Docker Tutorial

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Summary

Part 1.
Introduction

What is Docker (1/3)

"Docker is an open platform for developers and sysadmins to build, ship, and run distributed applications. Consisting of Docker Engine, a portable, lightweight runtime and packaging tool, and Docker Hub, a cloud service for sharing applications and automating workflows, Docker enables apps to be quickly assembled from components and eliminates the friction between development, QA, and production environments. As a result, IT can ship faster and run the same app, unchanged, on laptops, data center VMs, and any cloud."

source: `https://www.docker.com/whatisdocker/`

What is Docker (2/3)

- a container manager
  - lightweight virtualisation
    (host and guest systems share the same kernel)
  - based on linux namespaces and cgroups

- massively copy-on-write
  - immutable images
  - instant deployment
  - suitable for micro-services (one process, one container)

$\rightarrow$ immutable architecture

What is Docker (3/3)

- a build system
  - images may be build from sources
  - using a simple DSL (`Dockerfile`)
- a set of REST APIs
  - Engine API (control the docker engine)
  - Plugin API (extend the engine $\rightarrow$ network, storage, authorisation)
  - Registry API (publish/download images)
  - Swarm API (manage a clusted of docker machines)

How Docker helps?

- **normalisation:** same environment (container image) for
  - development
  - jobs on the computing grid
  - continuous integration
  - peer review
  - demonstrations, tutorials
  - technology transfer

- **archival** *(ever tried to reuse old codes)*
  - source → Dockerfile = recipe to rebuild the env from scratch
  - binary → docker image = immutable snapshot of the software with its runtime environment
    → can be rerun it at any time later

In practice

A docker image is an immutable snapshot of the filesystem

A docker container is

- a temporary file system
  - layered over an immutable fs (docker image)
  - fully writable (copy-on-write[1])
  - dropped at container's end of life (unless a `commit` is made)
- a network stack
  - with its own private address *(by defaut in 172.17.x.x)*
- a process group
  - one main process launched inside the container
  - all sub-process SIGKILLed when the main process exits

[1] several possible methods: overlayfs (default), btrfs, lvm, zfs, aufs

Installation

https://docs.docker.com/engine/installation/

Native installation:

- requires linux kernel >3.8

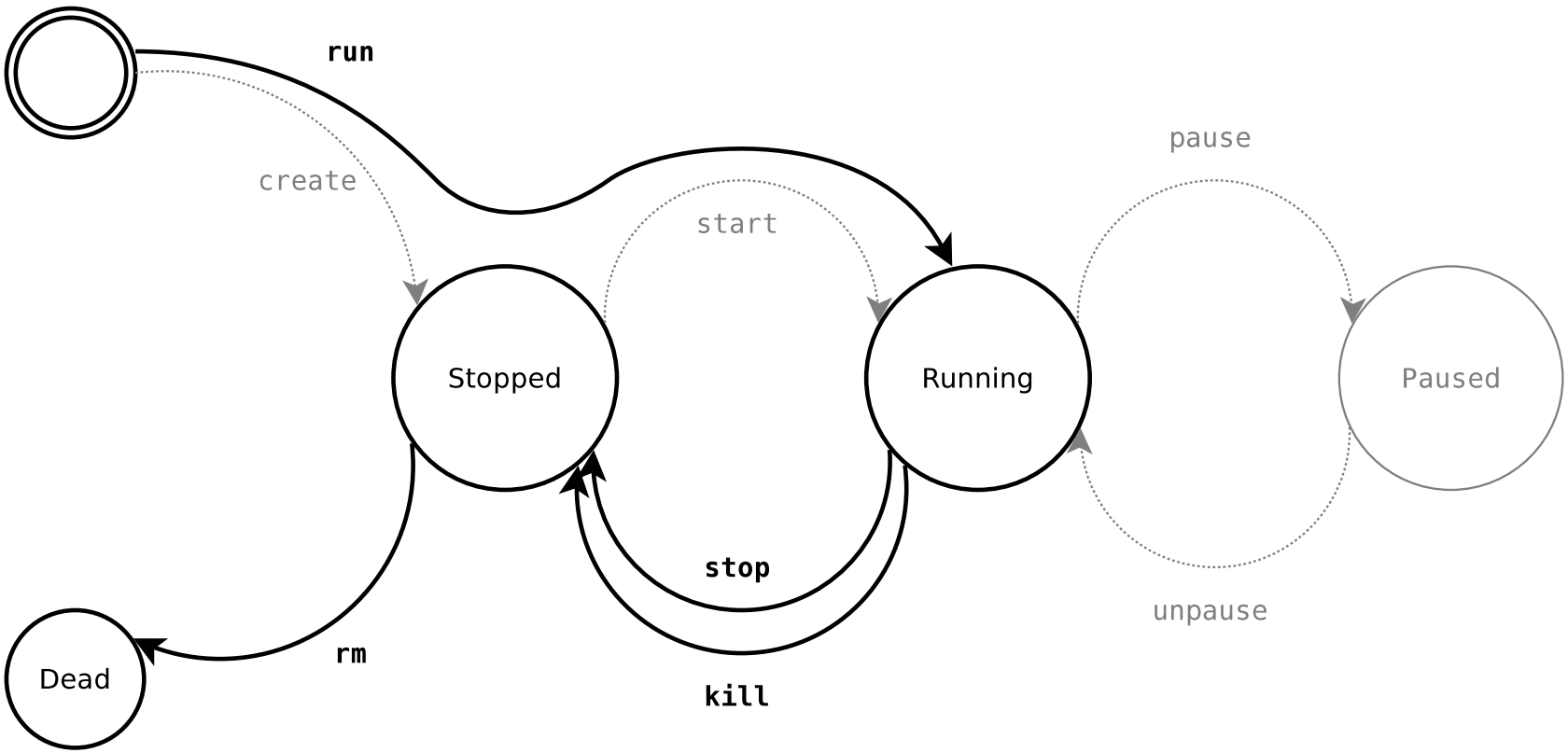
Docker Machine:

- a command for provisionning an managing docker nodes deployed:
  - in a local VM (virtualbox)
  - remotely (many cloud API supported)

Part 2.
Managing containers

- create/start/stop/remove containers
- inspect containers
- interact, commit new images

Lifecycle of a docker container



Container management commands

command	description
`docker create` *image* [*command*] `docker run` *image* [*command*]	create the container = `create` + `start`
`docker rename` *container new_name* `docker update` *container*	rename the container update the container config
`docker start` *container...* `docker stop` *container...* `docker kill` *container...* `docker restart` *container...*	start the container graceful[2] stop kill (SIGKILL) the container = `stop` + `start`
`docker pause` *container...* `docker unpause` *container...*	suspend the container resume the container
`docker rm` [`-f`[3]] *container...*	destroy the container

[2] send SIGTERM to the main process + SIGKILL 10 seconds later

[3] `-f` allows removing running containers (= `docker kill` + `docker rm`)

Notes about the container lifecycle

- the container filesystem is created in `docker create` and dropped in `docker rm`
  - it is persistent across `stop`/`start`
- the container configuration is mostly static
  - config is set in `create`/`run`
  - `docker update` may change only a few parameters (eg: cpu/ram/blkio allocations)
  - changing other parameters require destroying and re-creating the container
- other commands are rather basic

```
Usage:  docker create [OPTIONS] IMAGE [COMMAND] [ARG...]

Create a new container

  -a, --attach=[]                Attach to STDIN, STDOUT or STDERR
  --add-host=[]                  Add a custom host-to-IP mapping (host:ip)
  --blkio-weight=0               Block IO (relative weight), between 10 and 1000
  --cpu-shares=0                 CPU shares (relative weight)
  --cap-add=[]                   Add Linux capabilities
  --cap-drop=[]                  Drop Linux capabilities
  --cgroup-parent=               Optional parent cgroup for the container
  --cidfile=                     Write the container ID to the file
  --cpu-period=0                 Limit CPU CFS (Completely Fair Scheduler) period
  --cpu-quota=0                  Limit CPU CFS (Completely Fair Scheduler) quota
  --cpuset-cpus=                 CPUs in which to allow execution (0-3, 0,1)
  --cpuset-mems=                 MEMs in which to allow execution (0-3, 0,1)
  --device=[]                    Add a host device to the container
  --disable-content-trust=true   Skip image verification
  --dns=[]                       Set custom DNS servers
  --dns-opt=[]                   Set DNS options
  --dns-search=[]                Set custom DNS search domains
  -e, --env=[]                   Set environment variables
  --entrypoint=                  Overwrite the default ENTRYPOINT of the image
  --env-file=[]                  Read in a file of environment variables
  --expose=[]                    Expose a port or a range of ports
  --group-add=[]                 Add additional groups to join
  -h, --hostname=                Container host name
  --help=false                   Print usage
  -i, --interactive=false        Keep STDIN open even if not attached
  --ipc=                         IPC namespace to use
  --kernel-memory=               Kernel memory limit
  -l, --label=[]                 Set meta data on a container
  --label-file=[]                Read in a line delimited file of labels
  --link=[]                      Add link to another container
  --log-driver=                  Logging driver for container
  --log-opt=[]                   Log driver options
  --lxc-conf=[]                  Add custom lxc options
  -m, --memory=                  Memory limit
  --mac-address=                 Container MAC address (e.g. 92:d0:c6:0a:29:33)
  --memory-reservation=          Memory soft limit
  --memory-swap=                 Total memory (memory + swap), '-1' to disable swap
  --memory-swappiness=-1         Tuning container memory swappiness (0 to 100)
  --name=                        Assign a name to the container
  --net=default                  Set the Network for the container
  --oom-kill-disable=false       Disable OOM Killer
  -P, --publish-all=false        Publish all exposed ports to random ports
  -p, --publish=[]               Publish a container's port(s) to the host
  --pid=                         PID namespace to use
  --privileged=false             Give extended privileges to this container
  --read-only=false              Mount the container's root filesystem as read only
  --restart=no                   Restart policy to apply when a container exits
  --security-opt=[]              Security Options
  --stop-signal=SIGTERM          Signal to stop a container, SIGTERM by default
  -t, --tty=false                Allocate a pseudo-TTY
  -u, --user=                    Username or UID (format: <name|uid>[:<group|gid>])
  --ulimit=[]                    Ulimit options
  --uts=                         UTS namespace to use
  -v, --volume=[]                Bind mount a volume
  --volume-driver=               Optional volume driver for the container
  --volumes-from=[]              Mount volumes from the specified container(s)
  -w, --workdir=                 Working directory inside the container
```

```
Usage:  docker start [OPTIONS] CONTAINER [CONTAINER...]

Start one or more stopped containers

  -a, --attach=false         Attach STDOUT/STDERR and forward signals
  --help=false               Print usage
  -i, --interactive=false    Attach container's STDIN
```

```
Usage:  docker stop [OPTIONS] CONTAINER [CONTAINER...]

Stop a running container.
Sending SIGTERM and then SIGKILL after a grace period

  --help=false       Print usage
  -t, --time=10      Seconds to wait for stop before killing it
```

```
Usage:  docker restart [OPTIONS] CONTAINER [CONTAINER...]

Restart a container

  --help=false       Print usage
  -t, --time=10      Seconds to wait for stop before killing the container
```

```
Usage:  docker kill [OPTIONS] CONTAINER [CONTAINER...]

Kill a running container

  --help=false         Print usage
  -s, --signal=KILL    Signal to send to the container
```

```
Usage:  docker rm [OPTIONS] CONTAINER [CONTAINER...]

Remove one or more containers

  -f, --force=false      Force the removal of a running container (uses SIGKILL)
  --help=false           Print usage
  -l, --link=false       Remove the specified link
  -v, --volumes=false    Remove the volumes associated with the container
```

```
Usage:  docker pause [OPTIONS] CONTAINER [CONTAINER...]

Pause all processes within a container

  --help=false    Print usage
```

`docker run` — Run a container

https://docs.docker.com/reference/run/

`docker run [ options ] image [ arg0 arg1...]`

→ create a container and start it

- the container filesystem is initialised from image *image*
- *arg0..argN* is the command run inside the container (as PID 1)

```
$ docker run debian /bin/hostname
f0d0720bd373
$ docker run debian date +%H:%M:%S
17:10:13
$ docker run debian true ; echo $?
0
$ docker run debian false ; echo $?
1
```

`docker run` — Foreground mode vs. Detached mode

- Foreground mode is the default
  - *stdout* and *stderr* are redirected to the terminal
  - `docker run` propagates the exit code of the main process
- With `-d`, the container is run in detached mode:
  - displays the ID of the container
  - returns immediately

```
$ docker run debian date
Tue Jan 20 17:32:07 UTC 2015
$ docker run -d debian date
4cbdefb3d3e1331ccf7783b32b47774fefca426e03a2005d69549f3ff06b9306
$ docker logs 4cbdef
Tue Jan 20 17:32:16 UTC 2015
```

`docker run` — TTY allocation

Use `-t` to allocate a pseudo-terminal for the container

→ without a tty

```
$ docker run debian ls
bin
boot
dev
...
$ docker run debian bash
$
```

→ with a tty (`-t`)

```
$ docker run -t debian ls
bin   dev  home  lib64   mnt  proc  run   selinux  sys  usr
boot  etc  lib   media   opt  root  sbin  srv      tmp  var
$ docker run -t debian bash
root@10d90c09d9ac:/#
```

`docker run` — interactive mode

- By default containers are non-interactive
  - *stdin* is closed immediately
  - terminal signals are not forwarded[4]

```
$ docker run -t debian bash
root@6fecc2e8ab22:/# date
^C
$
```

- With `-i` the container runs interactively
  - *stdin* is usable
  - terminal signals are forwarded to the container

```
$ docker run -t -i debian bash
root@78ff08f46cdb:/# date
Tue Jan 20 17:52:01 UTC 2015
root@78ff08f46cdb:/# ^C
root@78ff08f46cdb:/#
```

