Inria

INVENTORS FOR THE DIGITAL WORLD

Introduction to Containerization with docker

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A bit of context

The big questions

For administrators and packagers:

- How to ensure an application will work (nearly) everywhere ?
- How to avoid it messing with my system ?
- How to isolate the various components of my application ?

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For administrators and packagers:

- How to ensure an application will work (nearly) everywhere ?
- How to avoid it messing with my system ?
- How to isolate the various components of my application ?

For developers:

- How to ensure everybody has the same build environment ?
- How to provide a sample to reproduce a bug ?

The Concept of Container

Concept of *Containerization* from freight transport

Transport

Isolation

The Concept of Container

Concept of *Containerization* from freight transport

Transport

- can be (un-)loaded/stacked efficiently
- can be loaded on ships, trains, trucks, . . .
- can be handled without being opened

Isolation

- OpenContainer Runtime Specification

The Concept of Container

Concept of *Containerization* from freight transport

Transport

Isolation

- can be (un-)loaded/stacked efficiently
- can be loaded on ships, trains, trucks, . . .
- can be handled without being opened

}

- OpenContainer Runtime Specification

- are tracked with an identification number
- have ISO-standard sizes (5 classes)

}

- OpenContainer Image Specification

A history of Isolation

1979	`chroot` (Version 7 Unix)
2000	`jail` (FreeBSD 4.0)
2005	Solaris Containers: *“chroot on steroids”* (Solaris 10)

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2013/02	User Namespaces (Linux Kernel 3.8)

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2015/06	Open Container Initiative (by Docker)

A history of Isolation

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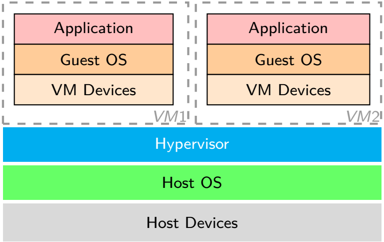
2015/06 Open Container Initiative (by Docker)

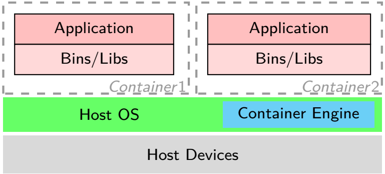
2016/04 Singularity (HPC-oriented)

Virtualization vs. Containerization

Type II Virtual Machine



Containerization



- Ability to run different kernel/OS
- Possibility to attach some of host devices

- Shared Kernel, handling isolation
- Kernel-handled virtual devices (network)

Different targets, different advantages

Virtualization

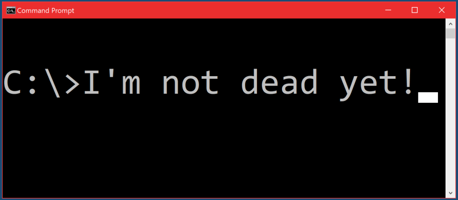
- Best isolation from the host
- Fine tuned resource quota
- Runs any guest OS
- Lots of management tools

Containerization

- Good enough isolation
- Benefit from kernel optimizations & quota
- Very low footprint
- Ease of use

Agenda

1. A bit of context (we just did it)
2. Docker:
   - Playing with `docker`
   - Docker images & registry
   - Docker compositions
   - Security (kind of)
3. Singularity
   - Short introduction to `singularity`
   - Singularity vs. Docker
4. Miscellaneous & Bonus (if you're good ☺)



```
C:\>I'm not dead yet!_
```

2

Playing with docker

Because nothing beats the command line

Warm up

- Check if `docker` works:
  - `docker info`
  - `docker run hello-world`
- If it fails...
  - Check if `docker` is installed (`docker-ce` package)
    - docs.docker.com/install/linux/docker-ce/debian/
  - Check if your user is in the `docker` group:

    ```
    groups | grep docker
    ```
  - If not:
    - Add yourself in: `sudo gpasswd -a $USER docker`
    - Restart your session (terminal won't be enough)

Docker on a Linux system

- On your machine:
  - Docker storage: `/var/lib/docker`
    - Only `root` can access this folder
    - Contains images, volumes and containers storage

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    - Only `root` and the `docker` group can access it
    - Default & recommended access to the local Docker Daemon

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    - Only `root` and the `docker` group can access it
    - Default & recommended access to the local Docker Daemon
- Docker can access remote locations:
  - Docker Daemon:
    - Docker official registry: Docker Hub
    - Private registries
  - Docker CLI
    - Manage a remote daemon via TCP/TLS
    - Manage a Docker Swarm

Hands on: Running a container

- `docker run debian`

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- `docker run -it --name MyContainer debian`

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  - Starts a container based on the **debian** image
  - No `stdin`, so `bash` exits immediately (end of file)
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- `docker run debian`
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- `docker run -it --name MyContainer debian`
  - `-i`: interactive mode (with `stdin`, `stdout`, `stderr`)
  - `-t`: with a valid TTY (screen size, coloration, . . .)
  - `--name`: Set a name to ease management (unique per host)

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- `docker ps`
  - Prints the list of active containers

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- `docker ps -a`
  - Prints the list of active containers
  - `-a`: also shows stopped containers

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- `docker ps -a`
  - Prints the list of active containers
  - -a: also shows stopped containers
- `docker rm    <CID/name>`
  - Removes a stopped container

Hands on: Running a container

- `docker run debian`
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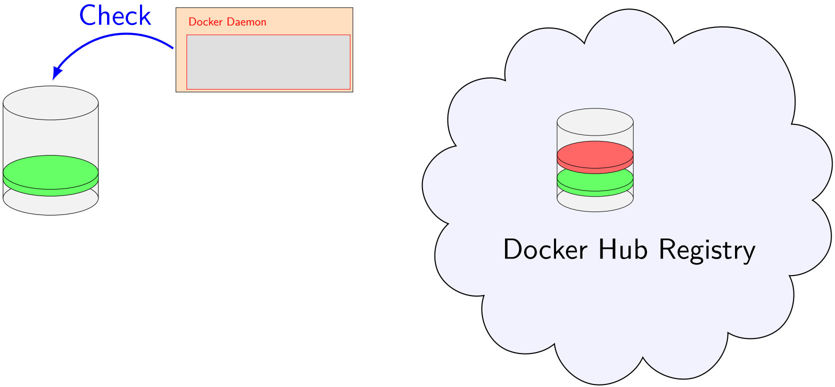
  - `--name`: Set a name to ease management (unique per host)

- `docker ps -a`
  - Prints the list of active containers
  - `-a`: also shows stopped containers

- `docker rm -f <CID/name>`
  - Removes a stopped container
  - `-f` stops the container if necessary

Docker Registry: local cache and registry

```
docker run debian ...
```



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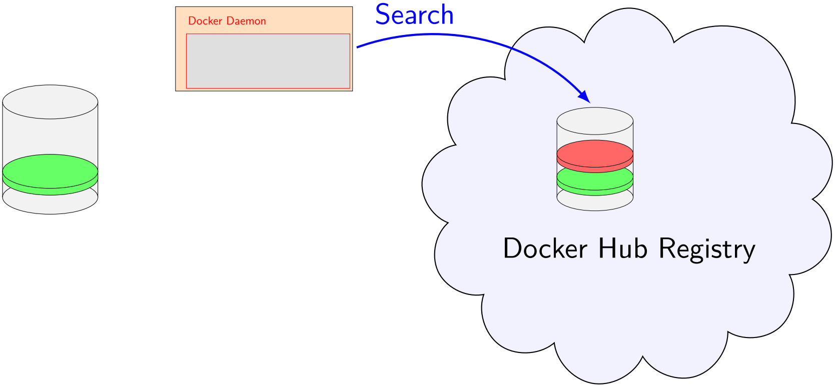

