Storage on Kubernetes

Learning From Failures

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Agenda

- Data loss.
- Security issues.
- Data corruption.
- Attach/detach issues.
- Open issues.

Data lost during migration

Data lost during migration

What happened?

1. User moves PV and PVC objects from "testing" to "production" clusters.
   - On the testing cluster:

```
$ kubectl get pv -o yaml > pvs.yaml
$ kubectl get pvc -o yaml > pvcs.yaml
```

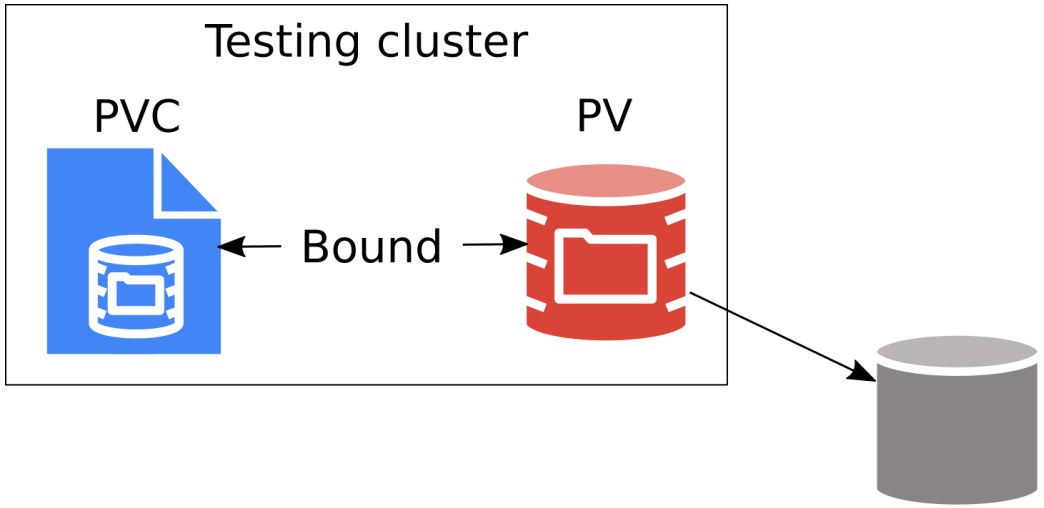
   - On the production cluster:

```
$ kubectl apply -f pvs.yaml
$ kubectl apply -f pvcs.yaml
```

2. **Kubernetes deletes PV and the volume in storage backend.**

Data lost during migration

Why?



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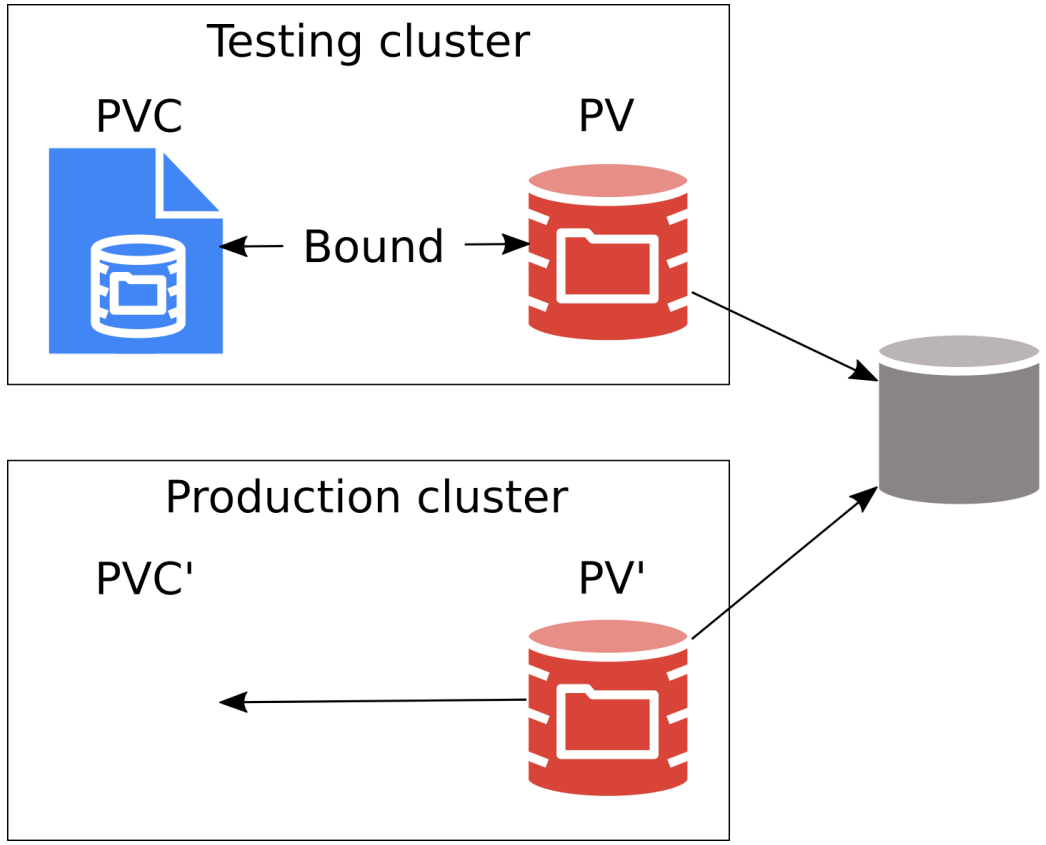

