A Practical Guide to Writing Secure Dockerfiles

WeAreDevelopers Live – Container Day

Madhu Akula

About Me

- Security Engineering @ Miro
- Creator of Kubernetes Goat, Hacker Container, tools.tldr.run, many other…
- Security (CloudNative, Containers, Kubernetes, Automation)
- Speaker & Trainer @ BlackHat, DEFCON, USENIX, OWASP, All Day DevOps, GitHub, DevSecCon, c0c0n, Nullcon, null, many other…
- Co-Author of Security Automation with Ansible 2
- Technical reviewer of Learn Kubernetes Security
- Never Ending Learner!

@madhuakula

https://madhuakula.com

What will you learn?

- What is Dockerfile?
- Why security of Dockerfiles?
- Best practices for writing Dockerfiles
- Linters, tools, techniques to validate
  - buildkit, dockle, hadolint, docker-slim, dive, plugins, etc.
- Introducing OPA, Rego & Conftest
- docker-security-checker
- Why custom security policies?
- Next steps
- Resources & Reference

What is Docker?

- Docker is an open source platform for building, deploying, and managing containerized applications
- Docker became the de facto standard to build and share containerized apps - from desktop, to the cloud, even edge devices
- Docker enables developers to easily pack, ship, and run any application as a lightweight, portable, self-sufficient container, which can run virtually anywhere
- Docker can build images automatically by reading the instructions from a Dockerfile

What is Dockerfile?

A Dockerfile is a text document that contains all the commands a user could call on the command line to assemble an image.

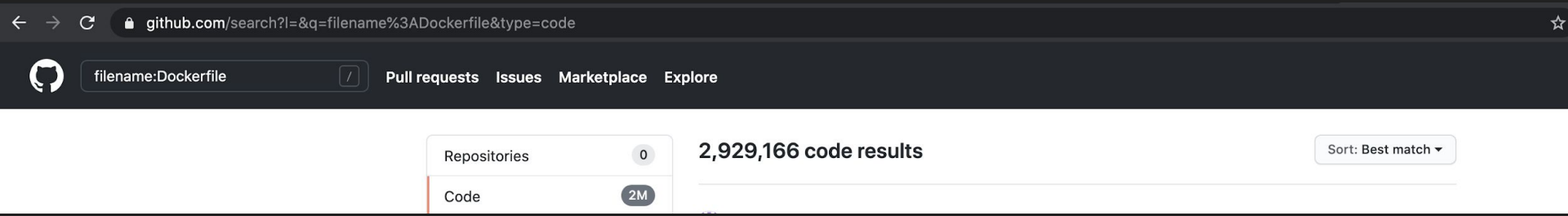
24 lines (18 sloc) | 701 Bytes

```
# Using official python runtime base image
FROM python:3.9-slim

# add curl for healthcheck
RUN apt-get update \
    && apt-get install -y --no-install-recommends \
    curl \
    && rm -rf /var/lib/apt/lists/*

# Set the application directory
WORKDIR /app

# Install our requirements.txt
COPY requirements.txt /app/requirements.txt
RUN pip install -r requirements.txt

# Copy our code from the current folder to /app inside the container
COPY . .

# Make port 80 available for links and/or publish
EXPOSE 80

# Define our command to be run when launching the container
CMD ["gunicorn", "app:app", "-b", "0.0.0.0:80", "--log-file", "-", "--access-logfile", "-", "--workers", "4", "--keep-alive", "0"]
```

https://github.com/dockersamples/example-voting-app/blob/master/vote/Dockerfile

Why should we focus on Dockerfile security?

- Dockerfiles are blueprint for building your docker container images
- Dockerfiles are codified version of what your application & infrastructure
- It is one of the key component for the entire supply chain security
- To maintain the highest level of security from the ground up
- Many possible security issues can happen due to insecure Dockerfiles



Dockerfile best practices from Docker itself

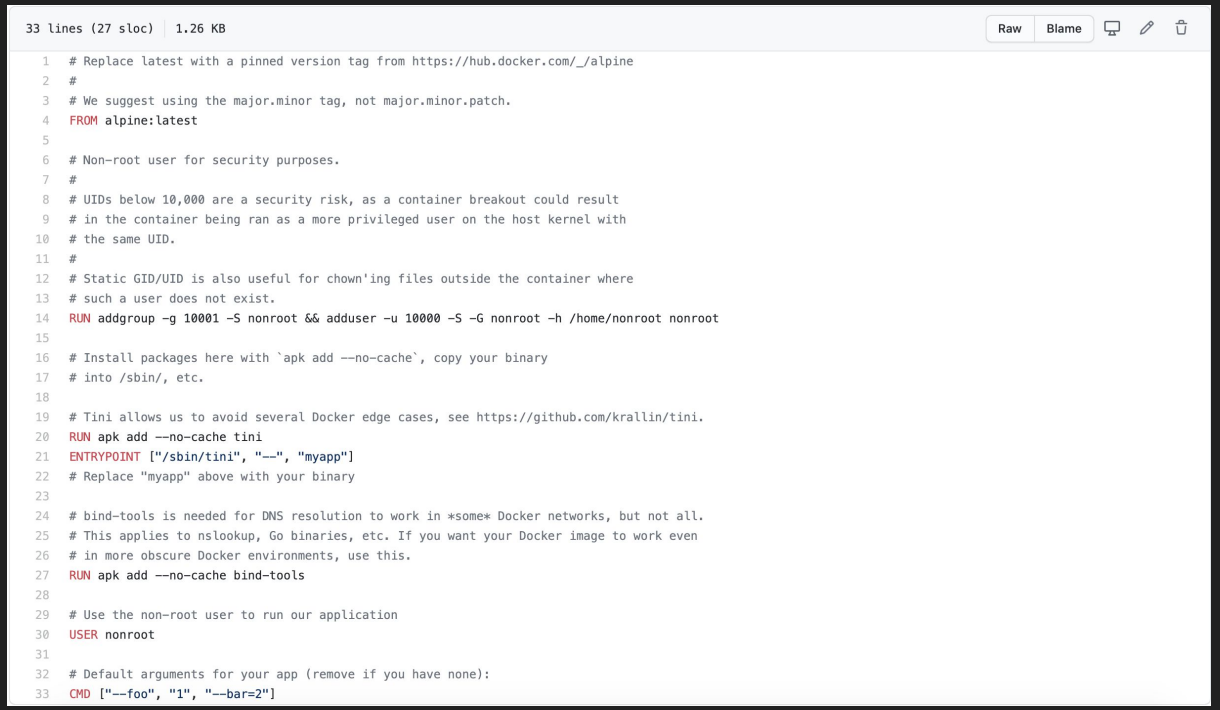
- Start with small version of the image
- Create ephemeral containers
- Understanding the build context
- Exclude files with .dockerignore like .gitignore
- Use multi stage builds - Only we need artifacts and reduce attack surface
- Don’t install unnecessary packages
- Minimize number of layers
- Create multi-line arguments in structured way and reduce the image layers
- Leverage the build cache
- Create your own base image like golden image

