Docker architecture, images and containers

Basic concepts

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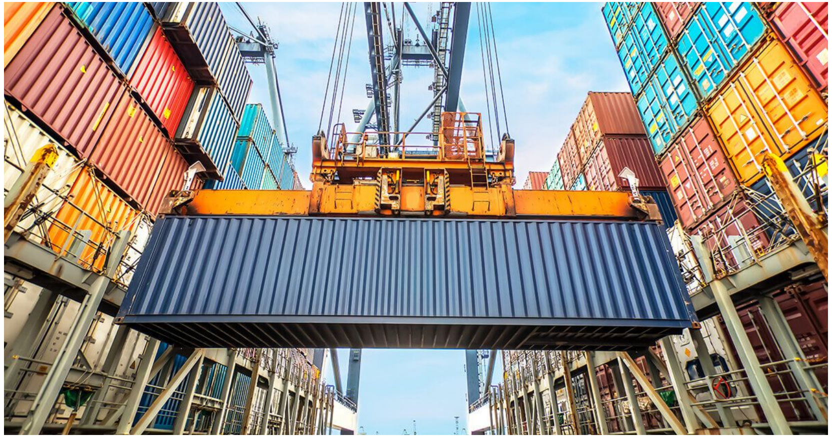
Outline

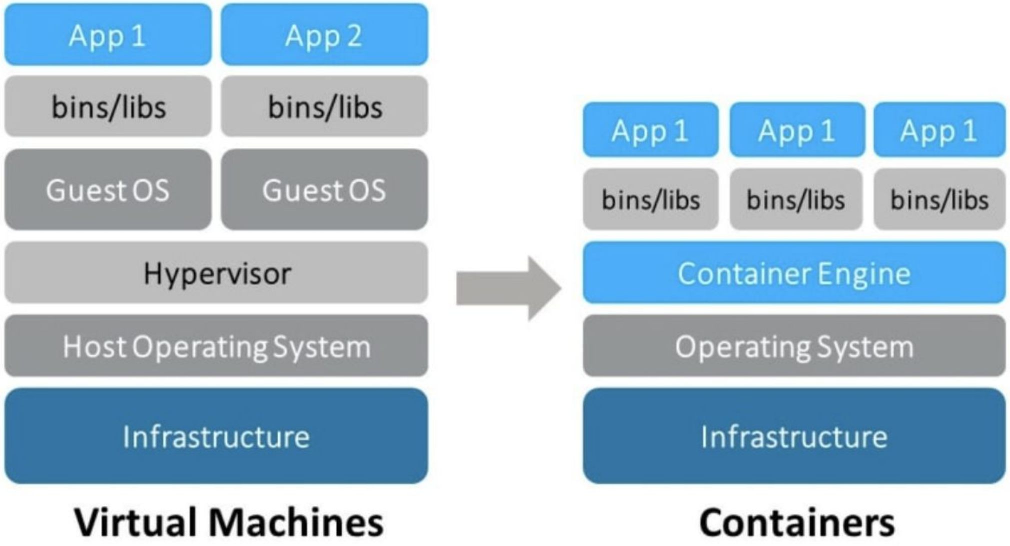
- What is a container?
- Docker architecture
- Docker main components
  - Images
  - Containers
  - Registries
- Docker CLI & GUI
- Hands-on#1
- References

What is a container?

- A way to **package** an application with all the necessary dependencies and configuration
- **Portable artifact**, easily shared and moved around
- Makes development and deployment **more efficient**