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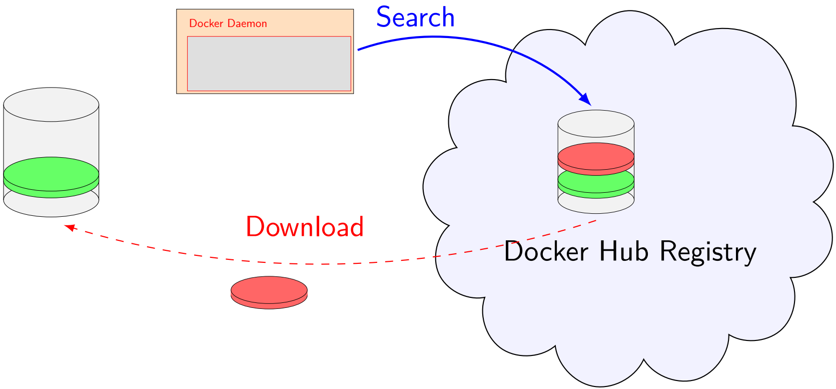
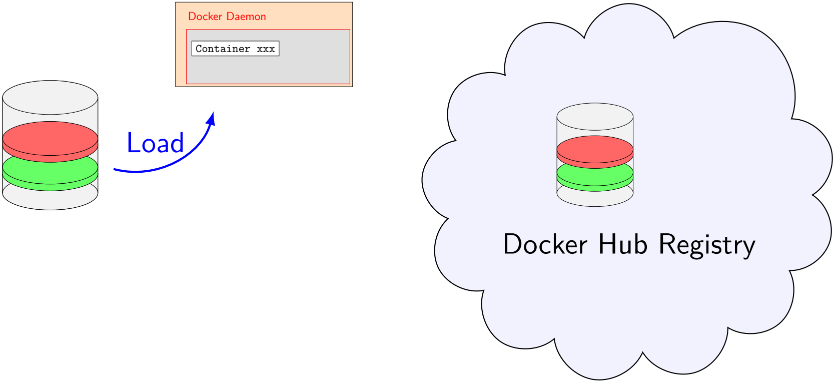


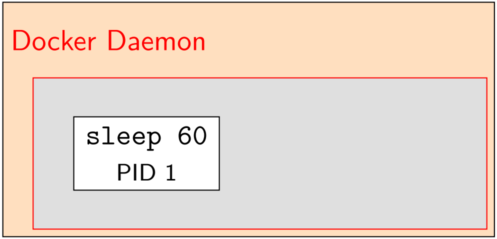
Docker Registry: local cache and registry

`docker run debian ...`



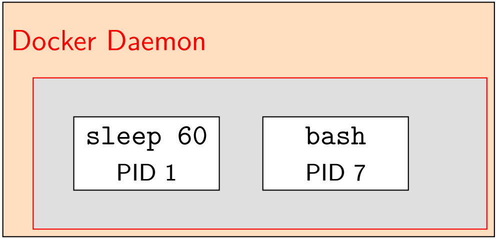
Running inside a container

- `docker run --name MyContainer -d debian sleep 60`
  - The container is started *detached* (`-d`)

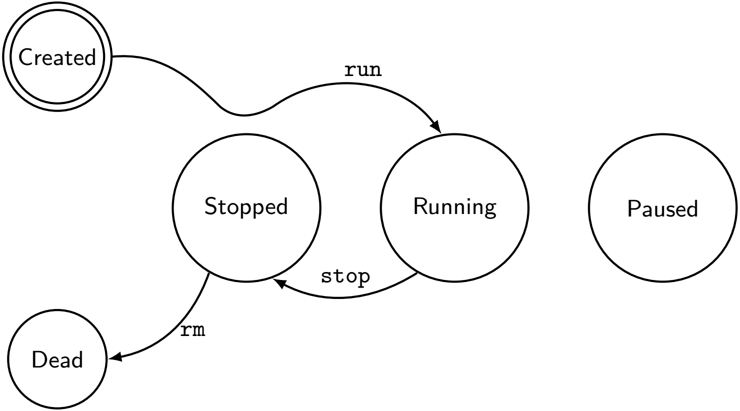


Running inside a container

- `docker run --name MyContainer -d debian sleep 60`
  - The container is started *detached* (`-d`)
- `docker exec -it MyContainer bash`
  - Starts a new `bash` process in the container



Container life cycle



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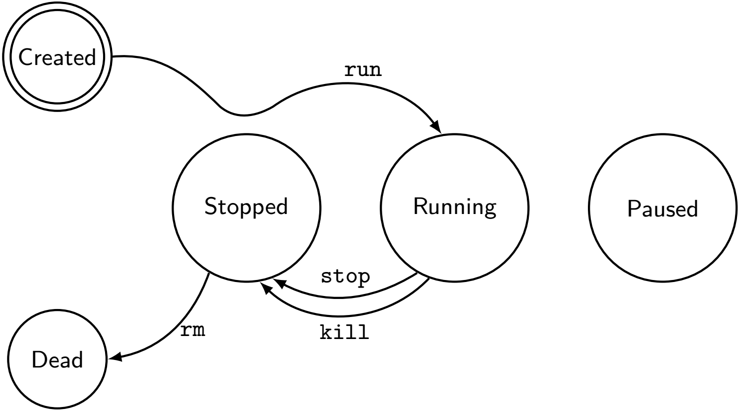

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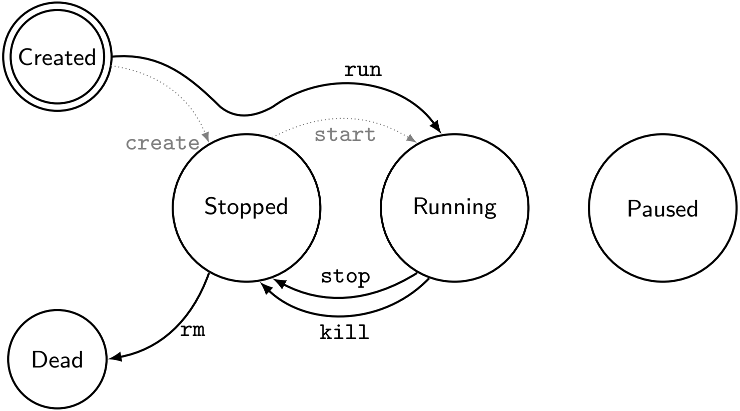

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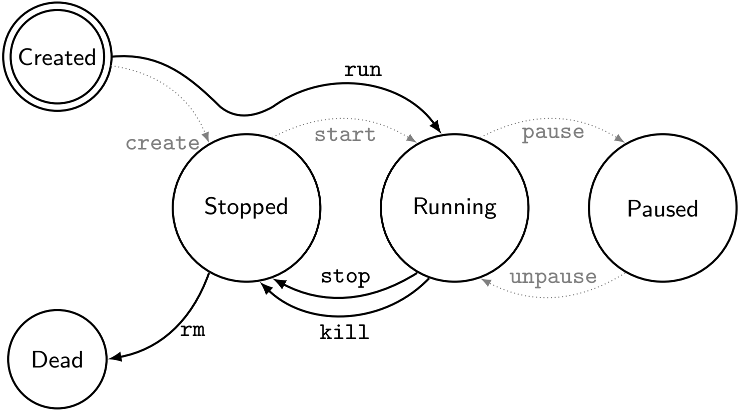

A word on life cycle

- Container file system is set up before the initial state (`created`)
  - It is cleaned up when going to the `Dead` state (with `rm`)
  - It is persistent across `stop`/`start`/`pause` operations
- The `kill` command sends a `SIGKILL` to the contained executable
- When running without a TTY, signals aren't forwarded
  - They are handled by the `docker` command, not by the contained executable
  - A `SIGINT` will therefore end the container with a `SIGKILL`

A journey through Docker Commands (1/6)

Step 1 (Host)	Start a new container: `docker run -it ubuntu bash`

A journey through Docker Commands (1/6)

