# Idempotency

Master System Design

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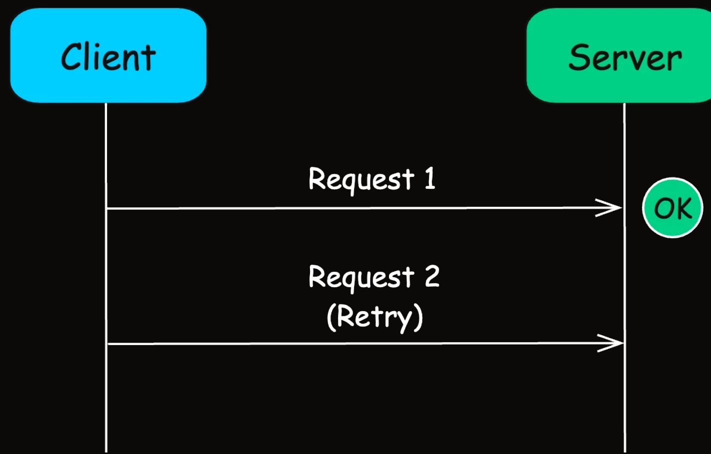
Imagine you're making a **purchase** from an online store.

You hit **"pay"** but the screen freezes, and you're unsure if the payment went through.

So, you **refresh** the page and **try again**.

Behind the scenes, how does the system ensure you aren't accidentally **charged twice**?

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This scenario highlights a common problem in distributed systems: **handling repeated operations gracefully.**

The solution to this problem lies in the concept of **idempotency.**

In this blog, we'll explore what idempotency is, why it matters, how to implement it, challenges, considerations and best practices to ensure robust and reliable systems.

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# 1. What is Idempotency?

> In mathematics, an operation is idempotent if applying it multiple times produces the same result as applying it once.

For example, the absolute value function is idempotent: `||-5|| = |-5| = 5.`

**Idempotency** is a property of certain operations whereby executing the same operation multiple times produces the same result as executing it once.

For example: If a request to delete an item is idempotent—all requests after the first will have no impact.

In programming, setting a value is idempotent, while incrementing a value is not.

`Idempotent: user.status = 'active'`

`Not Idempotent: user.login_count += 1`

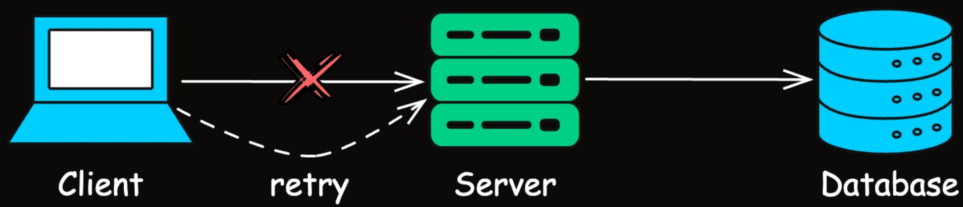
Some operations are naturally idempotent.

```
UPDATE users SET status = 'active' WHERE id = 123;
```

No matter how many times you run this, the result remains the same.

## Why Idempotency Matters

Distributed systems often require **fault tolerance** to ensure high availability. When a network issue causes a **timeout** or an **error**, the client might **retry** the request.




If the system handles retries without idempotency, every retry could change the system's state unpredictably.

By designing operations to be idempotent, engineers create a buffer against unexpected behaviors caused by retries.

This “safety net” prevents repeated attempts from distorting the outcome, ensuring stability and reliability.

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# 2. Strategies to Implement Idempotency

## 1. Unique Request Identifiers

One of the simplest techniques to achieve idempotency is by attaching a **unique identifier**, often called an **idempotency key** to each request.

When a client makes a request, it generates a **unique ID** that the server uses to track the request. If the server receives a request with the same ID later, it knows it’s a duplicate and discards it.

> **Example**: A payment service could require every transaction request to include a unique ID. If the client retries with the same ID, the server will skip the charge, preventing duplicate transactions.

**Code Example:**

Python

```
from flask import Flask, request, jsonify
import sqlite3

app = Flask(__name__)

# Initialize SQLite connection
def get_db():
    conn = sqlite3.connect('database.db')
    return conn

@app.route('/process_payment', methods=['POST'])
def process_payment():
    request_id = request.headers.get("Request-ID")
    db = get_db()
    cursor = db.cursor()

    # Check if request_id already processed
    cursor.execute("SELECT 1 FROM processed_requests
    if cursor.fetchone():
        return jsonify({"message": "Duplicate reques

    # Process payment
    # Here you would include your payment processing
    print("Processing payment...")

    # Mark request as processed
    cursor.execute("INSERT INTO processed_requests (
    db.commit()
    return jsonify({"message": "Payment processed su
```

```python
if __name__ == '__main__':
    app.run(debug=True)
```

In this example, each request includes a unique `request_id` stored in the database to track processed requests and prevent duplicates.