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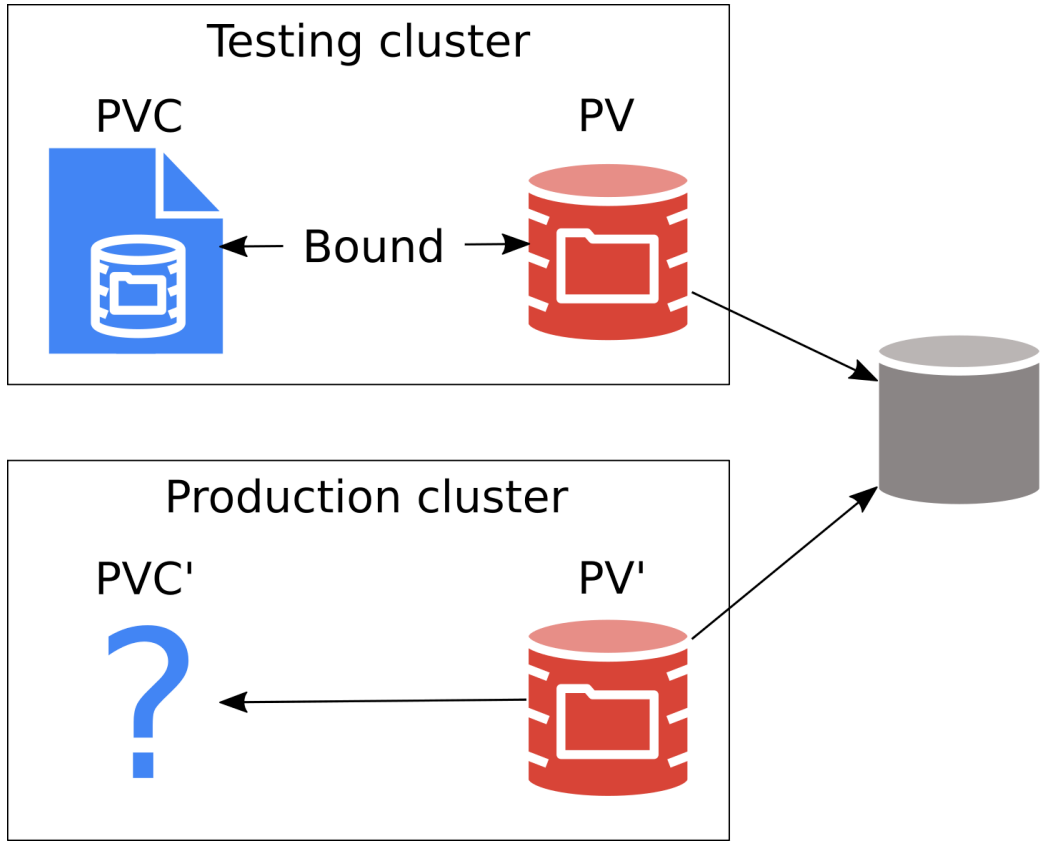

