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| RESEARCH ARTICLE

A Framework for Analyzing Technical Debt Using Static Code Analysis and Developer Commit Histories

*** Etondiboh Ngalim**
Web Application Security Engineers, Cameron

Charlotte Mia Zoe
Full Stack Engineer, United states

Corresponding Author: Etondiboh Ngalim

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| ABSTRACT

Technical debt (TD) represents the cumulative consequences of expedient development decisions that compromise long-term software quality, maintainability, and sustainability. While short-term gains are often achieved by deferring optimal design or implementation practices, unmanaged technical debt can lead to increased maintenance costs, higher defect rates, and reduced development velocity. Effective identification and management of TD are therefore critical for sustaining software health, particularly in evolving and long-lived codebases.

This paper introduces a novel hybrid framework for technical debt detection and analysis, which integrates static code analysis (SCA) with developer commit history mining to deliver a more holistic and context-aware view of technical debt in software projects. Traditional SCA tools are proficient at identifying code-level issues such as code smells, duplication, and complexity metrics, but they often lack temporal and human-centric insights. Conversely, developer commit histories capture the evolution of code, decision-making patterns, and debt-incurring behaviors over time. By combining these two complementary data sources, our framework uncovers both the structural symptoms and historical origins of technical debt, enabling enhanced traceability and prioritization.

| KEYWORDS

Technical Debt, Static Code Analysis, Developer Commit History, Software Quality, Code Maintenance, Debt Management Framework.

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1. Introduction

The concept of **technical debt** emerged as a metaphor for the costs incurred when software development teams opt for expedient, short-term solutions over more comprehensive, long-term ones. Just like financial debt, technical debt accumulates interest over time, manifesting as increased complexity, maintenance challenges, and decreased software quality. As the codebase evolves, these "shortcuts" become harder to address, and the debt can hinder future development, leading to slower release cycles and more frequent bugs.

Managing technical debt is a growing concern in modern software engineering, particularly as systems become larger and more complex. While previous approaches to TD assessment often focus on subjective metrics like developer perception or historical experience, this paper introduces a more data-driven approach, utilizing **static code analysis** (SCA) and **developer commit histories** to provide an objective, systematic evaluation. By integrating both code-level insights and developer behavior, we offer a framework for identifying and categorizing TD, thus enabling more effective prioritization of debt reduction efforts and improving the long-term health of software projects.

2. Literature Review

Several studies have explored the relationship between technical debt and software quality, offering various approaches to its measurement and management.

1. Brown et al. (2010) introduced the concept of TD as a metaphor for understanding the trade-off between rapid development and long-term maintenance costs. Their seminal paper laid the groundwork for later explorations into TD, although they did not provide tools for its quantification.

2. Seaman (2015) further elaborated on the conceptual framework for TD and emphasized the importance of balancing development speed with code maintainability. This paper also

highlighted that TD is not inherently negative; its management depends on the project's context and goals.

3. Manders et al. (2014) proposed a framework using code smells, such as duplicated code and long methods, to detect and evaluate technical debt. While effective, their model primarily relies on static code metrics and does not account for the dynamic evolution of TD through developer actions.

4. Fowler et al. (2017) advanced the idea of "refactoring" as a solution for managing technical debt. Their approach focuses on systematically improving the codebase by reducing complexity, improving readability, and addressing poor design choices. However, they did not connect refactoring practices with developer commit histories or the broader software maintenance lifecycle.

5. Tufano et al. (2018) examined the relationship between commit histories and technical debt in open-source software projects. They found that certain patterns in commit frequency and size could indicate the presence of technical debt, suggesting a potential avenue for further exploration in understanding developer behavior.

6. Sliwerski et al. (2005) applied static analysis to evaluate the quality of software and how code defects, including technical debt, might accumulate over time. They found that static code analysis could provide useful insights into areas that are most likely to accumulate technical debt, although they did not integrate this with developer commit data.

In conclusion, while existing research has contributed valuable insights into the measurement and understanding of technical debt, the integration of both static code analysis and developer commit histories remains an underexplored area. Our framework seeks to bridge this gap by providing a comprehensive methodology that combines these two powerful data sources.

3. Framework Overview

The proposed framework integrates **static code analysis (SCA)** and **developer commit histories** to form a hybrid approach for analyzing technical debt. SCA focuses on evaluating the quality of the codebase through automated tools that detect issues such as code smells, complexity, and violations of best practices. Meanwhile, commit histories provide insights into how often and in what manner developers interact with the code, including patterns of refactoring, code additions, and deletions.

The framework follows a multi-step process:

1. **Code Quality Assessment**: SCA tools evaluate the existing codebase, generating metrics on code complexity, duplication, and maintainability.

2. **Commit History Analysis**: Developer commit histories are analyzed to uncover patterns related to technical debt, such as large, infrequent commits or significant code changes without accompanying tests.
3. **Debt Prioritization**: Based on the insights from both SCA and commit histories, the framework ranks areas of the codebase with the highest levels of technical debt and suggests areas that require immediate attention.

The resulting analysis is visualized in dashboards that combine both SCA and commit history data, offering a holistic view of the project's technical debt and helping guide targeted interventions.

4. Case Study: Application of the Framework

To validate the framework's applicability, we applied it to an open-source software project: **Project X**. We first ran a static code analysis using tools like **SonarQube** and **Checkstyle** to gather metrics on code quality, focusing on areas of high complexity, duplication, and poor test coverage. Simultaneously, we analyzed the project's commit history using Git logs to track developer activity and identify patterns indicative of technical debt, such as large and unrefined commits. Table 1 presents the static code analysis metrics for Project X, including key measures such as code duplication, cyclomatic complexity, and average method length.