## 2. Database Design Adjustments (Upsert Operation)

Some database operations, such as inserting the same record multiple times, can lead to unintended duplicate entries.

Achieving idempotency in these cases often requires redesigning the database operations to be inherently idempotent.

This can involve using `upsert` operations (which updates a record if it exists or inserts it otherwise) or applying **unique constraints** that prevent duplicates from being added in the first place.

In this example, we use SQL `INSERT ... ON CONFLICT` to achieve an upsert operation, ensuring that duplicate entries don't affect the database state.

Sql

```sql
INSERT INTO inventory (item_id, stock)
VALUES (1, 10)
ON CONFLICT (item_id) DO UPDATE
SET stock = inventory.stock + EXCLUDED.stock;
```

This SQL statement inserts a new item if it doesn't exist. If it does exist (conflict on `item_id`), it updates the stock by adding the new stock quantity, ensuring the operation remains idempotent.

## 3. Idempotency in Messaging Systems

In a messaging system, we can enforce idempotency by storing a log of processed message IDs and checking against it for every incoming message.

Java

```java
import java.util.HashSet;
import java.util.Set;

public class MessageConsumer {
    private Set<String> processedMessages = new Hash

    public void processMessage(String messageId, Str
        if (processedMessages.contains(messageId)) -
            System.out.println("Duplicate message ig
```

```java
                return;
            }

            // Process the message here
            System.out.println("Processing message: " +

            // Add messageId to processed set
            processedMessages.add(messageId);
        }
    }
```

Each message has a unique `messageId`. Before processing, we check if the `messageId` is already in `processedMessages`. If it is, the message is ignored; otherwise, it's processed and added to the set to avoid duplicates.

## 4. Idempotency in HTTP Methods

HTTP defines several methods (verbs) for different types of requests.

These methods can be categorized by whether they are idempotent or non-idempotent, influencing how a system handles retries and preventing unintended side effects.

### Idempotent Methods:

#### GET

Retrieves data from a resource. GET requests are inherently idempotent because they only read data and do not alter the server's state.

- **Example:** Accessing a blog post by making a GET request to `/posts/123` will simply retrieve that post, without modifying any server data. Whether you retrieve it once or a thousand times, the post remains unchanged.

### PUT

Update or completely replace an existing resource. PUT requests are idempotent because the final state is the same whether the PUT request is executed once or multiple times.

- **Example:** Updating user information by making a PUT request to `/users/45` with updated user details will overwrite the user's data with the new information provided. Executing the same PUT request repeatedly results in the same final user data on the server.

### DELETE

Removes a resource from the server. DELETE requests are idempotent because deleting a resource that's already been deleted has no further effect.

- **Example:** Deleting an item by making a DELETE request to `/items/678` will remove the item. If you attempt the DELETE request again, it will have no effect since the item no longer exists.

**Non-Idempotent Methods:**

**POST**

Creates a new resource on the server. POST requests are non-idempotent because each request usually results in the creation of a new resource.

- **Example:** Creating a new order by making a POST request to `/orders` with order details will generate a new order each time the request is made.

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## 3. Challenges and Considerations

While idempotency is powerful, it comes with its own set of challenges:

1. **Performance Overhead**: Storing idempotency keys or checking for duplicate operations can add overhead and increase the overall latency.
2. **State Management**: Idempotency often requires main-

taining state, which can be challenging in stateless architectures.

3. **Distributed Systems**: Ensuring idempotency across distributed systems can be challenging and may require **distributed locking** or **consensus algorithms**.
4. **Time Window**: How long should idempotency guarantees be maintained? Forever, or for a limited time?
5. **Database Constraints**: Not all operations are idempotent by default; unique constraints or upsert logic may be necessary to avoid duplication.

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# 4. Best Practices

When implementing idempotency in your system, consider these best practices:

1. **Use Unique Identifiers**: Attach a unique ID (idempotency key) to each request to track and prevent duplicate processing.
2. **Design for Idempotency from the Start**: It's much easier to design for idempotency from the beginning than to add it later.
3. **Implement Retry with Backoff**: When retrying idempotent operations, use an exponential backoff strategy to

avoid overwhelming the system.

4. **Employ Idempotent HTTP Methods**: Prefer idempotent methods (GET, PUT, DELETE) for operations that may be retried; design POST with unique identifiers if idempotency is required.
5. **Document Idempotent Operations**: Clearly document which operations are idempotent in your API specifications.
6. **Test Thoroughly**: Implement tests that verify the idempotency of your operations, including edge cases and failure scenarios.
7. **Use Locks or Versioning**: Use locks, optimistic concurrency control, or version numbers to manage simultaneous requests safely.

Idempotency is a powerful concept in distributed systems that can greatly enhance the reliability and fault-tolerance of your systems.

Whether you're designing a distributed database, a payment processing system, or a simple web API, considering idempotency in your design can save you (and your users) from many headaches down the road.