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Building Docker Images

What is a Dockerfile? How do you build a Docker image?

Dockerfile: A file containing a series of instructions on how to build a Docker image

Example:

- `Dockerfile`

```
# Use an official Python runtime as the base image
FROM python:3.8-slim

# Sets the working directory inside the container
# Conceptually similar to `cd` command
WORKDIR /app

# Copies files/directories from the host to the container
COPY . /app

# Install any needed packages specified in requirements.txt
RUN pip install --no-cache-dir -r requirements.txt

# Exposes a port for external access
# Make port 80 available to the world outside this container
EXPOSE 80

# Define the command to run the application
CMD ["python", "app.py"]
```

- Build the image using:

```
docker build -t my-python-app .
```

- Create container from the image:

On this page

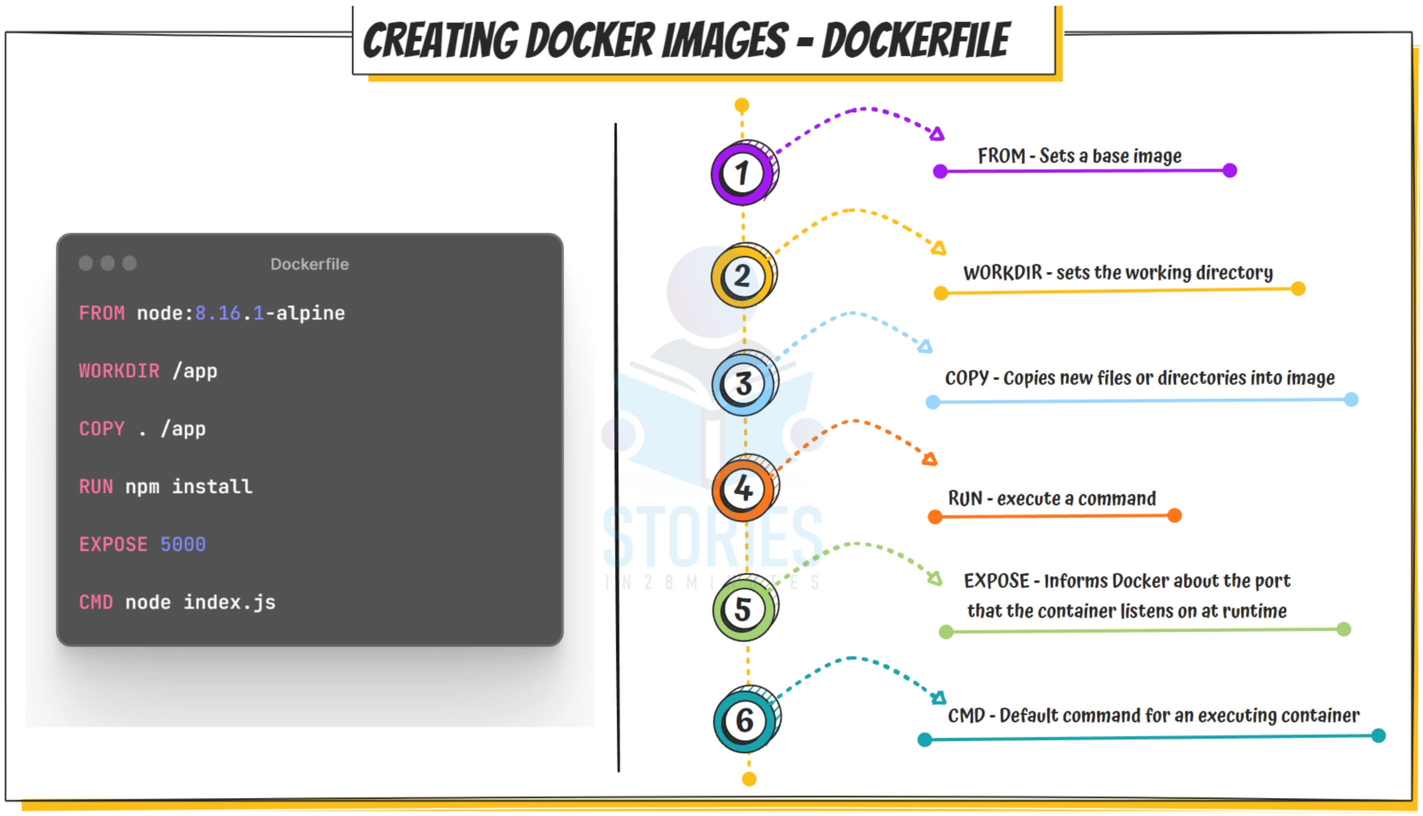
```
docker run -d -p 80:80 my-python-app

# Test
curl http://localhost
```