https://docs.docker.com/develop/develop-images/dockerfile_best-practices/

Generic Best Practices

- Order of the steps in Dockerfile (least to most frequently changing content)
- COPY only specific files required rather everything (don't do COPY . .)
- Perform same commands (RUN apt-get update && apt-get install -y curl)
- Only install what we need (--no-install-recommends)
- Remove package manager cache (&& rm -rf /var/lib/apt/lists/*)
- Don't use latest tag (be specific with with image tag)
- Non root user and group
- Disallow acquiring new privileges
- Only trusted and official base images
- Minimal base images, don't include not required software, packages, etc.
- Don't store secrets or sensitive information in Dockerfiles, file/directories
- Don't install SSH or similar services and expose your containers
- Image lifecycle management, updates if required
- Many others...

Generic Best Practices - Example Dockerfile



33 lines (27 sloc) | 1.26 KB — Raw | Blame

```
# Replace latest with a pinned version tag from https://hub.docker.com/_/alpine
#
# We suggest using the major.minor tag, not major.minor.patch.
FROM alpine:latest

# Non-root user for security purposes.
#
# UIDs below 10,000 are a security risk, as a container breakout could result
# in the container being ran as a more privileged user on the host kernel with
# the same UID.
#
# Static GID/UID is also useful for chown'ing files outside the container where
# such a user does not exist.
RUN addgroup -g 10001 -S nonroot && adduser -u 10000 -S -G nonroot -h /home/nonroot nonroot

# Install packages here with `apk add --no-cache`, copy your binary
# into /sbin/, etc.

# Tini allows us to avoid several Docker edge cases, see https://github.com/krallin/tini.
RUN apk add --no-cache tini
ENTRYPOINT ["/sbin/tini", "--", "myapp"]
# Replace "myapp" above with your binary

# bind-tools is needed for DNS resolution to work in *some* Docker networks, but not all.
# This applies to nslookup, Go binaries, etc. If you want your Docker image to work even
# in more obscure Docker environments, use this.
RUN apk add --no-cache bind-tools

# Use the non-root user to run our application
USER nonroot

# Default arguments for your app (remove if you have none):
CMD ["--foo", "1", "--bar=2"]
```

https://github.com/hexops/dockerfile/blob/main/Dockerfile

BuildKit

BuildKit is a toolkit for converting source code to build artifacts in an efficient, expressive and repeatable manner.

- From release of Docker 20.10 (Stable of BuildKit)
- Now by default enabled in latest release (export DOCKER_BUILDKIT=1)
- It improves a lot of performance, security features

BuildKit has support for securely passing secrets, forwarding SSH authentication agent from the host to the Docker build.

https://docs.docker.com/develop/develop-images/build_enhancements

BuildKit - Security Use Case (Secrets usage in build)

```
FROM baseimage
RUN  ...
ENV AWS_ACCESS_KEY=.......
ENV AWS_SECRET_ACCESS_KEY=.......
RUN ./get-data-from-aws.sh
RUN  ...
```


```
FROM baseimage
RUN  ...
ARG AWS_ACCESS_KEY
ARG AWS_SECRET_ACCESS_KEY
RUN ./get-data-from-aws.sh
RUN  ...
```

Passing the secrets to the Dockerfile rather hard coding or buildargs using BuildKit

```
# syntax=docker/dockerfile:1.2
FROM baseimage
RUN  ...
RUN --mount=type=secret,id=aws,target=/root/.aws/credentials,required ./get-data-from-aws.sh
RUN  ...
```

BuildKit - Security Use Case (SSH Socket)

