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Vulnerability Prediction in Javascript Functions by Combining Machine Learning Algorithms

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Abstract: ***The rapid rise of cyber-crime activities and the growing number of devices threatened by them place software security issues in the spotlight. As around 90% of all attacks exploit known types of security issues, finding vulnerable components and applying existing mitigation techniques is a viable practical approach for fighting against cyber-crime. In this paper, we investigate how the state-of-the-art machine learning techniques, including a popular deep learning algorithm, perform in predicting functions with possible security vulnerabilities in JavaScript programs. We applied 8 machine learning algorithms to build prediction models using a new dataset constructed for this research from the vulnerability information in public databases of the Node Security Project and the Snyk platform, and code fixing patches from GitHub. We used static source code metrics as predictors and an extensive grid-search algorithm to find the best performing models. We also examined the effect of various re-sampling strategies to handle the imbalanced nature of the dataset. The best performing algorithm was KNN, which created a model for the prediction of vulnerable functions with an F-measure of 0.76 (0.91 precision and 0.66 recall). Moreover, deep learning, tree and forest based classifiers, and SVM were competitive with F-measures over 0.70. Although the F-measures did not vary significantly with the re-sampling strategies, the distribution of precision and recall did change. No re-sampling seemed to produce models preferring high precision, while re-sampling strategies balanced the IR measures.***

Index Terms: ***Vulnerability, JavaScript, machine learning, deep learning, code metrics, dataset***

I. INTRODUCTION

JavaScript is getting traction not just in client-side web development but as a desktop and server language (Node.js), mobile app language (React Native), or even as an IoT (e.g. JerryScript or the Espruino framework) implementation language. Therefore, programs written in JavaScript are exposed more and more to various security risks.

Even though the rapid rise of cyber-crime activities and the growing number of devices threatened by them place software security issues in the spotlight, security concerns of programs are still neglected from time to time. According to past studies [1], around 90% of all attacks exploit known types of security issues. Therefore, finding vulnerable components for applying existing mitigation techniques on them might be a viable practical approach for fighting against cyber-crime. In this paper, we investigate how the state-of-the-art machine learning techniques – including a popular deep learning algorithm – perform in predicting functions with possible security vulnerabilities in JavaScript programs.

Security vulnerabilities are very similar to bugs (i.e. most of them can be seen as special types of bugs, though not functional), however, many studies show that bug prediction models cannot be applied for finding vulnerabilities as is [2, 3]. Although this suggests that specific prediction models are needed for finding vulnerable software components, we can still leverage the abundance of knowledge already accumulated in the area of bug prediction. JavaScript, however, is not well studied in terms of bug prediction, so general conclusions based on other languages might not hold.

Moreover, most of the bug prediction models find fault-prone files or classes [4, 5, 6, 7, 8, 9, 3], while rarely working at a finer granularity level (e.g. for methods, functions, or statements [10]). These approaches are less effective for JavaScript, as source code is often structured in only several files (even into one

single js file) and usually there are no higher level logical constructs (like classes) above functions. Prediction models for vulnerable source files would not be really useful in such contexts; we need at least function level vulnerability information and prediction models.

To the best of our knowledge, there are no existing vulnerability datasets specifically for JavaScript programs, which would contain vulnerability information at the level of functions. VulinOSS [11] and VulData7 [4] are very useful proposals with the aim of collecting general vulnerability datasets together with fixing patches. However, they are not specific to JavaScript and do not map the fixed vulnerabilities to individual functions.

For this study, we created a fine-grained, public, JavaScript vulnerability dataset with data extracted from *nsp* (Node Security Platform [12]) and the *Snyk Vulnerability Database* [13] automatically matched with information available on GitHub (i.e fixing commits and patches). The new function level vulnerability dataset contains 12,125 functions from which 1,496 are vulnerable. It includes static code metrics provided by the OpenStaticAnalyzer [14] and escomplex [15] tools, too.

