Report: Scientific Calculator with DevOps

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IMT2022115

Contents

1 Introduction

1.1 Project Overview

In this project, we were required to develop a scientific calculator with user driven menu operations. I developed a terminal-based application in Java. In order to build and deliver the project, I implemented a DevOps pipeline. The following report discusses the DevOps approach along with the setup details.

GitHub repository: Calculator_SPE
DockerHub registry: calculator_spe

1.2 What is DevOps?

Software developers usually adopt a structured process to design, develop, test, deploy, and maintain software applications. This ensures that the developed software meets the user requirements, while also being high-quality. Some of the methodologies used for this are:

1. **Waterfall Model:** A sequential approach. Each phase is started only after the previous phase ends.
2. **Agile Model:** A flexible and iterative approach. The work is broken down into small phases called sprints. Development happens incrementally.
3. **DevOps Model:** Extends agile with continuous integration and delivery. Blends development and operations for faster deployments.

1.3 Why is DevOps used?

In traditional models like `Waterfall` and `Agile`, developers solely focus on writing code. The operations team is responsible for deploying and maintaining the application. But, this often causes delays and miscommunication. This is clearly not desirable while developing any application.

The aim of `DevOps` is to integrate development and operations into a single collaborative process. It is a cultural philosophy that empowers teams to work together more effectively. Frequent updates and fixes can be deployed automatically, thus reducing manual work and human errors.

Various different tools are used to implement Continuous Integration and Continuous Deployment pipelines. Testing and monitoring of applications is also automated. This results in efficient resource usage which leads to lower costs.

2 Tools Used

2.1 Source Control Management

`GitHub` was used as the source control management system. It allows multiple developers to work on the same project without interfering in each other's work. It can also connect with tools like `Jenkins`, `Docker`, `Kubernetes`, and cloud services.

2.2 Test

The `JUnit` framework was used to create unit tests for the calculator application. Unit tests are meant to test small units of code. They help to catch errors at the unit level before they spread into larger modules.

2.3 Build

`Maven` was used to run the unit tests and build the Java project. It helps to automatically build processes and manage the various dependencies of the project.

2.4 Continuous Integration

Continuous integration is the practice of merging additional code into an already existing code repository. Each integration must be tested and build. `Jenkins` was used for this purpose.

`Jenkins` can be integrated with version control systems like `GitHub` to detect changes in the repository. After this, it can run the unit tests provided and then build the application. It can also works with tools like `Docker`, `Kubernetes`, and `Ansible` for deployment.

2.5 Containerization

A container is a self-contained unit that includes the code, runtime, libraries, and system tools required to run an application. Containerizing an application allows it to be portable and run in an isolated environment. For this, `Docker` was used.

`Docker` allows the developer to provide the necessary instructions to containerize an application. Using these instructions, a docker image can be created. This image can be run by end users in the form of containers.

2.6 Deployment

`Ansible` is an open-source IT automation tool that helps you manage systems, deploy applications, and orchestrate IT infrastructure. For this project, `Ansible` was used to deploy the application.

3 Setup

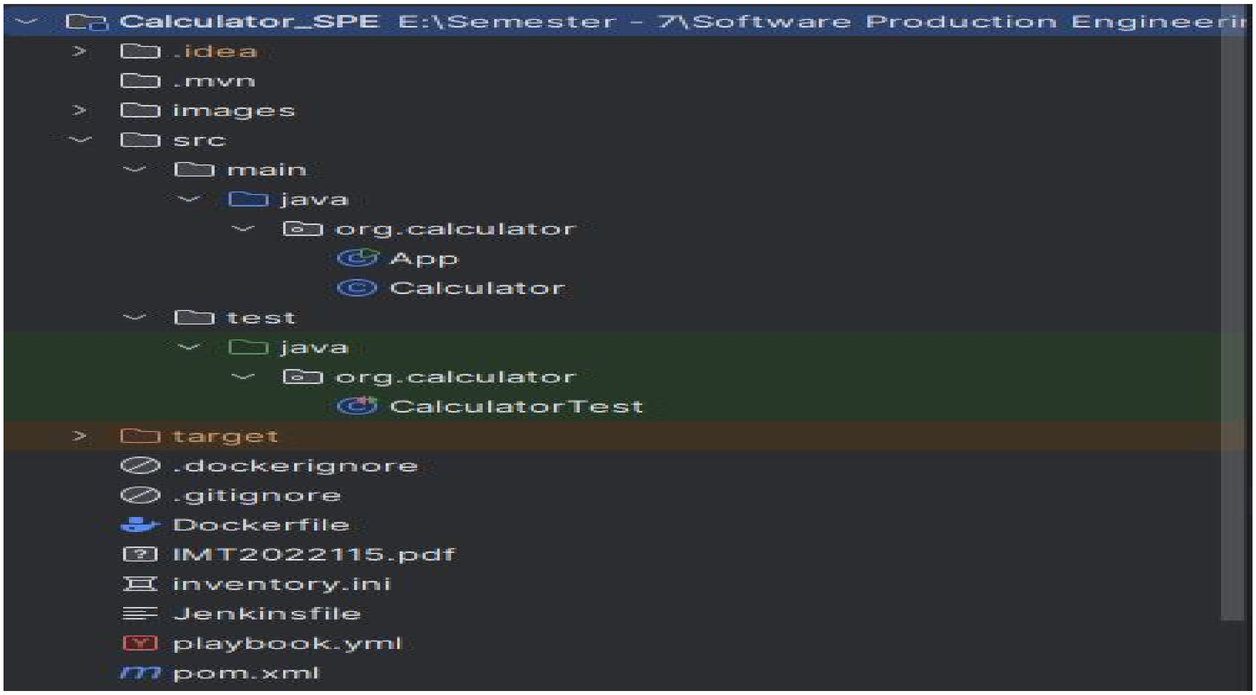
3.1 Creating a Maven Project

To develop the project, I used the `IntelliJ IDE`. I used `Java (21)` for this project.

Create a new `Maven` Project. Set the archetype to be `maven-archetype-quickstart`.
I used the bundled `Maven`, which was version **3.9.9**. Refer to my `GitHub` repository to get `pom.xml`.

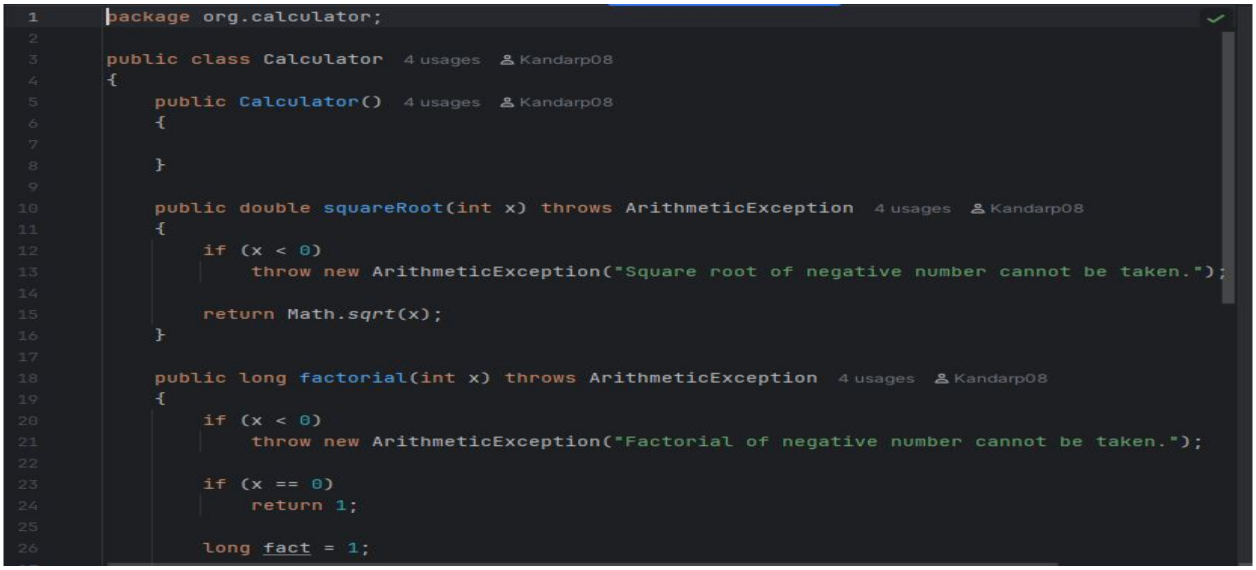
Note: Change the `mainClass` attribute in the `maven-jar-plugin` as per your main class. I used org.calculator.App as my main class.

Write your code in the `src` directory and tests in the `test` directory. Additionally, create `Jenkinsfile`, `Dockerfile`, `.dockerignore`, `inventory.ini`, and `playbook.yml` files in the **root directory** of the project.



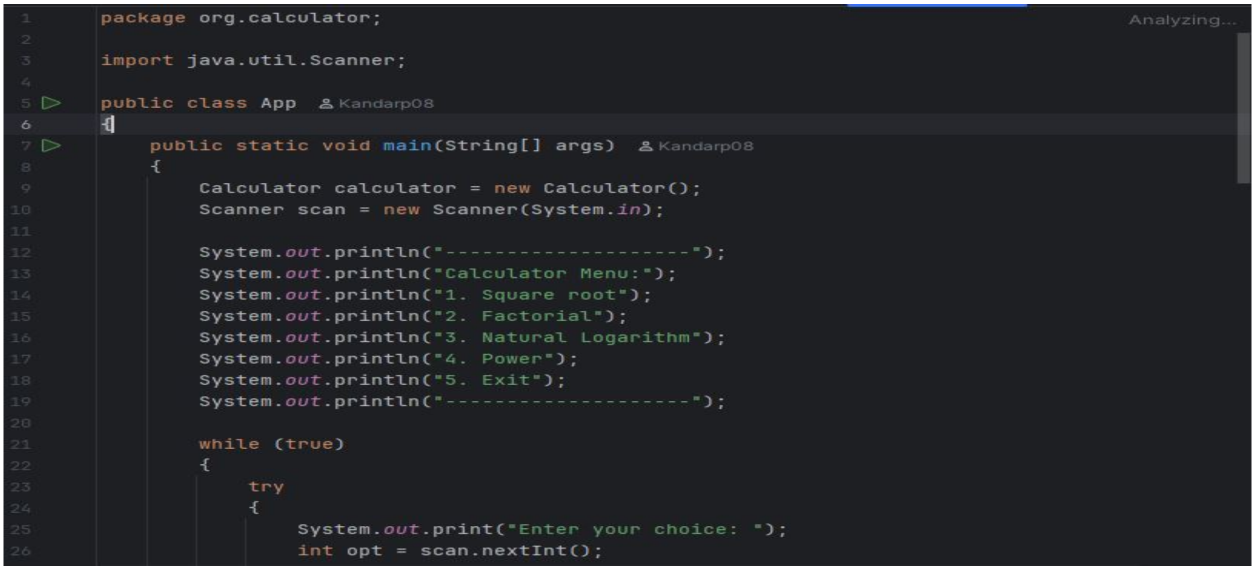
```
Calculator_SPE  E:\Semester - 7\Software Production Engineeri
  > .idea
    .mvn
  > images
  v src
    v main
      v java
        v org.calculator
            App
            Calculator
    v test
      v java
        v org.calculator
            CalculatorTest
  > target
    .dockerignore
    .gitignore
    Dockerfile
    IMT2022115.pdf
    inventory.ini
    Jenkinsfile
    playbook.yml
    pom.xml
```