Explore the following projects with detailed guides:

- [hello-world-java]
- [hello-world-node]
- [hello-world-python]

Example:


CREATING DOCKER IMAGES - DOCKERFILE
Dockerfile
1
FROM - Sets a base image
2
WORKDIR - sets the working directory
3
COPY - Copies new files or directories into image
4
RUN - execute a command
5
EXPOSE - Informs Docker about the port that the container listens on at runtime
6
CMD - Default command for an executing container

```
FROM node:8.16.1-alpine

WORKDIR /app

COPY . /app

RUN npm install

EXPOSE 5000

CMD node index.js
```

What is a Base Image?

- **Starting Point for Builds**: Provides an initial starting point to build your container images
- **Add Custom Things**: Add your application code, dependencies, and configurations
- **Huge Variety**: You have a variety of Base Images
  - **OS Images**: Examples include ubuntu:22.04, debian:12, alpine:3.20;
  - **Language Runtimes**: Examples include openjdk:28-jdk-slim, node:30-alpine, python:4.12-slim; these come with pre-installed runtime environments
  - **Minimal & Secure Options**: Such as alpine:3.20 or gcr.io/distroless/java21; they are tiny and have a smaller attack surface
  - **Blank Slate**: The 'scratch' image gives a completely empty starting point for maximum control

Why is the Base Image a Key Choice?

- **Size**: Smaller images lead to faster downloads and less storage usage
- **Security**: Choosing a minimal and well-maintained image reduces vulnerability risks
- **Performance**: Influences startup time and runtime efficiency of your container
- **Community Support**: Popular images often have better documentation and troubleshooting resources

What is the difference between ENTRYPOINT and CMD in a Dockerfile? explain with example

- **`ENTRYPOINT`**: Defines the main executable
  - **Main executable**: Sets the container's primary command
  - **Not easily overridden**: Not overridden by arguments unless `--entrypoint` is used.
- **`CMD`**: Default arguments to the ENTRYPOINT
  - **Default execution**: Provides default arguments for container run
  - **Can be easily overridden**: Can be overridden by arguments passed to `docker run`.

`ENTRYPOINT` Example:

```
#// Use an official Python runtime as a parent image
FROM python:3.8-slim

# Set the working directory
WORKDIR /app

# Copy the current directory contents into the container
COPY . /app

# Install dependencies
RUN pip install --no-cache-dir -r requirements.txt

# Set the entrypoint to run the Python interpreter with app.py
ENTRYPOINT ["python", "app.py"]
```

- `ENTRYPOINT` instruction sets the entry point for the container as `python app.py`
- When the container starts, it will run `python app.py` by default, and you cannot change this behavior by passing arguments to docker run

- To override the `ENTRYPOINT`, you need to use the `--entrypoint` flag with docker run:

  ```
  docker run --entrypoint /bin/bash myimage
  ```

`ENTRYPOINT` + `CMD`:

```
# Use an official Python runtime as a parent image
FROM python:3.8-slim

# Set the working directory
WORKDIR /app

# Copy the current directory contents into the container
COPY . /app

# Install dependencies
RUN pip install --no-cache-dir -r requirements.txt

# Set the entrypoint to run the Python interpreter
ENTRYPOINT ["python"]

# Define the default argument to run
CMD ["app.py"]
```

- This Dockerfile sets `ENTRYPOINT` to `python` and `CMD` to `app.py`
  - When the container starts, it will run `python app.py`
  - You can override the CMD argument like this:

    ```
    docker run myimage another_script.py
    ```

`CMD` Alone Example:

```
# Use an official Python runtime as a parent image
FROM python:3.8-slim

# Set the working directory
WORKDIR /app

# Copy the current directory contents into the container
COPY . /app

# Install dependencies
```

```
RUN pip install --no-cache-dir -r requirements.txt

# Define the default command to run when the container starts
CMD ["python", "app.py"]
```

- The `CMD` instruction specifies that the container should run `python app.py` by default
- You can override this command by specifying a different command when you run the container

```
docker run myimage python another_script.py
```

Difference between ADD and COPY in a Dockerfile

- **`COPY`**: Simply copies files and directories from the host to the container
- **`ADD`**: More powerful. Can copy files and directories and also supports URL downloads and automatic extraction of compressed files

Example:

```
# Copy a local file into the /app directory in the image
COPY localfile.txt /app/

# Download a file from a URL
# and unzip it into the /app directory in the image
ADD http://example.com/file.tar.gz /app/
```

How do you tag a Container image? Why is tagging important?

