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Machine Learning-Based Framework for Design Pattern Classification in Object-Oriented Software

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Abstract

Design patterns serve as reusable solutions to common software development challenges, enabling better organization, maintainability, and scalability of code. Despite their advantages, selecting the right design pattern during development can be a complex and subjective task, particularly for beginner programmers. This paper introduces an intelligent approach that utilizes machine learning to automatically recommend appropriate design patterns based on the structural characteristics of Java source code.The proposed framework begins by analyzing Java files to extract key structural features, which are then encoded into numerical vectors. These vectors capture the essential aspects of the code design and are used as input to machine learning algorithms such as Support Vector Machine (SVM), Decision Tree, and Random Forest. Additionally, an ontology-based similarity ranking method is employed to enhance the precision of predictions by measuring the closeness between the input code and existing pattern examples in the dataset.To make the solution user-friendly and accessible, the model is deployed as a RESTful API. Users can submit their source code through a web interface and receive instant feedback on the most likely design pattern classification, along with model confidence levels. Experimental evaluations indicate that the Random Forest model consistently delivers high accuracy in predicting one of the 13 predefined design patterns, outperforming the other classifiers tested.This system not only supports developers in making more informed design decisions but also contributes to the automation of software architecture practices. The integration of machine learning with software engineering principles creates a valuable resource for both academic research and industry application.

INTRODUCTION

1. Background and Motivation

In modern software development, achieving modularity, scalability, and maintainability is crucial. As applications become more complex, developers must rely on proven methodologies and frameworks to manage the growing intricacies of software design. Design patterns are among the most effective tools used to solve common problems that arise during software

construction. They offer reusable solutions to recurring design issues, making them an integral part of robust software architecture.

Originating from the seminal work of the "Gang of Four" (Gamma et al.), design patterns provide standardized ways of solving software design problems through tested and widely accepted practices. These patterns are not code implementations, but rather templates that describe how to structure classes and objects to achieve specific goals. Despite their utility, the selection and application of suitable design patterns often depend on the developer's experience, intuition, and familiarity with architectural concerns.

For novice programmers or even seasoned developers facing unfamiliar problem domains, determining the most appropriate design pattern can be difficult. Incorrect usage or overlooking an optimal pattern can lead to rigid, inefficient, and error-prone code. Thus, a tool that aids in recommending or predicting design patterns based on the structure of source code could significantly enhance software development quality and productivity.

2. Importance of Design Patterns in Software Engineering

Design patterns simplify communication among developers by providing a common vocabulary to discuss software architecture. For example, saying that a component follows the "Singleton" or "Observer" pattern immediately conveys the structure and intent to other developers. These patterns encourage best practices, reduce development time, and increase code reliability.

Typically, design patterns are categorized into three groups:

- Creational Patterns (e.g., Singleton, Factory Method): Deal with object creation mechanisms.
- Structural Patterns (e.g., Adapter, Composite): Focus on class and object composition.
- Behavioral Patterns (e.g., Observer, Strategy): Concerned with communication between objects.

Understanding when and how to apply these patterns appropriately can enhance the clarity and performance of software. However, mastering all patterns and their suitable application contexts is a daunting task, especially for beginners.

3. Challenges in Design Pattern Selection

The manual process of selecting a design pattern is inherently subjective and often lacks a systematic approach. Developers must consider multiple factors such as problem context, code structure, software requirements, and future maintainability. Moreover, many design patterns share similar structural features, making it challenging to differentiate them solely through manual analysis.

In educational environments, students may struggle to understand the real-world applications of these patterns. In industrial settings, time constraints and large codebases can hinder pattern discovery, leading to inconsistent or suboptimal design choices. As a result, software teams may benefit from tools that automate the identification and recommendation of design patterns, especially during the early stages of development.

4. Machine Learning as a Solution

Recent advancements in machine learning (ML) and artificial intelligence (AI) have shown promise in automating complex decision-making tasks in various domains. In the realm of software engineering, ML can be leveraged to analyze large volumes of source code and detect patterns, bugs, or code smells. When applied to design pattern prediction, machine learning models can be trained on labeled datasets to classify new code based on learned structural representations.

This paper proposes a machine learning-based framework that predicts design patterns from Java source code using structural features. The system incorporates widely used classification algorithms such as Random Forest, Support Vector Machine (SVM), and Decision Tree. These models are trained to recognize the characteristics of 13 different design patterns based on code samples.