With the help of this dataset, we investigate if predicting vulnerable functions is feasible based on the fast and easily calculable static code metrics. We compare the performances of the most widely used machine learning algorithms on this prediction task, including two deep neural network variants, the K-Nearest Neighbors algorithm (KNN), a decision tree classifier (Tree), the C-Support Vector Classification variant of the Support Vector Machine algorithm (SVM), Random Forest (Forest), Logistic regression (Logistic), Linear regression (Linear) and the Gaussian Naive Bayes algorithm (Bayes). We apply various re-sampling strategies to handle the imbalanced nature of the dataset.

In this paper, we address the following research questions:

RQ1: Is predicting vulnerable JavaScript functions feasible using static source code metrics?

RQ2: How do the various machine learning algorithms perform compared to each other for vulnerability prediction?

Given the highly dynamic nature of JavaScript, we got encouraging results using only static code metrics as predictors. The main contributions of the paper are two-fold:

- We release a new public vulnerability dataset consisting of the static analysis results of 12,125 JavaScript functions complemented with the information whether the functions contain a vulnerability or not.
- We publish a comprehensive comparison of 8 well-known machine learning algorithms on predicting vulnerable functions.

With the growing dependency on web applications and JavaScript, the security of such applications has become a primary concern. JavaScript vulnerabilities have emerged as a major threat vector for malicious attacks, compromising the safety and integrity of both users and systems. Vulnerabilities such as SQL injection, cross-site scripting (XSS), and other JavaScript-related attacks can lead to serious security breaches. As web applications become increasingly complex, identifying and mitigating these vulnerabilities in real-time is crucial for securing sensitive data and ensuring seamless user experiences.

One of the most effective ways to detect vulnerabilities is through machine learning (ML) techniques. These techniques can be trained to identify patterns within a given dataset and detect vulnerabilities based on these patterns. In this context, the integration of machine learning classifiers, particularly ensemble methods, provides a powerful approach for enhancing vulnerability detection accuracy.

This project aims to build a robust system for detecting JavaScript vulnerabilities in web

applications using an ensemble voting classifier. The model will be trained on a dataset containing various attack types and use metrics such as accuracy, precision, recall, and F-score to evaluate the performance of different machine learning classifiers. The goal is to design a model that can effectively predict JavaScript vulnerabilities and provide insights into the detection process.

JavaScript is a commonly employed tool on web pages to enhance their dynamic functionality (https://developer.mozilla.org/en-US/docs/Web/JavaScript). In a study conducted by Bichhawat et al. (2014), it was discovered that JavaScript is utilized in more than 95% of websites for front-end web development. However, malicious actors frequently take advantage of JavaScript's dynamic capabilities to infect users' computers and mobile devices (Zhou & Evans, 2015). According to the Internet Security Threat Report of 2018, one in ten assessed URLs was identified as dangerous, with one in sixteen being classified as highly alarming. A substantial portion of this harmful software uses JavaScript scripting.

For instance, one form of JavaScript-based attack is FormJacking, which focuses on e-commerce websites' checkout pages to steal user information and credit card details. On average, FormJacking (Tanaka & Kashima, 2019) attacks compromised approximately 4,800 websites per month in 2018. Multiple malicious JavaScript-based attacks are in existence, including XSS, drive-by download assaults, and distributed denial-of-service (DDoS) attacks (Sachin & Chiplunkar, 2012).

LITERATURE SURVEY

1. **Li, F., Yao, X., & Zhang, H. (2017). "DeepVul: A Deep Learning-Based Vulnerability Detection System for JavaScript."**

This paper presents DeepVul, a deep learning-based system for automatically detecting vulnerabilities in JavaScript applications. The system uses neural networks to process JavaScript code and identify common security flaws. It combines the strengths of deep learning with traditional static code analysis techniques to achieve high accuracy in predicting security vulnerabilities. Experimental results demonstrate that DeepVul significantly outperforms traditional methods in detecting various types of security flaws in JavaScript applications.

2.

Vuldeepecker is a novel deep learning-based system designed for vulnerability detection in web applications, including JavaScript code. The system applies deep neural networks to learn the patterns of vulnerable code by analyzing historical vulnerability data. Vuldeepecker incorporates both semantic and syntactic features of the code, resulting in high detection performance. The proposed system achieves state-of-the-art results, providing developers with an effective tool for improving the security of their web applications.