[4] `^C` only detaches the terminal, the container keeps running in background

`docker run` — override defaults (1/2)

user (`-u`)

```
$ docker run debian whoami
root
$ docker run -u nobody debian whoami
nobody
```

working directory (`-w`)

```
$ docker run debian pwd
/
$ docker run -w /opt debian pwd
/opt
```

`docker run` — override defaults (2/2)

environment variables (`-e`)

```
$ docker run debian sh -c 'echo $FOO $BAR'

$ docker run -e FOO=foo -e BAR=bar debian sh -c 'echo $FOO $BAR'
foo bar
```

hostname (`-h`)

```
$ docker run debian hostname
830e47237187
$ docker run -h my-nice-container debian hostname
my-nice-hostname
```

`docker run` — set the container name

`--name` assigns a name for the container
(by default a random name is generated)

```
$ docker run -d -t debian
da005df0d3aca345323e373e1239216434c05d01699b048c5ff277dd691ad535
$ docker run -d -t --name blahblah debian
0bd3cb464ff68eaf9fc43f0241911eb207fefd9c1341a0850e8804b7445ccd21
$ docker ps
CONTAINER ID   IMAGE       COMMAND      CREATED             ..  NAMES
0bd3cb464ff6   debian:7.5  "/bin/bash"  6 seconds ago           blahblah
da005df0d3ac   debian:7.5  "/bin/bash"  About a minute ago      drunk_darwin
$ docker stop blahblah drunk_darwin
```

Note: Names must be unique

```
$ docker run --name blahblah debian true
2015/01/20 19:31:21 Error response from daemon: Conflict, The name blahblah is already assigned
to 0bd3cb464ff6. You have to delete (or rename) that container to be able to assign blahblah to a
 container again.
```

docker run — autoremove

By default the container still exists after command exit

```
$ docker run --name date-ctr debian date
Tue Jan 20 18:38:21 UTC 2015
$ docker start date-ctr
date-ctr
$ docker logs date-ctr
Tue Jan 20 18:38:21 UTC 2015
Tue Jan 20 18:38:29 UTC 2015
$ docker rm date-ctr
date-ctr
$ docker start date-ctr
Error response from daemon: No such container: date-ctr
2015/01/20 19:39:27 Error: failed to start one or more containers
```

With `--rm` the container is automatically removed after exit

```
$ docker run --rm --name date-ctr debian date
Tue Jan 20 18:41:49 UTC 2015
$ docker rm date-ctr
Error response from daemon: No such container: date-ctr
2015/01/20 19:41:53 Error: failed to remove one or more containers
```

Common `rm` idioms

Launch an throwaway container for debugging/testing purpose

```
$ docker run --rm -t -i debian
root@4b71c9a39326:/#
```

Remove all zombie containers

```
$ docker ps -a
CONTAINER ID  IMAGE       COMMAND     CREATED              STATUS
2b291251a415  debian:7.5  "hostname"  About a minute ago   Exited (0) About a mi
6d36a2f07e18  debian:7.5  "false"     2 minutes ago        Exited (1) 2 minutes
0f563f110328  debian:7.5  "true"      2 minutes ago        Exited (0) 2 minutes
4b57d0327a20  debian:7.5  "uname -a"  5 minutes ago        Exited (0) 5 minutes
$ docker container prune
WARNING! This will remove all stopped containers.
Are you sure you want to continue? [y/N] y
Deleted Containers:
2b291251a415
6d36a2f07e18
0f563f110328
4b57d0327a20
```

Inspecting the container

command	description
`docker ps`	list running containers
`docker ps -a`	list all containers
`docker logs` [`-f`[5]] *container*	show the container output (*stdout+stderr*)
`docker top` *container* [*ps options*]	list the processes running inside the containers[6]
`docker stats` [*container*]	display live usage statistics[7]
`docker diff` *container*	show the differences with the image (modified files)
`docker port` *container*	list port mappings
`docker inspect` *container...*	show low-level infos (in json format)

[5] with `-f`, `docker logs` follows the output (à la `tail -f`)

[6] `docker top` is the equivalent of the `ps` command in unix

[7] `docker stats` is the equivalent of the `top` command in unix

Interacting with the container

command	description
`docker attach` *container*	attach to a running container (stdin/stdout/stderr)
`docker cp` *container:path hostpath*|- `docker cp` *hostpath*|- *container:path*	copy files from the container copy files into the container
`docker export` *container*	export the content of the container (tar archive)
`docker exec` *container args...*	run a command in an existing container (**useful** for debugging)
`docker wait` *container*	wait until the container terminates and return the exit code
`docker commit` *container image*	commit a new docker image (snapshot of the container)

docker commit example

```
$ docker run --name my-container -t -i debian
root@3b397d383faf:/# cat >> /etc/bash.bashrc <<EOF
> echo 'hello!'
> EOF
root@3b397d383faf:/# exit
$ docker start --attach my-container
my-container
hello!
root@3b397d383faf:/# exit
$ docker diff my-container
C /etc
C /etc/bash.bashrc
A /.bash_history
C /tmp
$ docker commit my-container hello
a57e91bc3b0f5f72641f19cab85a7f3f860a1e5e9629439007c39fd76f37c5dd
$ docker rm my-container
my-container
$ docker run --rm -t -i hello
hello!
root@386ed3934b44:/# exit
$ docker images -t
511136ea3c5a Virtual Size: 0 B
  af6bdc397692 Virtual Size: 115 MB
    667250f9a437 Virtual Size: 115 MB Tags: debian:wheezy, debian:latest
      a57e91bc3b0f Virtual Size: 115 MB Tags: hello:latest
```

Part 3.
Inputs/Outputs

- Data volumes (persistent data)
  - mounted from the host filesystem
  - named volumes (interal + volume plugins)
- Devices
- Links
- Publishing ports (NAT)

`docker run` — mount external volumes

```
docker run -v /hostpath:/containerpath[:ro] ...
```

`-v` mounts the location */hostpath* from the host filesystem at the location */containerpath* inside the container

With the "`:ro`" suffix, the mount is read-only

Purposes:

- store persistent data outside the container
- provide inputs: data, config files, . . . (read-only mode)
- inter-process communicattion (unix sockets, named pipes)

mount examples (1/2)

Persistent data

```
$ docker run --rm -t -i -v /tmp/persistent:/persistent debian
root@0aeedfeb7bf9:/# echo "blahblah" >/persistent/foo
root@0aeedfeb7bf9:/# exit
$ cat /tmp/persistent/foo
blahblah
$ docker run --rm -t -i -v /tmp/persistent:/persistent debian
root@6c8ed008c041:/# cat /persistent/foo
blahblah
```

Inputs (read-only volume)

```
$ mkdir /tmp/inputs
$ echo hello > /tmp/inputs/bar
$ docker run --rm -t -i -v /tmp/inputs:/inputs:ro debian
root@05168a0eb322:/# cat /inputs/bar
hello
root@05168a0eb322:/# touch /inputs/foo
touch: cannot touch `/inputs/foo': Read-only file system
```

mount examples (2/2)

Named pipe

```
$ mkfifo /tmp/fifo
$ docker run -d -v /tmp/fifo:/fifo debian sh -c 'echo blah blah> /fifo'
ff0e44c25e10d516ce947eae9168060ee25c2a906f62d63d9c26a154b6415939
$ cat /tmp/fifo
blah blah
```

Unix socket

```
$ docker run --rm -t -i -v /dev/log:/dev/log debian
root@56ec518d3d4e:/# logger blah blah blah
root@56ec518d3d4e:/# exit
$ sudo tail /var/log/messages | grep logger
Jan 21 08:07:59 halfoat logger: blah blah blah
```

`docker run` — named volumes

Named volumes

- stored inside `/var/lib/docker`
- lifecycle managed with the `docker volume` command
- plugin API to provide shared storage over a cluster/cloud[8]

```
$ docker volume create my-volume
my-volume
$ docker volume ls
DRIVER              VOLUME NAME
local               my-volume
$ docker run --rm -t -i -v my-volume:/vol busybox
/ # echo foo > /vol/bar
/ # ^D
$ docker volume inspect my-volume|grep Mountpoint
        "Mountpoint": "/var/lib/docker/volumes/my-volume/_data",
$ docker run --rm -t -i -v my-volume:/vol busybox cat /vol/bar
foo
$ docker volume rm my-volume
my-volume
```

[8] https://docs.docker.com/engine/tutorials/dockervolumes/

`docker run` — grant access to a device

By default devices are not usable inside the container

```
$ docker run --rm debian  fdisk -l /dev/sda
root@dcba37b0c0bd:/# fdisk -l /dev/sda
fdisk: cannot open /dev/sda: No such file or directory

$ docker run --rm debian  sh -c 'mknod /dev/sda b 8 0 && fdisk -l /dev/sda'
fdisk: cannot open /dev/sda: Operation not permitted

$ docker run --rm -v /dev/sda:/dev/sda debian  fdisk -l /dev/sda
fdisk: cannot open /dev/sda: Operation not permitted
```

They can be whitelisted with `--device`

`docker run --device` *`/hostpath[:/containerpath ]`* ...

```
$ docker run --rm --device /dev/sda debian  fdisk -l /dev/sda
Disk /dev/sda: 250.1 GB, 250059350016 bytes
...
```

`docker run` — inter-container links (legacy links[9])

Containers cannot be assigned a static IP address (by design)
→ service discovery is a must

Docker "links" are the most basic way to discover a service

`docker run --link` *ctr*:*alias* ...

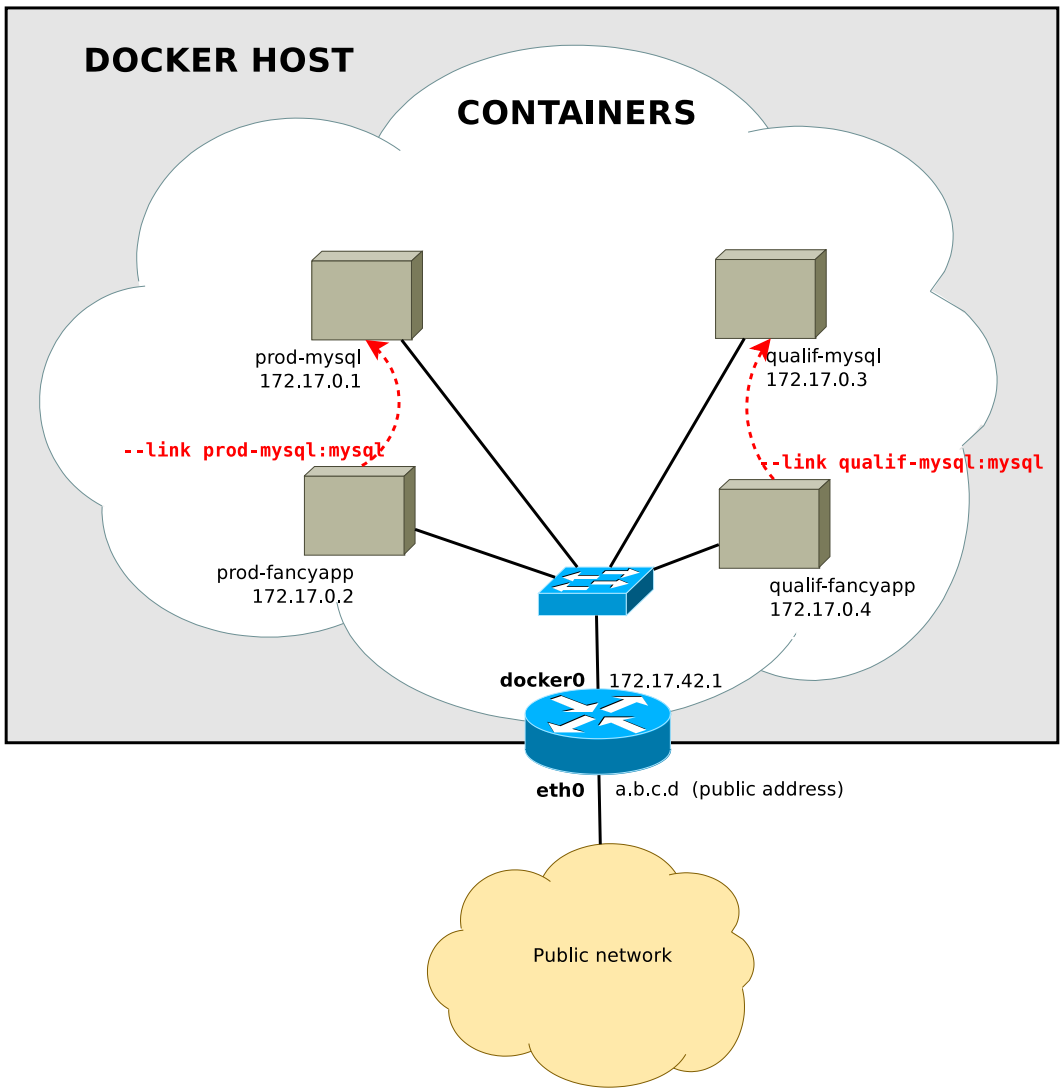
→ container *ctr* will be known as *alias* inside the new container

```
$ docker run --name my-server debian sh -c 'hostname -i && sleep 500' &
172.17.0.4

$ docker run --rm -t -i --link my-server:srv debian
root@d752180421cc:/# ping srv
PING srv (172.17.0.4): 56 data bytes
64 bytes from 172.17.0.4: icmp_seq=0 ttl=64 time=0.195 ms
```

