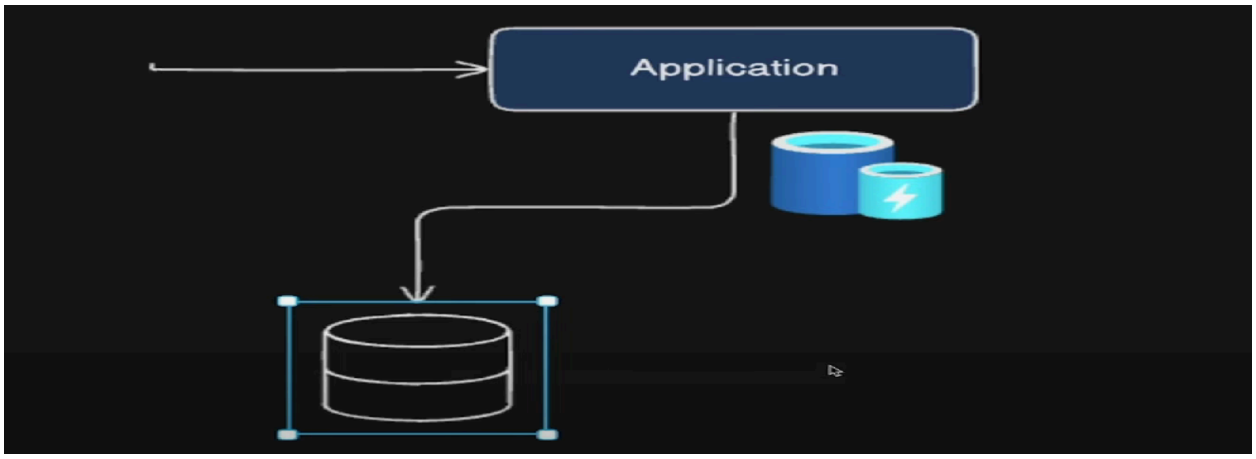
Spring Boot Caching , Hibernate Caching and Spring API Gateway

Spring Boot Caching

Caching is a **mechanism to store frequently accessed data** (like database results, API responses, etc.) in memory (or other fast-access stores).

A **cache** is a **temporary storage** that sits between your **app** and the **database** or **service** (or another service).
It saves **recent or frequently used data** so that when the same data is needed again, it can be returned **faster** without asking the database again.



Advantages of Caching

- **Decreases database load :** Since frequently requested data comes from cache, it reduces the number of expensive database queries**.**
- **Improves Performance :** Cache provides data directly from memory, avoiding the need to contact the database or external service, making it much quicker**.**
- **Increases Application Scalability :** With reduced backend load, the system can handle more users and requests without slowing down.
- **Speeds Up Response Time :** Users get faster results because the app avoids recalculating or reloading data.

Types of Caching

1. In-Memory Caching

Cache is stored **locally inside the application's JVM memory**.
Works well for **single-instance** or **monolithic applications**. Fast access and easy to use.

How it works:

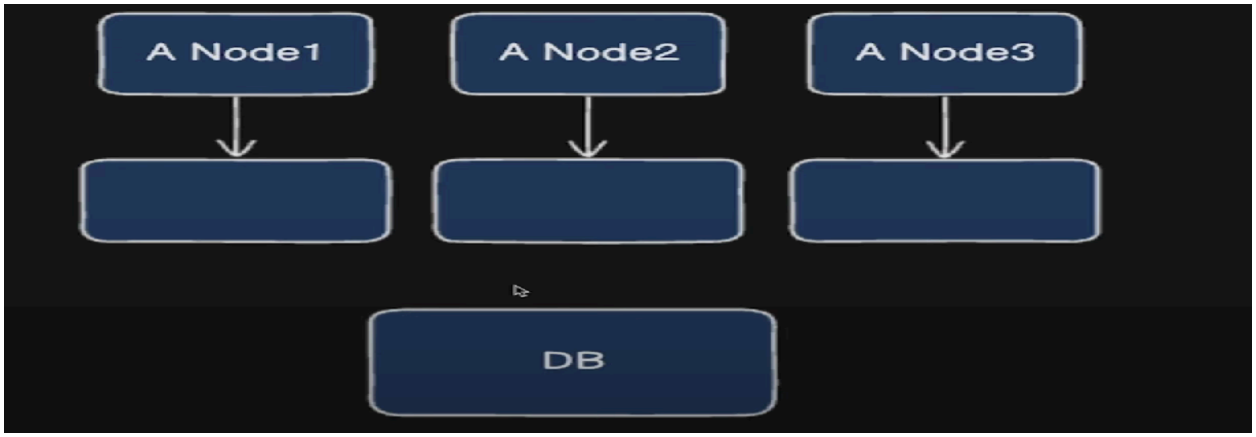
- Most frequently accessed data is stored in memory.
- When a method is called, it first checks if the result is already in the cache.
- If yes, it returns it instantly. If not, it executes the method and stores the result in cache.

