Virtual Machine :

A virtual machine (VM) is a computing environment that functions as an isolated system with its own CPU, memory, network interface, and storage, created from a pool of hardware resources. Software called a hypervisor isolates the necessary computing resources and enables the creation and management of VMs.

Advantages of VM's

Isolation and Security :

- VMs provide a layer of isolation between different environments, meaning that if one VM encounters a problem (e.g., crashes, security breach), it doesn't affect the host system or other VMs running on the same hardware.
- This isolation can be beneficial for testing software in a controlled environment or running potentially untrusted applications.

Resource Efficiency

- VMs allow for running multiple operating systems (OS) on a single physical machine. If you need to use different OSs for different tasks (e.g., Windows for development, Linux for testing), a VM can be a cost-effective way to do so without needing extra physical hardware.

Scalability and Easy Deployment

- If you need to quickly deploy a new environment (e.g., a web server, database server), VMs allow for the fast creation of these environments without the need for physical hardware setup.
- VMs are scalable, meaning you can easily allocate more resources (CPU, memory, storage) as needed.

Cost-Effectiveness (Cloud-Based)

- Cloud providers like AWS, Azure, and Google Cloud let you rent VMs on-demand. This model can be much more cost-effective compared to managing physical servers, especially for tasks that require occasional scaling or have unpredictable workloads.
- You only pay for the resources you use, which can lead to significant cost savings.

Disaster Recovery and Backups

- Since VMs are encapsulated in files, it is easier to back up, clone, and restore VMs than it is to manage entire physical machines.
- Virtualization solutions often come with built-in disaster recovery features, so you can quickly spin up a new instance from a backup.

Drawbacks of Virtual Machines (VMs):

Higher Resource Usage:

VMs require more resources (CPU, memory, storage) because each VM runs its own full operating system with its own kernel. This can lead to inefficient resource utilization, especially when running multiple VMs on the same host.

Slower Performance:

Due to the hypervisor layer and the need to run a full OS, VMs typically have more overhead, leading to slower boot times and performance compared to containers.

Longer Startup Time:

Starting a VM is slower because it needs to boot a full operating system, unlike containers, which can be started almost instantaneously.

Complex Management:

Managing VMs can be more complex, especially when scaling applications or maintaining multiple VMs across different environments. You often need a hypervisor and virtualization management tools.

Less Portability:
While VMs are portable in terms of moving them to different physical hardware, they are generally less portable than containers because they carry their full OS with them, making them larger and harder to move across different environments or clouds.

When to choose VM :

Isolation
If you need to run different operating systems or applications in isolated environments on the same physical machine, a VM provides this isolation. For example, you can run Linux and Windows on the same hardware without them interfering with each other.
Test Environments
VMs are great for creating temporary test environments. For instance, when testing new software or configurations, you can spin up a VM, perform the tests, and then destroy the VM once the tests are complete, avoiding any risk to the host system.
Cloud Services and Scalability
In cloud environments (like AWS, Azure, or Google Cloud), VMs are used to scale applications on-demand. If you need to scale up your infrastructure quickly, VMs provide the flexibility to create and remove resources as needed.

When to avoid VM :

High Resource Demands :
If your application requires large amounts of CPU, memory, or I/O throughput (e.g., databases with high transaction rates, large-scale data processing, or intensive scientific computations), a VM may not be able to provide sufficient resources. Physical machines offer more predictable and consistent resource allocation.

Limited Hardware Access
Some applications may require direct access to specialized hardware (e.g., GPUs, high-speed storage devices, or network cards). While VMs can pass through some hardware, they may not always provide the same level of access and performance as running directly on physical hardware.

DIFF BET DOCKER AND VM :

1. Architecture

VMs (Virtual Machines):

Full Virtualization: VMs run on top of a hypervisor, which is software that virtualizes the hardware. Each VM includes a full operating system (OS), as well as the application and its dependencies.

Host OS + Hypervisor: The host machine runs a hypervisor (e.g., VMware, Hyper-V, KVM), which manages multiple guest VMs. Each VM has its own kernel and OS.

Isolation: VMs are fully isolated from each other, running independently with their own operating systems.

Docker Containers:

Lightweight Virtualization: Docker containers run on top of the host OS using containerization. They share the host's kernel but have isolated user spaces, which makes them lightweight.

Host OS + Docker Engine: Containers run on a single OS kernel managed by Docker. Each container contains just the application and its dependencies, not a full OS.

Shared Kernel: Containers share the same OS kernel, so they do not require separate kernels like VMs. This makes them more efficient.

2. Resource Usage and Efficiency

VMs:

Heavyweight: Each VM includes its own complete operating system, which can be large and resource-intensive. VMs require more CPU, memory, and storage.

Overhead: Running multiple VMs can lead to significant overhead in terms of memory and storage, as each VM is essentially a separate system.

Docker Containers:

Lightweight: Containers share the host system's kernel and do not require a separate OS. This results in much lower overhead.

Faster Startup: Containers are much quicker to start than VMs because they don't need to boot up a full OS.

Resource Efficiency: Since containers share the host OS, they use fewer resources overall (e.g., less memory, less CPU) compared to VMs.

3. Performance

VMs:

More Overhead: Because VMs emulate entire machines with separate OSs, there's an inherent performance overhead due to the virtualization layer.

Better Isolation: VMs offer stronger isolation between workloads, meaning that security and stability are better guaranteed.

Docker Containers:

Minimal Overhead: Containers, due to their lightweight nature, have significantly lower overhead and offer better performance for certain workloads, especially for microservices or cloud-native applications.

Less Isolation: Containers share the host OS kernel, which means they offer less isolation than VMs. However, modern container tools like Docker and Kubernetes provide security features to mitigate this.

4. Isolation

VMs:

Strong Isolation: VMs provide strong isolation because each VM runs its own full OS and kernel. If one VM crashes or gets compromised, it doesn't directly affect the others.

Full OS Isolation: Each VM can run a completely different operating system (e.g., Linux and Windows), with complete separation.

Docker Containers:

Weaker Isolation: Containers share the host OS kernel, so they are less isolated compared to VMs. However, tools like Docker provide namespaces, control groups (cgroups), and security profiles to increase container isolation.

Single OS: Containers typically run the same OS as the host, though they can simulate different environments using the appropriate images (e.g., running Ubuntu containers on a Windows host).

5. Use Cases

VMs:

Running Multiple OSs: VMs are useful when you need to run multiple different operating systems on a single machine (e.g., running both Windows and Linux).

Legacy Systems: If you need to run legacy applications or software that requires specific OS configurations, VMs are a better choice.

Full Isolation: VMs are suitable when you need full isolation for security or resource contention purposes.

Monolithic Applications: VMs are often used for traditional monolithic applications that require a full operating system and more robust isolation.

Docker Containers:

Microservices & Cloud-Native Applications: Docker is ideal for running microservices architectures where you need lightweight, fast-starting, and easily scalable containers.

Development and CI/CD: Developers use containers for consistent, portable environments, and containers are widely used in continuous integration/continuous deployment (CI/CD) pipelines.

Scalability & Rapid Deployment: Containers excel in environments where you need rapid scaling and deployment, such as in cloud environments or Kubernetes-managed clusters.

6. Portability

VMs:

Portability: VMs are portable across different hardware platforms but may be more challenging to migrate compared to containers, particularly if you're using different hypervisors or configurations.

Size: VMs are generally larger in size due to the full operating system they contain.

Docker Containers:

Highly Portable: Containers are highly portable since they include everything needed to run an application (except the OS), and they can run consistently across any system that supports Docker.

Smaller Size: Docker images are usually much smaller because they don't include the full OS—just the application and its dependencies.

7. Security

VMs:

Better Isolation: VMs provide stronger isolation as each VM runs its own full OS, reducing the risk of one VM affecting another.

Security Overhead: VMs tend to have more security overhead since each OS within a VM needs to be patched and secured separately.

Docker Containers:

Less Isolation: Containers share the same kernel, so if a container is compromised, it can potentially affect others. This requires additional security measures.

Improved Over Time: Security has been improved for Docker containers with features like namespaces, groups, and user namespaces, but they still do not offer the same level of isolation as VMs.

8. Management and Orchestration

VMs:

Management: VM management often requires tools like VMware vSphere, Hyper-V, or KVM, which are designed to handle full virtualized environments.

Orchestration: VMs can be orchestrated using tools like VMware vSphere or OpenStack, but these systems are generally heavier and more complex compared to container orchestration tools.

Docker Containers:

Management: Docker provides simple commands to manage containers, and its ecosystem has evolved with tools like Docker Compose and Docker Swarm.

Orchestration: For large-scale container management, Kubernetes is the leading tool for orchestrating and scaling containers, providing advanced features like auto-scaling, load balancing, and self-healing.

Moving from VMs (Virtual Machines) to Docker can offer several advantages, especially for certain use cases in development, deployment, and scalability. Here's why you might want to consider Docker over traditional VMs:

1. Lightweight and Faster

Docker containers are lightweight compared to VMs. A VM requires a full OS installation (e.g., Linux or Windows), while Docker uses the host's OS and only isolates the application and its dependencies.

Faster Startup: Docker containers can start in seconds, while VMs typically take longer to boot due to the need to initialize an entire guest OS.

2. Resource Efficiency

Since Docker containers share the host operating system kernel, they use far fewer resources (CPU, memory, and storage) compared to VMs, which need their own OS.

Docker allows you to run many more containers on the same hardware compared to running VMs with isolated OS instances.

3. Portability

Docker containers can run anywhere—whether it's your local machine, a development environment, or a cloud server. Docker ensures that your application will work the same way across different environments, as long as Docker is available.

This makes Docker containers particularly attractive in CI/CD (Continuous Integration/Continuous Deployment) pipelines.

4. Consistency and Isolation

With Docker, the application and its dependencies are packaged together in a container, ensuring a consistent environment across different stages of the software lifecycle (development, testing, production).

Containers provide isolation at the application level, while VMs offer isolation at the hardware/OS level.

5. Simplified Development and CI/CD

Docker integrates easily with CI/CD pipelines, enabling developers to test, build, and deploy applications in consistent environments.

Docker makes it easier to create repeatable development environments, which can eliminate "it works on my machine" issues.

6. Better Scalability and Microservices

Docker is ideal for building and managing microservices. You can run each microservice in its own container, and Docker makes it easy to manage, scale, and orchestrate containers (especially with tools like Kubernetes).

Scaling with Docker is more efficient because you can deploy many small containers instead of provisioning large VMs.

7. Easier Versioning and Rollbacks

Docker images are versioned, so you can track changes to your application and easily roll back to a previous version if needed.

This makes it easier to maintain multiple versions of your app or service across different environments (e.g., staging, production).

8. Environment Consistency

When you use Docker, you encapsulate the environment (OS, libraries, configurations) along with your application, which ensures that everything required for the application to run is included.

This makes it easier for developers to collaborate without worrying about differences in local setups.

9. Ecosystem and Tooling

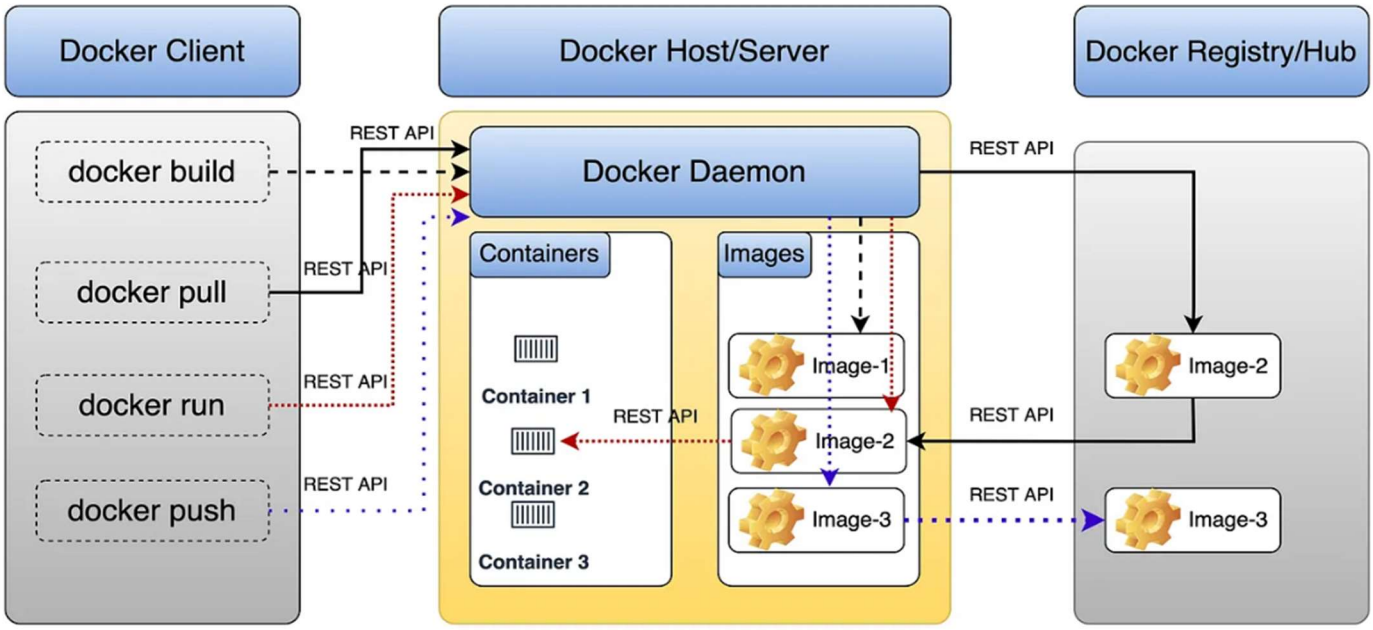
Docker has a rich ecosystem and robust tooling for management, orchestration, and networking (Docker Compose, Docker Swarm, Kubernetes).

With Docker, you can easily manage dependencies, configure services, and handle networking between containers.

Docker

- **Docker** is an open-source platform, that operate based on containerization technique.
- Containerization involves packaging the source code and its dependencies (libraries, tools, runtime etc…) into single unit, called container.
- A container is a self-contained unit that includes everything needed to run an application, such as the source code, libraries, tools, dependencies, and runtime environment.
- It allows the application to run consistently and independently, without relying on the host system's environment.
- This makes it easy to run the application anywhere, without worrying about differences in the underlying machine.

Architecture :



Docker Client : The Docker Client is a user interface for Docker, typically accessed through the terminal or command prompt, where users run various Docker commands. It acts as a communication bridge between the user and the Docker Engine. The Docker Engine handles container operations, but the Docker Client allows you to control those operations from your local machine.

Client will Interacts with Docker Daemon: The Docker Client sends commands to the Docker Daemon (Docker Engine), which is the core service responsible for managing containers and images. The client communicates over a REST API with the Docker Daemon, allowing you to build, run, and manage containers.

Command Execution: The Docker Client executes a variety of commands. Common commands include:

- docker build to build images.
- docker run to start containers from images.
- docker ps to list running containers.
- docker pull to download images from Docker Hub.
- docker push to upload images to Docker Hub or another registry.

How it Works:

You Issue a Command: When you run a command like docker run, you're telling the Docker Client what action you want to perform.
Docker Client Sends the Command: The client sends the command, along with necessary parameters (such as image names, environment variables, or ports to expose), to the Docker Daemon.
Docker Daemon Executes the Command: The Docker Daemon receives the request and performs the task, such as starting a container, creating an image, or pulling a resource from the Docker registry.
Docker Client Receives the Response: Once the task is completed, the Docker Daemon sends the result (such as success or error messages) back to the Docker Client, which displays it on your terminal.

Docker Daemon (docker-D):

- The Docker Daemon is a background service that runs on the host machine and manages Docker containers. It listens for API requests from the Docker client and manages container lifecycle operations like creating, starting, stopping, and deleting containers.
- It also manages the Docker images, volumes, and networks.
- The Docker daemon can communicate with other Docker daemons to create a multi-host Docker setup (Docker Swarm, for instance).
- It is responsible for managing the images in the local image repository and the interaction between containers and the underlying operating system.

Docker Registries:

- A Docker registry is a repository for storing Docker images. Docker Hub is the default registry that stores public Docker images, but private registries can also be set up (e.g., AWS ECR, Google Container Registry).
- Docker users can push images to a registry and pull images from it. The registry is used for sharing images between different users or systems.

Docker Network:
Docker provides networking capabilities to allow containers to communicate with each other and with external systems. The Docker daemon creates a default network (usually a bridge network), but users can create custom networks with different configurations (e.g., host network, overlay network).
Containers connected to the same network can communicate with each other using their container names or IP addresses.

Docker Volumes:
Volumes are used to store persistent data that containers need. Unlike container filesystems, which are ephemeral (i.e., data is lost when a container is removed), volumes persist even when containers are stopped or deleted.
Volumes are ideal for storing database files, application logs, and other data that needs to be preserved beyond the lifecycle of a container.

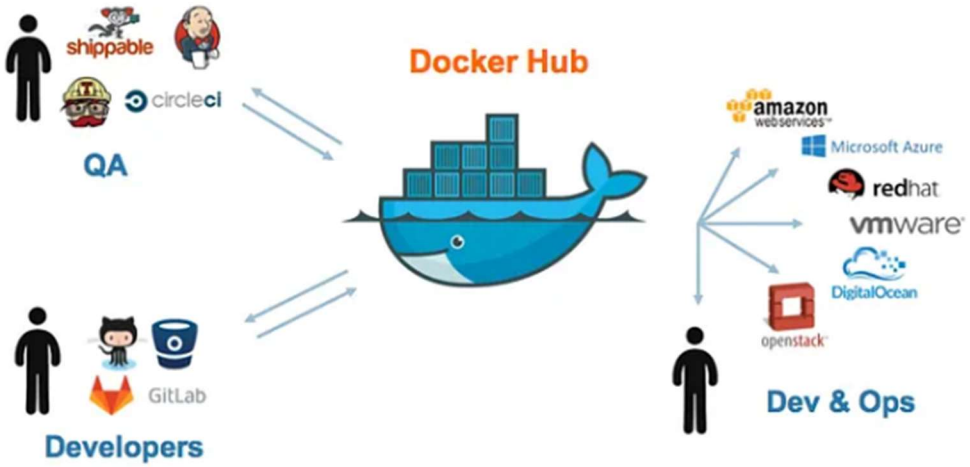
Docker Compose:
Docker Compose is a tool for defining and running multi-container Docker applications. Using a docker-compose.yml file, users can define the services (containers), networks, and volumes that make up an application.
Docker Compose makes it easier to manage complex applications by allowing developers to configure and deploy them as a set of interconnected services.