3. **Srinivasan, S., & Tiwari, A. (2018). "Security Vulnerability Detection in Web Applications: A Machine Learning Approach."**

This paper explores the use of machine learning techniques for detecting security vulnerabilities in web applications. By utilizing a dataset of known vulnerabilities, the authors apply various machine learning models, such as decision trees and support vector machines, to predict potential vulnerabilities in web application code, including JavaScript. The study finds that machine learning-based methods can efficiently identify potential security flaws with high accuracy, making them a valuable addition to traditional security auditing methods.

4. **Yuan, L., & Shen, Y. (2020). "Learning to Identify Vulnerabilities in Source Code Using Static Analysis and Machine Learning."**

In this paper, the authors propose an integrated approach for identifying vulnerabilities in source code by combining static analysis techniques with machine learning models. By leveraging static code features and vulnerability patterns extracted from source code, the approach employs classifiers like

random forests and support vector machines to predict security vulnerabilities. This model is shown to effectively identify vulnerabilities in JavaScript code, contributing to enhanced security practices in web development.

5. **Xu, W., & Pan, Y. (2019). "Vulnerability Detection in JavaScript using ML Models and Static Code Analysis**

This paper introduces a machine learning-based approach for detecting vulnerabilities in JavaScript code using static code analysis. The authors combine traditional static analysis techniques with machine learning classifiers to detect security flaws such as injection vulnerabilities, cross-site scripting, and others. The experimental results show that their model can accurately predict vulnerabilities, offering a practical tool for security assessment in JavaScript-based web applications.

6. **Huang, C., & Liu, Y. (2020). "JS-Safe: A Machine Learning Framework for Identifying Vulnerabilities in JavaScript Programs."**

JS-Safe is a machine learning framework designed to detect vulnerabilities in JavaScript programs. The system utilizes a combination of static code analysis and machine learning algorithms to analyze JavaScript codebases and identify potential security threats. JS-Safe is trained on a large dataset of known vulnerabilities and can identify critical vulnerabilities such as security misconfigurations and improper handling of user input. The framework provides developers with an automated tool to enhance the security of their JavaScript applications.

7. **Tian, X., & Zhang, Y. (2018). "Static Analysis and Machine Learning for Detecting JavaScript Vulnerabilities."**

This paper investigates the integration of static analysis and machine learning techniques for detecting vulnerabilities in JavaScript applications. By applying static code analysis to extract features from JavaScript code and training a machine learning model on these features, the authors propose a method for identifying vulnerabilities such as buffer overflows, code injection, and other security flaws. The proposed system is evaluated on real-world JavaScript codebases, demonstrating the effectiveness of this hybrid approach in improving vulnerability detection accuracy.

8. **Liu, F., & Yuan, L. (2021). "Vulnerability Detection in JavaScript using Deep Neural Networks**

This paper presents an approach for detecting vulnerabilities in JavaScript code using deep neural networks (DNNs). The authors design a DNN-based model that learns patterns in code behavior to predict the presence of vulnerabilities. The model is trained on a large dataset of JavaScript code, including both secure and insecure code samples. Experimental results show that the proposed method can effectively detect a wide range of vulnerabilities in JavaScript applications, outperforming traditional static analysis techniques.

II. PROPOSED METHOD

In this project you ask to detect multiple Javascript vulnerability attacks by using ensemble voting classifier which will train vulnerability dataset with multiple classifiers and then vote out and select best performing model.

Each model will be evaluated with different metrics like accuracy precision, recall and FSCORE. To train model we have used Javascript vulnerability dataset which contains 3 different classes such as 'No Attack, SQL Injection and Javascript Vulnerability'. This dataset contains nearly 50000 instances and below screen displaying dataset details