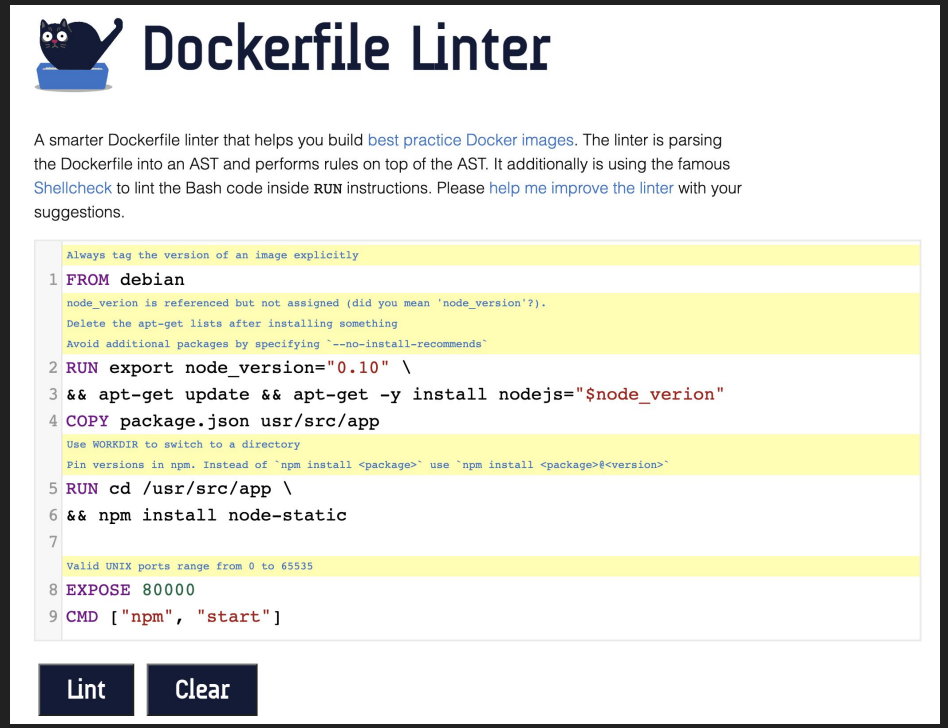
```
FROM baseimage
COPY ./keys/private.pem /root/.ssh/private.pem
RUN git clone git@github.com:org/repo /app && \
    cd /app && npm run build
```

Passing the SSH socket with mount by forwarding the SSH from host using BuildKit

```
FROM baseimage
RUN apk add --no-cache openssh-client
RUN mkdir -p -m 0700 ~/.ssh && ssh-keyscan github.com >> ~/.ssh/known_hosts
RUN --mount=type=ssh,required \
    git clone git@github.com:org/repo /app && \
    cd /app && npm run build
```

hadolint - Haskell Dockerfile Linter

A smarter Dockerfile linter that helps you build best practice Docker images. The linter is parsing the Dockerfile into an AST and performs rules on top of the AST. It is standing on the shoulders of ShellCheck to lint the Bash code inside RUN instructions.



https://hadolint.github.io/hadolint/

hadolint in action

```
❯ docker run --rm -i hadolint/hadolint < Dockerfile
/dev/stdin:1 DL3007 warning: Using latest is prone to errors if the image will ever update. Pin the version explicitly to a release tag
/dev/stdin:9 DL3020 error: Use COPY instead of ADD for files and folders
/dev/stdin:11 DL3020 error: Use COPY instead of ADD for files and folders
/dev/stdin:12 DL3004 error: Do not use sudo as it leads to unpredictable behavior. Use a tool like gosu to enforce root
/dev/stdin:14 DL3008 warning: Pin versions in apt get install. Instead of `apt-get install <package>` use `apt-get install <package>=<version>`
/dev/stdin:14 DL3009 info: Delete the apt-get lists after installing something
/dev/stdin:14 DL3015 info: Avoid additional packages by specifying `--no-install-recommends`
```

dockle

```
❯ dockle goodwithtech/dockle-test:v2
FATAL   - CIS-DI-0009: Use COPY instead of ADD in Dockerfile
        * Use COPY : /bin/sh -c #(nop) ADD file:81c0a803075715d1a6b4f75a29f8a01b21cc170cfc1bff6702317d1be2fe71a3 in /app/credentials.json
FATAL   - CIS-DI-0010: Do not store credential in ENVIRONMENT vars/files
        * Suspicious filename found : app/credentials.json
        * Suspicious ENV key found : MYSQL_PASSWD
FATAL   - DKL-DI-0005: Clear apt-get caches
        * Use 'rm -rf /var/lib/apt/lists' after 'apt-get install' : /bin/sh -c apt-get update && apt-get install -y git
FATAL   - DKL-LI-0001: Avoid empty password
        * No password user found! username : nopasswd
WARN    - CIS-DI-0001: Create a user for the container
        * Last user should not be root
INFO    - CIS-DI-0005: Enable Content trust for Docker
        * export DOCKER_CONTENT_TRUST=1 before docker pull/build
INFO    - CIS-DI-0006: Add HEALTHCHECK instruction to the container image
        * not found HEALTHCHECK statement
INFO    - CIS-DI-0008: Confirm safety of setuid/setgid files
        * setuid file: bin/mount urwxr-xr-x
        * setgid file: etc/passwd grw-r--r--
        * setuid file: app/suid.txt urw-r--r--
        * setgid file: usr/bin/chage grwxr-xr-x
        * setgid file: usr/bin/wall grwxr-xr-x
        * setgid file: usr/bin/ssh-agent grwxr-xr-x
        * setgid file: app/guid.txt grw-r--r--
        * setuid file: usr/lib/openssh/ssh-keysign urwxr-xr-x
        * setuid file: bin/su urwxr-xr-x
        * setuid file: etc/shadow urw-r-----
        * setuid file: usr/bin/chsh urwxr-xr-x
        * setuid file: usr/bin/passwd urwxr-xr-x
        * setuid file: bin/umount urwxr-xr-x
        * setuid file: usr/bin/chfn urwxr-xr-x
        * setgid file: usr/bin/expiry grwxr-xr-x
        * setgid file: sbin/unix_chkpwd grwxr-xr-x
~
```

