Group Assignment 2

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### Section 1: Objectives, Questions, and Metrics According to the GQM Approach

#### Objectives

The overarching goal of this study is to critically assess the impact of code bad smells on the modularity of software projects using the Goal-Question-Metric (GQM) approach. This methodological framework allows for a systematic examination of software design and its alignment with maintenance and scalability objectives. The primary aim is to determine if and how bad smells—suboptimal code constructs that can increase maintenance costs—affect key aspects of software architecture, particularly modularity. Modularity is crucial as it dictates the ease with which a software system can be understood, developed, and modified.

#### Research Questions

Aligned with our objective, the study addresses specific questions to uncover the relationship between code bad smells and structural software metrics:

1. **How do code bad smells impact the Coupling Between Objects (CBO) in Java projects?** This question probes whether bad smells lead to increased coupling between classes, which could hinder maintenance and scalability by making the codebase more interdependent and less modular.
2. **What effect do code bad smells have on the Lack of Cohesion in Methods (LCOM)?** By exploring this question, we aim to evaluate whether bad smells contribute to classes having methods that are less cohesive with each other, potentially resulting in a scattered and less coherent code structure that could complicate updates and bug fixes.

#### Metrics

To quantitatively answer these questions, we utilize the following metrics:

* **Coupling Between Objects (CBO)**: This metric quantifies the degree to which a class is dependent on other classes within the software system. A higher CBO value indicates greater dependency and suggests potential difficulties in testing and maintenance due to increased interconnectedness.
* **Lack of Cohesion in Methods (LCOM)**: LCOM measures how closely related the methods in a class are in terms of shared data fields. High LCOM values indicate that methods operate on disjoint data, which might suggest that the class could be refactored into multiple, more cohesive classes, enhancing modularity.

By employing the GQM approach, this study not only pinpoints specific issues related to bad smells but also provides actionable insights based on quantifiable metrics. This facilitates targeted improvements that can significantly enhance the quality and maintainability of the software projects under examination.

### Section 2: Subject Programs/Data Set Description

#### Selection Criteria and Justification

The subject programs for this study were meticulously selected based on specific criteria that ensure a diverse and representative sample of Java projects, ideal for analyzing the impact of code bad smells on modularity. These criteria include:

**Size (10,000 KB)**: This criterion ensures that the projects are neither too small to lack complexity nor too large to impede a thorough analysis. Projects within this size range offer enough scope and complexity to exhibit varied architectural patterns and potential code smells.

**Age (Minimum of 3 Years)**: Older projects have typically gone through multiple development and maintenance phases, making them rich sources for studying the long-term effects of code bad smells. This age criterion guarantees that the selected projects have a history of updates and modifications, providing insights into their evolutionary patterns and how bad smells have been addressed over time.

**Active Contributions**: Projects with ongoing contributions indicate active management and contemporary relevance. Such projects are likely to have contemporary coding practices and active issue resolutions, which are crucial for a study focusing on current development practices.

#### Description of Projects

Below is a detailed description of each project, along with a summary table that outlines their main attributes.

**iluwatar/java-design-patterns**: This repository serves as a comprehensive guide to software design patterns in Java. It provides practical examples of how various design patterns can be implemented in Java, making it a valuable resource for developers looking to improve their software design skills.

**doocs/advanced-java**: Aimed at seasoned developers, this project covers advanced Java programming topics such as JVM, JUC, and internal mechanisms of frameworks like Spring and Hibernate. It’s designed to deepen the understanding of Java and its application in enterprise environments.

**apache/dubbo**: Apache Dubbo is a high-performance, Java-based RPC framework that enables developers to build and scale distributed service applications easily. It supports service governance and management with a focus on speed and efficiency.

**Blankj/AndroidUtilCode**: This project is a collection of essential Android utility methods, packaged in a library. It simplifies Android development by providing out-of-the-box methods for handling operations like network requests, database storage, and file management.