- **Tagging Command**: Use `docker build -t imagename:tag .` to assign a tag
- **Importance**:
    - **Version Control**: Helps identify image versions
        - `microservice-a:v1,microservice-a:v2,microservice-a:v3`
        - `mysql:5.7, mysql:6.0`
        - `openjdk:8.0.0,openjdk:25.0.0`
    - **Rollbacks**: Easily revert to older versions of your image if newer ones fail

    - **Flexibility**: Gives teams flexibility w.r.t. deploying different versions in different environments (dev, staging, prod).
    - **Multiple Tags**: You can have multiple tags for an image
        - `latest` to indicate the latest version. Whoever want to use the latest version always can use the latest tag. `myapp:latest`

Example:

```
# Build an myapp image with a tag 1.0.0
docker build -t myapp:1.0.0 .

# You can have multiple tags for an image
# Add additional tag latest to myapp image with tag 1.0.0
docker tag myapp:1.0.0 myapp:latest
```

Explain the layered approach to building a Container image?

- **Layered builds**: Container images are created in layers
- **Example**: Most instructions in a Dockerfile, such as `FROM`, `RUN`, `COPY`, create a new, read-only layer on top of the previous one.
- **Why is this important?**
    - **Layers are cached**: Layers are cached for faster and more efficient builds
    - **However Be Cautious**: Changing one layer triggers a rebuild of subsequent layers
    - **Example Below**: In Changed Dockerfile, Every layer from `Instruction 2 CHANGED` is rebuilt again

Example Dockerfile

```
Instruction 1
Instruction 2
Instruction 3
Instruction 4
Instruction 5
Instruction 6
```

Changed Dockerfile

```
Instruction 1
Instruction 2 CHANGED
Instruction 3
Instruction 4
Instruction 5
Instruction 6
```

How can you design Dockerfiles to maximize layer reuse?

- **Application code changes often**: In applications, code changes often, libraries/dependencies change infrequently
  - Application code evolves to add new features, fix bugs, and adapt to changing requirements
  - Libraries and dependencies, on the other hand, tend to have more stable APIs and are updated less frequently, often for security patches, performance improvements, or new features
- **Recommended**: Build Layers with Libraries and Dependencies First and Code Later

Non-Optimized Dockerfile:

```
# Use an official Node.js runtime as a parent image
FROM node:24

# Set the working directory
WORKDIR /usr/src/app

# Copy application code + dependencies files
COPY . .

# Install dependencies - TAKES TIME!
RUN npm install

# Expose the application port
EXPOSE 3000

# Run the application
CMD ["node", "app.js"]
```

- In this Dockerfile, the `COPY . .` command copies the entire application code (`app.js`,...) + dependencies files (`package.json` and `package-lock.json`) before running npm install
- This means any change in the application code (even a small one) will cause Docker to invalidate the cache for the `COPY . .` instruction and all subsequent instructions, leading to frequent rebuilds of the npm install step

Optimized Dockerfile

```
# Use an official Node.js runtime as a parent image
FROM node:24

# Set the working directory
WORKDIR /usr/src/app

# Copy only package.json and package-lock.json first
COPY package*.json ./

# Install dependencies - TAKES TIME!
RUN npm install

# Copy the rest of the application code
COPY . .

# Expose the application port
EXPOSE 3000

CMD ["node", "app.js"]
```

- In this optimized Dockerfile, `package.json` and `package-lock.json` files are copied first
- The `RUN npm install` step runs only if dependencies change (`package.json` or `package-lock.json`)
  - `RUN npm install` will NOT if ONLY application code (`app.js`,...) changes!
- The `COPY . .` command copies the rest of the application code after installing dependencies.
- This ensures changes to the application code do not affect the dependencies layer, allowing Docker to cache the `npm install` step unless `package.json` or `package-lock.json` change

What is a multi-stage build, and how can it be used to reduce the size of a container image?

