Lab 4: Multi-Stage Dockerfiles

Overview

In this lab, we will discuss a normal Docker build. You will review and practice `Dockerfile` best practices and learn to create and optimize the size of the Docker images using a builder pattern and multi-stage `Dockerfile`.

Exercise 4.01: Building a Docker Image with the Normal Build Process

Your manager has asked you to dockerize a simple Golang application. You are provided with the Golang source code file, and your task is to compile and run this file. In this exercise, you will build a Docker image using the normal build process. You will then observe the image size of the final Docker image:

1. Create a new directory named `normal-build` for this exercise.
2. Navigate to the newly created `normal-build` directory:

   ```
   cd normal-build
   ```

3. Within the `normal-build` directory, create a file named `welcome.go`. This file will be copied to the Docker image during the build time.
4. Now, open the `welcome.go` file using your favorite text editor.
5. Add the following content to the `welcome.go` file, save it, and exit from the `welcome.go` file:

   ```
   package main
   import "fmt"
   func main() {
       fmt.Println("Welcome to multi-stage Docker builds")
   }
   ```

   This is a simple `hello world` application written in Golang. This will output `"Welcome to multi-stage Docker builds"` on execution.
6. Within the `normal-build` directory, create a file named `Dockerfile`.
7. Now, open the `Dockerfile` using your favorite text editor.
8. Add the following content to the `Dockerfile` and save the file:

   ```
   FROM golang:1.15.6
   WORKDIR /myapp
   COPY welcome.go .
   RUN go build -o welcome .
   ENTRYPOINT ["./welcome"]
   ```

   The `Dockerfile` starts with the `FROM` directive that specifies the latest Golang image as the parent image. This will set the `/myapp` directory as the current working directory of the Docker image. Then, the `COPY` directive will copy the `welcome.go` source file that you created in *step 3* to the Docker filesystem. Next is the `go build` command, which will build the Golang code that you created. Finally, the welcome code will be executed.
9. Now, build the Docker image:

```
docker build -t welcome:v1 .
```

You will see that the image is successfully built and tagged as `welcome:v1`:

```
C:\Users\fenago\Desktop>
C:\Users\fenago\Desktop>docker build -t welcome:v1 .
[+] Building 2.7s (9/9) FINISHED
 => [internal] load build definition from Dockerfile                                                                0.1s
 => => transferring dockerfile: 145B                                                                                0.0s
 => [internal] load .dockerignore                                                                                   0.1s
 => => transferring context: 2B                                                                                     0.0s
 => [internal] load metadata for docker.io/library/golang:1.15.6                                                    0.3s
 => [1/4] FROM docker.io/library/golang:1.15.6@sha256:de97bab9325c4c3904f8f7fec8eb469169a1d247bdc97dcab38c2c75cf4   0.0s
 => [internal] load build context                                                                                   0.0s
 => => transferring context: 138B                                                                                   0.0s
 => CACHED [2/4] WORKDIR /myapp                                                                                     0.0s
 => [3/4] COPY welcome.go .                                                                                         0.2s
 => [4/4] RUN go build -o welcome .                                                                                 1.4s
 => exporting to image                                                                                              0.4s
 => => exporting layers                                                                                             0.3s
 => => writing image sha256:f0df9dd84b801faf9960e3870354341a420865bbb4516d8131996c415740791d                        0.0s
 => => naming to docker.io/library/welcome:v1                                                                       0.0s

Use 'docker scan' to run Snyk tests against images to find vulnerabilities and learn how to fix them
```

10. Use the `docker image ls` command to list all the Docker images available on your computer:

    ```
    docker image ls
    ```

    The command should return the following output:

    ```
     /docker $ docker image ls
    REPOSITORY          TAG                 IMAGE ID            CREATED             SIZE
    welcome             v1                  cc0804e7c390        4 minutes ago       841MB
    golang              latest              75605a415539        2 weeks ago         839MB
     /docker $
    ```

It can be observed in the preceding output that the image size of the `welcome:v1` image.