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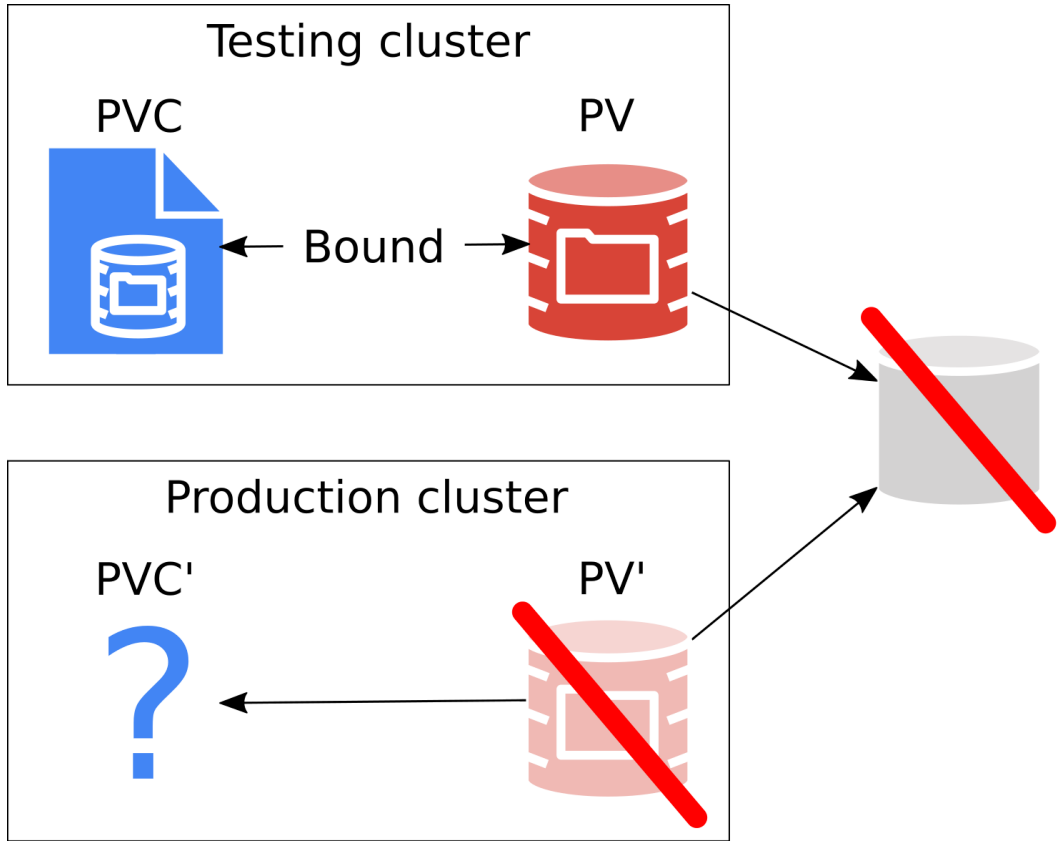

Data lost during migration

It's not a bug, it's a feature!

- Do regular backups!
- Do not mess up with PVs.
  - Use dedicated tools for migration, such as Ark / Velero.
    - *How to Backup and Restore Your Kubernetes Cluster - Annette Clewett & Dylan Murray, Tuesday 4:25pm.*

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- But if you want to…
  - Use `Retain` reclaim policy.
  - Sanitize PVCs and PVs before restoring them.
    - Clean `pv.spec.claimRef.UID`.
    - Clean Kubernetes annotations on PV/PVC.

Data lost during migration

Lessons learned:

- Education.
- Better documentation.

Volumes are recycled while they are used by pods

Volumes are recycled while they are used by pods

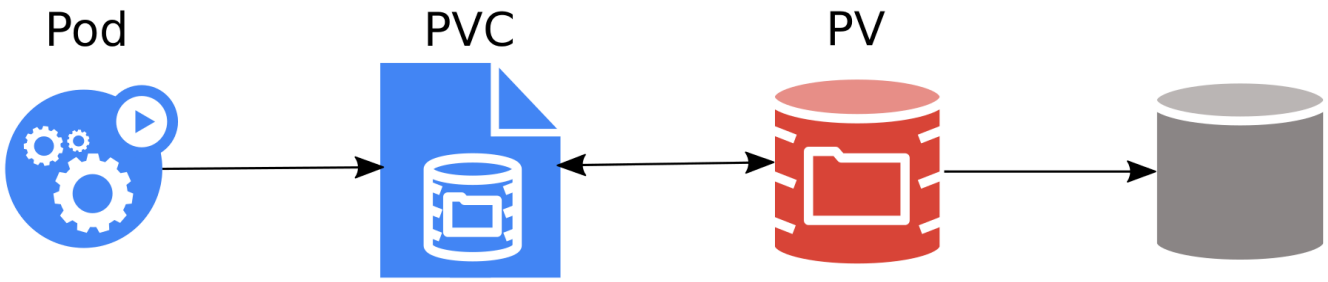
What happened?

- User deletes PVC while it's still used by a pod.
- All data on the volume are wiped.

Volumes are recycled while they are used by pods

Why?

- Kubernetes has no referential integrity.



