Use the OverlayFS storage driver

Estimated reading time: 18 minutes

OverlayFS is a modern *union filesystem* that is similar to AUFS, but faster and with a simpler implementation. Docker provides two storage drivers for OverlayFS: the original `overlay` , and the newer and more stable `overlay2` .

This topic refers to the Linux kernel driver as `OverlayFS` and to the Docker storage driver as `overlay` or `overlay2` .

> **Note: If you use OverlayFS, use the `overlay2` driver rather than the `overlay` driver, because it is more efficient in terms of inode utilization. To use the new driver, you need version 4.0 or higher of the Linux kernel, or RHEL or CentOS using version 3.10.0-514 and above.**
>
> For more information about differences between `overlay` vs `overlay2` , check Docker storage drivers (https://docs.docker.com/storage/storagedriver/select-storage-driver/).

Prerequisites

OverlayFS is supported if you meet the following prerequisites:

- The `overlay2` driver is supported on Docker CE, and Docker EE 17.06.02-ee5 and up, and is the recommended storage driver.
- Version 4.0 or higher of the Linux kernel, or RHEL or CentOS using version 3.10.0-514 of the kernel or higher. If you use an older kernel, you need to use the `overlay` driver, which is not recommended.
- The `overlay` and `overlay2` drivers are supported on `xfs` backing filesystems, but only with `d_type=true` enabled.

  Use `xfs_info` to verify that the `ftype` option is set to `1` . To format an `xfs` filesystem correctly, use the flag `-n ftype=1` .

> ⊗ **Warning**: Running on XFS without d_type support now causes Docker to skip the attempt to use the `overlay` or `overlay2` driver. Existing installs will continue to run, but produce an error. This is to allow users to migrate their data. In a future version, this will be a fatal error, which will prevent Docker from starting.

- Changing the storage driver makes existing containers and images inaccessible on the local system. Use `docker save` to save any images you have built or push them to Docker Hub or a private registry before changing the storage driver, so that you do not need to re-create them later.

Configure Docker with the `overlay` or `overlay2` storage driver

It is highly recommended that you use the `overlay2` driver if possible, rather than the `overlay` driver. The `overlay` driver is **not** supported for Docker EE.

To configure Docker to use the `overlay` storage driver your Docker host must be running version 3.18 of the Linux kernel (preferably newer) with the overlay kernel module loaded. For the `overlay2` driver, the version of your kernel must be 4.0 or newer.

Before following this procedure, you must first meet all the prerequisites (/storage/storagedriver/overlayfs-driver/#prerequisites).

The steps below outline how to configure the `overlay2` storage driver. If you need to use the legacy `overlay` driver, specify it instead.

1. Stop Docker.

   ```
   $ sudo systemctl stop docker
   ```

2. Copy the contents of `/var/lib/docker` to a temporary location.

   ```
   $ cp -au /var/lib/docker /var/lib/docker.bk
   ```

3. If you want to use a separate backing filesystem from the one used by `/var/lib/`, format the filesystem and mount it into `/var/lib/docker`. Make sure add this mount to `/etc/fstab` to make it permanent.

4. Edit `/etc/docker/daemon.json` . If it does not yet exist, create it. Assuming that the file was empty, add the following contents.

   ```
   {
     "storage-driver": "overlay2"
   }
   ```

   Docker does not start if the `daemon.json` file contains badly-formed JSON.

5. Start Docker.

   ```
   $ sudo systemctl start docker
   ```

6. Verify that the daemon is using the `overlay2` storage driver. Use the `docker info` command and look for `Storage Driver` and `Backing filesystem` .

   ```
   $ docker info

   Containers: 0
   Images: 0
   Storage Driver: overlay2
    Backing Filesystem: xfs
    Supports d_type: true
    Native Overlay Diff: true
   <output truncated>
   ```

Docker is now using the `overlay2` storage driver and has automatically created the overlay mount with the required `lowerdir` , `upperdir` , `merged` , and `workdir` constructs.