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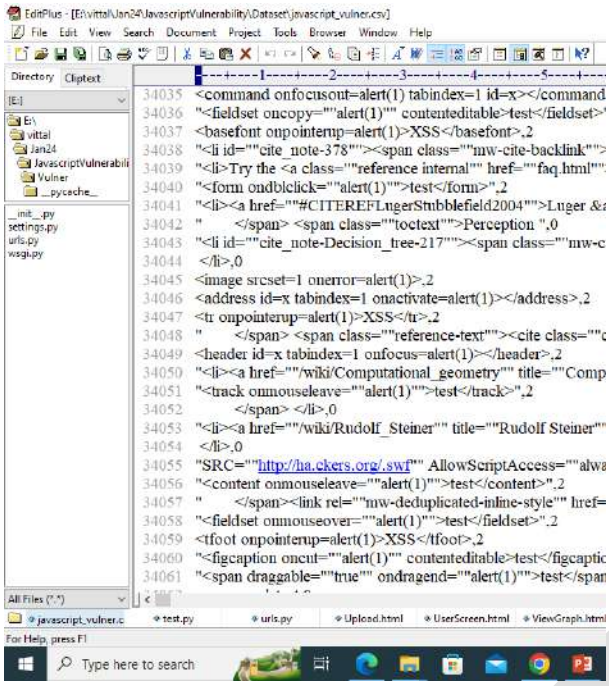
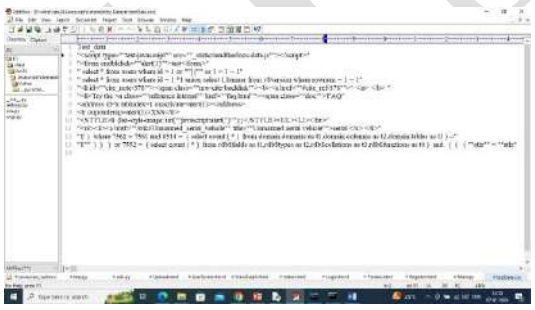


In above screen dataset contains two columns separated with comma were first column contains sentences related to Javascript code and SQL code and in last column we have class labels like 0 ('No Attack'), 1 (SQL injection vulnerability) and 2 (Javascript Vulnerability).

So to train Ensemble Classifier model we are using above dataset and this trained model will be applied on test Javascript and SQL codes to predict attack and in below screen we are showing some test codes



In above TEST codes screen we have only one column which contains Javascript and SQL code and there is no label available and after applying above test data on trained model we can get predicted attack type.

In below screen showing Ensemble classifier which will use 3 different classifiers such as SVM, Naïve Bayes and KNN.

In above screen read red colour comments to know about ensemble classifier training

To implement this project we have designed following modules.

1) User Register: As this is a web application so we are asking user to sign up with the application
2) User Login: registered user can login to application
3) Load Dataset: after login user can upload dataset which will be process by application and then convert entire dataset codes into numeric vector called TFIDF (term frequency inverse document frequency) which will replace each word in vector with average frequency. Processed dataset will be split into train and test where application using 80% dataset for training and 20% for testing
4) Run Ensemble Algorithms: 80% training data will be input to this module to train a classifier and this classifier will be applied on 20% test data to calculate prediction accuracy
5) Confusion Matrix Graph: using this module will plot predicted classes confusion matrix graph
6) Predict Vulnerability: in this module we will upload test data and then ensemble classifier will predict different vulnerability from uploaded test data