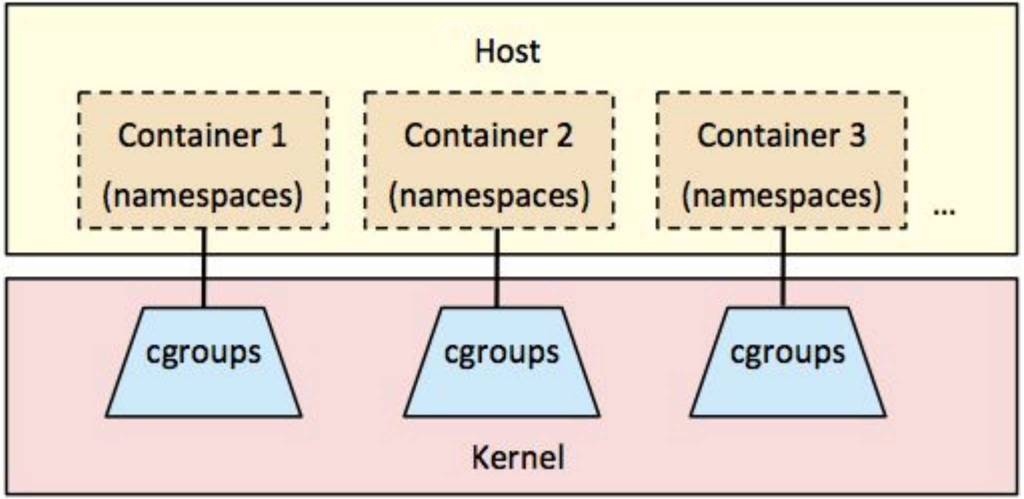


Virtual machines vs Containers



The Containers work on the concept of **Os-level virtualization**, i.e. the kernel's ability to make multiple isolated environments on a single host.
These environments encapsulate the programs and hide the true nature of the environment.
Three fundamental components enable OS-level virtualization: **Control Groups**, **Namespaces**, and **Union Filesystem**.

Containers = combination of namespaces & cgroups



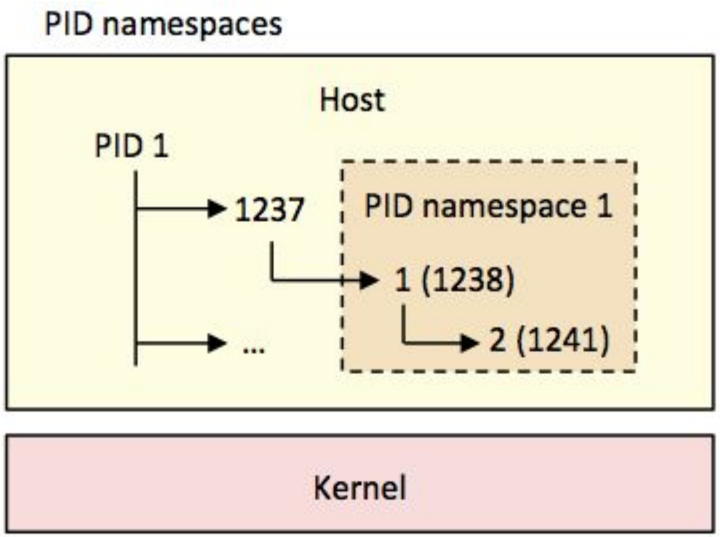
For further details have a look at this blog:
https://www.nginx.com/blog/what-are-namespaces-cgroups-how-do-they-work/

Restricting visibility: Namespaces

Linux namespaces: It is a feature of Linux kernel to isolate resources from each other. This allows one set of Linux processes to see one group of resources while allowing another set of Linux processes to see a different group of resources.

There are several kinds of namespaces in Linux: Mount (mnt), Process ID (PID), Network (net), User ID (user) and Interprocess Communication (IPC).

For example, two processes in two different mounted namespaces may have different views of what the mounted root file system is. Each container can be associated with a specific set of namespaces, and these namespaces are used inside these containers only.

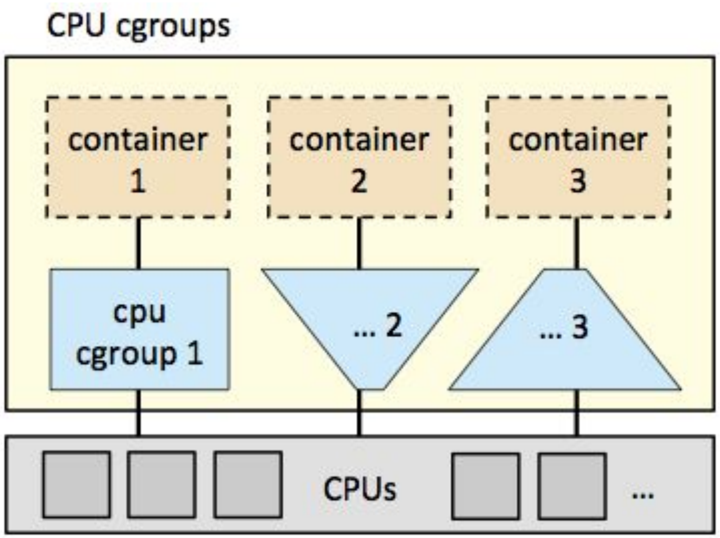


Restricting usage: Control groups

cgroups provide an effective mechanism for **resource limitation**.