Use case: Best for small-to-medium-sized data that changes infrequently and needs fast access.

Spring Boot's default cache type is **SimpleCache**, which uses ConcurrentHashMap

⚠️ Problem with In-Memory Cache:

Problem	Why it matters
❌ Not shared across instances	Each instance of your app has its **own separate memory cache.**
❌ Cache lost on restart	If the app restarts, the cache is gone.
❌ Not scalable	Doesn't work well in **multi-server or cloud environments.**



- You have **3 application nodes**: A Node1, A Node2, and A Node3
- Each node has **its own local in-memory cache**
- All nodes are connected to the **same DB**

❌ **Problem:**

- Cache is **not shared** across nodes.
- If Node1 caches a student, and the next request goes to Node2, it **won't find it in its local cache**, causing a **DB hit again**.
- This results in **redundant DB queries**, **higher latency**, and **wasted memory**.

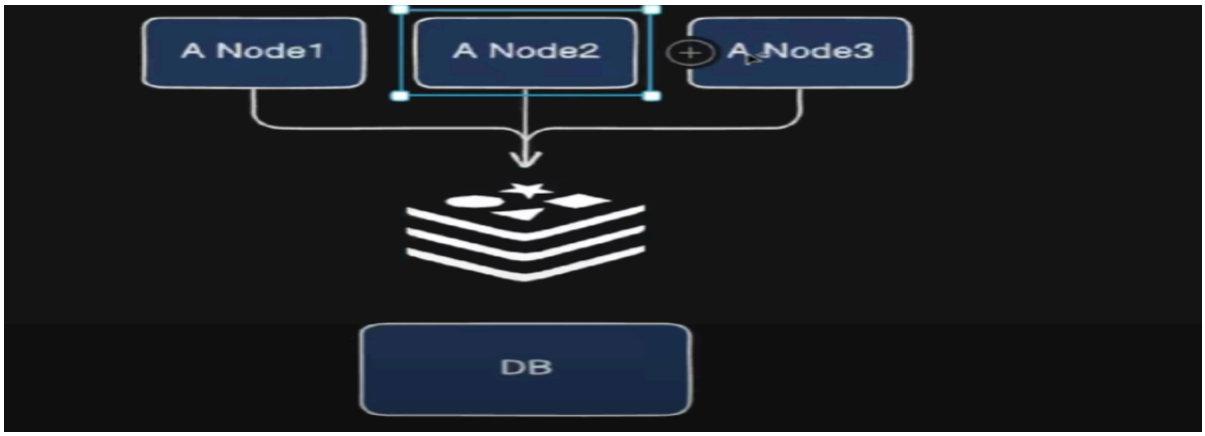
2. Distributed Caching

Cache is stored outside the application in a distributed system (like a separate server or cluster), accessible by multiple instances of the app.

Examples:

- **Redis**
- **Memcached**

Use case: Best for **large-scale applications** with multiple servers or microservices.