Continue reading for details about how OverlayFS works within your Docker containers, as well as performance advice and information about limitations of its compatibility with different backing filesystems.

How the `overlay2` driver works

If you are still using the `overlay` driver rather than `overlay2` , see How the overlay driver works (/storage/storagedriver/overlayfs-driver/#how-the-overlay-driver-works) instead.

OverlayFS layers two directories on a single Linux host and presents them as a single directory. These directories are called *layers* and the unification process is referred to as a *union mount*. OverlayFS refers to the lower directory as `lowerdir` and the upper directory a `upperdir` . The unified view is exposed through its own directory called `merged` .

The `overlay2` driver natively supports up to 128 lower OverlayFS layers. This capability provides better performance for layer-related Docker commands such as `docker build` and `docker commit` , and consumes fewer inodes on the backing filesystem.

Image and container layers on-disk

After downloading a five-layer image using `docker pull ubuntu` , you can see six directories under `/var/lib/docker/overlay2` .

> **Warning**: Do not directly manipulate any files or directories within `/var/lib/docker/` . These files and directories are managed by Docker.

```
$ ls -l /var/lib/docker/overlay2

total 24
drwx------ 5 root root 4096 Jun 20 07:36 223c2864175491657d238e266
4251df13b63adb8d050924fd1bfcdb278b866f7
drwx------ 3 root root 4096 Jun 20 07:36 3a36935c9df35472229c57f4a
27105a136f5e4dbef0f87905b2e506e494e348b
drwx------ 5 root root 4096 Jun 20 07:36 4e9fa83caff3e8f4cc83693fa
407a4a9fac9573deaf481506c102d484dd1e6a1
drwx------ 5 root root 4096 Jun 20 07:36 e8876a226237217ec61c4baf2
38a32992291d059fdac95ed6303bdff3f59cff5
drwx------ 5 root root 4096 Jun 20 07:36 eca1e4e1694283e001f200a66
7bb3cb40853cf2d1b12c29feda7422fed78afed
drwx------ 2 root root 4096 Jun 20 07:36 l
```

The new `l` (lowercase `L`) directory contains shortened layer identifiers as symbolic links. These identifiers are used to avoid hitting the page size limitation on arguments to the `mount` command.

```
$ ls -l /var/lib/docker/overlay2/l

total 20
lrwxrwxrwx 1 root root 72 Jun 20 07:36 6Y5IM2XC7TSNIJZZFLJCS6I4I4
-> ../3a36935c9df35472229c57f4a27105a136f5e4dbef0f87905b2e506e494e
348b/diff
lrwxrwxrwx 1 root root 72 Jun 20 07:36 B3WWEFKBG3PLLV737KZFIASSW7
-> ../4e9fa83caff3e8f4cc83693fa407a4a9fac9573deaf481506c102d484dd1
e6a1/diff
lrwxrwxrwx 1 root root 72 Jun 20 07:36 JEYMODZYFCZFYSDABYXD5MF6YO
-> ../eca1e4e1694283e001f200a667bb3cb40853cf2d1b12c29feda7422fed78
afed/diff
lrwxrwxrwx 1 root root 72 Jun 20 07:36 NFYKDW6APBCCUCTOUSYDH4DXAT
-> ../223c2864175491657d238e2664251df13b63adb8d050924fd1bfcdb278b8
66f7/diff
lrwxrwxrwx 1 root root 72 Jun 20 07:36 UL2MW33MSE3Q5VYIKBRN4ZAGQP
-> ../e8876a226237217ec61c4baf238a32992291d059fdac95ed6303bdff3f59
cff5/diff
```