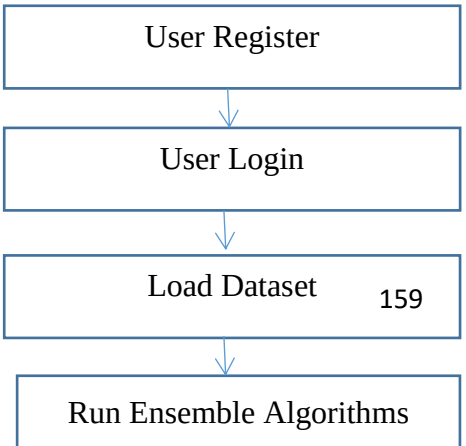


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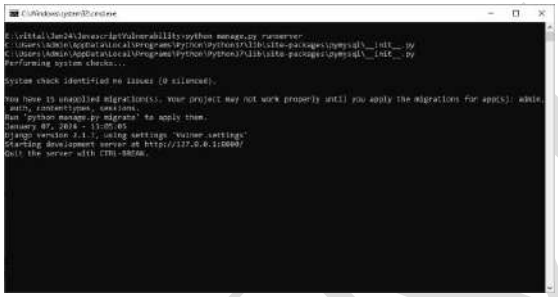
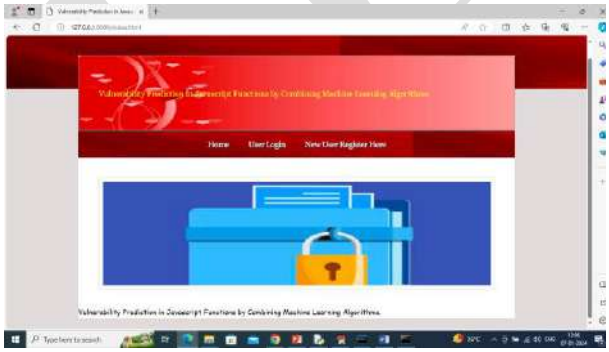
Fig Flowchart of proposed method

RESULT

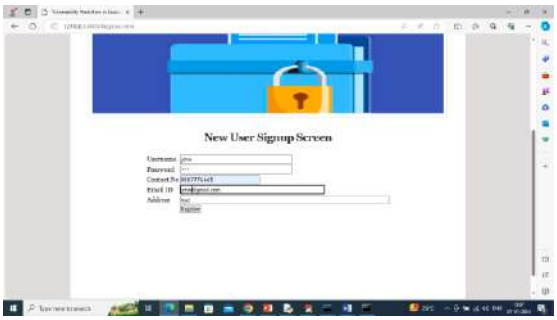
To run project double click on 'run.bat' file to start python web server and then will get below page



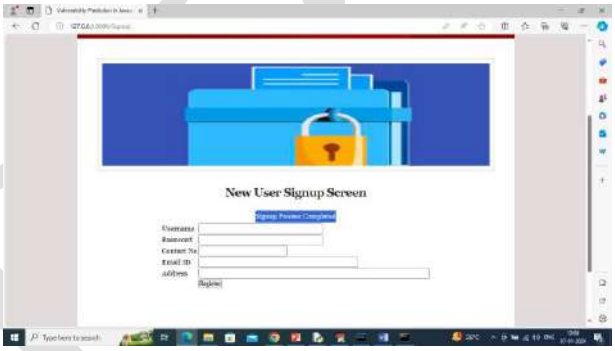
In above screen python web server started and now open browser and enter URL as http://127.0.0.1:8000/index.html and press enter key to get below page



In above screen click on 'New User Register Here' link to get below page

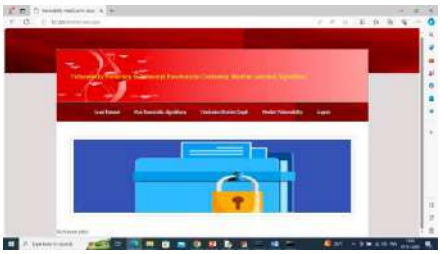


In above screen user is entering sign up details and then press enter key to get below page



In above screen sign up task completed and now click on 'User Login' link to get below page

In above screen user is login and after login will get below page



In above screen user can click on 'Load Dataset' link to get below page

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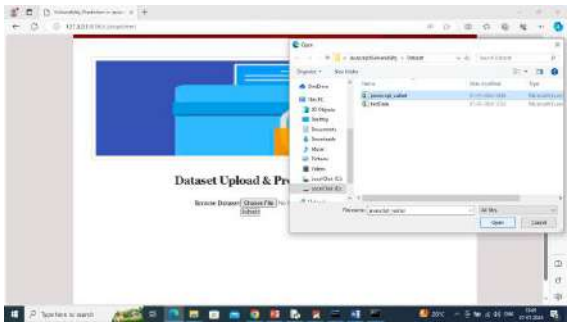
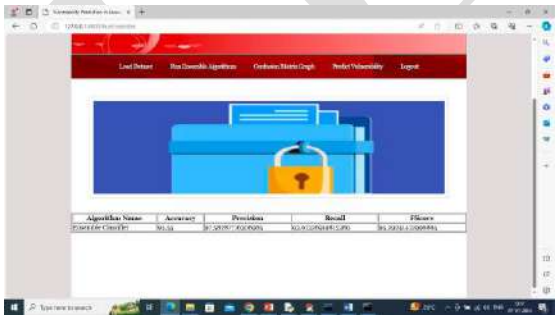