Docker Swarm:
Docker Swarm is Docker's native clustering and orchestration tool, used for managing a group of Docker hosts (called nodes). A Swarm cluster allows you to deploy and manage multi-container applications across multiple machines.
Swarm provides features like load balancing, scaling, and service discovery.
It enables high availability and fault tolerance by distributing containers across multiple nodes in the cluster.

Docker API:
The Docker API is the interface between the Docker client and the Docker daemon. The API allows developers and tools to interact programmatically with Docker.
The Docker API can be used to automate tasks or integrate Docker with other systems (e.g., for orchestration or monitoring).

Docker Hub

Docker Hub is a registry service where Docker images are stored. It provides both **public** and **private** repositories, allowing users to store and share Docker images in the cloud.



Docker Hub acts as a centralized Docker registry where users can:
Push Docker images: Developers can upload their custom-built Docker images to Docker Hub, making them available for sharing, versioning, and collaboration.
Pull Docker images: Users can download Docker images from Docker Hub and use them to create containers in their local environments.

The general flow with Docker Hub in Docker architecture is:

1. Docker Client interacts with the Docker Daemon.
2. The Daemon communicates with Docker Hub to pull pre-existing images or push custom images.
3. Docker Hub serves as a cloud-based repository to store and manage these images.

Example: When a developer wants to run a containerized app, they use the docker pull command to download an image from Docker Hub. If the developer makes changes to the app and builds a new image, they can push it to their own Docker Hub repository using the docker push command.

Public and Private Repositories:
Public Repositories: Images are accessible to anyone. Many open-source projects are hosted here.
Private Repositories: Accessible only to authorized users or teams. Ideal for proprietary applications.

4. Docker Hub Use Case:
For Individual Developers: They can store their Docker images in public repositories to share with the community. For Teams/Organizations: Docker Hub provides private repositories where team members can securely store and share Docker images.

Amazon Elastic Container Registry (ECR):

Amazon Elastic Container Registry (ECR) is Amazon Web Services' (AWS) fully managed Docker container registry service. It is a scalable and secure registry that integrates tightly with other AWS services like **Amazon ECS** (Elastic Container Service) and **Amazon EKS** (Elastic Kubernetes Service).

1. What is Amazon ECR?

Amazon ECR is a fully managed Docker container registry that allows you to store, manage, and deploy Docker container images within the AWS cloud. It provides a private, scalable environment to store Docker images and integrates seamlessly with AWS services.

2. Role of Amazon ECR in Docker Architecture:

Amazon ECR serves as a registry for Docker images, just like Docker Hub. However, it is tightly integrated with AWS tools and services, making it more suited for enterprises that rely on AWS infrastructure.

3. How Amazon ECR Works:

- **Storing Docker Images**: Developers can upload (push) Docker images to ECR repositories. These images are then available to use in various AWS services (like ECS, EKS, or EC2 instances).
- **Pulling Docker Images**: Docker clients (or services like ECS and EKS) pull Docker images from ECR to run containers.
- **Private Repositories**: ECR repositories are private by default, meaning only authorized users can access the images.

The general flow with Amazon ECR in Docker architecture is:

- **Docker Client** uses the **Docker Daemon** to communicate with Amazon ECR (via the AWS CLI or SDKs).
- The **Daemon** interacts with **ECR** to **pull** or **push** images to the registry.
- **Amazon ECR** provides a secure and scalable storage solution for Docker images, allowing easy integration with other AWS services like ECS or EKS for container orchestration.

4. ECR Key Features:

- **Fully Managed**: ECR eliminates the need for users to set up their own registry infrastructure, as it is fully managed by AWS.
- **Integration with AWS**: Tight integration with AWS container services like Amazon ECS, EKS, and AWS Lambda.
- **Security**: Supports private repositories with fine-grained access control using AWS IAM (Identity and Access Management).
- **Automatic Vulnerability Scanning**: ECR can automatically scan your images for known vulnerabilities using Amazon Inspector.
- **Scalability**: ECR is highly scalable and automatically scales to accommodate your image storage needs.
- **Versioning**: Supports tagging and versioning of Docker images, so users can track different image versions.

5. ECR Use Case:

- **For AWS-centric Teams**: ECR is a natural fit for teams using AWS infrastructure, especially those utilizing ECS for container orchestration or EKS for Kubernetes.
- **For Enterprises**: Since ECR is tightly integrated with AWS security, networking, and compliance services, it's a preferred choice for enterprise-level containerized applications.

Summary of Differences Between Docker Hub and Amazon ECR:

Feature	Docker Hub	Amazon ECR
Provider	Docker, Inc.	Amazon Web Services (AWS)
Deployment	Cloud-based public and private repositories	Cloud-based private repositories, AWS-centric
Integration	General use, integrates with any platform	Tight integration with AWS services (ECS, EKS)
Security	Role-based access, scanning (for paid plans)	AWS IAM integration, automatic security scanning
Pricing	Free (with limits), paid plans available	Pay-as-you-go, no upfront cost
Best For	Open-source projects, individual developers	AWS users, enterprise-grade solutions

Setup Docker in Linux machine :

Setup Linux VM (Amazon Linux / Ubuntu)

1) Login into AWS Cloud account
2) Create Linux VM and connect to it using MobaXterm or GitHub

- Install Docker In Amazon Linux VM

```
sudo yum update -y
sudo yum install docker -y
sudo service docker start
sudo usermod -aG docker ec2-user
exit
```

- Install Docker In Ubuntu VM

```
sudo apt update
curl -fsSL get.docker.com | /bin/bash
sudo usermod -aG docker ubuntu
exit
```

- Verify docker installation

```
docker -v
```

COMMONLY USED DOCKER COMMANDS

BASIC DOCKER COMMANDS

- docker version
  - Displays the Docker version installed.
- docker info
  - Shows detailed information about the Docker installation.
- docker help
  - Lists all available Docker commands or help on a specific command.

IMAGE MANAGEMENT

- docker images
  - Lists all locally available Docker images.
- docker pull <image>
  - Pulls an image from Docker Hub or another registry.
- docker build -t <name> .
  - Builds a Docker image from a Dockerfile in the current directory.
- docker rmi <image>
  - Removes one or more Docker images.
- docker tag <image> <new_tag>
  - Tags an image with a new name or version.
- docker save -o <file.tar> <image>
  - Saves a Docker image to a `.tar` archive.
- docker load -i <file.tar>
  - Loads a Docker image from a `.tar` archive.

CONTAINER MANAGEMENT

- docker ps
  - Lists all currently running containers.
- docker ps -a
  - Lists all containers, including stopped ones.
- docker run <image>
  - Runs a container based on an image.
- docker run -it <image>
  - Runs a container in interactive mode with terminal access.
- docker run -d <image>
  - Runs a container in detached mode (in the background).
- docker exec -it <container> <command>
  - Runs a command inside a running container.
- docker stop <container>
  - Stops a running container.
- docker start <container>
  - Starts a stopped container.
- docker restart <container>
  - Restarts a container.
- docker rm <container>
  - Removes one or more containers.

- docker logs <container>
  - Shows logs from a running or stopped container.

VOLUME & NETWORK MANAGEMENT

- docker volume create <name>

  Creates a Docker volume.

- docker volume ls
  - Lists all volumes.
- docker volume rm <name>
  - Deletes a Docker volume.
- docker network ls
  - Lists all Docker networks.
- docker network create <name>
  - Creates a new network.
- docker network rm <name>
  - Removes a network.

DOCKER COMPOSE

- docker-compose up
  - Builds, creates, starts, and attaches to containers for a service.
- docker-compose up -d
  - Runs services in the background (detached mode).
- docker-compose down
  - Stops and removes containers, networks, and volumes.
- docker-compose build
  - Builds or rebuilds services defined in the `docker-compose.yml` file.

DOCKER CONFIGURATION :

Def 1 :

Docker configuration refers to setting up Docker so it knows what to do, how to do it, and who to do it with.

Def 2 :

Docker configuration generally refers to how you set up and define the behavior of Docker containers—including what goes inside them, how they run, and how they interact with other systems.

Imagine you're giving instructions to a chef (Docker) to cook and serve a meal (your app). The configuration is the recipe and the serving plan.

Basic Docker Configuration

This usually involves:

- **Dockerfile** – a script that defines how to build a Docker image.
- **Dockercompose.yml** – a file to define and run multi-container Docker applications.
- **Docker CLI / Daemon settings** – configuration for how Docker runs on the host system.

You've created a Spring Boot project (.jar file) and want to run it using Docker. For Docker to do that, it needs instructions.
This is where **Docker configuration** comes in—it tells Docker:

1. **What your app is**
2. **How to build it**
3. **How to run it**
4. **What it needs to work**

Basic Docker Configuration (Dockerfile) :

```
FROM openjdk:17
COPY target/myapp.jar app.jar
ENTRYPOINT ["java", "-jar", "app.jar"]
```

What this means in simple terms:

- Use Java 17
- Take the .jar file you built from Spring Boot
- Run it using the java -jar command

Docker compose (multi-container)

Sometimes application needs other services like a **MySQL database**. Then we can use docker-compose.yml to set everything up together:

docker-compose.yml :

```
version: '3'
services:
  app:
    build: .
    ports:
      - "8080:8080"
    depends_on:
      - db
  db:
    image: mysql:8
    environment:
      MYSQL_ROOT_PASSWORD:
root
      MYSQL_DATABASE: mydb
```

Docker CLI / Docker Daemon Setting

- Docker CLI is how *you tell Docker what to do.*
- Docker Daemon is the *engine that does the work.*
- Daemon configuration is like setting the rules and environment for the engine (memory, logs, network, etc.)

Docker CLI:

- Commands

Docker Daemon Configuration

You can **configure the daemon** to control how Docker behaves on your system. This includes:

- Default storage location
- Network settings
- Logging settings
- Resource limits
- Whether Docker uses the proxy or not
- Registry mirrors (for faster image pulls)
- Enabling experimental features

(In ubuntu machine) Go to /etc/docker/daemon.json

```
{
  "insecure-registries": ["my-private-registry.com"],
  "storage-driver": "overlay2",
  "log-driver": "json-file",
  "log-level": "warn"
}
```

HOW TO CREATE CONTAINER :

- Build the Spring Boot project
- Create a Dockerfile
- Build the Docker image
- Run the Docker container

Built Spring-boot project :

This step compiles your Spring Boot application and packages it into an executable JAR file.

> ./mvnw clean package or > mvn clean package (if maven installed)

What it does:

- clean: Deletes the target/ directory (previous builds).
- package: Compiles the code, runs tests, and packages the app into a JAR file.

A jar file will be created in target folder. Like " target/my-app-0.0.1-SNAPSHOT.jar "

Additional Info about maven commands :

Command	Description
mvn clean	Deletes the target/ directory (removes previous build files)
mvn compile	Compiles the source code (no packaging)
mvn test	Runs unit tests
mvn package	Compiles, tests, and packages the app into a JAR/WAR
mvn install	Packages and installs the JAR to your local Maven repository
mvn verify	Runs integration tests after packaging
mvn spring-boot:run	Runs the Spring Boot app without creating a JAR (dev mode)

But commonly used combo is : maven clean package

DOCKER FILE :

A **Dockerfile** is a script with instructions to build a Docker image of your Spring Boot application. It's a plain text file named Dockerfile (no extension) that contains a list of commands Docker uses to:

- Set up an environment (like Java)
- Copy your JAR file
- Tell Docker how to run your app

Where to place it: Put the Dockerfile in the root folder of your Spring Boot project (same level as pom.xml).

Docker File Commands :

- MAINTAINER
  - ✅ Used to specify the author (Optional)

- FROM
  - ✅ **Purpose:**
    Defines the base image (like OS + Java) to start building your app image.
  - ❓ **Why should I use it?**
    It gives Docker a foundation to build upon. Without it, Docker doesn't know which system environment to use.
  - 📐 **Order:**
    Must be the first command (can be repeated in multi-stage builds).
  - 🛠️ **Syntax:**
    FROM <image>:<tag>
  - 🔁 Examples:

```
FROM ubuntu:20.04
FROM openjdk:17-jdk-slim
FROM maven:3.8 AS builder
FROM alpine@sha256:<digest>
```

❖ WORKDIR

✅ **Purpose:**
Sets the working directory inside the container.

❓ **Why should I use it?**
Avoids long path repetition, keeps files organized inside container.

📐 **Order:**
Use before COPY, RUN, CMD, etc. if those commands rely on a working directory.

🛠️ **Syntax:**
WORKDIR <path>

🔁 Examples:

```
WORKDIR /app
WORKDIR /usr/src/myapp
```

❖ COPY

✅ **Purpose:**
Copies files/folders from your host machine into the container.

❓ **Why should I use it?**
To add your application code, configs, or files needed by the app.

📐 **Order:**
Use after setting WORKDIR if you want to copy files into that directory.

🛠️ **Syntax:**
COPY <src> <dest>

🔁 Examples:

```
COPY . .
COPY target/*.jar app.jar
COPY config.yaml /etc/app/config.yaml
```

❖ ADD

✅ **Purpose:**
Like COPY, but with extra features (like extracting .tar.gz, or downloading from URL).

❓ **Why should I use it?**
Only if you need to extract archives or add remote files. Otherwise, prefer COPY (simpler & safer).

📐 **Order:**
Same as COPY.

🛠️ **Syntax:**
ADD <src> <dest>

🔁 Examples:

```
ADD myfile.tar.gz /app/
ADD https://example.com/file.zip /files/file.zip
```

❖ RUN

✅ **Purpose:**
Runs commands in the shell inside the container (like installing packages).

❓ **Why should I use it?**
To install dependencies, build files, or configure your environment.

📐 **Order:**
Use after FROM, before CMD or ENTRYPOINT.

🛠️ **Syntax:**
RUN <command>

🔁 **Examples:**

```
RUN apt-get update && apt-get install -y curl
RUN mkdir /app/logs
```

❖ CMD

✅ **Purpose:**
Specifies the default command to run when the container starts.

❓ **Why should I use it?**
To define the default runtime command (can be overridden at runtime).

📐 **Order:**
Usually placed at the end of Dockerfile.

🛠️ **Syntax:**
CMD ["executable", "param1", "param2"]

🔁 **Examples:**

```
CMD ["java", "-jar", "app.jar"]
CMD ["npm", "start"]
```

❖ ENTRYPOINT

✅ **Purpose:**
Also defines the start command, but it's more strict and cannot be overridden easily.

❓ **Why should I use it?**
Use when the container should always run this command (like starting your app).

📐 **Order:**
Usually at the end, before or after CMD.

🛠️ **Syntax:**
ENTRYPOINT ["executable", "param1", "param2"]

🔁 **Examples:**

```
ENTRYPOINT ["java", "-jar", "app.jar"]
ENTRYPOINT ["/bin/bash", "-c", "echo Hello"]
```

❖ EXPOSE

✅ **Purpose:**
Documents which port the app will use inside the container.

❓ **Why should I use it?**
To tell Docker (and other devs) that the app listens on that port.

📐 **Order:** Usually added near the end, before CMD or ENTRYPOINT.

🛠️ **Syntax:** EXPOSE <port>

🔁 **Examples:**

EXPOSE 8080
EXPOSE 80 443

❖ ENV

✅ Purpose: Sets environment variables inside the container.

❓ Why should I use it? To store config values (like DB URL, API keys, or secrets).

📐 Order: Anywhere before you need to use the variable.

🛠️ Syntax: ENV <key>=<value>

🔁 Examples:

- ENV JAVA_HOME=/usr/lib/jvm/java-17
- ENV DB_URL=jdbc:mysql://localhost:3306/mydb

❖ VOLUME

✅ Purpose: Declares a mount point that can be linked to host system or other containers.

❓ Why should I use it? To persist data even when container is destroyed (like DB data or logs).

📐 Order: Anywhere in the Dockerfile.

🛠️ Syntax: VOLUME ["/path/in/container"]

🔁 Examples:

- VOLUME ["/data"]
- VOLUME ["/var/log/app"]

❖ LABEL

✅ Purpose: Adds metadata to the image (e.g., author, version).

❓ Why should I use it? To identify images, authorship, versioning, etc.

📐 Order: Usually at the top.

🛠️ Syntax: LABEL key="value"

🔁 Examples:

- LABEL maintainer="you@example.com"
- LABEL version="1.0"

START CONTAINERIZING :

- Containerizing refers to the process of packaging an application and its dependencies (like libraries, frameworks, and configurations) into a container.
- A container is a lightweight, portable unit that can run consistently across various computing environments, whether it's on a developer's laptop, a test server, or a production cloud environment.
- A container is an isolated environment that includes everything an application needs to run: the code, runtime, libraries, and system tools. Containers are based on operating system-level virtualization (instead of hardware virtualization), which makes them more lightweight than virtual machines (VMs). The most popular tool for creating and managing containers is Docker.

Why Containerize?

- Portability: Containers can run anywhere (laptop, server, cloud), and they will behave the same because they include all dependencies.
- Consistency: Developers and operations teams face fewer problems related to "it works on my machine" because the container ensures the environment is the same everywhere.
- Isolation: Containers run independently of each other, preventing conflicts between applications.
- Scalability: Containers can be easily scaled horizontally (i.e., adding more containers) to handle increased load.

Step-by-step Plan to Containerize Your App

- Create a Dockerfile
- Choose the base image
- Set up working directory
- Install dependencies
- Copy your app into the image
- Expose ports
- Define the default command
- Build the image
- Run the container
- (Optional) Add network config and users

Dockerfile for Spring Boot – Explained Line-by-Line

Dockerfile

```
# Step 1: Use a base image with Java installed
FROM eclipse-temurin:17-jdk-jammy AS base

# Step 2: Set the working directory inside the container
WORKDIR /app

# Step 3: Copy the application JAR file to the image
COPY target/app.jar app.jar

# Step 4: Expose the port your app will listen on
EXPOSE 8080
```

```
# Step 5: Define the command to run your app
ENTRYPOINT ["java", "-jar", "app.jar"]
```

1. FROM

```
FROM eclipse-temurin:17-jdk-jammy AS base
```

Purpose: Sets the base image. This is the starting point for your container.

