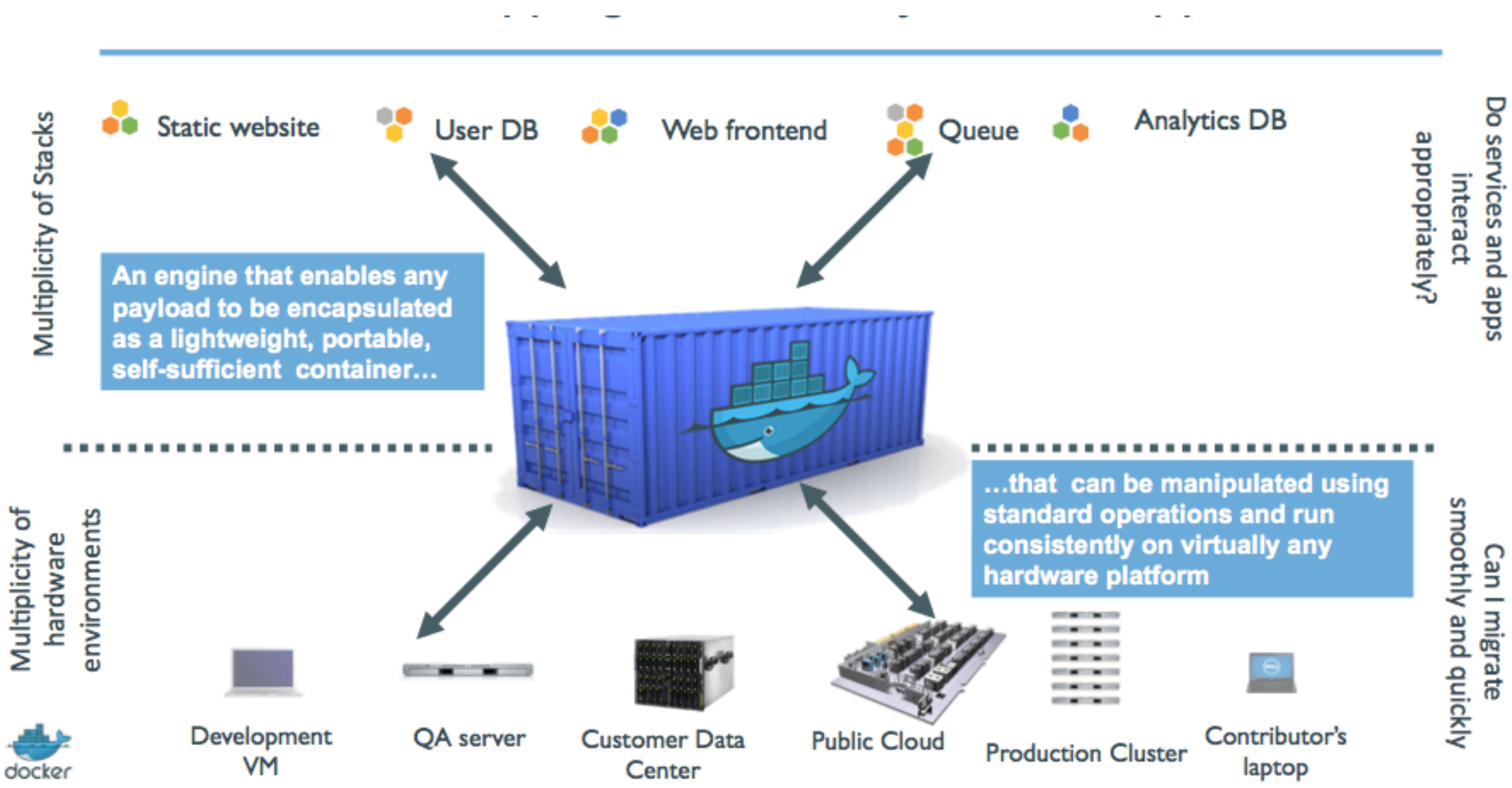
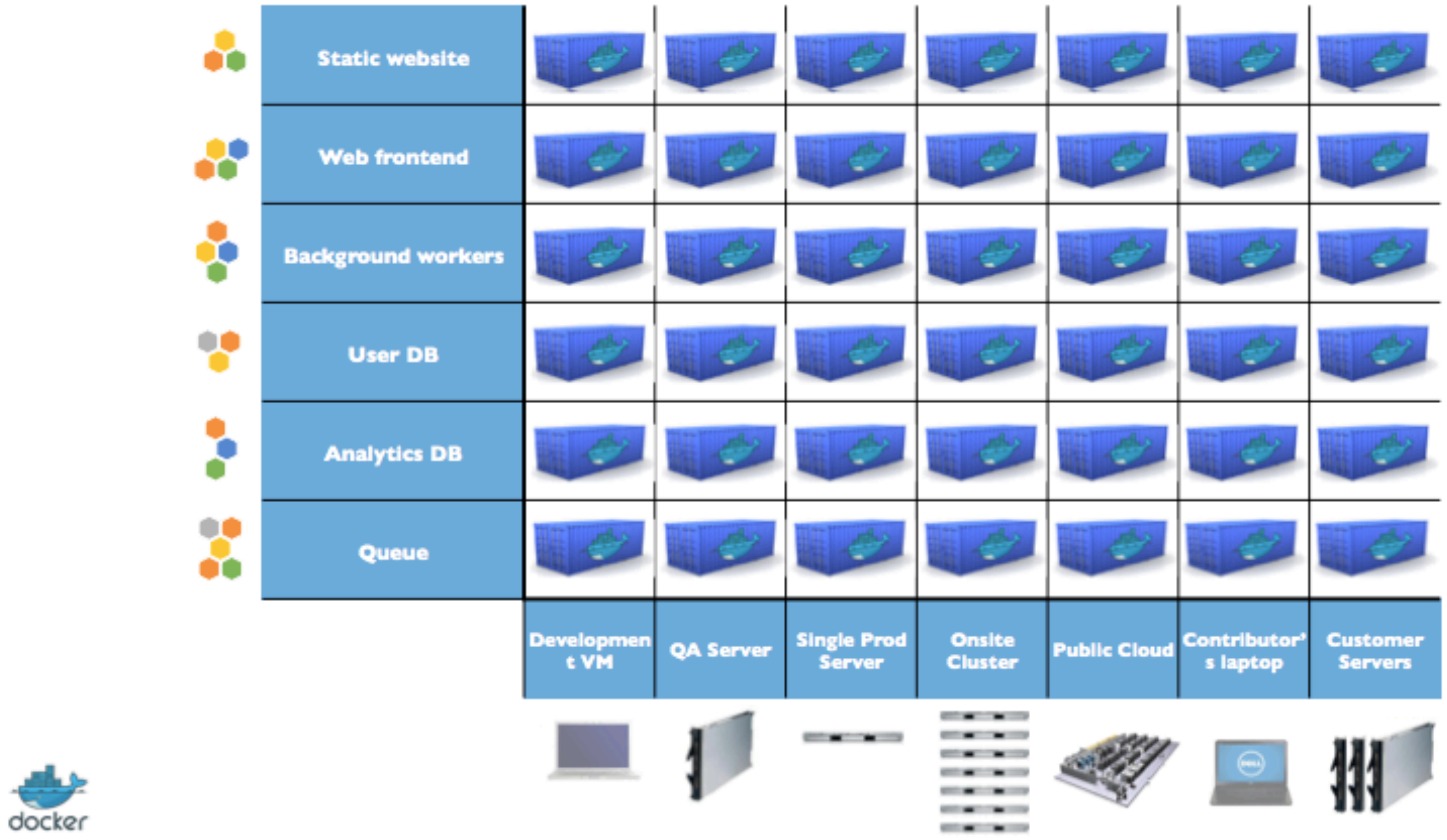
# Docker 101

# A shipping container system for applications



# Eliminate the matrix from hell



# Our training environment

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- If you are attending #DataEng
  - docker is an easy way to deploy various technologies without affecting your local environment
  - you don't have to worry about networking
  - you need to take care of persistence though
- For testing purposes use Play with Docker to instantly get a training environment

# Our first containers

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- Seen Docker in action.
- Started your first containers.
- Understood what is an image.
- What is a layer.
- The various image namespaces.
- How to search and download images.
- Image tags and when to use them.

# Hello World

In your Docker environment, just run the following command:

```
$ docker run busybox echo hello world
hello world
```

(If your Docker install is brand new, you will also see a few extra lines,
corresponding to the download of the `busybox` image.)

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- `busybox` is typically used in embedded systems (phones, routers...)
- We ran a single process and echo'ed `hello world`.

# A more useful container

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root@04c0bb0a6c07:/#
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  - `-i` tells Docker to connect us to the container's stdin.

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```

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- It runs a bare-bones, no-frills `ubuntu` system.
- `-it` is shorthand for `-i -t`.
  - `-i` tells Docker to connect us to the container's stdin.
  - `-t` tells Docker that we want a pseudo-terminal.

# Do something in our container

Try to run `figlet` in our container.

```
root@04c0bb0a6c07:/# figlet hello
bash: figlet: command not found
```

Alright, we need to install it.

# Install a package in our container

We want `figlet`, so let's install it:

```
root@04c0bb0a6c07:/# apt-get update
...
Fetched 1514 kB in 14s (103 kB/s)
Reading package lists... Done
root@04c0bb0a6c07:/# apt-get install figlet
Reading package lists... Done
...
```

One minute later, `figlet` is installed!

# Try to run our freshly installed program

The `figlet` program takes a message as parameter.

```
root@04c0bb0a6c07:/# figlet hello
 _          _ _       
| |__   ___| | | ___  
| '_ \ / _ \ | |/ _ \ 
| | | |  __/ | | (_) |
|_| |_|\___|_|_|\___/ 
```

Beautiful! .emoji[😍]

# Counting packages in the container

Let's check how many packages are installed there.

```
root@04c0bb0a6c07:/# dpkg -l | wc -l
190
```

How many packages do we have on our host?

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- `dpkg -l` lists the packages installed in our container

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- `dpkg -l` lists the packages installed in our container
- `wc -l` counts them

How many packages do we have on our host?