In this section, we discussed how to use the normal Docker build process to build a Docker image and observed its size. The result was a huge Docker image, over 800 MB in size. The main disadvantage of these large Docker images is that they will take significant time to build, deploy, push, and pull over the networks. So, it is recommended to create minimal-sized Docker images whenever possible. In the next section, we will discuss how we can use the builder pattern to optimize the image size.

Exercise 4.02: Building a Docker Image with the Builder Pattern

In *Exercise 4.01*, *Building a Docker Image with the Normal Build Process*, you created a Docker image to compile and run the Golang application. Now the application is ready to go live, but the manager is not happy with the size of the Docker image. You have been asked to create a minimal-sized Docker image to run the application. In this exercise, you will optimize the Docker image using the builder pattern:

1. Create a new directory named `builder-pattern` for this exercise.

2. Navigate to the newly created `builder-pattern` directory:

    ```
    cd builder-pattern
    ```

3. Within the `builder-pattern` directory, create a file named `welcome.go`. This file will be copied to the Docker image at build time.

4. Now, open the `welcome.go` file using your favorite text editor.
5. Add the following content to the `welcome.go` file, and then save and exit this file:

```
package main
import "fmt"
func main() {
 fmt.Println("Welcome to multi-stage Docker builds")
}
```

   This is a simple `hello world` application written in Golang. This will output `"Welcome to multi-stage Docker builds"` once executed.
6. Within the `builder-pattern` directory, create a file named `Dockerfile.build`. This file will contain all the instructions that you are going to use to create the `build` Docker image.
7. Now, open the `Dockerfile.build` using your favorite text editor.
8. Add the following content to the `Dockerfile.build` file and save the file:

```
FROM golang:1.15.6
WORKDIR /myapp
COPY welcome.go .
RUN go build -o welcome .
ENTRYPOINT ["./welcome"]
```

   This has the same content that you created for the `Dockerfile` in *Exercise 4.01*, *Building a Docker Image with the Normal Build Process*.
9. Next, create the `Dockerfile` for the runtime container. Within the `builder-pattern` directory, create a file named `Dockerfile`. This file will contain all the instructions that you are going to use to create the runtime Docker image.
10. Now, open the `Dockerfile` using your favorite text editor.
11. Add the following content to the `Dockerfile` and save the file:

```
FROM scratch
WORKDIR /myapp
COPY welcome .
ENTRYPOINT ["./welcome"]
```

    This `Dockerfile` uses the scratch image, which is the most minimal image in Docker, as the parent. Then, it will configure the `/myapp` directory as the working directory. Next, the welcome executable is copied from the Docker host to the runtime Docker image. Finally, the `ENTRYPOINT` directive is used to execute the welcome executable.
12. Create the shell script to copy the executables between Docker containers. Within the `builder-pattern` directory, create a file named `build.sh`. This file will contain the steps to coordinate the build process between the two Docker containers.
13. Now, open the `build.sh` file using your favorite text editor.
14. Add the following content to the shell script and save the file:

```
#!/bin/sh
echo "Creating welcome builder image"
docker image build -t welcome-builder:v1 -f Dockerfile.build .
docker container create --name welcome-builder-container   welcome-builder:v1
docker container cp welcome-builder-container:/myapp/welcome .
docker container rm -f welcome-builder-container
echo "Creating welcome runtime image"
docker image build -t welcome-runtime:v1 .
rm welcome
```

This shell script will first build the `welcome-builder` Docker image and create a container from it. Then it will copy the compiled Golang executable from the container to the local filesystem. Next, the `welcome-builder-container` container is removed as it is an intermediate container. Finally, the `welcome-runtime` image is built.