The lowest layer contains a file called `link`, which contains the name of the shortened identifier, and a directory called `diff` which contains the layer’s contents.

```
$ ls /var/lib/docker/overlay2/3a36935c9df35472229c57f4a27105a136f5
e4dbef0f87905b2e506e494e348b/

diff  link

$ cat /var/lib/docker/overlay2/3a36935c9df35472229c57f4a27105a136f
5e4dbef0f87905b2e506e494e348b/link

6Y5IM2XC7TSNIJZZFLJCS6I4I4

$ ls  /var/lib/docker/overlay2/3a36935c9df35472229c57f4a27105a136f
5e4dbef0f87905b2e506e494e348b/diff

bin  boot  dev  etc  home  lib  lib64  media  mnt  opt  proc  root
  run  sbin  srv  sys  tmp  usr  var
```

The second-lowest layer, and each higher layer, contain a file called `lower`, which denotes its parent, and a directory called `diff` which contains its contents. It also contains a `merged` directory, which contains the unified contents of its parent layer and itself, and a `work` directory which is used internally by OverlayFS.

```
$ ls /var/lib/docker/overlay2/223c2864175491657d238e2664251df13b63
adb8d050924fd1bfcdb278b866f7

diff  link  lower  merged  work

$ cat /var/lib/docker/overlay2/223c2864175491657d238e2664251df13b6
3adb8d050924fd1bfcdb278b866f7/lower

l/6Y5IM2XC7TSNIJZZFLJCS6I4I4

$ ls /var/lib/docker/overlay2/223c2864175491657d238e2664251df13b63
adb8d050924fd1bfcdb278b866f7/diff/

etc  sbin  usr  var
```

To view the mounts which exist when you use the `overlay` storage driver with Docker, use the `mount` command. The output below is truncated for readability.

```
$ mount | grep overlay

overlay on /var/lib/docker/overlay2/9186877cdf386d0a3b016149cf30c2
08f326dca307529e646afce5b3f83f5304/merged
type overlay (rw,relatime,
lowerdir=l/DJA75GUWHWG7EWICFYX54FIOVT:l/B3WWEFKBG3PLLV737KZFIASSW7
:l/JEYMODZYFCZFYSDABYXD5MF6YO:l/UL2MW33MSE3Q5VYIKBRN4ZAGQP:l/NFYKD
W6APBCCUCTOUSYDH4DXAT:l/6Y5IM2XC7TSNIJZZFLJCS6I4I4,
upperdir=9186877cdf386d0a3b016149cf30c208f326dca307529e646afce5b3f
83f5304/diff,
workdir=9186877cdf386d0a3b016149cf30c208f326dca307529e646afce5b3f8
3f5304/work)
```

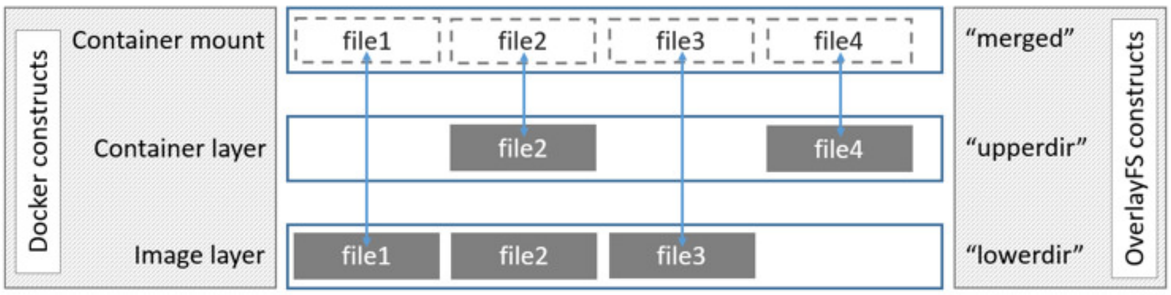
The `rw` on the second line shows that the `overlay` mount is read-write.

How the `overlay` driver works

This content applies to the `overlay` driver only. Docker recommends using the `overlay2` driver, which works differently. See How the overlay2 driver works (/storage/storagedriver/overlayfs-driver/#how-the-overlay2-driver-works) for `overlay2` .