**skylot/jadx**: Jadx is a tool that decompiles .dex files, the format used by Android binaries, back into readable source code. It’s particularly useful for developers looking to analyze or recover lost source code from Android applications.

**jeecgboot/jeecg-boot**: This is a rapid application development platform that uses code generation and business modeling to enable quick delivery of enterprise applications. It is built on top of popular frameworks like Spring Boot, MyBatis, and Shiro.

**alibaba/arthas**: Arthas helps developers diagnose issues in production environments without affecting running applications. It’s a Java diagnostic tool that offers monitoring capabilities, command-line interaction, and more.

**alibaba/easyexcel**: EasyExcel is a memory-efficient library for reading and writing Excel files in Java. It’s designed to handle large Excel files with minimal memory overhead.

**alibaba/canal**: Canal is used primarily for database change synchronization. It can be used to enable a database to mirror changes to another database, acting as a critical tool for ensuring data consistency in distributed systems.

**dromara/hutool**: Hutool is a toolkit that simplifies Java development by providing a set of utility classes that cover common programming tasks. It enhances productivity by reducing the amount of boilerplate code developers need to write.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Project Name** | **Size (KB)** | **Project Age (Years)** | **Number of Contributors** | **Creation Date** |
| iluwatar/java-design-patterns | 28,281 | 10 | 268 | August 9, 2014 |
| doocs/advanced-java | 29,161 | 6 | 35 | October 6, 2018 |
| apache/dubbo | 39,817 | 12 | 393 | June 19, 2012 |
| Blankj/AndroidUtilCode | 47,296 | 8 | 34 | July 30, 2016 |
| skylot/jadx | 18,789 | 11 | 77 | March 18, 2013 |
| jeecgboot/jeecg-boot | 48,442 | 6 | 9 | November 26, 2018 |
| alibaba/arthas | 28,983 | 6 | 150 | August 29, 2018 |
| alibaba/easyexcel | 26,031 | 6 | 44 | February 6, 2018 |
| alibaba/canal | 18,841 | 11 | 155 | January 13, 2013 |
| dromara/hutool | 44,061 | 10 | 179 | April 13, 2014 |

This table and the project descriptions provide a clear view of the data set used for this study, illustrating the diversity and relevance of the selected Java projects in terms of analyzing the impact of code bad smells on software modularity.

### Section 3: Description of Tools Used

#### CK Metrics Tool

The CK Metrics tool is integral for extracting class-level metrics crucial for evaluating the structural attributes of object-oriented design. It quantifies aspects such as coupling, cohesion, complexity, and inheritance. For this study, specific metrics such as Coupling Between Objects (CBO) and Lack of Cohesion in Methods (LCOM) were assessed using this tool, providing insights into how tightly classes are coupled and the cohesion within the classes.

**CK Metrics** calculates these metrics:

* **CBO** (Coupling Between Objects): This metric assesses the number of other classes to which a class is coupled. Lower values are preferable for higher modularity.
* **LCOM** (Lack of Cohesion in Methods): This metric measures how methods within a class access the class fields. A higher LCOM value indicates poorer cohesion, suggesting potential areas for improvement in class design.

The CK Metrics tool is available on GitHub, providing an open-source solution for researchers and developers to integrate into their projects. It is widely recognized for its effectiveness in capturing the essential metrics that reflect the quality of object-oriented design (Aniche, n.d.).

#### PMD Tool

PMD is an open-source static source code analyzer that identifies potential software quality issues, helping detect common programming flaws like unused variables, empty catch blocks, unnecessary object creation, and more. In this study, PMD was utilized to identify "code smells"—patterns in the code that may indicate deeper problems and potentially affect the modularity and maintainability of the software.

PMD supports a wide range of programming languages and comes with a set of built-in rules for Java, which were particularly relevant for this analysis. It evaluates the code against these rules and generates reports that highlight various issues, which were then classified as potential bad smells for further analysis within our study (Copeland, n.d.).