[9] since v1.9.0, links are superseded by user-defined networks

Legacy links

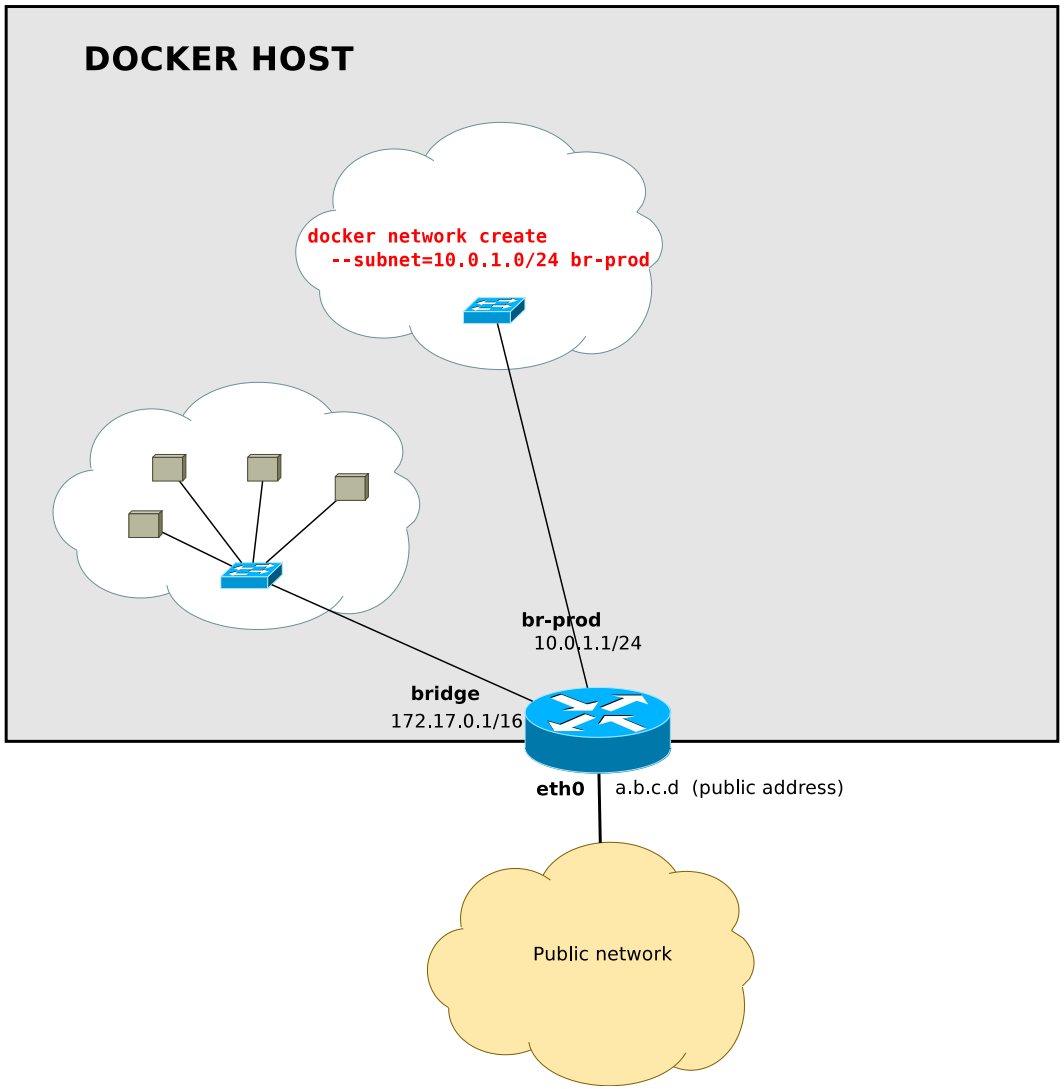
⚠ deprecated feature



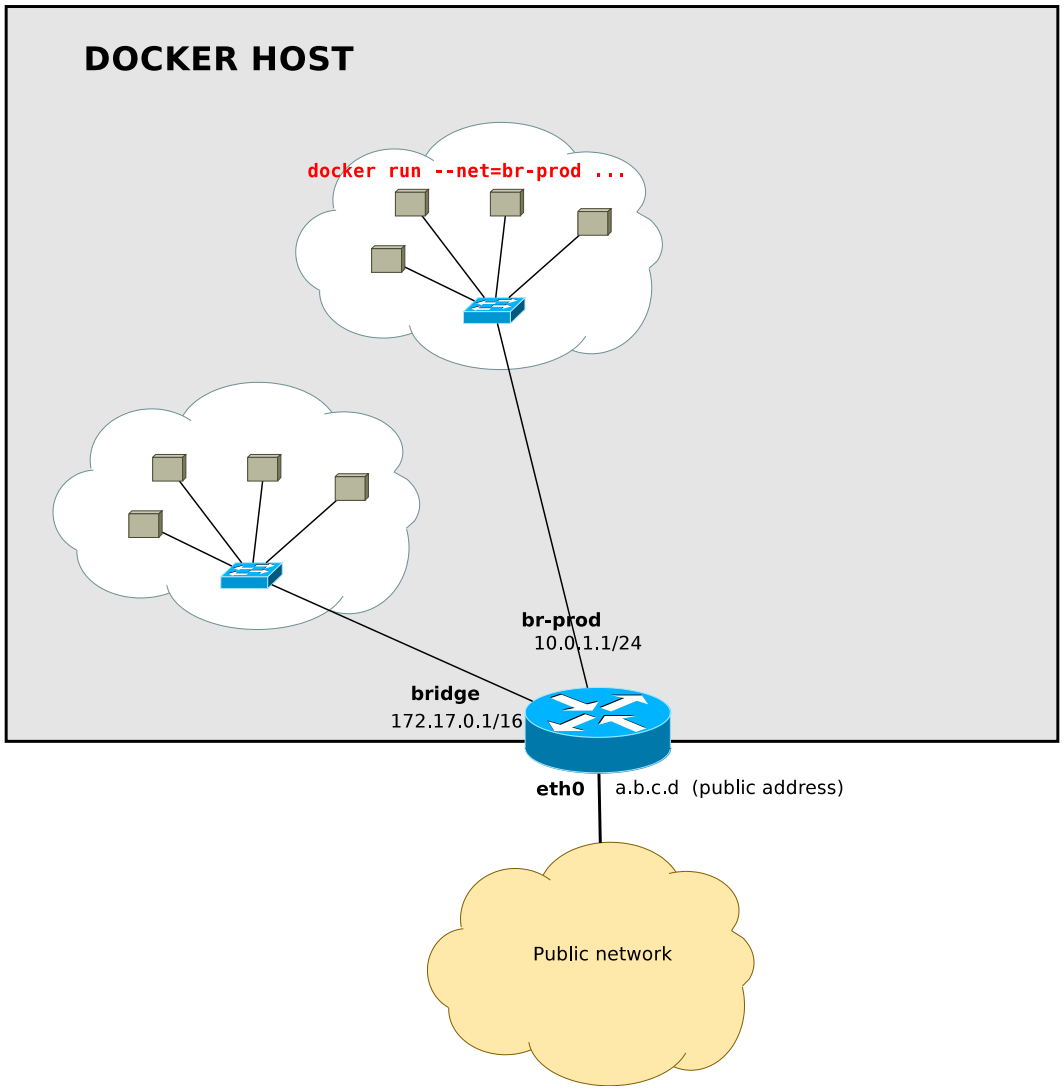
User-defined networks (since v1.9.0)

- by default new containers are connected to the main network (named "bridge", 172.17.0.0/16)
- the user can create additional networks:
  `docker network create` *NETWORK*
- newly created containers are connected to one network:
  `docker run --net=`*NETWORK*
- container may be dynamically attached/detached to any network:
  `docker network connect` *NETWORK CONTAINER*
  `docker network disconnect` *NETWORK CONTAINER*
- networks are isolated from each other, communications is possible by attaching a container to multiple networks