# Counting packages on the host

Exit the container by logging out of the shell, like you would usually do.

(E.g. with `^D` or `exit`)

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root@04c0bb0a6c07:/# exit
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Now, try to:

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Now, try to:

- run `dpkg -l | wc -l`. How many packages are installed?
- run `figlet`. Does that work?

# Comparing the container and the host

Exit the container by logging out of the shell, with `^D` or `exit`.

Now try to run `figlet`. Does that work?

(It shouldn't; except if, by coincidence, you are running on a machine where figlet was installed before.)

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- Installing something on the host doesn't expose it to the container.
- And vice-versa.
- Even if both the host and the container have the same Linux distro!
- We can run *any container* on *any host*.

  (One exception: Windows containers cannot run on Linux machines; at least not yet.)

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- We will see later how to get back to that container.

# Starting another container

What if we start a new container, and try to run `figlet` again?

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$ docker run -it ubuntu
root@b13c164401fb:/# figlet
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- We started a *brand new container*.
- The basic Ubuntu image was used, and `figlet` is not here.

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- That seems complicated!

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- And what's the point?

  *This puts a strong emphasis on automation and repeatability. Let's see why ...*

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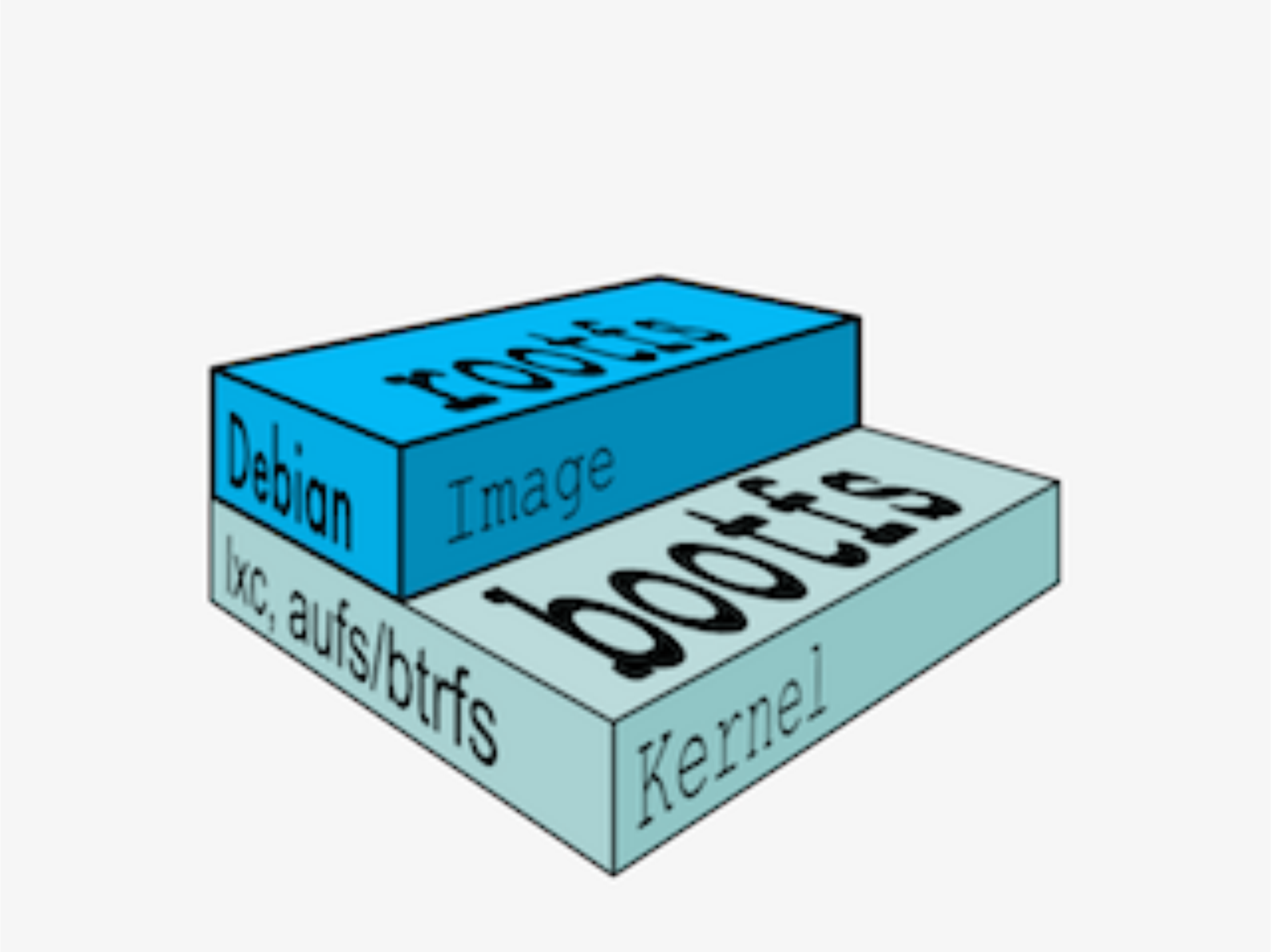
- We have a clear definition of our environment, and can share it reliably with others.
- Let's see in the next chapters how to bake a custom image with `figlet`!

# Build first Image



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- Images are made of *layers*, conceptually stacked on top of each other.
- Each layer can add, change, and remove files and/or metadata.
- Images can share layers to optimize disk usage, transfer times, and memory use.

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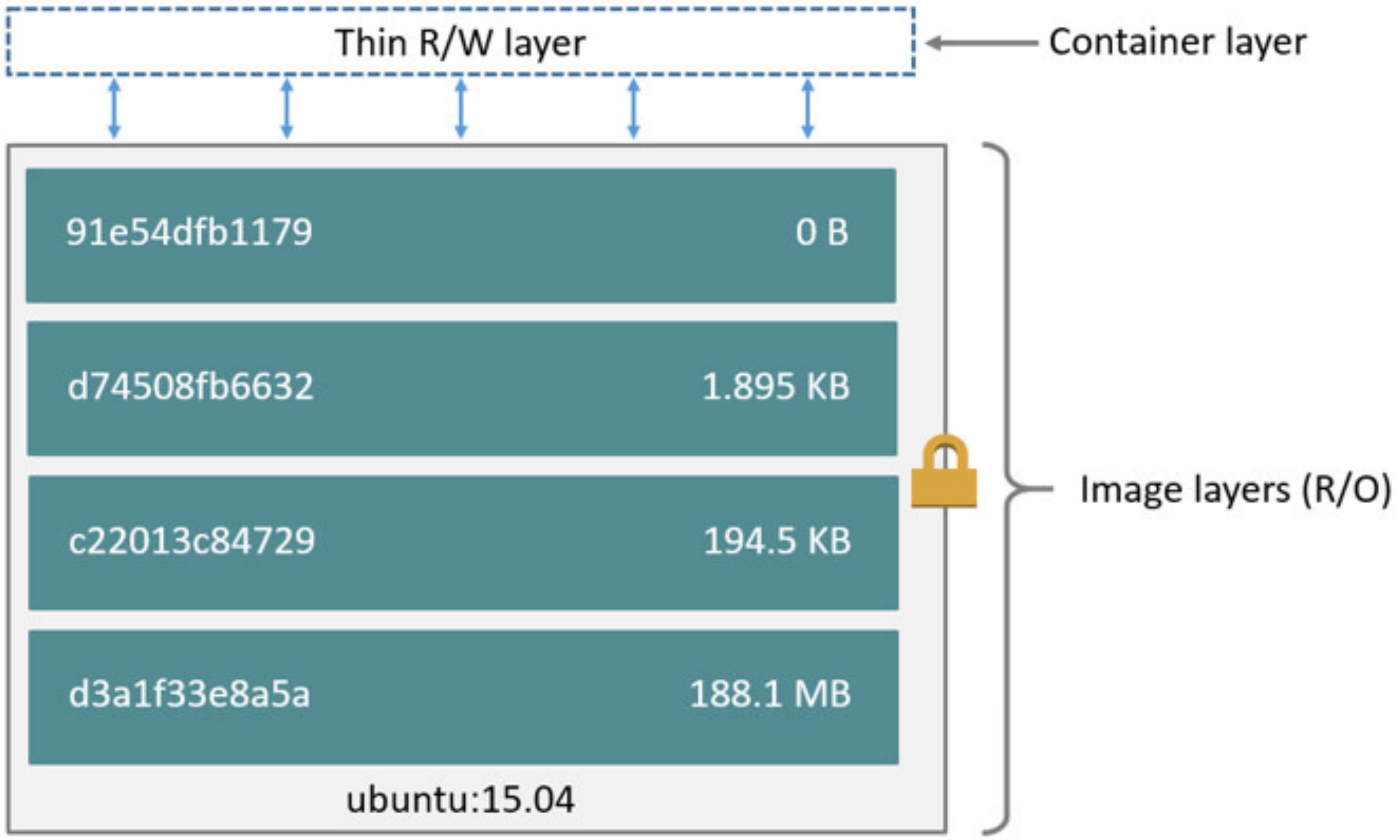
- Our application configuration

# The read-write layer




Container
(based on ubuntu:15.04 image)