OverlayFS layers two directories on a single Linux host and presents them as a single directory. These directories are called *layers* and the unification process is referred to as a *union mount*. OverlayFS refers to the lower directory as `lowerdir` and the upper directory a `upperdir` . The unified view is exposed through its own directory called `merged` .

The diagram below shows how a Docker image and a Docker container are layered. The image layer is the `lowerdir` and the container layer is the `upperdir`. The unified view is exposed through a directory called `merged` which is effectively the containers mount point. The diagram shows how Docker constructs map to OverlayFS constructs.



Where the image layer and the container layer contain the same files, the container layer "wins" and obscures the existence of the same files in the image layer.

The `overlay` driver only works with two layers. This means that multi-layered images cannot be implemented as multiple OverlayFS layers. Instead, each image layer is implemented as its own directory under `/var/lib/docker/overlay`. Hard links are then used as a space-efficient way to reference data shared with lower layers. The use of hardlinks causes an excessive use of inodes, which is a known limitation of the legacy `overlay` storage driver, and may require additional configuration of the backing filesystem. Refer to the overlayFS and Docker performance (/storage/storagedriver/overlayfs-driver/#overlayfs-and-docker-performance) for details.

To create a container, the `overlay` driver combines the directory representing the image's top layer plus a new directory for the container. The image's top layer is the `lowerdir` in the overlay and is read-only. The new directory for the container is the `upperdir` and is writable.

Image and container layers on-disk

The following `docker pull` command shows a Docker host downloading a Docker image comprising five layers.

```
$ docker pull ubuntu

Using default tag: latest
latest: Pulling from library/ubuntu

5ba4f30e5bea: Pull complete
9d7d19c9dc56: Pull complete
ac6ad7efd0f9: Pull complete
e7491a747824: Pull complete
a3ed95caeb02: Pull complete
Digest: sha256:46fb5d001b88ad904c5c732b086b596b92cfb4a4840a3abd0e3
5dbb6870585e4
Status: Downloaded newer image for ubuntu:latest
```

THE IMAGE LAYERS

Each image layer has its own directory within `/var/lib/docker/overlay/` , which contains its contents, as shown below. The image layer IDs do not correspond to the directory IDs.

> **Warning**: Do not directly manipulate any files or directories within `/var/lib/docker/` . These files and directories are managed by Docker.

```
$ ls -l /var/lib/docker/overlay/

total 20
drwx------ 3 root root 4096 Jun 20 16:11 38f3ed2eac129654acef11c32
670b534670c3a06e483fce313d72e3e0a15baa8
drwx------ 3 root root 4096 Jun 20 16:11 55f1e14c361b90570df46371b
20ce6d480c434981cbda5fd68c6ff61aa0a5358
drwx------ 3 root root 4096 Jun 20 16:11 824c8a961a4f5e8fe4f4243da
b57c5be798e7fd195f6d88ab06aea92ba931654
drwx------ 3 root root 4096 Jun 20 16:11 ad0fe55125ebf599da124da17
5174a4b8c1878afe6907bf7c78570341f308461
drwx------ 3 root root 4096 Jun 20 16:11 edab9b5e5bf73f2997524eebe
ac1de4cf9c8b904fa8ad3ec43b3504196aa3801
```

The image layer directories contain the files unique to that layer as well as hard links to the data that is shared with lower layers. This allows for efficient use of disk space.

```
$ ls -i /var/lib/docker/overlay/38f3ed2eac129654acef11c32670b53467
0c3a06e483fce313d72e3e0a15baa8/root/bin/ls

19793696 /var/lib/docker/overlay/38f3ed2eac129654acef11c32670b5346
70c3a06e483fce313d72e3e0a15baa8/root/bin/ls

$ ls -i /var/lib/docker/overlay/55f1e14c361b90570df46371b20ce6d480
c434981cbda5fd68c6ff61aa0a5358/root/bin/ls

19793696 /var/lib/docker/overlay/55f1e14c361b90570df46371b20ce6d48
0c434981cbda5fd68c6ff61aa0a5358/root/bin/ls
```