15. Add execution permissions to the `build.sh` shell script:

```
chmod +x build.sh
```

16. Now that you have the two `Dockerfiles` and the shell script, build the Docker image by executing the `build.sh` shell script:

```
./build.sh
```

The image will be successfully built and tagged as `welcome-runtime:v1`:

```
Sending build context to Docker daemon  2.042MB
Step 1/4 : FROM scratch
 --->
Step 2/4 : WORKDIR /myapp
 ---> Using cache
 ---> 78f84b9685c1
Step 3/4 : COPY welcome .
 ---> Using cache
 ---> fff4a492c4d3
Step 4/4 : ENTRYPOINT ["./welcome"]
 ---> Using cache
 ---> be3b3f630159
Successfully built be3b3f630159
Successfully tagged welcome-runtime:v1
 /docker $
```

17. Use the `docker image` ls command to list all the Docker images available on your computer:

```
docker image ls
```

You should get the list of all the available Docker images as shown in the following figure:

```
 /docker $ docker image ls
REPOSITORY          TAG                 IMAGE ID            CREATED             SIZE
welcome-runtime     v1                  be3b3f630159        2 minutes ago       2.03MB
welcome-builder     v1                  cc0804e7c390        7 minutes ago       841MB
welcome             v1                  cc0804e7c390        7 minutes ago       841MB
golang              latest              75605a415539        2 weeks ago         839MB
 /docker $
```

As you can see from the preceding output, there are two Docker images available. welcome-builder has all the builds tools and is 805 MB, while welcome-runtime has a significantly lower image size of 4.01 MB. `golang:1.15.6` is the Docker image we used as the parent image of `welcome-builder`.

In this exercise, you learned how to use the builder pattern to reduce the size of the Docker image. However, using the builder pattern to optimize the size of the Docker image means that we have to maintain two `Dockerfiles` and one shell script. In the next section, let's observe how we can eliminate them by using a multi-stage `Dockerfile`.

Introduction to Multi-Stage Dockerfiles

Multi-stage Docker builds allow us to create minimal-sized Docker images that are similar to the builder pattern but eliminate the problems associated with it. As we have seen in the previous example, the builder pattern needs to maintain two `Dockerfiles` and a shell script. In contrast, multi-stage Docker builds will need only one `Dockerfile` and do not require any shell script to copy the executables between Docker containers. Also, the builder pattern requires that you copy the executables to the Docker host before copying them to the final Docker image. This is not required with the multi-stage Docker builds as we can use the `--from` flag to copy the executables between Docker images without copying them to the Docker host.

Now, let's observe the structure of a multi-stage `Dockerfile`:

```
# Start from latest golang parent image
FROM golang:1.15.6
# Set the working directory
WORKDIR /myapp
# Copy source file from current directory to container
COPY helloworld.go .
# Build the application
RUN go build -o helloworld .
# Start from latest alpine parent image
FROM alpine:latest
# Set the working directory
WORKDIR /myapp
# Copy helloworld app from current directory to container
COPY --from=0 /myapp/helloworld .
# Run the application
ENTRYPOINT ["./helloworld"]
```

The main difference between a normal `Dockerfile` and a multi-stage `Dockerfile` is that a multi-stage `Dockerfile` will use multiple `FROM` directives to build each phase. Each new phase will start with a new parent image and does not contain anything from the previous image other than the selectively copied executables. `COPY --from=0` is used to copy the executable from the first stage to the second stage.

Create `helloworld.go` and add following code in the file:

```
package main
import "fmt"
func main() {
    fmt.Println("Welcome to multi-stage Docker builds")
}
```

Build the Docker image and tag the image as `multi-stage:v1`:

```
docker image build -t multi-stage:v1 .
```

Now, you can list the available Docker images:

```
REPOSITORY    TAG      IMAGE ID       CREATED         SIZE
multi-stage   latest   75e1f4bcabd0   7 seconds ago   7.6MB
```

You can see that this has resulted in a Docker image of the same size that we observed with the builder pattern.

By default, the stages in the multi-stage `Dockerfile` are referred to by an integer number, starting with `0` from the first stage. These stages can be named to increase readability and maintainability by adding `AS <NAME>` to the `FROM` directive. The following is the improved version of the multi-stage `Dockerfile` that you observed in the preceding code block:

```
# Start from latest golang parent image
FROM golang:1.15.6 AS builder
# Set the working directory
WORKDIR /myapp
# Copy source file from current directory to container
COPY helloworld.go .
# Build the application
RUN go build -o helloworld .
# Start from latest alpine parent image
FROM alpine:latest AS runtime
# Set the working directory
WORKDIR /myapp
# Copy helloworld app from current directory to container
COPY --from=builder /myapp/helloworld .
# Run the application
ENTRYPOINT ["./helloworld"]
```