With cgroups, you can control and manage system resources (CPU, Memory, Networking, ...) per Linux process, increasing overall resource utilization efficiency.

Cgroups allow to control resource utilization per container.

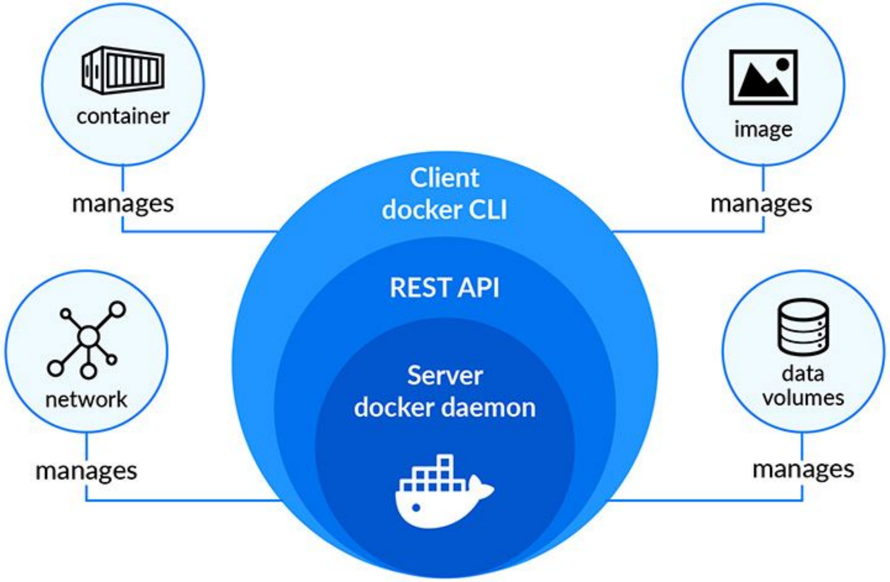


Docker architecture

Docker is an open source platform for building, deploying, and managing containerized applications

Docker works on a client-server architecture:

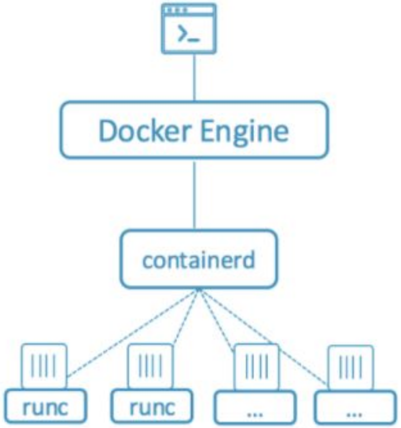
- a server with a long-running daemon process **dockerd**.
- **APIs** which specify interfaces that programs can use to talk to and instruct the Docker daemon.
- A command line interface (**CLI**) client docker.



docker, containerd, runc

When you run a container with *docker*, you're actually running it through the Docker daemon, containerd, and then runc.

- **containerd** is an industry standard high-level runtime for containers. It's main responsibility is to maintain the container's lifecycle (create/update/stop/restart or delete).
- **runc** is the runtime specification given by **OCI** (Open Container Initiative) for running containers, interacting with existing low-level Linux features, like namespaces and control groups.
  - after the creation of the container *runc* exits and the lifecycle of the container is managed by the *shim*(*) process (that becomes parent of the container).



(*) In tech terms, a shim is a component in a software system, which acts as a bridge between different APIs, or as a compatibility layer. A shim is sometimes added when you want to use a third-party component, but you need a little bit of glue code to make it work.

Docker on MacOS and Windows

- The Docker platform runs natively on Linux (on x86-64, ARM and many other CPU architectures) and on Windows (x86-64).
  - To run a Windows container you must have a supported container runtime available on your machine. The runtimes currently supported on Windows are *containerd*, *Moby*, and the *Mirantis Container Runtime*.
- **Docker Desktop** is an easy-to-install application for your **Mac** or **Windows** environment that enables you to build and share containerized applications and microservices.
- Some of the magic Docker Desktop takes care of for developers includes:
  - A secure, optimized Linux VM that runs Linux tools and containers
  - Seamless plumbing into the host OS giving containers access to the filesystem and networking
  - Bundled container tools including Kubernetes, Docker Compose, buildkit, scanning
  - Docker Dashboard for visually managing all your container content
  - A simple one click installer for Mac and Windows

Docker main components

- **Docker containers**: Isolated user-space environments running the same or different applications and sharing the same host OS kernel. Containers are created from Docker images.
- **Docker images**: Docker templates that include application libraries and applications. Images are used to create containers and you can bring up containers immediately. You can create and update your own custom images as well as download build images from Docker's public registry.
- **Docker registries**: This is an images store. Docker registries can be public or private, meaning that you can work with images available over the internet or create your own registry for internal purposes. One popular public Docker registry is Docker Hub.