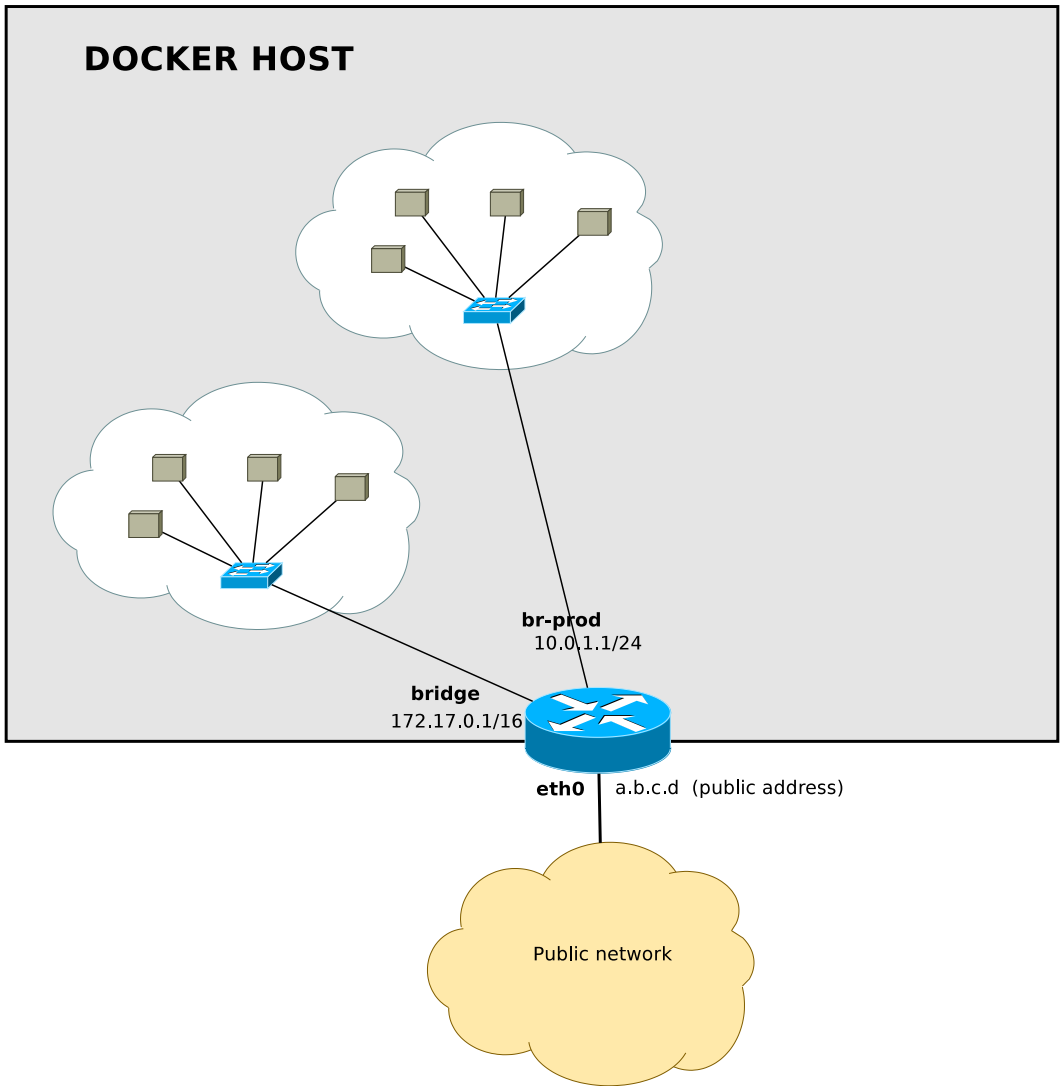
User-defined networks example



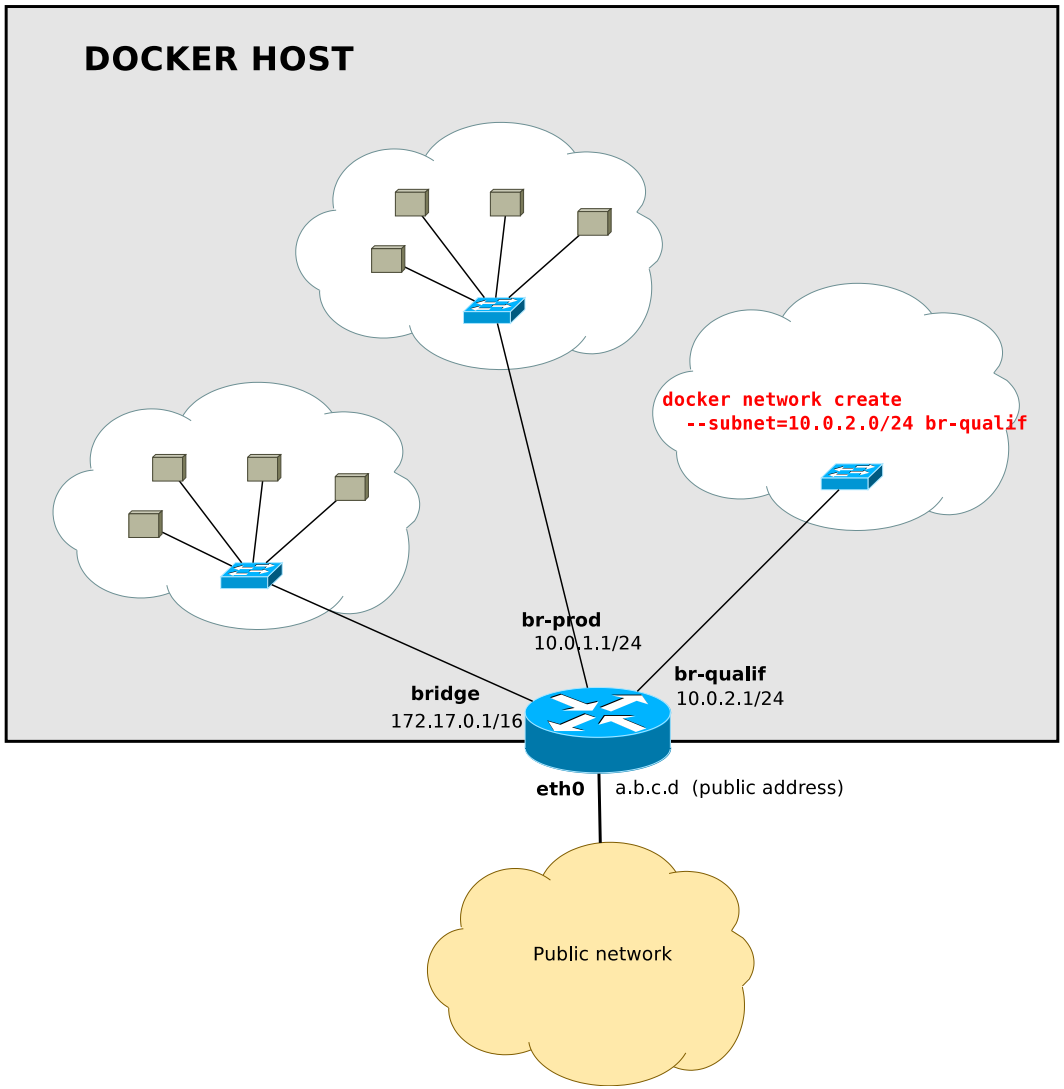
User-defined networks example



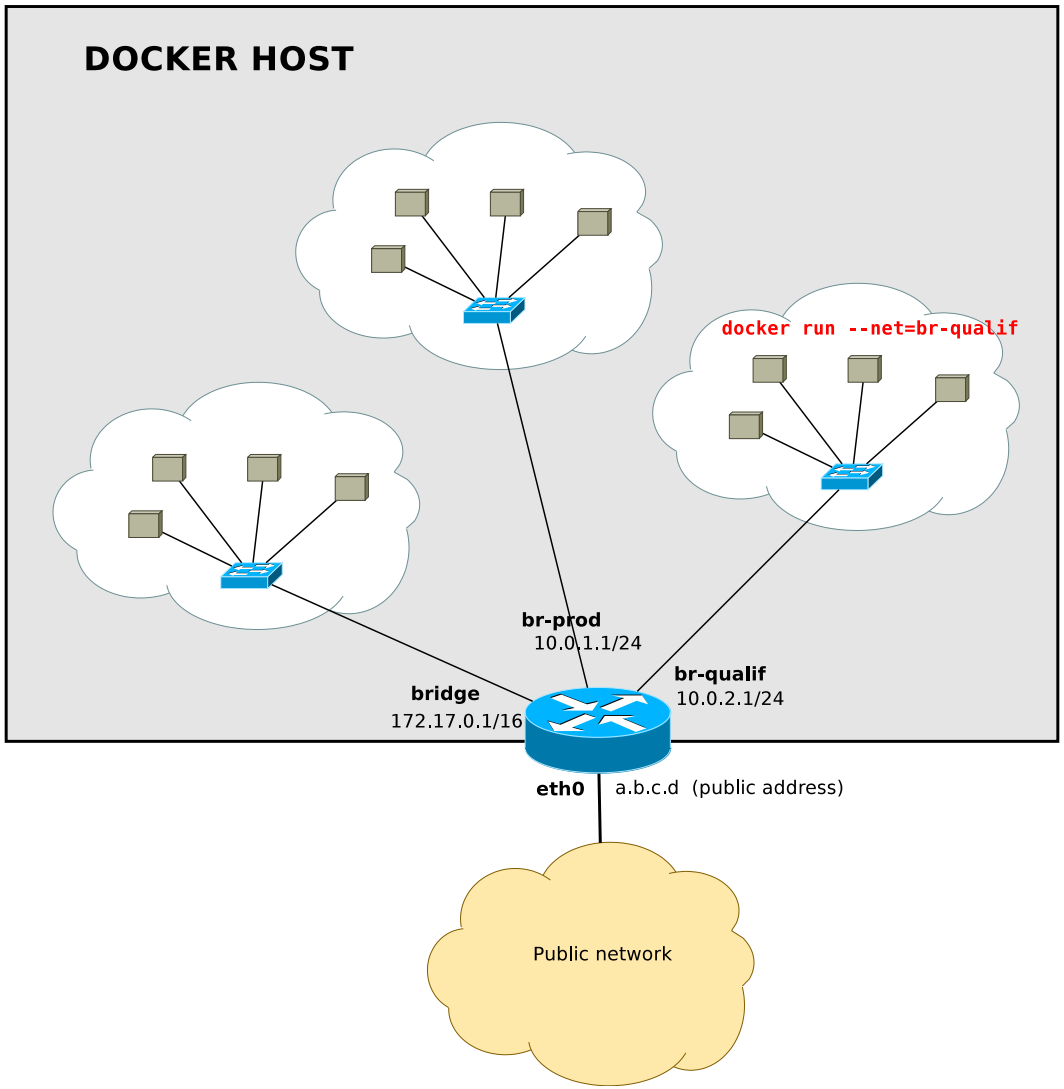
User-defined networks example



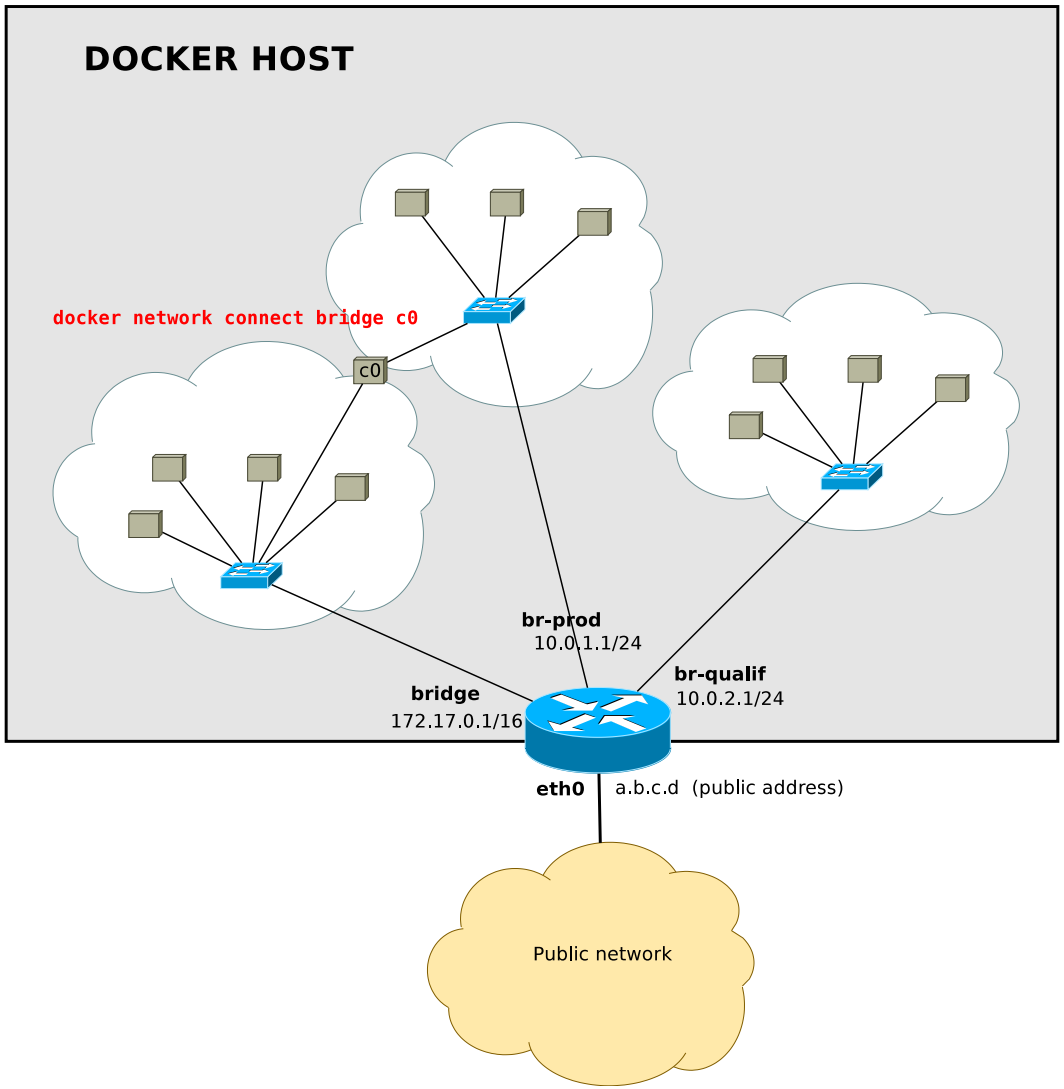
User-defined networks example



User-defined networks example



User-defined networks example



`docker run` — publish a TCP port

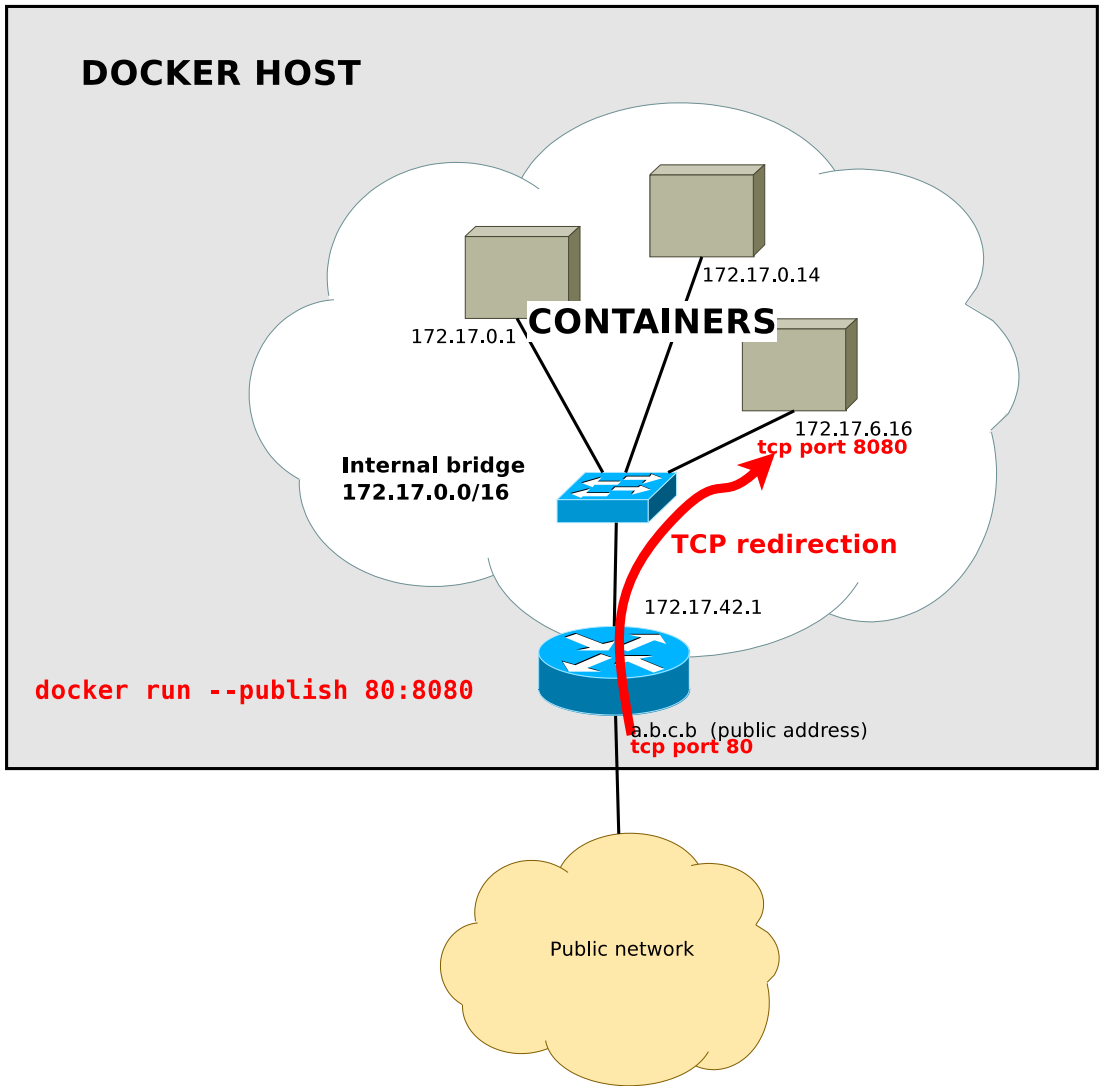
Containers are deployed in a private network, they are not reachable from the outside (unless a redirection is set up)

`docker run -p` [*ipaddr*:]*hostport*:*containerport*

→ redirect incoming connections to the TCP port *hostport* of the host to the TCP port *containerport* of the container