Container Image Linter for Security, Helping build the Best-Practice Docker Image, Easy to start

https://github.com/goodwithtech/dockle

dockle - CIS Benchmark Checks

CIS Benchmark	Dockle	Docker Bench for Security	Hadolint	Clair
1. Create a user for the container	✅	✅	✅	-
2. Use trusted base images for containers	🔺	🔺	-	-
3. Do not install unnecessary packages in the container	-	-	-	-
4. Scan and rebuild the images to include security patches	-	-	-	✅
5. Enable Content trust for Docker	✅	✅	-	-
6. Add HEALTHCHECK instruction to the container image	✅	✅	-	-
7. Do not use update instructions alone in the Dockerfile	✅	✅	✅	-
8. Remove setuid and setgid permissions in the images	✅	-	-	-
9. Use COPY instead of ADD in Dockerfile	✅	✅	✅	-
10. Do not store secrets in Dockerfiles	✅	-	-	-
11. Install verified packages only	-	-	-	-

dockle - Checks

Original Checkpoints	Dockle	Docker Bench for Security	Hadolint	Clair
1. Avoid null password user (CVE-2019-5021)	✅	-	-	-
2. Be unique UID/GROUPs	✅	-	-	-
3. Avoid `sudo` command	✅	-	✅	-
4. Avoid sensitive directory mounting	✅	-	-	-
5. Avoid `apt-get upgrade`, `apk upgrade`, `dist-upgrade`	✅	-	✅	-
6. Use `apk add` with `--no-cache`	✅	-	✅	-
7. Clear `apt-get` caches	✅	-	✅	-
8. Avoid `latest` tag	✅	-	✅	-

DockerSlim - Minify and Secure Docker Containers

```
$ head -n 1 Dockerfile
FROM ubuntu:14.04

$ docker images my/sample-node-app
REPOSITORY                TAG                 IMAGE ID            CREATED             SIZE
my/sample-node-app        latest              31be09316a19        4 minutes ago       432MB

$ docker-slim build --http-probe my/sample-node-app
docker-slim[build]: state=started
docker-slim[build]: info=params target=my/sample-node-app continue.mode=enter
docker-slim[build]: state=inspecting.image
docker-slim[build]: state=inspecting.container
docker-slim[build]: info=container ... target.port.list=[32908] target.port.info=[8000/tcp => 0.0.0.0:32908]
docker-slim[build]: info=prompt message='press <enter> when you are done using the container'
docker-slim[build]: state=http.probe.starting
docker-slim[build]: info=http.probe.call status=200 method=GET target=http://127.0.0.1:32908/ attempt=1 error=none
docker-slim[build]: state=http.probe.done
docker-slim[build]: state=processing
docker-slim[build]: state=building message='building minified image'
docker-slim[build]: state=completed
docker-slim[build]: info=results status='MINIFIED BY 30.88X [432330078 (432 MB) => 14002579 (14 MB)]'
docker-slim[build]: info=results image.name=my/sample-node-app.slim image.size='14 MB' data=true

$ docker images my/sample-node-app.slim
REPOSITORY                TAG                 IMAGE ID            CREATED             SIZE
my/sample-node-app.slim   latest              b72b685be7fe        1 minute ago        14 MB
```

https://dockersl.im

DockerSlim - Usage and Features

```
❯ docker-slim --help
Incorrect Usage. flag: help requested

NAME:
   docker-slim - optimize and secure your Docker containers!

USAGE:
   docker-slim [global options] command [command options] [arguments...]

VERSION:
   darwin|Transformer|1.34.0|a5cb54043b3ab3cf747165aad745f19db680434e|2021-01-29_10:00:49PM

COMMANDS:
   build, b         Analyzes, profiles and optimizes your container image auto-generating Seccomp and AppArmor security profiles
   containerize, c  Containerize the target artifacts
   convert, k       Convert container image
   edit, e          Edit container image
   help, h          Show help info
   lint, l          Analyzes container instructions in Dockerfiles
   probe, prb       Probe target
   profile, p       Collects fat image information and generates a fat container report
   run, r           Run one or more containers
   server, s        Run as an HTTP server
   update, u        Updates docker-slim
   version, v       Shows docker-slim and docker version information
   xray, x          Shows what's inside of your container image and reverse engineers its Dockerfile
```