What is a docker registry?

A Docker registry is a **storage and distribution system** for named Docker images.

The same image might have multiple different versions, identified by their **tags**.

A Docker registry is organized into **Docker repositories** , where a repository holds all the versions of a specific image.

The registry allows Docker users to pull images locally, as well as push new images to the registry (given adequate access permissions when applicable).

By default, the Docker engine interacts with DockerHub, Docker's public registry instance.

Private registries

Use cases for running a private registry on-premise (internal to the organization) include:

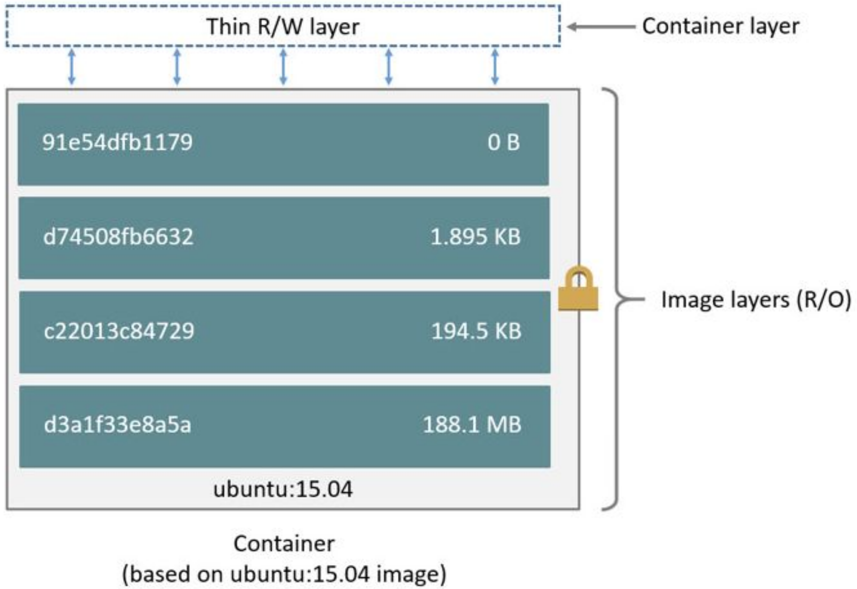
- **Distributing images inside an isolated network** (not sending images over the Internet)
- **Creating faster CI/CD pipelines** (pulling and pushing images from internal network), including faster deployments to on-premise environments
- **Deploying a new image over a large cluster of machines**
- **Tightly controlling where images are being stored**

Private registries: some open-source implementations

- Docker Registry is a stateless, highly scalable server side application that stores and lets you distribute Docker images .
- GitLab Container Registry is tightly integrated with GitLab CI's workflow, with minimal setup.
  - INFN SSNN provide a container registry as part of the platform baltig.infn.it based on GitLab
- Harbor (CNCF Graduated project) is an open source registry that secures artifacts with policies and role-based access control, ensures images are scanned and free from vulnerabilities, and signs images as trusted.
  - INFN Cloud has implemented a docker registry based on Harbor: https://harbor.cloud.infn.it/
- JFrog Container Registry supporting Docker containers and Helm Chart repositories for Kubernetes deployments.

Docker image layers

- A Docker Image consists of read-only layers built on top of each other.
- Docker uses the **Union File System** (UFS) to build an image.
- The image is shared across containers.
- Each time Docker launches a container from an image, it adds a thin writable layer, known as the container layer, which stores all changes to the container throughout its runtime.