The listening socket binds to 0.0.0.0 (all interfaces) by default or to *ipaddr* if given

publish example



publish example

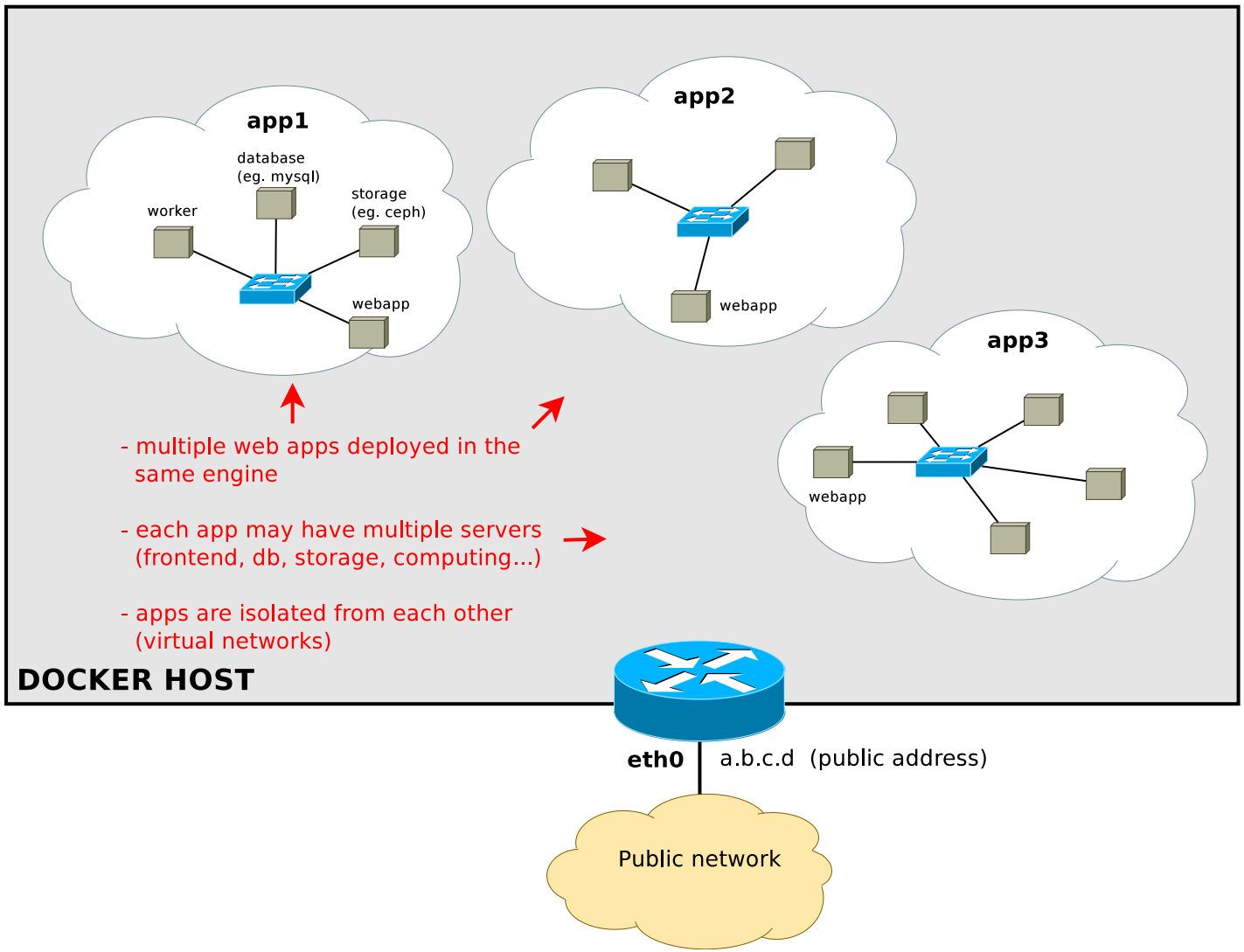
bind to all host addresses

```
$ docker run -d -p 80:80 nginx
52c9105e1520980d49ed00ecf5f0ca694d177d77ac9d003b9c0b840db9a70d62

$ wget -nv http://localhost/
2016-01-12 18:32:52 URL:http://localhost/ [612/612] -> "index.html" [1]
$ wget -nv http://172.17.42.1/
2016-01-12 18:33:14 URL:http://172.17.42.1/ [612/612] -> "index.html" [1]
```

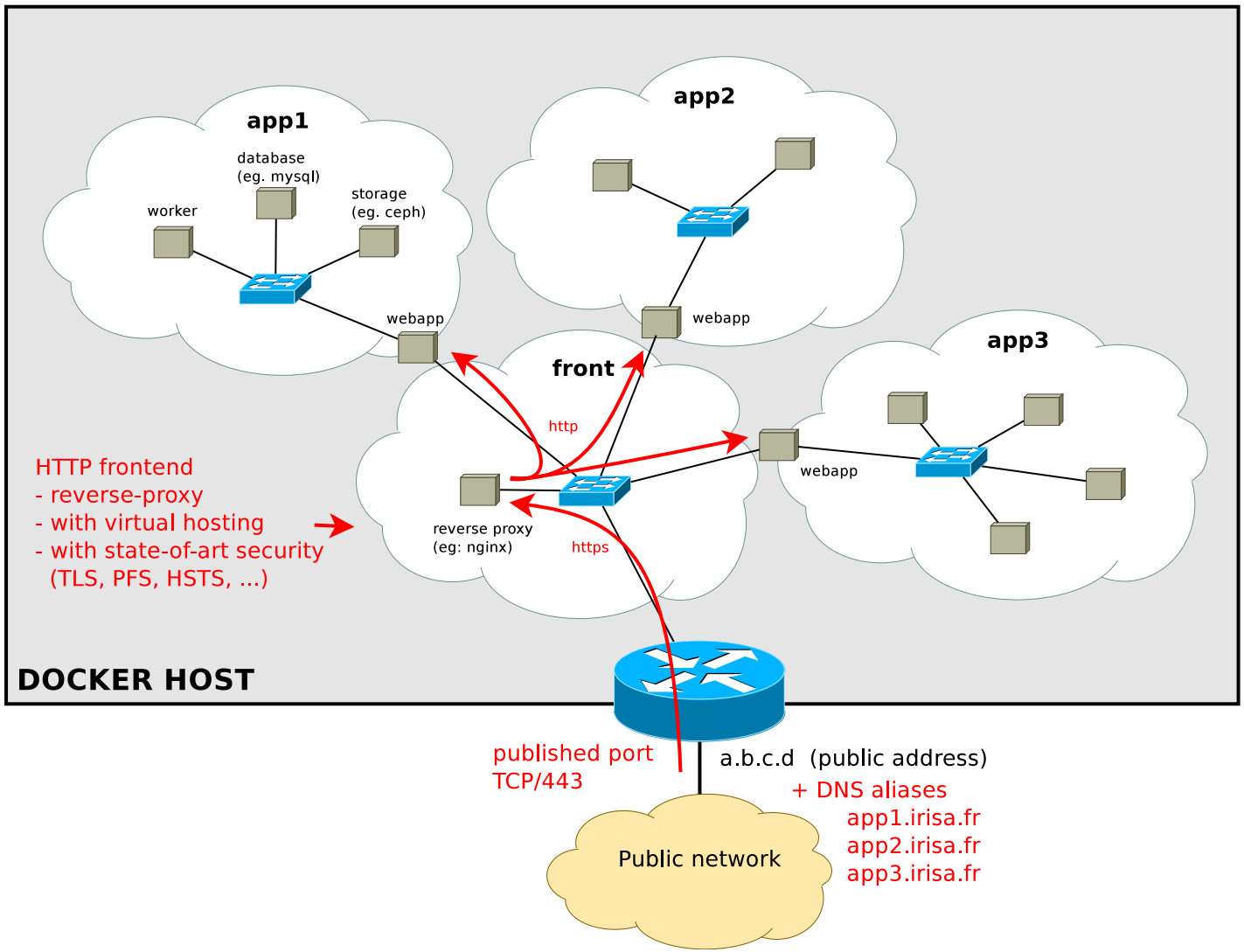
bind to 127.0.0.1

```
$ docker run -d -p 127.0.0.1:80:80 nginx
4541b43313b51d50c4dc2722e741df6364c5ff50ab81b828456ca55c829e732c

$ wget -nv http://localhost/
2016-01-12 18:37:10 URL:http://localhost/ [612/612] -> "index.html.1" [1]
$ wget http://172.17.42.1/
--2016-01-12 18:38:32--  http://172.17.42.1/
Connecting to 172.17.42.1:80... failed: Connection refused.
```

The whole picture



The whole picture



Part 4.
Managing docker images

Docker images

A docker image is a snapshot of the filesystem + some metadata

- immutable
- copy-on-write storage
  - for instantiating containers
  - for creating new versions of the image (multiple layers)
- identified by a unique hex ID (hashed from the image content)
- may be tagged[10] with a human-friendly name
  eg: `debian:wheezy` `debian:jessie` `debian:latest`

[10] possibly multiple times

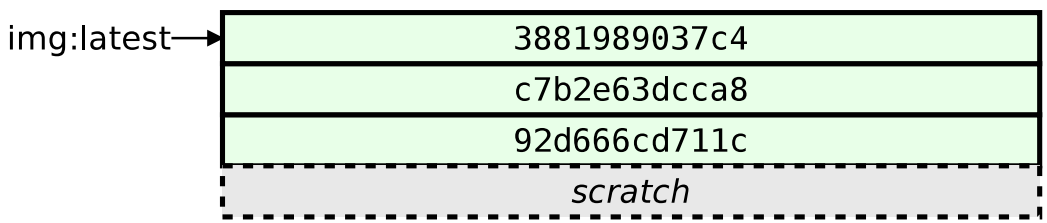
Image management commands

command	description
`docker images`	list all local images
`docker history` *image*	show the image history (list of ancestors)
`docker inspect` *image...*	show low-level infos (in json format)
`docker tag` *image tag*	tag an image
`docker commit` *container image*	create an image (from a container)
`docker import` *url*|- [*tag*]	create an image (from a tarball)
`docker rmi` *image...*	delete images

Example: images & containers

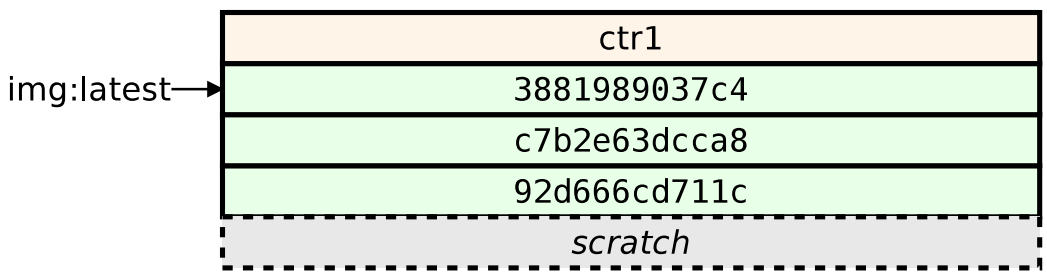
Example: images & containers

```
docker pull img
```



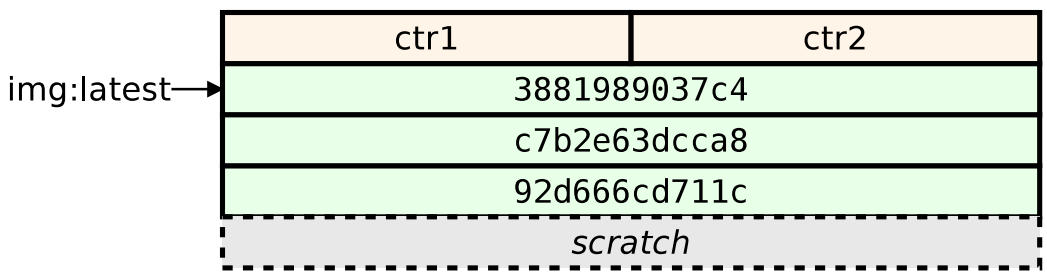
Example: images & containers

```
docker run --name ctr1 img
```



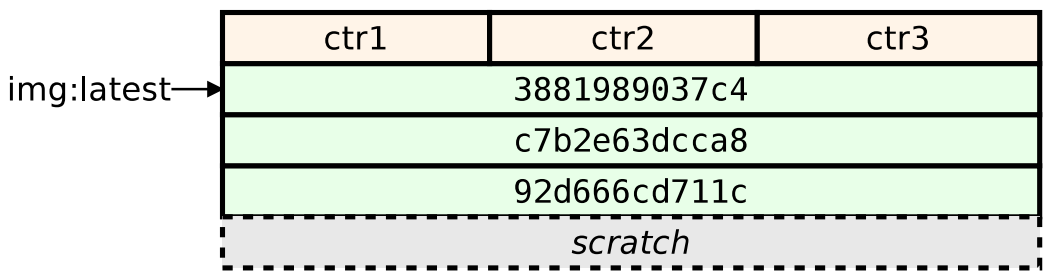
Example: images & containers

```
docker run --name ctr2 img
```



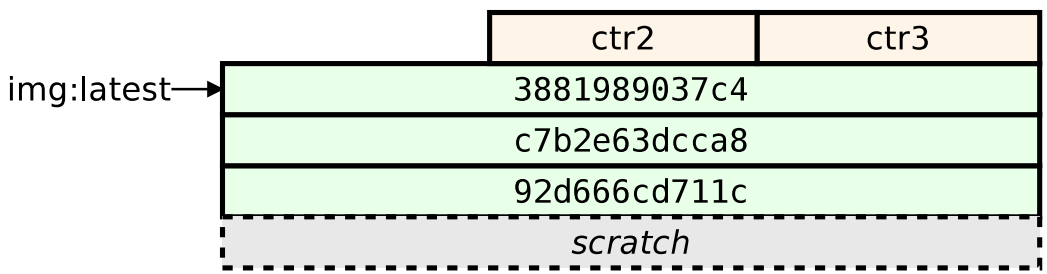
Example: images & containers

```
docker run --name ctr3 img
```



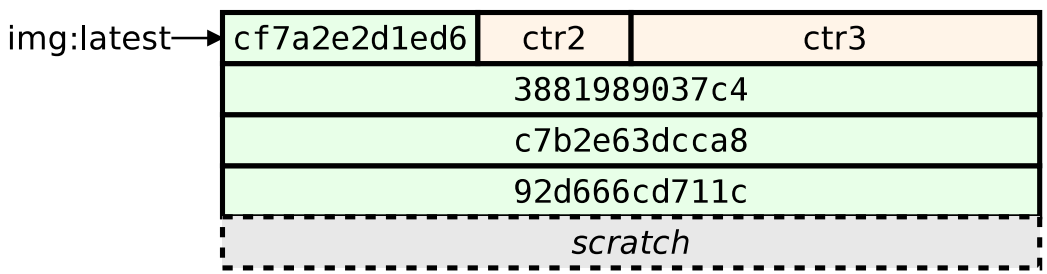
Example: images & containers

```
docker rm ctr1
```



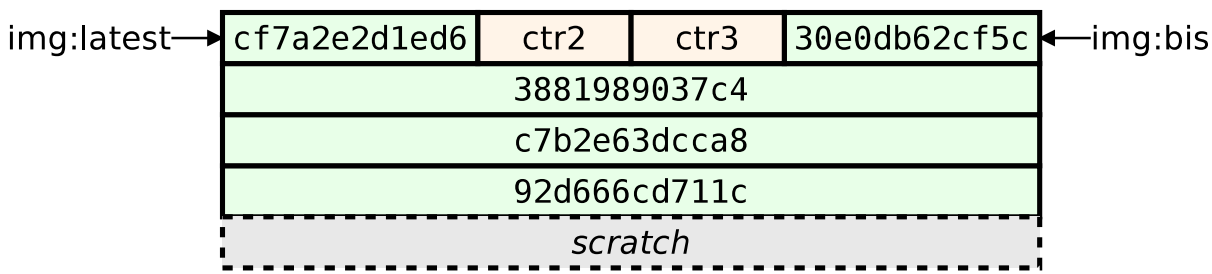
Example: images & containers

```
docker commit ctr2 img
```