- eclipse-temurin:17-jdk-jammy → A stable, open-source JDK image based on Ubuntu Jammy (22.04) with Java 17 installed.
- AS base → Optional alias for multi-stage builds (good practice).

☑ **Alternative:**

```
FROM openjdk:17-jdk-alpine
```

2. WORKDIR

```
WORKDIR /app
```

Purpose: Sets the current working directory in the container.

- Any command or file copy after this will be relative to /app.
- Automatically creates the directory if it doesn't exist.

3. COPY

```
COPY target/app.jar app.jar
```

Purpose: Copies files from your host system into the container.

- target/app.jar → Path on your local machine.
- app.jar → Destination path inside the container (in /app).

Alternative:

```
COPY target/*.jar app.jar
```

4. EXPOSE

```
EXPOSE 8080
```

Purpose: Documents the port your application will listen on.

- **Note:** Doesn't actually expose the port. You must use -p flag in docker run to map ports.

5. ENTRYPOINT

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

Purpose: Defines the command that runs when the container starts.

- JSON format avoids shell parsing issues.
- This runs your Spring Boot app.

Alternative:

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

ENTRYPOINT vs CMD:

- ENTRYPOINT is the main startup command.
- CMD provides default args that can be overridden.

Building the Docker Image

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

- docker build: Builds a Docker image from your Dockerfile.
- -t my-springboot-app: Tags the image with a name.
- .: Current directory as the build context.

Running the Container
docker run -d -p 8080:8080 my-springboot-app

- docker run: Starts a container.
- -d: Runs the container in detached mode (in background).
- -p 8080:8080: Maps your local machine's port 8080 to the container's port.
- my-springboot-app: Name of the image you built.

WORKING WITH DOCKER IMAGES (SPRING-WEBMVC AND SPRING BOOT):

Working with Docker images for **Spring Boot** and **Spring Web MVC** applications involves several steps, including:

1. **Creating a Dockerfile**
2. **Building a Docker Image**
3. **Running the Container**
4. **Pushing to a Docker Registry (Optional)**

Let's go through each step:
1. Creating a Dockerfile
A Dockerfile defines how your Spring Boot application will be containerized.

Example Dockerfile for Spring Boot

```
# Use an official OpenJDK runtime as a base image
FROM eclipse-temurin:17-jdk-jammy
# Set the working directory inside the container
WORKDIR /app
# Copy the JAR file into the container
COPY target/your-springboot-app.jar app.jar
# Expose the port your app runs on (default for Spring Boot is 8080)
EXPOSE 8080
# Command to run the application
ENTRYPOINT ["java", "-jar", "app.jar"]
```

For a Spring Web MVC (WAR) Application

If your app is a traditional WAR file (deployed on Tomcat), use:

```
FROM tomcat:9.0-jdk17
# Remove default Tomcat apps (optional)
RUN rm -rf /usr/local/tomcat/webapps/*
# Copy WAR file to Tomcat webapps directory
COPY target/your-webmvc-app.war /usr/local/tomcat/webapps/ROOT.war
# Expose port 8080 (Tomcat default)
EXPOSE 8080
# Start Tomcat
CMD ["catalina.sh", "run"]
```

2. Building the Docker Image

Before building, ensure:

- Your Spring Boot app is built (mvn clean package or gradle build).
- The JAR/WAR file is in the target/ directory.
- Run the following command in the same directory as your Dockerfile:

```
>docker build -t your-spring-app:1.0 .
```

- -t assigns a tag (name:version).
- specifies the build context (current directory).

3. Running the Docker Container

After building, run the container:

```
>docker run -d -p 8080:8080 --name spring-app your-spring-app:1.0
```

- -d runs in detached mode (background).
- -p 8080:8080 maps host port 8080 to container port 8080.
- --name assigns a name to the container.

Verify the container is running:

```
> docker ps
```

Check the logs:

```
>docker logs -f spring-app
```

4. Pushing to a Docker Registry (Optional)

If you want to share your image, push it to Docker Hub or a private registry.

Login to Docker Hub

```
>docker login
```

Tag and Push

```
docker tag your-spring-app:1.0 your-dockerhub-username/your-spring-app:1.0
docker push your-dockerhub-username/your-spring-app:1.0
```

Best Practices:

Use Multi-stage Builds (to reduce image size):

Dockerfile:

```
FROM eclipse-temurin:17-jdk-jammy AS builder
WORKDIR /app
RUN ./mvnw clean package
FROM eclipse-temurin:17-jre-jammy
WORKDIR /app
 --from=builder /app/target/*.jar app.jar
EXPOSE 8080
ENTRYPOINT ["java", "-jar", "app.jar"]
```

Use .dockerignore (to exclude unnecessary files):

```
target/
.git/
.idea/
*.iml
```

Environment Variables (for configuration):

```
>docker run -e "SPRING_PROFILES_ACTIVE=prod" -p 8080:8080 your-spring-app:1.0
```

Customizing the containers:

- Container customization means changing a standard Docker container to better fit your specific needs.
- Think of it like buying a plain white t-shirt (the standard container) and then adding your own designs, pockets, or buttons (your customizations) to make it perfect for you.
- For boot (like Spring Boot) and MVC (like ASP.NET MVC) applications, customization typically involves:
    - Adding special software your app needs
    - Changing configuration settings
    - Setting up security features
    - Optimizing performance
- **Why Customization:**
    1. **Makes Your App Work Right**: Just like some plants need special soil, your app might need special settings in its container.
    2. **Saves Money**: A well-customized container uses only what it needs, like packing just right for a trip instead of bringing your whole house.
    3. **More Secure**: You can remove unnecessary parts that hackers might try to use.
    4. **Consistent Environments**: Works the same on your laptop, your coworker's computer, and the cloud server.

When is Customization Useful? (With Examples)

Example 1: Spring Boot Application

Problem: Your Spring Boot app needs a special version of Java and connects to a PostgreSQL database.

```
# Start with official Java image
FROM openjdk:11-jdk
# Add PostgreSQL client tools
RUN apt-get update && apt-get install -y postgresql-client
# Set environment variables for database
ENV DB_HOST=db
ENV DB_PORT=5432
# Copy your Spring Boot application
COPY target/myapp.jar /app/myapp.jar
# Set the command to run your app
CMD ["java", "-jar", "/app/myapp.jar"]
```

Real Developer Benefits

1. **Faster Development**: Once set up, everyone uses the same environment.
    - No more "but it works on my machine" problems
2. **Easier Debugging**: When problems happen, you know exactly what's in the container.
3. **Better Deployments**: Custom containers ensure production matches development.
4. **Team Consistency**: New team members get running quickly with the right setup.

Running Containers with Docker – Commands & Use Cases

Docker allows you to run applications in isolated environments called containers. Below are the essential commands with use cases:

1. docker run – Start a New Container

Runs a container from an image.

Basic Syntax:

docker run [OPTIONS] IMAGE [COMMAND] [ARG...]

Use Cases & Examples:

a. Run a Container in Foreground (Interactive Mode)

docker run -it ubuntu /bin/ba

-i → Interactive mode (keeps STDIN open)
-t → Allocates a pseudo-TTY (terminal)
Use Case: Debugging inside a container.

b. Run a Container in Detached Mode (Background)

docker run -d nginx
-d → Detached mode (runs in background)
Use Case: Running a web server like Nginx.

c. Run with Port Mapping

docker run -d -p 8080:80 nginx
-p HOST_PORT:CONTAINER_PORT → Maps host port to container port
Use Case: Exposing a web app to the host machine.

d. Run with Volume Mounting

docker run -v /host/path:/container/path ubuntu
-v → Binds a host directory to the container
Use Case: Persisting database files outside the container.

e. Run with Environment Variables

docker run -e "MY_VAR=value" ubuntu
-e → Sets environment variables
Use Case: Configuring apps (e.g., database credentials).

2. docker start – Restart a Stopped Container

Starts an existing (stopped) container.
Syntax:

docker start [OPTIONS] CONTAINER

Example:

docker start my_container

Use Case: Resuming a stopped container.

f. Run with Container Name

docker run --name my_container redis
--name → Assigns a custom name to the container
Use Case: Easier container management.

g. Run and Auto-Remove After Exit

docker run --rm alpine echo "Hello"
--rm → Removes container after it stops
Use Case: Temporary tasks (e.g., testing).

h. Run with Resource Limits

docker run --memory="512m" --cpus="1.5" ubuntu
--memory → Limits RAM usage
--cpus → Limits CPU usage
Use Case: Preventing a container from consuming too many resources.

3. docker stop – Gracefully Stop a Running Container

Stops a running container gracefully (SIGTERM).
Syntax:
docker stop CONTAINER

Example:
docker stop my_container
Use Case: Safely utting down a container.

4. docker restart – Restart a Running Container

Restarts a container.

Syntax:

docker restart CONTAINER

Example:

docker restart my_container

Use Case: Applying configuration changes

Docker Port Forwarding:

- Port forwarding (or port mapping) in Docker allows communication between a host machine and a container by binding a host port to a container port.
- Example:
  docker run -p 8080:80 nginx
  - 8080 (Host port) → 80 (Container port)
  - Accessible via http://localhost:8080 on the host.
- **Why is Port Forwarding Important?**
  - Allows external access to services running inside containers (e.g., web servers, databases).
  - Enables multi-container communication (e.g., app server connecting to a DB).
  - Essential for development & production deployments.

When to Use Port Forwarding?

- Web Applications (Nginx, Apache, Node.js)
- Databases (MySQL, PostgreSQL, MongoDB)
- APIs & Microservices (Flask, Django, Spring Boot)
- Testing & Debugging (Exposing temporary ports for access)

Where to Configure Port Forwarding?

Command Line (docker run -p)

docker run -p 3000:3000 node-app

Docker Compose (ports:)

yaml

```
services:
  web:
    ports:
      - "8080:80"
```

Kubernetes (ports: in Pod/Service YAML)

Necessary Precautions

⚠️ Avoid Binding to Well-Known Ports (e.g., 80, 443) unless necessary.
⚠️ Use Specific IP Binding to restrict access:
docker run -p 127.0.0.1:8080:80 nginx # Only localhost
⚠️ Limit Exposure in Production (Use firewalls, reverse proxies like Nginx).
⚠️ Avoid -P (Random Ports) unless auto-discovery is needed.

Common Errors & Fixes

Error	Cause	Solution
Port already in use	Host port is occupied	Change host port (-p 8081:80)
Connection refused	Container not listening on port	Check EXPOSE in Dockerfile
Permission denied	Nonroot user on port <1024	Use sudo or higher port (e.g., 8080)
Firewall blocking traffic	Host firewall rules	Allow port in firewall (ufw allow 8080)

Syntax & Use Case Examples

Basic Port Forwarding
docker run -p 8080:80 nginx # Host:8080 → Container:80

Bind to Specific Host IP
docker run -p 192.168.1.100:8080:80 nginx # Restrict to LAN

UDP Port Forwarding
docker run -p 5000:5000/udp dns-server

Multiple Ports
docker run -p 8080:80 -p 3306:3306 mysql

Dynamic Port Assignment (-P)
docker run -P nginx # Random host port (check with `docker ps`)

Practical Use Cases

1. Running a Web Server
   docker run -d -p 80:80 --name webserver nginx
   Access via http://localhost.

2. Exposing a Database
   docker run -d -p 3306:3306 -e MYSQL_ROOT_PASSWORD=1234 mysql
   Connect via mysql -h 127.0.0.1 -P 3306 -u root -p.

3. Debugging a Flask App
   docker run -p 5000:5000 flask-app
   Test API at http://localhost:5000.

Multi-Container App (Docker Compose)

```
yaml
services:
  web:
    ports:
      - "8000:8000"
  redis:
    ports:
      - "6379:6379"
```

Summary

- Port forwarding connects host ports to container ports.
- Critical for accessibility (web apps, APIs, databases).
- Secure with IP binding & firewalls in production.
- Common errors include port conflicts and firewall blocks.
- For advanced networking, explore Docker bridge networks and reverse proxies (e.g., Traefik, Nginx).

Dockerfile Directives: Purpose, Importance, and Practical Applications

1. Why Dockerfile Directives Are Important

Dockerfile directives are the **building blocks** of containerization that enable:

- **Reproducible environments** (eliminates "works on my machine" issues)
- **Automated image creation** (consistent deployments)
- **Optimized container performance** (smaller images, faster builds)
- **Security hardening** (non-root users, minimal dependencies)
- **Standardization** across development, testing, and production

2. When to Use Dockerfile Directives

Scenario	Key Directives	Reason
Creating a new image	`FROM`, `RUN`, `COPY`	Bootstrap container environment
Configuring runtime	`ENV`, `WORKDIR`, `USER`	Set execution context
Optimizing builds	Multi-stage builds (`FROM AS`)	Reduce final image size
Defining container behavior	`CMD`, `ENTRYPOINT`	Control startup process
Network services	`EXPOSE`, `HEALTHCHECK`	Document and monitor ports

3. Where to Apply Dockerfile Concepts

A. Development Environment Setup

```
FROM node:18
WORKDIR /app
COPY package.json .
RUN npm install  # Layer caching optimization
COPY . .
CMD ["npm", "run", "dev"]
```

B. Production deployment

```
# Build stage
FROM python:3.9 as builder
COPY requirements.txt .
RUN pip install --user -r requirements.txt
# Runtime stage
FROM python:3.9-slim
COPY --from=builder /root/.local /root/.local
COPY app.py .
ENV PATH=/root/.local/bin:$PATH
USER appuser
CMD ["gunicorn", "app:app", "-b", "0.0.0.0:8000"]
```

C. CI/CD Pipelines

```
FROM golang:1.20 as tester
COPY . .
RUN go test ./...
FROM builder as release
ARG VERSION
LABEL version=$VERSION
RUN make build
```

Directive Selection Guide

Need	Primary Directive	Alternatives
Base image	FROM	None (required)
Install software	RUN	Shell script in COPY+RUN
Configuration	ENV	--env at runtime
File addition	COPY	ADD (for special cases)
Default command	CMD	docker run override
Persistent storage	VOLUME	-v at runtime

6. Anti-Patterns to Avoid

1. **RUN apt-get update && apt-get install -y without cleanup**
   → Leads to bloated images
2. **Using ADD when COPY suffices**
   → Unnecessary complexity
3. **CMD service nginx start**
   → Use foreground process like nginx -g 'daemon off;'
4. **Root user in production**
   → Always specify USER
5. **Unpinned base image versions (FROM node)**
   → Use FROM node:18-bullseye-slim

USER and RUN Directives in Dockerfiles

RUN Directive Purpose: Executes commands during the image build process to modify the container filesystem.
Key Characteristics:

- Creates a new layer for each RUN instruction
- Two forms:
  - Shell form: RUN apt-get update && apt-get install -y curl
  - Exec form: RUN ["/bin/bash", "-c", "echo Hello"]

When to Use:

- Installing system packages (apt-get, yum, apk)
- Downloading dependencies (npm install, pip install)
- Building application code (make, go build)
- Configuring the system (creating users/directories)

Best Practices:

- Chain related commands with && to minimize layers: RUN apt-get update &&
  apt-get install -y curl wget &&
  rm -rf /var/lib/apt/lists/*
- Clean up in the same RUN to avoid storing temporary files
- Sort multi-line commands alphabetically for maintainability: RUN apt-get update &&
  apt-get install -y
  curl
  git
  wget &&
  rm -rf /var/lib/apt/lists/*

Advanced Use Cases:

- Cache directories (BuildKit): RUN --mount=type=cache,target=/var/cache/apt
  apt-get update && apt-get install -y git
- Secrets (BuildKit): RUN --mount=type=secret,id=mysecret
  echo "Password is $(cat /run/secrets/mysecret)"

USER Directive Purpose:
Sets the runtime user for subsequent instructions and container execution.
Key Characteristics:

- Affects both build-time and container runtime instructions

- Requires the user/group to exist

When to Use:

- Security hardening (avoid running as root)
- Permission management
- Service-specific user requirements (e.g., postgres)

Best Practices:

- Always create a dedicated user: RUN groupadd -r appuser && useradd -r -g appuser USER appuser
- Set USER before copying files to ensure correct ownership: RUN chown -R appuser:appuser /app USER appuser COPY --chown=appuser:appuser . .
- Combine with WORKDIR for predictability: WORKDIR /home/appuser USER appuser

RUN: Setup environment

RUN apk add --no-cache curl &&
addgroup -S appgroup &&
adduser -S appuser -G appgroup
WORKDIR /app

USER: Switch before copying files

USER appuser
COPY --chown=appuser:appgroup package*.json . RUN npm ci --only=production
COPY --chown=appuser:appgroup . .

Final runtime configuration

ENV NODE_ENV=production EXPOSE 3000 CMD ["node", "server.js"]

5. Troubleshooting RUN Issues:

- Permission denied: Use USER root or sudo
- Cache invalidation: Move volatile operations to the end

USER Issues:

- User doesn't exist: Ensure creation before use
- Permission errors: Use COPY --chown or RUN chown
- Service won't start: Some require root (e.g., ports <1024)

Order of Execution in Docker

Dockerfile Instruction Execution Order When building an image, Docker executes instructions in a Dockerfile in the following order:

FROM → ARG → LABEL → RUN → COPY/ADD → USER → WORKDIR → ENV → EXPOSE → CMD/ENTRYPOINT

Key Points:

- FROM must be the first instruction (except ARG, which can appear before FROM)
- Each instruction creates a new image layer
- Instructions are executed sequentially unless Docker's cache is used

Container Startup Order When a container starts, the following steps occur:

- Filesystem is initialized from the image layers
- Network interfaces are created
- Environment variables are set
- ENTRYPOINT is prepared
- CMD arguments are combined with ENTRYPOINT
- The container's main process starts
- Health checks begin (if configured)

Multi-Container Applications (Docker Compose) In Docker Compose, services start in a dependency-aware order:

- Networks and volumes defined in the Compose file are created
- Services start based on depends_on relationships
- Each service's container follows its own startup sequence

Control Mechanisms:

- depends_on: Defines service dependencies
- healthcheck: Waits for services to become healthy before continuing
- restart policies: Determines how failed containers are restarted

Container Lifecycle Order A container typically goes through this sequence:

- docker create: Defines and creates the container but does not start it
- docker start: Starts the container
  - The main process defined by CMD or ENTRYPOINT runs
- docker stop: Sends SIGTERM to the main process
  - If the process doesn't exit within the grace period, SIGKILL is sent
- The container transitions to the "exited" state

Understanding these execution sequences helps in structuring Dockerfiles, orchestrating containerized services, and managing lifecycle behaviors effectively.