All 3 nodes: A Node1, A Node2, A Node3 are **connected to a single shared Redis cache**

Redis is used as the **central distributed cache**

Advantages:

- Cached data is **shared between all app nodes**
- If Node1 caches a student, Node2 and Node3 can also **read that same data**
- **Improved performance**
- **Less load on the DB**
- **Scales well in cloud and microservices environments**

How to Enable Caching in Spring Boot (In-Memory Caching)

1. Add Dependency

If you're using **Spring Boot Starter**, it's often already included.

```
<dependency>
        <groupId>org.springframework.boot</groupId>
        <artifactId>spring-boot-starter-web</artifactId>
</dependency>
```

Otherwise:

```
<!-- Add in pom.xml -->
<dependency>
   <groupId>org.springframework.boot</groupId>
   <artifactId>spring-boot-starter-cache</artifactId>
</dependency>
```

2. Enable Caching in Main Application

EnableCaching is a Spring annotation used to enable caching support across the entire application.

Without it, annotations like @Cacheable, @CachePut, and @CacheEvict **won't have any effect**.

```
@SpringBootApplication
@EnableCaching
public class CollegeManagementApplication {
	public static void main(String[] args) {
		SpringApplication.run(CollegeManagementApplication.class, args);
	}
}
```

3. Use @Cacheable to Cache Method Results

@Cacheable is a Spring annotation that stores the result of a method (like a database call) in cache, so the next time the method is called with the same input, the cached result is returned instead of fetching from the database again.

```
@Cacheable(value = "studentByName", key = "#name")
	public List<Student> findByName(String name) {
		List<Student> std =
studentRepository.findByNameContainingIgnoreCase(name);
		if (std.isEmpty()) {
			throw new StudentsNotFoundException("No Students found in the
database.");
		}
		return std;
	}

@Cacheable(value = "students")
	public List<Student> getAllStudents() {
		List<Student> std = studentRepository.findAll();
		if (std.isEmpty()) {
			throw new StudentsNotFoundException("No Students found in the
database.");
		}
		return std;
	}
```

```
	@Cacheable(value = "studentById", key = "#id")
	public Student getStudentById(Long id) {
		Student std = studentRepository.findById(id)
				.orElseThrow(() -> new StudentNotFoundException("Student with
ID " + id + " not found."));
		return std;
	}
```

4. Use @CacheEvict to Remove Cache When Updating

@CacheEvict tells Spring to **remove entries from the cache**.

This annotation tells Spring **"remove entries from the cache"** when this method runs.

Case-1 : **It removes only the entry for that id**.

```
@CacheEvict(value = "students", key = "#id")
```

This **evicts (removes) only one entry** from the students cache based on the key.

If you're caching **students by ID**, like this:

```
@Cacheable(value = "students", key = "#id")
public Student getStudentById(Long id) { ... }
```

Then you can use:

```
@CacheEvict(value = "students", key = "#id")
public void updateStudent(Long id, Student student) { ... }
```

Case-2: **Remove all entries from these caches.**

```
@CacheEvict(value = { "studentById", "students", "studentByName" }, allEntries = true)
	public String deleteStudent(Long id) {
		Student std = studentRepository.findById(id)
				.orElseThrow(() -> new StudentNotFoundException("Student with
ID " + id + " not found."));
		studentRepository.deleteById(std.getId());
		return "Student with ID " + id + " deleted";
	}
```

These are the **names of the caches** that we want to evict from.

You're using **three separate caches** elsewhere in your service:

Cache Name	Where Used
`"studentById"`	Caches result of `getStudentById(Long id)`
`"students"`	Caches result of `getAllStudents()`
`"studentByName"`	Caches result of `findByName(String name)`

So here, you're saying:

> "Clear all the entries in the above three caches."

allEntries = true

By default, Spring evicts a **single key** from the cache. But with allEntries = true, you're telling it:

"Remove all entries from these caches."

5. Use @CachePut to Update Cache Along with DB

@CachePut tells Spring to **execute the method and update the cache** with the return value.

To **update the cache with new values**, typically used in **update operations**.