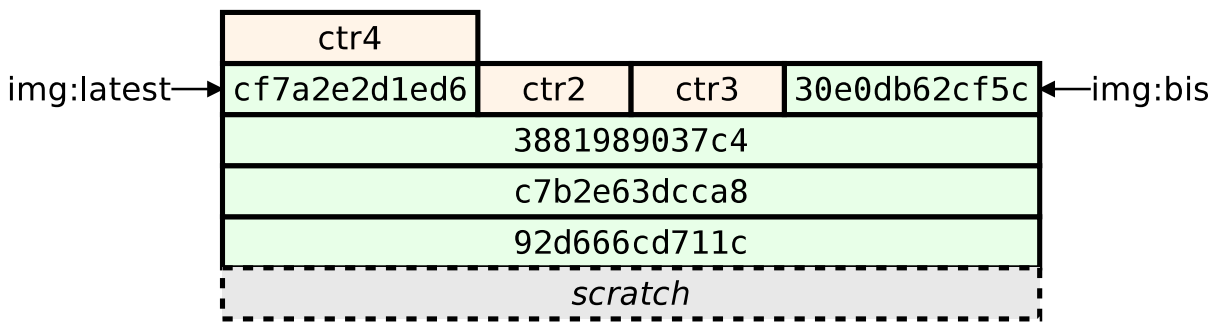
Example: images & containers

```
docker commit ctr3 img:bis
```



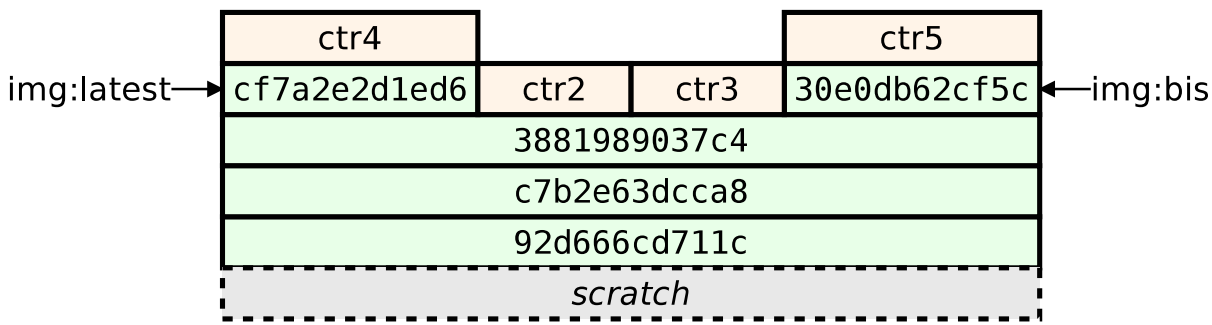
Example: images & containers

```
docker run --name ctr4 img
```



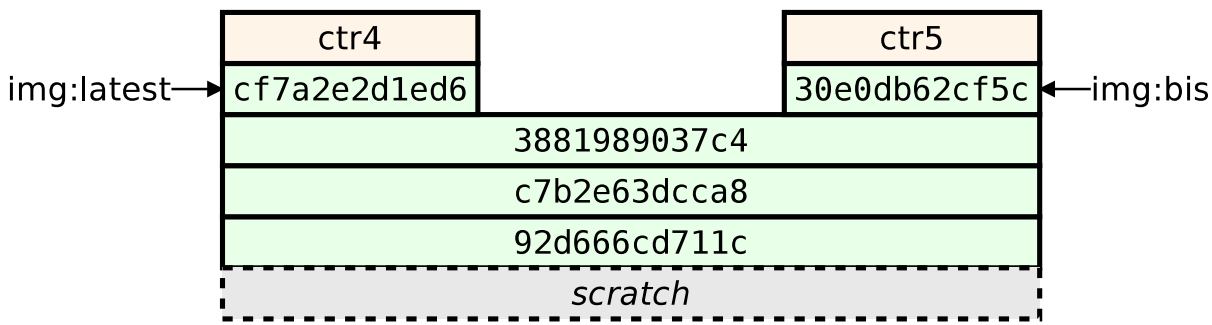
Example: images & containers

```
docker run --name ctr5 img:bis
```



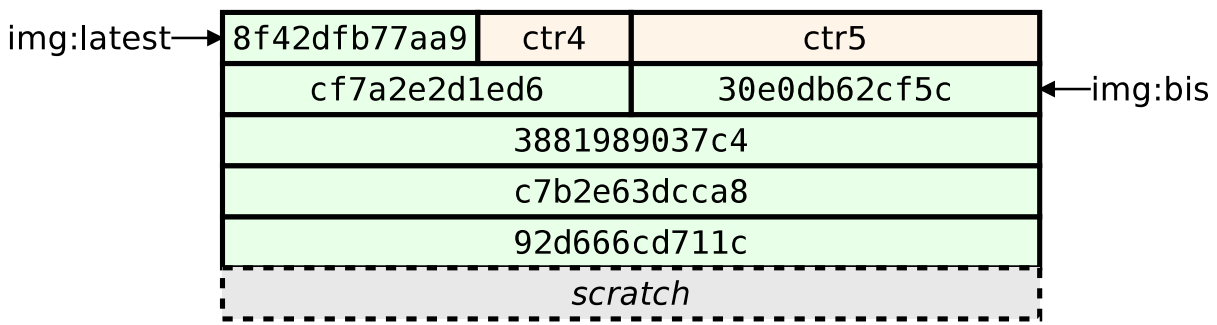
Example: images & containers

```
docker rm ctr2 ctr3
```



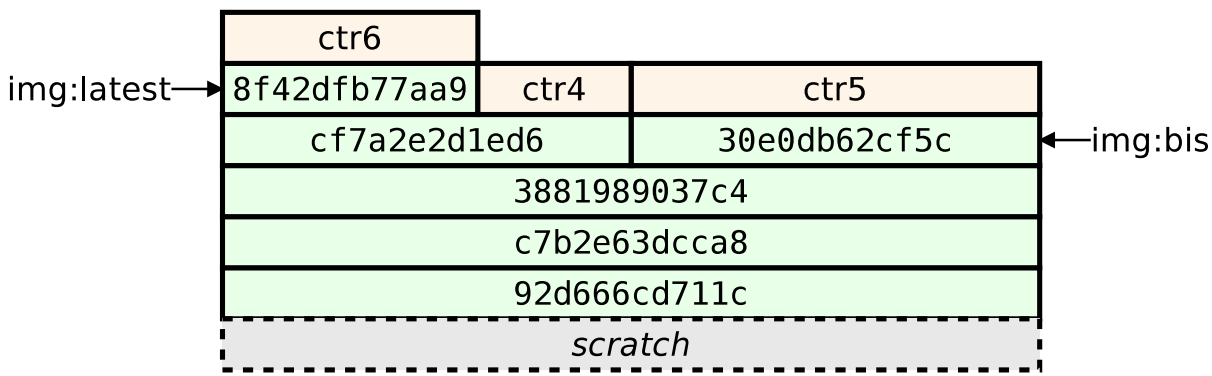
Example: images & containers

```
docker commit ctr4 img
```



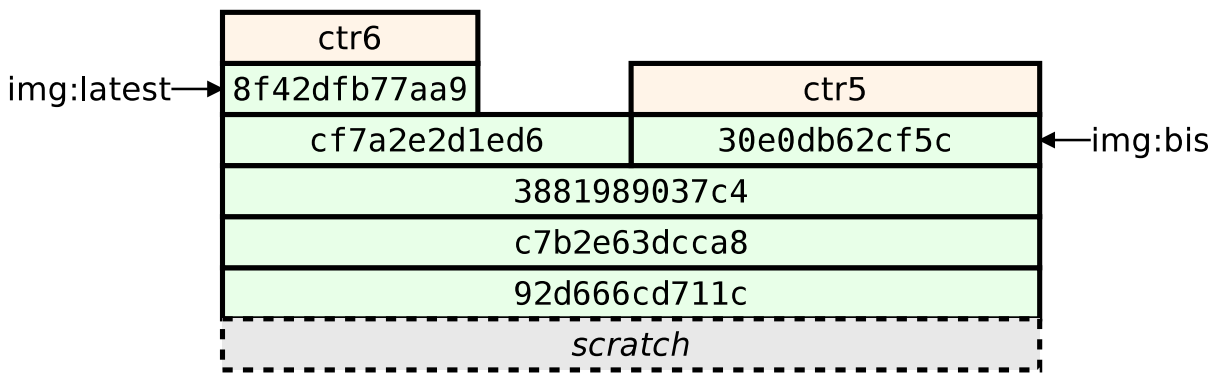
Example: images & containers

```
docker run --name ctr6 img
```



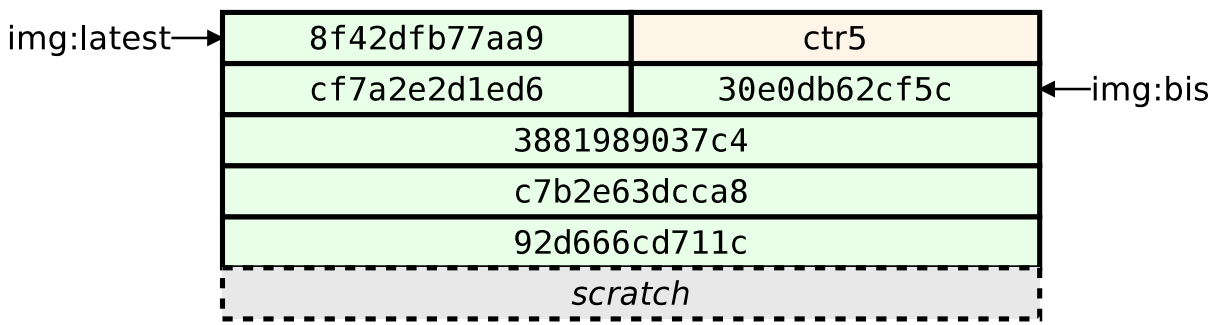
Example: images & containers

```
docker rm ctr4
```



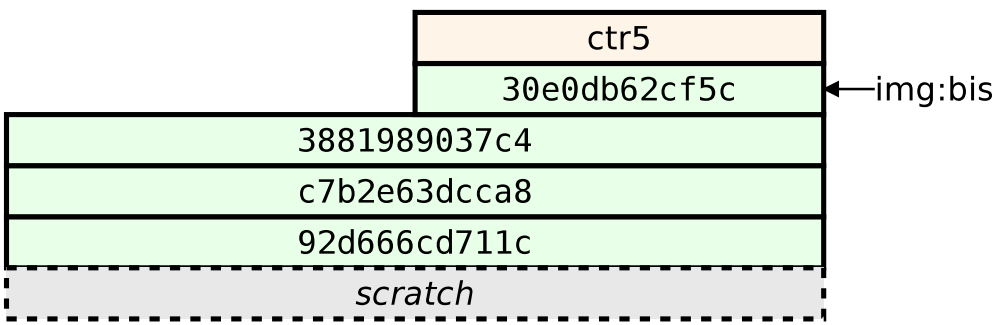
Example: images & containers

```
docker rm ctr6
```



Example: images & containers

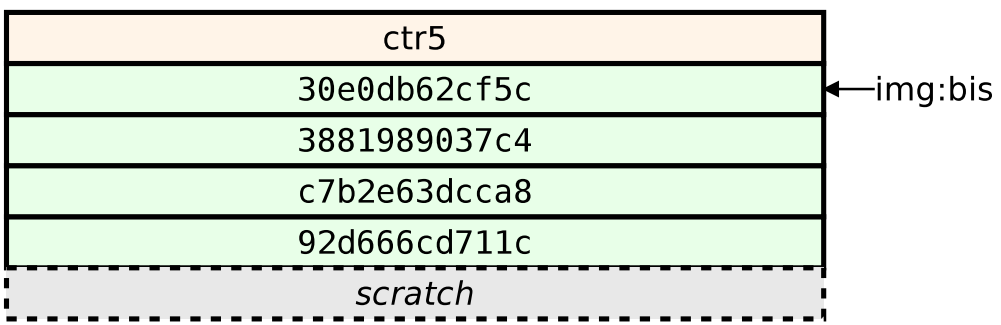
```
docker rmi img
```



Example: images & containers

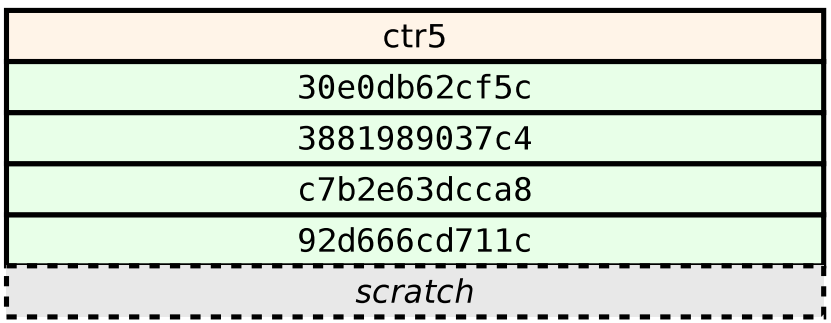
```
docker rmi img:bis
```

Error: image img:bis is reference by ctr5



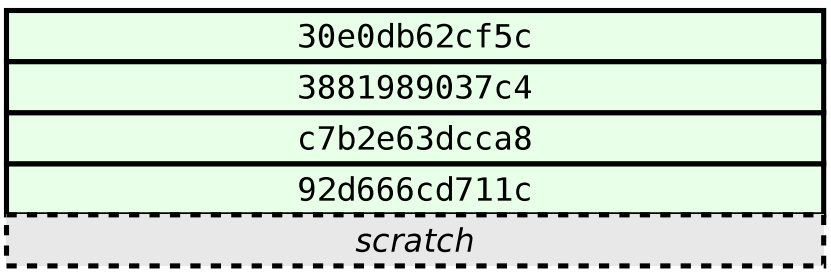
Example: images & containers

```
docker rmi -f img:bis
```



