labels **should be present on nodes in the cluster** before Trident is installed for Trident to be topology aware.

```
kubectl get nodes -o=jsonpath='{range .items[*]}[{.metadata.name},
{.metadata.labels}]{"\n"}{end}' | grep --color "topology.kubernetes.io"
[node1,
{"beta.kubernetes.io/arch":"amd64","beta.kubernetes.io/os":"linux","kube
rnetes.io/arch":"amd64","kubernetes.io/hostname":"node1","kubernetes.io/
os":"linux","node-
role.kubernetes.io/master":"","topology.kubernetes.io/region":"us-
east1","topology.kubernetes.io/zone":"us-east1-a"}]
[node2,
{"beta.kubernetes.io/arch":"amd64","beta.kubernetes.io/os":"linux","kube
rnetes.io/arch":"amd64","kubernetes.io/hostname":"node2","kubernetes.io/
os":"linux","node-
role.kubernetes.io/worker":"","topology.kubernetes.io/region":"us-
east1","topology.kubernetes.io/zone":"us-east1-b"}]
[node3,
{"beta.kubernetes.io/arch":"amd64","beta.kubernetes.io/os":"linux","kube
rnetes.io/arch":"amd64","kubernetes.io/hostname":"node3","kubernetes.io/
os":"linux","node-
role.kubernetes.io/worker":"","topology.kubernetes.io/region":"us-
east1","topology.kubernetes.io/zone":"us-east1-c"}]
```

Step 1: Create a topology-aware backend

Trident storage backends can be designed to selectively provision volumes based on availability zones. Each backend can carry an optional `supportedTopologies` block that represents a list of zones and regions that

are supported. For StorageClasses that make use of such a backend, a volume would only be created if requested by an application that is scheduled in a supported region/zone.

Here is an example backend definition:

YAML

```yaml
---
version: 1
storageDriverName: ontap-san
backendName: san-backend-us-east1
managementLIF: 192.168.27.5
svm: iscsi_svm
username: admin
password: password
supportedTopologies:
  - topology.kubernetes.io/region: us-east1
    topology.kubernetes.io/zone: us-east1-a
  - topology.kubernetes.io/region: us-east1
    topology.kubernetes.io/zone: us-east1-b
```

JSON

```json
{
  "version": 1,
  "storageDriverName": "ontap-san",
  "backendName": "san-backend-us-east1",
  "managementLIF": "192.168.27.5",
  "svm": "iscsi_svm",
  "username": "admin",
  "password": "password",
  "supportedTopologies": [
    {
      "topology.kubernetes.io/region": "us-east1",
      "topology.kubernetes.io/zone": "us-east1-a"
    },
    {
      "topology.kubernetes.io/region": "us-east1",
      "topology.kubernetes.io/zone": "us-east1-b"
    }
  ]
}
```

`supportedTopologies` is used to provide a list of regions and zones per backend. These regions and zones represent the list of permissible values that can be provided in a StorageClass. For StorageClasses that contain a subset of the regions and zones provided in a backend, Trident creates a volume on the backend.

You can define `supportedTopologies` per storage pool as well. See the following example:

```
---
version: 1
storageDriverName: ontap-nas
backendName: nas-backend-us-central1
managementLIF: 172.16.238.5
svm: nfs_svm
username: admin
password: password
supportedTopologies:
  - topology.kubernetes.io/region: us-central1
    topology.kubernetes.io/zone: us-central1-a
  - topology.kubernetes.io/region: us-central1
    topology.kubernetes.io/zone: us-central1-b
storage:
  - labels:
      workload: production
    supportedTopologies:
      - topology.kubernetes.io/region: us-central1
        topology.kubernetes.io/zone: us-central1-a
  - labels:
      workload: dev
    supportedTopologies:
      - topology.kubernetes.io/region: us-central1
        topology.kubernetes.io/zone: us-central1-b
```

In this example, the `region` and `zone` labels stand for the location of the storage pool. `topology.kubernetes.io/region` and `topology.kubernetes.io/zone` dictate where the storage pools can be consumed from.

Step 2: Define StorageClasses that are topology aware

Based on the topology labels that are provided to the nodes in the cluster, StorageClasses can be defined to contain topology information. This will determine the storage pools that serve as candidates for PVC requests made, and the subset of nodes that can make use of the volumes provisioned by Trident.

