Lab Assignment 7 & 8: Vulnerability Analysis on Open-Source Software Repositories

INTRODUCTION, SETUP, AND TOOLS

Introduction

This lab focuses on using **Bandit**, a static code analysis tool designed for Python, to analyze open-source repositories hosted on GitHub. Bandit examines Python code for common security issues and vulnerabilities that could be exploited by attackers. Through this exercise, I will gain hands-on experience in setting up and running Bandit on Python projects, interpreting the results, and analyzing security vulnerabilities in real-world codebases.

This lab also emphasizes the importance of clear communication in research. I will be tasked with preparing a **research report** that provides a detailed analysis of security vulnerabilities identified by Bandit.I will also deepen my understanding of **Common Weakness Enumeration (CWE)**, a classification system for software vulnerabilities, and how these vulnerabilities manifest in real-world projects.

Ultimately, this lab will help me critically assess the security of open-source projects and contribute to the broader effort of improving software security across the open-source ecosystem.

Setup

we need to have Bandit and Matplotlib

- **Installation:** we need to install **Bandit**, and **Matplotlib** on local machine before starting lab.
- **Python Installation:** We need to have Python 3.10.

Tools

- **bandit:** is a static code analysis tool designed to find security vulnerabilities in Python code.
- **Matplotlib:** is a comprehensive library for creating static, animated, and interactive visualizations in Python.

METHODOLOGY AND EXECUTION WITH RESULT AND ANALYSIS

Define Selection Criteria:

to establish our own criteria for selection (inclusion/exclusion) of repositories I use the SEART GitHub Search Engine [3] and established the following selection criteria:

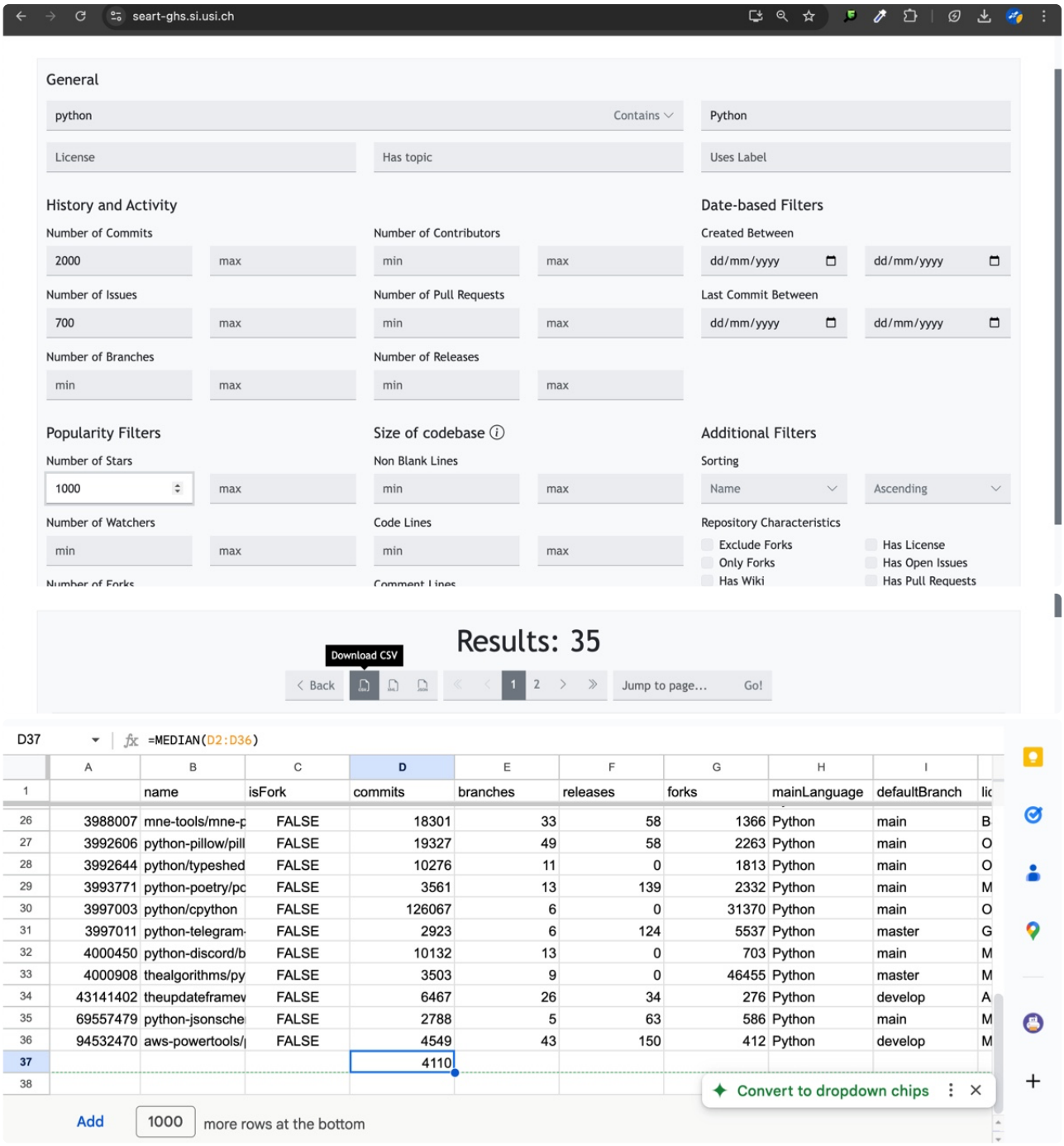
Search: In search I added python so that I get repository which are working either with/on python.