Figure 1: Maven Project Structure.



```
package org.calculator;

public class Calculator  4 usages  Kandarp08
{
    public Calculator()  4 usages  Kandarp08
    {

    }

    public double squareRoot(int x) throws ArithmeticException  4 usages  Kandarp08
    {
        if (x < 0)
            throw new ArithmeticException("Square root of negative number cannot be taken.");

        return Math.sqrt(x);
    }

    public long factorial(int x) throws ArithmeticException  4 usages  Kandarp08
    {
        if (x < 0)
            throw new ArithmeticException("Factorial of negative number cannot be taken.");

        if (x == 0)
            return 1;

        long fact = 1;
```

Figure 2: Calculator class.



```
package org.calculator;

import java.util.Scanner;

public class App  Kandarp08
{
    public static void main(String[] args)  Kandarp08
    {
        Calculator calculator = new Calculator();
        Scanner scan = new Scanner(System.in);

        System.out.println("--------------------");
        System.out.println("Calculator Menu:");
        System.out.println("1. Square root");
        System.out.println("2. Factorial");
        System.out.println("3. Natural Logarithm");
        System.out.println("4. Power");
        System.out.println("5. Exit");
        System.out.println("--------------------");

        while (true)
        {
            try
            {
                System.out.print("Enter your choice: ");
                int opt = scan.nextInt();
```

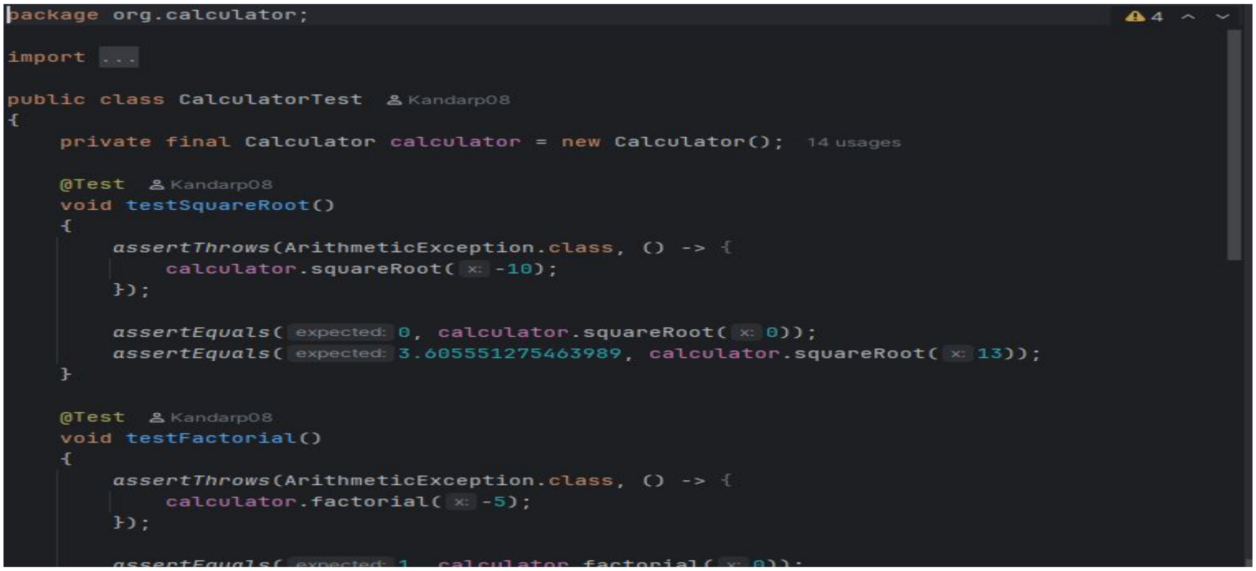
Figure 3: App class.

3.2 Setting up the GitHub repository

Create a new **public** repository on GitHub. In your root directory of the maven project, run these commands:

```
git init
git add .
git commit -m "Initial commit"
git remote add origin https://github.com/your-username/your-repo.git
git branch -M main
git push -u origin main
```

This will push your maven project to GitHub.



```
package org.calculator;

import ...

public class CalculatorTest  Kandarp08
{
    private final Calculator calculator = new Calculator();  14 usages

    @Test  Kandarp08
    void testSquareRoot()
    {
        assertThrows(ArithmeticException.class, () -> {
            calculator.squareRoot( x: -10);
        });

        assertEquals( expected: 0, calculator.squareRoot( x: 0));
        assertEquals( expected: 3.605551275463989, calculator.squareRoot( x: 13));
    }

    @Test  Kandarp08
    void testFactorial()
    {
        assertThrows(ArithmeticException.class, () -> {
            calculator.factorial( x: -5);
        });

        assertEquals( expected: 1, calculator.factorial( x: 0));
```

Figure 4: CalculatorTest class.

3.3 Creating a Jenkins project

3.3.1 Installation

First, make sure that `java` is installed. After that, install `Jenkins`.

Start the `Jenkins` service.

```
sudo systemctl start jenkins
sudo systemctl status jenkins
```

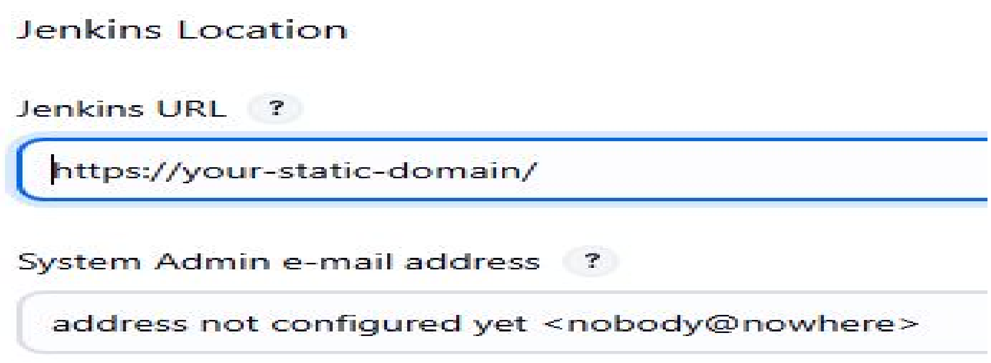
You should see that `Jenkins` is active and running. Open `Jenkins` on your browser. The url is `http://localhost:8080`. Follow the instructions given. You may also create a new user if needed.

3.3.2 Exposing Jenkins using ngrok

`Jenkins` is currently running locally. In order to integrate it with `GitHub`, we must expose it so that `GitHub` can connect with it. This can be done using `ngrok`. First, sign up on ngrok.com. Then, install `ngrok` on your system.

Connect to your ngrok account using the `authtoken`. You can get this token from here once you sign in.

Each ngrok user has access to a static domain. It can be found here. Go to **Jenkins** > **Manage Jenkins** > **System** and update the **Jenkins URL**.



Jenkins Location

Jenkins URL ?

https://your-static-domain/

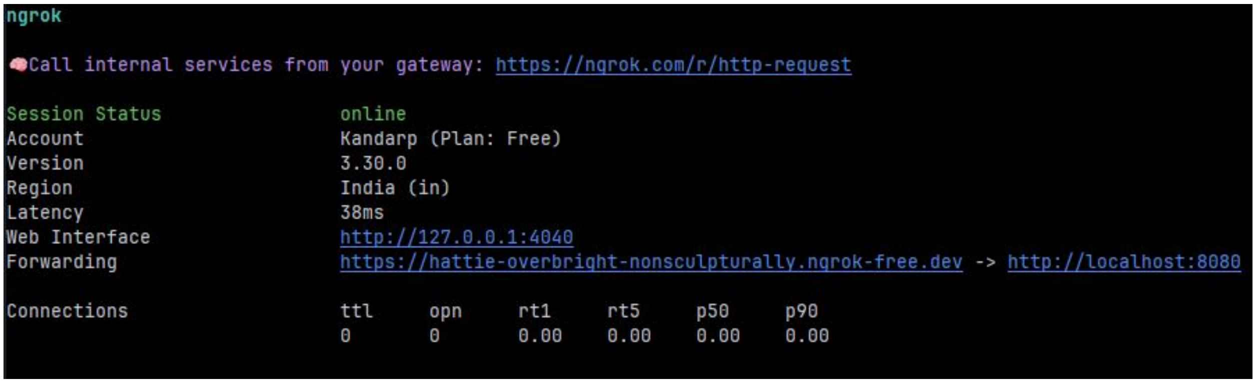
System Admin e-mail address ?

address not configured yet <nobody@nowhere>

Figure 5: Update Jenkins URL.