In addition, the system introduces an ontology-based ranking method that enhances classification by comparing semantic similarities between test and training samples. This hybrid approach—combining traditional ML with ontology ranking—provides more accurate and context-aware predictions.

5. Problem Statement

Despite the benefits of design patterns, developers face several challenges:

- Difficulty in identifying the most appropriate design pattern during development.
- Lack of tools that integrate structural code analysis with intelligent pattern suggestion.
- Limited access to systems that support pattern prediction through user-friendly interfaces.

Therefore, there is a strong need for an automated, intelligent system capable of recommending relevant design patterns based

on the structure and semantics of the input source code.

6. Objectives of the Study

This research aims to develop a system that automates the process of design pattern prediction using machine learning. The key objectives are:

- To analyze and extract structural features from Java source code for machine learning input.
- To train and evaluate various classification models—SVM, Random Forest, and Decision Tree—for predicting design patterns.
- To integrate an ontology-based ranking algorithm to enhance the model's prediction accuracy.
- To deploy the trained model as a RESTful web API that provides real-time pattern prediction upon code upload.
- To assess the performance of different models and identify the most efficient one for practical use.

7. Contributions

This study presents the following contributions:

- A dataset of Java files labeled with 13 design patterns used to train and evaluate machine learning models.
- A preprocessing pipeline that converts source code into structured numerical representations.
- Implementation and comparison of three machine learning models: SVM, Decision Tree, and Random Forest.
- Integration of an ontology ranking mechanism to refine prediction outcomes.
- Development of a web-accessible REST API for real-time pattern prediction from user-uploaded Java code.
- Experimental validation showing the superiority of the Random Forest classifier in prediction tasks.

These contributions aim to support developers in making faster, more accurate architectural decisions, thereby improving the quality and maintainability of software systems.

RELATED WORKS

Over the years, various studies have explored the automation of design pattern detection and recommendation in source code. Traditional approaches have primarily focused on rule-based or static analysis techniques, while more recent works have adopted machine learning and deep learning to improve accuracy and scalability.

Rule-Based and Static Analysis Approaches:
Early research in this domain relied heavily on manually defined heuristics and structural matching rules. Brown et al. [1] introduced a system that identifies design patterns using graph-based models, where class relationships are represented and compared against pattern templates. Similarly, Prechelt et al. [2] employed metrics such as class coupling, inheritance depth, and method count to manually detect design patterns. However, these approaches are often rigid and fail to generalize across diverse codebases or large-scale software systems.

Pattern Mining and Clone Detection:
Some studies attempted to extract patterns by mining software repositories. Tsantalis et al. [3] developed algorithms that identify micro-patterns and code clones that match known design pattern structures. These methods, although effective to an extent, struggle with polymorphic behavior and dynamic pattern variations.

Ontology-Based Pattern Detection:
A few researchers proposed ontology-driven methods to improve semantic understanding during pattern classification. Dong et al. [4] used ontology graphs to represent relationships among software entities and match them against pattern ontologies. This provided a more contextual approach, yet it lacked adaptability to unseen or evolving patterns.

Machine Learning and Classification Techniques:
More recent efforts have embraced machine learning models for predicting design patterns from code features. Jobst and Trifu [5] employed decision trees to classify Java classes into design pattern categories. Taneja and Sharma [6] explored support vector machines and logistic regression, reporting moderate accuracy with manual feature engineering. While these models marked progress, they often required extensive domain knowledge to curate meaningful features.

Deep Learning for Code Analysis:
Some works, such as those by Allamanis et al. [7], adopted deep learning techniques like recurrent neural networks and graph neural networks to analyze source code as sequences or graphs. These methods showed promise in capturing code semantics, but their computational demands and data requirements are high. Furthermore, most deep learning

models lack explainability, which can hinder adoption in critical systems.

Gaps in Existing Literature:
Despite notable advancements, several limitations remain in existing systems:

- Lack of real-time or interactive tools for developers.
- Limited comparison between multiple machine learning classifiers.
- Inadequate integration of semantic similarity through ontology-based ranking.
- Few tools are available as deployable APIs or services.

This research addresses these limitations by integrating structural code analysis, supervised learning, and ontology-based ranking into a unified system. Unlike prior works, the proposed system offers a web-accessible REST API and evaluates multiple classifiers for robust pattern prediction.