https://dockersl.im

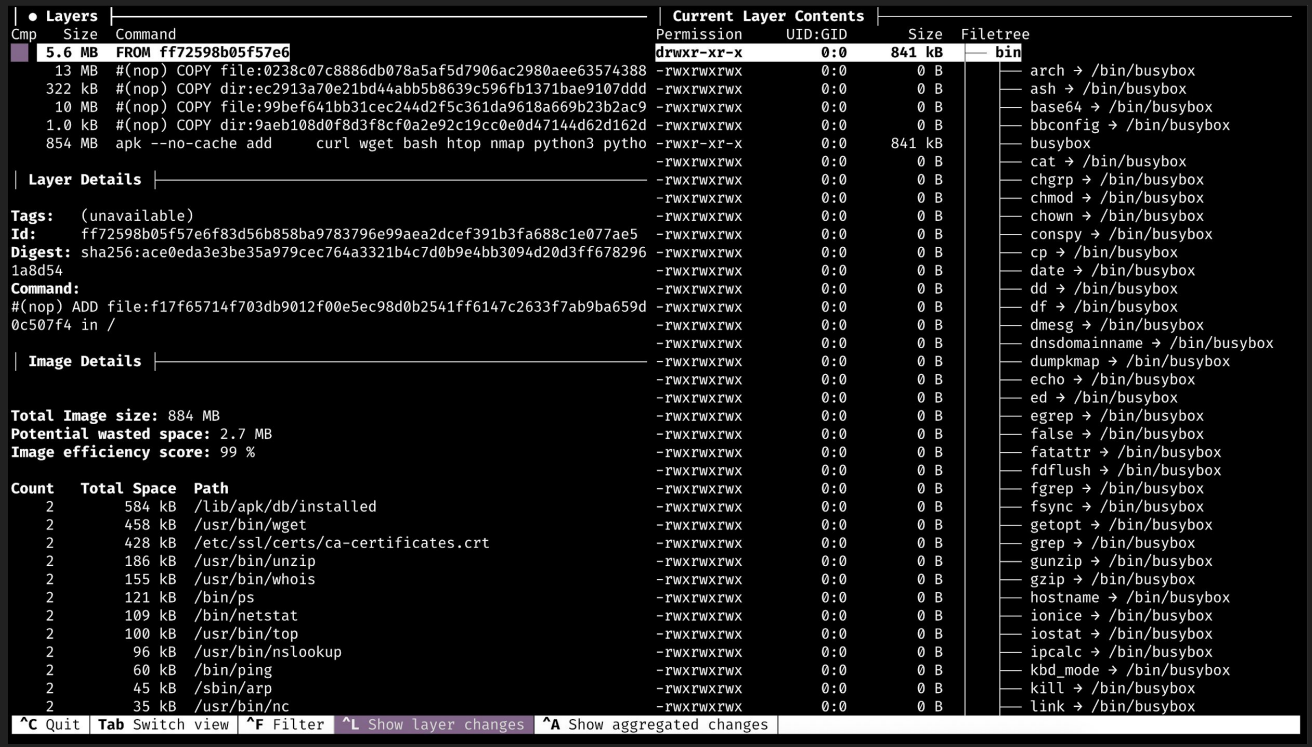
DockerSlim - Security Profiles

- The goal is to auto-generate Seccomp, AppArmor, (and potentially SELinux) profiles based on the collected information
  - AppArmor Profiles
  - Seccomp Profiles
- Generating the Seccomp profiles (I have tried it, doesn't work for all cases)
  - Run DockerSlim
    - docker-slim build your-name/your-app
  - Use the generated Seccomp profile
    - docker run --security-opt seccomp:<docker-slim directory>/.images/<YOUR_APP_IMAGE_ID>/artifacts/your-name-your-app-seccomp.json <your other run params> your-name/your-app

https://github.com/docker-slim/docker-slim

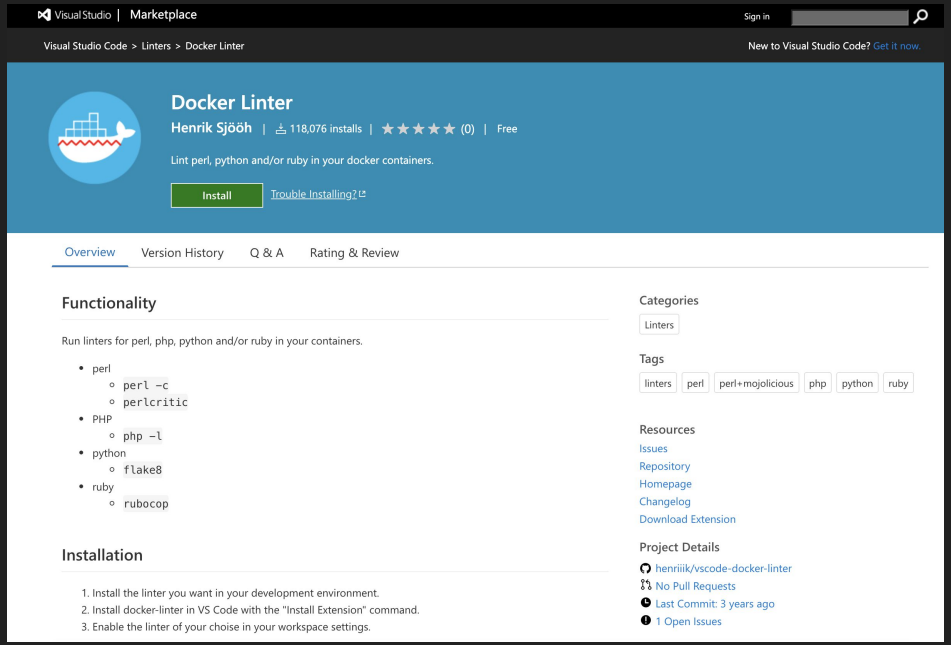
dive

A tool for exploring a docker image, layer contents, and discovering ways to shrink the size of your Docker/OCI image.



https://github.com/wagoodman/dive

Your code editor linters



https://marketplace.visualstudio.com/items?itemName=henriiik.docker-linter

Introducing OPA

Open Policy Agent is a Policy-based control for cloud native environments.