ENTRYPOINT and EXPOSE Execution Order

In a Dockerfile, ENTRYPOINT and EXPOSE operate in different execution phases:

EXPOSE Instruction:

- Execution Phase: Image build time
- Purpose: Documents which ports the container will listen on (does not actually publish them)
- Effect:
  - Adds metadata to the image
  - Used by `docker run -P` to auto-publish ports
  - Serves as documentation for users

ENTRYPOINT Instruction:
- Execution Phase: Container runtime
- Purpose: Defines the executable that will run as PID 1 inside the container
- Effect:
  - Configures the default command that cannot be overridden by CMD (but can be overridden via `--entrypoint`)
  - CMD values become arguments to ENTRYPOINT if both are used

Example Dockerfile:
```
FROM ubuntu:latest
# EXPOSE happens during build
EXPOSE 8080
# ENTRYPOINT is configured during build but runs at container startup
ENTRYPOINT ["python3"]
# CMD provides default arguments to ENTRYPOINT
CMD ["app.py"]
```

Key Differences:

Instruction	Execution Phase	Overridable	Purpose
EXPOSE	Build time	No	Documents container network ports
ENTRYPOINT	Runtime	Yes (via --entrypoint)	Defines the container's main process

Important Notes:
- EXPOSE does not make ports accessible from the host; use `-p` in `docker run`
- ENTRYPOINT runs after all other container initialization (e.g., networking, volumes)
- The order these appear in the Dockerfile does not affect their execution timing

Docker Container Volume Management

- When you run a Docker container, any data created inside the container is lost when the container stops or is removed. To save data even after the container is gone, we use Volumes.
- A Docker Volume is a special location outside the container's filesystem where we can store data permanently.
- **Why Use Volumes?**
  Data Persistence: Data remains even if the container is deleted.
  Sharing Data: Volumes can be shared between multiple containers.
  Backup & Restore: Easier to back up and restore volumes than container data.

Types of volumes:

1) Anonymous Volume
2) Named Volume
3) Bind Mount

Anonymous Volume:

- An anonymous volume is a volume that Docker creates automatically when you use the -v flag with only a container path, but without a volume name or host path.
- Docker picks a random name for this volume and stores it on your host.

Key Points

- Created automatically by Docker.
- No custom name—you don't manage it directly.
- Data is stored outside the container in Docker's volume storage.
- Useful for quick testing or when you don't need to reuse the volume.

> docker run -it -v /app/data busybox

What this does:

- Launches a busybox container.
- Mounts an anonymous volume to /app/data inside the container.
- Docker creates a random volume name and links it to /app/data.

Where Is the Volume Stored?

Docker stores volumes on the host in a special directory, typically:
/var/lib/docker/volumes/<random_id>/_data

OR

Check the list of available volumes in docker using a command:

```
>docker volume ls
DRIVER    VOLUME NAME
local     3fa45bc7a7d34e68eebc23d4c6d456cb
```

Inspect the volume:

```
>docker volume inspect 3fa45bc7a7d34e68eebc23d4c6d456cb
```

This will show: 1. Mount path 2. Driver (usually local) 3. What container is using it

What Happens When the Container is Removed?

- By default, the anonymous volume still exists after the container is deleted!
- But if you use --rm, Docker will clean it up:
  docker run --rm -v /app/data busybox

When to Use Anonymous Volumes

Use anonymous volumes when:

- You want temporary storage for a container.
- You don't care about the data after the container stops.
- You're testing or running short-lived containers.

Clean Up Anonymous Volumes

```
>docker volume prune
```

Named Volume:

What is a Named Volume?

A **Named Volume** in Docker is a volume that you create and name yourself. Unlike anonymous volumes, named volumes are easier to manage, reuse, and inspect.

Why Use Named Volumes?

- To **store data permanently**, even if the container is deleted.
- To **share data** between multiple containers.
- To **backup and restore** data easily.
- To have **control** by giving the volume a specific name.

Creating and Using a Named Volume

Step 1: Create a Volume

```
>docker volume create mydata
```

This creates a volume named mydata.

Step 2: Use the Volume in a Container

```
>docker run -it -v mydata:/app/data busybox
```

This mounts the mydata volume into the /app/data folder inside the container.
Any files written to /app/data will be stored in the volume named mydata, which exists outside the container.

Volume Mounting Syntax and Options
Basic Syntax:

docker run -**v** <volume_name>:<container_path> <image>

Common Options:

- ro – Mount the volume as **read-only**:
- docker run -v mydata:/app/data:ro busybox
  The container can **read** from /app/data but **cannot write** to it.
- rw – Mount the volume as **read-write** (default):
- docker run -v mydata:/app/data:rw busybox
  The container can both **read** and **write** to /app/data.
- --mount (alternative to -v, more readable):
- docker run --mount source=mydata,target=/app/data busybox
  This is clearer for more complex setups and is recommended for production.

Share Named Volume Between Containers
You can reuse the same volume across multiple containers:

>docker run -it -v mydata:/app/data ubuntu

Now this Ubuntu container can access the same data stored in the mydata volume.

Inspect and Manage Named Volumes

List All Volumes

>docker volume ls

Inspect a Volume

>docker volume inspect mydata

Remove a Volume

>docker volume rm mydata

Note: You must stop and remove all containers using the volume first.

Where is the Data Stored?
Docker stores volumes on your host system (usually):

/var/lib/docker/volumes/mydata/_data

You can go to this directory to see the files stored by your container.

Volume Persistence

- The volume exists **even after the container is deleted**.
- If you want to delete unused volumes,
  use: docker volume prune

Use Cases for Named Volumes

- Storing **databases** like MySQL, PostgreSQL, etc.
- Saving user uploads or logs.
- Sharing configuration or code between multiple services.

Summary Table

Feature	Named Volume
Created by	User
Named	Yes (e.g., mydata)
Persistent	Yes
Sharable	Yes
Use Case	Long-term data storage, multi-container access
Management	Easy (inspect, delete, backup)
Access Mode	ro (read-only) or rw (read-write, default)
Mount Option	-v or --mount

- Named volumes are one of the most reliable and clean ways to handle persistent data in Docker.
- They're easy to manage and work across many use cases like development, testing, and production.
- Let me know if you'd like an example with Docker Compose or want to see a backup/restore process using named volumes!

Bind Mount

- ❖ What is a Bind Mount? A Bind Mount is a volume type where you directly connect a specific folder from your host system to a folder inside the container.
- ❖ This means any change made in that folder on the host will reflect inside the container and vice versa.

Why Use Bind Mounts?

- To access local project files inside a container (especially during development)
- To edit code or config files on your host and see changes instantly in the container
- To store logs or output data from the container on the host

Creating and Using a Bind Mount

Example: Mount a Host Directory

```
>docker run -it -v /home/user/myapp:/app busybox
```

This command:

- Mounts the local folder /home/user/myapp into the container at /app
- Files inside /home/user/myapp are now accessible from /app in the container

Two-Way Sync

- If you create a file inside /app in the container, it will appear in /home/user/myapp on your host.
- If you delete a file from the host directory, it's gone from the container too.
  This makes Bind Mounts ideal for development.

Syntax and Options

Basic Bind Mount Syntax:

```
>docker run -v /host/path:/container/path
```

With Read-Only Access:

```
>docker run -v /host/path:/container/path:ro
```

Using --mount (recommended format): docker run --mount

type=bind,source=/host/path,target=/container/path

Important Notes

- The host directory must exist; Docker will not create it.
- Be careful: any file changes are permanent on your host.
- Security: Containers can access your real system files if you're not careful.

Real-World Use Cases

- Mounting your codebase into a Node.js or Python container for live development
- Collecting logs from containers into a host directory
- Reading configuration files from the host machine

Summary Table

Feature	Bind Mount
Created by	User (host path must exist)
Named	No
Persistent	Yes (depends on host folder)
Sharable	Yes
Use Case	Development, live editing, log storage
Management	Manual (via host filesystem)
Access Mode	ro or rw
Mount Option	-v or –mount type=bind

Bind mounts are best for development environments, where fast feedback and access to local files is key. For production, named volumes are usually safer and easier to manage.

Docker Commands and Structures - Detailed Guide

1. Inspect Container Processes

Definition: Inspect running processes inside a container to monitor performance, debug issues, or analyze logs.

Importance:

- Helps troubleoot application failures.
- Monitors CPU, memory, and network usage.
- Ensures containers are running as expected.

When to Use:

- Debugging craes or high resource usage.
- Checking logs for errors.
- Verifying running services inside a container.

Syntax & Examples:

```
# View running processes in a container
docker top <container_name_or_id>
# Monitor real-time resource usage
docker stats <container_name_or_id>
# View container logs
docker logs <container_name_or_id>
# Execute a command inside a running container
docker exec -it <container_name_or_id> ba
```

2. Previous Container Management

Definition: Manage stopped, exited, or old containers (start, restart, remove).
Importance:

- Prevents disk space wastage.
- Helps maintain a clean Docker environment.

When to Use:

- Cleaning up unused containers.
- Restarting a craed container.

Syntax & Examples:

```
# List all containers (including stopped ones)
docker ps -a
# Start a stopped container
docker start <container_name_or_id>
# Remove a stopped container

docker rm <container_name_or_id>

# Remove all stopped containers

docker container prune
```

3. Controlling Port Exposure on Containers
Definition:
Map host machine ports to container ports for network communication.
Importance:

- Allows external access to containerized apps (e.g., web servers).
- Enables inter-container communication.

When to Use:

- Running a web server (e.g., Nginx, Apache).
- Connecting apps to databases.

Syntax & Examples:

```
# Bind host port 8080 to container port 80

docker run -p 8080:80 nginx

# Auto-assign a random host port

docker run -P nginx
```

4. Naming Our Containers

Definition: Assign custom names to containers for easier management.

Importance:

- Avoids reliance on auto-generated IDs.
- Simplifies container reference in commands.

When to Use:

- Running long-lived containers (e.g., databases).
- Managing multiple containers in production.

Syntax & Examples:

```
# Run a container with a custom name

docker run --name my_nginx nginx

# Rename an existing container

docker rename old_name new_name
```

5. Docker Events

Definition:

Monitor real-time Docker daemon events (container start, stop, create, etc.).

Importance:

- Debugging container lifecycle issues.
- Automating actions based on events (e.g., auto-restart).

When to Use:

- Tracking unexpected container stops.
- Logging Docker activities.

Syntax & Examples:

```
# Stream live Docker events
docker events
# Filter events (e.g., only container events)
docker events --filter type=container
```

6. Managing and Removing Base Images

Definition:

Clean up unused or dangling Docker images to free disk space.

Importance:

- Prevents disk bloat from unused images.
- Keeps the Docker environment optimized.

When to Use:

After testing or building new images.
When disk space is low.

Syntax & Examples:

```
# List all images
docker images
# Remove a specific image
docker rmi <image_id>
# Remove all unused images
docker image prune -a
```

7. Saving and Loading Docker Images

Definition:

Export/import Docker images as .tar files for offline use.

Importance:

- are images without a registry.
- Backup images for disaster recovery.

When to Use:

- Transferring images between air-gapped systems.
- Archiving old versions.

Syntax & Examples:

```
# Save an image to a .tar file
docker save -o my_image.tar nginx:latest
# Load an image from a .tar file
docker load -i my_image.tar
```

8. Image History
Definition:
Inspect the build history and layers of a Docker image.

Importance:
- Debugs inefficient image builds.
- Understands image composition.

When to Use:
- Optimizing Dockerfile layers.
- Auditing third-party images.

Syntax & Examples:

```
# View image layer history
docker history nginx
# Inspect detailed metadata
docker inspect nginx
```

9. Taking Control of Our Tags
Definition:
Manage image tags for versioning and deployment.
Importance:
- Ensures reproducibility in deployments.
- Avoids latest tag pitfalls in production.

When to Use:
- Releasing new app versions.
- Maintaining stable vs. development builds.

Syntax & Examples:

```
# Tag an image
docker tag nginx myrepo/nginx:v1.0
# Pu to Docker Hub
docker pu myrepo/nginx:v1.0
```

10. Puing to Docker Hub
Definition:
Upload Docker images to a registry (e.g., Docker Hub).

Importance:
- ares images publicly/privately.
- Enables CI/CD deployments.

When to Use:
- Deploying to cloud platforms.
- Collaborating with teams.

Syntax & Examples:

```
# Log in to Docker Hub
docker login
# Tag and pu an image
docker tag nginx username/repo:v1
docker pu username/repo:v1
```

Exercise Solutions

1. Base Image Maintenance & Cleanup

```
>docker images
>docker image prune -a  # Removes unused images
>df -h  # Checks disk space
```

2. Advanced Container Creation

```
>docker run --name my_nginx -p 8080:80 --rm nginx
```

3. Dockerized Web Server

Dockerfile:

```
FROM nginx
 index.html /usr/are/nginx/html
```

Commands:

```
docker build -t my_web_server .
docker run -p 80:80 my_web_server
```

Docker Networking Explained with Practical Use Cases

Docker Networking Explained with Practical Use Cases

Let's break down Docker networking with real-world scenarios to understand how different network drivers work and when to use them.

1. Default Bridge Network (Single-Host Communication) **Use Case:** Running a Web App with a Database You have a Flask app (app.py) that connects to a Redis database. Both containers need to communicate.

How It Works:

- Docker creates a default bridge network (docker0).
- Each container gets an internal IP (e.g., 172.17.0.2, 172.17.0.3).
- Containers can talk to each other via IP or container name (if on the same network).

Steps: Run Redis in a container:

docker run -d --name redis redis:alpine

Run Flask app and connect to Redis:

docker run -d --name flask-app -p 5000:5000 --link redis my-flask-app

Test connectivity:

docker exec -it flask-app ping redis

Problem:

- The default bridge is not secure (all containers can communicate).

Solution:

- Create a custom bridge network for isolation.

2. Custom Bridge Network (Better Isolation) **Use Case:** Secure Microservices Communication You have a frontend (nginx), backend (nodejs), and database (postgres) that should only talk to each other.

Steps: Create a custom bridge:

docker network create --driver bridge my_secure_net

Run services on this network:

docker run -d --name postgres --network my_secure_net postgres

docker run -d --name node-backend --network my_secure_net -p 3000:3000 node-app

docker run -d --name nginx --network my_secure_net -p 80:80 nginx

Verify:

docker exec -it node-backend ping postgres

docker exec -it node-backend ping google.com

When to use:

- Best for single-host multi-container apps (e.g., dev environments).

3. Host Network (Maximum Performance) **Use Case:** High-Performance Web Server (No NAT Overhead) You're running an Nginx load balancer and want bare-metal performance.

Steps:

docker run -d --name nginx-lb --network host nginx

Pros:

- Faster (no NAT overhead).

- Simpler networking (no port conflicts if managed properly).

Cons:

- No isolation (security risk).
- Port conflicts if another service uses port 80.

When to use:

- Performance-critical apps (e.g., load balancers, gaming servers).

4. Macvlan (Containers as Physical Devices) **Use Case:** Running IoT Devices on a LAN You want Docker containers to appear as real devices on your network.

Steps: Create a Macvlan network:

```
docker network create -d macvlan \
  --subnet=192.168.1.0/24 \
  --gateway=192.168.1.1 \
  -o parent=eth0 \
  my_macvlan
```

Run a container:

```
docker run -d --name sensor --network my_macvlan --ip=192.168.1.100 sensor-app
```

When to use:

- IoT applications
- Legacy apps that expect real network interfaces

5. Overlay Network (Multi-Host Docker Swarm) **Use Case:** Distributed Microservices Across Servers You have a Docker Swarm cluster (3 servers).

Steps: Initialize Swarm:

```
docker swarm init
```

Create an overlay network:

```
docker network create -d overlay my_overlay_net
```

Deploy services:

```
docker service create --name redis --network my_overlay_net redis
```

```
docker service create --name api --network my_overlay_net -p 8000:8000 my-api
```

When to use:

- Swarm/Kubernetes clusters
- Multi-cloud deployments

6. None Network (Totally Isolated) **Use Case:** Secure Offline Data Processing You have a container that processes sensitive data and must not have network access.

Steps:

docker run -d --name secure-processor --network none data-processor

When to use:

- Secure/offline data processing

Summary: When to Use Which Network?

Network Type	Use Case	Example
Bridge	Single-host apps	Flask + Redis
Custom Bridge	Secure microservices	Nginx + Node + Postgres
Host	High-performance apps	Nginx LB
Macvlan	IoT/Physical devices	Smart sensors
Overlay	Multi-host clusters	Docker Swarm
None	No network access	Secure data processing

Final Tips:

- Default bridge is insecure → Prefer custom bridges.
- Need performance? → Try host or macvlan.
- Multi-host? → Use overlay.
- No network? → Use none.

Docker Networking: List, Inspect, and Manage Networks

Docker networks provide isolated environments for containers to communicate. Docker includes several built-in networks and allows users to create custom ones. Understanding how to manage these networks is essential for working with multi-container applications.