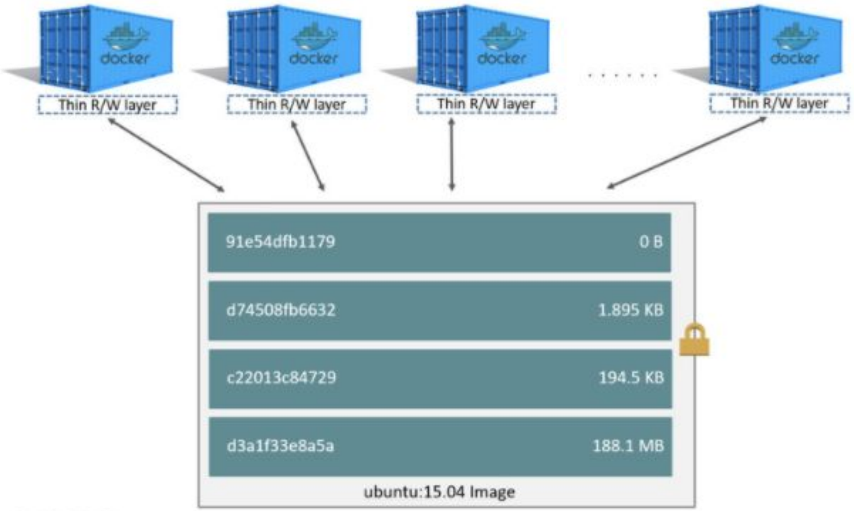


Docker image vs container

Each container has its own writable container layer, and all changes are stored in this container layer.

Multiple containers can share access to the same underlying image and yet have their own data state.

When the container is deleted, the writable layer is also deleted. The underlying image remains unchanged.



Copy-On-Write mechanism

COW is a standard UNIX pattern that provides a single shared copy of some data until the data is modified.

Docker makes use of copy-on-write technology with both images and containers. This **CoW strategy optimizes both image disk space usage and the performance of container start times**. At start time, Docker only has to create the thin writable layer for each container.

Containers that write a lot of data consume more space than containers that do not. This is because most write operations consume new space in the container's thin writable top layer.

Note: for write-heavy applications, you should not store the data in the container. Instead, use Docker volumes, which are independent of the running container and are designed to be efficient for I/O. In addition, volumes can be shared among containers and do not increase the size of your container's writable layer. (Source: Docker docs)

Docker storage drivers

Storage drivers allow you to create data in the **writable layer** of your container. The files **won't be persisted** after the container is deleted, and both read and write speeds are **lower** than native file system performance.

Docker supports the following storage drivers:

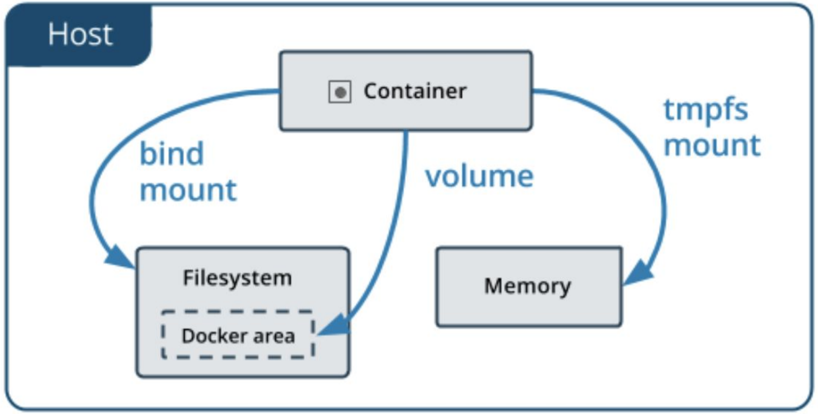
- ***overlay2*** is the preferred storage driver, for all currently supported Linux distributions, and requires no extra configuration.
- ***aufs*** was the preferred storage driver for Docker 18.06 and older, when running on Ubuntu 14.04 on kernel 3.13 which had no support for overlay2.
- ***fuse-overlayfs*** is preferred only for running Rootless Docker on a host that does not provide support for rootless overlay2. On Ubuntu and Debian 10, the fuse-overlayfs driver does not need to be used as overlay2 works even in rootless mode.
- ***devicemapper*** is supported, but requires direct-lvm for production environments, because loopback-lvm, while zero-configuration, has very poor performance. devicemapper was the recommended storage driver for CentOS and RHEL, as their kernel version did not support overlay2. However, current versions of CentOS and RHEL now have support for overlay2, which is now the recommended driver.
- The ***btrfs*** and ***zfs*** storage drivers are used if they are the backing filesystem (the filesystem of the host on which Docker is installed). These filesystems allow for advanced options, such as creating "snapshots", but require more maintenance and setup. Each of these relies on the backing filesystem being configured correctly.
- The ***vfs*** storage driver is intended for testing purposes, and for situations where no copy-on-write filesystem can be used. Performance of this storage driver is poor, and is not generally recommended for production use.