To expose `localhost:8080` to this static domain, run the command:

```
ngrok http --url=your-static-domain 8080
```

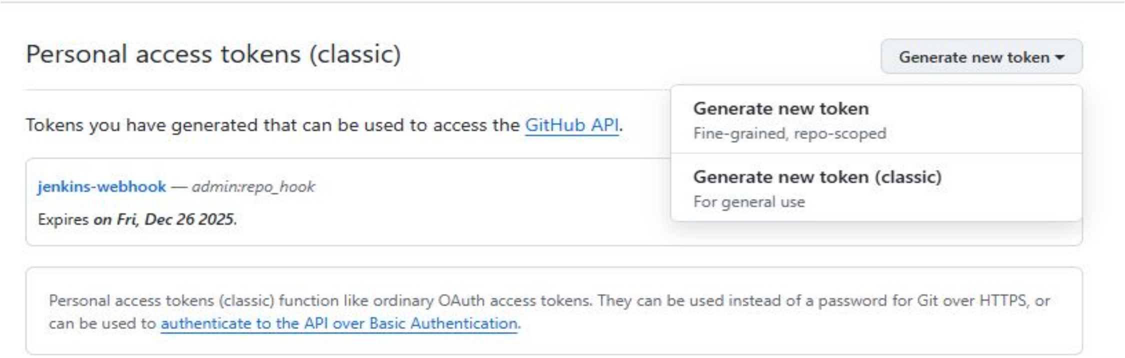


```
ngrok

Call internal services from your gateway: https://ngrok.com/r/http-request

Session Status                online
Account                       Kandarp (Plan: Free)
Version                       3.30.0
Region                        India (in)
Latency                       38ms
Web Interface                 http://127.0.0.1:4040
Forwarding                    https://hattie-overbright-nonsculpturally.ngrok-free.dev -> http://localhost:8080

Connections                   ttl     opn     rt1     rt5     p50     p90
                              0       0       0.00    0.00    0.00    0.00
```

Figure 6: Using ngrok to expose jenkins.

3.3.3 Create GitHub Webhook

On your `GitHub` profile, go to **Settings** > **Developer Settings** > **Personal access tokens** > **Tokens (classic)**. Generate a new class token and copy the secret text.



Personal access tokens (classic)

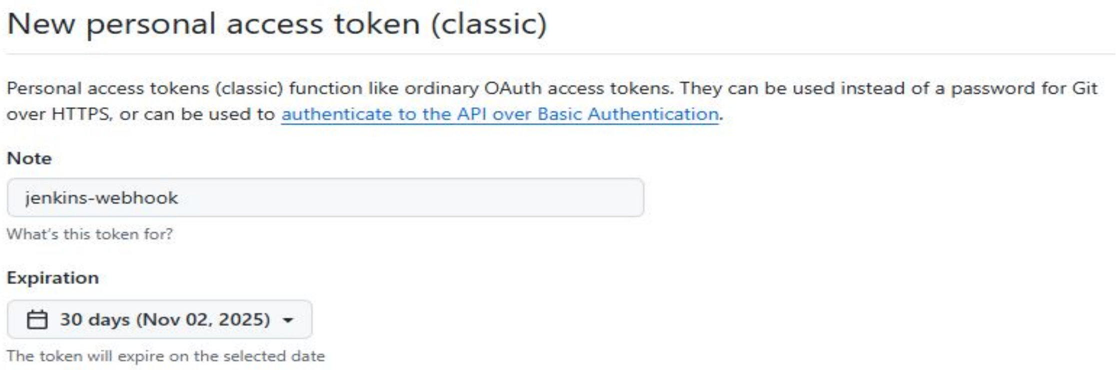
Tokens you have generated that can be used to access the GitHub API.

jenkins-webhook — *admin:repo_hook*

Expires *on Fri, Dec 26 2025*.

Personal access tokens (classic) function like ordinary OAuth access tokens. They can be used instead of a password for Git over HTTPS, or can be used to authenticate to the API over Basic Authentication.

Figure 7: Generate new token (classic).



New personal access token (classic)

Personal access tokens (classic) function like ordinary OAuth access tokens. They can be used instead of a password for Git over HTTPS, or can be used to authenticate to the API over Basic Authentication.

Note

jenkins-webhook

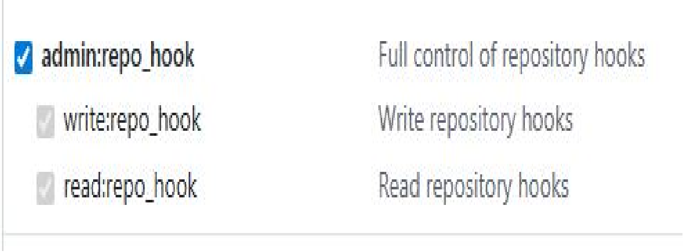
What's this token for?

Expiration

30 days (Nov 02, 2025)

The token will expire on the selected date

Figure 8: Set appropriate name and expiration date.

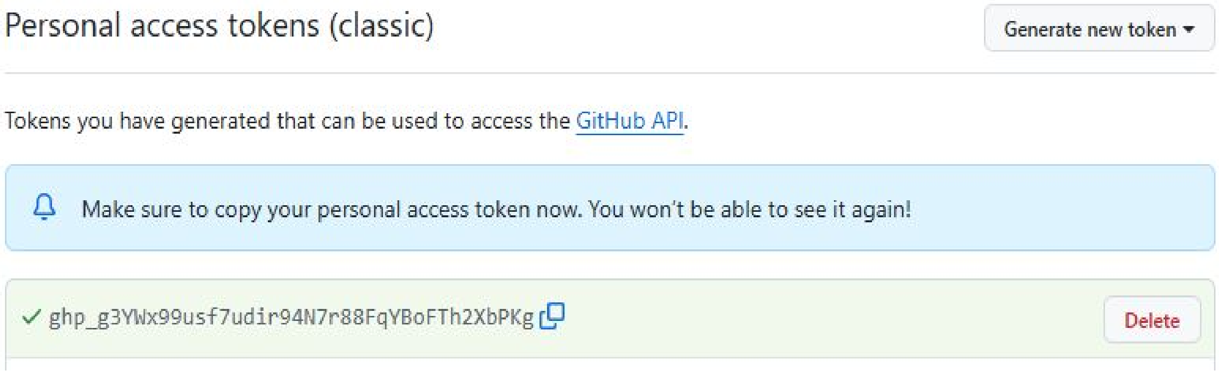


☑ admin:repo_hook Full control of repository hooks

☑ write:repo_hook Write repository hooks

☑ read:repo_hook Read repository hooks

Figure 9: Set appropriate control.



Personal access tokens (classic)

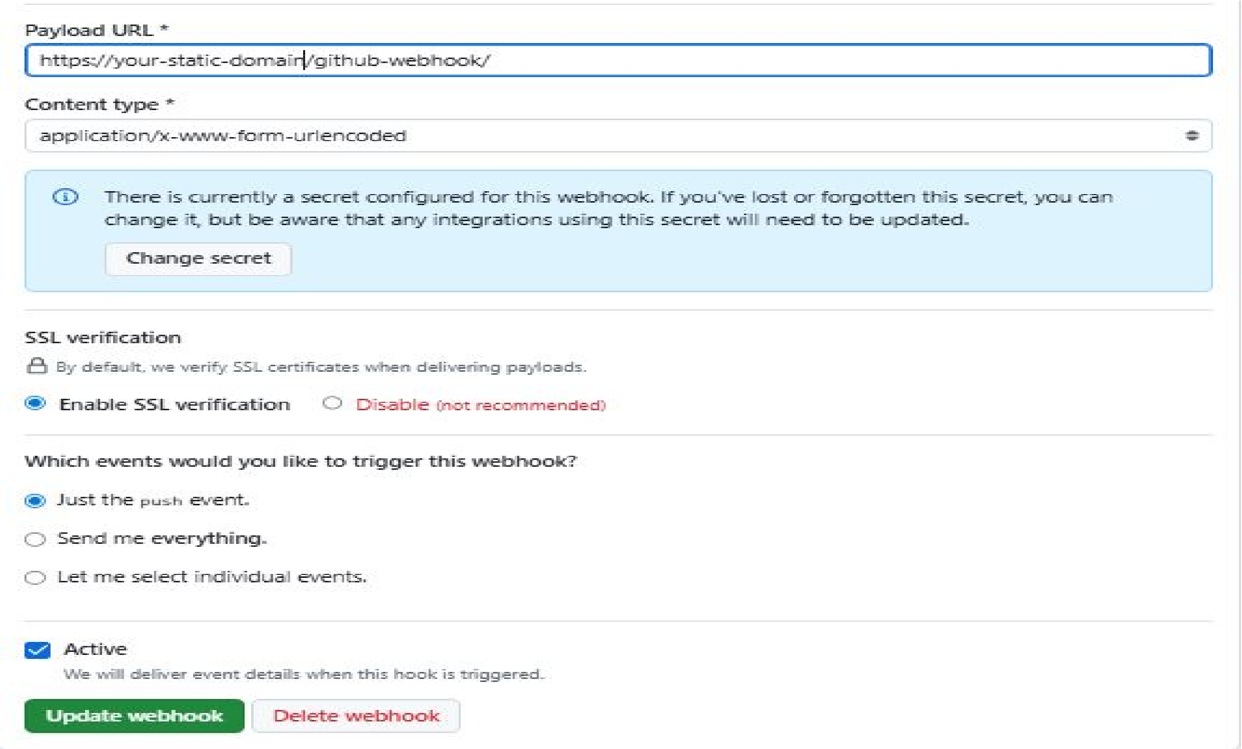
Tokens you have generated that can be used to access the GitHub API.

Make sure to copy your personal access token now. You won't be able to see it again!

✓ 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

Figure 10: Get token. Make sure to copy it.

In your `GitHub` repository, go to **Settings** > **Webhooks** and click on `Add webhook`. Refer to the image for the creation of the webhook. Copy the token generated in the previous step here.



Payload URL *

https://your-static-domain/github-webhook/

Content type *

application/x-www-form-urlencoded

There is currently a secret configured for this webhook. If you've lost or forgotten this secret, you can change it, but be aware that any integrations using this secret will need to update.

SSL verification

By default, we verify SSL certificates when delivering payloads.

● Enable SSL verification ○ Disable (not recommended)

Which events would you like to trigger this webhook?

● Just the push event.