In above screen browse and upload 'javascript_vulner.csv' file and this file you can find inside 'Dataset' folder and then click on 'Open' and 'Submit' button to get below output

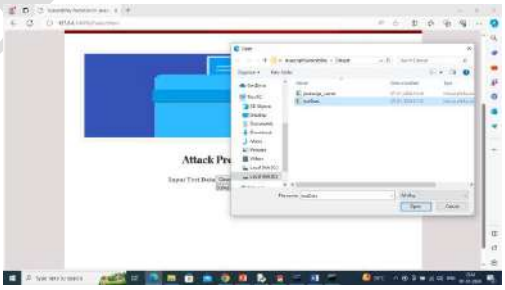
In above screen in blue colour text can see total dataset size and then can see train and test size and can see generated features vector and now click on 'Run Ensemble Algorithms' link to train all 3 classifiers on above features and then get accuracy of best performing model



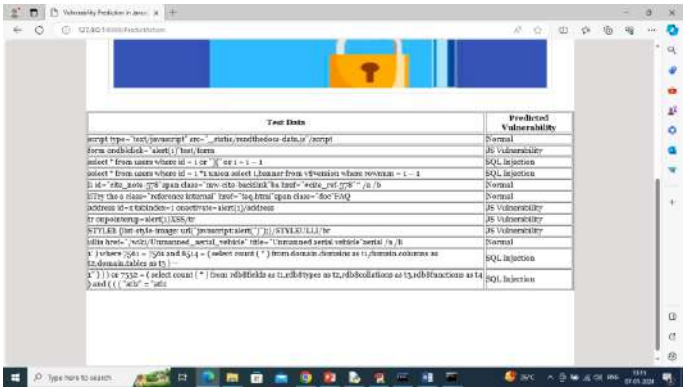
In above screen can see accuracy of ensemble classifier is more than 95% and can see other metrics like precision, recall and FSCORE and now click on 'Confusion Matrix Graph' link to get below page

In above confusion matrix graph x-axis represents Predicted Labels and y-axis represents true labels and all different colour boxes in diagnol represents correct prediction count and all blue boxes represents incorrect prediction count which are very few and now click on 'Predict Vulnerability' link to get below page

In above screen click on 'Choose File' and then upload test data file like below screen



In above screen selecting and uploading 'testData.csv' file and then click on 'Open' and 'Submit' button to get below output



In above screen in first column can see "test codes of SQL and Javascript' and in second column can see predicted attack type.

Similarly by following above screens you can run whole code and can add new attacks in 'testData.csv' file which is available inside 'Dataset' folder

CONCLUSION

In this paper, we published a novel JavaScript vulnerability dataset to be used for building prediction models. The dataset contains various JavaScript functions together with their static source code metrics and a flag indicating whether the function contains a vulnerability or not. This information was assembled by mining public vulnerability data sources of nsp and Snyk and collecting fixing patches from GitHub.

We presented an assessment of existing machine learning algorithms for building function level vulnerability prediction models using this dataset. We analyzed the performances of 8 different types of algorithms using the training set as is, and also by applying various re-sampling strategies.

Our results show that even for such a highly dynamic language as JavaScript, static source code metrics are suitable predictors of vulnerabilities. However, we experienced large variances in prediction performances depending on the applied sampling strategy and hyper-parameters. Using the appropriate machine learning algorithm (DNN, KNN, Tree, Forest, or SVM) and suitable hyper-parameters, a prediction with F-measure of 0.7 and above can be achieved. Nonetheless, there is a clear trade-off between precision and recall; over-sampling tends to improve recall, but decreases precision, while intensive under-sampling improves precision, but reduces recall significantly.

We plan to extend the set of predictors with history and textual metrics in order to further improve vulnerability prediction at the level of JavaScript functions.

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