More info at https://docs.docker.com/storage/storagedriver/select-storage-driver/

Persist data with volumes

Docker provides the following options for containers to store files in the host machine, so that the files are persisted even after the container stops

- volumes
- bind mounts
- tmpfs



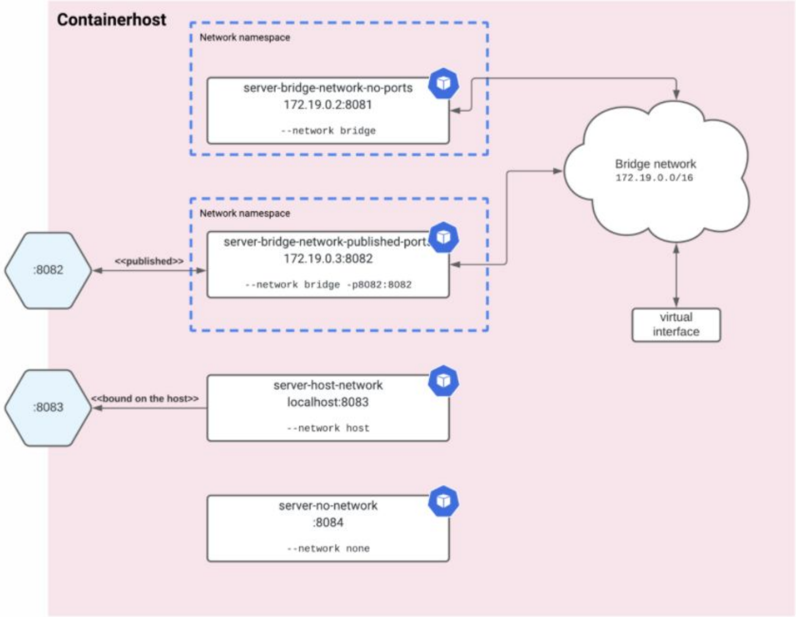
- **volumes** are stored in a part of the host filesystem which is **managed by Docker** (/var/lib/docker/volumes/ on Linux). Non-Docker processes should not modify this part of the filesystem. Volumes are the best way to persist data in Docker.
- **bind mounts** may be stored **anywhere on the host system**. They may even be important system files or directories. Non-Docker processes on the Docker host or a Docker container can modify them at any time.
- **tmpfs** mounts are stored in the host system's memory only, and are never written to the host system's filesystem

Docker networking

A network in Docker is another logical object like a container and image.

By default Docker has the following networking drivers:

- **bridge**: the default networking driver in Docker. This can be used when multiple containers are running in standard mode and need to communicate with each other
- **host**: removes the network isolation completely. Any container running under a host network is basically attached to the network of the host system. Host mode networking can be useful to optimize performance, and in situations where a container needs to handle a large range of ports, as it does not require network address translation (NAT), and no “userland-proxy” is created for each port
- **none**: this driver disables networking for containers altogether
- **overlay**: this is used for connecting multiple Docker daemons across computers
- **macvlan**: it allows assignment of MAC addresses to containers, making them function like physical devices in a network
- **ipvlan**: similar to macvlan, the key difference being that the endpoints have the same MAC address.



Docker cli

$ docker help

```
Usage:  docker [OPTIONS] COMMAND

A self-sufficient runtime for containers

Options:
      --config string      Location of client config files (default "/home/tutor1/.docker")
  -c, --context string     Name of the context to use to connect to the daemon (overrides DOCKER_HOST env var and default context set with "docker context use")
  -D, --debug              Enable debug mode
  -H, --host list          Daemon socket(s) to connect to
  -l, --log-level string   Set the logging level ("debug"|"info"|"warn"|"error"|"fatal") (default "info")
      --tls                Use TLS; implied by --tlsverify
      --tlscacert string   Trust certs signed only by this CA (default "/home/tutor1/.docker/ca.pem")
      --tlscert string     Path to TLS certificate file (default "/home/tutor1/.docker/cert.pem")
      --tlskey string      Path to TLS key file (default "/home/tutor1/.docker/key.pem")
      --tlsverify          Use TLS and verify the remote
  -v, --version            Print version information and quit

Management Commands:
  app*        Docker App (Docker Inc., v0.9.1-beta3)
  builder     Manage builds
  buildx*     Build with BuildKit (Docker Inc., v0.5.1-docker)
  config      Manage Docker configs
  container   Manage containers
  context     Manage contexts
  image       Manage images
  manifest    Manage Docker image manifests and manifest lists
  network     Manage networks
  node        Manage Swarm nodes
  plugin      Manage plugins
  scan*       Docker Scan (Docker Inc., v0.7.0)
  secret      Manage Docker secrets
  service     Manage services
  stack       Manage Docker stacks
  swarm       Manage Swarm
  system      Manage Docker
  trust       Manage trust on Docker images
  volume      Manage volumes
```