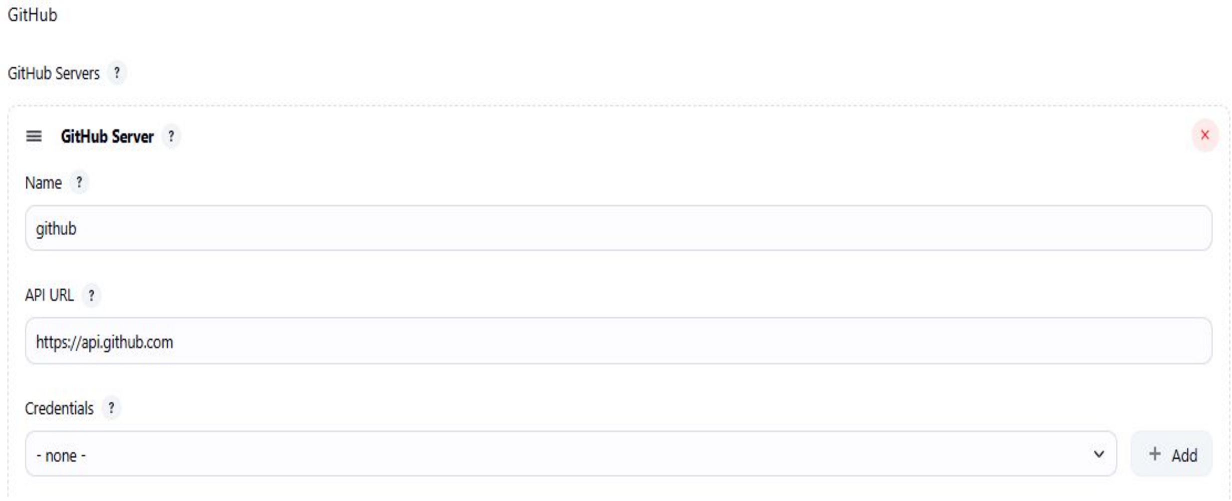
○ Send me everything.

○ Let me select individual events.

☑ Active

We will deliver event details when this hook is triggered.

Figure 11: Create webhook.



GitHub

GitHub Servers ?

GitHub Server ?

Name ?

github

API URL ?

https://api.github.com

Credentials ?

- none -

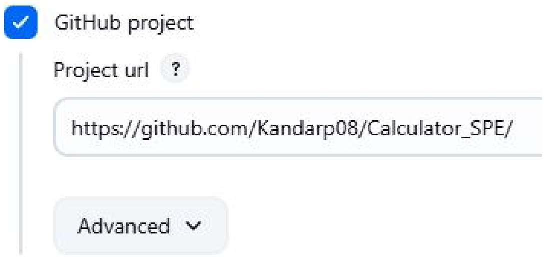
Figure 12: Also setup credentials in **Jenkins** > **System**.

3.3.4 Create Jenkins Pipeline project

On the `Jenkins` Dashboard, click on `New Item` and create a **Pipeline** project. Apply these configurations:

- **GitHub project:** Provide `GitHub` url.
- **Triggers:** GitHub hook trigger for GITScm polling.
- **Pipeline:** Pipeline script from SCM.

- SCM: Git.
- Repository URL: Your `GitHub` url.
- Credentials: Add a secret text credential. The secret has to be the same as provided in the GitHub webhook.
- Branches to build: */main.
- Script path: Jenkinsfile

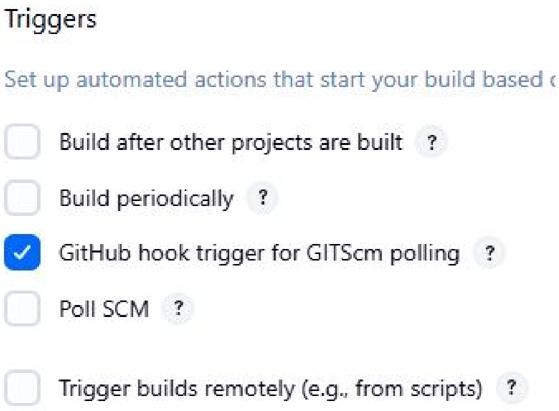


☑ GitHub project

Project url ?

https://github.com/Kandarp08/Calculator_SPE/

Figure 13: Pipeline Project.



Triggers

Set up automated actions that start your build based

☐ Build after other projects are built ?

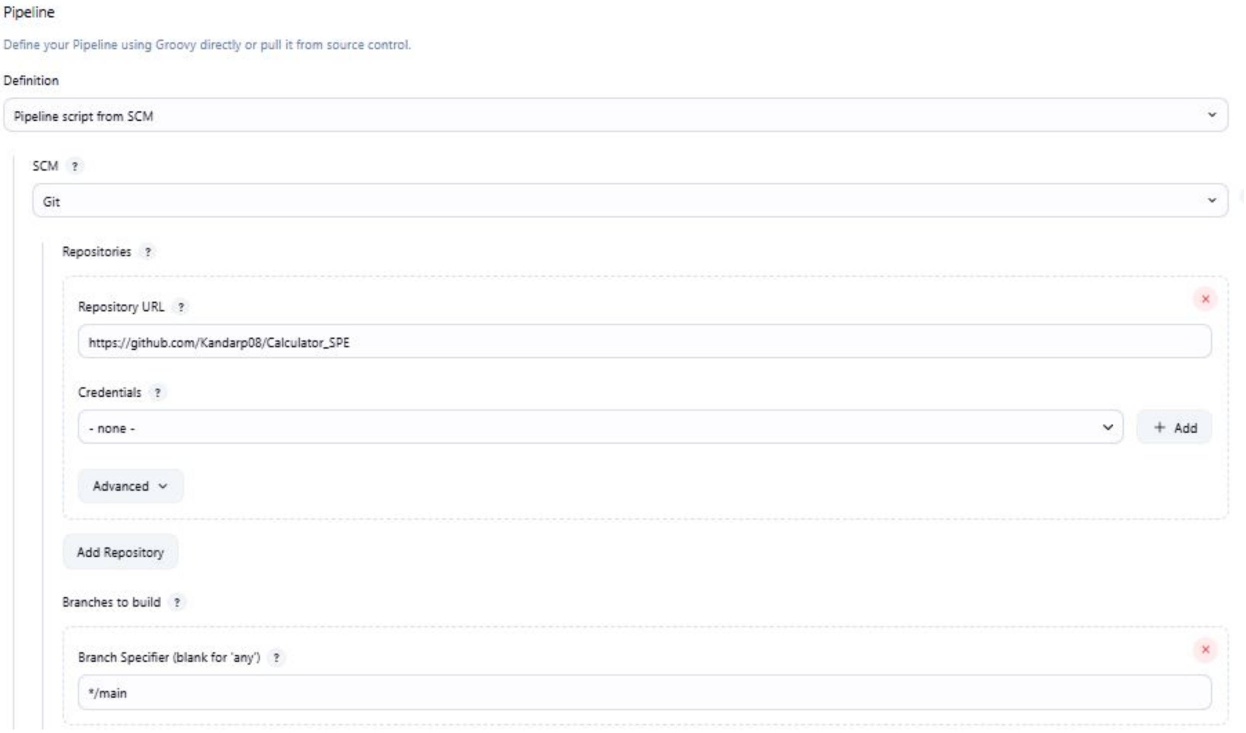
☐ Build periodically ?

☑ GitHub hook trigger for GITScm polling ?

☐ Poll SCM ?

☐ Trigger builds remotely (e.g., from scripts) ?

Figure 14: Pipeline Project.



Pipeline

Define your Pipeline using Groovy directly or pull it from source control.

Definition

Pipeline script from SCM

SCM ?

Git

Repositories ?

Repository URL ?

https://github.com/Kandarp08/Calculator_SPE

Credentials ?

- none -

Branches to build ?

Branch Specifier (blank for 'any') ?

*/main

Figure 15: Pipeline Script.

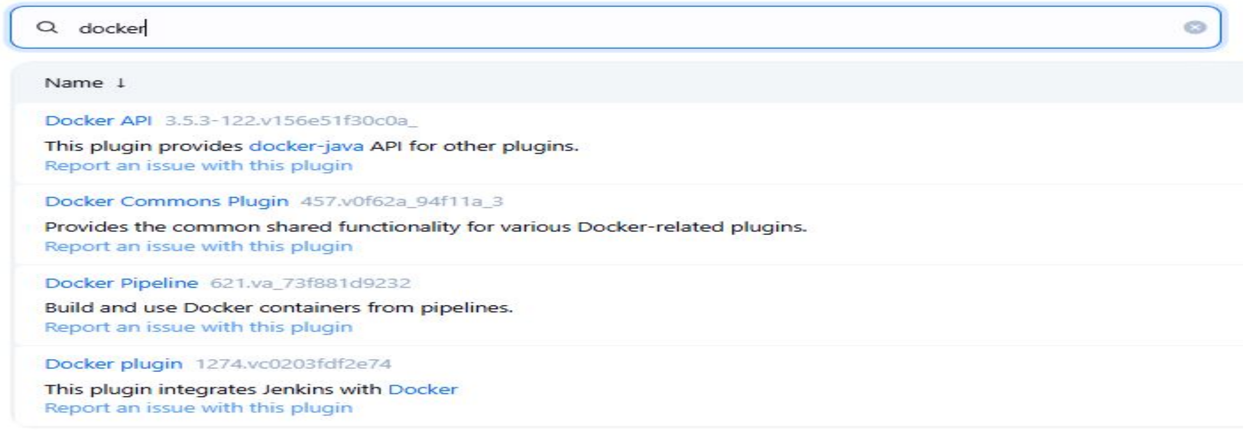
3.4 Integrating Docker with Jenkins

3.4.1 Installation

After installing docker locally, sign up on DockerHub.

3.4.2 Integration with Jenkins

In `Jenkins`, install the necessary `Docker` plugins.



docker

Name ↓

Docker API 3.5.3-122.v156e51f30c0a_
This plugin provides docker-java API for other plugins.
Report an issue with this plugin

Docker Commons Plugin 457.v0f62a_94f11a_3
Provides the common shared functionality for various Docker-related plugins.
Report an issue with this plugin

Docker Pipeline 621.va_73f881d9232
Build and use Docker containers from pipelines.
Report an issue with this plugin

Docker plugin 1274.vc0203fdf2e74
This plugin integrates Jenkins with Docker
Report an issue with this plugin

Figure 16: Install `Docker` plugins.

Add `Jenkins` user to `Docker` group.

```
sudo usermod -aG docker jenkins
sudo systemctl restart jenkins
```

Also add `DockerHub` credentials in your `Jenkins`.