Step 1 (Host)

Start a new container:

```
docker run -it ubuntu bash
```

Step 2 (Docker)

Create a file in the container:

```
echo "Hello, World" > /root/greetings.txt
```

A journey through Docker Commands (1/6)

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Start a new container:

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docker run -it ubuntu bash
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Create a file in the container:

```
echo "Hello, World" > /root/greetings.txt
```

Step 3 (Docker)

Print the hostname of the container (its ID):

```
hostname
```

A journey through Docker Commands (1/6)

Step 1 (Host)

Start a new container:

```
docker run -it ubuntu bash
```

Step 2 (Docker)

Create a file in the container:

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echo "Hello, World" > /root/greetings.txt
```

Step 3 (Docker)

Print the hostname of the container (its ID):

```
hostname
```

Step 4 (Docker)

Detach from the container:

Press `Ctrl+P` `Ctrl+Q`

Step 5 (Host)

Keep track the Container ID:

```
CID="ID_obtained_in_step_3"
```

A journey through Docker Commands (2/6)

Step 6 (Host)

Copy the file from the container:

```
docker cp ${CID}:/root/greetings.txt \
greetings.txt
```

A journey through Docker Commands (2/6)

Step 6 (Host) Copy the file from the container:

```
docker cp ${CID}:/root/greetings.txt \
greetings.txt
```

Step 7 (Host) Edit/create a file on the host:

```
echo "Hello from host" > host.txt
```

A journey through Docker Commands (2/6)

Step 6 (Host)

Copy the file from the container:

```
docker cp ${CID}:/root/greetings.txt \
greetings.txt
```

Step 7 (Host)

Edit/create a file on the host:

```
echo "Hello from host" > host.txt
```

Step 8 (Host)

Send the file to the container:

```
docker cp host.txt ${CID}:/root/host.txt
```

A journey through Docker Commands (3/6)

Step 9
(Host)

Reconnect the container:

```
docker attach $CID
```

Step 10
(Docker)

Check the new file:

```
cat /root/host.txt
```

A journey through Docker Commands (3/6)

Step 9 (Host)

Reconnect the container:

```
docker attach $CID
```

Step 10 (Docker)

Check the new file:

```
cat /root/host.txt
```

Step 11 (Docker)

Re-detach the container (`Ctrl+P Ctrl+Q`)

A journey through Docker Commands (4/6)

Step 12 (Host)	List the modified files: `docker diff $CID`

A journey through Docker Commands (4/6)

Step 12 (Host)

List the modified files:

```
docker diff $CID
```

Step 13 (Host)

Look what has been written to `stdout/stderr`:

```
docker logs $CID
```

A journey through Docker Commands (4/6)

Step 12 (Host)

List the modified files:

```
docker diff $CID
```

Step 13 (Host)

Look what has been written to `stdout/stderr`:

```
docker logs $CID
```

Step 14 (Host)

Export the content:

```
docker export --output content.tar $CID
```

A journey through Docker Commands (5/6)

Step 15 (Host) Execute a detached process:

```
docker exec -d $CID sleep 1h
```

A journey through Docker Commands (5/6)

Step 15 (Host)

Execute a detached process:

```
docker exec -d $CID sleep 1h
```

Step 16 (Host)

View running processes:

```
docker exec $CID ps aux
```

A journey through Docker Commands (5/6)

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Execute a detached process:

```
docker exec -d $CID sleep 1h
```

Step 16 (Host)

View running processes:

```
docker exec $CID ps aux
docker top $CID
```

A journey through Docker Commands (5/6)

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Execute a detached process:

```
docker exec -d $CID sleep 1h
```

Step 16 (Host)

View running processes:

```
docker exec $CID ps aux
docker top $CID aux
ps aux
```

A journey through Docker Commands (5/6)

Step 15 (Host)

Execute a detached process:

```
docker exec -d $CID sleep 1h
```

Step 16 (Host)

View running processes:

```
docker exec $CID ps aux
docker top $CID aux
ps aux
```

Step 17 (Host)

Execute an interactive process:

```
docker exec -it $CID bash
```

A journey through Docker Commands (6/6)

Step 18 (Host)

Stop the container (from the host):

```
docker stop $CID
```

A journey through Docker Commands (6/6)

Step 18 (Host)
Stop the container (from the host):

```
docker stop $CID
```

Step 19 (Host)
See reclaimable space:

```
docker system df
```

A journey through Docker Commands (6/6)

Step 18 (Host)

Stop the container (from the host):

```
docker stop $CID
```

Step 19 (Host)

See reclaimable space:

```
docker system df
```

Step 20 (Host)

Clean up:

```
docker container prune
docker volume prune
docker image prune
```

A journey through Docker Commands (6/6)

Step 18 (Host)

Stop the container (from the host):

```
docker stop $CID
```

Step 19 (Host)

See reclaimable space:

```
docker system df
```

Step 20 (Host)

Clean up:

```
docker container prune
docker volume prune
docker image prune
```

All in one:

```
docker system prune
```

Last but not least

Step 21 (Host)

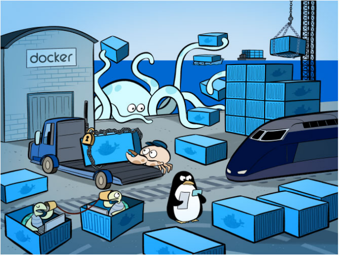
Run a container and wait for it to finish:

```
CID1=$(docker run -d debian sleep 60)
CID2=$(docker run -d debian sleep 10)
docker wait $CID1 $CID2
```

Before we go...

Let Docker download images in background
(this can last some minutes)