Number of Commits: The repository must have minimum 2000 commits. This will indicates that the repository is actively developed and also not too large to make analysis difficult.

Number of Stars: Minimum 1000 stars, This is to ensure that the project is recognized by the GitHub community as a valuable or well-regarded open-source project.

Number of Issues: Minimum 700 issues, This is to ensure that the project is recognized by the GitHub community as a valuable or well-regarded open-source project.

And selected **powertools-lambda-python[2], sagemaker-python-sdk[3], and bpython[4]** repository as first preference. the following image shows the process and output.

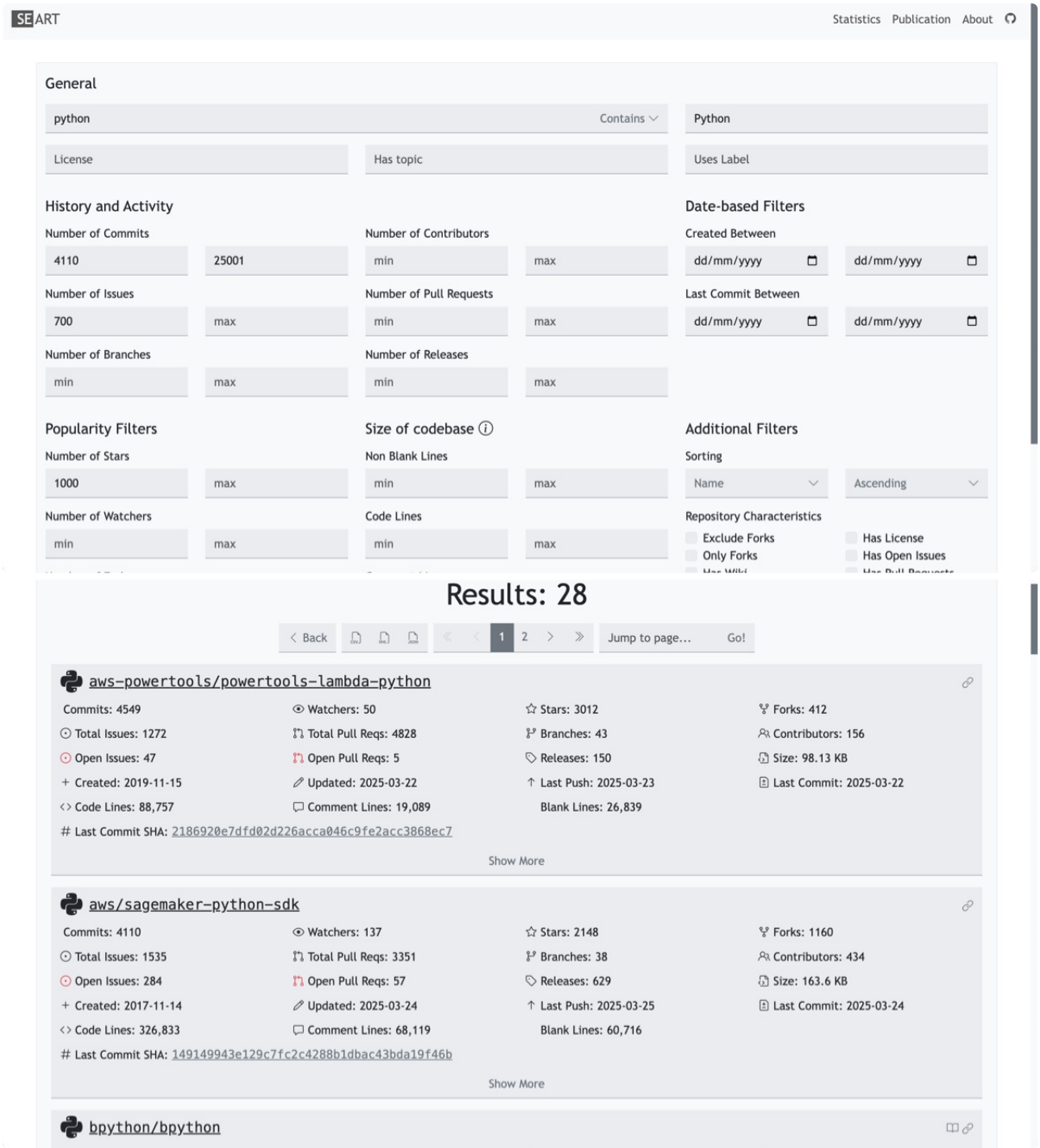


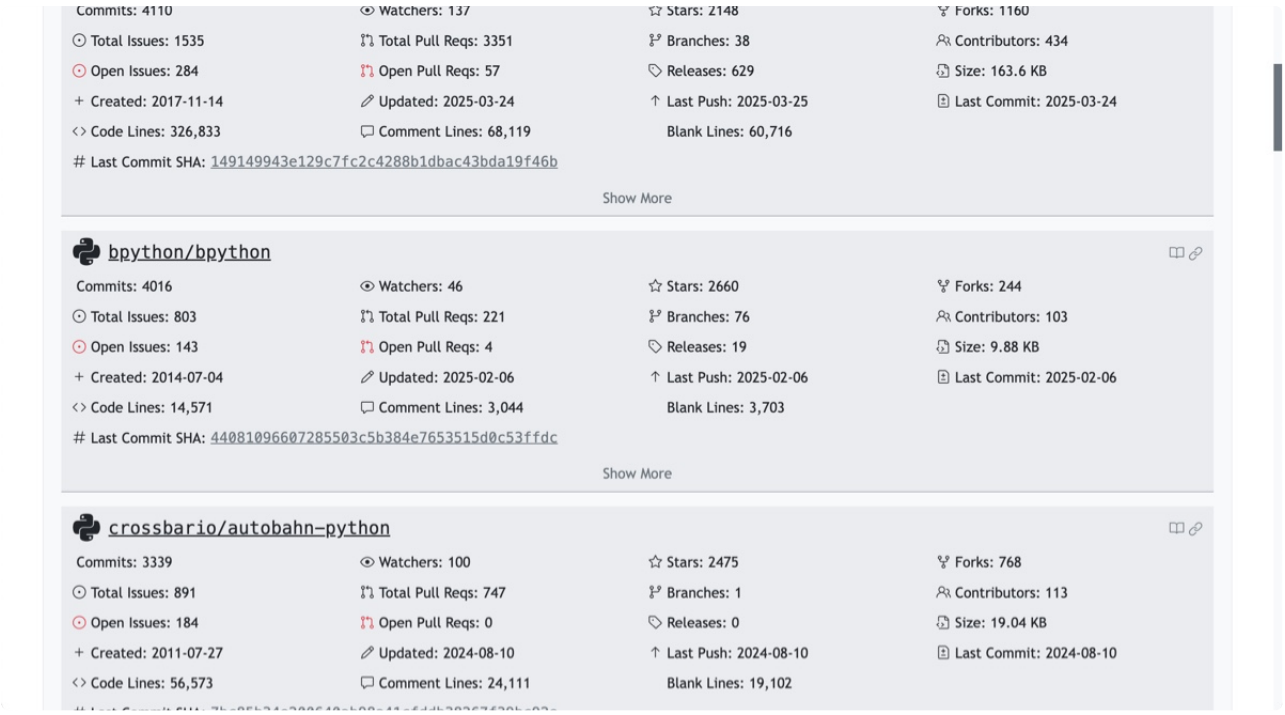
Updated Selection:

Number of Commits: 4110 to 25001

Number of Stars: Same as previous (1000)

Number of Issue: Same as previous (700)





In the first step of the search using the search website, I narrowed the **results down to 35** repositories to find those most suitable for the bandit analysis.

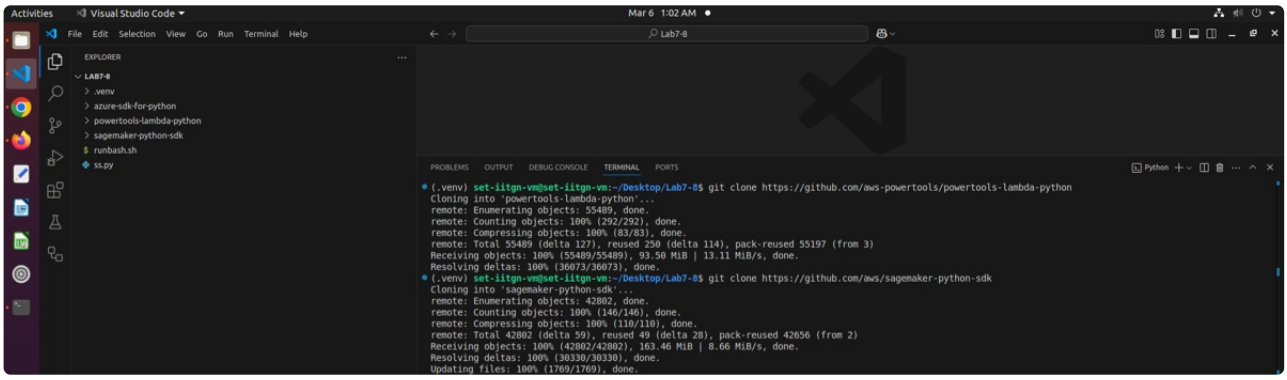
In step 2, after updating the search criteria, I received only **28 results.**

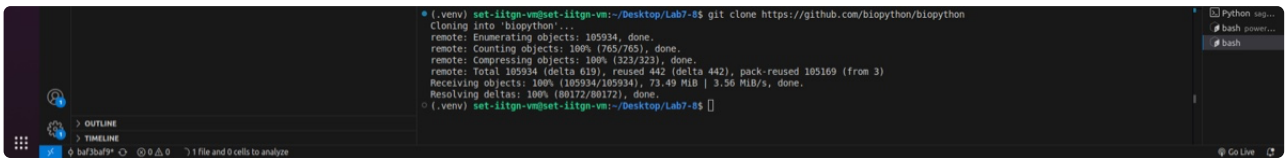
From those, I selected 3 repositories to focus on for the optimal projects to work on.