See the following example:

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  name: netapp-san-us-east1
provisioner: csi.trident.netapp.io
volumeBindingMode: WaitForFirstConsumer
allowedTopologies:
  - matchLabelExpressions:
    - key: topology.kubernetes.io/zone
      values:
        - us-east1-a
        - us-east1-b
    - key: topology.kubernetes.io/region
      values:
        - us-east1
parameters:
  fsType: ext4
```

In the StorageClass definition provided above, `volumeBindingMode` is set to `WaitForFirstConsumer`. PVCs that are requested with this StorageClass will not be acted upon until they are referenced in a pod. And, `allowedTopologies` provides the zones and region to be used. The `netapp-san-us-east1` StorageClass creates PVCs on the `san-backend-us-east1` backend defined above.

Step 3: Create and use a PVC

With the StorageClass created and mapped to a backend, you can now create PVCs.

See the example `spec` below:

```
---
kind: PersistentVolumeClaim
apiVersion: v1
metadata: null
name: pvc-san
spec: null
accessModes:
  - ReadWriteOnce
resources:
  requests:
    storage: 300Mi
storageClassName: netapp-san-us-east1
```

Creating a PVC using this manifest would result in the following:

```
kubectl create -f pvc.yaml
persistentvolumeclaim/pvc-san created
kubectl get pvc
NAME      STATUS    VOLUME   CAPACITY   ACCESS MODES   STORAGECLASS
AGE
pvc-san   Pending                                      netapp-san-us-east1
2s
kubectl describe pvc
Name:          pvc-san
Namespace:     default
StorageClass:  netapp-san-us-east1
Status:        Pending
Volume:
Labels:        <none>
Annotations:   <none>
Finalizers:    [kubernetes.io/pvc-protection]
Capacity:
Access Modes:
VolumeMode:    Filesystem
Mounted By:    <none>
Events:
  Type    Reason                Age   From                         Message
  ----    ------                ----  ----                         -------
  Normal  WaitForFirstConsumer  6s    persistentvolume-controller  waiting
for first consumer to be created before binding
```

For Trident to create a volume and bind it to the PVC, use the PVC in a pod. See the following example:

```
apiVersion: v1
kind: Pod
metadata:
  name: app-pod-1
spec:
  affinity:
    nodeAffinity:
      requiredDuringSchedulingIgnoredDuringExecution:
        nodeSelectorTerms:
        - matchExpressions:
          - key: topology.kubernetes.io/region
            operator: In
            values:
            - us-east1
      preferredDuringSchedulingIgnoredDuringExecution:
      - weight: 1
        preference:
          matchExpressions:
          - key: topology.kubernetes.io/zone
            operator: In
            values:
            - us-east1-a
            - us-east1-b
  securityContext:
    runAsUser: 1000
    runAsGroup: 3000
    fsGroup: 2000
  volumes:
  - name: vol1
    persistentVolumeClaim:
      claimName: pvc-san
  containers:
  - name: sec-ctx-demo
    image: busybox
    command: [ "sh", "-c", "sleep 1h" ]
    volumeMounts:
    - name: vol1
      mountPath: /data/demo
    securityContext:
      allowPrivilegeEscalation: false
```

This podSpec instructs Kubernetes to schedule the pod on nodes that are present in the `us-east1` region, and choose from any node that is present in the `us-east1-a` or `us-east1-b` zones.

See the following output:

```
kubectl get pods -o wide
NAME        READY   STATUS    RESTARTS   AGE   IP               NODE
NOMINATED NODE   READINESS GATES
app-pod-1   1/1     Running   0          19s   192.168.25.131   node2
<none>           <none>
kubectl get pvc -o wide
NAME      STATUS   VOLUME                                     CAPACITY
ACCESS MODES   STORAGECLASS          AGE   VOLUMEMODE
pvc-san   Bound    pvc-ecb1e1a0-840c-463b-8b65-b3d033e2e62b   300Mi
RWO            netapp-san-us-east1   48s   Filesystem
```

Update backends to include `supportedTopologies`

Pre-existing backends can be updated to include a list of `supportedTopologies` using `tridentctl backend update`. This will not affect volumes that have already been provisioned, and will only be used for subsequent PVCs.

Find more information

- Manage resources for containers
- nodeSelector
- Affinity and anti-affinity
- Taints and Tolerations

Work with snapshots

Kubernetes volume snapshots of Persistent Volumes (PVs) enable point-in-time copies of volumes. You can create a snapshot of a volume created using Trident, import a snapshot created outside of Trident, create a new volume from an existing snapshot, and recover volume data from snapshots.

Overview

Volume snapshot is supported by `ontap-nas`, `ontap-nas-flexgroup`, `ontap-san`, `ontap-san-economy`, `solidfire-san`, `azure-netapp-files`, and `google-cloud-netapp-volumes` drivers.

Before you begin

You must have an external snapshot controller and Custom Resource Definitions (CRDs) to work with snapshots. This is the responsibility of the Kubernetes orchestrator (for example: Kubeadm, GKE, OpenShift).

If your Kubernetes distribution does not include the snapshot controller and CRDs, refer to Deploy a volume snapshot controller.

> Don’t create a snapshot controller if creating on-demand volume snapshots in a GKE environment. GKE uses a built-in, hidden snapshot controller.

Create a volume snapshot

Steps

1. Create a `VolumeSnapshotClass`. For more information, refer to VolumeSnapshotClass.
   - The `driver` points to the Trident CSI driver.
   - `deletionPolicy` can be `Delete` or `Retain`. When set to `Retain`, the underlying physical snapshot on the storage cluster is retained even when the `VolumeSnapshot` object is deleted.

     Example

     ```
     cat snap-sc.yaml
     ```

     ```
     apiVersion: snapshot.storage.k8s.io/v1
     kind: VolumeSnapshotClass
     metadata:
       name: csi-snapclass
     driver: csi.trident.netapp.io
     deletionPolicy: Delete
     ```

2. Create a snapshot of an existing PVC.

   Examples

   - This example creates a snapshot of an existing PVC.

     ```
     cat snap.yaml
     ```

     ```
     apiVersion: snapshot.storage.k8s.io/v1
     kind: VolumeSnapshot
     metadata:
       name: pvc1-snap
     spec:
       volumeSnapshotClassName: csi-snapclass
       source:
         persistentVolumeClaimName: pvc1
     ```

   - This example creates a volume snapshot object for a PVC named `pvc1` and the name of the snapshot is set to `pvc1-snap`. A VolumeSnapshot is analogous to a PVC and is associated with a `VolumeSnapshotContent` object that represents the actual snapshot.

```
kubectl create -f snap.yaml
volumesnapshot.snapshot.storage.k8s.io/pvc1-snap created

kubectl get volumesnapshots
NAME                    AGE
pvc1-snap               50s
```

- You can identify the `VolumeSnapshotContent` object for the `pvc1-snap` VolumeSnapshot by describing it. The `Snapshot Content Name` identifies the VolumeSnapshotContent object which serves this snapshot. The `Ready To Use` parameter indicates that the snapshot can be used to create a new PVC.

```
kubectl describe volumesnapshots pvc1-snap
Name:         pvc1-snap
Namespace:    default
...
Spec:
  Snapshot Class Name:    pvc1-snap
  Snapshot Content Name:  snapcontent-e8d8a0ca-9826-11e9-9807-
525400f3f660
  Source:
    API Group:
    Kind:       PersistentVolumeClaim
    Name:       pvc1
Status:
  Creation Time:  2019-06-26T15:27:29Z
  Ready To Use:   true
  Restore Size:   3Gi
...
```

Create a PVC from a volume snapshot

You can use `dataSource` to create a PVC using a VolumeSnapshot named `<pvc-name>` as the source of the data. After the PVC is created, it can be attached to a pod and used just like any other PVC.

The PVC will be created in the same backend as the source volume. Refer to KB: Creating a PVC from a Trident PVC Snapshot cannot be created in an alternate backend.

The following example creates the PVC using `pvc1-snap` as the data source.

```
cat pvc-from-snap.yaml
```

```
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: pvc-from-snap
spec:
  accessModes:
    - ReadWriteOnce
  storageClassName: golden
  resources:
    requests:
      storage: 3Gi
  dataSource:
    name: pvc1-snap
    kind: VolumeSnapshot
    apiGroup: snapshot.storage.k8s.io
```

Import a volume snapshot

Trident supports the Kubernetes pre-provisioned snapshot process to enable the cluster administrator to create a `VolumeSnapshotContent` object and import snapshots created outside of Trident.

Before you begin

Trident must have created or imported the snapshot's parent volume.

Steps

1. **Cluster admin:** Create a `VolumeSnapshotContent` object that references the backend snapshot. This initiates the snapshot workflow in Trident.
   - Specify the name of the backend snapshot in `annotations` as `trident.netapp.io/internalSnapshotName: <"backend-snapshot-name">`.
   - Specify `<name-of-parent-volume-in-trident>/<volume-snapshot-content-name>` in `snapshotHandle`. This is the only information provided to Trident by the external snapshotter in the `ListSnapshots` call.

     The `<volumeSnapshotContentName>` cannot always match the backend snapshot name due to CR naming constraints.

     Example

     The following example creates a `VolumeSnapshotContent` object that references backend snapshot `snap-01`.