3.5 Ansible

3.5.1 Installation

```
sudo apt update
sudo apt upgrade -y

sudo apt install ansible -y
```

3.5.2 Integration with Jenkins

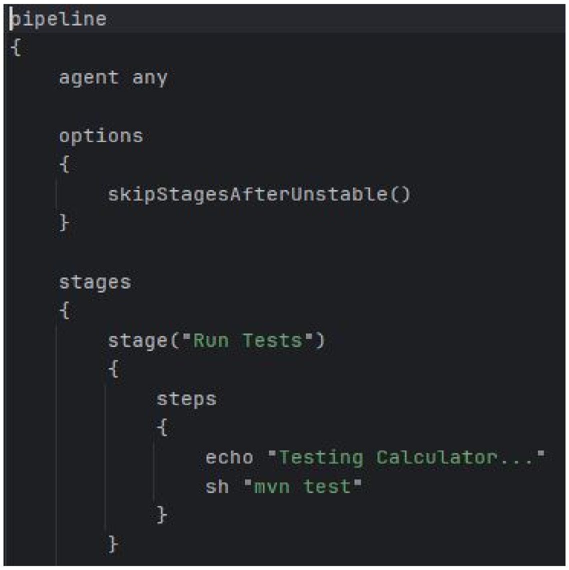
Make sure to give appropriate permissions to the `jenkins` user in order to run the `ansible-playbook` command.

4 Pipeline Explanation

1. **Push changes to GitHub:** Write/Modify your source code. After that, push your code to your `GitHub` repository. This will activate the webhook, which communicates the changes to Jenkins.

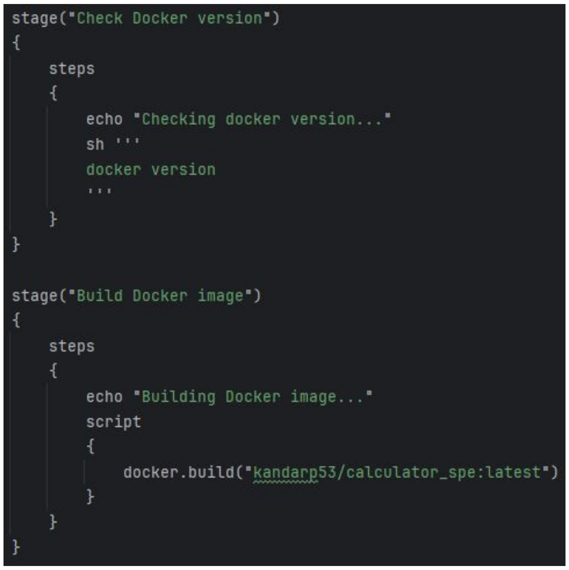
2. **Jenkins pipeline execution**

   The stages of the pipeline are mentioned in `Jenkinsfile`.



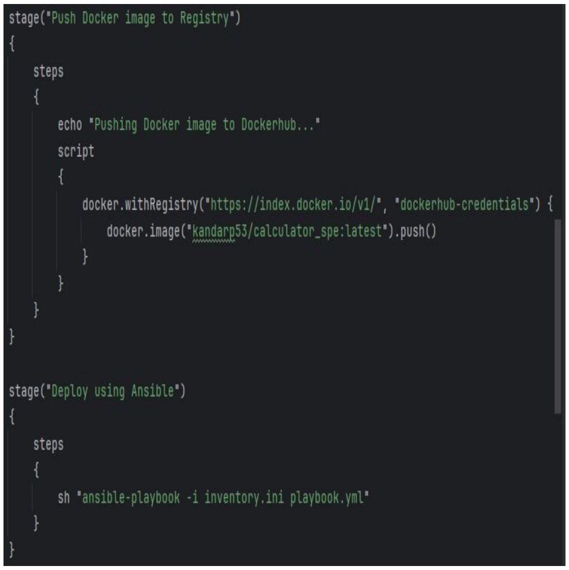
```
pipeline
{
    agent any

    options
    {
        skipStagesAfterUnstable()
    }

    stages
    {
        stage("Run Tests")
        {
            steps
            {
                echo "Testing Calculator..."
                sh "mvn test"
            }
        }
```

Figure 17: Jenkinsfile screenshot 1.



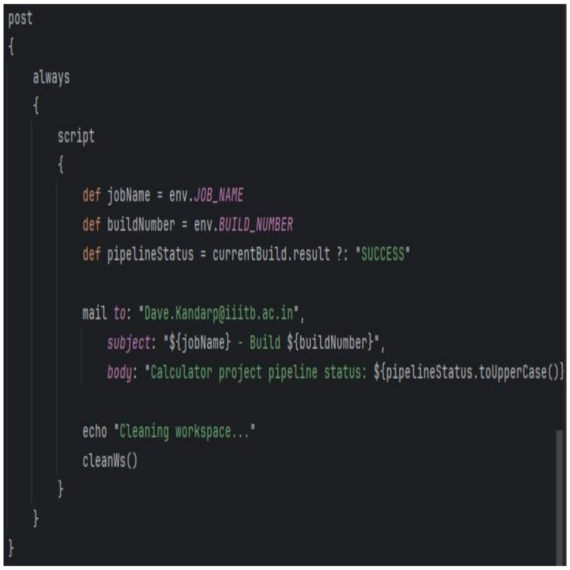
```
stage("Check Docker version")
{
    steps
    {
        echo "Checking docker version..."
        sh '''
        docker version
        '''
    }
}

stage("Build Docker image")
{
    steps
    {
        echo "Building Docker image..."
        script
        {
            docker.build("kandarp53/calculator_spe:latest")
        }
    }
}
```

Figure 18: Jenkinsfile screenshot 2.



```
stage("Push Docker image to Registry")
{
    steps
    {
        echo "Pushing Docker image to Dockerhub..."
        script
        {
            docker.withRegistry("https://index.docker.io/v1/", "dockerhub-credentials") {
                docker.image("kandarp53/calculator_spe:latest").push()
            }
        }
    }
}

stage("Deploy using Ansible")
{
    steps
    {
        sh "ansible-playbook -i inventory.ini playbook.yml"
    }
}
```

Figure 19: Jenkinsfile screenshot 3.



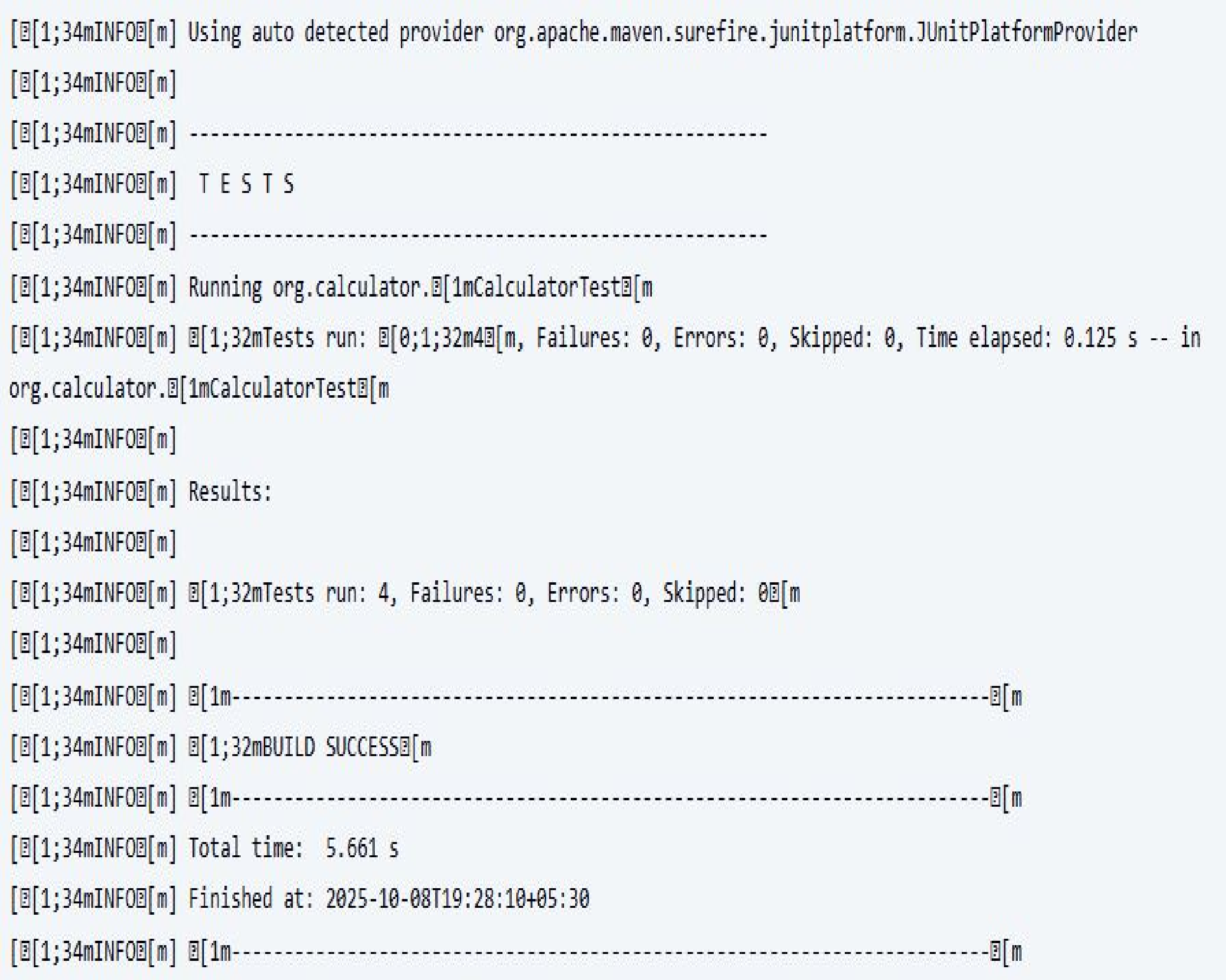
```
post
{
    always
    {
        script
        {
            def jobName = env.JOB_NAME
            def buildNumber = env.BUILD_NUMBER
            def pipelineStatus = currentBuild.result ?: "SUCCESS"

            mail to: "Dave.Kandarp@iiitb.ac.in",
                subject: "${jobName} - Build ${buildNumber}",
                body: "Calculator project pipeline status: ${pipelineStatus.toUpperCase()}

            echo "Cleaning workspace..."
            cleanWs()
        }
    }
}
```

Figure 20: Jenkinsfile screenshot 4.

agent any: Run the pipeline on any available node in the `Jenkins` environment. Note that the chosen node must have all the tools (`Maven`, `Docker`, `Ansible`, etc.) installed.

options: If at any stage the pipeline becomes unstable, then none of the subsequent stages are executed. This happens when the tests fail but the build is not marked as **FAILURE**.