```
docker pull python:3.7
docker pull registry:2
docker pull nginx
docker pull hyper/docker-registry-web
```

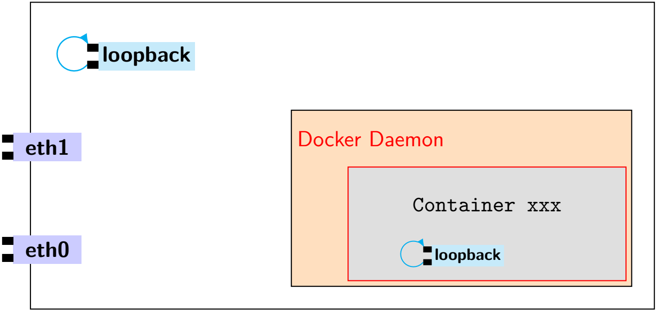


3 Basic interaction with the host

Network & Files

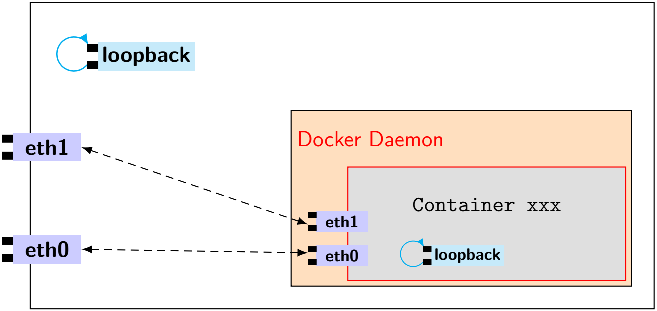
Docker default network configuration – `none`

`none` No network stack but `loopback`



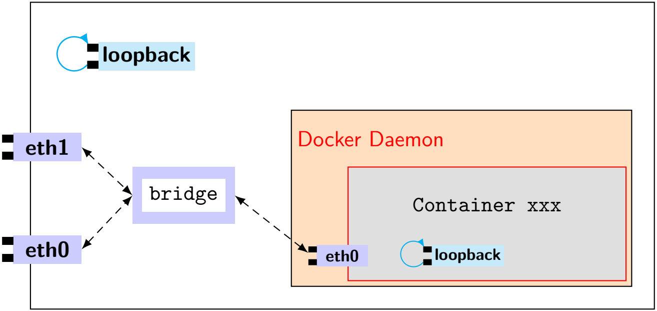
Docker default network configuration – `host`

`host` Host's network interfaces



Docker default network configuration – `bridge`

`bridge` Virtual switch handled by Docker (default behavior)



Docker networks – all configurations

- Kinds of networks:

`none`	No network stack but `loopback`	
`host`	Host's network interfaces	
`bridge`	Virtual switch handled by Docker	(**default**)
`overlay`	A `bridge` network across hosts	(*Swarm only*)

- Custom networks:
  - `docker network create -d bridge my-net --subnet 10.0.5.0/24`
  - Only of type `bridge`, `overlay` or from a plugged-in type

- Multiple networks can be attached to a container

Docker networks – command setup

- Run a `debian` image with a specific network:
  - `docker run --rm -it debian ip addr`

Docker networks – command setup

- Run a debian image with a specific network:
  - `docker run --rm -it --network bridge debian ip addr`

Docker networks – command setup

- Run a `debian` image with a specific network:
  - `docker run --rm -it --network bridge debian ip addr`
    - Loopback and private IP
    - Access to external network (through the bridge to host's networks)

Docker networks – command setup

- Run a `debian` image with a specific network:
  - `docker run --rm -it --network bridge debian ip addr`
    - Loopback and private IP
    - Access to external network (through the bridge to host's networks)
  - `docker run --rm -it --network host debian ip addr`

Docker networks – command setup

- Run a `debian` image with a specific network:
  - `docker run --rm -it --network bridge debian ip addr`
    - Loopback and private IP
    - Access to external network (through the bridge to host's networks)
  - `docker run --rm -it --network host debian ip addr`
    - Loopback and host's IPs
    - Direct access to host's network interfaces

Docker networks – command setup

- Run a `debian` image with a specific network:
  - `docker run --rm -it --network bridge debian ip addr`
    - Loopback and private IP
    - Access to external network (through the bridge to host's networks)
  - `docker run --rm -it --network host debian ip addr`
    - Loopback and host's IPs
    - Direct access to host's network interfaces
  - `docker run --rm -it --network none debian ip addr`
    - Loopback only
    - No access to the outside world nor to the host

Publish a port: command line

- `-p`, `--publish`: gives access to a container port from the outside

`-p CC`	Host random port	⇒	Container port `CC`
`-p HH:CC`	Host port `HH`	⇒	Container port `CC`
`-p IP:HH:CC`	Same, but bound to host address IP		

Publish a port: example

- Run an nginx image:

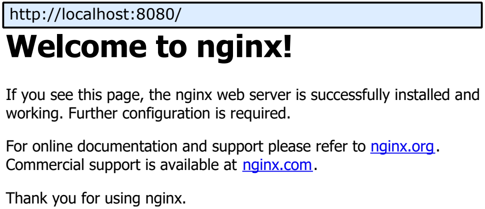
  ```
  docker run --rm -it -p 8080:80 nginx
  ```

Publish a port: example

- Run an `nginx` image:
  `docker run --rm -it -p 8080:80 nginx`
  - Server available on `http://localhost:8080/`
  - Also from the host interfaces, if the firewall allows it

Publish a port: example

- Run an `nginx` image:
  `docker run --rm -it -p 8080:80 nginx`
  - Server available on `http://localhost:8080/`
  - Also from the host interfaces, if the firewall allows it



http://localhost:8080/

Welcome to nginx!

If you see this page, the nginx web server is successfully installed and working. Further configuration is required.

For online documentation and support please refer to nginx.org.
Commercial support is available at nginx.com.

Thank you for using nginx.

Figure: `nginx` is up & running

Docker volumes: command line

- `-v`, `--volume`: defines a new volume

Docker volumes: command line

- `-v`, `--volume`: defines a new volume
- `docker run -v /host/path:/path ...`
  - Mounts a *bound* volume to `/path`
  - Also support a final `:ro` flag, to bind a read-only volume: `docker run -v /host/path:/path:ro ...`

Docker volumes: command line

- `-v`, `--volume`: defines a new volume
- `docker run -v /host/path:/path ...`
  - Mounts a *bound* volume to `/path`
  - Also support a final `:ro` flag, to bind a read-only volume: `docker run -v /host/path:/path:ro ...`
- `docker run -v /path ...`
  - Creates a *data* volume for the `/path` folder
  - Volume will be kept even if the container is deleted
  - It will be visible in `docker volume ls`
  - It can be mounted as a named volume on another container

Docker volumes: example

On the host, in a new folder:

- Create a simple HTML page: `./www/index.html`

```html
<html>
<body><h1>Hello World, from Docker</h1></body>
</html>
```

- Create an `nginx` configuration: `./site.conf`

```
server {
    listen 80;
    root /www;
    autoindex on;
}
```

- Source files available on:

`http://sed.inrialpes.fr/docker-tuto/index_dockersingularity.html`

Docker volumes: example

- Run the container with the following volumes:
  - `./site.conf` ⇒ `/etc/nginx/conf.d/default.conf`
  - `./www/` ⇒ `/www`

Docker volumes: example

- Run the container with the following volumes:
  - ./site.conf ⇒ /etc/nginx/conf.d/default.conf
  - ./www/ ⇒ /www

```
docker run --rm \
  -p 8080:80 \
  -v $(pwd)/site.conf:/etc/nginx/conf.d/default.conf \
  -v $(pwd)/www:/www \
  nginx
```

Docker volumes: plug-ins

- Docker can be extended with Volume Drivers
- Example: the NetShare.io plug-in
  - Plug-in to be installed separately;
    see `http://netshare.containx.io/`
  - Gives access to NFS & CIFS shared folders as volumes

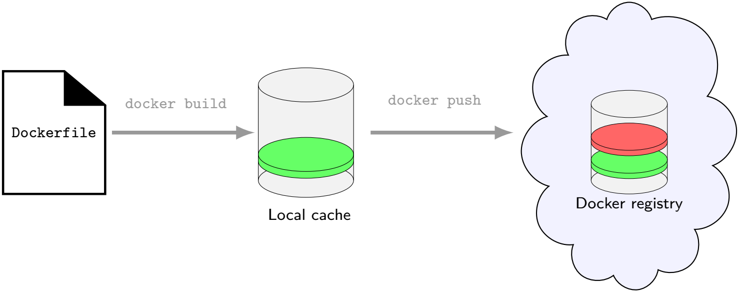
-
  ```
  docker volume create -d nfs --name shared-data \
      -o share=nfs-server:/shared/path
  ```
  - Creates a *named volume* with the NetShare driver
  - NetShare accepts `fstab` options as configuration
-
  ```
  docker run -v shared-data:/path ...
  ```

4
Create a Docker image

Bring your own container

Principles

`Dockerfile`	File describing how the image is built
`docker build`	Command line to build the `Dockerfile`
Local cache	Local image store
`docker push`	Command line to send the image to a registry
Docker registry	Image store (public or private)



Dockerfile: Jupyter notebook service

- Objective:
  - Provide a Jupyter notebook within a simple user workspace
- Required environment:
  - Python 3.7 (because we want to try its latest features)
  - Jupyter, to work with notebooks
  - A non-root user (`karadoc`)

Dockerfile: Jupyter notebook service

- Objective:
  - Provide a Jupyter notebook within a simple user workspace
- Required environment:
  - Python 3.7 (because we want to try its latest features)
  - Jupyter, to work with notebooks
  - A non-root user (`karadoc`)
- `Dockerfile` is available at:

  `http://sed.inrialpes.fr/docker-tuto/index_dockersingularity.html`

Dockerfile: Jupyter notebook service

```
FROM python:3.7
```

Parent image

Name:	Python (official)
Tag:	3.7

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"
```