In the preceding example, we named the first stage `builder` and second stage `runtime`, as shown here:

```
FROM golang:1.15.6 AS builder
FROM alpine:latest AS runtime
```

Then, while copying the artifacts in the second stage, you used the name `builder` for the `--from` flag:

```
COPY --from=builder /myapp/helloworld .
```

While building a multi-stage `Dockerfile`, there might be instances where you want to build only up to a specific build stage. Consider that your `Dockerfile` has two stages. The first one is to build the development stage and contains all the build and debug tools, and the second is to build the production image that will contain only the

runtime tools. During the code development phase of the project, you might only need to build up to the development stage to test and debug your code whenever necessary. In this scenario, you can use the `--target` flag with the `docker build` command to specify an intermediate stage as the final stage for the resulting image:

```
docker image build --target builder -t multi-stage-dev:v1 .
```

In the preceding example, you used `--target builder` to stop the build at the builder stage.

In the next exercise, you will learn to use a multi-stage `Dockerfile` to create a size-optimized Docker image.

Exercise 4.03: Building a Docker Image with a Multi-Stage Docker Build

In *Exercise 4.02*, *Building a Docker Image with the Builder Pattern*, you used the builder pattern to optimize the size of the Docker image. However, there is an operational burden, as you need to manage two `Dockerfiles` and a shell script during the Docker image build process. In this exercise, you are going to use a multi-stage `Dockerfile` to eliminate this operational burden.

1. Create a new directory named `multi-stage` for this exercise:

   ```
   mkdir multi-stage
   ```

2. Navigate to the newly created `multi-stage` directory:

   ```
   cd multi-stage
   ```

3. Within the `multi-stage` directory, create a file named `welcome.go`. This file will be copied to the Docker image during the build time.

4. Now, open the `welcome.go` file using your favorite text editor.

5. Add the following content to the `welcome.go` file, and then save and exit this file:

   ```
   package main
   import "fmt"
   func main() {
       fmt.Println("Welcome to multi-stage Docker builds")
   }
   ```

This is a simple `hello world` application written in Golang. This will output `"Welcome to multi-stage Docker builds"` once executed.

Within the multi-stage directory, create a file named `Dockerfile`. This file will be the multi-stage `Dockerfile`.

6. Now, open the `Dockerfile` using your favorite text editor.

7. Add the following content to the `Dockerfile` and save the file:

   ```
   FROM golang:1.15.6 AS builder
   WORKDIR /myapp
   COPY welcome.go .
   RUN go build -o welcome .
   FROM scratch
   WORKDIR /myapp
   ```

```
COPY --from=builder /myapp/welcome .
ENTRYPOINT ["./welcome"]
```

This multi-stage `Dockerfile` uses the latest `golang` image as the parent image and this stage is named `builder`. Next, the `/myapp` directory is specified as the current working directory. Then, the `COPY` directive is used to copy the `welcome.go` source file and the `RUN` directive is used to build the Golang file.

The next stage of the `Dockerfile` uses the `scratch` image as the parent image. This will set the `/myapp` directory as the current working directory of the Docker image. Then, the `COPY` directive is used to copy the `welcome` executable from the builder stage to this stage. Finally, `ENTRYPOINT` is used to run the `welcome` executable.