1. Existing System
Several existing systems have been developed to detect and recommend design patterns in software source code, primarily using rule-based or heuristic-driven approaches. Traditional tools rely on predefined structural rules and static analysis techniques to match known patterns within the codebase. These systems analyze object-oriented relationships like inheritance, class hierarchies, and method invocations to detect design patterns. While they provide a structured way to identify patterns, they are often rigid, requiring exact pattern conformance and failing to adapt to modified or partially implemented patterns. Some semi-automated systems enhance detection using software metrics such as cyclomatic complexity, class coupling, or cohesion to guide heuristic decisions. In more recent developments, machine learning techniques like Support Vector Machines (SVMs), Decision Trees, and Random Forests have been introduced for pattern classification, showing promising results by learning from labeled datasets. However, these systems often suffer from limited dataset diversity, lack of semantic context, and inadequate integration with developer-friendly interfaces. Moreover, few of these systems have been deployed as real-time APIs or services, making them less practical for real-world use.

1.1 Limitations of Existing Systems

- Dependence on rigid, rule-based logic that lacks flexibility for pattern variations.
- Inability to understand semantic relationships between classes and methods.
- Manual feature engineering required for machine learning models.
- Lack of large, diverse, labeled datasets for effective model training.
- Limited scalability to large or complex codebases.
- Absence of real-time prediction interfaces or user-friendly APIs.
- Poor generalization to dynamically evolving code structures or custom implementations.

2. Proposed System
The proposed system introduces an intelligent and flexible approach to design pattern prediction using machine learning and ontology-based ranking. Unlike traditional rule-based tools, this system leverages a set of extracted software metrics and code features to train multiple machine learning classifiers, such as Decision Tree, Random Forest, and Support Vector Machine (SVM), enabling the system to identify patterns in a more adaptable and data-driven manner. The use of an ontology-based ranking mechanism enhances the semantic matching of predicted patterns by comparing structural and conceptual similarities between the uploaded class and known design patterns. To ensure usability and accessibility, the system is deployed as a RESTful API, allowing developers to interact with it via simple file uploads and receive real-time predictions along with the top-ranked matching patterns. The integration of both syntactic and semantic analysis, along with machine learning, positions the proposed system as a practical tool for modern software developers and researchers.

2.1 Advantages of the Proposed System

- Utilizes multiple machine learning classifiers for improved prediction accuracy.
- Applies ontology-based ranking to ensure semantic relevance of suggestions.
- Offers real-time design pattern prediction through a user-friendly REST API.
- Reduces manual effort in identifying design patterns from source code.
- Supports flexible and partial pattern detection, even in modified code.
- Scales effectively across varied project sizes and code complexities.
- Facilitates deployment in real-world environments for educational or industrial use.

PROPOSED METHODOLOGY
The proposed methodology is designed to automate the process of detecting design patterns in source code using a hybrid approach that integrates machine learning classifiers and

semantic similarity analysis. The methodology consists of several key stages, from code preprocessing to final pattern recommendation, ensuring both structural and contextual accuracy in predictions.

1. Dataset Collection and Preprocessing
The system begins by collecting a labeled dataset of Java class files that represent different design patterns. These source files are preprocessed to extract relevant features, including class names, inheritance trees, method declarations, variable counts, object creation instances, and inter-class relationships. The extracted data is then transformed into numerical representations suitable for training machine learning models.

2. Feature Engineering
From each class file, specific software metrics are calculated, such as the number of methods, attributes, coupling between classes, cohesion, depth of inheritance, and class size. These features are used to build a feature vector that serves as input for training various classifiers. This stage is crucial for enabling the model to distinguish among different patterns based on structural characteristics.

3. Machine Learning Model Training
Multiple supervised learning algorithms—such as Decision Tree, Random Forest, and Support Vector Machine (SVM)—are trained on the feature vectors. Each classifier learns to associate a specific combination of features with a corresponding design pattern. The model is validated using performance metrics such as accuracy, precision, recall, and F1-score to ensure robustness and generalizability.

4. Pattern Prediction
Once the model is trained, users can upload a Java class file through the REST API interface. The uploaded file undergoes the same preprocessing and feature extraction pipeline. The trained model then predicts the most likely design pattern based on the learned features.

5. Ontology-Based Ranking
To improve the relevance and confidence of predictions, an ontology-based ranking mechanism is applied. It compares the predicted class against a knowledge base of design patterns using semantic similarity measures. This allows the system to refine its suggestions, accounting for contextual and conceptual similarities beyond just structural features.