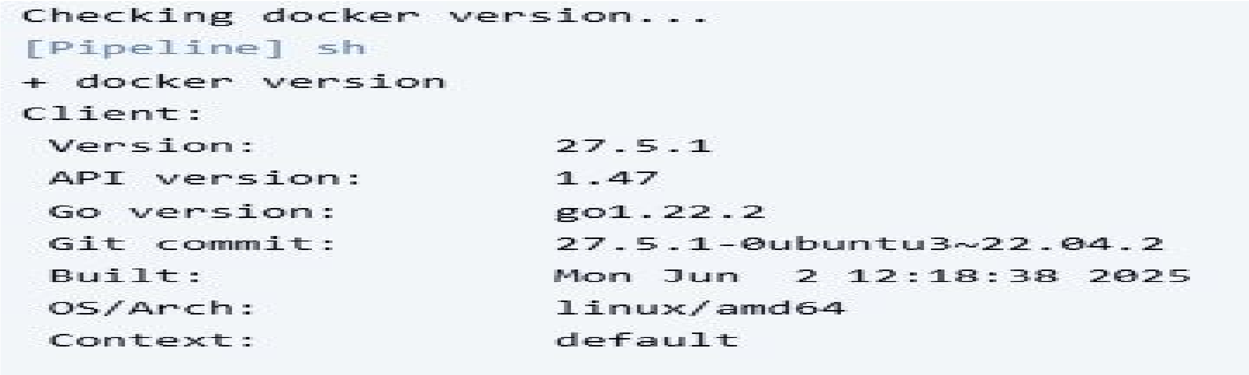
(a) Run Tests:
Run the `JUnit` tests as mentioned in the `CalculatorTest` class. This must be done to ensure that the code is not erroneous and passes all the mentioned testcases.



```
[□[1;34mINFO□[m] Using auto detected provider org.apache.maven.surefire.junitplatform.JUnitPlatformProvider
[□[1;34mINFO□[m]
[□[1;34mINFO□[m] -------------------------------------------------------
[□[1;34mINFO□[m]  T E S T S
[□[1;34mINFO□[m] -------------------------------------------------------
[□[1;34mINFO□[m] Running org.calculator.□[1mCalculatorTest□[m
[□[1;34mINFO□[m] □[1;32mTests run: □[0;1;32m4□[m, Failures: 0, Errors: 0, Skipped: 0, Time elapsed: 0.125 s -- in
org.calculator.□[1mCalculatorTest□[m
[□[1;34mINFO□[m]
[□[1;34mINFO□[m] Results:
[□[1;34mINFO□[m]
[□[1;34mINFO□[m] □[1;32mTests run: 4, Failures: 0, Errors: 0, Skipped: 0□[m
[□[1;34mINFO□[m]
[□[1;34mINFO□[m] □[1m------------------------------------------------------------------------□[m
[□[1;34mINFO□[m] □[1;32mBUILD SUCCESS□[m
[□[1;34mINFO□[m] □[1m------------------------------------------------------------------------□[m
[□[1;34mINFO□[m] Total time:  5.661 s
[□[1;34mINFO□[m] Finished at: 2025-10-08T19:28:10+05:30
[□[1;34mINFO□[m] □[1m------------------------------------------------------------------------□[m
```

Figure 21: Running `JUnit` tests using `Maven`.

(b) Check Docker version:
While implementing the pipeline, I faced several issues like `Docker` plugins not installed and missing permissions. The main aim of this stage is to quickly verify whether `Jenkins` is able to run the `docker` command or not.



```
Checking docker version...
[Pipeline] sh
+ docker version
Client:
 Version:           27.5.1
 API version:       1.47
 Go version:        go1.22.2
 Git commit:        27.5.1-0ubuntu3~22.04.2
 Built:             Mon Jun  2 12:18:38 2025
 OS/Arch:           linux/amd64
 Context:           default
```

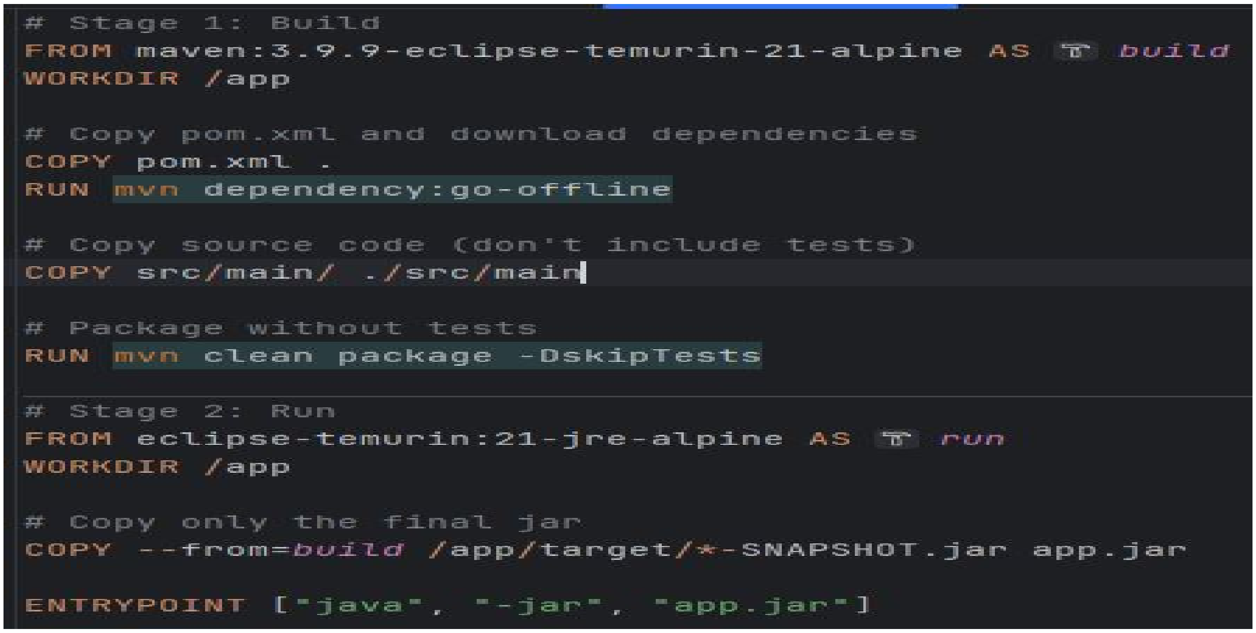
Figure 22: Checking `Docker` version.

(c) Build Docker image:

After verifying that `Jenkins` can indeed run `docker`, we proceed to build the docker image. The steps to build the image are mentioned in the Dockerfile. It is a multi-stage build.

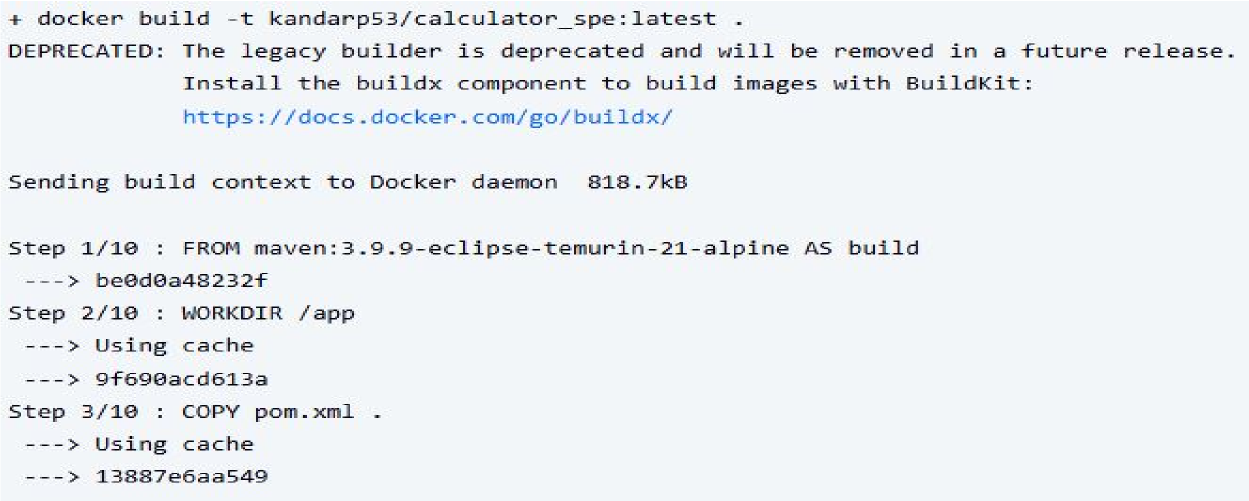
Stage 1: Build: A lightweight maven image is used for the build. First, the dependencies are installed based on the `pom.xml` file. The project is not yet built, only the dependencies are installed. After that, the code present in `src/main` directory is copied into the `/app` directory of the container. Note that we exclude the test code here. We skip testing since it is already done in the earlier stage. A JAR file for the application is created.

Stage 2: Run: For running the JAR file, we use a lightweight image which contains only the Java JRE, and not the JDK. From the build stage, the JAR file is copied to `/app` directory. The ENTRYPOINT defines the default command to run when the container starts.



```
# Stage 1: Build
FROM maven:3.9.9-eclipse-temurin-21-alpine AS build
WORKDIR /app

# Copy pom.xml and download dependencies
COPY pom.xml .
RUN mvn dependency:go-offline

# Copy source code (don't include tests)
COPY src/main/ ./src/main

# Package without tests
RUN mvn clean package -DskipTests

# Stage 2: Run
FROM eclipse-temurin:21-jre-alpine AS run
WORKDIR /app

# Copy only the final jar
COPY --from=build /app/target/*-SNAPSHOT.jar app.jar

ENTRYPOINT ["java", "-jar", "app.jar"]
```