```
apiVersion: snapshot.storage.k8s.io/v1
kind: VolumeSnapshotContent
metadata:
  name: import-snap-content
  annotations:
    trident.netapp.io/internalSnapshotName: "snap-01"  # This is the
name of the snapshot on the backend
spec:
  deletionPolicy: Retain
  driver: csi.trident.netapp.io
  source:
    snapshotHandle: pvc-f71223b5-23b9-4235-bbfe-e269ac7b84b0/import-
snap-content # <import PV name or source PV name>/<volume-snapshot-
content-name>
  volumeSnapshotRef:
    name: import-snap
    namespace: default
```

2. **Cluster admin:** Create the `VolumeSnapshot` CR that references the `VolumeSnapshotContent` object. This requests access to use the `VolumeSnapshot` in a given namespace.

   Example

   The following example creates a `VolumeSnapshot` CR named `import-snap` that references the `VolumeSnapshotContent` named `import-snap-content`.

   ```
   apiVersion: snapshot.storage.k8s.io/v1
   kind: VolumeSnapshot
   metadata:
     name: import-snap
   spec:
     # volumeSnapshotClassName: csi-snapclass (not required for pre-
   provisioned or imported snapshots)
     source:
       volumeSnapshotContentName: import-snap-content
   ```

3. **Internal processing (no action required):** The external snapshotter recognizes the newly created `VolumeSnapshotContent` and runs the `ListSnapshots` call. Trident creates the `TridentSnapshot`.
   - The external snapshotter sets the `VolumeSnapshotContent` to `readyToUse` and the `VolumeSnapshot` to `true`.
   - Trident returns `readyToUse=true`.
4. **Any user:** Create a `PersistentVolumeClaim` to reference the new `VolumeSnapshot`, where the `spec.dataSource` (or `spec.dataSourceRef`) name is the `VolumeSnapshot` name.

   Example

The following example creates a PVC referencing the `VolumeSnapshot` named `import-snap`.

```
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: pvc-from-snap
spec:
  accessModes:
    - ReadWriteOnce
  storageClassName: simple-sc
  resources:
    requests:
      storage: 1Gi
  dataSource:
    name: import-snap
    kind: VolumeSnapshot
    apiGroup: snapshot.storage.k8s.io
```

Recover volume data using snapshots

The snapshot directory is hidden by default to facilitate maximum compatibility of volumes provisioned using the `ontap-nas` and `ontap-nas-economy` drivers. Enable the `.snapshot` directory to recover data from snapshots directly.

Use the volume snapshot restore ONTAP CLI to to restore a volume to a state recorded in a prior snapshot.

```
cluster1::*> volume snapshot restore -vserver vs0 -volume vol3 -snapshot
vol3_snap_archive
```

When you restore a snapshot copy, the existing volume configuration is overwritten. Changes made to volume data after the snapshot copy was created are lost.

In-place volume restoration from a snapshot

Trident provides rapid, in-place volume restoration from a snapshot using the `TridentActionSnapshotRestore` (TASR) CR. This CR functions as an imperative Kubernetes action and does not persist after the operation completes.

Trident supports snapshot restore on the `ontap-san`, `ontap-san-economy`, `ontap-nas`, `ontap-nas-flexgroup`, `azure-netapp-files`, `google-cloud-netapp-volumes`, and `solidfire-san` drivers.

Before you begin

You must have a bound PVC and available volume snapshot.

- Verify the PVC status is bound.

```
kubectl get pvc
```

- Verify the volume snapshot is ready to use.

```
kubectl get vs
```

Steps

1. Create the TASR CR. This example creates a CR for PVC `pvc1` and volume snapshot `pvc1-snapshot`.

   The TASR CR must be in a namespace where the PVC & VS exist.

```
cat tasr-pvc1-snapshot.yaml
```

```
apiVersion: trident.netapp.io/v1
kind: TridentActionSnapshotRestore
metadata:
  name: trident-snap
  namespace: trident
spec:
  pvcName: pvc1
  volumeSnapshotName: pvc1-snapshot
```

2. Apply the CR to restore from the snapshot. This example restores from snapshot `pvc1`.