Example: images & containers

```
docker rm ctr5
```

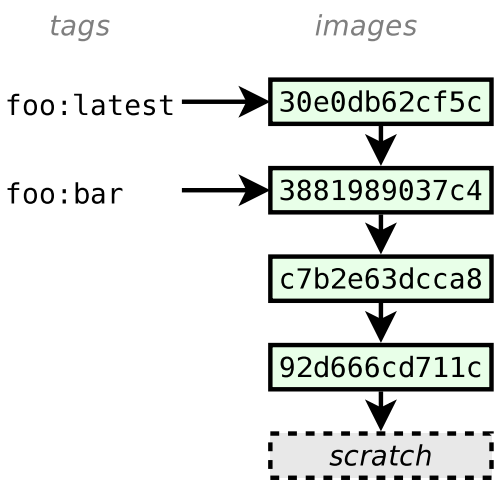


Example: images & containers

```
docker rmi 30e0
```

Images vs. Layers

docker < v1.10
no distinction between images & layers



docker >= v1.10
layers are hidden to the user
(implementation detail)

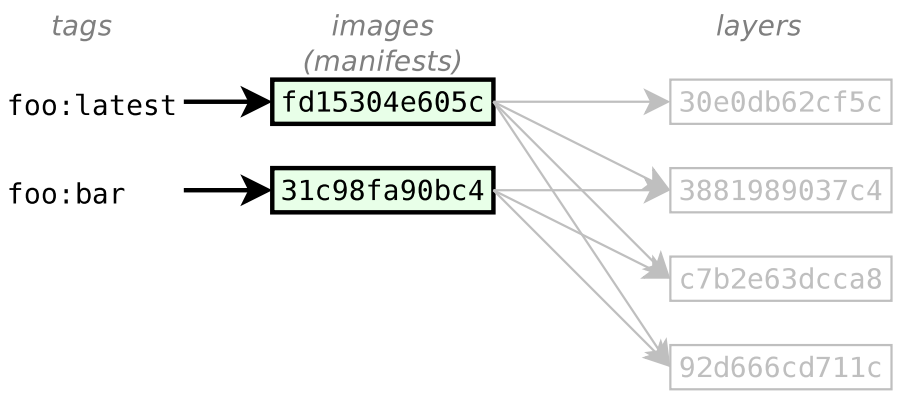


Image tags

A docker tag is made of two parts: *"REPOSITORY*: *TAG"*

The *TAG* part identifies the version of the image. If not provided, the default is "`:latest`"

```
$ docker images
REPOSITORY  TAG           IMAGE ID      CREATED        VIRTUAL SIZE
debian      8             835c4d274060  2 weeks ago    122.6 MB
debian      8.0           835c4d274060  2 weeks ago    122.6 MB
debian      jessie        835c4d274060  2 weeks ago    122.6 MB
debian      rc-buggy      350a74df81b1  7 months ago   159.9 MB
debian      experimental  36d6c9c7df4c  7 months ago   159.9 MB
debian      6.0.9         3b36e4176538  7 months ago   112.4 MB
debian      squeeze       3b36e4176538  7 months ago   112.4 MB
debian      wheezy        667250f9a437  7 months ago   115 MB
debian      latest        667250f9a437  7 months ago   115 MB
debian      7.5           667250f9a437  7 months ago   115 MB
debian      unstable      24a4621560e4  7 months ago   123.6 MB
debian      testing       7f5d8ca9fdcf  7 months ago   121.8 MB
debian      stable        caa04aa09d69  7 months ago   115 MB
debian      sid           f3d4759f77a7  7 months ago   123.6 MB
debian      7.4           e565fbbc6033  9 months ago   115 MB
debian      7.3           b5fe16f2ccba  11 months ago  117.8 MB
```

Tagging conventions (1/2)

Local tags may have arbitrary names, however the `docker push` and `docker pull` commands expect some conventions

The *REPOSITORY* identifies the origin of the image, it may be:

- a name (eg: `debian`)
  → refers to a repository on the official registry
  → `https://store.docker.com/`

- a hostname+name (eg: `some.server.com/repo`)
  → refers to an arbitrary server supporting the registry API
  → `https://docs.docker.com/reference/api/registry_api/`

Tagging conventions (2/2)

Use slashes to delimit namespaces (for subprojects):

image name	**description**
`debian`	(semi-)official debian images
`fedora`	official fedora images
`fedora/apache`	apache images provided by the fedora project
`fedora/couchdb`	couchdb images provided by the fedora project

Image transfer commands

Using the registry API

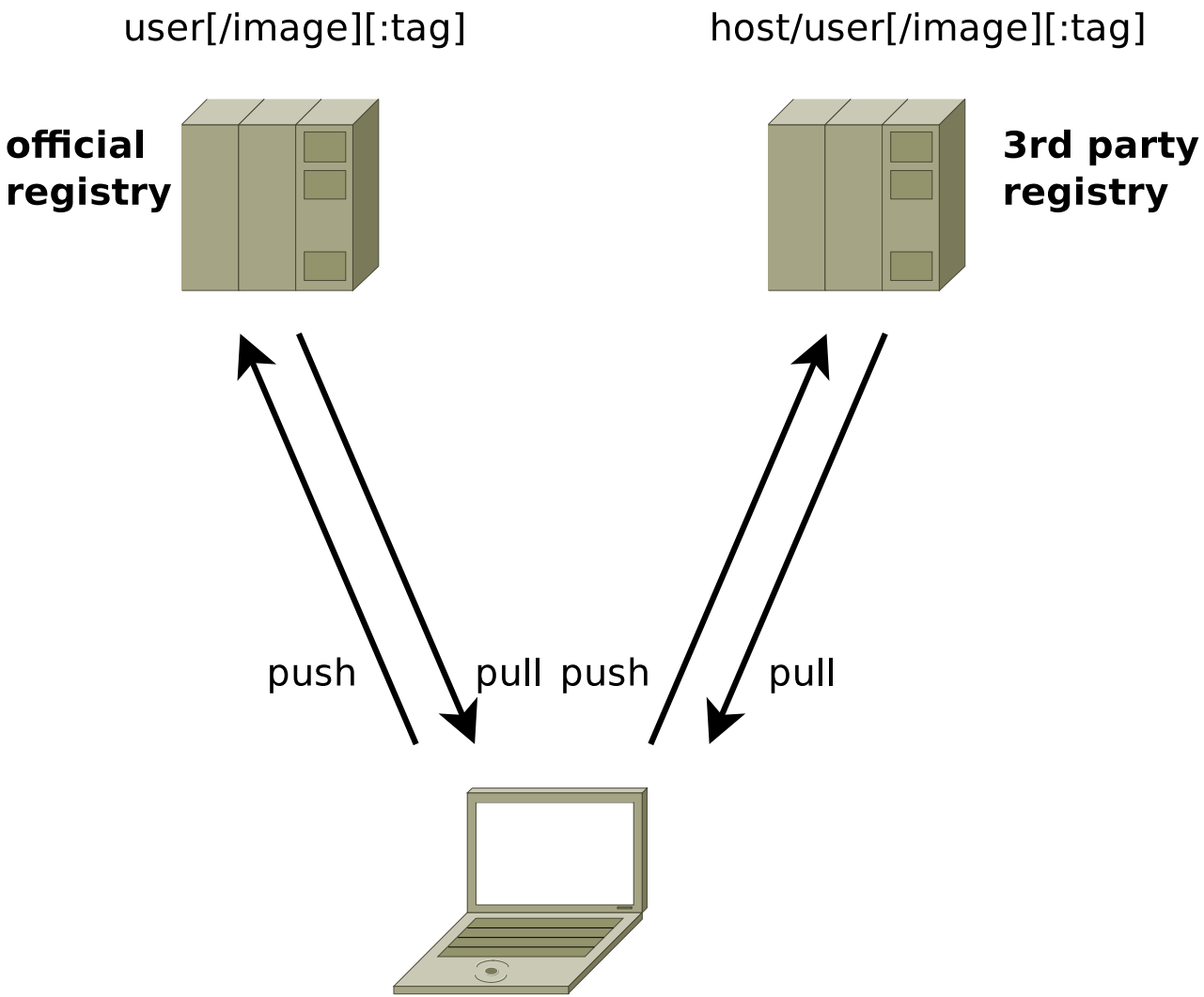
`docker pull` *repo*[:*tag*]...	pull an image/repo from a registry
`docker push` *repo*[:*tag*]...	push an image/repo from a registry
`docker search` *text*	search an image on the official registry
`docker login` ...	login to a registry
`docker logout` ...	logout from a registry

Manual transfer

`docker save` *repo*[:*tag*]...	export an image/repo as a tarbal
`docker load`	load images from a tarball
`docker-ssh`[11] ...	proposed script to transfer images between two daemons over ssh

[11] `https://github.com/a-ba/docker-utils/`

Transferring images



Part 5.
Docker builder

What is the Docker builder ?

Docker's builder relies on

- a DSL describing how to build an image
- a cache for storing previous builds and have quick iterations

The builder input is a **context**, i.e. a directory containing:

- a file named `Dockerfile` which describe how to build the container
- possibly other files to be used during the build

Build an image

```
docker build [ -t tag ] path
```

→ build an image from the context located at *path* and optionally tag it as *tag*

The command:

1. makes a tarball from the content[12] of *path*
2. uploads the tarball to the docker daemon which will:
   - 2.1 execute the content of `Dockerfile`, committing an intermediate image **after each** command
   - 2.2 (if requested) tag the final image as *tag*

[12] unwanted files may be excluded if they match patterns listed in `.dockerignore`

Dockerfile example

```
# base image: last debian release
FROM debian:wheezy

# install the latest upgrades
RUN apt-get update && apt-get -y dist-upgrade

# install nginx
RUN apt-get -y install nginx

# set the default container command
# -> run nginx in the foreground
CMD ["nginx", "-g", "daemon off;"]

# Tell the docker engine that there will be somenthing listening on the tcp port 80
EXPOSE 80
```

`Dockerfile` format

`https://docs.docker.com/reference/builder/`

- comments start with "#"
- commands fit on a single line
  (possibly continuated with \)
- first command must be a `FROM`
  (indicates the parent image or `scratch` to start from scratch)

Builder instructions (1/3)

Instructions affecting the image filesystem

instruction	description
`FROM` *image*|`scratch`	base image for the build
`COPY` *path dst*	copy *path* from the context into the container at location *dst*
`ADD` *src dst*	same as `COPY` but untar archives and accepts http urls
`RUN` *command*	run an arbitrary command inside the container

Note: commands may be expressed as a list (exec) or a string (shell)

```
# exec form
RUN ["apt-get", "update"]

# shell form
RUN apt-get update       # equivalent to: RUN ["/bin/sh", "-c", "apt-get update"]
```

Builder instructions (2/3)

Instructions setting the default container config[14]

instruction	description
`CMD` *command* `ENTRYPOINT` *command*	command run inside the container entrypoint[13]
`USER` *name*[:*group*] `WORKDIR` *path* `ENV` *name*="*value*"...	user running the command working directory environment variables
`STOPSIGNAL` *signal*	signal to be sent to terminate the container*(instead of SIGTERM)*
`HEALTHCHECK CMD` *command*	test command to check if the container works well
`EXPOSE` *port*... `VOLUME` *path*...	listened TCP/UDP ports mount-point for external volumes
`LABEL` *name*="*value*"...	arbitrary metadata

[13] the `ENTRYPOINT` is a commmand that wraps the `CMD` command

[14] i.e. the default configuration of containers running this image

Builder instructions (3/3)

Extra instructions

instruction	description
`ARG` *name[=value]*	build-time variables
`ON BUILD` *instruction*	instruction run when building a derived image

- build-time variables are usable anywhere in the Dockerfile (*by variable expansion:* `$VARNAME`) and are tunable at build time: "`docker build --build-arg` *name=value ...*"
- instructions prefixed with `ONBUILD` are not run in this build, their execution is triggered when building a derived image

Builder cache

Each layer created by the builder is fingerprinted according to:

- the ID of the previous image
- the command and its arguments
- the content of the imported files (for `ADD` and `COPY`)

⚠ `RUN`'s side-effects are not fingerprinted

When rebuilding an image docker will reuse a previous image if its fingerprint is the same

Good practices[15] for docker files

- use stable base images (eg. `debian:jessie`)
- run the app as PID 1 inside the container (to be killable)
  → write `CMD ["app", "arg"]` instead of `CMD app arg`
- standardise the config, but allow the admin to override it with env variables or additional config files
  (eg. `ENV MYSQL_HOST="mysql"`)

[15] see also `https://docs.docker.com/engine/userguide/eng-image/dockerfile_best-practices/`

Multi-stage build (since v17.05)

```
#======= Stage 1: build the app from sources =======#
FROM debian:stretch AS builder
# update the package lists an install the build dependencies
RUN apt-get -qqy update
RUN apt-get -qqy install gcc make libacme-dev

# install the sources in /opt/src and build them
COPY . /opt/src
RUN cd /opt/src && ./configure && make

# install the files in a tmp dir and make an archive that we can deploy elsewhere
RUN cd /opt/src && make install DESTDIR=/tmp/dst \
 && cd /tmp/dst && tar czvf /tmp/myapp.tgz .

#======= Stage 2: final image ================#
FROM debian:stretch
# update the package lists and install the runtime dependencies
RUN apt-get -qqy update
RUN apt-get -qqy install libacme1.0

# install the app built in stage 1
COPY --from=builder /tmp/myapp.tgz /tmp/
RUN cd / && tar zxf /tmp/myapp.tgz

CMD ["myapp"]
```

Part 6. Security

- host/container isolation
- container/container isolation
- other security considerations

Security strategies

Docker containers are not really sandboxed from the host machine. They talk with the **same kernel**. You may want to consider strategies to reduce the risks of privilege escalation.