https://docs.docker.com/engine/reference/commandline/cli/

Commands to manage docker objects

```
Usage:  docker container COMMAND

Manage containers

Commands:
  attach      Attach local standard input, output, and error streams to a running container
  commit      Create a new image from a container's changes
  cp          Copy files/folders between a container and the local filesystem
  create      Create a new container
  diff        Inspect changes to files or directories on a container's filesystem
  exec        Run a command in a running container
  export      Export a container's filesystem as a tar archive
  inspect     Display detailed information on one or more containers
  kill        Kill one or more running containers
  logs        Fetch the logs of a container
  ls          List containers
  pause       Pause all processes within one or more containers
  port        List port mappings or a specific mapping for the container
  prune       Remove all stopped containers
  rename      Rename a container
  restart     Restart one or more containers
  rm          Remove one or more containers
  run         Run a command in a new container
  start       Start one or more stopped containers
  stats       Display a live stream of container(s) resource usage statistics
  stop        Stop one or more running containers
  top         Display the running processes of a container
  unpause     Unpause all processes within one or more containers
  update      Update configuration of one or more containers
  wait        Block until one or more containers stop, then print their exit codes
```

```
Usage:  docker image COMMAND

Manage images

Commands:
  build       Build an image from a Dockerfile
  history     Show the history of an image
  import      Import the contents from a tarball to create a filesystem image
  inspect     Display detailed information on one or more images
  load        Load an image from a tar archive or STDIN
  ls          List images
  prune       Remove unused images
  pull        Pull an image or a repository from a registry
  push        Push an image or a repository to a registry
  rm          Remove one or more images
  save        Save one or more images to a tar archive (streamed to STDOUT by default)
  tag         Create a tag TARGET_IMAGE that refers to SOURCE_IMAGE
```

```
Usage:  docker volume COMMAND

Manage volumes

Commands:
  create      Create a volume
  inspect     Display detailed information on one or more volumes
  ls          List volumes
  prune       Remove all unused local volumes
  rm          Remove one or more volumes
```

```
Usage:  docker network COMMAND

Manage networks

Commands:
  connect     Connect a container to a network
  create      Create a network
  disconnect  Disconnect a container from a network
  inspect     Display detailed information on one or more networks
  ls          List networks
  prune       Remove all unused networks
  rm          Remove one or more networks
```

Miscellaneous commands

- `docker ps`: list running containers
    - -a to list also stopped containers
    - -s to show container sizes
- `docker stats`: display container(s) usage statistics
- `docker system df`: show docker disk usage
- `docker system prune`: remove unused data