Meta information

- Maintainer, version, . . .
- Visible in `docker inspect`

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"

# Ensure a sane environment
ENV LANG=C.UTF-8 LC_ALL=C.UTF-8
```

Environment variables

- Set for the whole container
- Can’t reference current line

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"

# Ensure a sane environment
ENV LANG=C.UTF-8 LC_ALL=C.UTF-8

# Update the image & install some tools
RUN apt update && apt -y dist-upgrade && \
    pip --no-cache-dir install jupyter
```

Dependencies setup

- Update the system first
- Install only what's necessary
- Regroup install commands
- Clean up caches immediately

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"

# Ensure a sane environment
ENV LANG=C.UTF-8 LC_ALL=C.UTF-8

# Update the image & install some tools
RUN apt update && apt -y dist-upgrade && \
    pip --no-cache-dir install jupyter

# Set arguments
ARG user=karadoc
ARG home=/kaamelott/kitchen
# Create the user and its directory
RUN mkdir -p $home && \
    useradd $user --home-dir $home && \
    chown -R $user: $home
```

Create the user and its directory

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"

# Ensure a sane environment
ENV LANG=C.UTF-8 LC_ALL=C.UTF-8

# Update the image & install some tools
RUN apt update && apt -y dist-upgrade && \
    pip --no-cache-dir install jupyter

# Set arguments
ARG user=karadoc
ARG home=/kaamelott/kitchen
# Create the user and its directory
RUN mkdir -p $home && \
    useradd $user --home-dir $home && \
    chown -R $user: $home


# Switch to the new user
USER $user
# Change working directory
RUN mkdir $home/notebooks
WORKDIR $home/notebooks
```

Switch to the new user

- Only a new `USER` command can switch back to `root`

Dockerfile: Jupyter notebook service

```
FROM python:3.7
LABEL maintainer="SED RA <sed-gra@inria.fr>"

# Ensure a sane environment
ENV LANG=C.UTF-8 LC_ALL=C.UTF-8

# Update the image & install some tools
RUN apt update && apt -y dist-upgrade && \
    pip --no-cache-dir install jupyter

# Set arguments
ARG user=karadoc
ARG home=/kaamelott/kitchen
# Create the user and its directory
RUN mkdir -p $home && \
    useradd $user --home-dir $home && \
    chown -R $user: $home


# Switch to the new user
USER $user
# Change working directory
RUN mkdir $home/notebooks
WORKDIR $home/notebooks


# Set the default entry point & arguments
ENTRYPOINT ["jupyter", "notebook", "--no-browser"]
CMD ["--port=8888", "--ip=’*’",  "--NotebookApp.token=’’"]
```

Run commands as user

- Set default program and arguments

Dockerfile: Build an image

Step 1 Download the Dockerfile:

`http://sed.inrialpes.fr/docker-tuto/docker/Dockerfile`

Dockerfile: Build an image

Step 1 Download the Dockerfile:

```
http://sed.inrialpes.fr/docker-tuto/docker/Dockerfile
```

Step 2 Build the image:

```
docker build -t aubergiste .
```

Dockerfile: Build an image

Step 1 Download the Dockerfile:

```
http://sed.inrialpes.fr/docker-tuto/docker/Dockerfile
```

Step 2 Build the image:

```
docker build -t aubergiste .
```

- tag (name) of the image

Dockerfile: Build an image

Step 1 Download the Dockerfile:

```
http://sed.inrialpes.fr/docker-tuto/docker/Dockerfile
```

Step 2 Build the image:

```
docker build -t aubergiste .
```

- tag (name) of the image
- context: folder where to find files referenced in `Dockerfile`

Dockerfile: Build an image

Step 3 Run it :

```
docker run --rm -it -p 8888:8888 aubergiste
```

Launch a browser on host : `http://localhost:8888`

Dockerfile: Build an image

Step 3 Run it :

```
docker run --rm -it -p 8888:8888 aubergiste
```

Launch a browser on host : `http://localhost:8888`

Step 4 Give it a parameter:

```
docker run --rm -it aubergiste --help
```

Dockerfile: Build an image

Step 3 Run it :

```
docker run --rm -it -p 8888:8888 aubergiste
```

Launch a browser on host : `http://localhost:8888`

Step 4 Give it a parameter:

```
docker run --rm -it aubergiste --help
```

Step 5 Run a shell instead of a notebook:

```
docker run --rm -it --entrypoint /bin/bash aubergiste
```

Dockerfile: Basic instructions

Description

`FROM`	Parent image
`LABEL`	Metadata to describe the image
`ARG`	Variable to be given at build time

Instructions

`ENV`	Sets environment variables
`RUN`	Executes shell commands
`SHELL`	Sets the shell executing `RUN` commands
`WORKDIR`	Sets the working directory

Behavior

`ENTRYPOINT`	Sets the command line to execute (`$SHELL` by default)
`CMD`	Sets the default arguments for the entry point

Dockerfile: More instructions

Files

`COPY`	Copies/Downloads a file to the image (**recommended**)
`ADD`	Copies/Downloads and auto-decompresses a file
`VOLUME`	Declares a folder as a data volume

Network

`EXPOSE`	Declares ports to expose to other containers

User management

`USER`	Switches to the given user. The user must have been creat with `useradd`

Docker images in a nutshell

- Stored as layers of modifications
  - Layers are shared between images

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  - Layers are shared between images
- Named in the `<name>:<tag>` format
  - Default *tag*: `latest`
  - The name can be prefixed by the address of a custom registry

Docker images in a nutshell

- Stored as layers of modifications
  - Layers are shared between images
- Named in the `<name>:<tag>` format
  - Default *tag*: `latest`
  - The name can be prefixed by the address of a custom registry
- Stored in a Docker Registry
  - Either the official Docker Hub (hub.docker.com)
  - or a private instance of the `registry` image
  - or a compatible registry (Nexus plugin, . . .)

Docker images in a nutshell

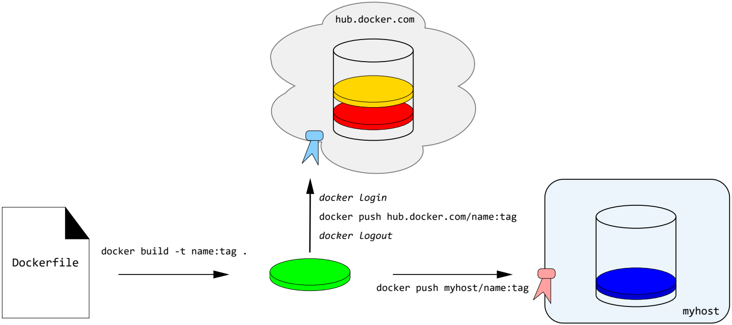
- Local cache: `/var/lib/docker/<driver>`
- Available drivers:

Overlay2	Replaces AUFS on Debian
AUFS	Historic, fallback on Debian flavor
Device Mapper	Historic, default on Red Hat flavor
BTRFS	Default on Suse, could replace Device Mapper
ZFS	"*Not recommended [...] unless you have substantial experience with ZFS on Linux*"

- Configuration:
  - `storage-driver` in `/etc/docker/daemon.json`

Docker Registry: where images are found

- Official registry:
  - hub.docker.com
  - User authentication: `docker login`, `docker logout`
- Private registries, running the official `registry` image
- All registries must provide a **signed** certificate


hub.docker.com
Dockerfile
docker build -t name:tag .
docker login
docker push hub.docker.com/name:tag
docker logout
docker push myhost/name:tag
myhost

Setup a Docker registry

Step 1 Download the composition setup at:

`http://sed.inrialpes.fr/docker-tuto/index_dockersingularity.html`

Step 2 Decompress the file and run the composition from the extracted folder:

```
docker-compose up -d
```

(download can take a while)

