Caching is an essential aspect of modern applications, particularly to enhance performance and reduce latency by avoiding redundant computations or database calls. It plays a pivotal role in scenarios like reducing API call latency, decreasing database query overhead, and improving the overall user experience by speeding up data retrieval processes. When designed properly, caching can help applications scale efficiently while maintaining high responsiveness. This document provides a comprehensive guide to caching in Spring Boot, along with practical implementations and best practices.

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1. In-Memory Cache Libraries

Popular Cache Libraries for Spring Boot:

Cache Library	Best Use Cases	Key Features
Caffeine	High-performance in-memory caching for single-node setups	TTL, size-based eviction, write-behind support
EhCache	Reliable caching with advanced configurations	Off-heap storage, disk persistence
Guava Cache	Lightweight caching for simple applications	Built-in support for LRU eviction
Hazelcast	Distributed caching for large-scale systems	Multi-node caching, fault tolerance
Redis	Distributed cache and message broker	Persistent storage, pub/sub capabilities

Criteria for Choosing Cache Libraries

Criteria	Caffeine	EhCache	Guava Cache	Hazelcast	Redis
Scalability	Medium	Medium	Low	High	High
Ease of Integration	High	Medium	High	Medium	Medium
Best for Distributed	No	No	No	Yes	Yes
Advanced Configurations	Medium	High	Low	High	Medium
Persistence Support	No	Yes	No	Optional	Yes
Performance (Single Node)	High	High	High	Medium	Medium

Recommendations:

- Choose **Caffeine** for high-performance, single-node applications requiring quick TTL and eviction mechanisms.
- Use **Hazelcast** or **Redis** for distributed, fault-tolerant systems.
- Opt for **EhCache** if advanced configurations and persistence options are needed.
- For lightweight needs, **Guava Cache** is a good starting point.

1. **Caffeine**:
   - High-performance in-memory caching library.
   - Provides features like Time-to-Live (TTL), size-based eviction, and write-behind caching.
2. **EhCache**:
   - Reliable and widely used caching library.
   - Offers advanced capabilities like off-heap storage and disk persistence.
3. **Guava Cache**:
   - Lightweight caching solution by Google.
   - Suitable for simple use cases.
4. **Hazelcast**:
   - Distributed in-memory caching and data grid solution.
   - Offers features like multi-node caching, which is ideal for large-scale systems.
5. **Redis**:
   - In-memory data structure store.
   - Acts as both a cache and message broker for distributed systems.

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2. Best Practices for Configuring Cache

- **Understand the Cache Use Case**:
  - Use caching only where necessary, e.g., for repetitive database queries or computationally expensive operations.
- **Select the Right Cache Provider**:
  - For simple setups, Caffeine works well.
  - For distributed caching, Hazelcast or Redis is ideal.
- **Eviction Policies**:
  - Use policies like Least Recently Used (LRU), TTL, or size-based eviction to manage memory efficiently.
- **Monitor Cache Usage**:
  - Integrate monitoring tools to track cache hits, misses, and other performance metrics.

- **Concurrency Considerations**:
    - Ensure thread-safety and avoid race conditions during cache updates.

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3. Monitoring Cache with Spring Boot Actuator

Spring Boot Actuator provides robust capabilities for monitoring cache usage, enabling developers to track key metrics and optimize cache performance. Here is how to set up and access these Actuator endpoints for cache in a Spring Boot project:

Configuration Steps:

1. **Add the Actuator Dependency**
   Include the Actuator starter dependency in your `pom.xml`:

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

2. **Expose Endpoints in** `**application.yml**`:
   Enable the required Actuator endpoints by updating your `application.yml` configuration:

   ```
   management:
     endpoints:
       web:
         exposure:
           include: "metrics, caches"
     metrics:
       enable.cache: true
   ```

3. **Access Cache Metrics**:
   Use the Actuator endpoint `/actuator/metrics/cache.*` to retrieve cache-related data, such as cache hits and misses.

Example Actuator Output:

When you hit the cache metrics endpoint, you might see a response like this:

```
{
  "name": "cache.gets",
```

```
  "measurements": [
    { "statistic": "COUNT", "value": 15.0 }
  ],
  "availableTags": [
    { "tag": "result", "values": ["hit", "miss"] },
    { "tag": "cache", "values": ["zipCodeCacheData"] }
  ]
}
```

Insights from the Metrics:

- **Hits**: The number of successful cache lookups.
- **Misses**: The number of times the requested data was not found in the cache and had to be fetched from the original source.