- **Scenario**: Imagine needing a full compiler or SDK to build your app — but once it's built, you only need the tiny binary to run it. Do you really want to ship all that extra baggage in production? There's a better way.
- **Multi-Stage Build**: A Docker technique that lets you use multiple images in one `Dockerfile` — one for building your app and another for running it
- **Build Big, Run Small**: Use a larger image (like `node`, `maven`, or `golang`) to compile your app — then copy just the final output into a much smaller runtime image

- **Reduces Image Size Dramatically**: Final image contains only what's necessary to run the app — no compilers, dev tools, or source code
- **Improves Security by Design**: Smaller images have fewer vulnerabilities because they include fewer packages and libraries
- **Makes CI/CD More Efficient**: Smaller images mean faster downloads, deployments, and less storage usage across environments
- **How Does It Work?**:
    - **Multiple FROM statements**: Each FROM starts a new build stage
    - **Artifact copying**: Transfer only necessary artifacts between stages to keep the final image small

Golang Example 1: Larger Image Size Final image includes unnecessary build tools, making it larger than needed

```
FROM golang:1.16

WORKDIR /app

COPY main.go .

RUN go build main.go

CMD ["./main"]
```

Golang Example 1: Multi Stage Build Separate build stage, copy only compiled binary to minimal base

```
# Stage 1: Build the Go application
FROM golang:1.16 AS builder

WORKDIR /app

COPY main.go .

RUN go build main.go

# Stage 2: Create a minimal image with the built binary
FROM alpine:latest  # MINIMAL BASE IMAGE

WORKDIR /root/

COPY --from=builder /app/main . # COPY WHAT WE WANT!

CMD ["./main"]
```

Is it possible to make changes to an existing Container image?

- **Read-only design**: Container images are immutable — you cannot directly modify them.
    - This ensures consistency, reproducibility, and follows the principle of immutable infrastructure.
- **Commit changes**: However, Modifications can be made to a running container and then committed to create a new image
- **New image creation**: Instead of updating the existing image, a new one is created, following immutable infrastructure principles

Example: Commit changes from container & Create new image

- **Step 1**: Run a container from the `nginx:latest` image

```
docker run --name test1 -d -p 80:80 nginx

# Test
curl http://localhost:80
```

- **Step 2**: Modify the running container

```
docker exec test1 sh -c \
'echo "<h1 style="font-size:400px">Testing</h1>" > /usr/share/nginx/html/

# Test
curl http://localhost:80
```

- **Step 3**: Create new container image from running container

```
docker commit test1 newnginx:modified
```

- **Step 4**: Run a container from the `newnginx:modified` image (newly created)

```
docker run --name test2 -d -p 81:80 newnginx:modified

# Test
curl http://localhost:81
```

What is the purpose of the .dockerignore file?

- **Exclude files**: `.dockerignore` prevents specific files and directories from being copied into the Container image during the build and make image lightweight
- **Pattern matching**: Define file and directory patterns (similar to .gitignore)that Docker should skip during the build process

Example `.dockerignore` File:

```
# Ignore node_modules directory
node_modules

# Ignore log files
*.log

# Ignore development or editor-specific files
.DS_Store
.vscode/
.idea/
```

What Are Alternatives to Writing Dockerfile?

- **Manual Dockerfile Challenges**: Writing good Dockerfile is challenging
    - Mistakes can lead to security issues, large images and long build times (inefficient caching)
- **Jib**: Java-specific tool that eliminates the need for Dockerfiles
    - **Layer Caching**: Built-in optimization to speed up image building process
    - **Security Features**: Reduce risks by automating best practices
- **Buildpacks**: Multi-language support (Java, Node.js, Python, etc.), no Dockerfile required
    - **Layer Caching**: Built-in optimization to speed up image building process
    - **Security Features**: Reduce risks by automating best practices
    - **Language Compatibility**: Supports a variety of programming languages

```
# Build a Java image with JIB
mvn compile com.google.cloud.tools:jib-maven-plugin:build \
  -Dimage=gcr.io/my-project/my-app

# Build a Java image with packeto build pack
pack build my-spring-app \
  --builder paketobuildpacks/builder:base \
  --env BP_JVM_VERSION=24 \
  --env BP_LOG_LEVEL=debug

# Use Spring Boot Maven Plugin (Uses packeto build pack)
mvn spring-boot:build-image
```

What is OCI and Why Is It Important?

- **Problem Before OCI**: Proprietary formats led to vendor lock-in and limited interoperability
- **Open Container Initiative(OCI)**: Defines open, vendor-neutral specifications for containers
  - **Image Spec**: Standard format for container images
  - **Runtime Spec**: Standardization for running containers across different platforms
  - **Distribution Spec**: Standardized methods for pushing and pulling images through container registries (Supported by Docker Hub, Google Artifact Registry, Amazon Elastic Container Registry, ...)
- **Open Governance**: Managed by the Linux Foundation, ensuring open collaboration and transparency
- **OCI is Supported By Almost All Container Based Tools and Cloud Platforms**: Docker, Podman, Buildpacks, Kubernetes, containerd, AWS, Azure, Google Cloud

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