Case-1 : It removes **only** the entry for that id.

```
@CachePut(value = "products", key = "#product.id")
public Product updateProduct(Product product) {

  return product;
}
```

case-2

```
@CachePut(value = "studentById", key = "#id")
	@CacheEvict(value = {"students", "studentByName"}, allEntries = true)
	public Student updateStudent(Long id, Student updatedStudent) {
		Student std = studentRepository.findById(id)
				.orElseThrow(() -> new StudentNotFoundException("Student with
ID " + id + " not found."));
		std.setName(updatedStudent.getName());
		std.setAge(updatedStudent.getAge());
		std.setAddress(updatedStudent.getAddress());
		return studentRepository.save(std);
	}
```

You **update the cache for the specific student**.

You **clear list and search caches**, which are now invalid due to the update.

Simple Steps to Check Cache Behavior

Step 1: Add a Print Statement in Your Cached Method

```
@Cacheable(value = "studentById", key = "#id")
	public Student getStudentById(Long id) {
		 System.out.println("Fetching from DB for ID: " + id);
		Student std = studentRepository.findById(id)
				.orElseThrow(() -> new StudentNotFoundException("Student with
ID " + id + " not found."));
		return std;
	}
```

Step 2: Call the API Endpoint Twice

For example:

First call (cache miss or DB hit): http://localhost:8091/CollegeManagement/api/students/1

```java
    @Cacheable(value = "studentById", key = "#id")
    public Student getStudentById(Long id) {
         System.out.println("Fetching from DB for ID: " + id);
        Student std = studentRepository.findById(id)
                .orElseThrow(() -> new StudentNotFoundException("Student with ID " + id + " not fou
        return std;
    }
```

Problems Javadoc Declaration Console

```
CollegeManagementApplication [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe  (19-Jun-2025, 9:20:28 pm) [pid: 23480]
2025-06-19T21:20:36.884+05:30  INFO 23480 --- [  restartedMain] o.s.b.w.embedded.tomcat.TomcatWebServer
2025-06-19T21:20:36.895+05:30  INFO 23480 --- [  restartedMain] c.s.p.CollegeManagementApplication
2025-06-19T21:21:00.365+05:30  INFO 23480 --- [nio-8091-exec-2] o.a.c.c.C.[.[.[/CollegeManagement]
2025-06-19T21:21:00.365+05:30  INFO 23480 --- [nio-8091-exec-2] o.s.web.servlet.DispatcherServlet
2025-06-19T21:21:00.370+05:30  INFO 23480 --- [nio-8091-exec-2] o.s.web.servlet.DispatcherServlet
2025-06-19T21:21:00.981+05:30  INFO 23480 --- [nio-8091-exec-9] o.springdoc.api.AbstractOpenApiResource
Fetching from DB for ID: 1
```

Second call (cache hit): http://localhost:8091/CollegeManagement/api/students/1

```java
    @Cacheable(value = "studentById", key = "#id")
    public Student getStudentById(Long id) {
         System.out.println("Fetching from DB for ID: " + id);
        Student std = studentRepository.findById(id)
                .orElseThrow(() -> new StudentNotFoundException("Student with ID " + id + " not found."));
        return std;
    }
```

Problems Javadoc Declaration Console

```
CollegeManagementApplication [Java Application] C:\Program Files\Java\jdk-17.0.5\bin\javaw.exe  (19-Jun-2025, 9:20:28 pm) [pid: 23480]
2025-06-19T21:20:36.895+05:30  INFO 23480 --- [  restartedMain] c.s.p.CollegeManagementApplication       : Started
2025-06-19T21:21:00.365+05:30  INFO 23480 --- [nio-8091-exec-2] o.a.c.c.C.[.[.[/CollegeManagement]       : Initiali
2025-06-19T21:21:00.365+05:30  INFO 23480 --- [nio-8091-exec-2] o.s.web.servlet.DispatcherServlet        : Initiali
2025-06-19T21:21:00.370+05:30  INFO 23480 --- [nio-8091-exec-2] o.s.web.servlet.DispatcherServlet        : Complete
2025-06-19T21:21:00.981+05:30  INFO 23480 --- [nio-8091-exec-9] o.springdoc.api.AbstractOpenApiResource  : Init dur
Fetching from DB for ID: 1
Fetching from DB for ID: 2
```

You **will NOT** see the print statement.