2. Listing Docker Networks

Command:
docker network ls
Description: Lists all networks available in the Docker engine.
Example Output:

```
NETWORK ID     NAME      DRIVER    SCOPE
f1e3a4c9b567   bridge    local
3ad3e3cb9c8e   host      local
7c9e3a0b8f93   none      null      local
```

- **bridge**: Default network for containers
- **host**: Shares the host network namespace
- **none**: Disables networking for the container

3. Inspecting a Docker Network

Command:
docker network inspect <network-name-or-id>
Description: Shows detailed information about a network, including connected containers, IP addresses, subnet configurations, and drivers.
Example:
docker network inspect bridge
Partial Output:

```
[
  {
    "Name": "bridge",
    "Id": "f1e3a4c9b567",
    "Driver": "bridge",
    "IPAM": {
      "Config": [
        {
          "Subnet": "172.17.0.0/16",
          "Gateway": "172.17.0.1"
        }
      ]
    },
    "Containers": {
      "abc123...": {
        "Name": "my_container",
        "IPv4Address": "172.17.0.2/16"
      }
    }
  }
]
```

4. Creating a Custom Network

Command:
docker network create <network-name>
Optional Flags:

- --driver bridge|host|overlay
- --subnet <CIDR>
- --gateway <IP>

Example:
docker network create --driver bridge my_custom_network

5. Connecting and Disconnecting Containers

Connect a container:
docker network connect <network-name> <container-name>
Disconnect a container:
docker network disconnect <network-name> <container-name>

6. Removing a Network

Command:

docker network rm <network-name>

Note: Only unused networks (i.e., no containers attached) can be removed.

7. Tips

- Use custom networks for better isolation and communication between services.
- Containers on the same custom bridge network can communicate using container names.
- Docker Compose automatically creates a dedicated network for each project.

List and Inspect:

When working with Spring Boot applications in Docker, networking is crucial for enabling communication between containers. Let me explain how to list and inspect Docker networks, particularly in the context of Spring Boot applications.

Listing docker networks: >docker network ls

NETWORK ID	NAME	DRIVER	SCOPE
a1b2c3d4e5f6	bridge	local	
d7e8f9g0h1i2	host	local	
j3k4l5m6n7o8	none	null	local
p9q0r1s2t3u4	mynet	bridge	local

Inspecting a Docker Network

To get detailed information about the existing network:

>docker network inspect <network-name-or-id>

Common Network Scenarios for Spring Boot Apps

1. Default Bridge Network When you run Spring Boot containers without specifying a network, they use the default bridge network.

Limitations:

- Containers can communicate via IP addresses
- No automatic DNS resolution between containers
- Not ideal for multi-container Spring Boot applications

2. User-Defined Bridge Network Better approach for Spring Boot microservices:

Create a user-defined network:
docker network create spring-network

Then run containers with:
docker run --network spring-network --name app1 my-spring-app
docker run --network spring-network --name app2 my-other-app

Advantages:

- Automatic DNS resolution (can connect using container names)
- Better isolation
- All containers on the network can communicate

3. Connecting Spring Boot to Databases

Create a network:
docker network create app-network

Run MySQL:
docker run --network app-network --name mysql -e MYSQL_ROOT_PASSWORD=pass -d mysql

Run Spring Boot app:
docker run --network app-network --name app -e SPRING_DATASOURCE_URL=jdbc:mysql://mysql:3306/mydb -p 8080:8080 my-spring-app

Practical Example with Spring Boot

Create a network:
docker network create spring-mysql-net

Run MySQL:
docker run --network spring-mysql-net --name mysql-db -e MYSQL_ROOT_PASSWORD=secret -e MYSQL_DATABASE=myapp -d mysql:8.0

Run Spring Boot app:
docker run --network spring-mysql-net --name spring-app -e SPRING_DATASOURCE_URL=jdbc:mysql://mysql-db:3306/myapp -p 8080:8080 -d my-spring-app

Inspecting the Network After running these containers, inspect the network:
docker network inspect spring-mysql-net

You'll see JSON output containing:

- Containers attached to the network
- Their IP addresses
- Network configuration
- Gateway information

Important Notes for Spring Boot

Service Discovery: In the Spring Boot application.properties or application.yml, use container names as hostnames:
spring.datasource.url=jdbc:mysql://mysql-db:3306/myapp

For microservices communicating with each other, use container names:
```
@FeignClient(name = "inventory-service", url = "http://inventory-service:8081")
public interface InventoryClient {
    // ...
}
```

When using Docker Compose, networks are automatically created and configured.

Docker Commands and Structures:

Inspect Container Processes Definition: The process of examining running applications inside a Docker container at the operating system level.
Technical Components:

- Utilizes Linux namespaces for process isolation
- Leverages cgroups for resource visibility
- Accesses /proc filesystem of the container

Use Cases:

- Production Debugging: Identify memory leaks in Java/Spring Boot apps; Detect zombie processes
- Performance Tuning: Analyze thread contention in Python apps; Monitor DB connections
- Security Auditing: Detect unexpected processes; Verify services match manifest

Practical Examples:

```
# View Java process details
docker exec -it spring-app jcmd 1 VM.flags

# Monitor MySQL connections
docker exec mysql mysqladmin processlist

# Continuous monitoring
watch -n 1 "docker exec app ps aux --sort=-%cpu"
```

Advantages / Disadvantages:

Advantage	Disadvantage
Real-time visibility	No historical data
No agent required	Limited to single host
Works with any image	Security risks if misconfigured

2. Previous Container Management Definition: Managing containers that have stopped or exited.

Technical Components:

- Container state transitions
- Storage drivers and writable layers
- Log driver for STDOUT/STDERR

Use Cases:

- CI/CD Pipelines: Cleanup after test; Debug failed containers
- Disaster Recovery: Restart crashed containers
- Storage Optimization: Regular cleanup; Data retention

Practical Examples:

```
# Cleanup script
docker ps -aq --filter "status=exited" | xargs -r docker rm -v

# Inspect logs
docker inspect --format='{{.LogPath}}' failed-container

# Bulk remove
docker container prune --filter "until=24h"
```

Advantages / Disadvantages:

Advantage	Disadvantage
Prevents disk bloat	Manual by default
Recovers resources	Potential data loss
Maintains health	Requires careful scheduling

3. Controlling Port Exposure Definition: Managing network connectivity through port mapping.

Technical Components:

- iptables NAT rules
- docker-proxy
- Kernel socket forwarding

Use Cases:

- Microservices: Spring Boot on separate ports
- Security: Port whitelisting, specific bindings
- Legacy Migration: Port preservation

Practical Examples:

```
# Bind to localhost
docker run -p 127.0.0.1:5432:5432 postgres

# Range mapping
docker run -p 8080-8090:8080-8090 app-cluster

# Check mappings
ss -tulpn | grep docker
```

Advantages / Disadvantages:

Advantage	Disadvantage
Flexible networking	Complex NAT debugging
Host-agnostic	Port conflicts
Security isolation	Requires careful planning

4. Naming Our Containers Definition: Assigning readable identifiers to containers.

Technical Components:

- DNS in user networks
- Naming constraints
- Service discovery integration

Use Cases:

- Orchestration: Predictable discovery
- Development: Easy debugging
- Automation: Reliable references in scripts

Practical Examples:

```
# Naming convention
docker run --name payment-service-${ENV}-${REGION} payment-image

# Dynamic naming
docker run --name "build-${BUILD_NUMBER}" test-image

# DNS discovery
nslookup payment-service.user-network
```

Advantages / Disadvantages:

Advantage	Disadvantage
Improved readability	Name collisions
Better automation	Requires naming policy
Simplified debug	Limited characters

5. Docker Events Definition: Real-time Docker daemon activity stream.

Technical Components:

- Docker event API
- JSON payloads
- Subscription channels

Use Cases:

- Security: Unauthorized creation alerts
- CI/CD: Post-build actions
- Compliance: Audit trails

Practical Examples:

```
# Health status change
docker events --filter 'event=health_status'

# ELK integration
docker events --format '{{json .}}' | logstash -f docker-events.conf

# Custom alert
docker events --filter 'event=die' | xargs -I {} send_alert "Container died: {}"
```

Advantages / Disadvantages:

Advantage	Disadvantage
Real-time visibility	No persistent storage
Full coverage	High volume in busy systems
API integration	Requires parsing logic

6. Managing Base Images Definition: Optimizing and securing base images.

Technical Components:

- Union filesystem
- Image manifest
- Content-addressable storage

Use Cases:

- Vulnerability Management: CVE patches
- Cost: Reduce size
- Compliance: Approved images, SBOM

Practical Examples:

```
# Find CVEs
docker scout cves my-image
```

```
# Multi-stage builds
docker build -t optimized --target runtime .

# Analyze layers
docker dive my-image
```

Advantages / Disadvantages:

Advantage	Disadvantage
Security hardening	Requires maintenance
Performance boost	Build complexity
Standardization	Regression risks

7. Saving/Loading Images Definition: Serializing Docker images to archives.

Technical Components:

- TAR format
- Gzip compression
- Manifest preservation

Use Cases:

- Air-gapped: Military, secure envs
- Recovery: Backups
- Bulk: Migrate registries

Practical Examples:

```
# Compress save
docker save my-image | pigz > image.tgz

# Split archive
docker save my-image | split -b 2G - image_part

# Verify content
tar -tvf image.tar | grep manifest.json
```

Advantages / Disadvantages:

Advantage	Disadvantage
Offline ready	Large files
Fidelity	Manual process
No registry need	No delta transfers

8. Image History Definition: Commands and layers behind an image.

Technical Components:

- SHA256 hashes
- Build metadata
- Timestamps

Use Cases:

- Debug: Trace failing builds
- Security: Detect tampering
- Optimization: Heavy layers

Practical Examples:

```
# Time per layer
docker history --format "{{.CreatedSince}}\t{{.Size}}\t{{.CreatedBy}}" my-image

# Large layers
docker history --format "{{.Size}}" my-image | numfmt --from=iec | sort -n

# Diff history
diff <(docker history image1) <(docker history image2)
```

Advantages / Disadvantages:

Advantage	Disadvantage
Transparency	No runtime info
Size analysis	Squashed images lose history
Auditing support	Manual review needed

9. Tag Management Definition: Versioning Docker images with tags.

Technical Components:

- Image manifest refs
- Registry APIs
- Addressable storage

Use Cases:

- Releases: Semver, rollbacks
- Promotion: dev → prod
- Architecture: Platform tags

Practical Examples:

```
# Auto tag
docker tag my-app:${GIT_SHA:0:8} registry/my-app:${BUILD_NUMBER}

# Sign images
docker trust sign my-company/my-image:1.0

# Tag cleanup
regctl tag ls my-repo | grep -E 'v[0-9]+\.[0-9]+\.[0-9]+' | sort -V | head -n -10 | xargs -I {} regctl tag delete my-repo:{}
```

Advantages / Disadvantages:

Advantage	Disadvantage
Precise deployments	Tag sprawl
Rollback safety	Storage costs
Consistent envs	Needs discipline

10. Pushing to Docker Hub Definition: Uploading Docker images to a shared registry.

Technical Components:

- Registry API v2
- OCI spec
- Auth tokens

Use Cases:

- Team: Shared artifacts
- Cloud: ECS, K8s
- Public: OSS images

Practical Examples:

```
# Multi-arch build push
docker buildx build --platform linux/amd64,linux/arm64 --push -t user/repo:latest .

# Auto tag and push
docker tag app:build-${BUILD_NUMBER} myrepo/app:${BUILD_NUMBER}
docker push myrepo/app:${BUILD_NUMBER}

# Scan before push
docker scan --file Dockerfile my-image
```

Advantages / Disadvantages:

Advantage	Disadvantage
Centralized sharing	Internet dependency
Access control	Storage costs
Global distribution	Rate limits

Docker Networking Notes for Spring Boot/MVC Applications

---

1. Networking Overview in Docker

Core Concepts

Docker networking enables communication between:

- Containers and the host system
- Multiple containers (e.g., microservices)
- Containers and external networks

Key Components

- **Network Drivers**: Define how containers communicate (e.g., bridge, host, overlay)
- **Network Interfaces**: Virtual Ethernet devices (veth pairs) connect containers to networks
- **DNS Resolution**: Enables automatic container name resolution
- **Port Mapping**: Maps container ports to host ports

Spring Boot Relevance

- REST API communication between microservices
- Connecting to databases like MySQL/PostgreSQL
- Enables service discovery in cloud-native environments

---

2. The Default Bridge Network

Definition

- A pre-configured network named bridge that Docker automatically creates

Inspecting

docker network inspect bridge

- Subnet: usually 172.17.0.0/16
- Gateway: 172.17.0.1
- DNS: Internal resolver

Spring Boot Use Case

docker run -p 8080:8080 my-spring-app

- IP assigned like 172.17.0.2
- Exposes app on localhost:8080

Key Characteristics

Feature	Description	Spring Boot Impact
Isolation	Containers are isolated	Ports must be explicitly exposed
DNS	No name resolution	Must use IPs or --link
Performance	NAT overhead	Slight latency

Example: Connect Spring Boot to MySQL

docker run --name mysql-db -e MYSQL_ROOT_PASSWORD=secret -d mysql
spring.datasource.url=jdbc:mysql://172.17.0.2:3306/mydb

Limitations:

- IPs change on restart
- No built-in service discovery
- Port conflicts

---

3. User-Defined Bridge Networks (Recommended for Spring Boot)

Benefits

- DNS-based service discovery
- Isolated and more secure
- Avoids NAT performance issues

Implementation

```
docker network create spring-network

docker run --network spring-network --name mysql-db -d mysql

docker run --network spring-network -p 8080:8080 my-app
```

Spring Boot Config

```
spring.datasource.url=jdbc:mysql://mysql-db:3306/mydb
service.url=http://inventory-service:8081
```

Communication Flow

```
sequenceDiagram
  Browser->>Spring-App: http://host:8080
  Spring-App->>MySQL: mysql-db:3306
  Spring-App->>Inventory-Svc: inventory-service:8081
```

---

4. Host Networking (High Performance)

Use When

- Need max performance
- Require direct host network access

Implementation

```
docker run --network host my-spring-app
```

Spring Boot Config

```
server.port=8080
```

Caution:

- Risk of port conflicts
- Less isolation and security

---

5. Overlay Networks (For Swarm/Kubernetes)

Use Case

- Deploying Spring Boot apps in Docker Swarm or Kubernetes
- Enables service communication across multiple hosts

Implementation

```
docker swarm init

docker network create --driver overlay spring-overlay

docker service create --network spring-overlay --name my-app -p 8080:8080 my-spring-app
```

6. Network Aliases (Advanced DNS)

Use Cases

- Support multiple access names (e.g., versioning)
- Smooth blue/green deployments

Example

```
docker run --network spring-net \
  --network-alias api \
  --network-alias api-v2 \
  my-spring-app
```

Spring Boot Usage

```
service.url=http://api:8080
legacy.url=http://api-v2:8080
```

Best Practices for Spring Boot/MVC Apps

1. **Always Use User-Defined Networks**

```
docker network create app-net
```

2. **Name Your Containers**

```
docker run --name auth-service --network app-net auth-image
```

3. **Externalize Configuration**

```
db.host=${DB_HOST:mysql-db}
```

4. **Add Health Checks**

```
HEALTHCHECK --interval=30s CMD curl -f http://localhost:8080/actuator/health
```

5. **Network Segmentation**

```
docker network create frontend
docker network create backend
```

Separate frontend and backend for better security and organization.

Docker Networking Concepts (Spring Boot Focus)

---

1. Isolating Containers

Definition & Purpose:

- Ensures security boundaries between applications
- Controls communication channels
- Prevents "noisy neighbor" issues

Implementation Methods: Network-Level Isolation

```
# Create isolated networks
docker network create finance-net
docker network create inventory-net

# Attach containers to specific networks
docker run --network finance-net --name accouting-app accounting-image
docker run --network inventory-net --name stock-app inventory-image
```

Spring Boot Implications

```
# application.properties in accounting-app
# Cannot access:
inventory.service.url=http://stock-app:8080  # Fails - different networks
```

Technical Details:

- Uses Linux network namespaces
- Each network gets separate bridge interface
- iptables rules enforce isolation

Use Cases:

- **Multi-Tenant Applications:** Separate customer environments
- **PCI Compliance:** Isolate payment processing
- **Microservices Security:** Limit attack surface

Isolation Comparison

Method	Isolation Level	Performance Impact
Separate networks	High	Low
Default bridge	Low	Medium
Host network	None	Best

---

2. Aliases & Container Names

Container Naming Fundamentals:

```
docker run --name web-app -d nginx
```

- Must be unique per Docker host
- Valid chars: [a-zA-Z0-9_.-]
- Becomes DNS name in user-defined networks

Network Aliases (Advanced DNS):

```
docker run --name payment-service \
  --network ecommerce-net \
  --network-alias payments \
  --network-alias billing \
  payment-image
```

Spring Boot Integration:

```
# application.properties
payment.url=http://payments:8080/api
legacy.url=http://billing:8080/v1
```

Key Benefits:

- **DNS Resolution:** Containers can ping payment-service or payments
- **Versioned Endpoints:** Use --network-alias api-v1 and api-v2
- **Blue/Green Deployments:** Switch aliases between versions

Practical Example:

```
# Service discovery in custom network
docker exec -it order-service ping payments
> PING payments (172.18.0.3) 56(84) bytes of data
```

---

3. Links (Legacy Feature)

Original Purpose:

- Name resolution in default bridge
- Environment variable injection
- Dependency ordering

Syntax (Deprecated but Still Works):

```
docker run --name mysql-db -d mysql
docker run --link mysql-db:database spring-app
```

What It Creates:

- **/etc/hosts Entry:** 172.17.0.2 database mysql-db
- **Environment Variables:**

```
DATABASE_PORT_3306_TCP_ADDR=172.17.0.2
DATABASE_NAME=/app2/database
```

Spring Boot Usage (Legacy):
spring.datasource.url=jdbc://${DATABASE_PORT_3306_TCP_ADDR}:3306/db
Why Avoid Links?
- Limited to Single Host
- Creates Hidden Dependencies
- Replaced by Better Alternatives

Modern Replacement:
Use custom networks instead
docker network create app-net
docker run --network app-net --name mysql-db -d mysql
docker run --network app-net --name spring-app spring-image

---

4. How Updates Affect Networking
Scenario 1: Container Restart
docker restart spring-app
- **IP Address:** May change (default bridge)
- **DNS Resolution:** Preserved in custom networks
- **Connections:** Existing TCP connections break

Scenario 2: Image Update
docker stop old-app && docker rm old-app
docker run --network app-net --name spring-app new-image
- **Network Identity:** Maintained (same name)
- **Service Discovery:** Unaffected
- **Best Practice:** Use docker service update in Swarm

Scenario 3: Network Configuration Changes
docker network disconnect app-net spring-app
docker network connect new-net spring-app --alias api
- **Impact:** Brief network downtime
- **Recovery:** Application reconnection logic needed

Spring Boot Considerations: Connection Pooling
spring.datasource.hikari.connection-timeout=30000
spring.datasource.hikari.max-lifetime=600000
Service Discovery: Use Spring Cloud Kubernetes/Consul for dynamic updates
Circuit Breakers:
@CircuitBreaker(name = "inventoryService")
Update Strategies

Strategy	Network Impact	Recommended For
Rolling restart	Minimal	Production
Blue/green	Zero downtime	Critical systems
Recreate	Brief outage	Dev environments

Best Practices Summary
Isolate by Default
docker network create --internal secure-net
Use DNS Names
# application.properties
db.url=jdbc://db-host:3306/mydb
Avoid Legacy Links
- Replace with custom networks

Handle Updates Gracefully
- Use connection pooling, retry logic, circuit breakers

Monitor Network Changes

```
docker events --filter 'event=network'
watch docker network inspect app-net
```

Troubleshooting Checklist

Connectivity Issues

```
docker exec -it app curl -v http://api:8080
```

DNS Resolution

```
docker exec -it app nslookup api
```

Port Conflicts

```
ss -tulpn | grep 8080
```

Network Inspection

```
docker network inspect app-net --format '{{json .Containers}}'
```

6. Using External Networks

Definition

External networks in Docker are pre-existing networks created outside the current docker-compose.yml or CLI context. These allow multiple containers or services across different Compose files or standalone containers to share a common communication network.