THE CONTAINER LAYER

Containers also exist on-disk in the Docker host's filesystem under `/var/lib/docker/overlay/` . If you list a running container's subdirectory using the `ls -l` command, three directories and one file exist:

```
$ ls -l /var/lib/docker/overlay/<directory-of-running-container>

total 16
-rw-r--r-- 1 root root   64 Jun 20 16:39 lower-id
drwxr-xr-x 1 root root 4096 Jun 20 16:39 merged
drwxr-xr-x 4 root root 4096 Jun 20 16:39 upper
drwx------ 3 root root 4096 Jun 20 16:39 work
```

The `lower-id` file contains the ID of the top layer of the image the container is based on, which is the OverlayFS `lowerdir` .

```
$ cat /var/lib/docker/overlay/ec444863a55a9f1ca2df72223d459c5d940a
721b2288ff86a3f27be28b53be6c/lower-id

55f1e14c361b90570df46371b20ce6d480c434981cbda5fd68c6ff61aa0a5358
```

The `upper` directory contains the contents of the container's read-write layer, which corresponds to the OverlayFS `upperdir` .

The `merged` directory is the union mount of the `lowerdir` and `upperdir` , which comprises the view of the filesystem from within the running container.

The `work` directory is internal to OverlayFS.

To view the mounts which exist when you use the `overlay` storage driver with Docker, use the `mount` command. The output below is truncated for readability.

```
$ mount | grep overlay

overlay on /var/lib/docker/overlay/ec444863a55a.../merged
type overlay (rw,relatime,lowerdir=/var/lib/docker/overlay/55f1e14
c361b.../root,
upperdir=/var/lib/docker/overlay/ec444863a55a.../upper,
workdir=/var/lib/docker/overlay/ec444863a55a.../work)
```

The `rw` on the second line shows that the `overlay` mount is read-write.

How container reads and writes work with `overlay` or `overlay2`

Reading files

Consider three scenarios where a container opens a file for read access with overlay.

- **The file does not exist in the container layer**: If a container opens a file for read access and the file does not already exist in the container (`upperdir`) it is read from the image (`lowerdir)` . This incurs very little performance overhead.
- **The file only exists in the container layer**: If a container opens a file for read access and the file exists in the container (`upperdir`) and not in the image (`lowerdir`), it is read directly from the container.
- **The file exists in both the container layer and the image layer**: If a container opens a file for read access and the file exists in the image layer and the container layer, the file's version in the container layer is read. Files in the container layer (`upperdir`) obscure files with the same name in the image layer (`lowerdir`).

Modifying files or directories

Consider some scenarios where files in a container are modified.

- **Writing to a file for the first time**: The first time a container writes to an existing file, that file does not exist in the container (`upperdir`). The `overlay` / `overlay2` driver performs a *copy_up* operation to copy the file from the image (`lowerdir`) to the container (`upperdir`). The container then writes the changes to the new copy of the file in the container layer.

However, OverlayFS works at the file level rather than the block level. This means that all OverlayFS copy_up operations copy the entire file, even if the file is very large and only a small part of it is being modified. This can have a noticeable impact on container write performance. However, two things are worth noting:

   - The copy_up operation only occurs the first time a given file is written to. Subsequent writes to the same file operate against the copy of the file already copied up to the container.
   - OverlayFS only works with two layers. This means that performance should be better than AUFS, which can suffer noticeable latencies when searching for files in images with many layers. This advantage applies to both `overlay` and `overlay2` drivers. `overlayfs2` is slightly less performant than `overlayfs` on initial read, because it must look through more layers, but it caches the results so this is only a small penalty.