This means the method was skipped → result returned from **cache**.

Distributed Caching

Spring Boot uses in-memory caching by default unless specified otherwise.

You can use **Redis as a distributed cache** with the same annotations: @Cacheable, @CachePut, and @CacheEvict.

To switch to Redis, simply:

1. Add the Redis dependency

```
<dependency>
   <groupId>org.springframework.boot</groupId>
   <artifactId>spring-boot-starter-data-redis</artifactId>
</dependency>
```

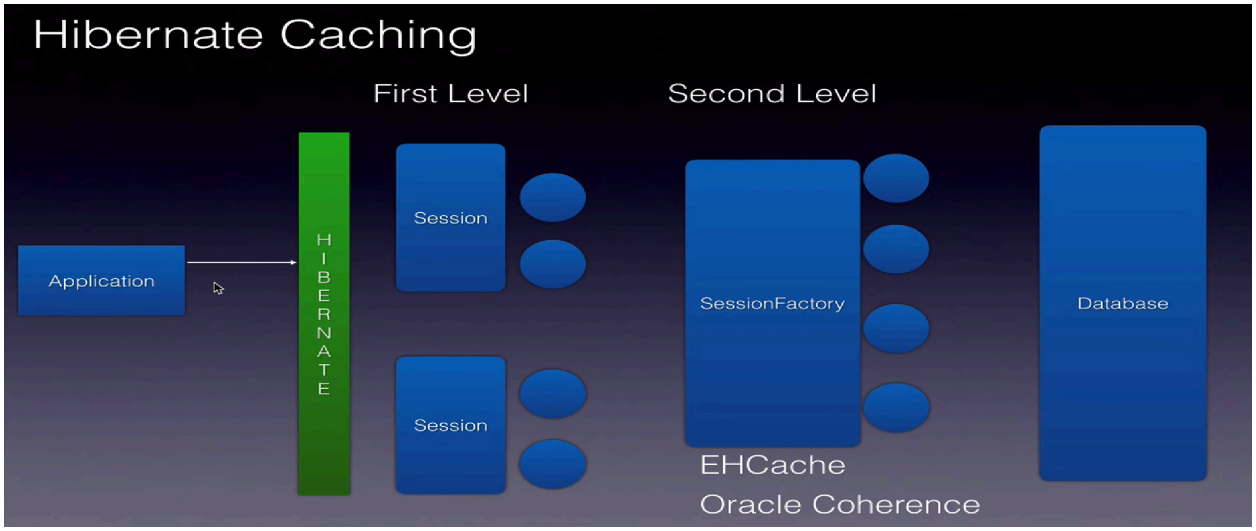
2. Configure the following in application.properties:

```
spring.cache.type=redis
spring.redis.host=localhost
spring.redis.port=6379
```

Hibernate Caching

Hibernate provides **built-in caching** to improve performance by **reducing database hits** for entity data.

Hibernate Caching is a mechanism used to reduce the number of database queries by storing frequently accessed data in memory. This improves application performance by minimizing costly database calls.



Hibernate offers **two levels of caching**:

1. First-Level Cache (L1 Cache)

- **Enabled by default**.
- Associated with the **Hibernate Session**.
- Data is cached **per session**.
- Cleared when the session is closed.

Example:

```
Session session = sessionFactory.openSession();

Student student1 = session.get(Student.class, 1); // Query goes to DB
Student student2 = session.get(Student.class, 1); // Data comes from cache

session.close();
```

The second get() call doesn't hit the database—it retrieves from the **session's cache**.