Step 3 Wait for the server to come up: `https://localhost`

Docker image: commands

Step 4 Build an image (back to the folder with the Dockerfile):

```
docker build -t aubergiste:1.0 .
```

Docker image: commands

Step 4 Build an image (back to the folder with the Dockerfile):

```
docker build -t aubergiste:1.0 .
```

Step 5 Tag it as *latest*:

```
docker tag aubergiste:1.0 aubergiste
```

Docker image: commands

Step 4 Build an image (back to the folder with the Dockerfile):

```
docker build -t aubergiste:1.0 .
```

Step 5 Tag it as *latest*:

```
docker tag aubergiste:1.0 aubergiste
```

Step 6 See the content of the local cache:

```
docker images
```

Docker image: commands

Step 7 Tag the image for a private registry:

```
docker tag aubergiste localhost/aubergiste
```

Docker image: commands

Step 7 Tag the image for a private registry:

```
docker tag aubergiste localhost/aubergiste
```

Step 8 Upload it:

```
docker push localhost/aubergiste
```

Step 9 Remove the local reference:

```
docker rmi aubergiste
```

Docker image: commands

Step 7 Tag the image for a private registry:

```
docker tag aubergiste localhost/aubergiste
```

Step 8 Upload it:

```
docker push localhost/aubergiste
```

Step 9 Remove the local reference:

```
docker rmi aubergiste
```

Step 10 Stop the registry composition (from the composition folder):

```
docker-compose down
```

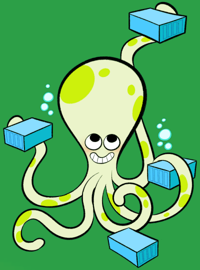
What about docker commit?

- Principle: save the current state of a container as a image
- Some use cases:
  - when an application setup is interactive
  - when the setup comes from a volume
  - when the setup is large (10GB+)
- Usage:

```
docker commit ${CID} <image>:<tag>
```

5
Link containers together

Unity makes strength



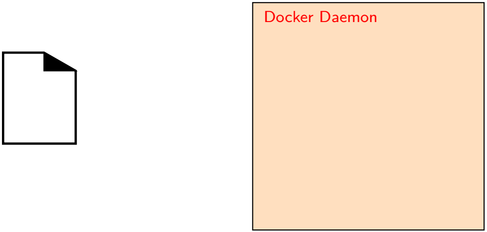
Expose, Links & Networks

- Expose (`Dockerfile` or `run` argument)
  - Defines ports accessible by other containers, even without ICC
- Links (`run` argument, composition)
  - Indicates Docker that a container can communicate with another
  - Allows to give a network alias to access the container
- Networks
  - All containers of a network can communicate
  - No port restriction inside the network

Compositions: Docker Compose

- A Python script to manage sets of containers
  - The standalone version is recommended, see `https://docs.docker.com/compose/install`
  - `pip install docker-compose` on recent OSes
- Same capabilities as the `run` command
- Compositions written in YAML format

Principles

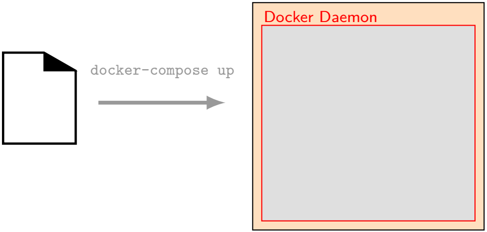


Docker Daemon

```
version: "3"
services:
 nginx:
  image: nginx
  ports:
    - 443:443
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: registry:2
   environment:
     REGISTRY_STORAGE: /data
   volumes:
     - ./data:/data
```

Principles

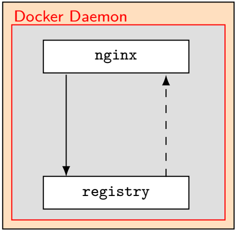


- `docker-compose up -d`

```yaml
version: "3"
services:
 nginx:
  image: nginx
  ports:
    - 443:443
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: registry:2
   environment:
     REGISTRY_STORAGE: /data
   volumes:
     - ./data:/data
```

Principles

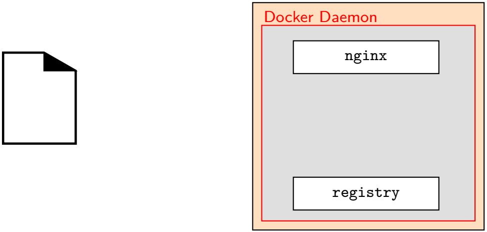


- ▶ `docker-compose up -d`

```
version: "3"
services:
 nginx:
  image: nginx
  ports:
    - 443:443
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: registry:2
   environment:
     REGISTRY_STORAGE: /data
   volumes:
     - ./data:/data
```

Principles



- `docker-compose up -d`
- `docker-compose stop`

```
version: "3"
services:
 nginx:
  image: nginx
  ports:
    - 443:443
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: registry:2
   environment:
     REGISTRY_STORAGE: /data
   volumes:
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```
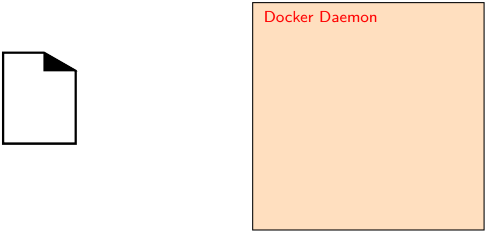

Principles



```
version: "3"
services:
 nginx:
  image: nginx
  ports:
    - 443:443
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: registry:2
   environment:
     REGISTRY_STORAGE: /data
   volumes:
     - ./data:/data
```

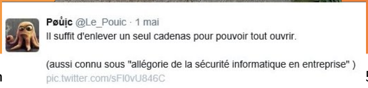
- `docker-compose up -d`
- `docker-compose stop`
- `docker-compose down`

docker-compose.yml

```
version: "3"
services:
 nginx:
  image: "nginx"
  ports:
    - "443:443"
  links:
    - registry:registry-srv
  volumes:
    - ./nginx/:/etc/nginx/conf.d

 registry:
   image: "registry:2"
   environment:
     REGISTRY_STORAGE_FILESYSTEM_ROOTDIRECTORY: /data
   volumes:
     - ./data:/data
```

6 Security

(kind of)



Pøůįc @Le_Pouic · 1 mai

Il suffit d'enlever un seul cadenas pour pouvoir tout ouvrir.

(aussi connu sous "allégorie de la sécurité informatique en entreprise")

pic.twitter.com/sFI0vU846C

What Docker is about

- Docker isolates **processes** from the host

What Docker is about

- Docker isolates **processes** from the host
    - Untrusted applications should be executed with high isolation

What Docker is about

- Docker isolates **processes** from the host
  - Untrusted applications should be executed with high isolation
  - Avoid loosing the leash:
    - Avoid `--privileged`
    - Don't add capabilities to the container
    - Don't disable namespaces

What Docker is about

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  - Avoid loosing the leash:
    - Avoid `--privileged`
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    - Don't disable namespaces

- Docker **doesn't** isolate the **user** from the host
  - A user in the `docker` is `root` on the machine
  - Not suitable for children (and untrusted users)
  - "*With Great Power Comes Great Responsibility*"

What Docker is about

- Docker isolates **processes** from the host
  - Untrusted applications should be executed with high isolation
  - Avoid loosing the leash:
    - Avoid `--privileged`
    - Don't add capabilities to the container
    - Don't disable namespaces
- Docker **doesn't** isolate the **user** from the host
  - A user in the `docker` is `root` on the machine
  - Not suitable for children (and untrusted users)
  - "*With Great Power Comes Great Responsibility*"