6. RESTful API Deployment
The system is deployed as a REST API that allows users to upload source code, receive predictions, and view the top ranked design patterns. The backend is implemented using Flask/Django, and the machine learning models are integrated using libraries like Scikit-learn. The API ensures seamless integration with external applications and can be accessed via simple HTTP requests.

RESULTS
The proposed system for design pattern prediction was rigorously tested using a structured Java dataset encompassing multiple well-known design patterns. A comprehensive set of experiments was conducted to evaluate the effectiveness of the machine learning models and the ontology-based ranking mechanism. The system was deployed via a RESTful API, offering a user-friendly interface for uploading source code and receiving predictions.

1. Dataset Processing and Vectorization
The dataset containing Java source files corresponding to 13 different design patterns was loaded into the system through the interface. The class files were preprocessed to extract feature vectors by converting the code into a structured numerical format. This transformation facilitated compatibility with machine learning classifiers. The successful vectorization process was confirmed through system-generated logs and user interface outputs.

2. Model Training and Performance
Three different classifiers—Decision Tree, Support Vector Machine (SVM), and Random Forest—were trained using an 80:20 train-test split. The following performance metrics were computed:

Table I: Performance Comparison of ML Classifiers

Classifier	Accuracy	Precision	Recall	F1-Score
Decision Tree	85.7%	84.9%	85.3%	85.1%
Random Forest	**91.2%**	**90.8%**	91.5%	**91.1%**
SVM	88.4%	87.9%	88.2%	88.0%

Among the three, the Random Forest classifier demonstrated superior accuracy and robustness in predicting the correct design patterns.

3. Ontology-Based Pattern Ranking
The ontology-based ranking mechanism played a crucial role in improving prediction reliability.

For each uploaded source code, the predicted pattern was semantically compared against known patterns, and a ranked list of top 3 matches was generated. In more than 93% of test cases, the correct design pattern appeared in the top 3, validating the semantic enrichment of results.

Table II: Ontology-Based Ranking Accuracy

Rank Position	Success Rate (%)
Top 1	88.5%
Top 2	91.7%
Top 3	**93.2%**

The integration of ontology significantly improved prediction confidence and interpretability.

4. Real-Time API Output Screens

The deployed API allowed users to interact with the system by uploading Java class files. The prediction results, along with ranking scores and performance metrics, were displayed on the user interface. Sample output screens included:

Table III: Identification of Abstract Factory Pattern in jbehave-core Project

Project Name	Class Name	Pattern Name
jbehave-core	AbstractStepsFactory	AbstractFactory
jbehave-core	CompositeStepsFactory	AbstractFactory
jbehave-core	InjectableStepsFactory	AbstractFactory
jbehave-core	InstanceStepsFactory	AbstractFactory
jbehave-core	ProvidedStepsFactory	AbstractFactory
jbehave-core	GroovyStepsFactory	AbstractFactory
jbehave-core	GuiceStepsFactory	AbstractFactory
jbehave-core	PicoStepsFactory	AbstractFactory

These output screens demonstrate the system's practical usability and real-time performance, with prediction times consistently under 2 seconds.

CONCLUSION

In this study, an intelligent system was developed to automatically detect and classify software design patterns from Java source code using a combination of machine learning and ontology-based semantic analysis. The proposed model demonstrated strong performance across key metrics such as accuracy, precision, recall, and F1-score, with the Random Forest classifier emerging as the most effective algorithm. The integration of an ontology module further enhanced prediction interpretability by providing ranked semantic outputs.The system was also equipped with a user-friendly interface for dataset processing, model training, and real-time prediction visualization, making it practical for use in software engineering workflows. Evaluations on open-source projects like jbehave-core showed that the system could reliably identify complex patterns such as Abstract Factory across multiple class files, validating its real-world applicability.

The findings confirm that automating design pattern detection not only accelerates software analysis but also contributes to better software reuse and architecture understanding. The developed framework lays a solid foundation for further advancements in intelligent code analysis and pattern-aware software development tools.

The current system can be extended by incorporating additional design patterns, including behavioral and concurrent types, to improve coverage. Future work may also explore deep learning models such as graph neural networks for better context understanding. Integrating the tool with popular IDEs can enable real-time pattern detection during development. Additionally, a user feedback mechanism could help improve prediction accuracy through continuous learning.

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