If I want to use first level cache in spring boot application

```
//first level cache example code in service layer
        @Transactional
        public void demonstrateFirstLevelCache(Long id) {
           System.out.println("1st call to findById:");
           Student student1 = studentRepository.findById(id).orElse(null); // Hits DB
           System.out.println("2nd call to findById:");
           Student student2 = studentRepository.findById(id).orElse(null); // Served from L1
Cache
           System.out.println("Are both objects same? " + (student1 == student2));
        }

//first level cache example code in controller
@GetMapping("/students/cache/test/{id}")
        public void testFirstLevelCache(@PathVariable Long id) {
           studentService.demonstrateFirstLevelCache(id);
        }
```

2. Second-Level Cache (L2 Cache)

- **Optional**: Not enabled by default.
- Works **across sessions**.
- Requires **explicit configuration** and **external caching provider** (like Ehcache, Infinispan, Redis, etc.).
- Caches entities, collections, queries, etc.

Configuration Steps:

1. **Enable second-level cache** in hibernate.cfg.xml or application.properties.
2. Choose a cache provider (e.g., Ehcache).
3. Annotate or configure your entities to be cacheable.

Example using Ehcache:

a. Maven dependencies:

```
<dependency>
 <groupId>org.hibernate</groupId>
 <artifactId>hibernate-ehcache</artifactId>
 <version>5.6.15.Final</version> <!-- Use the version compatible with your Hibernate version
-->
</dependency>
```

b. Configuration in hibernate.cfg.xml:

```
<property name="hibernate.cache.use_second_level_cache">true</property>
<property name="hibernate.cache.region.factory_class">
  org.hibernate.cache.ehcache.EhCacheRegionFactory
</property>
```

c. Entity Setup:

```
@Entity
@Cacheable
@org.hibernate.annotations.Cache(usage = CacheConcurrencyStrategy.READ_WRITE)
public class Student {
 @Id
 private int id;
 private String name;
 // other fields
}
```

✅ **CacheConcurrencyStrategy options:**

- **READ_ONLY** – good for reference data; no updates allowed.
- **READ_WRITE** – allows updates; uses a strategy to prevent stale data.
- **NONSTRICT_READ_WRITE** – allows updates, no strict locking.
- **TRANSACTIONAL** – for JTA and transactional caching.

If I want to use second level cache in spring boot application

1. Add Ehcache (or another provider) to pom.xml

```
<dependency>
 <groupId>org.hibernate</groupId>
 <artifactId>hibernate-ehcache</artifactId>
 <version>5.6.15.Final</version> <!-- Use the version compatible with your Hibernate version
-->
</dependency>
```

2. Enable Hibernate L2 Cache in application.properties

```
# Enable Hibernate second-level cache
spring.jpa.properties.hibernate.cache.use_second_level_cache=true
spring.jpa.properties.hibernate.cache.use_query_cache=true
# Set Ehcache as the cache provider
spring.jpa.properties.hibernate.cache.region.factory_class=org.hibernate.cache.ehcache.EhCache
RegionFactory
# Optional: show SQL logs
spring.jpa.show-sql=true
spring.jpa.properties.hibernate.format_sql=true
```

3. Add ehcache.xml to resources/ folder

```
<ehcache xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="http://ehcache.org/ehcache.xsd">
  <defaultCache
     maxEntriesLocalHeap="1000"
     eternal="false"
     timeToIdleSeconds="120"
     timeToLiveSeconds="300"
     overflowToDisk="false" />
  <cache name="com.spring.project.entity.Student"
        maxEntriesLocalHeap="500"
        eternal="false"
        timeToIdleSeconds="120"
        timeToLiveSeconds="300"
        overflowToDisk="false" />
</ehcache>
```

4. Make Student Entity Cacheable

```
@Entity
@Table(name = "student_table")
@Data
@NoArgsConstructor
@AllArgsConstructor
@Cacheable
@Cache(usage = CacheConcurrencyStrategy.READ_WRITE)
public class Student {
        @Id
```

```
    @GeneratedValue(strategy = GenerationType.IDENTITY)
    private Long id;
    private String name;
    private int age;
    private String address;
}
```

API Gateway

What is an API Gateway?

An **API Gateway** is like the **front door** for all your backend microservices.