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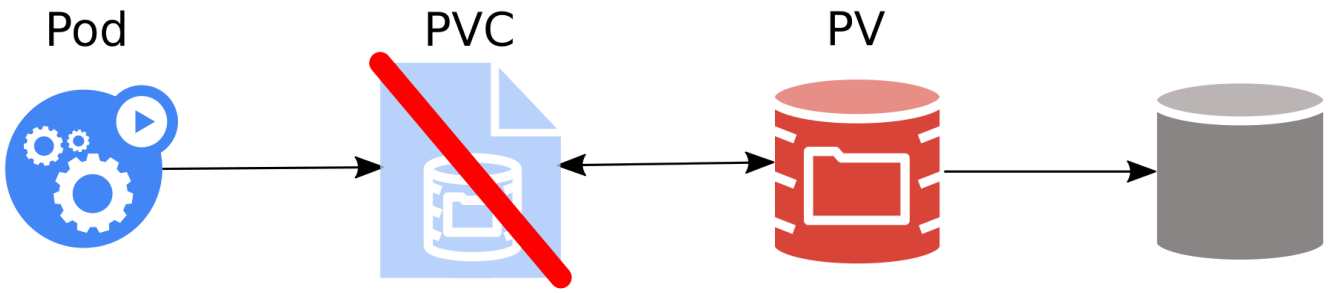

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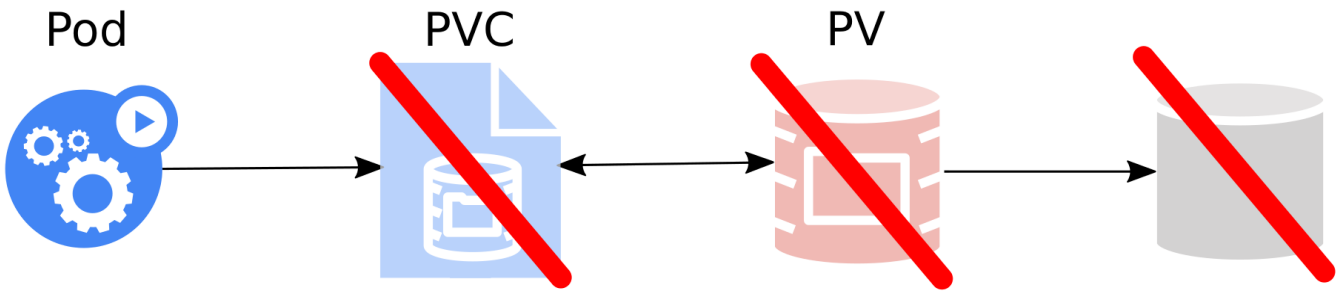

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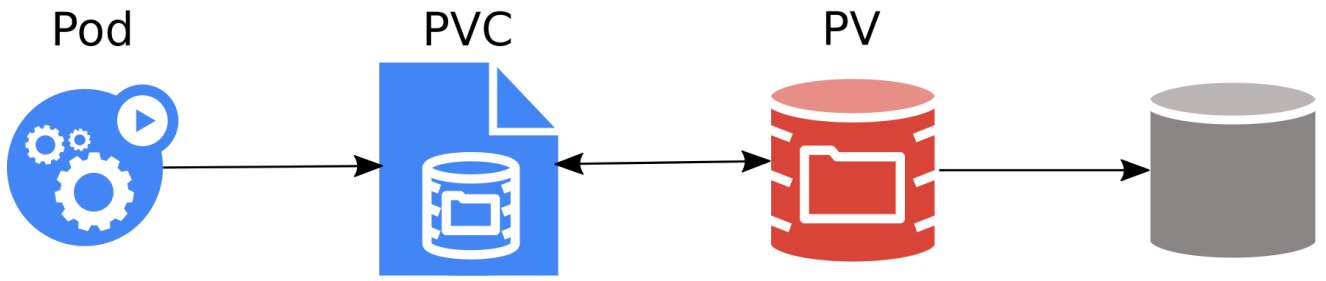
How we fixed it?

- Using `Finalizers`.
- StorageInUseProtection admission plugin and controller.



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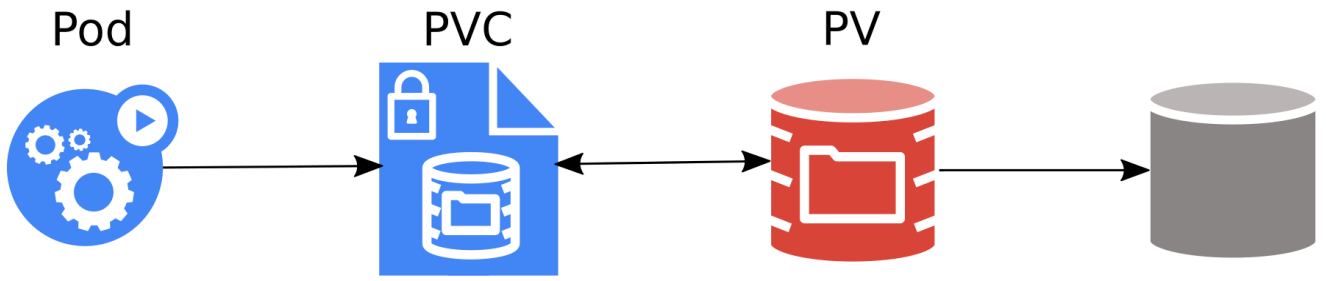