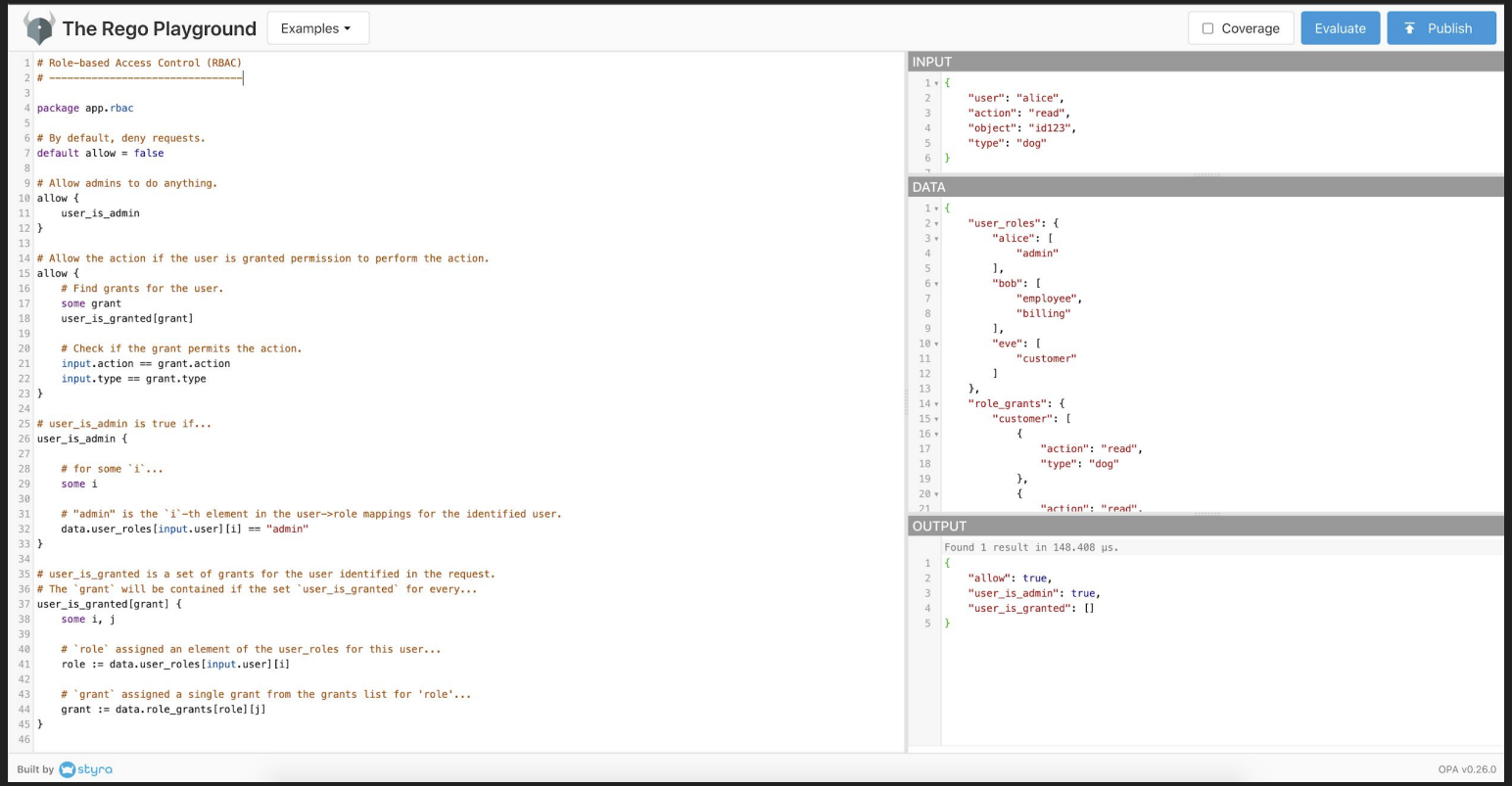
OPA is an open source, general-purpose policy engine that unifies policy enforcement across the stack. It provides a high-level declarative language that lets you specify policy as code and simple APIs to offload policy decision-making from your software.

https://www.openpolicyagent.org

Introduction to rego policies

- OPA policies are expressed in a high-level declarative language called Rego. Rego (pronounced “ray-go”) is purpose-built for expressing policies over complex hierarchical data structures
- Rego was inspired by Datalog, which is a well understood, decades old query language. Rego extends Datalog to support structured document models such as JSON
- Rego queries are assertions on data stored in OPA. These queries can be used to define policies that enumerate instances of data that violate the expected state of the system

Sample Rego policy example



https://play.openpolicyagent.org/

What is conftest?

Conftest is a utility to help you write tests against structured configuration data. For instance you could write tests for your Kubernetes configurations, Terraform code, Serverless configs or any other structured data. In our context, we will use it to write validation policies for Dockerfiles.