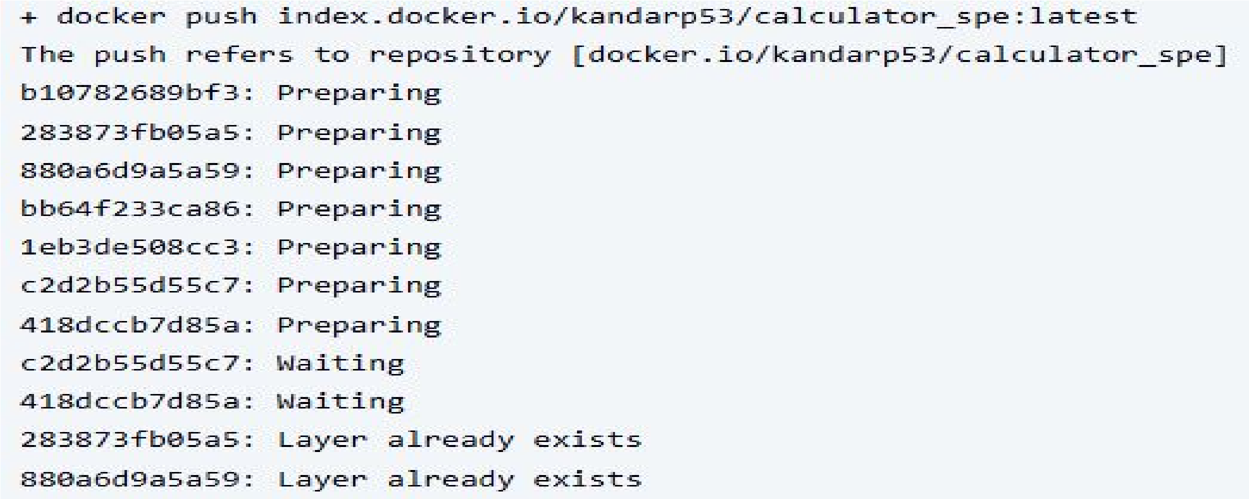
Figure 23: Dockerfile.



```
+ docker build -t kandarp53/calculator_spe:latest .
DEPRECATED: The legacy builder is deprecated and will be removed in a future release.
            Install the buildx component to build images with BuildKit:
            https://docs.docker.com/go/buildx/

Sending build context to Docker daemon  818.7kB

Step 1/10 : FROM maven:3.9.9-eclipse-temurin-21-alpine AS build
 ---> be0d0a48232f
Step 2/10 : WORKDIR /app
 ---> Using cache
 ---> 9f690acd613a
Step 3/10 : COPY pom.xml .
 ---> Using cache
 ---> 13887e6aa549
```

Figure 24: Build Docker image.

(d) Push Docker image to Registry:
After the Docker image is built, we need to push it to `DockerHub` so that it can be pulled whenever needed. Using the `DockerHub` credentials, we push the image to our `DockerHub` registry.

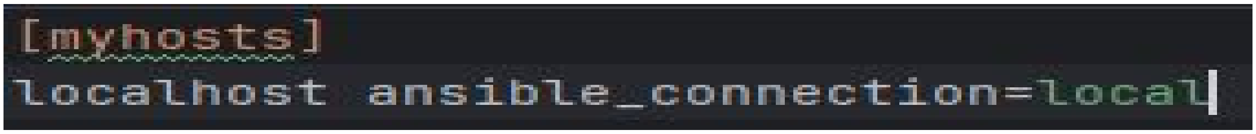


```
+ docker push index.docker.io/kandarp53/calculator_spe:latest
The push refers to repository [docker.io/kandarp53/calculator_spe]
b10782689bf3: Preparing
283873fb05a5: Preparing
880a6d9a5a59: Preparing
bb64f233ca86: Preparing
1eb3de508cc3: Preparing
c2d2b55d55c7: Preparing
418dccb7d85a: Preparing
c2d2b55d55c7: Waiting
418dccb7d85a: Waiting
283873fb05a5: Layer already exists
880a6d9a5a59: Layer already exists
```

Figure 25: Push docker image to `DockerHub`.

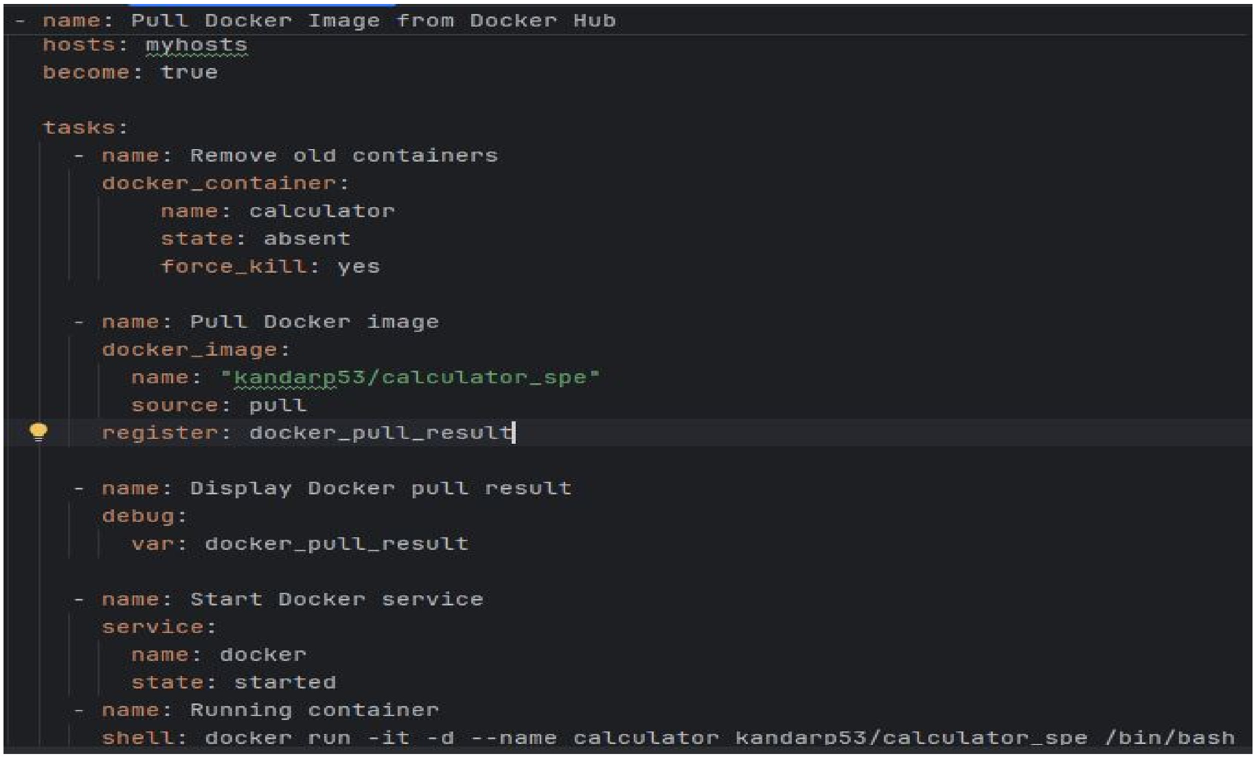
(e) Deploy using Ansible:
Using `Ansible`, we can deploy our docker image to one or more target hosts. In our case, the target host is our system itself.

The `inventory.ini` file specifies which hosts Ansible should connect to. SSH username and password need to be mentioned for each host. In this project, since we are deploying the application in our local system, no username and password were mentioned. The `playbook.yml` file mentions what tasks to run on the specified hosts. In this application, the task is to pull the image from `DockerHub` and create a running container. Any existing container is first removed.



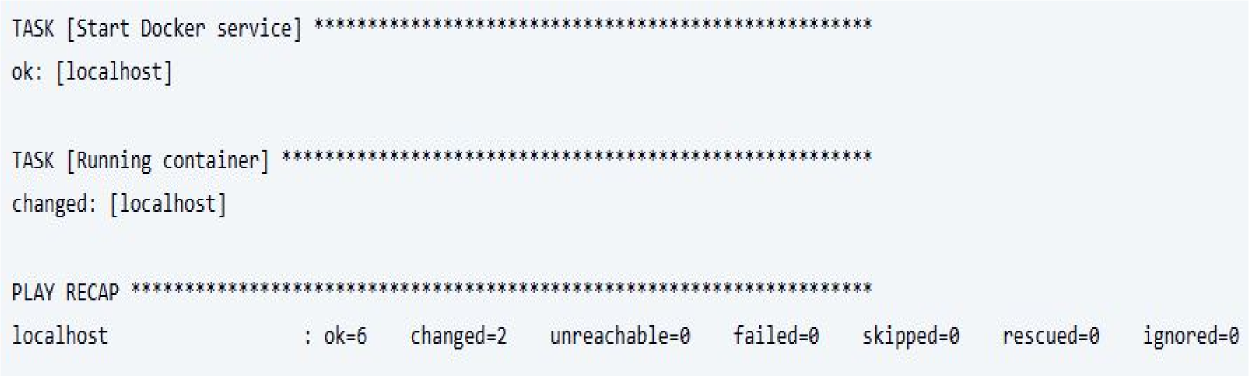
```
[myhosts]
localhost ansible_connection=local
```

Figure 26: inventory.ini.



```
- name: Pull Docker Image from Docker Hub
  hosts: myhosts
  become: true

  tasks:
    - name: Remove old containers
      docker_container:
          name: calculator
          state: absent
          force_kill: yes

    - name: Pull Docker image
      docker_image:
        name: "kandarp53/calculator_spe"
        source: pull
      register: docker_pull_result

    - name: Display Docker pull result
      debug:
        var: docker_pull_result

    - name: Start Docker service
      service:
        name: docker
        state: started
    - name: Running container
      shell: docker run -it -d --name calculator kandarp53/calculator_spe /bin/bash
```

Figure 27: playbook.yml.