Container/Host isolation

- run the container with an ordinary user (`docker run -u`)
- reduce root privileges (*capabilities*, *seccomp*, *apparmor*)
- configure a user namespace
- run the docker engine inside a VM

Container/Container isolation

- disable intercontainer communications (`--icc=false`)
- isolate containers in different networks

Running containers as normal user

`docker run -u` *USER ...*

should be safe, but...

- setuid executables in the docker image
  → *should mount* `/var/lib/docker` *with* '`-o nosuid`'
- setuid executables in external volumes
  → *should mount all data volumes with* '`-o nosuid`'
- `/etc/passwd` in the docker image
  → *should use numeric ids: (*`docker run -u` *UID:GID)*

→ not easily enforcable if the image provider is malicious

Reduced root capabilities

- kernel capabilities supported since docker v1.2
- containers use a default set limited to 14 capabilities[16]:

AUDIT_WRITE	CHOWN	NET_RAW	SETPCAP
DAC_OVERRIDE	FSETID	SETGID	KILL
NET_BIND_SERVICE	FOWNER	SETUID	
SYS_CHROOT	MKNOD	SETFCAP	

- add additional capabilities: `docker run --cap-add=`*XXXXX* ...
- drop unnecessary capabilities: `docker run --cap-drop=`*XXXXX* ...
  → should use `--cap-drop=all` for most containers

```
$ docker run --rm -t -i debian
root@04223cbb1334:/# ip addr replace 172.17.0.42/16 dev eth0
RTNETLINK answers: Operation not permitted
root@04223cbb1334:/# exit

$ docker run --rm -t -i --cap-add NET_ADMIN debian
root@9bf2a570a6a6:/# ip addr replace 172.17.0.42/16 dev eth0
root@9bf2a570a6a6:/#
```

[16] over the 38 capabilities defined in the kernel (man 7 capabilities)

Reduced syscall whitelist

seccomp-bpf == fine-grained acces control to kernel syscalls

- enabled by default since docker v1.10
- default built-in profile[17] whitelists only harmless syscalls[18]
- alternative configs:
  - disable seccomp (`--security-opt=seccomp:unconfined`)
  - provide a customised profile (derived from the default[19])

```
$ docker run --rm debian date -s 2016-01-01
date: cannot set date: Operation not permitted
$ docker run --rm --cap-add sys_time debian date -s 2016-01-01
date: cannot set date: Operation not permitted
$ docker run --rm --security-opt seccomp:unconfined debian date -s 2016-01-01
date: cannot set date: Operation not permitted
$ docker run --rm --cap-add sys_time --security-opt seccomp:unconfined debian date -s 2016-01-01
Fri Jan  1 00:00:00 UTC 2016
```

[17] https://docs.docker.com/engine/security/seccomp/

[18] harmful means everything that deals with administration (eg: set time) or debugging (eg: ptrace)

[19] https://github.com/moby/moby/blob/master/profiles/seccomp/default.json

User namespaces

since docker v1.10 but not enabled by default

- UIDs/GIDs inside the containers mapped to another range outside the container
- useful for:
  - preventing fs-based attacks *(eg: root user inside the container creates a setuid executable in an external volume)*
  - isolating docker users from each other *(one docker daemon for each user, with uids remapped to different ranges)*
- limits (as of v1.10)
  - global config only (daemon scope)
  - coarse mapping only (hardcoded range: 0..65535)

Docker is not a sandbox !

Even with *capabilities+seccomp+user_namespaces* enabled, you may still be vulnerable, because the kernel's attack surface is **big**

CVE-2019-5736

runc through 1.0-rc6, as used in Docker before 18.09.2 and other products, allows attackers to overwrite the host runc binary (and consequently obtain host root access) by leveraging the ability to execute a command as root within one of these types of containers: (1) a new container with an attacker-controlled image, or (2) an existing container, to which the attacker previously had write access, that can be attached with docker exec. This occurs because of file-descriptor mishandling, related to /proc/self/exe.

Run the docker engine inside a VM

Hypervisors have a smaller attack surface and are much more mature that containers. **Use a VM if you need good isolation!**

- either manually-administrated VMs
- either transparently-launched VMs
  - on a per-engine basis (docker daemon inside a VM)
    docker machine: `https://docs.docker.com/machine/overview/`
  - on a per-container basis (each container in a separate VM)
    kata containers: `https://katacontainers.io/`
    runv: `https://github.com/hyperhq/runv`
    gvisor: `https://github.com/google/gvisor`

Container/Container isolation

- by default all containers can connect to any other container (located in the same bridge)
  - run the daemon with `--icc=false`
    - all communications filtered by default
    - whitelist-based access with `--link`
      (only `EXPOSE`*d ports will be whitelisted)*
  - attach containers to different networks
- by default RAW sockets are enabled (allows ARP spoofing)[20]
  → use `docker run --cap-drop=NET_RAW`

[20] `http://lwn.net/Articles/689453`

Other security considerations

- images are immutable
  → need a process to apply automatic security upgrades, e.g:
  - apply upgrades & commit a new image
  - regenerate the image from the Dockerfile

- docker engine control == root on the host machine
  - give access to the docker socket only to trusted users

- avoid `docker run --privileged` (gives full root access)

- avoid the insecure v1 registry API (for `push`/`pull`)

  → run the daemon with `--insecure-registry=false --disable-legacy-registry`

- beware of symlinks in external volumes

  eg. ctr1 binds `/data`, ctr2 binds `/data/subdir`, if both are malicious and cooperate, ctr1 replaces `/data/subdir`with a symlink to `/`, then on restart ctr2 has access the whole host filesystem

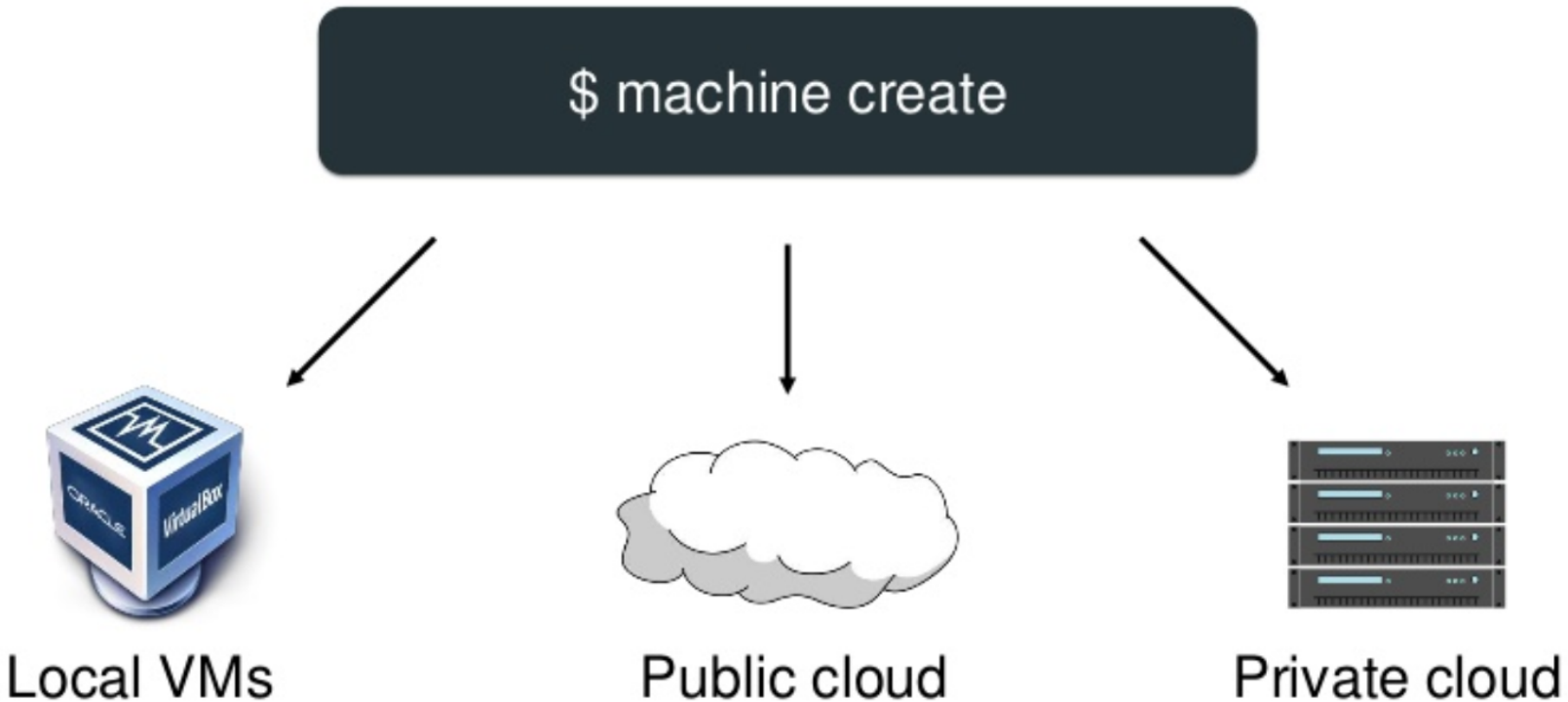
  → avoid binding subdirectories, prefer using named volumes

Part 7.
Docker Ecosystem

- infrastructure
  - docker machine (provisioning)
  - docker swarm (clustering)
  - swarm mode (clustering)
  - underlying projects (moby, containerd, infrakit, ...)
- container deployment & configuration
  - docker compose
- image distribution
  - docker distribution (registry)
  - docker notary (content trust, image signing)

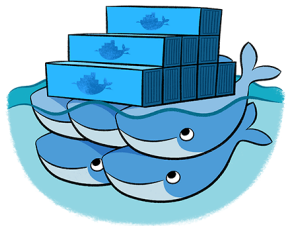
Docker Machine

abstraction for provisionning and using docker hosts



Docker Swarm

manage a cluster of hosts running docker

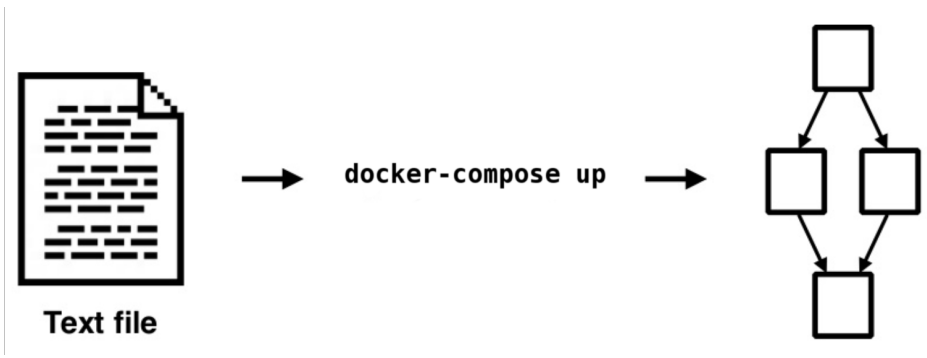


⚠ Docker Inc. folks are misleading: the name **swarm** is actually used for two different products:

- **docker swarm** (or **legacy swarm** or just **swarm**)
  - early solution (first released in dec 2014)
  - standalone server
  - superset of the docker engine API
  - requires a an external discovery service (eg. etcd, consul)
  - network-agnostic (overlay networks to be configured separately)
- the **swarm mode**
  - embedded within the docker engine (since v1.12 in july 2016)
  - turnkey cluster (integrated discovery service, distributed, network aware, encryption by default)
  - API break: introduces the **service** abstration

Docker Compose

configure and deploy a collection of containers



group.yml

```yaml
name: counter

containers:
  web:
    build: .
    command: python app.py
    ports:
      - "5000:5000"
    volumes:
      - .:/code
    links:
      - redis
  redis:
    image: redis:latest
```

Part 8.
The Future is Now

- swarm mode (since v1.12)
- plugins (since v1.13)
- experimental features
- Docker EE & time-based releases
- The Orchestration Wars

The Future is Now

- Swarm mode (since v1.12)
  - service abstraction
    - scaling
    - service discovery & load balancing
    - rolling updates
  - stack deployment (docker-compose) (since v1.13)
  - secrets management (since v1.13) + config objects (since v17.06)
- plugins API for datacenter integration (since v1.13)
  - volume plugins (eg: flocker)
  - network plugins (eg: contiv)
  - authorization plugins
  - swarm secrets (since v17.07)

Docker CE & Docker EE

since march 2017

Docker inc's business strategy:

1. be flexible and interoperable with everybody (especially cloud providers) so that no competing tool emerges

   → open source engine, plugin API for network, storage, authorization integrations

2. sell Docker EE

docker EE = docker CE + support + off-the-shelves datacenter management (ldap integration, role-based access-control, security scanning, vulnerability monitoring)

Time-based release

since march 2017 (docker v17.03.0-ce)

- Docker CE
  - open source
  - edge version released every month
  - stable version released every 3 months
  - security upgrades during 4 months
- Docker EE
  - proprietary
  - stable version released every 3 months
  - security upgrades during 1 year

The Orchestration Wars

The *Container Wars* will actually be the *Orchestration Wars*

- under the hood the base building blocs (runc, containerd) are open and the competitors cooperate to keep them standard.
- docker itselfs is still free software, although the company ulture is shifting towards something more “corporate”
- the real fight will be on orchestration solutions
  - managing clouds, service hosting
  - swarm has opponents (Mesos, Kubernetes, Openshift, ...) and is lagging.

Apache Mesos

- predates Docker
- designed for very large clusters
- agnostic to the virtualisation technology
  - multiple virtualisation tool may coexist in the same cluster
  - two-level management
- hard to configure

Kubernetes (k8s)

- project started in 2014 by a group of google developers
- inspired from Google's internal orchestration framework
- large scale, very sophisticated, not easy to learn
- now hosted by a fundation and adopted by others that use it as their orchestration backend
  - Openshift
  - Docker EE

The Open Container Initiative (OCI)

https://github.com/opencontainers/

A Linux Foundation standard for linux containers:

- v1.0.0 released in July 2017
  - runtime-spec (launching containers)
  - image-spec (image interoperability)