Why Use External Networks?

- Reuse a central network across multiple projects
- Enable inter-application communication
- Maintain a consistent network configuration across environments

Creating an External Network

```
# Create a named network (shared among multiple apps)
docker network create shared-net
```

Declaring External Networks in Compose

```
version: '3.8'
services:
  spring-app:
    image: spring-image
    networks:
      - shared-network

networks:
  shared-network:
    external: true
    name: shared-net
```

Spring Boot Use Case

Assume a Spring Boot application in one repo needs to talk to a Redis container defined in another project:

Compose File (Spring Boot App):

```
services:
  api-service:
    image: spring-app
    networks:
      - backend

networks:
  backend:
    external: true
    name: shared-net
```

application.properties

```
spring.redis.host=redis-server
```

Benefits for Spring Boot

- **Cross-project communication:** Share networks among apps
- **Centralized databases or caches:** Common Redis/MySQL services
- **Simplified DNS resolution:** Use container names in any project

Important Considerations

Factor	Note
Naming consistency	Must match created external name
Manual creation	Must be created manually before Compose up
Network scope	Ensure it is not --internal if cross-project

Best Practices

- Use external: true only when intentionally sharing
- Validate with docker network inspect that the network includes expected containers
- Combine with service discovery tools for dynamic updates

Troubleshooting

```
# Ensure container is attached to network
docker network inspect shared-net

# Check DNS name resolution
docker exec -it spring-app nslookup redis-server
```

Summary

External networks offer a flexible way to structure and connect services across multiple Compose files or projects. For Spring Boot microservices, this pattern supports scalable, shared environments while keeping configurations clear and isolated.

Docker Compose: Simplified Multi-Container Management

What is Docker Compose?
Docker Compose is a tool that helps you define and run multi-container Docker applications using a single configuration file called docker-compose.yml. It allows you to:

- Declare all your containers and their configurations in one place.
- Start or stop all services with a single command.

Commands:

```
docker-compose up     # Starts all defined containers
docker-compose down   # Stops and removes all defined containers
```

Why is Docker Compose Important in Docker Architecture?

Benefit	Explanation
Simplifies Management	One config file to manage all containers
Ensures Consistency	Same setup works across dev, test, and prod
Manages Networking	Automatically sets up container networking
Handles Dependencies	Starts containers in correct order
Reproducibility	Recreates exact environments with docker-compose up

---

Old Technologies Before Docker Compose

1. **Manual docker run Commands**
   Tedious for multi-container apps.
2. docker run -d --name db postgres:13
   docker run -d --name web -p 80:80 --link db nginx
3. **Shell Scripts / Makefiles**
   Hard to maintain and non-portable.
4. # deploy.sh
5. docker start db
6. sleep 5
   docker start web
7. **Vagrant + Ansible/Chef**
   Heavy VM-based setups, slower and more complex.
8. **Kubernetes**
   Too complex for small or local projects.

Why Move to Docker Compose? (With Use Cases)

Reason	Explanation	Use Case Example
Single Command Setup	Start everything with one command	Launching WordPress with MySQL
Dependency Management	depends_on ensures order	Flask app depends on PostgreSQL
Networking Automation	Compose creates a default network	React frontend talking to Node.js backend
Environment Parity	Same docker-compose.yml works everywhere	Avoids "works on my machine" syndrome
Volume & Secret Mgmt	Simplified persistent storage and env variables	Database volume persists data across restarts

When Should You Use Docker Compose?

☑ **Ideal For:**

- Local development
- Testing in CI/CD pipelines
- Small to medium microservices
- Quick prototypes

❌ **Not Ideal For:**

- Large-scale production clusters
- Apps needing dynamic horizontal scaling

Standard Docker Compose Template

```
version: '3.8'

services:
  web:
    image: nginx
    ports:
      - "80:80"
    volumes:
      - ./app:/app
    depends_on:
      - db

  db:
    image: postgres
    environment:
      POSTGRES_PASSWORD: password
    volumes:
      - db_data:/var/lib/postgresql/data

volumes:
  db_data:
```

Key Terms to Know

Term	Description
Service	A containerized component (e.g., web, db)
Volume	Persistent storage for container data
Network	Virtual network for containers to communicate
depends_on	Defines container startup order
environment	Environment variables passed to containers
ports	Maps container ports to host machine
build	Defines Dockerfile build context

Conclusion
Docker Compose transforms complex multi-container setups into manageable configurations. It shines in local development, testing, and controlled environments. For high-scale production and dynamic needs, Kubernetes is a better fit.

Docker Compose for Spring Boot and MVC Applications

Introduction
Docker Compose is a tool used to define and run multi-container Docker applications using a single YAML configuration file—docker-compose.yml. It's especially helpful in scenarios where applications require multiple services like backend, frontend, and databases.

Why Docker Compose?
In traditional setups:
- Manual docker run commands were used, which were tedious and error-prone.
- Shell scripts or Makefiles became messy and hard to maintain.
- Vagrant/Ansible/Chef were VM-based and overkill for containerized services.
- Kubernetes was too complex for small apps or quick prototyping.

Docker Compose solves these problems by:

Key Components in docker-compose.yml
- services: Define each container (e.g., web, db)
- volumes: Persist data beyond container lifecycle
- networks: Define how containers communicate
- environment: Set environment variables
- depends_on: Ensure order of service startup
- ports: Map host to container ports
- build: Build from local Dockerfile

When Should You Use Docker Compose?

✅ Ideal For:

- Local development
- CI/CD pipelines
- Microservices (small to medium scale)
- Quick prototyping

❌ Avoid For:

- Large-scale production (use Kubernetes instead)
- Dynamic scaling needs

Configuring Docker Compose for Spring Boot

Use Case: REST API backed by a MySQL database

Spring Boot docker-compose.yml

```
version: '3.8'


services:
  backend:
    build: ./backend
    ports:
      - "8080:8080"
    environment:
      - SPRING_DATASOURCE_URL=jdbc:mysql://db:3306/mydb
      - SPRING_DATASOURCE_USERNAME=root
      - SPRING_DATASOURCE_PASSWORD=password
    depends_on:
      - db
    networks:
      - app-network

  db:
    image: mysql:8.0
    environment:
      MYSQL_ROOT_PASSWORD: password
      MYSQL_DATABASE: mydb
    volumes:
      - db_data:/var/lib/mysql
    networks:
      - app-network

volumes:
  db_data:

networks:
```

```
  app-network:
    driver: bridge
```

Spring MVC docker-compose.yml

```
version: '3.8'

services:
  web:
    build: ./backend
    ports:
      - "8080:8080"
    environment:
      - SPRING_DATASOURCE_URL=jdbc:postgresql://db:5432/mydb
      - SPRING_DATASOURCE_USERNAME=postgres
      - SPRING_DATASOURCE_PASSWORD=password
    depends_on:
      - db
    volumes:
      - ./backend:/app

  db:
    image: postgres:13
    environment:
      POSTGRES_PASSWORD: password
      POSTGRES_DB: mydb
    volumes:
      - db_data:/var/lib/postgresql/data

volumes:
  db_data:
```

Standard Template

```
version: '3.8'


services:

  app:

    build: ./backend

    ports: ["8080:8080"]

    depends_on: [db]

    environment:

      SPRING_DATASOURCE_URL: jdbc:mysql://db:3306/mydb

      SPRING_DATASOURCE_USERNAME: root

      SPRING_DATASOURCE_PASSWORD: password
```

```
    networks:
      - app-network

  db:
    image: mysql:8.0
    environment:
      MYSQL_ROOT_PASSWORD: password
    volumes:
      - db_data:/var/lib/mysql

volumes:
  db_data:

networks:
  app-network:
    driver: bridge
```

Real-World Examples

1. Django + PostgreSQL
2. Spring Boot + PostgreSQL
3. Django + React + PostgreSQL

Best Practices

- Use `.env` Files for secrets and credentials.
- Separate Dev/Prod Compose Files with `override.yml` or flags.
- Enable Health Checks to ensure services are ready before dependent services start.

Healthcheck Example

```
healthcheck:
  test: ["CMD-SHELL", "pg_isready -U postgres"]
  interval: 5s
  timeout: 5s
  retries: 5
```

Key Terms Recap
- build: Builds container from Dockerfile

- volumes: Persist container data

- depends_on: Controls startup order

- networks: Defines secure communication

- ports: Exposes container ports

- environment: Inject environment variables

Conclusion
Docker Compose is the go-to solution for simplifying development and testing environments for Spring Boot, MVC, and full-stack apps. It abstracts container orchestration into a clean YAML file, reducing complexity and improving team collaboration. For large-scale deployments, consider Kubernetes.

Bringing an Environment Up with Docker Compose

Definition
Bringing an environment up means starting all the containers and services defined in your docker-compose.yml file. This is done using the command:

docker-compose up

It tells Docker to build the images (if needed), create the containers, set up networks, attach volumes, and start the services as defined.

Why Is It Important?
It helps automate and streamline the process of running an entire multi-service environment (e.g., frontend + backend + DB) with a single command.

Imagine running a Spring Boot app, PostgreSQL, and a frontend React app—managing them individually is tedious. Docker Compose handles everything for you.

When Can You Apply It?
Use "bringing an environment up" when:

- Local Development: Easily spin up a local dev environment
- Testing in CI/CD: Automate app + database for tests
- Onboarding New Developers: Let them start full stack with 1 command
- Building Microservices Locally: Run multiple services with correct dependencies
- Prototyping/Proof of Concepts: Quickly test new tech stacks

Real-World Use Cases

Use Case 1: Django + PostgreSQL
Start Django + DB locally for development:
docker-compose up

Use Case 2: Spring Boot + Redis for Caching
Develop and test locally with Redis for cache:
docker-compose up

Use Case 3: Node.js Backend + React Frontend + MongoDB
Develop a full-stack MERN app:
docker-compose up

Use Case 4: CI Pipeline
Trigger docker-compose up in your GitHub Actions to spin up your app + test DB before running integration tests.

Advantages

- Simplicity: One command runs all services
- Consistency: Same setup across all machines
- Dependency Handling: Auto-starts services in order (depends_on)
- Isolation: Each project runs in its own network/volume
- Efficiency: Auto mounts volumes, uses caching
- Reusability: Shareable docker-compose.yml config

How to Do It (Procedure)

Step 1: Write Your docker-compose.yml

Example:

```
version: '3.8'
services:
  app:
    build: ./app
    ports:
      - "8080:8080"
    depends_on:
      - db
  db:
    image: postgres
    environment:
      POSTGRES_PASSWORD: secret
      POSTGRES_DB: mydb
    volumes:
      - pgdata:/var/lib/postgresql/data
volumes:
  pgdata:
```

Step 2: Navigate to the Project Directory
cd your-project-folder/

Step 3: Run the Environment
docker-compose up

Or run in detached (background) mode:
docker-compose up -d

Step 4: Verify Services
Check running containers:
docker ps

Check logs:
docker-compose logs

Step 5: Stop the Environment
docker-compose down

Optional: Build Services Before Running
docker-compose up --build

Best Practices
- Use .env files to manage secrets/configs.
- Use docker-compose.override.yml for dev-specific configs.
- Use healthcheck to make sure DB is ready before starting the app.
- Keep your services modular for reusability.

Conclusion
"Bringing an environment up" is a fundamental practice in containerized development. It abstracts the complexity of running multi-container applications and offers a repeatable, reliable, and scalable method to run entire app stacks from development to CI environments.

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Example:

```
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services:
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    build: ./app
    ports:
      - "8080:8080"
    depends_on:
      - db
  db:
    image: postgres
    environment:
      POSTGRES_PASSWORD: secret
      POSTGRES_DB: mydb
    volumes:
      - pgdata:/var/lib/postgresql/data
volumes:
  pgdata:
```

Step 2: Navigate to the Project Directory

```
cd your-project-folder/
```

Step 3: Run the Environment

```
docker-compose up
```

Or run in detached (background) mode:

```
docker-compose up -d
```

Step 4: Verify Services
Check running containers:
docker ps
Check logs:
docker-compose logs
Step 5: Stop the Environment
docker-compose down
Optional: Build Services Before Running
docker-compose up --build

Best Practices
- Use .env files to manage secrets/configs.
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Conclusion
"Bringing an environment up" is a fundamental practice in containerized development. It abstracts the complexity of running multi-container applications and offers a repeatable, reliable, and scalable method to run entire app stacks from development to CI environments.

Changing a Running Environment

Understanding Environment Changes in Application Deployment

Changing a running environment refers to the process of modifying the configuration, dependencies, or infrastructure of an application while it's operational, often with minimal or zero downtime. This concept is crucial in modern DevOps practices and cloud-native application development.

Key Aspects of Environment Changes:

- **Configuration updates**: Changing environment variables or config files
- **Dependency updates**: Modifying linked services or libraries
- **Infrastructure changes**: Altering the underlying platform or resources
- **Feature toggles**: Enabling/disabling features without redeployment
- **Data migration**: Modifying database schemas or data structures

Real Use Cases with Docker, Spring Boot, and Spring Web MVC

1. Configuration Changes Without Redeployment

- **Scenario**: Your Spring Boot application needs different database credentials between development and production.
- **Solution**: Use environment variables in Docker with Spring's `@Value` annotation.

```
@Value("${db.url}")
private String dbUrl;
```

Docker Command:

```
docker run -e "DB_URL=jdbc:mysql://prod-db:3306/appdb" my-spring-app
```

Change Process:

- Update the environment variable in Docker run or compose file
- For running containers:

```
docker update --env-add DB_URL=jdbc:mysql://new-prod-db:3306/appdb <container_id>
```

- Use Spring's `@RefreshScope` and actuator to reload values without restart

2. Blue-Green Deployment for Zero-Downtime Updates

- **Scenario**: Update your Spring Web MVC application with new features without downtime.
- **Solution**: Use Docker with a reverse proxy (Nginx) to switch traffic.

Docker Compose:

```
version: '3'
services:
  app-blue:
    image: my-spring-app:1.0
    ports:
      - "8080:8080"
  app-green:
    image: my-spring-app:1.1
    ports:
      - "8081:8080"
  nginx:
    image: nginx
    ports:
      - "80:80"
    volumes:
      - ./nginx.conf:/etc/nginx/nginx.conf
```

nginx.conf:

```
upstream backend {
    server app-blue:8080;
    # server app-green:8081; # Uncomment to switch to green
}
```

3. Database Migration During Runtime

- **Scenario**: Schema changes while serving users.
- **Solution**: Use Flyway with Spring Boot in Docker.

Dependency:

```
<dependency>
    <groupId>org.flywaydb</groupId>
    <artifactId>flyway-core</artifactId>
</dependency>
```

application.properties:

```
spring.flyway.url=jdbc:mysql://${DB_HOST}:3306/mydb
spring.flyway.user=${DB_USER}
spring.flyway.password=${DB_PASSWORD}
spring.flyway.locations=classpath:db/migration
```

Docker Compose:

```
services:
  app:
    image: my-spring-app
    environment:
      - DB_HOST=db
      - DB_USER=user
      - DB_PASSWORD=pass
  db:
    image: mysql:5.7
    environment:
      - MYSQL_DATABASE=mydb
      - MYSQL_USER=user
      - MYSQL_PASSWORD=pass
      - MYSQL_ROOT_PASSWORD=rootpass
```

Change Process:

- Add migration scripts
- Deploy container
- Flyway auto-applies migrations

4. Dynamic Feature Toggles

- **Scenario**: Enable a new feature for 10% of users
- **Solution**: Use Spring Cloud Config and Docker

Example Controller:

```
@RestController
@RefreshScope
public class FeatureController {
    @Value("${feature.newCheckout:false}")
    private boolean newCheckoutEnabled;

    @GetMapping("/checkout")
    public String checkout() {
        return newCheckoutEnabled ? "New Checkout" : "Old Checkout";
    }
}
```

Docker Deployment:

```
docker run -e "SPRING_CLOUD_CONFIG_URI=http://config-server:8888" my-spring-app
```

Change Process:

- Update config in Git repo
- Call actuator refresh endpoint:

```
curl -X POST http://container-ip:port/actuator/refresh
```

5. Scaling Spring MVC Applications Horizontally

- **Scenario**: Handle increased traffic
- **Solution**: Use Docker Swarm or Kubernetes

Commands:

```
docker swarm init
docker service create --name spring-app --replicas 3 -p 8080:8080 my-spring-app
docker service scale spring-app=5
docker service update --image my-spring-app:1.1 spring-app
```

Session Configuration:

```
@EnableRedisHttpSession
public class SessionConfig {
    @Bean
    public LettuceConnectionFactory connectionFactory() {
        return new LettuceConnectionFactory();
    }
}
```

Best Practices

- **Immutable Containers**: Build new images
- **Health Checks**: Use `/actuator/health`
- **Externalized Config**: Env vars, ConfigMaps
- **Backward Compatibility**: API & DB changes
- **Rollback Strategy**: Prepare for quick revert
- **Monitoring**: Use tools like Prometheus, ELK

Challenges & Solutions

- **Session Persistence**: Use Spring Session + Redis
- **Database Consistency**: Use Flyway
- **Service Discovery**: Eureka/Kubernetes
- **Config Management**: Spring Cloud Config

By applying these strategies, developers can ensure scalable, flexible, and resilient deployments using Docker and Spring Boot/Web MVC.