8. Build the Docker image using the following command:

```
docker build -t welcome-optimized:v1 .
```

The image will be successfully built and tagged as `welcome-optimized:v1`:

```
C:\Users\fenago\Desktop\multi-stage>docker build -t welcome-optimized:v1 .
[+] Building 2.0s (11/11) FINISHED
 => [internal] load build definition from Dockerfile                                                0.0s
 => => transferring dockerfile: 32B                                                                 0.0s
 => [internal] load .dockerignore                                                                   0.0s
 => => transferring context: 2B                                                                     0.0s
 => [internal] load metadata for docker.io/library/golang:1.15.6                                    1.6s
 => [builder 1/4] FROM docker.io/library/golang:1.15.6@sha256:de97bab9325c4c3904f8f7fec8eb469169a1d247bdc97dcab38  0.0s
 => [stage-1 1/2] WORKDIR /myapp                                                                    0.0s
 => [internal] load build context                                                                   0.1s
 => => transferring context: 31B                                                                    0.0s
 => CACHED [builder 2/4] WORKDIR /myapp                                                             0.0s
 => CACHED [builder 3/4] COPY welcome.go .                                                          0.0s
 => CACHED [builder 4/4] RUN go build -o welcome .                                                  0.0s
 => CACHED [stage-1 2/2] COPY --from=builder /myapp/welcome .                                       0.0s
 => exporting to image                                                                              0.0s
 => => exporting layers                                                                             0.0s
 => => writing image sha256:4462aeac5719e3ded12da28a302906852f4fd1964bf87633f2400123416a20e7        0.0s
 => => naming to docker.io/library/welcome-optimized:v1                                             0.0s
```

9. Use the `docker image ls` command to list all the Docker images available on your computer. These images are available on your computer, either when you pull them from Docker Registry or when you build them on your computer:

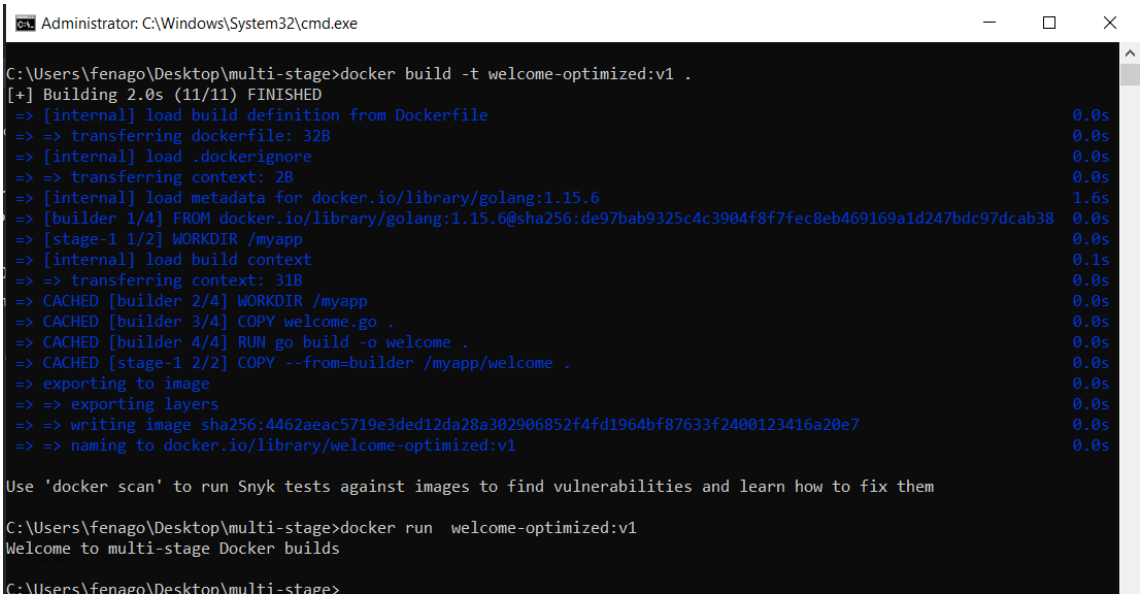
```
docker images
```

As you can see from the following output, the `welcome-optimized` image has the same size as the `welcome-runtime` image that you built in *Exercise 4.02, Building a Docker Image with the Builder Pattern*:

```
 /docker $ docker images
REPOSITORY          TAG                 IMAGE ID            CREATED             SIZE
welcome-optimized   v1                  04cf352dfc37        25 seconds ago      2.03MB
welcome-runtime     v1                  be3b3f630159        3 minutes ago       2.03MB
welcome-builder     v1                  cc0804e7c390        8 minutes ago       841MB
welcome             v1                  cc0804e7c390        8 minutes ago       841MB
golang              latest              75605a415539        2 weeks ago         839MB
 /docker $
```

Run the docker image by running following command:

```
docker run welcome-optimized:v1
```



Activity 4.01: Deploying a Golang HTTP Server with a Multi-Stage Docker Build

Imagine that you have been tasked with deploying a Golang HTTP server to a Docker container. Your manager has asked you to build a minimal-sized Docker image and observe best practices while building the `Dockerfile`.