- It sits **between clients (web, mobile, etc.) and microservices**.
- Clients don't call microservices directly → Instead, they call the **Gateway**, and it forwards requests to the correct service.
- It provides **centralized features**:
    - Routing (send request to right microservice)
    - Load balancing
    - Security (authentication/authorization)
    - Rate limiting (avoid overload)
    - Logging & monitoring
    - Request/response transformations

Before and After API Gateway

🟠 **Before API Gateway (Direct Communication)**

Client → User Service (http://localhost:8081/users)
Client → Order Service (http://localhost:8082/orders)
Client → Payment Service (http://localhost:8083/payments)

Problems:

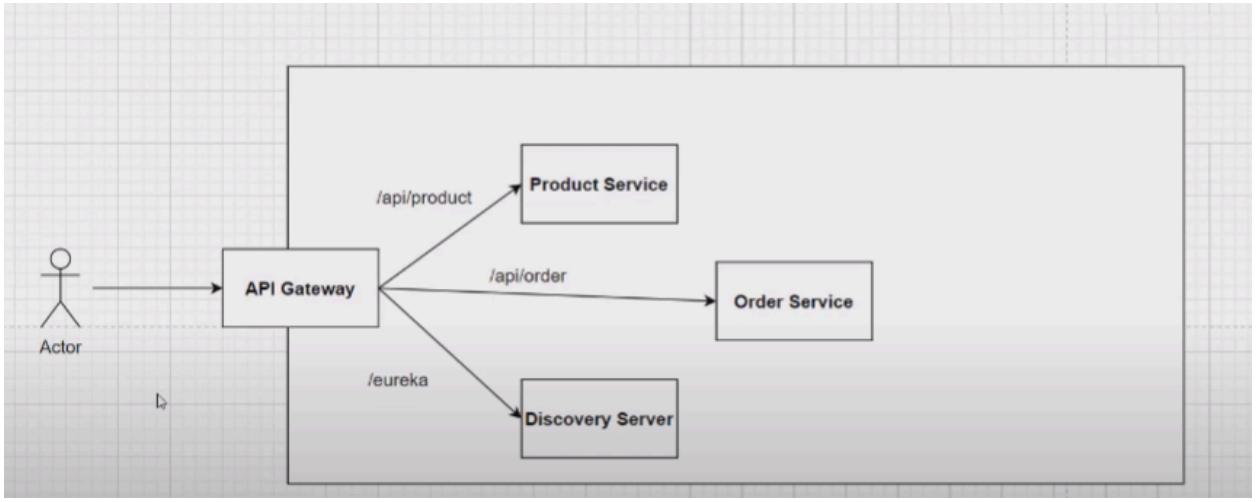
- Clients must know all microservice URLs.
- Hard to manage changes (if a service port changes, client must update).
- No centralized logging/security.

After API Gateway (Single Entry Point)

Client → API Gateway (http://localhost:8080/api)
↳ /users → User Service
↳ /orders → Order Service
↳ /payments → Payment Service

Benefits:

- Client only talks to **one URL**.
- Gateway routes request to correct microservice.
- Security, logging, rate limiting handled at **one place**.



STEP 1 : **Eureka Server**

- Create a new Spring Boot project and add **Eureka Server** Dependencies.
- Add @EnableEurekaServer in the main class
    - @SpringBootApplication

```
@EnableEurekaServer  // 🔑 this makes the app act as Eureka Server
public class EurekaServerApplication {
   public static void main(String[] args) {
      SpringApplication.run(EurekaServerApplication.class, args);
   }
}
```

- Configure application.properties

```
# Server port for Eureka Dashboard
server.port=8761

# Application name
spring.application.name=eureka-server

# Don't register this server with itself
eureka.client.register-with-eureka=false
eureka.client.fetch-registry=false
```

- Run the Eureka Server : Open in browser: 👉 http://localhost:8761

STEP 2 : Microservice 1 (Customer Service)