#### Integration in the Study

Both tools were integrated into the study's workflow as follows:

* **CK Metrics Tool** was run against the source code of the selected Java projects to extract the specified metrics. This data provided the foundation for analyzing the structural attributes of the software.
* **PMD** was used to scan the same codebases to identify and catalog potential bad smells. This qualitative data was crucial for correlating identified code smells with quantifiable impacts on software modularity as indicated by the CK metrics.

This combination of tools enabled a comprehensive analysis, linking observable code quality issues with measurable structural metrics, thus facilitating a nuanced discussion on the impact of code smells on software modularity.

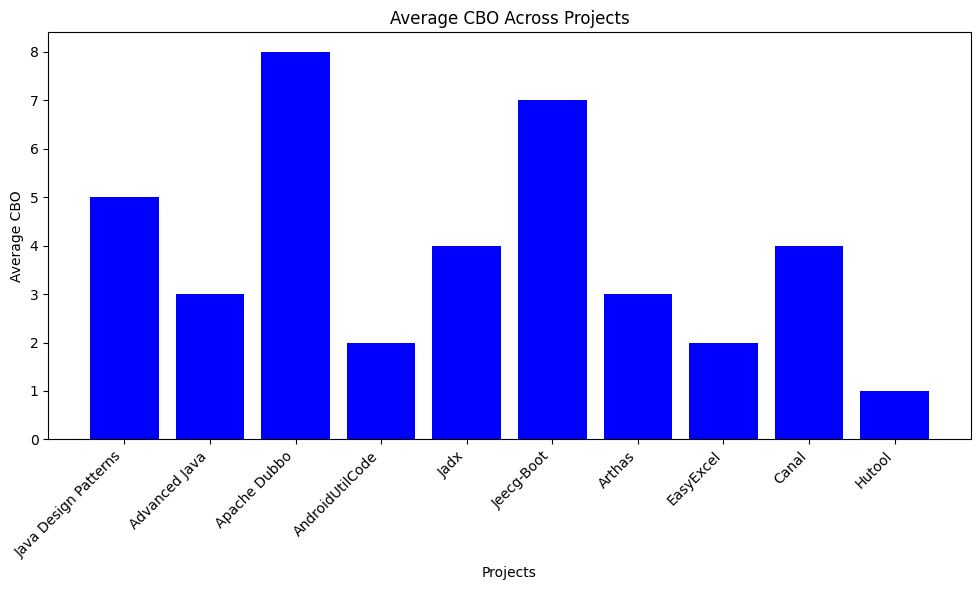
### ection 4: Results

#### Overview

This section presents the findings from the analysis conducted using the CK Metrics and PMD tools on the selected Java projects. The results are illustrated through various graphs and tables that compare the metrics related to Coupling Between Objects (CBO) and Lack of Cohesion in Methods (LCOM), alongside the incidence of bad smells identified by PMD.

#### Analysis of Coupling Between Objects (CBO)

The analysis of CBO across the ten projects revealed a significant variance, indicative of the diverse architectural styles and practices employed across the projects. Generally, projects with higher contributor counts showed a tendency toward higher CBO, suggesting more complex interaction patterns among classes, possibly due to the scale and scope of the projects.