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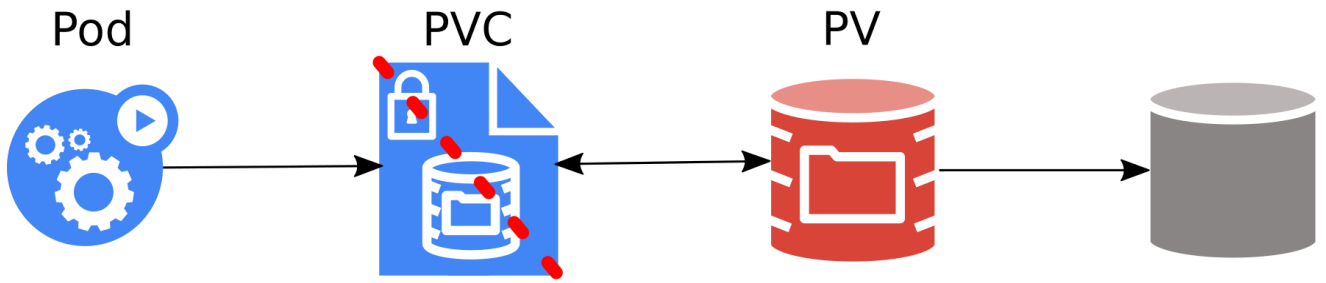

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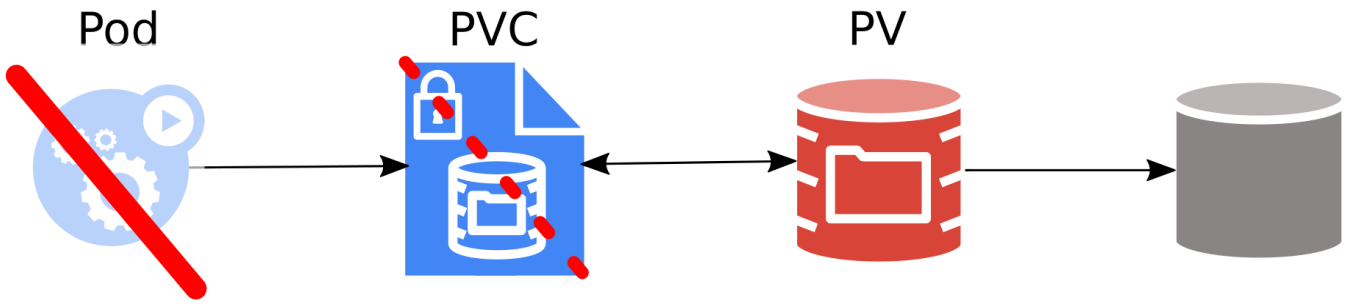

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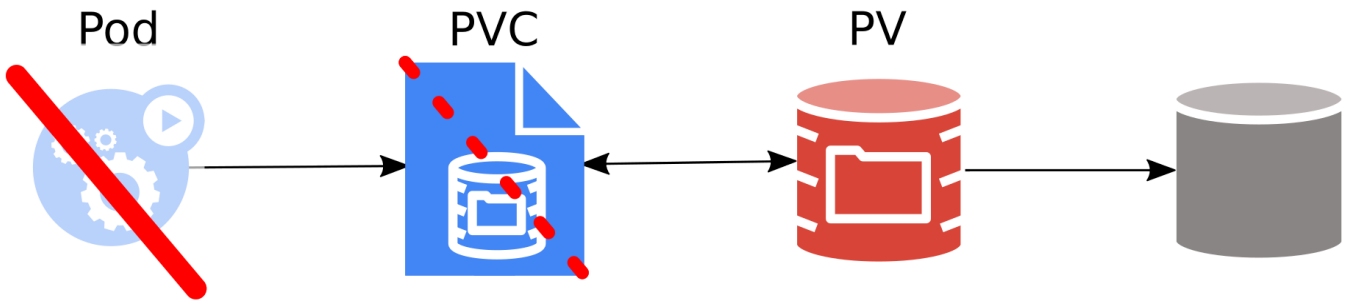