```
kubectl create -f tasr-pvc1-snapshot.yaml
```

```
tridentactionsnapshotrestore.trident.netapp.io/trident-snap created
```

Results

Trident restores the data from the snapshot. You can verify the snapshot restore status:

```
kubectl get tasr -o yaml
```

```
apiVersion: trident.netapp.io/v1
items:
- apiVersion: trident.netapp.io/v1
  kind: TridentActionSnapshotRestore
  metadata:
    creationTimestamp: "2023-04-14T00:20:33Z"
    generation: 3
    name: trident-snap
    namespace: trident
    resourceVersion: "3453847"
    uid: <uid>
  spec:
    pvcName: pvc1
    volumeSnapshotName: pvc1-snapshot
  status:
    startTime: "2023-04-14T00:20:34Z"
    completionTime: "2023-04-14T00:20:37Z"
    state: Succeeded
kind: List
metadata:
  resourceVersion: ""
```

- In most cases, Trident will not automatically retry the operation in case of failure. You will need to perform the operation again.
- Kubernetes users without admin access might have to be granted permission by the admin to create a TASR CR in their application namespace.

Delete a PV with associated snapshots

When deleting a Persistent Volume with associated snapshots, the corresponding Trident volume is updated to a "Deleting state". Remove the volume snapshots to delete the Trident volume.

Deploy a volume snapshot controller

If your Kubernetes distribution does not include the snapshot controller and CRDs, you can deploy them as follows.

Steps

1. Create volume snapshot CRDs.

```
cat snapshot-setup.sh
```

```
#!/bin/bash
# Create volume snapshot CRDs
kubectl apply -f https://raw.githubusercontent.com/kubernetes-
csi/external-snapshotter/release-
6.1/client/config/crd/snapshot.storage.k8s.io_volumesnapshotclasses.yaml
kubectl apply -f https://raw.githubusercontent.com/kubernetes-
csi/external-snapshotter/release-
6.1/client/config/crd/snapshot.storage.k8s.io_volumesnapshotcontents.yam
l
kubectl apply -f https://raw.githubusercontent.com/kubernetes-
csi/external-snapshotter/release-
6.1/client/config/crd/snapshot.storage.k8s.io_volumesnapshots.yaml
```

2. Create the snapshot controller.

```
kubectl apply -f https://raw.githubusercontent.com/kubernetes-
csi/external-snapshotter/release-6.1/deploy/kubernetes/snapshot-
controller/rbac-snapshot-controller.yaml
```

```
kubectl apply -f https://raw.githubusercontent.com/kubernetes-
csi/external-snapshotter/release-6.1/deploy/kubernetes/snapshot-
controller/setup-snapshot-controller.yaml
```

If necessary, open `deploy/kubernetes/snapshot-controller/rbac-snapshot-controller.yaml` and update `namespace` to your namespace.

Related links

- Volume snapshots
- VolumeSnapshotClass

Work with volume group snapshots

Kubernetes volume group snapshots of Persistent Volumes (PVs) NetApp Trident provides the ability to create snapshots of multiple volumes (a group of volume snapshots). This volume group snapshot represents copies from multiple volumes that are taken at the same point-in-time.

VolumeGroupSnapshot is a beta feature in Kubernetes with beta APIs. Kubernetes 1.32 is the minimum version required for VolumeGroupSnapshot.

Create volume group snapshots

Volume group snapshot is supported with the following storage drivers:

- `ontap-san` driver - only for the iSCSI and FC protocols, not for the NVMe/TCP protocol.
- `ontap-san-economy` - only for the iSCSI protocol.
- `ontap-nas`

> Volume group snapshot is not supported for NetApp ASA r2 or AFX storage systems.

Before you begin

- Ensure that your Kubernetes version is K8s 1.32 or higher.
- You must have an external snapshot controller and Custom Resource Definitions (CRDs) to work with snapshots. This is the responsibility of the Kubernetes orchestrator (for example: Kubeadm, GKE, OpenShift).

  If your Kubernetes distribution does not include the external snapshot controller and CRDs, refer to Deploy a volume snapshot controller.

  > Don't create a snapshot controller if creating on-demand volume group snapshots in a GKE environment. GKE uses a built-in, hidden snapshot controller.

- In the snapshot controller YAML, set the `CSIVolumeGroupSnapshot` feature gate to 'true' to ensure that volume group snapshot is enabled.
- Create the required volume group snapshot classes before creating a volume group snapshot.
- Ensure that all PVCs/volumes are on the same SVM to be able to create VolumeGroupSnapshot.

Steps

- Create a VolumeGroupSnapshotClass prior to creating a VolumeGroupSnapshot. For more information, refer to VolumeGroupSnapshotClass.