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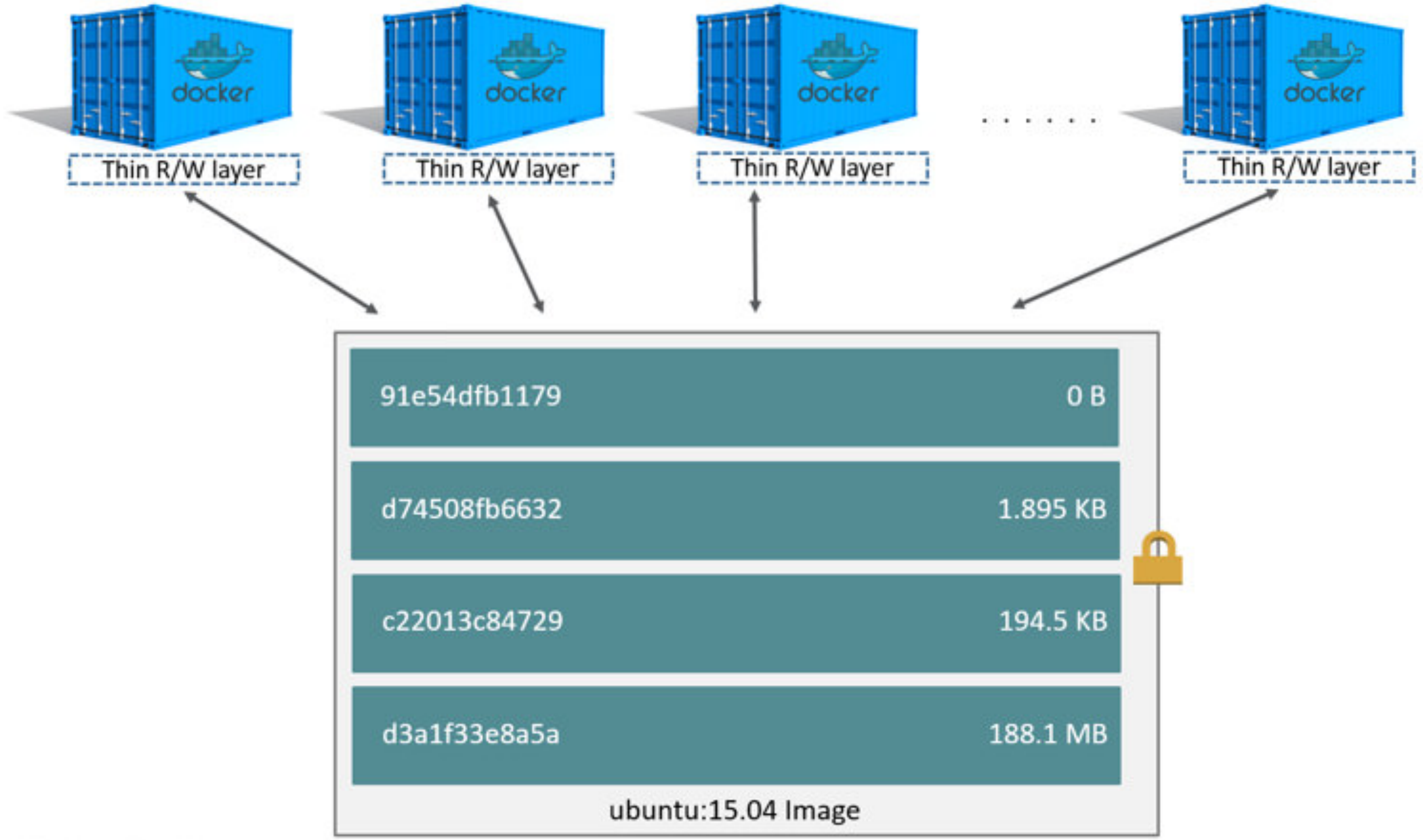
- An image is a read-only filesystem.
- A container is an encapsulated set of processes,

  running in a read-write copy of that filesystem.
- To optimize container boot time, *copy-on-write* is used instead of regular copy.
- `docker run` starts a container from a given image.

# Multiple containers sharing the same image



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- Images are conceptually similar to *classes*.
- Layers are conceptually similar to *inheritance*.
- Containers are conceptually similar to *instances*.

# Wait a minute...

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- We create a new container from that image.
- Then we make changes to that container.
- When we are satisfied with those changes, we transform them into a new layer.
- A new image is created by stacking the new layer on top of the old image.

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- Help!

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- The imported tarball becomes a standalone image.
- That new image has a single layer.

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`docker commit`

`docker build` **(used 99% of the time)**

We will explain both methods in a moment.

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- This is the preferred method!

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# Images namespaces

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  e.g. `ubuntu`, `busybox` ...

- User (and organizations) images

  e.g. `jpetazzo/clock`

- Self-hosted images

  e.g. `registry.example.com:5000/my-private/image`

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# Root namespace

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They are gated by Docker Inc.

They are generally authored and maintained by third parties.

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- Distro images to be used as bases for your builds, like ubuntu, fedora...
- Ready-to-use components and services, like redis, postgresql...
- Over 150 at this point!

# User namespace

The user namespace holds images for Docker Hub users and organizations.

For example:

`jpetazzo/clock`

The Docker Hub user is:

`jpetazzo`

The image name is:

`clock`

# Showing current images

Let's look at what images are on our host now.

```
$ docker images
REPOSITORY        TAG      IMAGE ID       CREATED          SIZE
fedora            latest   ddd5c9c1d0f2   3 days ago       204.7 MB
centos            latest   d0e7f81ca65c   3 days ago       196.6 MB
ubuntu            latest   07c86167cdc4   4 days ago       188 MB
redis             latest   4f5f397d4b7c   5 days ago       177.6 MB
postgres          latest   afe2b5e1859b   5 days ago       264.5 MB
alpine            latest   70c557e50ed6   5 days ago       4.798 MB
debian            latest   f50f9524513f   6 days ago       125.1 MB
busybox           latest   3240943c9ea3   2 weeks ago      1.114 MB
training/namer    latest   902673acc741   9 months ago     289.3 MB
jpetazzo/clock    latest   12068b93616f   12 months ago    2.433 MB
```

# Downloading images

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- Explicitly, with `docker pull`.
- Implicitly, when executing `docker run` and the image is not found locally.

# Pulling an image

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Pulling repository debian
b164861940b8: Download complete
b164861940b8: Pulling image (jessie) from debian
d1881793a057: Download complete
```

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- As seen previously, images are made up of layers.
- Docker has downloaded all the necessary layers.
- In this example, `:jessie` indicates which exact version of Debian we would like.

  It is a *version tag*.

# Image and tags

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- `docker pull ubuntu` will refer to `ubuntu:latest`.
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**Don't specify tags:**

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This is similar to what we would do with `pip install`, `npm install`, etc.

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- To ensure repeatability later.

This is similar to what we would do with `pip install`, `npm install`, etc.

# Section summary

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# Building Docker images with a Dockerfile

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We will build a container image automatically, with a `Dockerfile`.

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- The `docker build` command builds an image from a `Dockerfile`.

# Writing our first `Dockerfile`

Our Dockerfile must be in a **new, empty directory**.

```
$ mkdir myimage
```

```
$ cd myimage
$ vim Dockerfile
```

Of course, you can use any other editor of your choice.

# Writing our first `Dockerfile`

Our Dockerfile must be in a **new, empty directory**.

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FROM ubuntu
RUN apt-get update
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(No input can be provided to Docker during the build.)

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- `FROM` indicates the base image for our build.
- Each `RUN` line will be executed by Docker during the build.
- Our `RUN` commands **must be non-interactive.**

(No input can be provided to Docker during the build.)

- In many cases, we will add the `-y` flag to `apt-get`.

# Build it!

Save our file, then execute:

```
$ docker build -t figlet .
```

We will talk more about the build context later.

To keep things simple for now: this is the directory where our Dockerfile is located.

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- `-t` indicates the tag to apply to the image.
- `.` indicates the location of the *build context*.

We will talk more about the build context later.

To keep things simple for now: this is the directory where our Dockerfile is located.

# What happens when we build the image?

The output of `docker build` looks like this:

```
docker build -t figlet .
Sending build context to Docker daemon  2.048kB
Step 1/3 : FROM ubuntu
 ---> f975c5035748
Step 2/3 : RUN apt-get update
 ---> Running in e01b294dbffd
(...output of the RUN command...)
Removing intermediate container e01b294dbffd
 ---> eb8d9b561b37
Step 3/3 : RUN apt-get install figlet
 ---> Running in c29230d70f9b
(...output of the RUN command...)
Removing intermediate container c29230d70f9b
 ---> 0dfd7a253f21
Successfully built 0dfd7a253f21
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- Be careful (or patient) if that directory is big and your link is slow.
- You can speed up the process with a `.dockerignore` file
  - It tells docker to ignore specific files in the directory
  - Only ignore files that you won't need in the build context!

# Executing each step

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- The build container (`e01b294dbffd`) is removed.
- The output of this step will be the base image for the next one.

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  - `RUN apt-get install figlet cowsay`

    is different from

    `RUN apt-get install cowsay figlet`
  - `RUN apt-get update` is not re-executed when the mirrors are updated

You can force a rebuild with `docker build --no-cache ....`

# Running the image

The resulting image is not different from the one produced manually.

```
$ docker run -ti figlet
root@91f3c974c9a1:/# figlet hello
 _          _ _
| |__   ___| | | ___
| '_ \ / _ \ | |/ _ \
| | | |  __/ | | (_) |
|_| |_|\___|_|_|\___/
```

Yay! .emoji[🎉]

# The Container Network Model

# Objectives

We will learn about the CNM (Container Network Model).

At the end of this lesson, you will be able to:

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- Create a private network for a group of containers.
- Use container naming to connect services together.
- Dynamically connect and disconnect containers to networks.
- Set the IP address of a container.

We will also explain the principle of overlay networks and network plugins.

# The Container Network Model

Docker has "networks".

We can manage them with the `docker network` commands; for instance:

```
$ docker network ls
NETWORK ID          NAME                DRIVER
6bde79dfcf70        bridge              bridge
8d9c78725538        none                null
eb0eeab782f4        host                host
4c1ff84d6d3f        blog-dev            overlay
228a4355d548        blog-prod           overlay
```

New networks can be created (with `docker network create`).

(Note: networks `none` and `host` are special; let's set them aside for now.)