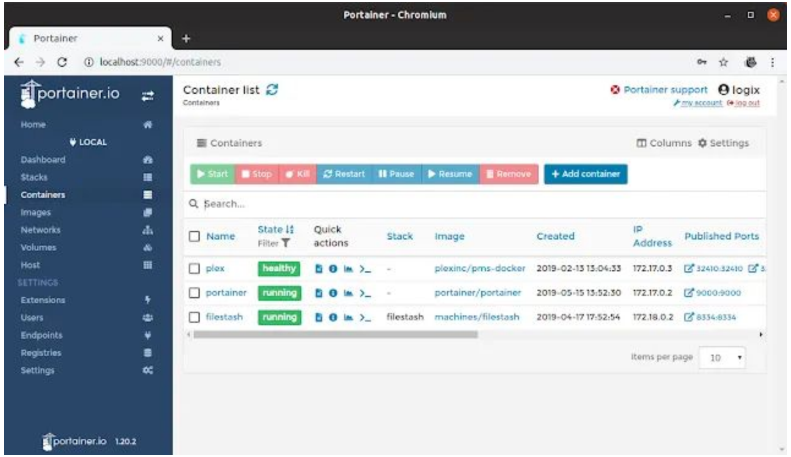
Docker Graphical Interface

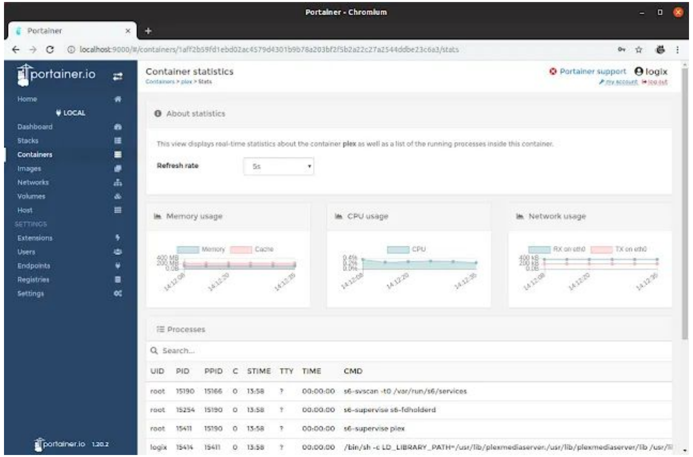
Portainer is a lightweight management UI which allows you to easily manage your different Docker environments.

The tool, which is compatible with the standalone Docker engine, Docker Swarm, Nomad and Kubernetes, is simple to both use and deploy, being available as a Docker container itself. It can be used both on the local machine as well as a remote Docker GUI.

Portainer allows you to manage all your Docker resources (containers, images, volumes, networks and more)

For more details: https://docs.portainer.io/





Docker alternatives

One of the drawbacks of Docker is that the Docker engine requires root privileges to run containers.

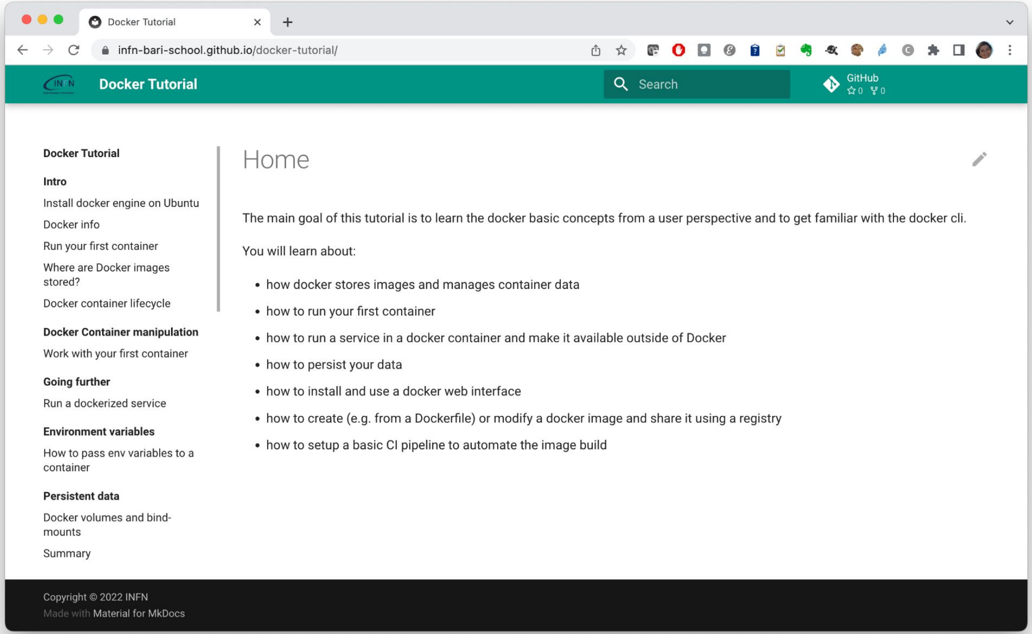
udocker is an open source project and provides the same basic functionality the Docker engine does but without root privileges.

> It works by creating a chroot-like environment over the extracted container and uses various implementation strategies to mimic chroot execution with just user-level privileges. One of the execution environments you can use is runC, the same one used by Docker.

Podman is a daemon-less, open-source, Linux-native container engine developed by RedHat, that is used to build, run and manage Linux OCI containers and container images. Containers can either be run as root or in rootless mode

Docker Hands-on#1

https://infn-bari-school.github.io/docker-tutorial/



References & credits

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https://medium.com/zero-equals-false/docker-introduction-what-you-need-to-know-to-start-creating-containers-8ffaf064930a

http://100daysofdevops.com/21-days-of-docker-day-21/

https://awesome-docker.netlify.app/