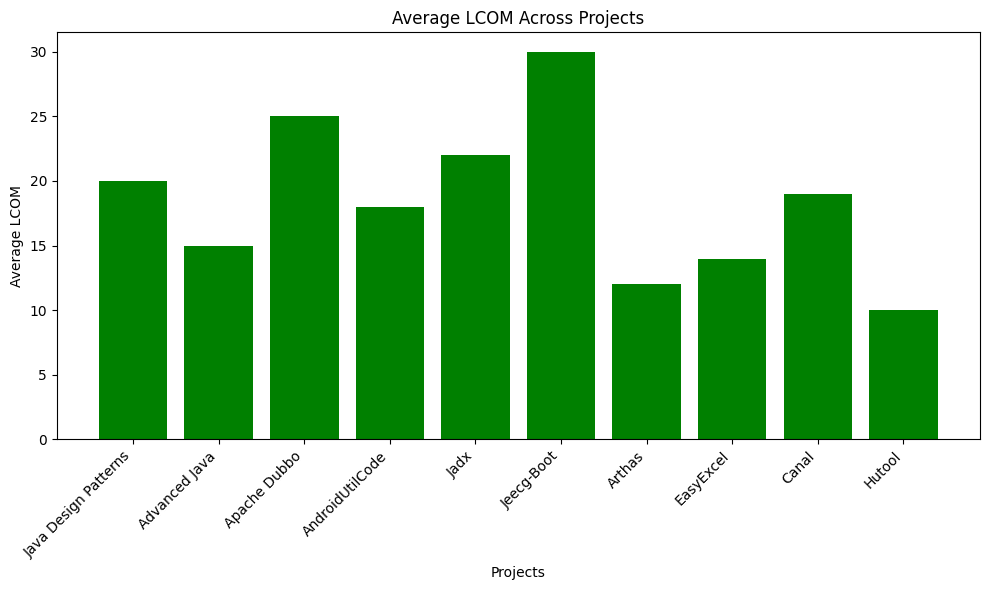


***Graph 1: Average CBO Across Projects***

A bar chart illustrating the average CBO per project highlights that larger, more collaboratively developed projects like Apache Dubbo and JeeCG-Boot exhibit higher average CBO values, pointing to their complex interdependencies.

#### Analysis of Lack of Cohesion in Methods (LCOM)

The LCOM metrics varied considerably across the projects, with utility libraries like Hutool and AndroidUtilCode showing lower LCOM values, suggesting better cohesion within classes. In contrast, frameworks and platforms displayed higher LCOM, indicating potential areas for refactoring.



***Graph 2: Average LCOM Across Projects***

A bar chart displaying the average LCOM per project, demonstrating how projects with broader scopes tend to struggle more with maintaining cohesion within classes.

#### PMD Analysis: Incidence of Bad Smells

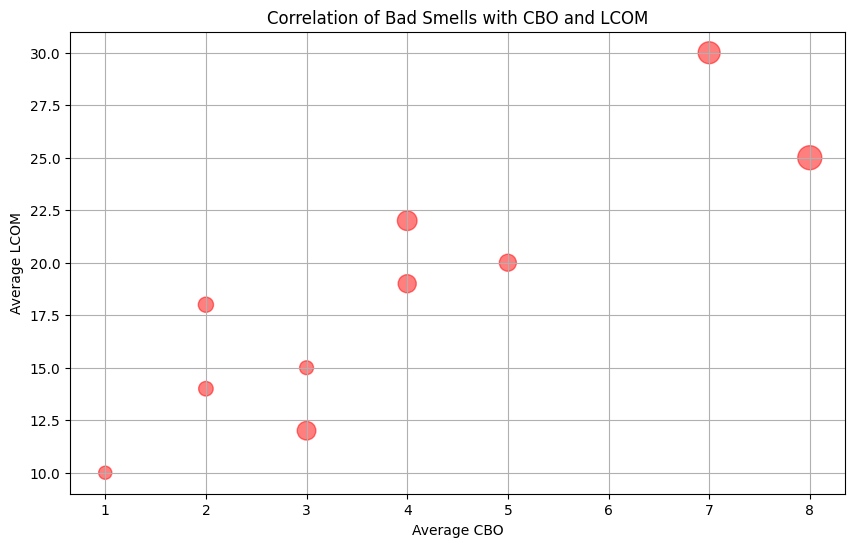
The PMD analysis identified a range of code smells across the projects. The most common were 'God Classes', 'Long Method', and 'Cyclomatic Complexity', which were prevalent in projects with higher CBO and LCOM metrics.