# What's a network?

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- Each network has its own subnet (IP address range)

- A network can be local (to a single Docker Engine) or global (span multiple hosts)

- Containers can have *network aliases* providing DNS-based service discovery

  (and each network has its own "domain", "zone", or "scope")

# Service discovery

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  (i.e. if they do a DNS lookup on `db`, it will give the container's address)

- We can have a different `db` container in each network

  (this avoids naming conflicts between different stacks)

- When we name a container, it automatically adds the name as a network alias

  (i.e. `docker run --name xyz ...` is like `docker run --net-alias xyz ...`

# Network isolation

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- By default, containers in network A cannot reach those in network B
- A container connected to both networks A and B can act as a router or proxy
- Published ports are always reachable through the Docker host address

  (`docker run -P ...` makes a container port available to everyone)

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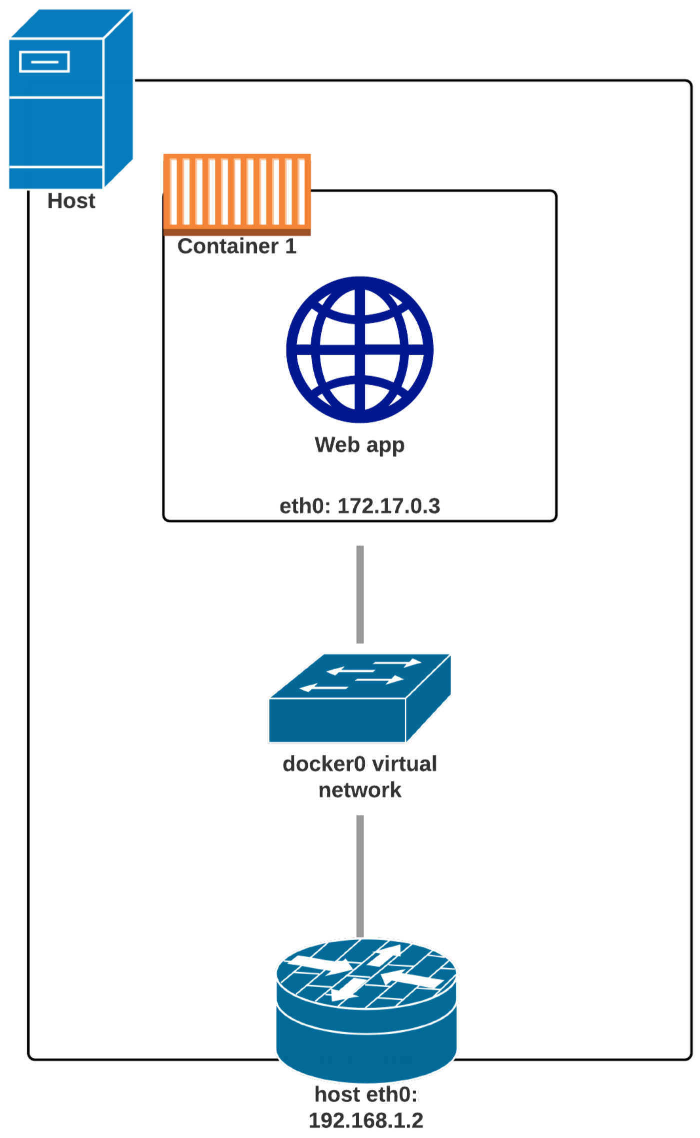
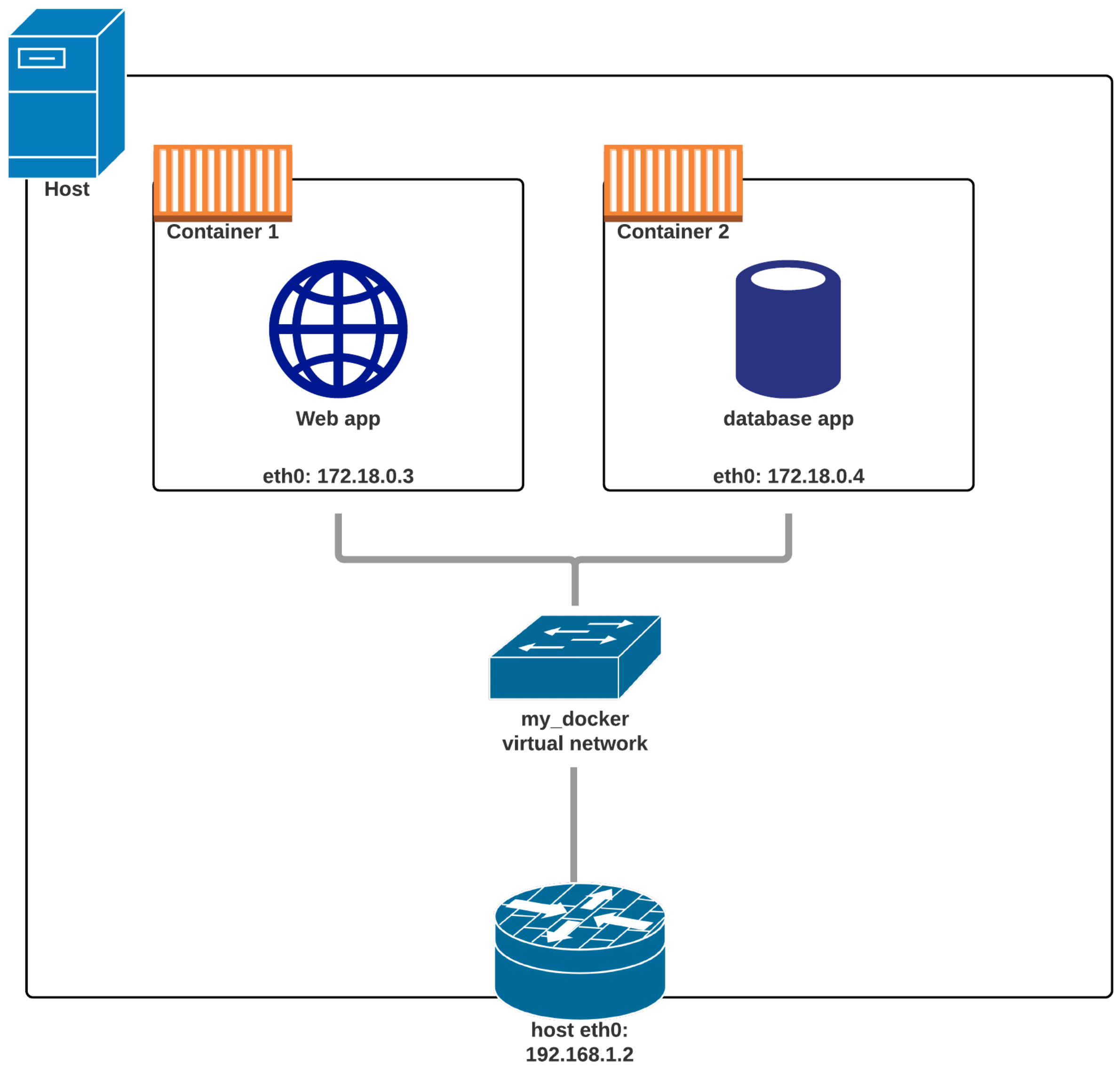
# How to use networks

- We typically create one network per "stack" or app that we deploy
- More complex apps or stacks might require multiple networks (e.g. `frontend`, `backend`, ...)
- Networks allow us to deploy multiple copies of the same stack (e.g. `prod`, `dev`, `pr-442`, ....)
- If we use Docker Compose, this is managed automatically for us

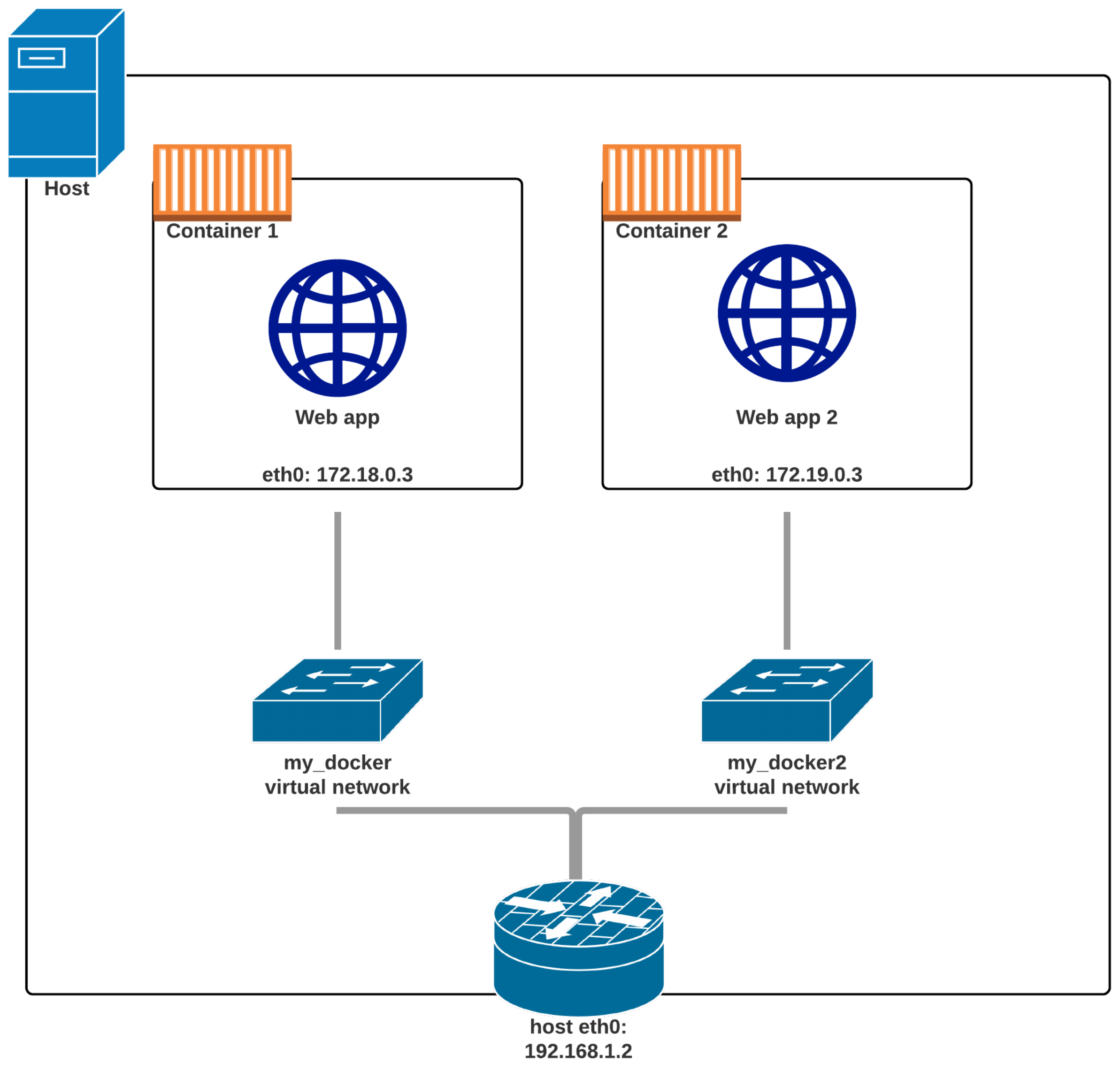
# Single container in a Docker network



# Two containers on a single Docker network



# Two containers on two Docker networks



# Creating a network

Let's create a network called `dev`.

```
$ docker network create dev
4c1ff84d6d3f1733d3e233ee039cac276f425a9d5228a4355d54878293a889ba
```

The network is now visible with the `network ls` command:

```
$ docker network ls
NETWORK ID          NAME                DRIVER
6bde79dfcf70        bridge              bridge
8d9c78725538        none                null
eb0eeab782f4        host                host
4c1ff84d6d3f        dev                 bridge
```

# Placing containers on a network

We will create a *named* container on this network.