Conftest relies on the Rego language from Open Policy Agent for writing the assertions.

https://www.conftest.dev/

Supported formats by Conftest

- YAML
- JSON
- INI
- TOML
- HOCON
- HCL
- HCL 2
- CUE
- Dockerfile
- EDN
- VCL
- XML
- Jsonnet

```
package main

deny[msg] {
  input.kind == "Deployment"
  not input.spec.template.spec.securityContext.runAsNonRoot

  msg := "Containers must not run as root"
}

deny[msg] {
  input.kind == "Deployment"
  not input.spec.selector.matchLabels.app

  msg := "Containers must provide app label for pod selectors"
}
```

```
$ conftest test deployment.yaml
FAIL - deployment.yaml - Containers must not run as root
FAIL - deployment.yaml - Containers must provide app label for pod selectors

2 tests, 0 passed, 0 warnings, 2 failures, 0 exceptions
```

https://www.conftest.dev/

Sample Dockerfile

16 lines (11 sloc) | 319 Bytes

```
1  FROM ubuntu:latest
2  LABEL MAINTAINER "Madhu Akula"
3
4  ENV SECRET AKIGG23244GN2344GHG
5  ENV GITLAB_API_ID gig32oig3bgi34gb43gb43uigb43i
6
7  WORKDIR /app
8
9  ADD app /app
10 COPY README.md /app/README.md
11 ADD code /tmp/code
12 RUN sudo apt-get udpate
13
14 RUN apt-get update && apt-get install -y htop
15
16 CMD ["/bin/bash", "/app/entrypoint.sh"]
```

https://github.com/madhuakula/docker-security-checker/blob/master/Dockerfile

Policy for checking ADD usage instead of COPY

Here in the below example input contains the Dockerfile in a JSON format and we are looking for any command we find ADD and if we find in the Dockerfile we are returning the deny message.

```
warn[msg] {
    input[i].Cmd == "add"
    val := concat(" ", input[i].Value)
    msg = sprintf("Use COPY instead of ADD: %s", [val])
 }
```

Running docker-security-checker

```
❯ conftest test Dockerfile

WARN - Dockerfile - main - Do not use latest tag with image: ["ubuntu:latest"]
FAIL - Dockerfile - main - Suspicious ENV key found: ["SECRET", "AKIGG23244GN2344GHG"]
FAIL - Dockerfile - main - Use COPY instead of ADD: app /app
FAIL - Dockerfile - main - Use COPY instead of ADD: code /tmp/code
FAIL - Dockerfile - main - Avoid using 'sudo' command: sudo apt-get udpate

6 tests, 1 passed, 1 warning, 4 failures, 0 exceptions
```

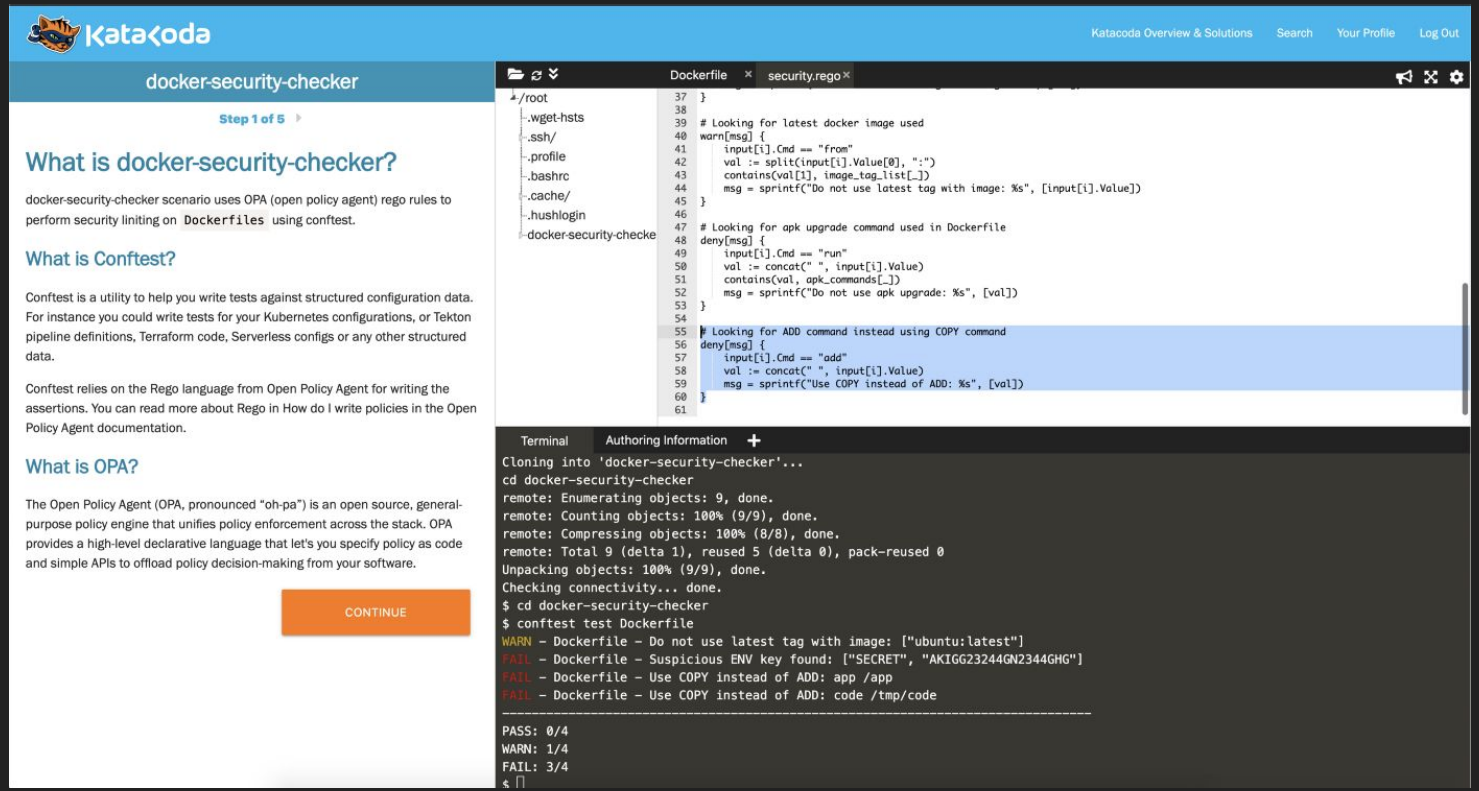
https://github.com/madhuakula/docker-security-checker

Why custom policies?