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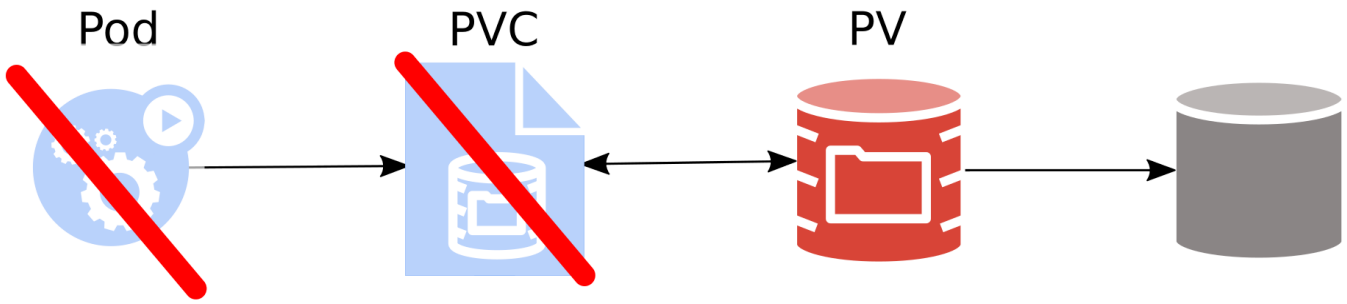

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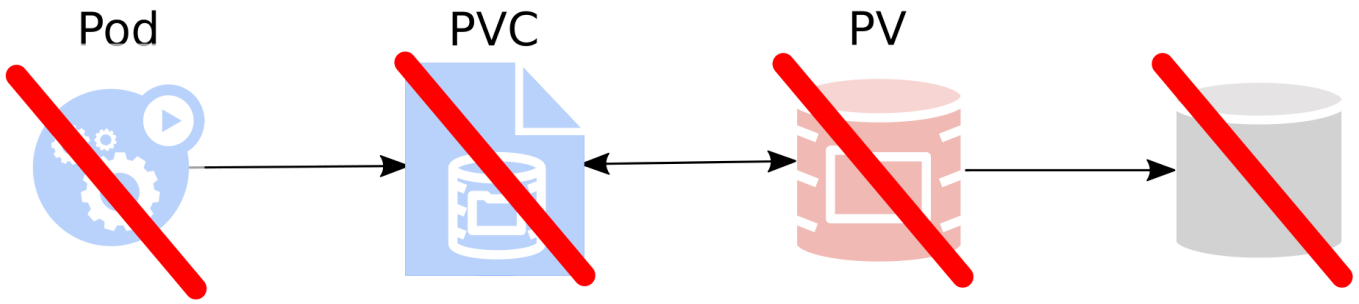

Data on `PersistentVolume` wiped after kubelet restart

Data on PV wiped after kubelet restart

What happened?

- Kubelet is offline and a running pod is deleted in the API server.
- Newly (re)started kubelet deletes all data on a volume that the pod used.

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What happened?

- Kubelet is offline and a running pod is deleted in the API server.
- Newly (re)started kubelet deletes all data on a volume that the pod used.

Why?

- Newly (re)started kubelet does not see the pod in API server.
  - kubelet did not unmount the volume.
  - Orphan directory scan removed all files in presumably empty pod directory.

Data on PV wiped after kubelet restart

How we fixed it?

- Review all `os.RemoveAll` in Kubernetes.
  - Never delete orphan directories across filesystem boundary.

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- Introduce *reconstruction*.
  - Scan `/var/lib/kubelet` on kubelet start and reconstruct caches.

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Lessons learned

- Introduced `[Distuptive]` tests for kubelet restart.

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What happened?

- A directory on the root disk used as local volume wiped out.
- Same scenario as above.

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- Root disk used as a local volume does not introduce filesystem boundary.
- The local volume was used with `SubPath` feature.

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How we fixed it?

- Check for SubPath volumes before removing orphan directories.

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How we fixed it?

- Check for SubPath volumes before removing orphan directories.

Lessons learned

- Introduce `[Disruptive]` tests for kubelet restart with `SubPath`.

CVE-2017-1002101

Subpath volume mount handling allows arbitrary file access in host filesystem

CVE-2017-1002101

What happened?

"Subpath volume mount handling allows arbitrary file access in host filesystem"

A pod can get access to full host filesystem, including:

- Container runtime socket.
- Any Secrets present on the node.
- Any Pod volume present on the node.
- ...

CVE-2017-1002101

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"Subpath volume mount handling allows arbitrary file access in host filesystem"

A pod can get access to full host filesystem, including:

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- Any Secrets present on the node.
- Any Pod volume present on the node.
- ...

Why?

- Symlinks created *in a pod* were evaluated *outside of the pod*.

CVE-2017-1002101

How we fixed it?

KubeCon NA 2018: How Symlinks Pwned Kubernetes (And How We Fixed It) - Michelle Au, Google & Jan Šafránek, Red Hat.

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Lessons learned

- Don't trust user.
- Containers can introduce security issues not seen before.
- Kubernetes Security Response Team (aka Product Security Committee) works and is helpful.