```
docker run --rm -it -v /:/mnt/host debian
```

User namespace remap

- All actions from the container are seen as subuser's ones
- Privileged mode is disabled
- Configure the daemon: `/etc/docker/daemon.conf`
  - Activate *User Namespace Remap*: `userns-remap: default`
- Or, with a given sub user:
  - The user must exist in `/etc/passwd`
  - Configure the daemon: `userns-remap: bohort`
  - Set the `/etc/subuid`: `bohort:100000:65536`
  - Set the `/etc/subgid`: `bohort:100000:65536`
  - Be careful not to overstep a real UID or GID

Hey guys, you're kind of quiet. Anyone want to troll us to wake us up?
Ah yeah. I've got an idea, but it's not really trolling...
Try anyway
Do you agree that Docker is just a kind of light-weight VM?
?!
NO
Pfff
You're crazy!
!
Docker isn't a VIRTUAL MAC
You can do "ONE CONTAINER per PROCESS" or "ONE CONTAINER per APP"
It's a
for A SINGLE PROCESS ONLY!
Just look at it for a second, God dammit!
Of course!
How could you SAY that?!

CommitStrip.com

7

A short introduction to `singularity`

Before it becomes a standard

What is it?

- HPC-oriented “isolation”
- Based on a single image file to ease transfers
- Code is executed with user’s rights
- Shares by default, constrains by arguments
- Aims to replace Virtual Machines, not Docker
  - Note that Docker and Singularity philosophies are opposite

Shares by default, you said?

- By default, `singularity` will share a lot from the host:
  - Current environment variables
  - Your home directory
  - Some system directories (`/dev`, `/proc`, `/tmp`, ...)
- This can lead to some tricky situations
  - Process crashing due to an invalid host-inherited environment variable
  - Installation right into your host home directory
    e.g. `pip install --user -U setuptools`
- Constraint arguments:

`-e/--cleanenv`	Clean up environment variables
`-c/--contain`	Use virtual folders (except part of `/dev`) Environment is not cleaned.
`-C/--containall`	Both `-e` and `-c`, plus namespaces isolation

Host sharing/isolation arguments

- Networking:

Argument	Behaviour	Docker equivalent
default	Use host network	`--net=host`
`-n`	No network (loopback only)	`--net=none`

- Mount points:
  - `-B /opt`: mount host `/opt` as `/opt` in container
  - `-B /opt:/inner`: mount host `/opt` as `/inner` in container
  - Multiple shares at once: `-B /etc/my-app,/opt:/inner`

Mount points – Home directory

The Home directory is treated with a specific argument:

- `-H $HOME/lower`
  - Mounts `$HOME/lower` as home folder
  - Path will be the same inside the container
  - Parent hierarchy won't be mounted.
- `-H $HOME/lower:/home/toto`
  - Mounts `$HOME/lower` as home folder
  - Makes it appear as `/home/toto` in the container

Container recipe

Single file (no default name) separated into multiple sections:

Header

`Bootstrap:`	Kind of source image (`docker`, `shub`, `debootstrap`, `busybox`, ...)
`From:`	Name of the source image (content depends on `Bootstrap`)

Metadata

`%help`	A help message on how to use the image
`%labels`	Labels to describe/tag the image

Container recipe

Content Setup **(executed with `root` rights)**

`%setup`	Script executed **on the host**
`%files`	List of host files to copy inside the image

Container setup

`%environment`	Environment variables in the container
`%post`	Commands executed to construct the image (inside a temporary container)
`%runscript`	Commands executed on `singularity run`
`%test`	Commands executed at the end of build to check the image

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7
```

Parent image

- From a Docker image
- python:3.7 (Docker official image)

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7

%labels
AUTHOR sed-gra@inria.fr
```

Meta information

- Maintainer, version, . . .
- Visible in `singularity inspect`

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7

%labels
AUTHOR sed-gra@inria.fr

%files
run_jupyter.sh /opt/run_jupyter.sh
```

Files to copy in the image

- Copies are done before running commands
- Files can be generated on host in the %setup section

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7

%labels
AUTHOR sed-gra@inria.fr

%files
run_jupyter.sh /opt/run_jupyter.sh

%environment
export LANG=C.UTF-8
export LC_ALL=C.UTF-8
```

Environment variables

- In fact, a shell file sourced at start-up
- Don't forget to `EXPORT` them

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7

%labels
AUTHOR sed-gra@inria.fr

%files
run_jupyter.sh /opt/run_jupyter.sh

%environment
export LANG=C.UTF-8
export LC_ALL=C.UTF-8

%post
apt update && apt -y dist-upgrade
pip install jupyter
```

Commands executed in the image

- A shell file executed in a temporary folder

Container recipe – Notebook sample

```
Bootstrap: docker
From: python:3.7

%labels
AUTHOR sed-gra@inria.fr

%files
run_jupyter.sh /opt/run_jupyter.sh

%environment
export LANG=C.UTF-8
export LC_ALL=C.UTF-8

%post
apt update && apt -y dist-upgrade
pip install jupyter
chmod ugo+x /opt/run_jupyter.sh

%runscript
mkdir -p $HOME/notebooks
/opt/run_jupyter.sh --notebook-dir=$HOME/notebooks --ip="*" --port 8888
```

Script to be sourced on

- `singularity run`

Container recipe – Apps

- *Apps* are a way to use the same image for multiple pre-defined usages
- Listed with `singularity apps <img>`
- Defined alongside base image sections
- Ran with `singularity run --app <app> <img file>`
  - `singularity run jupyter.img`
  - `singularity run --app console jupyter.img`
  - `singularity run --app qtconsole jupyter.img`

Container recipe – Apps

Application sections

`%apphelp`	Description of the application
`%applabels`	Metadata of the application
`%appenv`	Environment variables for the application
`%appfiles`	Host files to copy inside image
`%appinstall`	Commands executed inside the image
`%apprun`	Commands executed on `run --app <app>`

- **No** `%appsetup` **section**
- Use relative path when copying files for an *app*
- Access it using the `$SCIF_APPROOT` environment variable

Container recipe – App Example

```
%appfiles console
sample.conf

%appinstall console
pip install readline

%apprun console
echo "Starting in console mode..."
cat $SCIF_APPROOT/sample.conf
jupyter console
```

Singularity Basic commands

Files available at

http://sed.inrialpes.fr/docker-tuto/index_dockersingularity.html

```
# Build the image file
sudo singularity build jupyter.img Jupyter.singularity

# Basic
singularity run jupyter.img
# Highly recommended
singularity run -e jupyter.img
# Run a shell in the image
singularity shell -e jupyter.img
# Run an app
singularity run -e --app console jupyter.img
```

Singularity Container images

- Singularity uses a single file as a container image
- Supported image formats:
  - SquashFS: the current default format
    - Read-only
  - ext3: the previous default format
    - Possible read-write mode
  - sandbox: based on a local directory instead of a single file
    - Writeable
    - Can be seen as a `chroot` directory
  - `.tar`, `.tar.gz`, `.tar.bz2`: a compressed sandbox
    - Read-only

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Singularity — Docker

The Persuaders

Most visible differences

Singularity	Docker
No daemon (uses SUID)	Unique daemon per host
Share by default	Constrain by default
Processes run with user's rights	Processes run with inner rights
Sees host with user's rights	Sees host with `root` rights
Single file images	Multi-layer images
Targets shared computer	Targets service-hosting servers

Work with NVidia GPUs

- Requires the NVIDIA drivers to be installed on the host
- On Docker:
  - Official Open Source plugin from NVIDIA:
    `github.com/NVIDIA/nvidia-docker`
  - Install the `nvidia-docker2` package
  - Run containers with the `--runtime=nvidia` argument
- On Singularity:
  - Support is included in Singularity (*beta*)
  - Add the `--nv` flag when starting the container

Emulate Singularity with Docker

The following command is equivalent to:
`singularity shell docker://debian`

```
docker run \
    -it --rm \
    --pid=host --ipc=host \
    --net=host --uts=host \
    -v /tmp:/tmp \
    -v /etc/passwd:/etc/passwd:ro \
    -v "$HOME":"$HOME" -w "$HOME" \
    --user="$(id -u):$(id -g)" \
    --env-file=<(bash -c set) \
    --entrypoint "/bin/bash" \
    debian
```