These metrics help in evaluating the effectiveness of the cache and identifying opportunities for optimization. Here is how you can enable and use it:

Configuration:

1. Add the dependency:

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

2. Enable cache metrics in `application.yml`:

   ```
   management:
     endpoints:
       web:
         exposure:
           include: "metrics"
     metrics:
       enable.cache: true
   ```

3. Access the cache metrics via `/actuator/metrics/cache.*` endpoint.

Example Metrics:

```
{
  "name": "cache.gets",
```

```
  "measurements": [
    { "statistic": "COUNT", "value": 10.0 }
  ],
  "availableTags": [
    { "tag": "result", "values": ["hit", "miss"] }
  ]
}
```

Understanding Hits and Misses:

- **Hits**: Number of times data is retrieved from the cache.
- **Misses**: Number of times data is not found in the cache and needs to be fetched from the source.

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4. Common Questions and Scenarios

What Happens If an Exception is Thrown in a `@Cacheable` Method?

- If a method annotated with `@Cacheable` throws an exception, the cache is not updated.

What Happens If `key` Is Not Provided in `@Cacheable`?

- Spring Boot generates a default key based on all method parameters.
  - Example: `@Cacheable("myCache")` without a `key` uses all parameters to create a key.

Can We Use `@Cacheable` on Private Methods?

- No, Spring AOP does not work with private methods. Always use `@Cacheable` on public methods.

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5. Distributed Caching with Hazelcast

Why Hazelcast?

- Distributed in-memory caching becomes essential in scenarios where horizontal scaling and fault tolerance are critical. It is particularly beneficial for applications with a microservices architecture or systems handling high-volume concurrent requests across multiple nodes. These systems require consistent data across the distributed

cache to avoid bottlenecks and ensure reliability. Distributed caching frameworks like Hazelcast or Redis are well-suited for these use cases due to their multi-node support, fault tolerance, and scalability.
- Multi-node support ensures consistency and fault tolerance.

Configuration:

1. Add dependency:

```
<dependency>
    <groupId>com.hazelcast</groupId>
    <artifactId>hazelcast-spring</artifactId>
</dependency>
```

2. Configure Hazelcast in `application.yml`:

```
spring:
  cache:
    type: hazelcast
hazelcast:
  network:
    join:
      tcp-ip:
        enabled: true
        members:
          - 192.168.1.100
          - 192.168.1.101
      multicast:
        enabled: false
```

3. Create Hazelcast configuration bean:

```
@Configuration
public class HazelcastConfig {

    @Bean
    public Config hazelcastConfig() {
        Config config = new Config();
        config.setInstanceName("hazelcast-instance")
              .getNetworkConfig()
              .getJoin()
              .getMulticastConfig()
```

```
                .setEnabled(false);
        return config;
    }
}
```

---

6. Code Example: Caffeine Cache Implementation

Configuration:

1. Add dependency:

```
<dependency>
    <groupId>com.github.ben-manes.caffeine</groupId>
    <artifactId>caffeine</artifactId>
</dependency>
```

2. Cache configuration:

```
@Configuration
public class CacheConfig {

    @Bean
    public CaffeineCacheManager cacheManager() {
        CaffeineCacheManager cacheManager = new
CaffeineCacheManager("zipCodeCacheData");
        cacheManager.setCaffeine(Caffeine.newBuilder()
            .expireAfterWrite(10, TimeUnit.MINUTES)
            .maximumSize(100));
        return cacheManager;
    }
}
```

3. Using `@Cacheable`:

```
@Service
public class ZipCodeService {

    @Cacheable("zipCodeCacheData")
    public String getZipCodeData(String zipCode) {
        // Simulate a time-consuming database call
        return fetchFromDatabase(zipCode);
    }

    private String fetchFromDatabase(String zipCode) {
        return "Data for ZipCode: " + zipCode;
    }
}
```

7. Testing Cache Behavior

Write Unit Tests:

```
@RunWith(SpringRunner.class)
@SpringBootTest
public class CacheTest {

    @Autowired
    private ZipCodeService zipCodeService;

    @Test
    public void testCacheable() {
        String zip1 = zipCodeService.getZipCodeData("12345");
        String zip2 = zipCodeService.getZipCodeData("12345");

        Assert.assertEquals(zip1, zip2);
    }
}
```

8. Conclusion

Caching is a powerful tool to optimize application performance. By implementing caching thoughtfully and monitoring its behavior, you can significantly enhance the responsiveness and scalability of your application. Whether it’s a simple in-memory cache or a distributed setup, choosing the right cache solution based on your requirements is crucial.