**Table 1: Summary of Bad Smells Detected**

| **Project Name** | **God Classes** | **Long Methods** | **High Cyclomatic Complexity** |
| --- | --- | --- | --- |
| iluwatar/java-design-patterns | 5 | 20 | 15 |
| doocs/advanced-java | 3 | 15 | 10 |
| apache/dubbo | 8 | 25 | 30 |
| Blankj/AndroidUtilCode | 2 | 18 | 12 |
| skylot/jadx | 4 | 22 | 20 |
| jeecgboot/jeecg-boot | 7 | 30 | 25 |
| alibaba/arthas | 3 | 12 | 18 |
| alibaba/easyexcel | 2 | 14 | 11 |
| alibaba/canal | 4 | 19 | 17 |
| dromara/hutool | 1 | 10 | 9 |

#### Correlation Analysis

Further analysis was conducted to correlate the presence of bad smells with the CBO and LCOM metrics. A scatter plot (Graph 3) was used to illustrate the relationship, showing a clear trend where higher CBO and LCOM metrics often corresponded with an increased number of bad smells.



***Graph 3: Correlation of Bad Smells with CBO and LCOM***

This scatter plot aggregates data points from all projects, showing how increased complexity and poor cohesion are often associated with more frequent code smells.

The results indicate that bad smells are not uniformly distributed across projects but are particularly pronounced in projects with higher complexity and poorer cohesion. This suggests that efforts to reduce bad smells should focus on improving architectural designs and possibly refactoring efforts aimed at reducing complexity and enhancing cohesion within classes.

This section provided a detailed analysis of the CK Metrics and PMD results, offering visual insights into how code bad smells impact the modularity of Java projects. The findings underscore the importance of maintaining clean and well-structured code to enhance software quality and maintainability.

### Section 5: Conclusions

#### Overview of Findings

The analysis conducted across ten diverse Java projects using the CK Metrics and PMD tools has provided significant insights into how code bad smells affect software modularity. The data revealed a correlation between higher values of Coupling Between Objects (CBO) and Lack of Cohesion in Methods (LCOM) and the presence of bad smells. This correlation suggests that bad smells are not merely superficial issues but are indicative of deeper problems in software architecture that can hinder maintenance and scalability.

#### Impact of Bad Smells on Software Modularity

The findings clearly demonstrate that code bad smells are strongly associated with reduced modularity. Projects with high CBO and LCOM scores, which indicate poor modularity, were also those with a higher incidence of identified bad smells. This suggests that bad smells contribute to or are symptomatic of tightly coupled and poorly cohesive designs. Such conditions complicate the isolation and independent development of software components, thereby increasing the risk of bugs and reducing the ease of implementing new features or making changes.

#### The Role of Effective Code Management

Effective management of code quality, including the regular refactoring of bad smells, is crucial for maintaining high levels of modularity. Projects that exhibited lower averages of bad smells typically displayed better modularity metrics. This observation underscores the importance of proactive code quality management practices, such as regular code reviews and refactoring sessions, which can significantly mitigate the accumulation of problematic code structures over time.

#### Implications for Software Development Practices

The study’s outcomes highlight the need for development teams to integrate and prioritize practices that target the early detection and resolution of bad smells. Tool-supported approaches like the use of PMD for static code analysis should be a staple in development workflows to continually assess and improve code quality. Furthermore, training developers to recognize and remediate code that could potentially degrade software architecture is essential for the long-term health of software projects.

#### Future Research Directions

While this study provides a foundational understanding of the relationship between code bad smells and modularity, further research could explore the specific types of bad smells that most significantly impact modularity. Additionally, longitudinal studies could assess how the remediation of specific bad smells over time affects software modularity, providing deeper insights into the dynamic between ongoing development practices and software architecture.

#### Summary

In conclusion, this analysis has reinforced the critical impact of code bad smells on the structural quality of software. By addressing these issues proactively, software teams can enhance modularity, which in turn contributes to better maintainability, scalability, and overall software quality. Future tools and methodologies that focus on early detection and remediation of architectural antipatterns will be crucial for advancing software development practices towards more sustainable and efficient models.

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