```
apiVersion: groupsnapshot.storage.k8s.io/v1beta1
kind: VolumeGroupSnapshotClass
metadata:
  name: csi-group-snap-class
  annotations:
    kubernetes.io/description: "Trident group snapshot class"
driver: csi.trident.netapp.io
deletionPolicy: Delete
```

- Create PVCs with required labels using existing storage classes, or add these labels to existing PVCs.

  The following example creates the PVC using `pvc1-group-snap` as the data source and label `consistentGroupSnapshot: groupA`. Define the label key and value based on your requirements.

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: pvc1-group-snap
  labels:
    consistentGroupSnapshot: groupA
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 100Mi
  storageClassName: sc1-1
```

- Create a VolumeGroupSnapshot with the same label (`consistentGroupSnapshot: groupA`) specified in the PVC.

  This example creates a volume group snapshot:

```
apiVersion: groupsnapshot.storage.k8s.io/v1beta1
kind: VolumeGroupSnapshot
metadata:
  name: "vgs1"
  namespace: trident
spec:
  volumeGroupSnapshotClassName: csi-group-snap-class
  source:
    selector:
      matchLabels:
        consistentGroupSnapshot: groupA
```

Recover volume data using a group snapshot

You can restore individual Persistent Volumes using the individual snapshots which have been created as part of the Volume Group Snapshot. You cannot recover the Volume Group Snapshot as a unit.

Use the volume snapshot restore ONTAP CLI to to restore a volume to a state recorded in a prior snapshot.

```
cluster1::*> volume snapshot restore -vserver vs0 -volume vol3 -snapshot
vol3_snap_archive
```

When you restore a snapshot copy, the existing volume configuration is overwritten. Changes made to volume data after the snapshot copy was created are lost.

In-place volume restoration from a snapshot

Trident provides rapid, in-place volume restoration from a snapshot using the `TridentActionSnapshotRestore` (TASR) CR. This CR functions as an imperative Kubernetes action and does not persist after the operation completes.

For more information, see In-place volume restoration from a snapshot.

Delete a PV with associated group snapshots

When deleting a group volume snapshot:

- You can delete VolumeGroupSnapshots as a whole, not individual snapshots in the group.
- If PersistentVolumes are deleted while a snapshot exists for that PersistentVolume, Trident will move that volume to a "deleting" state because the snapshot must be removed before the volume can be safely removed.
- If a clone has been created using a grouped snapshot and then the group is to be deleted, a split-on-clone operation will begin and the group cannot be deleted until the split is complete.

Deploy a volume snapshot controller

If your Kubernetes distribution does not include the snapshot controller and CRDs, you can deploy them as follows.

Steps

1. Create volume snapshot CRDs.

```
cat snapshot-setup.sh
```

```
#!/bin/bash
# Create volume snapshot CRDs
kubectl apply -f https://raw.githubusercontent.com/kubernetes-csi/external-snapshotter/release-8.2/client/config/crd/groupsnapshot.storage.k8s.io_volumegroupsnapshotclasses.yaml
kubectl apply -f https://raw.githubusercontent.com/kubernetes-csi/external-snapshotter/release-8.2/client/config/crd/groupsnapshot.storage.k8s.io_volumegroupsnapshotcontents.yaml
kubectl apply -f https://raw.githubusercontent.com/kubernetes-csi/external-snapshotter/release-8.2/client/config/crd/groupsnapshot.storage.k8s.io_volumegroupsnapshots.yaml
```

2. Create the snapshot controller.

```
kubectl apply -f https://raw.githubusercontent.com/kubernetes-csi/external-snapshotter/release-8.2/deploy/kubernetes/snapshot-controller/rbac-snapshot-controller.yaml
```

```
kubectl apply -f https://raw.githubusercontent.com/kubernetes-csi/external-snapshotter/release-8.2/deploy/kubernetes/snapshot-controller/setup-snapshot-controller.yaml
```

If necessary, open `deploy/kubernetes/snapshot-controller/rbac-snapshot-controller.yaml` and update `namespace` to your namespace.

Related links

- VolumeGroupSnapshotClass
- Volume snapshots

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