Run Singularity inside Docker

- Because... why not?
- `Dockerfile`:
  - Debian + Backport repository + `singularity-container`
  - Executed with a new user
  - User can do `sudo singularity` without password
- Execution:

```
docker run -it --rm \
    --privileged \
    -v $(pwd):/src \
    singularity \
    sudo singularity build /src/out.img /src/Singularity
```

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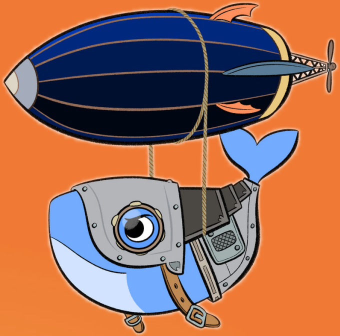
Miscellaneous



Singularity Image Registry

- Open Source registry available on GitHub
  `https://github.com/singularityhub/sregistry`
- Available as a Docker composition:
  1. `git clone https://github.com/singularityhub/sregistry.git`
  2. `cp shub/settings/dummy_secrets.py shub/settings/secrets.py`
  3. Edit `secrets.py` (at least the `SECRET_KEY` variable)
  4. If necessary, edit `shub/settings/config.py`
  5. Run `docker-compose up -d`
  6. Registry is available at `http://localhost`

Containers on ARM

- Both Docker & Singularity have packages for ARM
- Only works with `arm` images
  - Most are from `armhf` on the Docker Hub
  - `https://hub.docker.com/u/armhf/`
- Sample Docker usage on a Raspberry Pi:
  - `http://blog.alexellis.io/getting-started-with-docker-on-raspberry-pi/`

Docker on Windows

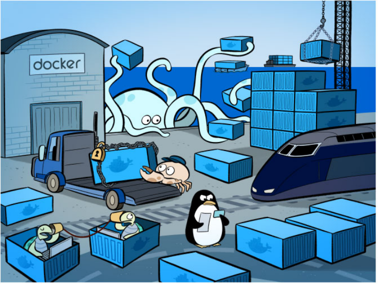
- Requires Windows 10 Pro or Windows Server 2016
  - with the “`Containers`” and “`Hyper-V`” features
- Two base images are available (in multiple versions):
  - `microsoft/windowsservercore`
  - `microsoft/nanoserver` (for 64 bits apps only)
- Many images now have a Windows version
  - Python, Node.js, …
- `docker info`:

```
[...]
Server Version: 18.06.1-ce
Storage Driver: windowsfilter
Default Isolation: hyperv
Kernel Version: 10.0 17134 (17134.1.amd64fre.rs4_release.180410-1804)
Docker Root Dir: C:\ProgramData\Docker
[...]
```

Thanks for your attention

Credits:

- CommitStrip
- Laurel
- xkcd



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Montbonnot-Saint-Martin

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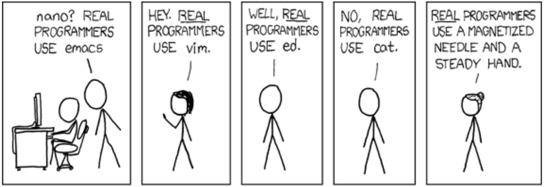
Bonus slides

There's always more

A word about `rkt`

- Started in 2014 to "*fix*" some Docker *flaws*
- Aims security (versus usability)
  - No central `root` daemon
- Compatible with the OpenContainer specification
  - . . . so with Docker images
- Same conflict as "vim vs. emacs" or "etcd vs. consul"


nano? REAL PROGRAMMERS USE emacs
HEY. REAL PROGRAMMERS USE vim.
WELL, REAL PROGRAMMERS USE ed.
NO, REAL PROGRAMMERS USE cat.
REAL PROGRAMMERS USE A MAGNETIZED NEEDLE AND A STEADY HAND.

Why not unlocking security?

-
  ```
  docker run -it -d
       --privileged --net=host
       -v /:/host
       -v /dev:/dev -v /run:/run
       -e sysimage=/host
       debian
  ```

- Inside the container:

```
nsenter --mount=/host/proc/1/ns/mnt -- /bin/bash
```

Some snippets

- *A posteriori* port forwarding:
  - `docker exec <CID> ip addr | grep 172.`
  - `iptables -t nat -A DOCKER -p tcp --dport 9000 -j DNAT --to-destination <CIP>:8080`

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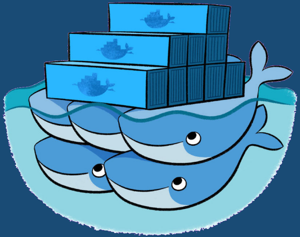
Scale up with Swarm



What is Docker Swarm ?

- Docker on a multi-host cluster
  - Based on *overlay* networks (linking local *bridge* networks)

What is Docker Swarm ?

- Docker on a multi-host cluster
  - Based on *overlay* networks
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- Adds the concept of *service*
  - Containers replicated or not on multiple machines
  - Restarted automatically
  - Migrated on host failure

What is Docker Swarm ?

- Docker on a multi-host cluster
  - Based on *overlay* networks
    (linking local *bridge* networks)
- Adds the concept of *service*
  - Containers replicated or not on multiple machines
  - Restarted automatically
  - Migrated on host failure
- At least one *manager*, no limit on *workers*
  - Managers act like workers
  - All nodes keep track of the Swarm state: the Swarm can fully restart if at least one node stays alive
  - `swarm` commands can only be run on managers

Setup a Swarm

- On the first manager host (*swarm leader*):
  - `docker swarm init`
  - `docker swarm join-token manager`
  - `docker swarm join-token worker`
- On other hosts (*swarm nodes*):

  -
    ```
    docker swarm join --token SWMTKN-...\
        <manager-IP>:2377
    ```

Nodes Handling

- Nodes inspection:
  - `docker node ls`
  - `docker node inspect <node>`
  - `docker node ps <node>`
  - `docker node rm <node>`

Nodes Handling

- Nodes inspection:
  - `docker node ls`
  - `docker node inspect <node>`
  - `docker node ps <node>`
  - `docker node rm <node>`
- Node mode switch:
  - `docker node promote <node>`
  - `docker node demote <node>`

Define a service

- Similar capabilities as the `run` command
- Useful commands:
  - `docker service create ...`
  - `docker service ls`
  - `docker service ps <service>`
  - `docker service rm <service>`

Define a service

- Similar capabilities as the `run` command
- Useful commands:
  - `docker service create ...`
  - `docker service ls`
  - `docker service ps <service>`
  - `docker service rm <service>`
- Sample:

```
docker service create --name postgres \
    --env POSTGRES_PASSWORD="toto" \
    --env POSTGRES_USER=hive \
    --env POSTGRES_DB=metastore \
    postgres:9.5
```

Docker Swarm: Stacks

- Compatible with docker-compose V3 files
  - With some limitations: no links (mandatory use of networks)
  - And some new capabilities: deploy configuration
- docker deploy --compose-file ./hdfs_stack.yml hdfs

```
version: '3'
services:
  namenode:
    image: registry/hdfs-namenode
    env_file: ./hadoop.env
    environment:
      CLUSTER_NAME: tyrex
    ports:
      - "8020:8020"
      - "50070:50070"
    networks:
      - tls-net
    volumes:
      - /local/namenode:/dfs/name
    deploy:
      placement:
        constraints:
          - node.hostname == realhost

  datanode:
    image: registry/hdfs-datanode
    env_file: ./hadoop.env
    networks:
      - tls-net
    volumes:
      - /local/datanode:/dfs/data
    deploy:
      mode: global

networks:
  tls-net:
    external: true
```