This Golang HTTP server will return different responses based on the invoke URL:

Invoke URL	Message
http://127.0.0.1:<port>/	Home Page
http://127.0.0.1:<port>/contact	Contact Us
http://127.0.0.1:<port>/login	Login Page

Your task is to dockerize the Golang application given in the following code block using a multi-stage `Dockerfile`:

```
package main
import (
    "net/http"
    "fmt"
    "log"
    "os"
)
func main() {
    http.HandleFunc("/", defaultHandler)
    http.HandleFunc("/contact", contactHandler)
```

```
    http.HandleFunc("/login", loginHandler)
    port := os.Getenv("PORT")
    if port == "" {
        port = "8080"
    }
    log.Println("Service started on port " + port)
    err := http.ListenAndServe(":"+port, nil)
    if err != nil {
        log.Fatal("ListenAndServe: ", err)
        return
    }
}
func defaultHandler(w http.ResponseWriter, r *http.Request) {
    fmt.Fprintf(w, "<h1>Home Page</h1>")
}
func contactHandler(w http.ResponseWriter, r *http.Request) {
    fmt.Fprintf(w, "<h1>Contact Us</h1>")
}
func loginHandler(w http.ResponseWriter, r *http.Request) {
    fmt.Fprintf(w, "<h1>Login Page</h1>")
}
```

Execute the following steps to complete this activity:

1. Create a folder to store the activity files.
2. Create a `main.go` file with the code provided in the preceding code block.
3. Create a multi-stage `Dockerfile` with two stages. The first stage will use the `golang` image. This stage will build the Golang application using the `go build` command. The second stage will use an `alpine` image. This stage will copy the executable from the first stage and execute it.
4. Build and run the Docker image.
5. Once completed, stop and remove the Docker container.

You should get the following output when you navigate to the URL `http://127.0.0.1:8080/`:

Activity 4.01 Solution

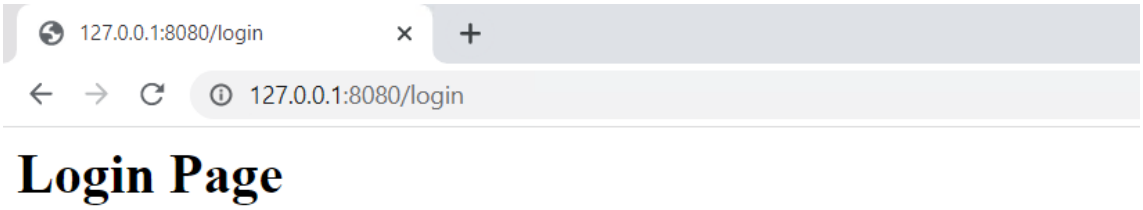
Activity solution is present in `docker-course\lab04\Activity4.01` folder. Run the following command in the terminal to build and run the docker image:

```
docker image build -t activity:4.01 .

docker container run -p 8080:8080 --name activity4.01 -d activity:4.01
```

Output:

`http://127.0.0.1:8080/login`



You can stop and delete the container by running following commands:

```
docker container stop activity4.01

docker container rm activity4.01
```

Summary

We started this lab by defining a normal Docker build and creating a simple Golang Docker image using the normal Docker build process. Then we observed the size of the resulting Docker image and discussed how a minimal-sized Docker image can speed up the build and deployment times for Docker containers and enhance security by reducing the attack surface.

We then used the builder pattern to create minimal-sized Docker images, utilizing two `Dockerfiles` and a shell script in this process to create the image. We explored multi-stage Docker builds---a new feature introduced to Docker in version 17.05 that can help to eliminate the operational burden of having to maintain two `Dockerfiles` and a shell script. Finally, we discussed the best practices for writing `Dockerfiles` and how these best practices can ensure reduced build time, reduced image size, and increased security, while increasing the maintainability of the Docker image.

In the next lab, we will cover `docker-compose` and how it can be used to define and run multi-container Docker applications.