Changing a Running Environment: In-Depth Explanation with Real Use Cases

Understanding Environment Changes in Application Deployment

Changing a running environment refers to modifying the configuration, dependencies, or infrastructure of an application while it remains operational, ideally with zero or minimal downtime. This is a critical practice in DevOps and modern cloud-native development.

Key Aspects of Environment Changes

- **Configuration updates**: Modifying environment variables or config files
- **Dependency updates**: Changing linked services or libraries
- **Infrastructure changes**: Updating underlying platform/resources
- **Feature toggles**: Enabling/disabling app features without redeployment
- **Data migration**: Changing database schema/data without downtime

---

Real Use Cases with Docker, Spring Boot, and Spring Web MVC

1. Configuration Changes Without Redeployment

Scenario: Different DB credentials for dev and prod.

Solution: Use Spring's `@Value` with Docker env vars.

```
@Value("${db.url}")
private String dbUrl;
```

Docker:

```
docker run -e "DB_URL=jdbc:mysql://prod-db:3306/appdb" my-spring-app
```

Change Running Container:

```
docker update --env-add DB_URL=jdbc:mysql://new-prod-db:3306/appdb <container_id>
```

Use Spring Actuator `@RefreshScope` to reload values.

---

2. Blue-Green Deployment for Zero-Downtime

Scenario: Push updates without interrupting users.

Approach:

- Run two versions (blue & green)
- Route traffic via Nginx

Docker Compose:

```
version: '3'
services:
  app-blue:
    image: my-spring-app:1.0
    ports:
      - "8080:8080"
  app-green:
    image: my-spring-app:1.1
    ports:
      - "8081:8080"
  nginx:
    image: nginx
    volumes:
      - ./nginx.conf:/etc/nginx/nginx.conf
    ports:
      - "80:80"
```

nginx.conf:

```
upstream backend {
```

```
    server app-blue:8080;
    # server app-green:8081;
}
```

---

3. Database Migration During Runtime

Scenario: Schema updates without stopping service.

Solution: Use Flyway with Docker + Spring Boot

Dependencies:

```
<dependency>
  <groupId>org.flywaydb</groupId>
  <artifactId>flyway-core</artifactId>
</dependency>
```

application.properties:

```
spring.flyway.url=jdbc:mysql://${DB_HOST}:3306/mydb
spring.flyway.user=${DB_USER}
spring.flyway.password=${DB_PASSWORD}
spring.flyway.locations=classpath:db/migration
```

Compose:

```
services:
  app:
    image: my-spring-app
    environment:
      - DB_HOST=db
      - DB_USER=user
      - DB_PASSWORD=pass
  db:
    image: mysql:5.7
    environment:
      - MYSQL_DATABASE=mydb
```

---

4. Dynamic Feature Toggles

Scenario: Enable feature for 10% of users

Solution: Use Spring Cloud Config + `@RefreshScope`

```
@Value("${feature.newCheckout:false}")
private boolean newCheckoutEnabled;
```

Trigger Refresh:

```
curl -X POST http://<ip>:<port>/actuator/refresh
```

---

5. Scaling Spring MVC Applications

Scenario: Handle increased traffic

Solution: Use Docker Swarm

```
docker swarm init
docker service create --name spring-app --replicas 3 -p 8080:8080 my-spring-app
docker service scale spring-app=5
```

Spring Session with Redis:

```
@EnableRedisHttpSession
public class SessionConfig {
  @Bean
  public LettuceConnectionFactory connectionFactory() {
    return new LettuceConnectionFactory();
  }
}
```

Best Practices

- Immutable containers for code changes
- Externalize config
- Implement health checks
- Ensure backward compatibility
- Monitor and log changes

Challenges and Solutions

Challenge	Solution
Session persistence	Use Spring Session + Redis
DB schema updates	Use Flyway + backward compatible SQL
Service discovery	Use Eureka or K8s services
Config consistency	Use Spring Cloud Config

Introspecting On An Environment in Docker (Spring Boot/MVC Applications)

What Is Environment Introspection?

The ability to inspect the configuration, runtime state, and behavior of a Dockerized app to support debugging, security, scaling, and dynamic decisions.

Importance

- Debugging and observability
- Adaptive logic (e.g., based on active profile)

- Security and compliance checks
- Pre-deployment validation

Tools and Techniques

1. Container-Level

```
docker ps
docker inspect <id>
docker logs <id>
docker stats <id>
```

2. Spring Boot Actuator

Expose all endpoints:

```
management.endpoints.web.exposure.include=*
```

Useful endpoints:

- `/actuator/env`
- `/actuator/health`
- `/actuator/info`
- `/actuator/metrics`

3. Network-Level

```
docker network ls
docker network inspect <name>
docker exec -it <container> ping <other>
```

Practical Use Cases

1. Profile-Based Behavior

```
@Value("${spring.profiles.active}")
private String activeProfile;
docker run -e "SPRING_PROFILES_ACTIVE=prod" my-spring-app
```

2. Health-Based Routing

```
HEALTHCHECK CMD curl -f http://localhost:8080/actuator/health || exit 1
```

3. Auto-Scaling with Prometheus

```
management.metrics.export.prometheus.enabled=true
```

4. Security Audits

```
docker exec <container> printenv
curl http://localhost:8080/actuator/env
```

Advanced Introspection Techniques

Custom Endpoints

```
@GetMapping("/api/diagnostics/jvm")
public Map<String, String> getJvmInfo() { ... }
```

Container Metadata

```
@Value("${HOSTNAME:unknown}")
private String containerId;
```

Docker API Integration

```
DockerClient docker = DefaultDockerClient.fromEnv().build();
```

Best Practices for Introspection

- Use least privilege principle
- Secure actuator endpoints
- Document diagnostics interfaces
- Rate limit to prevent abuse
- Log critical observations

By mastering environment change strategies and runtime introspection in Dockerized Spring applications, developers can achieve high availability, observability, and agility across development and production systems.

Taking a Docker Environment Down

Definition

Taking an environment down in Docker refers to stopping and removing the containers, networks, volumes, and other resources that were created when the environment was brought up (typically via `docker-compose up` or similar commands). For MVC (Model-View-Controller) and Boot (Spring Boot) applications, this means stopping the web servers, application servers, databases, and any other services that make up your application stack.

Importance

Taking an environment down is crucial for:

- **Resource management**: Frees up system resources (CPU, memory) when the environment isn't needed
- **Cost optimization**: Stops cloud-based containers that may incur charges
- **Clean development cycles**: Ensures a fresh start when bringing the environment back up
- **Security**: Reduces attack surface when applications aren't actively being used
- **Configuration changes**: Allows for clean implementation of new configurations

When to Take an Environment Down

Consider taking your Docker environment down when:

- You're done with development/testing for the day
- You need to make significant configuration changes
- You're switching between different projects/branches
- The environment has become unstable or containers are misbehaving
- You need to perform system maintenance or upgrades
- Before deploying updates to production (during maintenance windows)

Necessary Precautions During Down Process

- **Data persistence**: Ensure critical data is backed up or stored in persistent volumes
- **Dependency order**: Be aware of shutdown order if manually stopping containers
- **Graceful shutdown**: Allow applications to complete current requests (Spring Boot apps should handle SIGTERM properly)
- **Network considerations**: Understand that taking down will remove default networks
- **Other users**: Check if other team members are using the environment
- **Scheduled jobs**: Consider if any scheduled tasks will be interrupted

How to Take an Environment Down

For a typical Docker Compose setup:

```
docker-compose down
```

Common options:

- `-v` or `--volumes`: Remove named volumes declared in the volumes section
- `--rmi all`: Remove all images used by services
- `-t` or `--timeout`: Set shutdown timeout (default 10s)

For individual containers:

```
docker stop <container_name>
docker rm <container_name>
```

Restarting/Changing Status from Down to Up

To restart your environment:

```
docker-compose up -d
```

For a completely clean start (recommended when changing configurations):

```
docker-compose down -v  # Remove volumes too if needed
docker-compose up -d --build
```

Additional Considerations

- **Stateful vs Stateless**: Databases and other stateful services need special handling
- **Blue-Green Deployment**: In production, consider maintaining uptime with alternate strategies
- **Orchestration tools**: In Kubernetes/OpenShift, concepts differ (pods vs containers)
- **Log preservation**: Ensure important logs are saved before taking down
- **CI/CD pipelines**: Automated pipelines often include down/up cycles

Best Practices

- Always document your down/up procedures
- Use version control for your Docker configurations
- Implement health checks in your containers
- Consider using `docker-compose stop` instead of `down` if you plan to restart soon
- For production, plan downtime windows and notify users

For Spring Boot Applications Specifically:

- Ensure proper shutdown hooks are configured
- Use actuator endpoints for graceful shutdown (`/actuator/shutdown`)
- Consider connection draining if behind a load balancer

Taking an environment down is a routine but essential part of managing Dockerized Spring Boot and MVC applications. Doing it properly ensures clean, secure, and predictable development and deployment workflows.

Docker Swarm:

1. Docker Swarm Overview Docker Swarm is Docker's native clustering and orchestration tool that turns multiple Docker hosts into a single virtual Docker host. It provides:

- Native clustering capabilities (built into Docker Engine)
- Declarative service model
- Scaling and load balancing
- Rolling updates and rollbacks

Practical Definition: Imagine you have 5 servers - Swarm makes them act like one big computer. When you deploy your Spring Boot/MVC app, Swarm decides where to put containers, handles failures, and balances traffic automatically.

---

2. Pre-Swarm Technologies (and Why We Moved Away) Previously Used:

- **Manual Deployment:** SSH into each server, run containers manually
  - *Issues:* Inconsistent deployments, no failover
- **Custom Scripts:** Bash/Python scripts to manage containers
  - *Issues:* Fragile, hard to maintain
- **Other Orchestrators:** Mesos/Marathon, Kubernetes
  - *Issues:* Steep learning curve, overkill for many Java apps

Why Swarm?

- Built into Docker (no extra install)
- Simpler than Kubernetes for typical MVC apps
- Good enough for 80% of use cases

---

3. Why Use Swarm for Boot/MVC Apps?

- **High Availability:** If a node crashes, Swarm restarts containers elsewhere
- **Load Balancing:** Automatic traffic distribution, built-in DNS round-robin
- **Rolling Updates:** Update apps with zero downtime
- docker service update --image new-version
- **Secrets Management:** Secure DB/API keys
- docker secret create db_pass ./password.txt
- **Scalability:**
- docker service scale myapp=5

---

4. Implementation Procedure for Boot/MVC Apps Step 1: Prepare Your Dockerfile

```
FROM openjdk:17-jdk
COPY target/myapp.jar /app.jar
ENTRYPOINT ["java","-jar","/app.jar"]
```

Step 2: Initialize Swarm

```
docker swarm init --advertise-addr <MANAGER_IP>
```

Step 3: Deploy Stack (docker-compose.yml)

```
version: '3.8'
services:
  myapp:
    image: myapp:latest
    ports:
      - "8080:8080"
    deploy:
      replicas: 3
      update_config:
        parallelism: 1
        delay: 10s
```

Step 4: Deploy

```
docker stack deploy -c docker-compose.yml myapp
```

---

5. Key Swarm Commands

Command	Purpose
docker swarm init	Create swarm
docker node ls	List nodes
docker service create	Deploy service
docker service ps <service>	Check tasks
docker service scale <service>=5	Scale out
docker service update --image new-img	Rolling update
docker stack deploy -c file.yml	Deploy full stack

---

6. Common Issues & Solutions Issue 1: Networking Problems

- *Symptom:* Containers can't talk to each other
- *Fix:*

```
docker network create -d overlay mynet
```

Issue 2: Database Connections Exhausted

- *Cause:* Too many Spring Boot replicas hitting DB
- *Solution:* Use connection pooling (HikariCP), add `deploy.endpoint_mode: dnsrr`

Issue 3: Memory Leaks (Java Apps)

- *Prevention:* Set memory limits in compose:

```
deploy:
  resources:
    limits:
      memory: 512M
```

Issue 4: Failed Rollbacks

- *Best Practice:* Always test rollbacks

```
docker service rollback myapp
```

---

7. Developer Benefits

- **Production-Like Testing:** Simulate HA locally with `docker swarm init`
- **Simplified CI/CD:** Same commands work from dev to prod
- **Built-In Observability:**

```
docker service logs -f myapp
```

- **Infrastructure as Code:** Define environments in compose files

Best Practice Tip:

- Set JVM memory limits (`-Xmx`) lower than container memory limits
- Use health checks in your services
- Use structured logging (e.g., JSON format) for better monitoring in Swarm

Docker Swarm for Spring Boot/MVC Applications

1. Why Use Docker Swarm for Spring Boot/MVC Apps? Docker Swarm is ideal for Java web applications because it provides:

- Zero-downtime deployments (critical for production)
- Automatic load balancing across instances
- Self-healing (restarts failed containers)
- Seamless scaling (handle traffic spikes)
- Rolling updates (update apps without downtime)
- Centralized configuration & secrets (DB credentials, API keys)

---

2. Creating a Swarm Cluster for Spring Boot Apps Step 1: Prepare 3 Nodes (1 Manager + 2 Workers)

- Docker installed on all nodes
- Open ports: 2377 (Swarm), 7946 (node communication), 4789 (overlay network)
- Unique hostnames: manager, worker1, worker2

Step 2: Initialize Swarm on Manager

```
# On manager node
docker swarm init --advertise-addr <MANAGER_IP>
# Example
docker swarm init --advertise-addr 192.168.1.100
```

This outputs a join command for workers.

Step 3: Join Workers to Swarm

```
# On worker1 and worker2
docker swarm join --token <TOKEN> <MANAGER_IP>:2377
```

Step 4: Verify Cluster Status

```
# On manager
docker node ls
```

Example Output:

```
ID            HOSTNAME   STATUS  AVAILABILITY   MANAGER STATUS
x1y2z3 *      manager    Ready   Active         Leader
a2b3c4        worker1    Ready   Active
d4e5f6        worker2    Ready   Active
```

---

3. Deploying a Spring Boot/MVC App in Swarm Step 1: Dockerize Your Spring Boot App

```
FROM openjdk:17-jdk-slim
COPY target/myapp.jar /app.jar
ENTRYPOINT ["java", "-jar", "/app.jar"]
EXPOSE 8080
```

Step 2: Build & Push Image

```
docker build -t myapp:latest .
docker tag myapp:latest myregistry/myapp:latest
docker push myregistry/myapp:latest
```

Step 3: Create docker-compose.yml for Swarm

```
version: '3.8'

services:
  app:
    image: myregistry/myapp:latest
    deploy:
      replicas: 3
      update_config:
        parallelism: 1
        delay: 10s
      restart_policy:
        condition: on-failure
    ports:
      - "8080:8080"
    networks:
      - app_net

networks:
  app_net:
    driver: overlay
```

Step 4: Deploy the Stack

```
docker stack deploy -c docker-compose.yml myapp
```

Step 5: Verify Deployment

```
docker service ls
docker service ps myapp_app
```

---

4. Key Swarm Commands for Spring Boot Apps

Command	Purpose
docker service scale myapp_app=5	Scale app to 5 replicas
docker service update --image new-image myapp_app	Rolling update
docker service logs -f myapp_app	View logs
docker service rollback myapp_app	Revert failed update
docker node update --availability drain worker1	Take node offline

---

5. Common Issues & Fixes for Java Apps Issue 1: High Memory Usage (OOM Errors)

- *Fix:*

```
deploy:
  resources:
    limits:
      memory: 1G
```

Issue 2: Database Connection Pool Exhausted

- *Fix:*
  - Use HikariCP
  - Set: spring.datasource.hikari.maximum-pool-size=20

Issue 3: Slow Startup (Health Checks Fail)

- *Fix:*

```
healthcheck:
  test: ["CMD", "curl", "-f", "http://localhost:8080/actuator/health"]
  interval: 10s
  timeout: 5s
  retries: 3
```

Issue 4: Logs Not Centralized

- *Fix:* Use docker service logs or integrate with ELK stack

---

6. Best Practices for Spring Boot in Swarm

- ☑ Use ConfigMaps for application.properties
- ☑ Enable Spring Boot Actuator for health checks
- ☑ Set JVM memory limits (-Xmx) lower than container memory limits
- ☑ Use restart_policy: on-failure
- ☑ Monitor with Prometheus + Grafana

---

7. Alternatives to Docker Swarm

- **Kubernetes:** More complex, better for large-scale systems
- **Nomad:** Lightweight, but fewer features
- **Manual Docker:** No orchestration features

Why Swarm Wins for Most Java Apps?

- ✔ Simpler than Kubernetes
- ✔ Built into Docker (no extra setup)
- ✔ Good enough for 90% of use cases

Final Thoughts Docker Swarm is perfect for Spring Boot/MVC apps needing scalability & high availability without the complexity of Kubernetes.

Next Steps:

- Deploy a sample app
- Test rolling updates using docker service update
- Simulate node failure with docker node rm

Docker Swarm Mode What is Swarm Mode? Swarm Mode is Docker's native clustering and orchestration system built directly into the Docker Engine. It allows you to:

- Create and manage a cluster of Docker nodes (machines)
- Deploy containerized applications as services
- Automatically distribute workloads across nodes
- Handle failures, scaling, and updates seamlessly

2. Key Features of Swarm Mode ✔ Built Into Docker

- No additional installation required (unlike Kubernetes).
- Enabled via `docker swarm init`.

✔ Declarative Service Model

- Define desired state (e.g., "Run 5 replicas of my Spring Boot app").
- Swarm ensures the actual state matches.

✔ Automatic Load Balancing

- Uses Ingress Networking to distribute traffic.
- Built-in DNS-based service discovery.

✔ Self-Healing

- Automatically restarts failed containers.
- Reschedules tasks if a node goes down.

✔ Rolling Updates & Rollbacks

- Deploy new versions without downtime.
- Rollback if something goes wrong.