- **Deleting files and directories**:
   - When a *file* is deleted within a container, a *whiteout* file is created in the container (`upperdir`). The version of the file in the image layer (`lowerdir`) is not deleted (because the `lowerdir` is read-only). However, the whiteout file prevents it from being available to the container.
   - When a *directory* is deleted within a container, an *opaque directory* is created within the container (`upperdir`). This works in the same way as a whiteout file and effectively prevents the directory from being accessed, even though it still exists in the image (`lowerdir`).
- **Renaming directories**: Calling `rename(2)` for a directory is allowed only when both the source and the destination path are on the top layer. Otherwise, it returns `EXDEV` error (“cross-device link not permitted”). Your application needs to be designed to handle `EXDEV` and fall back to a “copy and unlink” strategy.

OverlayFS and Docker Performance

Both `overlay2` and `overlay` drivers are more performant than `aufs` and `devicemapper` . In certain circumstances, `overlay2` may perform better than `btrfs` as well. However, be aware of the following details.

- **Page Caching**. OverlayFS supports page cache sharing. Multiple containers accessing the same file share a single page cache entry for that file. This makes the `overlay` and `overlay2` drivers efficient with memory and a good option for high-density use cases such as PaaS.
- **copy_up**. As with AUFS, OverlayFS performs copy-up operations whenever a container writes to a file for the first time. This can add latency into the write operation, especially for large files. However, once the file has been copied up, all subsequent writes to that file occur in the upper layer, without the need for further copy-up operations.

  The OverlayFS `copy_up` operation is faster than the same operation with AUFS, because AUFS supports more layers than OverlayFS and it is possible to incur far larger latencies if searching through many AUFS layers. `overlay2` supports multiple layers as well, but mitigates any performance hit with caching.
- **Inode limits**. Use of the legacy `overlay` storage driver can cause excessive inode consumption. This is especially true in the presence of a large number of images and containers on the Docker host. The only way to increase the number of inodes available to a filesystem is to reformat it. To avoid running into this issue, it is highly recommended that you use `overlay2` if at all possible.

Performance best practices

The following generic performance best practices also apply to OverlayFS.

- **Use fast storage**: Solid-state drives (SSDs) provide faster reads and writes than spinning disks.
- **Use volumes for write-heavy workloads**: Volumes provide the best and most predictable performance for write-heavy workloads. This is because they bypass the storage driver and do not incur any of the potential overheads introduced by thin provisioning and copy-on-write. Volumes have other benefits, such as allowing you to share data among containers and persisting your data even if no running container is using them.

Limitations on OverlayFS compatibility

To summarize the OverlayFS's aspect which is incompatible with other filesystems:

- **open(2)**: OverlayFS only implements a subset of the POSIX standards. This can result in certain OverlayFS operations breaking POSIX standards. One such operation is the *copy-up* operation. Suppose that your application calls `fd1=open("foo", O_RDONLY)` and then `fd2=open("foo", O_RDWR)`. In this case, your application expects `fd1` and `fd2` to refer to the same file. However, due to a copy-up operation that occurs after the second calling to `open(2)`, the descriptors refer to different files. The `fd1` continues to reference the file in the image (`lowerdir`) and the `fd2` references the file in the container (`upperdir`). A workaround for this is to `touch` the files which causes the copy-up operation to happen. All subsequent `open(2)` operations regardless of read-only or read-write access mode reference the file in the container (`upperdir`).

  `yum` is known to be affected unless the `yum-plugin-ovl` package is installed. If the `yum-plugin-ovl` package is not available in your distribution such as RHEL/CentOS prior to 6.8 or 7.2, you may need to run `touch /var/lib/rpm/*` before running `yum install`. This package implements the `touch` workaround referenced above for `yum`.

- **rename(2)**: OverlayFS does not fully support the `rename(2)` system call. Your application needs to detect its failure and fall back to a “copy and unlink” strategy.

container (https://docs.docker.com/glossary/?term=container), storage (https://docs.docker.com/glossary/?term=storage), driver (https://docs.docker.com/glossary/?term=driver), OverlayFS (https://docs.docker.com/glossary/?term=OverlayFS), overlay2 (https://docs.docker.com/glossary/?term=overlay2), overlay (https://docs.docker.com/glossary/?term=overlay)