- Most organisations have common patterns across their workflows
- Some policies can be custom to their organisation, for example the below policy showcase that any base image not from exampletrustedregistry.com not allowed
    - Using these simple but powerful policies can easily prevent using untrusted images directly from the public registries and only allow developers and users to use internal private registries

```
deny[msg] {
    input[i].Cmd == "from"
    image := input[i].Value
    not startswith(image, "exampletrustedregistry.com/")
    msg := sprintf("Base image '%v' is used from untrusted registry", [image])
}
```

Try it out yourself

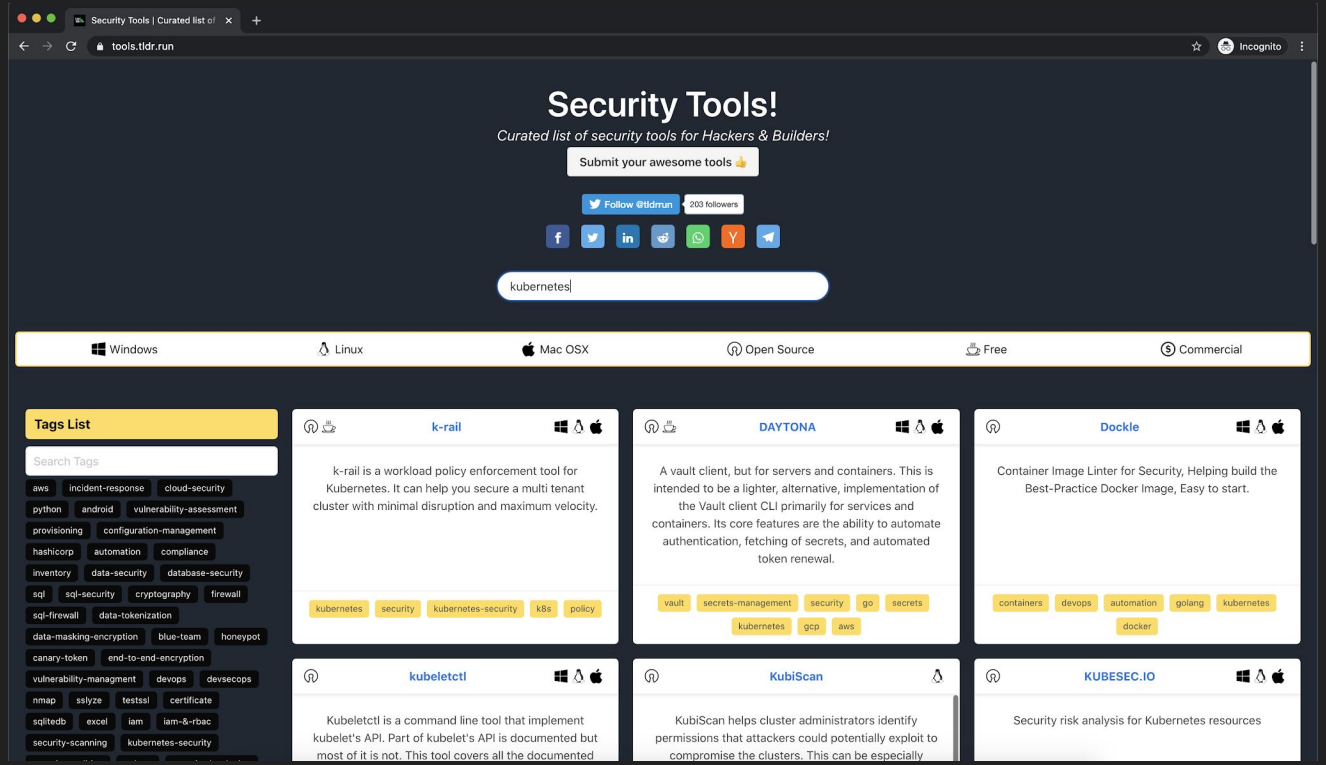


https://katacoda.com/madhuakula/scenarios/docker-security-checker

Next steps

- Try possible following the best practices when writing itself by using linters
- You can also use these check in your GitOps workflow, part of your git hooks
- You can create and standardise organisation wide custom policies as required for your workflow
- Adding these checks in CI/CD pipelines as part of your workflow will enable and validate security best practices
- Go beyond Dockerfiles and implement at each layer of your workflows

Are you interested to learn more tools around security?



https://tools.tldr.run

References & Resources

- https://docs.docker.com/engine/reference/builder
- Dockerfile Best Practices talk at dockercon 19
- https://docs.docker.com/develop/develop-images/dockerfile_best-practices
- https://github.com/hexops/dockerfile
- https://engineering.bitnami.com/articles/best-practices-writing-a-dockerfile.html
- https://snyk.io/blog/10-docker-image-security-best-practices
- https://pythonspeed.com/docker/
- https://github.com/moby/buildkit
- https://github.com/goodwithtech/dockle
- https://github.com/hadolint/hadolint
- https://github.com/docker-slim/docker-slim
- https://www.openpolicyagent.org
- https://play.openpolicyagent.org
- https://www.conftest.dev
- https://github.com/madhuakula/docker-security-checker

Thank You!

Madhu Akula
https://madhuakula.com