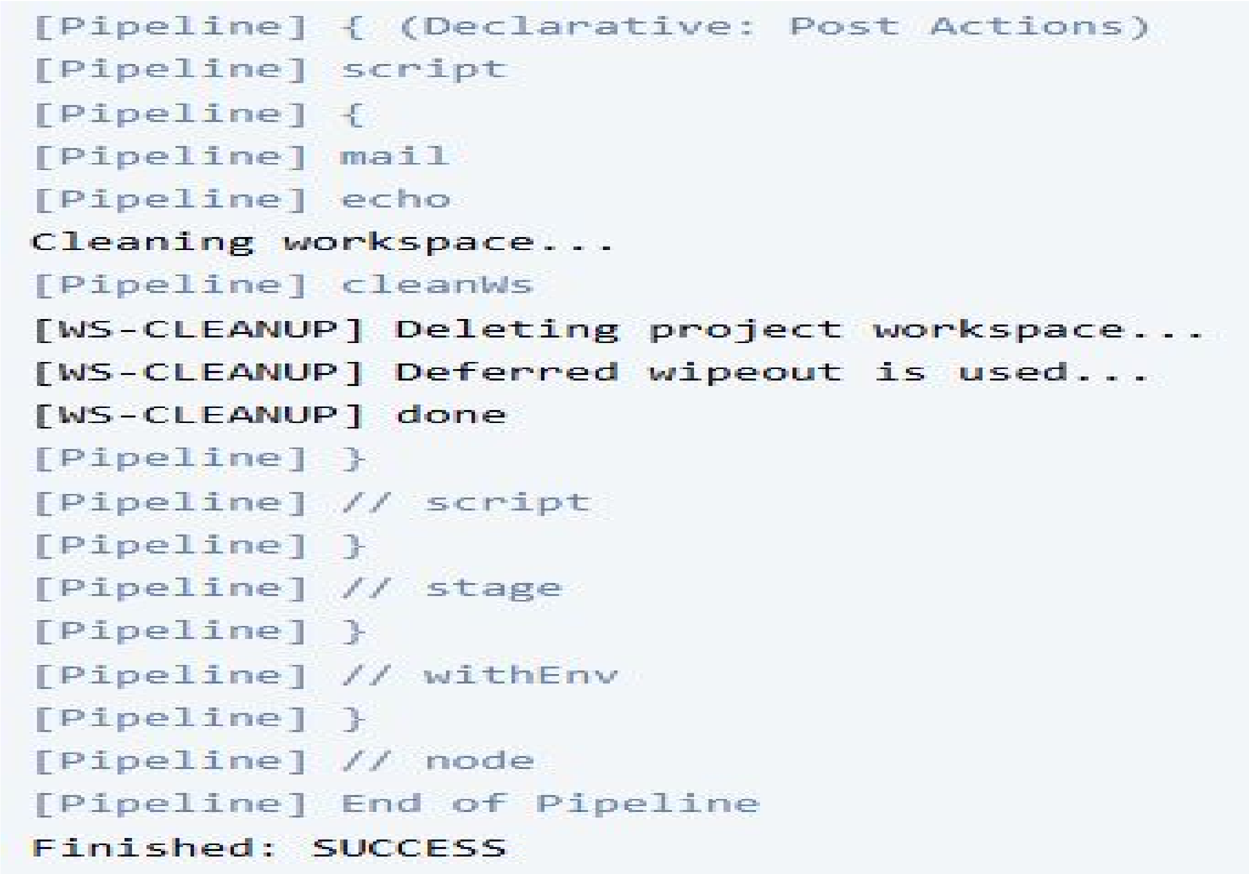


```
TASK [Start Docker service] ****************************************************
ok: [localhost]

TASK [Running container] *******************************************************
changed: [localhost]

PLAY RECAP *********************************************************************
localhost                  : ok=6    changed=2    unreachable=0    failed=0    skipped=0    rescued=0    ignored=0
```

Figure 28: Executing ansible playbook.

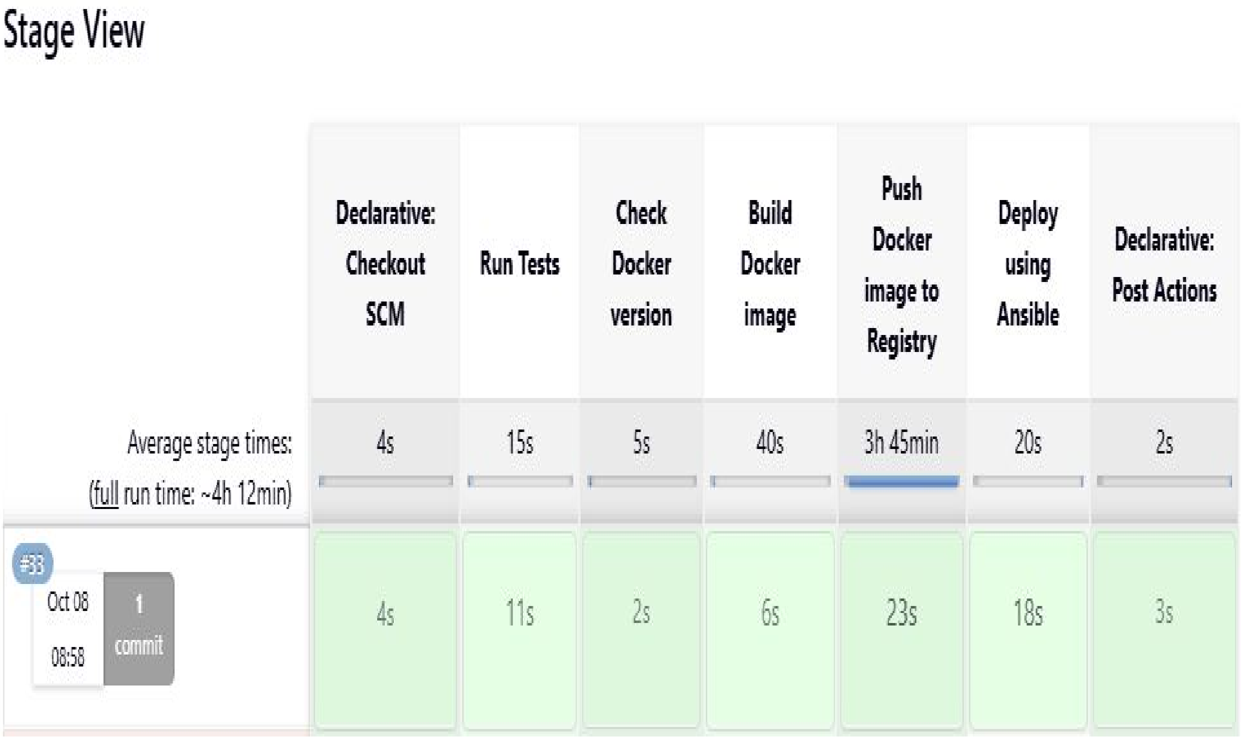
Post Actions:

After the pipeline is executed, the post actions are executed. The `always` keyword means that regardless of the pipeline status, these actions must be done. In our case, the first post-action is email notification. An email is sent which shows the result of executing the pipeline. The second post-action is clearing the workspace. All the files that are created during pipeline execution are removed.



```
[Pipeline] { (Declarative: Post Actions)
[Pipeline] script
[Pipeline] {
[Pipeline] mail
[Pipeline] echo
Cleaning workspace...
[Pipeline] cleanWs
[WS-CLEANUP] Deleting project workspace...
[WS-CLEANUP] Deferred wipeout is used...
[WS-CLEANUP] done
[Pipeline] }
[Pipeline] // script
[Pipeline] }
[Pipeline] // stage
[Pipeline] }
[Pipeline] // withEnv
[Pipeline] }
[Pipeline] // node
[Pipeline] End of Pipeline
Finished: SUCCESS
```

Figure 29: Post Actions.



Stage View

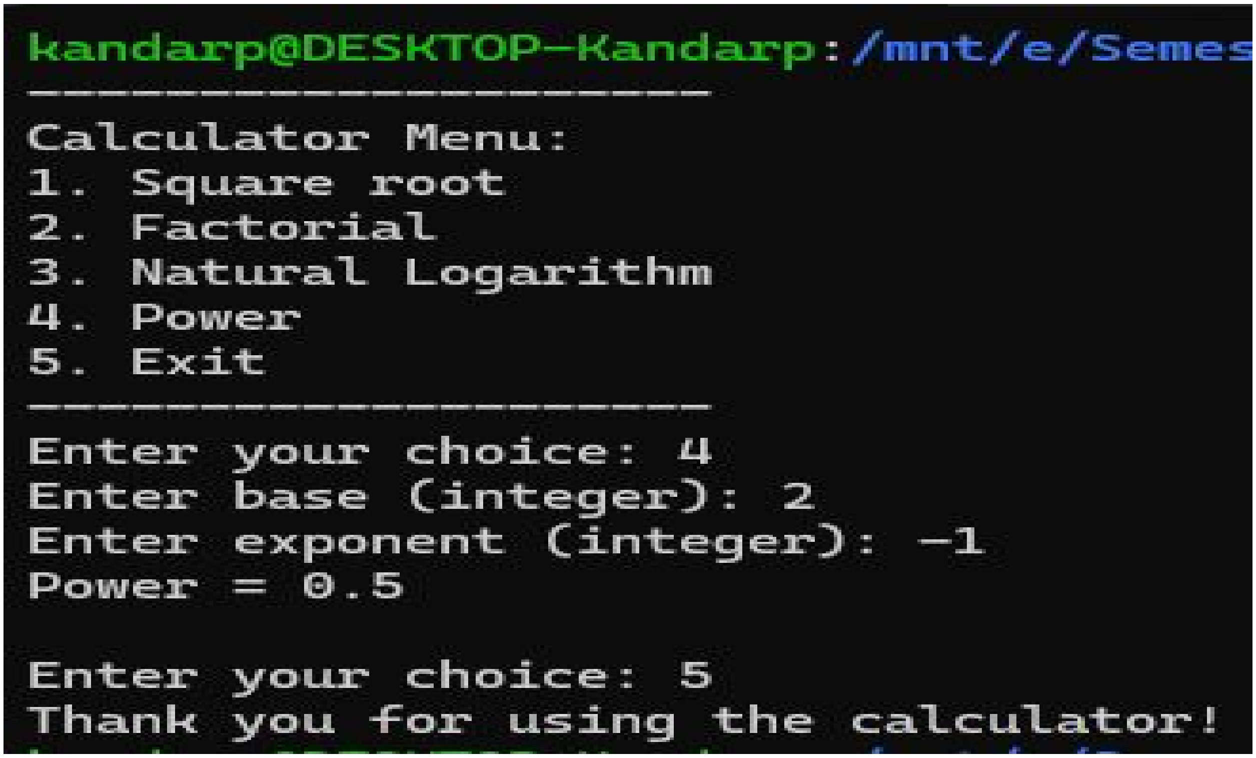
	Declarative: Checkout SCM	Run Tests	Check Docker version	Build Docker image	Push Docker image to Registry	Deploy using Ansible	Declarative: Post Actions
Average stage times: (full run time: ~4h 12min)	4s	15s	5s	40s	3h 45min	20s	2s
#33 Oct 08 08:58 1 commit	4s	11s	2s	6s	23s	18s	3s

Figure 30: Pipeline Execution.

3. **Run the application:**

   If the `Jenkins` pipeline gets successfully executed, then a docker container named `calculator` is created on the user's system. In order to execute the application, use the command:

   ```
   docker exec -it calculator java -jar /app/app.jar
   ```



```
kandarp@DESKTOP-Kandarp:/mnt/e/Semes
--------------------
Calculator Menu:
1. Square root
2. Factorial
3. Natural Logarithm
4. Power
5. Exit
--------------------
Enter your choice: 4
Enter base (integer): 2
Enter exponent (integer): -1
Power = 0.5

Enter your choice: 5
Thank you for using the calculator!
```

Figure 31: Execute the application.