- **Create a Spring Boot project** with **Spring Web** + **Eureka Discovery Client** dependencies.
- **Enable Discovery Client** in main class:

```
@SpringBootApplication
@EnableDiscoveryClient
public class CustomerServiceApplication {
  public static void main(String[] args) {
   SpringApplication.run(CustomerServiceApplication.class, args);
   }
}
```

- **application.properties**

```
server.port=8081

spring.application.name=customer-service

# Register with Eureka

eureka.client.service-url.defaultZone=http://localhost:8761/eureka
```

STEP 3 : Microservice 2 (Order Service)

- **Create a Spring Boot project** with **Spring Web** + **Eureka Discovery Client** dependencies.
- **Enable Discovery Client** in main class:

```
@SpringBootApplication
@EnableDiscoveryClient
public class OrderServiceApplication {
  public static void main(String[] args) {
   SpringApplication.run(OrderServiceApplication.class, args);
   }
}
```

- **application.properties**

```
server.port=8082

spring.application.name=order-service

# Register with Eureka

eureka.client.service-url.defaultZone=http://localhost:8761/eureka
```

STEP 3 : API Gateway

- **Create a Spring Boot project** with **Spring Cloud Gateway** and **Eureka Discovery Client** dependencies.
- **Enable Discovery Client** in main class:

```
@SpringBootApplication
```

```
@EnableDiscoveryClient
public class APIGatewayApplication {
  public static void main(String[] args) {
   SpringApplication.run(APIGatewayApplication.class, args);
   }
}
```

- **application.properties**

```
server.port=8080

spring.application.name=api-gateway


# Eureka Server URL

eureka.client.service-url.defaultZone=http://localhost:8761/eureka/


# Route definitions (map paths to services)

spring.cloud.gateway.routes[0].id=order-service

spring.cloud.gateway.routes[0].uri=lb://order-service

spring.cloud.gateway.routes[0].predicates[0]=Path=/orders/**


spring.cloud.gateway.routes[1].id=customer-service

spring.cloud.gateway.routes[1].uri=lb://customer-service

spring.cloud.gateway.routes[1].predicates[0]=Path=/customers/**
```

spring.cloud.gateway.routes

In **Spring Cloud Gateway**, we define **routes**.
Each **route** says:
👉 "If a request matches certain conditions (predicates), forward it to a specific destination (URI)."

1️⃣ id

- Just a **unique name** for the route.
- Helps identify the route in logs/monitoring.
- Example: spring.cloud.gateway.routes[0].id=order-service

  Here, the route is named "order-service".

2️⃣ uri

- Defines **where to forward the request** if it matches.
- Can be:
  - **Direct URL** (e.g., http://localhost:8082)
  - **Load-balanced service from Eureka** (e.g., lb://order-service)

In your setup: spring.cloud.gateway.routes[0].uri=lb://order-service

This means → look up order-service in **Eureka**, and forward there.

3️⃣ predicates

- Think of **conditions/filters**: "When should this route apply?"
- Common predicate → **Path**: matches the request path.
- Example: spring.cloud.gateway.routes[0].predicates[0]=Path=/orders/**

  If the URL starts with /orders/ (e.g., /orders/123), then forward to this route (order-service).

What this means:

- order-service → microservice that manages **orders** (CRUD for orders).
- customer-service → microservice that manages **customers** (CRUD for customers).
- Path=/orders/** → Any request like http://localhost:8080/orders/... will go to **order-service**.
- Path=/customers/** → Any request like http://localhost:8080/customers/... will go to **customer-service**.
- lb:// → load balanced, resolved using **Eureka Service Registry**.

Instead of exposing **each microservice URL** (like http://localhost:8081/customers or http://localhost:8082/orders), you expose **only one URL** → the **API Gateway**.

With API Gateway

Clients always call **Gateway URL**:

- http://localhost:8080/customers/1 → Gateway → Eureka → Customer Service (8081)
- http://localhost:8080/orders/5 → Gateway → Eureka → Order Service (8082)
- http://localhost:8080/payments/22 → Gateway → Eureka → Payment Service (8083)