Corrupted filesystem on ReadWriteOnce volumes

Corrupted filesystem on ReadWriteOnce volumes

Story of two bugs, two years apart:

- Nobody wants this in their Kernel logs

```
[2480314.265276] XFS (dm-43): Unmounting Filesystem
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- Reported on: November 2017

Corrupted filesystem on ReadWriteOnce volumes

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What happened?

- Same volume could be temporarily mounted on more than one node.

Corrupted filesystem on ReadWriteOnce volumes

What happened?

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How do we fix it?

- Storage Provider should fix it.
- Enforce AccessModes.

Corrupted filesystem on ReadWriteOnce volumes

So what are AccessModes?

Corrupted filesystem on ReadWriteOnce volumes

So what are AccessModes?

- ReadWriteOnce
- ReadWriteMany
- ReadOnlyMany

Corrupted filesystem on ReadWriteOnce volumes

So what are AccessModes?

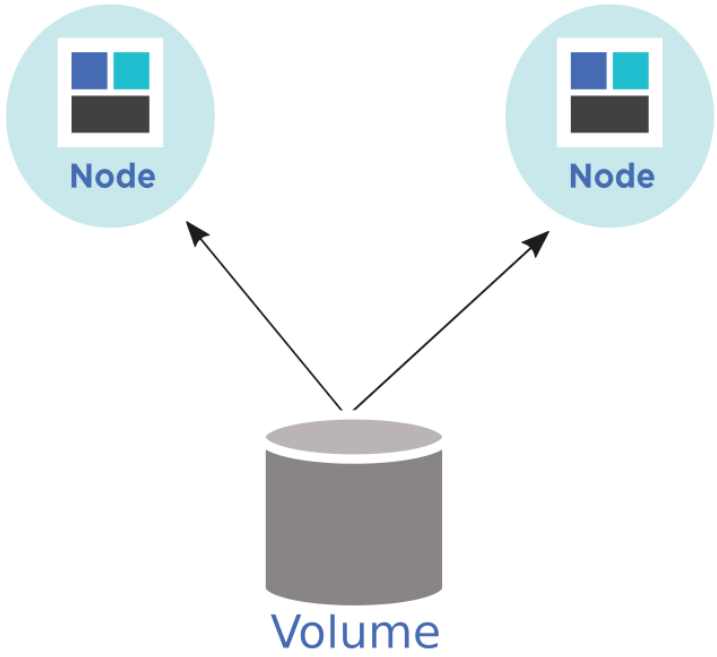
- ReadWriteOnce
- ReadWriteMany
- ReadOnlyMany

You can request a volume of specific AccessMode while creating a PVC:

```
kind: PersistentVolumeClaim
apiVersion: v1
metadata:
  name: myclaim
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 1Gi
```

Corrupted filesystem on ReadWriteOnce volumes

Kubernetes did not enforce AccessModes at all until version 1.7/1.8



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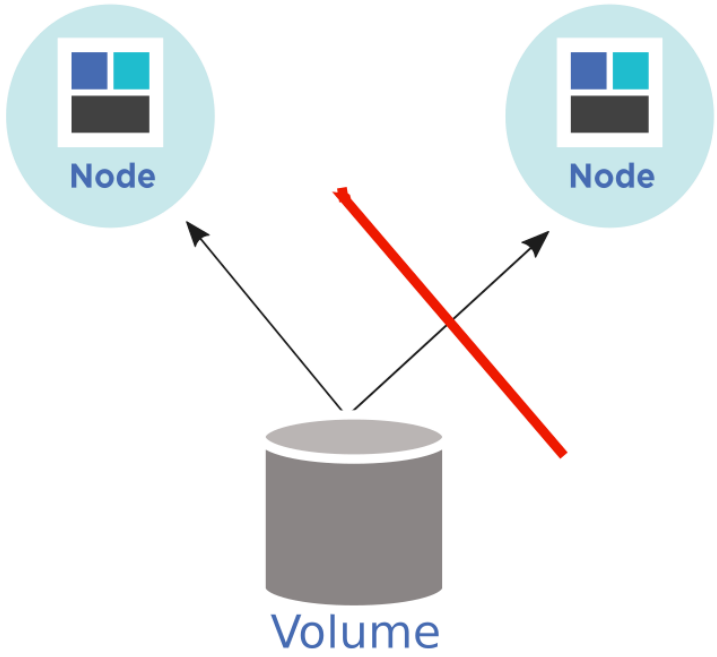

Corrupted filesystem on ReadWriteOnce volumes

But those two bugs are newer - 1.10 and 1.14!

Corrupted filesystem on ReadWriteOnce volumes

Limitations of AccessMode enforcement in Kubernetes

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- It only works for volume types that are Attachable.

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Limitations of AccessMode enforcement in Kubernetes

- It only works for volume types that are Attachable.
- It does not prevent 2 pods from using same volume on same node.
- It is based on cached volume state in controller-manager.

Corrupted filesystem on ReadWriteOnce volumes

Attachable volumes:

- AWS EBS
- OpenStack Cinder
- GCE PD
- vSphere disks
- CSI volume that does have `PUBLISH_UNPUBLISH_VOLUME` capability.

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Volume types which are not attachable:

- iSCSI
- Ceph-RBD
- Fiber Channel
- CSI volume that does not have `PUBLISH_UNPUBLISH_VOLUME` capability.

Corrupted filesystem on ReadWriteOnce volumes

Fix for non-attachable volumes(in-tree)

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Fix for non-attachable volumes(in-tree)

- Implement a dummy `Attach` and `Detach` interface which is basically a NOOP for `iSCSI`, `FC` and `Ceph-RBD`.

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Fix for non-attachable volumes(in-tree)

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- This would basically turn non-attachable volume types into attachable.

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Fix for non-attachable volumes(in-tree)

- Implement a dummy `Attach` and `Detach` interface which is basically a NOOP for `iSCSI`, `FC` and `Ceph-RBD`.
- This would basically turn non-attachable volume types into attachable.
- It will ensure that volume is made available on a node via control-plane attach/detach controller and not directly.

Corrupted filesystem on ReadWriteOnce volumes

Recommendations for CSI Drivers

- Whenever possible implement strong control-plane based fencing for publishing volumes to a node.

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- External-Attacher CSI sidecar can support NOOP attach/detach of volumes which don't have `PUBLISH_UNPUBLISH_VOLUME` capability.
  - Ensure that external-attacher is running even if CSI driver does not support attach/detach.
  - Do not disable attach/detach from `CSIDriver` object.

Corrupted filesystem on ReadWriteOnce volumes

Prefer use of StatefulSet over Deployment for workloads that use Storage

Volumes not attached / detached on AWS

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What happened?

- AWS EBS volume was *attaching* / *detaching* forever.
- Very hard to reproduce.

Volumes not attached / detached on AWS

Kubernetes AWS cloud provider device allocator

- Re-using a device that was just released can lead to volume *attaching* forever.
  - LRU of free device names.

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Kubernetes AWS cloud provider device allocator

- Re-using a device that was just released can lead to volume *attaching* forever.
  - LRU of free device names.
- Node is unusable after force-detach.
  - Don't force-detach volumes on AWS!
  - Tainting nodes where attach times out.

Volumes not attached / detached on AWS

Eventual consistency

Why?

- Volume is detached, but AWS says it's attached.
- Volume is attached, but AWS says it's detached.
- Can go back in time.
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  3. ...
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We still love AWS!

Open Issues

Recursive `chown`

```
$ kubectl explain pod.spec.securityContext.fsGroup

FIELD:    fsGroup <integer>

DESCRIPTION:
     A special supplemental group that applies to all containers in a pod. Some
     volume types allow the Kubelet to change the ownership of that volume to be
     owned by the pod [...]
```

- kubelet does recursive `chown` to set ownership of **all** files on the volume.
  - Slow on large volumes.
- Design in progress.
  - Take shortcuts? Some files may have wrong owner.
  - Make `chown` optional? Requires API change.
  - Use overlay FS? Requires the overlay installed on nodes.

Detaching volumes from shutdown nodes

- Kubernetes will not automatically detach volumes from nodes which have been shutdown.
  - Kubernetes does evict Pods from shutdown nodes automatically.
  - Replacement Pods on new nodes may not be able to start if they are using Persistent volumes.

Detaching volumes from shutdown nodes

Kubernetes will not detach volumes from shutdown nodes

- Pods on shutdown node do not automatically get deleted and stay in "unknown" state.
- Kubernetes does not detach volumes from Pods in "unknown" state.

Detaching volumes from shutdown nodes

How do we recover from it?

- On cloudprovider managed clusters such as AWS, GCE - running a cluster in Autoscaling group will cause a shutdown node to be deleted and replaced.
  - Volumes are automatically detached from a deleted node.
- For bare-metal clusters or cloudproviders that don't allow easy replacement of a node, this is a bigger problem.
  - An external controller can monitor for shutdown nodes and force delete pods in "unknown" state from those nodes.
- Kubernetes community is working on a design consensus that should solve this for good.
  - Add node shutdown KEP

`EmptyDir` volumes share I/O

- `EmptyDir` shares I/O bandwidth with the system and all other pods.
- Rogue pod may trash I/O performance for the others.

AWS EBS encrypted volumes occasionaly do not mount

- Sometimes newly created encrypted EBS volumes are not zeroed.
- Kubernetes does not overwrite existing data.

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- Still learning from our failures.
  - Huge e2e test matrix.
- Kubernetes does not loose data *most* of the time.
  - Unless users ask for it.
- Still amazed by user creativity.


Questions?