✔ Secure by Default

- Encrypted communications between nodes.
- Secrets management for sensitive data (e.g., DB passwords).

3. How Swarm Mode Works Cluster Roles:

Role	Responsibility
Manager Nodes	Control the cluster, schedule tasks, maintain state
Worker Nodes	Execute tasks (run containers)

Key Components:

- **Services**: Define how containers should run (e.g., `docker service create`). Can be replicated or global.
- **Tasks**: A single running container (part of a service).
- **Overlay Network**: Allows containers across different nodes to communicate securely.
- **Raft Consensus**: Ensures high availability with multiple manager nodes.

4. Why Use Swarm Mode for Spring Boot/MVC Apps? ☑ Zero-Downtime Deployments:

```
docker service update --image myapp:v2 myapp_service
```

☑ Automatic Scaling:

```
docker service scale myapp_service=5
```

☑ High Availability:

- If a node crashes, Swarm reschedules containers on healthy nodes.

☑ Secrets Management:

```
echo "db_password" | docker secret create db_pass -
```

☑ Load Balancing:

- Swarm routes traffic to all healthy containers.

5. Example: Deploying a Spring Boot App Step 1: Initialize Swarm

```
docker swarm init --advertise-addr <MANAGER_IP>
```

Step 2: Create a Service

```
docker service create \
  --name myapp \
  --replicas 3 \
  --publish 8080:8080 \
  myapp:latest
```

Step 3: Verify

```
docker service ls
docker service ps myapp
```

6. Swarm Mode vs. Kubernetes | Feature | Swarm Mode | Kubernetes | |-----------------|-----------------|-----------------| | Complexity | Simple | Complex | | Setup | Built into Docker| Requires additional components | | Scaling | Easy | More configurable | | Best For | Small/medium apps| Large-scale systems |

Why Choose Swarm Mode?

- ✔ Easier to learn
- ✔ Good enough for most Java apps
- ✔ No extra infrastructure needed

7. Common Swarm Mode Commands | Command | Purpose | |-------------------------------|-----------------------------| | `docker swarm init` | Start a Swarm | | `docker node ls` | List nodes | | `docker service create` | Deploy a service | | `docker service scale` | Scale a service | | `docker service update` | Update a service | | `docker service logs` | View logs | | `docker stack deploy` | Deploy a full stack |
8. When Not to Use Swarm Mode?

- Very large clusters (100+ nodes) → Use Kubernetes.
- Need advanced networking (like Istio).

- Require custom scaling policies.

Final Verdict Swarm Mode is perfect for:

- Small/medium Spring Boot/MVC apps
- Teams that want simplicity
- Projects needing fast deployment

```
docker swarm init
docker service create --name web --publish 80:80 nginx
```

Creating Your First Service and Scaling It Locally in Docker Swarm

Docker Swarm enables you to manage a cluster of Docker nodes and deploy services across them. You can experiment with Swarm's features on a single machine to understand its orchestration capabilities.

Step 1: Initialize Docker Swarm

```
docker swarm init
```

This command initializes Swarm mode and makes your machine a Swarm manager.

Step 2: Create a Service

```
docker service create \
  --name myweb \
  --publish 8080:80 \
  --replicas 1 \
  nginx
```

- `--name myweb`: Name of the service
- `--publish 8080:80`: Maps port 8080 on your machine to port 80 in the container
- `--replicas 1`: Starts with 1 instance of the service
- `nginx`: The container image used

Visit `http://localhost:8080` to check if it's running.

Step 3: Scale the Service

```
docker service scale myweb=3
```

This command increases the number of replicas to 3.

Step 4: Inspect the Service

```
docker service ls
```

Shows all running services.

```
docker service ps myweb
```

Shows details of the `myweb` service and its running containers.

Step 5: View Logs

```
docker service logs -f myweb
```

This will stream logs from all replicas of the service.

Step 6: Remove the Service

```
docker service rm myweb
```

Cleans up the service and associated containers.

Why Practice Locally?

- Learn core Swarm features
- Simulate scaling and load balancing
- Practice deployment, updates, and failures before production

---

Docker Swarm Basic Features & Practical Workflow Integration

1. Core Features of Docker Swarm

- Service Scaling

  - Runs multiple identical containers (replicas) of your app
  - Automatically distributes them across nodes
  - **Command:** `docker service scale myapp=5`
  - **Use Cases:** Handling traffic spikes, expanding capacity after adding worker nodes

- Rolling Updates

  - Updates containers with zero downtime
  - **Command:**
  - `docker service update \`
  - `  --image myregistry/spring-app:v2 \`
  - `  --update-parallelism 2 \`
  - `  --update-delay 10s \`
  - `  myapp`
  - **Best Practices:** Test updates in staging; use health checks

- Self-Healing

  - Restarts failed containers automatically
  - Reschedules on healthy nodes if host fails
  - **No manual intervention needed**

🔹 Load Balancing

- Distributes traffic evenly using built-in DNS-based service discovery
- **Compose Example:**
- `services:`
- `  app:`
- `    image: myapp`
- `    ports:`
- `      - "8080:8080"`
- `    deploy:`
- `      endpoint_mode: vip`

🔹 Secrets Management

- Securely handles credentials (e.g., DB passwords)
- **Command:**
- `echo "dbpassword123" | docker secret create db_pass -`
- **Integration:** Secrets appear in `/run/secrets/<secret_name>`

2. Practical Workflow Integration

📚 Development Phase

```
docker swarm init
docker stack deploy -c docker-compose.yml dev
```

🏐 CI/CD Pipeline

```
docker build -t myapp:$BUILD_NUMBER .
docker push myapp:$BUILD_NUMBER
docker service update --image myapp:$BUILD_NUMBER prod_app
```

🌐 Production Maintenance

```
docker node update --availability drain worker1
docker service ps prod_app
```

3. Essential Swarm Commands | Command | Purpose | Example | |--------|---------|---------| | docker node ls | Check cluster status | docker node ls | | docker service logs | View logs | docker service logs -f myapp | | docker service inspect | Debug services | docker service inspect myapp | | docker node promote | Promote to manager | docker node promote worker2 | | docker stack deploy | Full deployment | docker stack deploy -c prod.yml myapp |
4. Common Workflow Scenarios

🔹 Scenario 1: Deploy Spring Boot App

```
docker swarm init --advertise-addr 192.168.1.100
docker stack deploy -c docker-compose.yml myapp
docker service ls
```

🔹 Scenario 2: Handle Node Failure

```
docker node ls
docker node rm --force worker3
docker swarm join-token worker
```

- Scenario 3: Blue-Green Deployment

```
docker service create --name myapp_v2 --publish 8081:8080 myapp:v2
curl http://localhost:8081/health
docker service update --publish-rm 8080:8080 --publish-add 8080:8080 myapp_v2
```

5. Pro Tips for Java Developers

- JVM Memory Settings

```
ENTRYPOINT ["java", "-Xmx512m", "-jar", "/app.jar"]
```

- Health Checks

```
healthcheck:
  test: ["CMD", "curl", "-f", "http://localhost:8080/actuator/health"]
  interval: 30s
  timeout: 10s
```

- Logging

```
logging.pattern.console=%d{ISO8601} %-5level [%thread] %logger : %msg%n
```

6. Troubleshooting Checklist | Issue | Command | |-------|---------| | Containers not starting | docker service ps --no-trunc myapp | | Network problems | docker network inspect myapp_net | | High memory usage | docker stats | | Update stuck | docker service rollback myapp |
7. Final Recommendation Start with these in your workflow:

- Service scaling with `docker service scale`
- CI/CD via `docker service update`
- Secrets handling
- Health checks for Spring Boot

Next Steps:

- Try a zero-downtime deployment
- Test `docker service update --force` for rollback simulation

Docker Swarm: Scaling Out with Overlay Networking

What is Overlay Networking?

Overlay networking in Docker Swarm allows containers running on different Docker nodes to communicate with each other over a virtual, secure network. It's critical for enabling microservices and distributed applications.

---

1. Why Use Overlay Networking?

- Allows services to communicate across nodes
- Ensures traffic is encrypted and isolated
- Provides service discovery via built-in DNS
- Required for scaling services across multiple hosts

---

2. Creating an Overlay Network

Create an overlay network before deploying services:

```
docker network create \
  --driver overlay \
  --attachable \
  my_overlay_net
```

- `--driver overlay`: Specifies use of overlay driver
- `--attachable`: Allows containers to join the network manually (e.g., for testing)

---

3. Using Overlay Network in docker-compose.yml

```
version: '3.8'

services:
  app:
    image: myapp:latest
    deploy:
      replicas: 3
    networks:
      - my_overlay_net
    ports:
      - "8080:8080"

networks:
  my_overlay_net:
    external: true
```

- The service will join the overlay network
- Ensure the network is created before deploying the stack

---

4. Scaling Out Services

```
docker service scale app=5
```

- Distributes containers (replicas) across available nodes
- Overlay network allows seamless communication between all instances

---

5. Verifying Connectivity Between Containers

```
# Enter a container shell
docker exec -it $(docker ps -q -f name=app) sh

# Test connection to another service
ping db
```

- Use service names instead of IP addresses (DNS-based service discovery)

---

6. Benefits for Spring Boot/MVC Apps

- Easy horizontal scaling (add more app replicas)
- Transparent communication between services (e.g., web ↔ database)
- High availability and fault tolerance
- Simplified networking configuration

Summary

Overlay networking is essential for distributed applications in Swarm. It allows Spring Boot and MVC-based microservices to scale out across multiple nodes while maintaining secure and consistent communication.

Next Step: Try deploying a multi-service Java app using overlay networks and scale it using `docker service scale`.

Multi-Service, Multi-Node Web App using Spring Boot & Docker

✨ Overview

A guide to building a multi-service architecture with Spring Boot (MVC/REST), containerized using Docker, and orchestrated via Docker Compose.

Services:

- **API Gateway** (Spring Cloud Gateway)
- **User Service** (Spring Boot MVC)
- **Product Service** (Spring Boot MVC)
- **MySQL Database**

🗁 Project Structure

```
multi-service-app/
|
|-- api-gateway/
|-- user-service/
|-- product-service/
|-- docker-compose.yml
|-- .env (optional)
```

---

1. ✨ Spring Boot App Creation

Use Spring Initializr to generate three Spring Boot apps:

Common Dependencies:

- Spring Web
- Spring Boot DevTools
- Spring Data JPA
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- Spring Cloud Gateway (only for API Gateway)

---

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Entity - `User.java`

```
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    @GeneratedValue(strategy = GenerationType.IDENTITY)
    private Long id;
    private String name;
    private String email;
}
```

Repository - `UserRepository.java`

```
public interface UserRepository extends JpaRepository<User, Long> {}
```

Controller - `UserController.java`

```
@RestController
@RequestMapping("/users")
public class UserController {
    @Autowired
    private UserRepository userRepository;

    @GetMapping
    public List<User> getAllUsers() {
        return userRepository.findAll();
    }

    @PostMapping
    public User addUser(@RequestBody User user) {
        return userRepository.save(user);
    }
}
```

`application.properties`

```
spring.datasource.url=jdbc:mysql://mysql-db:3306/userdb
spring.datasource.username=root
spring.datasource.password=pass
spring.jpa.hibernate.ddl-auto=update
server.port=8081
```

---

3. Product Service

Structure it similarly to User Service with a Product entity, repository, and controller.

Change `server.port` to `8082` and use `productdb` as the DB name.

---

4. API Gateway

`application.yml`

```
server:
  port: 8080

spring:
  cloud:
    gateway:
      routes:
        - id: user-service
          uri: http://user-service:8081
          predicates:
            - Path=/users/**
        - id: product-service
          uri: http://product-service:8082
          predicates:
            - Path=/products/**
```

Main Class

```
@SpringBootApplication
public class ApiGatewayApplication {
    public static void main(String[] args) {
        SpringApplication.run(ApiGatewayApplication.class, args);
```

```
    }
}
```

---

5. Docker Setup

Dockerfile for each service

```
FROM openjdk:17-jdk-alpine
VOLUME /tmp
ARG JAR_FILE=target/*.jar
COPY ${JAR_FILE} app.jar
ENTRYPOINT ["java","-jar","/app.jar"]
```

docker-compose.yml

```
version: '3.8'
services:

  mysql-db:
    image: mysql:8
    environment:
      MYSQL_ROOT_PASSWORD: pass
      MYSQL_DATABASE: userdb
    ports:
      - "3306:3306"

  user-service:
    build: ./user-service
    ports:
      - "8081:8081"
    depends_on:
      - mysql-db

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    build: ./product-service
    ports:
      - "8082:8082"
    depends_on:
      - mysql-db

  api-gateway:
    build: ./api-gateway
    ports:
      - "8080:8080"
    depends_on:
      - user-service
      - product-service
```

---

6. Build & Run

Build All JARs:

```
mvn clean package
```

Run with Docker Compose:

```
docker-compose up --build
```

🌐 Accessing Services

- API Gateway: `http://localhost:8080`
- User Service: `http://localhost:8080/users`
- Product Service: `http://localhost:8080/products`

🚀 Extend Further

- Add service discovery with Eureka
- Add security with Spring Security / OAuth2
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}
```

`application.properties`

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---

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```
server:
  port: 8080

spring:
  cloud:
    gateway:
      routes:
        - id: user-service
          uri: http://user-service:8081
          predicates:
            - Path=/users/**
        - id: product-service
          uri: http://product-service:8082
          predicates:
            - Path=/products/**
```

Main Class

```
@SpringBootApplication
public class ApiGatewayApplication {
    public static void main(String[] args) {
        SpringApplication.run(ApiGatewayApplication.class, args);
```

```
    }
}
```

---

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Dockerfile for each service

```
FROM openjdk:17-jdk-alpine
VOLUME /tmp
ARG JAR_FILE=target/*.jar
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docker-compose.yml

```
version: '3.8'
services:

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    image: mysql:8
    environment:
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      MYSQL_DATABASE: userdb
    ports:
      - "3306:3306"

  user-service:
    build: ./user-service
    ports:
      - "8081:8081"
    depends_on:
      - mysql-db

  product-service:
    build: ./product-service
    ports:
      - "8082:8082"
    depends_on:
      - mysql-db

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    build: ./api-gateway
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📌 Service Placement Preference: Boot vs. MVC

1. Boot (Application Startup) Placement

Centralizes service registration and configuration at the application's startup.

Characteristics:

- All services registered in `Program.cs` (or `Startup.cs`)
- Centralized configuration at startup
- Uses extension methods for organization

Example (.NET Core):

```
// In Program.cs
var builder = WebApplication.CreateBuilder(args);

builder.Services.AddControllers();
builder.Services.AddDbContext<AppDbContext>(options =>
    options.UseSqlServer(builder.Configuration.GetConnectionString("Default")));
builder.Services.AddScoped<IUserService, UserService>();
builder.Services.AddTransient<IEmailService, EmailService>();
```

Advantages:

- Centralized visibility of dependencies
- Easier auditing and modification
- Consistent configuration
- Simplifies dependency injection

Disadvantages:

- Becomes bloated in large apps
- Reduces modularity
- Tight startup coupling

2. MVC (Model-View-Controller) Placement

Distributes service registration across modules or features.

Characteristics:

- Services are registered per feature
- Modular and organized
- Uses extension methods per module

Example:

```
// UserModule.cs
public static class UserModuleServices
{
    public static IServiceCollection AddUserServices(this IServiceCollection services)
    {
        services.AddScoped<IUserService, UserService>();
        services.AddScoped<IUserRepository, UserRepository>();
        return services;
    }
}

// Program.cs
builder.Services.AddUserServices();
```

Advantages:

- Clear separation of concerns
- Better modularity
- Independent feature development
- Easier maintenance in large apps

Disadvantages:

- Harder to track all registrations
- Risk of duplication
- More complex dependencies

When to Use Which

Use Boot Placement when:

- App is small or medium-sized
- You need centralized control
- Architecture is simple
- Team is small

Use MVC Placement when:

- App is large or modular
- Microservice architecture
- Independent feature teams
- Isolation is critical

Hybrid Approach

Most real-world apps use both:

```
// Program.cs
builder.Services.AddInfrastructureServices(config);
builder.Services.AddFeatureA();
builder.Services.AddFeatureB();
```

This provides centralized control for core services and modularity for features.

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```

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---

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builder.Services.AddFeatureB();
```

This provides centralized control for core services and modularity for features.

Node Availability in Docker Swarm

Node availability in Docker Swarm refers to how worker and manager nodes participate in the swarm cluster and how their status affects service deployment and operation.

Types of Node Availability

1. Active (Available)

- Node participates fully in the swarm
- Can run tasks assigned by manager
- Receives health checks
- Ideal for normal operations

2. Paused

- Temporarily removed from scheduling
- Existing tasks continue to run
- No new tasks scheduled
- Use for maintenance without full removal

```
docker node update --availability pause <NODE>
```

3. Drain

- Removed from scheduling entirely
- Running tasks are stopped and moved
- No new tasks scheduled
- Useful for zero-downtime maintenance

```
docker node update --availability drain <NODE>
```

How Availability Affects Services

- **Service Deployment:** Only active nodes receive new tasks
- **Replica Management:** Swarm reschedules tasks to maintain replicas
- **Rolling Updates:** Updates occur only on available nodes

Checking Availability

```
docker node ls
```

Example Output:

```
ID            HOSTNAME   STATUS    AVAILABILITY   MANAGER STATUS
x1y2z3 *      manager1   Ready     Active         Leader
a2b3c4        worker1    Ready     Active
d5e6f7        worker2    Ready     Paused
g8h9i0        worker3    Ready     Drain
```

Common Use Cases

Maintenance Mode

```
# Prepare for maintenance
docker node update --availability drain worker1

# After maintenance
docker node update --availability active worker1
```

Troubleshooting

```
# Pause problematic node
docker node update --availability pause worker2
```

Load Management

```
# Stop new task assignments
docker node update --availability pause worker3
```

Important Notes

- Manager nodes should usually stay "Active" to maintain quorum
- Availability is separate from node status (e.g., Ready, Down)
- Use "Drain" for zero-downtime upgrades
- Nodes in "Paused" or "Drain" are skipped for deployments

Understanding node availability helps ensure smooth updates, maintenance, and high availability in Docker Swarm clusters.