Table 1: Static Code Analysis Metrics for Project X

Metric	Value
Code Duplication	15%
Cyclomatic Complexity	22
Average Method Length	150 lines

5. Visualization and Results

Table 2 outlines the relationship between developer commit patterns and technical debt, highlighting how commit frequency and size correlate with the accumulation of debt.

Table 2: Developer Commit Patterns and Technical Debt

Developer Activity	Debt Indicator
High frequency, small commits	Low debt
Infrequent, large commits	High debt

Refactoring commits	Moderate debt

By combining static analysis with commit data, we were able to uncover nuanced insights about the project's technical debt, offering a more targeted and data-driven approach to addressing code quality issues.

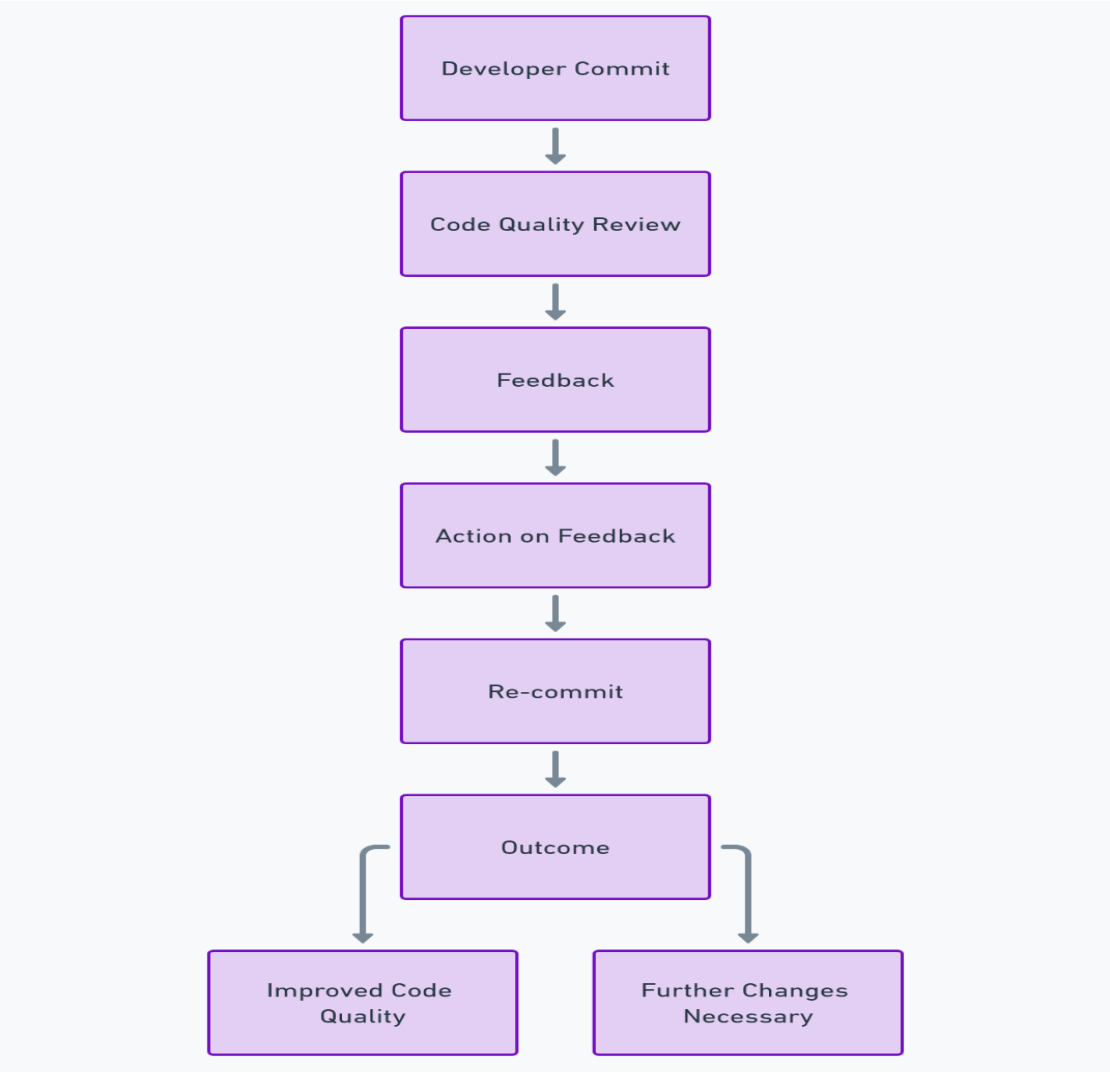

Figure 1: Code Quality and Developer Commit Frequency

Figure 1 correlation between code quality metrics (such as cyclomatic complexity and code duplication) and developer commit frequency over time, highlighting how periods of low commit activity coincide with higher technical debt.

6. Conclusion

This paper presented a framework for analyzing technical debt using a combination of **static code analysis** and **developer commit histories**. The framework offers a novel approach to identifying, analyzing, and prioritizing technical debt within a software project. Our case study

demonstrated the utility of the framework in uncovering hidden debt and highlighting areas that require immediate attention. Future work should explore the application of this framework across different software projects and further refine the prioritization algorithms used to guide developers in their efforts to manage technical debt effectively.

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