It will be reachable with its name, `es`.

```
$ docker run -d --name es --net dev elasticsearch:2
8abb80e229ce8926c7223beb69699f5f34d6f1d438bfc5682db893e798046863
```

# Communication between containers

Now, create another container on this network.

```
$ docker run -ti --net dev alpine sh
root@0ecccdfa45ef:/#
```

From this new container, we can resolve and ping the other one, using its assigned name:

```
/ # ping es
PING es (172.18.0.2) 56(84) bytes of data.
64 bytes from es.dev (172.18.0.2): icmp_seq=1 ttl=64 time=0.221 ms
64 bytes from es.dev (172.18.0.2): icmp_seq=2 ttl=64 time=0.114 ms
64 bytes from es.dev (172.18.0.2): icmp_seq=3 ttl=64 time=0.114 ms
^C
--- es ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2000ms
rtt min/avg/max/mdev = 0.114/0.149/0.221/0.052 ms
root@0ecccdfa45ef:/#
```

# Resolving container addresses

Since Docker Engine 1.10, name resolution is implemented by a dynamic resolver.

Archeological note: when CNM was intoduced (in Docker Engine 1.9, November 2015)
name resolution was implemented with `/etc/hosts`, and it was updated each time CONTAINERs were added/removed. This could cause interesting race conditions since `/etc/hosts` was a bind-mount (and couldn't be updated atomically).

```
[root@0ecccdfa45ef /]# cat /etc/hosts
172.18.0.3  0ecccdfa45ef
127.0.0.1       localhost
::1     localhost ip6-localhost ip6-loopback
fe00::0 ip6-localnet
ff00::0 ip6-mcastprefix
ff02::1 ip6-allnodes
ff02::2 ip6-allrouters
172.18.0.2      es
172.18.0.2      es.dev
```

# Service discovery with containers

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# Service discovery with containers

- Let's try to run an application that requires two containers.
- The first container is a web server.
- The other one is a redis data store.
- We will place them both on the `dev` network created before.

# Running the web server

Start the container, exposing all its ports:

```
$ docker run --net dev -d -P jpetazzo/trainingwheels
```

Check the port that has been allocated to it:

```
$ docker ps -l
```

# Running the web server

- The application is provided by the container image `jpetazzo/trainingwheels`.

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# Running the web server

- The application is provided by the container image `jpetazzo/trainingwheels`.
- We don't know much about it so we will try to run it and see what happens!

Start the container, exposing all its ports:

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$ docker run --net dev -d -P jpetazzo/trainingwheels
```

Check the port that has been allocated to it:

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$ docker ps -l
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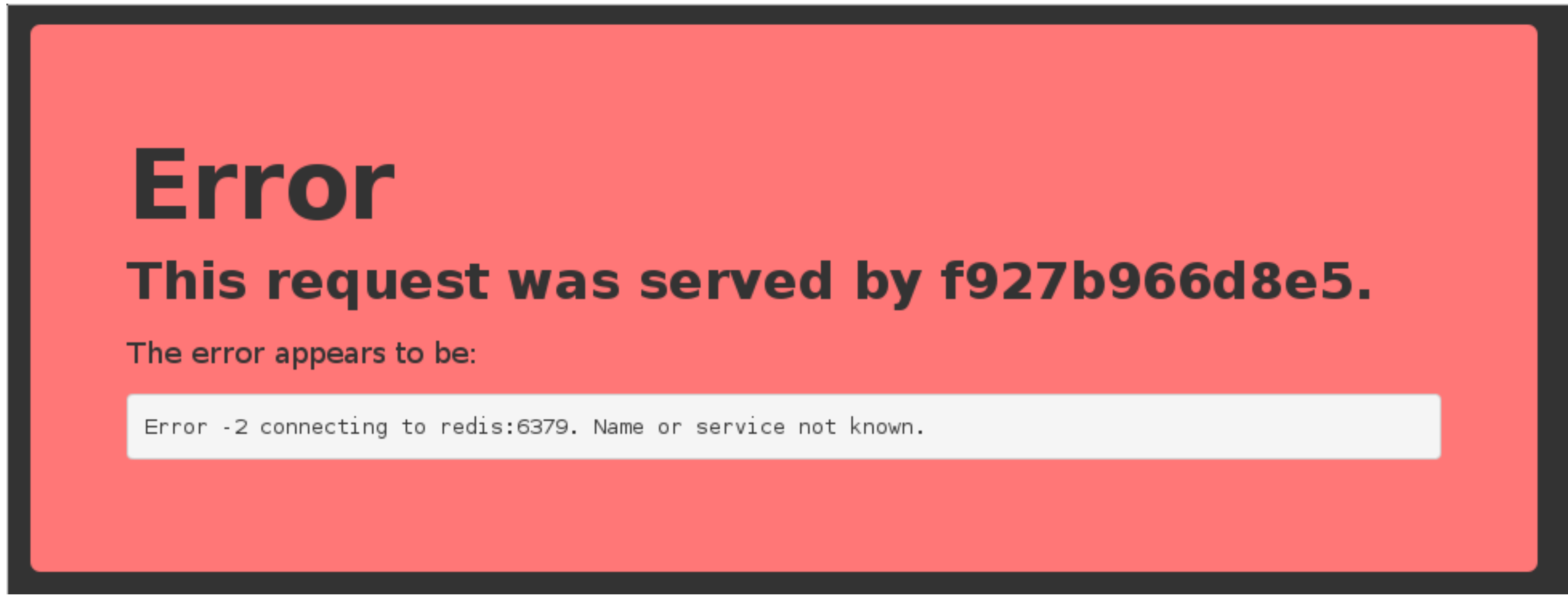
# Test the web server




Note: we're not using a FQDN or an IP address here; just `redis`.

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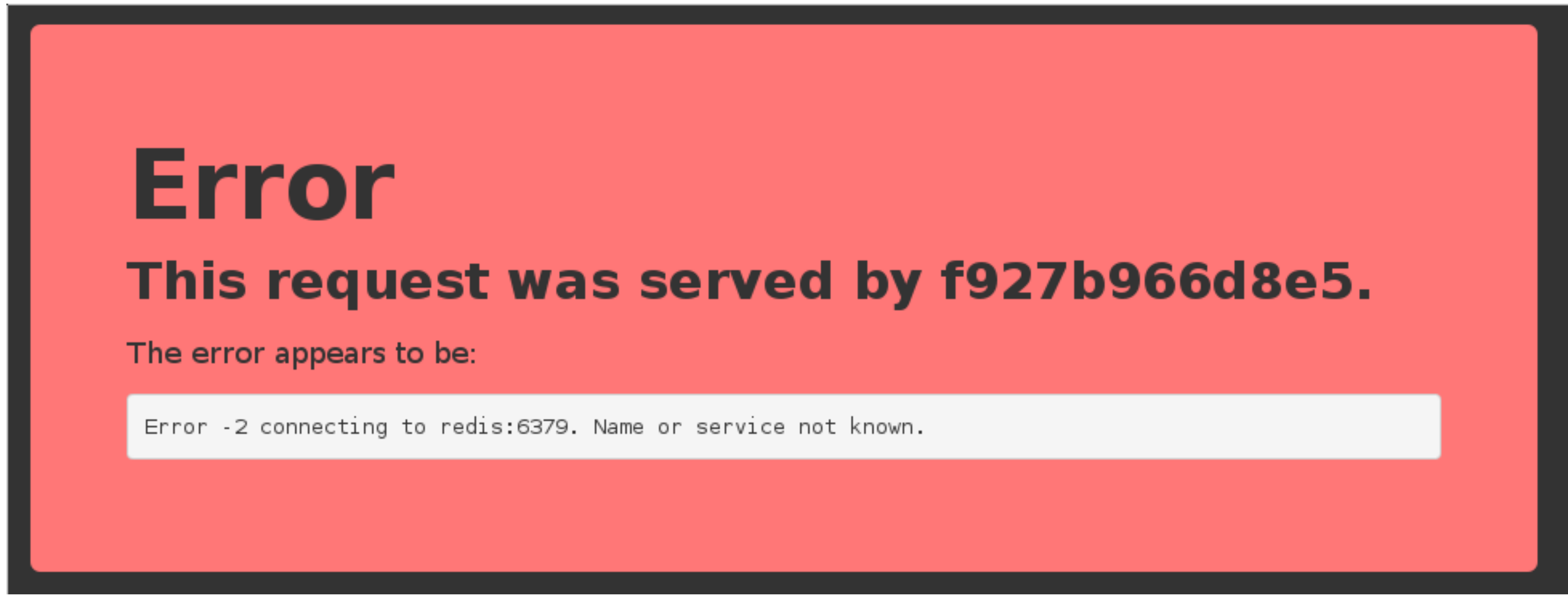
- If we connect to the application now, we will see an error page:

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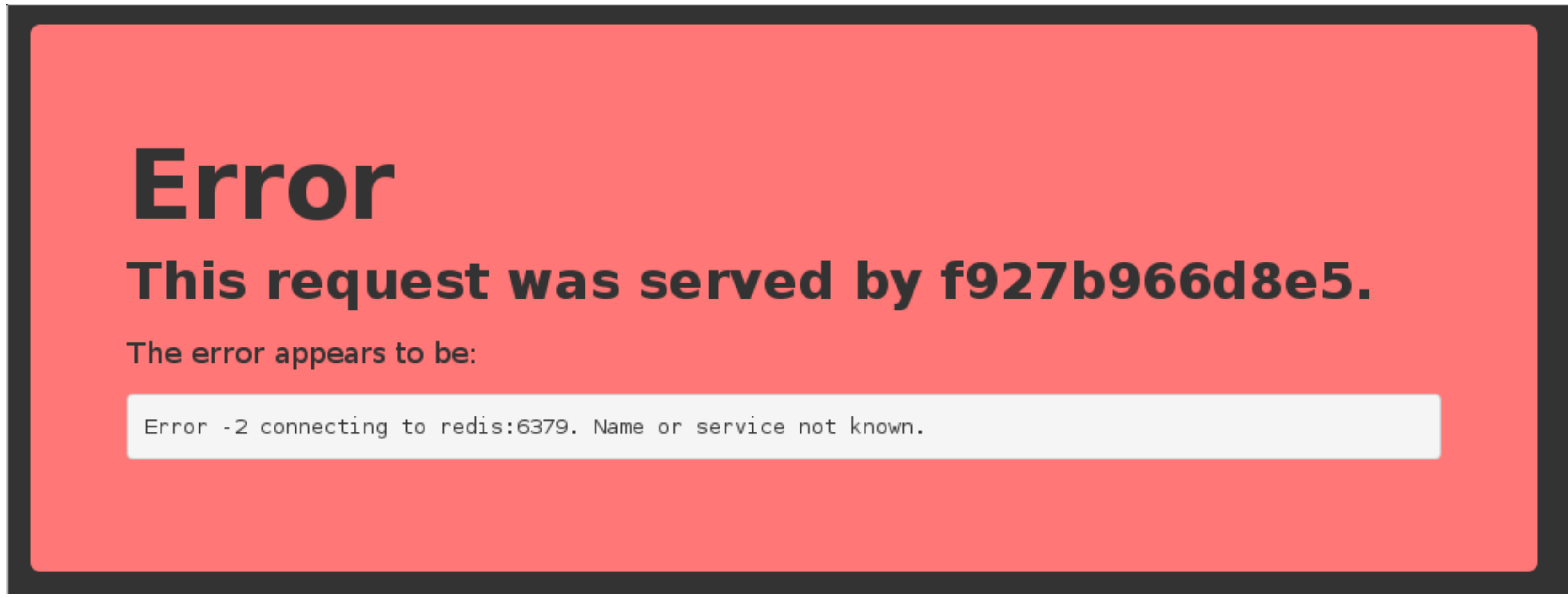


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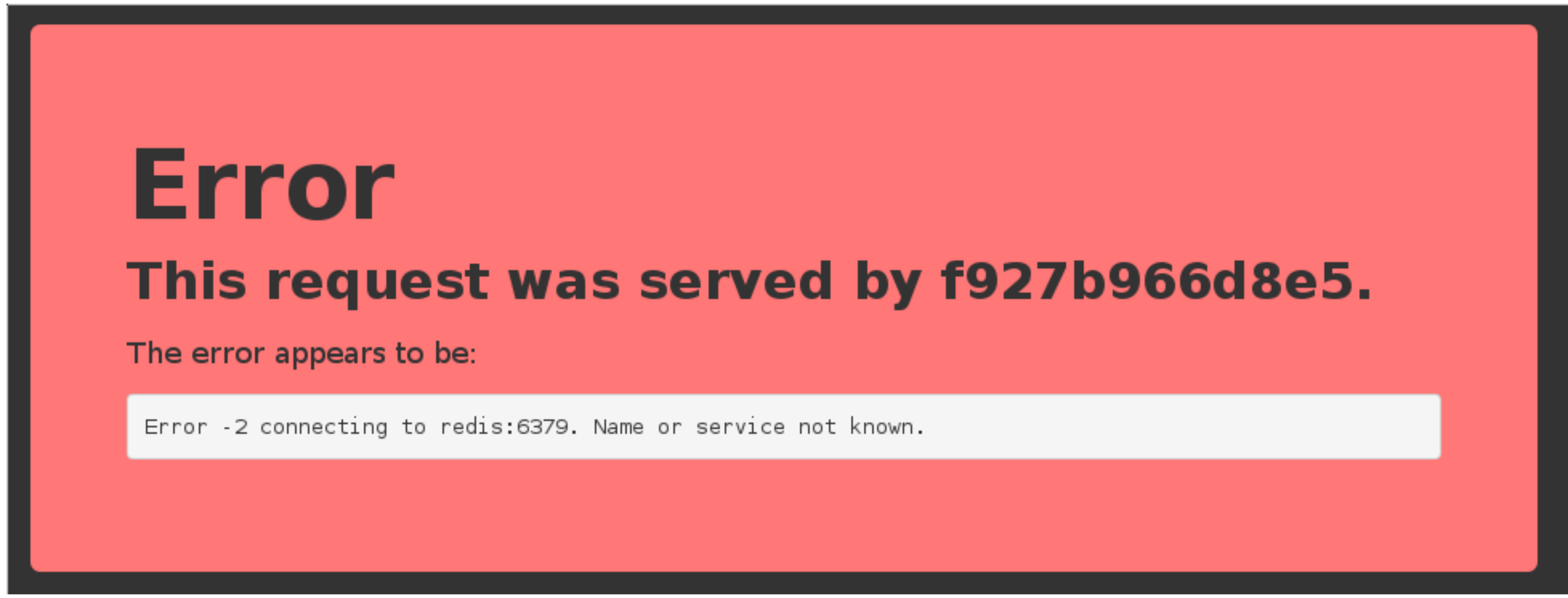
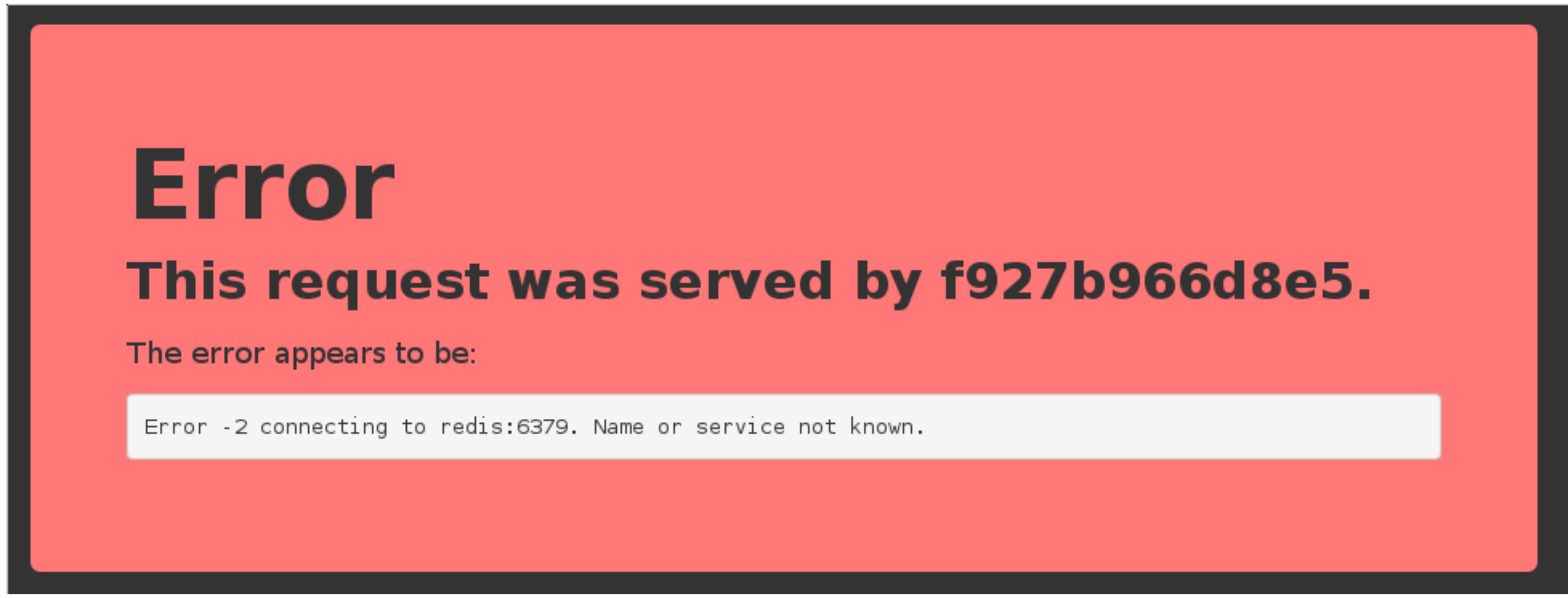


# Test the web server

- If we connect to the application now, we will see an error page:
- This is because the Redis service is not running.
- This container tries to resolve the name `redis`.

Note: we're not using a FQDN or an IP address here; just `redis`.



# Start the data store

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- That container must be on the same network as the web server.

Start the container:

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```

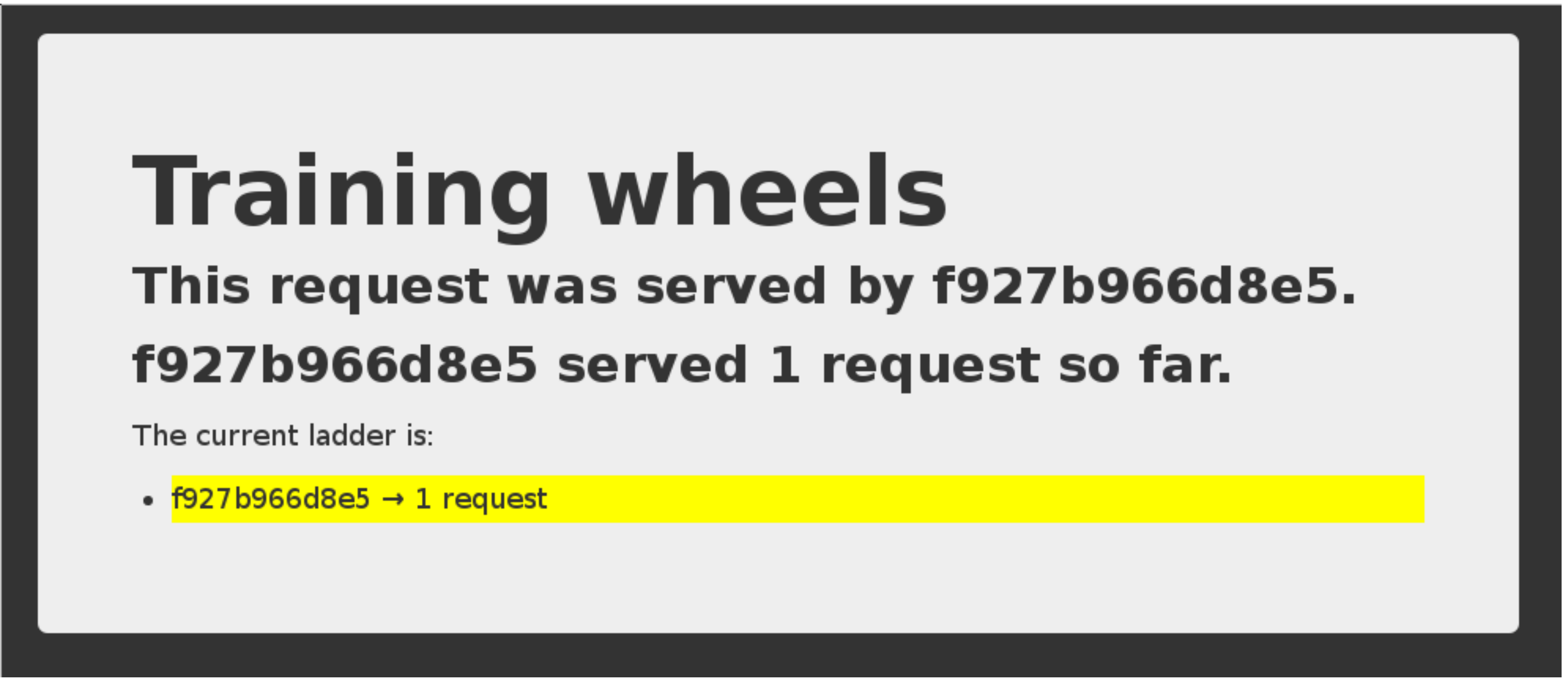
# Start the data store

- We need to start a Redis container.
- That container must be on the same network as the web server.
- It must have the right network alias (`redis`) so the application can find it.

Start the container:

```
$ docker run --net dev --net-alias redis -d redis
```

# Test the web server again



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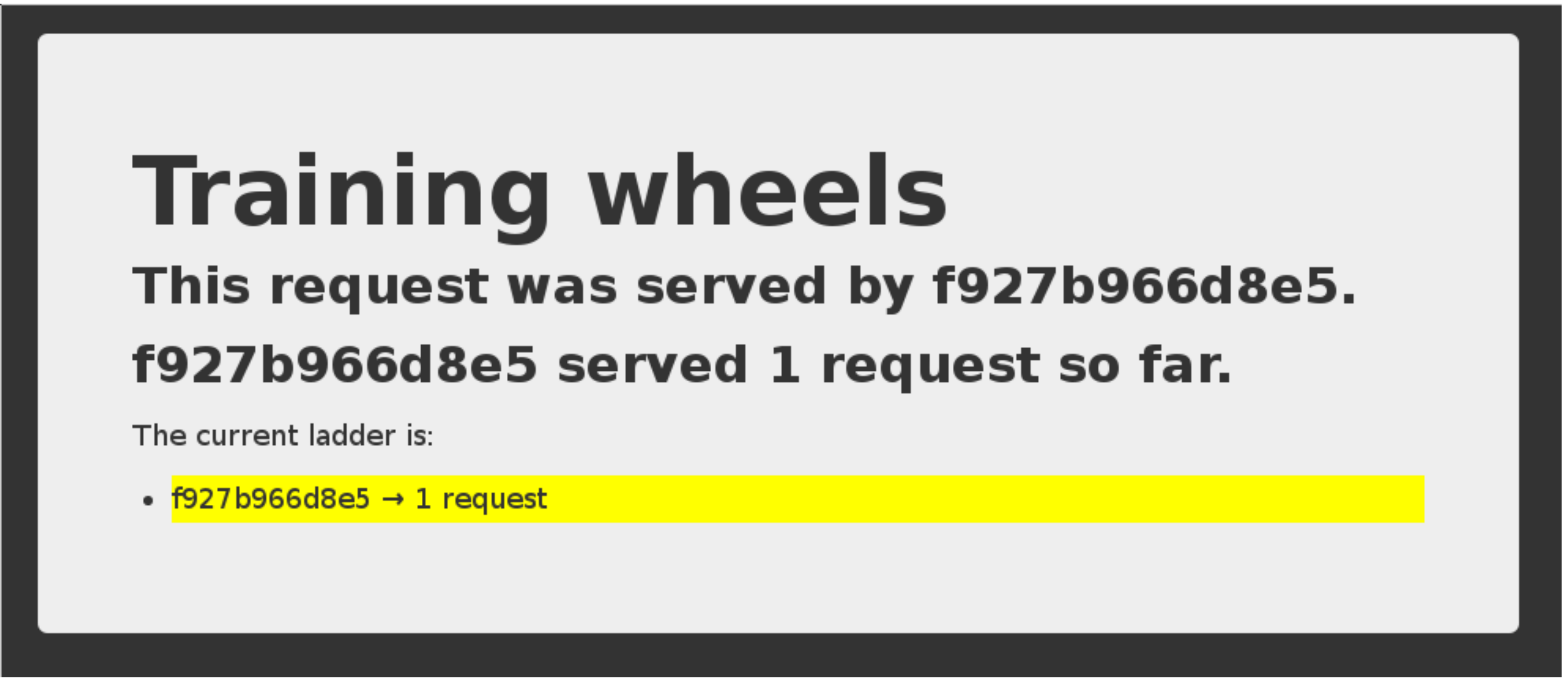


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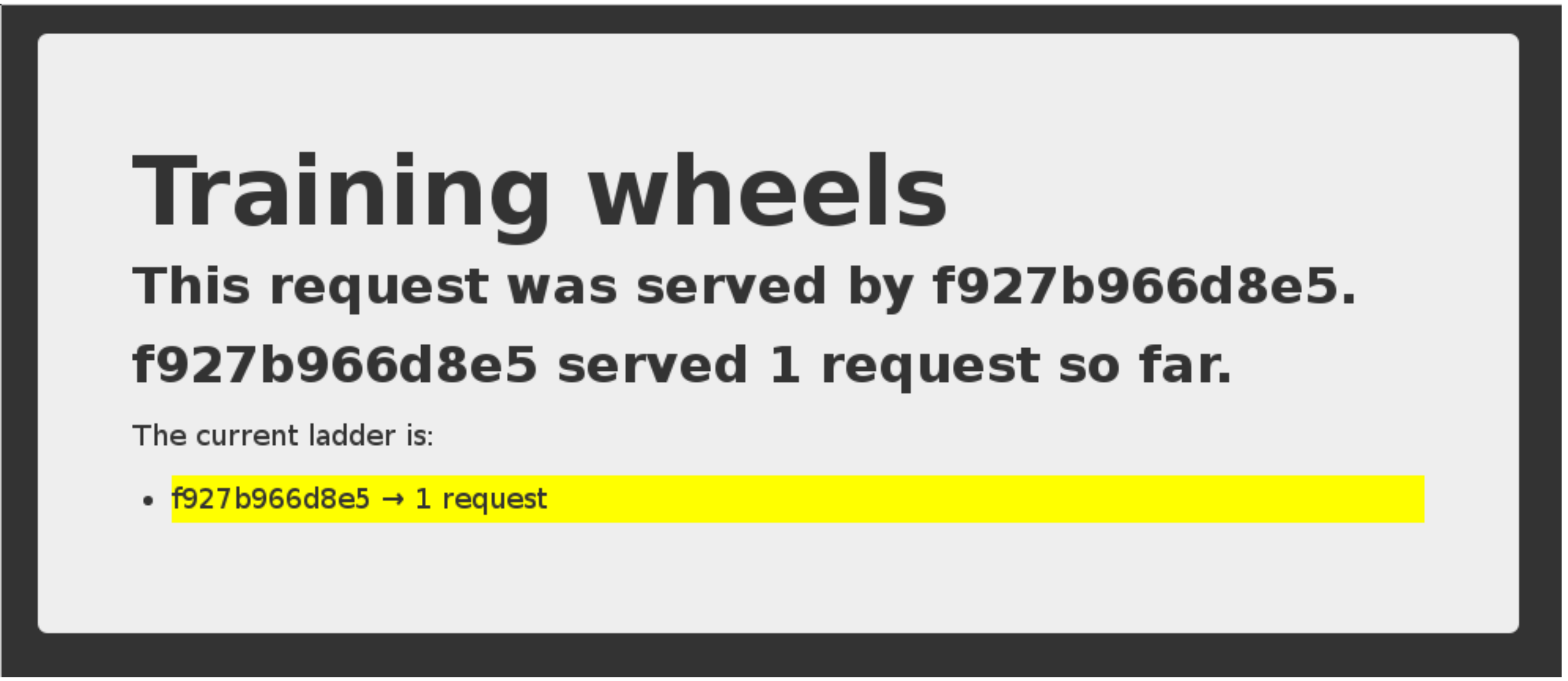

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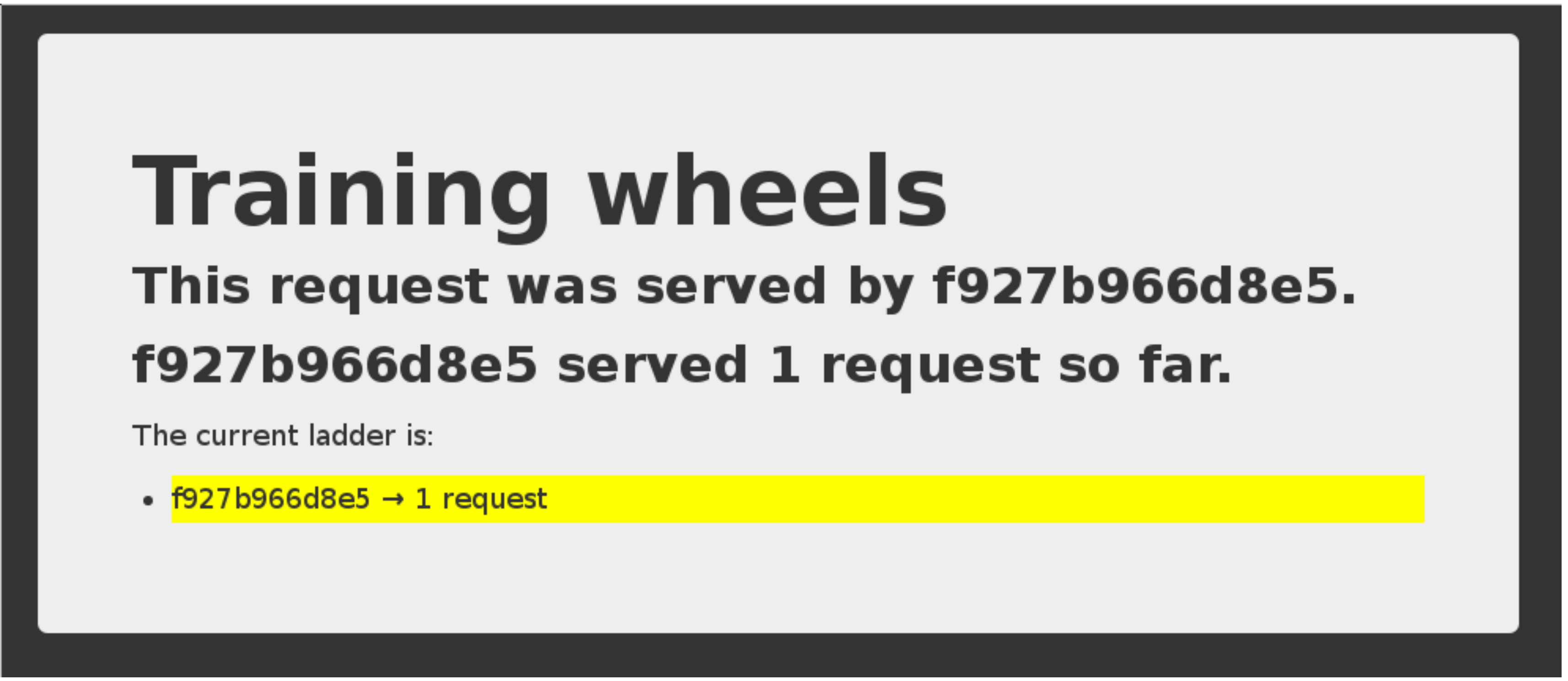


- If we connect to the application now, we should see that the app is working correctly:
- When the app tries to resolve `redis`, instead of getting a DNS error, it gets the IP address of our Redis container.

# A few words on *scope*

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- We can have the same network alias in different networks:

```bash
docker run --net dev --net-alias redis ...
docker run --net prod --net-alias redis ...
```

- We can even have multiple containers with the same alias in the same network

  (in that case, we get multiple DNS entries, aka "DNS round robin")

# Names are *local* to each network

Let's try to ping our `es` container from another container, when that other container is *not* on the `dev` network.

```
$ docker run --rm alpine ping es
ping: bad address 'es'
```

Names can be resolved only when containers are on the same network.

Containers can contact each other only when they are on the same network (you can try to ping using the IP address to verify).

# Docker Compose

# Compose for development stacks

Dockerfiles are great to build container images.

But what if we work with a complex stack made of multiple containers?

Eventually, we will want to write some custom scripts and automation to build, run, and connect
our containers together.

There is a better way: using Docker Compose.

In this section, you will use Compose to bootstrap a development environment.

# What is Docker Compose?

Docker Compose (formerly known as `fig`) is an external tool.

Unlike the Docker Engine, it is written in Python. It's open source as well.

The general idea of Compose is to enable a very simple, powerful onboarding workflow:

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Unlike the Docker Engine, it is written in Python. It's open source as well.

The general idea of Compose is to enable a very simple, powerful onboarding workflow:

1. Checkout your code.

2. Run `docker-compose up`.

3. Your app is up and running!

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- Compose can run the containers in the background, or in the foreground.
- When containers are running in the foreground, their aggregated output is shown.

Before diving in, let's see a small example of Compose in action.


$ d

# Checking if Compose is installed

If you are using the official training virtual machines, Compose has been pre-installed.

If you are using Docker for Mac/Windows or the Docker Toolbox, Compose comes with them.

If you are on Linux (desktop or server environment), you will need to install Compose from its release page or with `pip install docker-compose`.

You can always check that it is installed by running:

```
$ docker-compose --version
```

# Launching Our First Stack with Compose

First step: clone the source code for the app we will be working on.

```
$ cd
$ git clone --branch docker https://github.com/DataSystemsGroupUT/dataeng.git
...
$ cd dataeng
```

# Launching Our First Stack with Compose

Second step: start your app.

```
$ docker-compose up
```

Watch Compose build and run your app with the correct parameters,
including linking the relevant containers together.


$ d

# Launching Our First Stack with Compose

In a new terminal

```
$ docker ps
```

```
CONTAINER ID        IMAGE                          COMMAND                  CREATED             STATUS              PORTS                       NAMES
60d8f5b92115        dataeng_words                  "/bin/sh -c 'exec ja…"   3 seconds ago       Up 3 seconds        0.0.0.0:32783->8080/tcp     dataeng_words_1
d95c558b5413        jupyter/datascience-notebook   "tini -g -- start-no…"   3 seconds ago       Up 3 seconds        0.0.0.0:8888->8888/tcp      dataeng_notebook_1
2946248e06e2        dataeng_web                    "./dispatcher"           3 seconds ago       Up 3 seconds        0.0.0.0:32784->80/tcp       dataeng_web_1
e188ac32ab0b        dataeng_db                     "docker-entrypoint.s…"   3 seconds ago       Up 3 seconds        5432/tcp                    dataeng_db_1
riccardo@mbp: ~/_Projects/dataeng (docker) $
```

# Stopping the app

When you hit `^C`, Compose tries to gracefully terminate all of the containers.

After ten seconds (or if you press `^C` again) it will forcibly kill them.

# The `docker-compose.yml` file

Here is the file used in the demo:

```yaml
version: "3"

services:
  web:
    build: web
    ports:
    - 80
  db:
    build: db
  words:
    build: words
    ports:
    - 8080
```

# Compose file structure

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(By default, containers will be connected on a private, per-compose-file network.)

- `volumes` is optional and can define volumes to be used and/or shared by the containers.

# Compose file versions

The Docker documentation
has excellent information about the Compose file format if you need to know more about versions.

# Compose file versions

- Version 1 is legacy and shouldn't be used.

  (If you see a Compose file without `version` and `services`, it's a legacy v1 file.)

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- Version 3 added support for deployment options (scaling, rolling updates, etc).

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has excellent information about the Compose file format if you need to know more about versions.

# Containers in `docker-compose.yml`

Each service in the YAML file must contain either `build`, or `image`.

The other parameters are optional.

They encode the parameters that you would typically add to `docker run`.

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- `image` indicates an image name (local, or on a registry).
- If both are specified, an image will be built from the `build` directory and named `image`.

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# Container parameters

For the full list, check: https://docs.docker.com/compose/compose-file/

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You can specify local ports (i.e. `x:y` to expose public port `x`).

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You can specify local ports (i.e. `x:y` to expose public port x).

- `volumes` translates to one (or multiple) `-v` options.

You can use relative paths here.

For the full list, check: https://docs.docker.com/compose/compose-file/

# Compose commands

We already saw `docker-compose up`, but another one is `docker-compose build`.

It will execute `docker build` for all containers mentioning a `build` path.

It can also be invoked automatically when starting the application:

```
docker-compose up --build
```

Another common option is to start containers in the background:

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

# Check container status

It can be tedious to check the status of your containers with `docker ps`, especially when running multiple apps at the same time.

Compose makes it easier; with `docker-compose ps` you will see only the status of the
containers of the current stack:

```
$ docker-compose ps
Name                        Command               State            Ports
------------------------------------------------------------------------------
trainingwheels_redis_1   /entrypoint.sh red    Up      6379/tcp
trainingwheels_www_1     python counter.py     Up      0.0.0.0:8000->5000/tcp
```

# Cleaning up (1)

If you have started your application in the background with Compose and want to stop it easily, you can use the `kill` command:

```
$ docker-compose kill
```

Likewise, `docker-compose rm` will let you remove containers (after confirmation):

```
$ docker-compose rm
Going to remove trainingwheels_redis_1, trainingwheels_www_1
Are you sure? [yN] y
Removing trainingwheels_redis_1...
Removing trainingwheels_www_1...
```

# Cleaning up (2)

Alternatively, `docker-compose down` will stop and remove containers.

It will also remove other resources, like networks that were created for the application.

```
$ docker-compose down
Stopping trainingwheels_www_1 ... done
Stopping trainingwheels_redis_1 ... done
Removing trainingwheels_www_1 ... done
Removing trainingwheels_redis_1 ... done
```

Use `docker-compose down -v` to remove everything including volumes.

# Special handling of volumes

Compose is smart. If your container uses volumes, when you restart your
application, Compose will create a new container, but carefully re-use
the volumes it was using previously.

This makes it easy to upgrade a stateful service, by pulling its new image and just restarting your stack with Compose.

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  E.g. in the previous example, service www will create a container `ocarina_www_1`.

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- All resources created by Compose are tagged with this project name.
- The project name also appears as a prefix of the names of the resources.

  E.g. in the previous example, service www will create a container `ocarina_www_1`.
- The project name can be overridden with `docker-compose -p`.