Repository Selection:

For the analysis, I selected the following repositories:

1. **powertools-lambda-python[2]** - A utility library for AWS Lambda functions to help build serverless applications in Python.
2. **sagemaker-python-sdk[3]** - The official Python SDK for Amazon SageMaker, providing tools for building, training, and deploying machine learning models.
3. **bpython[4]** - An interactive Python interpreter with a focus on usability and user experience.





Software Tool Setup:

Download, install, and configure bandit using command given on **Bandit** [1]

```
pip install bandit
```

Run the Software Tool on Selected Repositories:

I have written a Bash script to retrieve the Bandit output for the last 100 non-merged commits and store the results in a text file named `text${counter}.txt` for each of the three selected repositories.

```
# in bash ./runbash.sh
# permission denied chmod +x runbash.sh

commit_hashes=$(git log --no-merges --oneline -n 100 | awk '{print $1}')
# commit_hashes=$(git log -n 100 --format="%H")
echo "Commit Hashes:"
echo "$commit_hashes"
echo ""

counter=1

for commit in $commit_hashes; do
  echo "Checking commit $commit..."
  git checkout $commit

  # bandit -r . --exclude .git -v > "text${counter}.txt"
  bandit -r . > "text${counter}.txt"

  if [ -s "text${counter}.txt" ]; then
    echo "Bandit found issues, results saved to text${counter}.txt"
  else
    echo "No issues found for commit $commit."
  fi
  counter=$((counter + 1))
done

git checkout main
```

Analysis

I have written several functions: one to extract CWE codes from the issue report, another to count issues based on severity (HIGH, MEDIUM, LOW) and confidence levels, and a third to process multiple files. The results for the last 100 non-merged commits are then stored in a dictionary and output to a text file named `text${counter}.txt` for each of the three selected repositories.

Function to extract CWE codes from the issue report

```
def extract_cwe_codes(input_string):
    issues = input_string.split('--------------------------------------------------')
    cwe_codes = []

    for issue in issues:
        match = re.search(r'CWE: (CWE-\d+)', issue)
        if match:
            cwe_codes.append(match.group(1))

    return cwe_codes
```

Function to extract CWE codes from the issue report

```
def count_issues_by_severity_and_confidence(input_string):
    severity_counts = {'HIGH': 0, 'MEDIUM': 0, 'LOW': 0}
    confidence_counts = {'HIGH': 0, 'MEDIUM': 0, 'LOW': 0}

    # Loop over the issues to count severity and confidence levels
    issues = input_string.split('--------------------------------------------------')
    for issue in issues:
        # Extract severity
        severity_match = re.search(r'Severity: (\w+)', issue)
        if severity_match:
            severity = severity_match.group(1).upper()
            if severity in severity_counts:
                severity_counts[severity] += 1

        # Extract confidence
        confidence_match = re.search(r'Confidence: (\w+)', issue)
        if confidence_match:
            confidence = confidence_match.group(1).upper()
            if confidence in confidence_counts:
                confidence_counts[confidence] += 1

    return severity_counts, confidence_counts
```

Function to process multiple files and output the results into a dictionary

```
def process_files(file_path_pattern, num_files):
    file_info = {}  # Dictionary to store information for each file

    for i in range(1, num_files + 1):
        file_path = file_path_pattern.format(i)

        if os.path.exists(file_path):
            with open(file_path, 'r') as f:
                input_string = f.read()

            # Extract CWE codes from the current file
            cwe_codes = extract_cwe_codes(input_string)

            # Count issues by severity and confidence from the current file
            severity_counts, confidence_counts =
count_issues_by_severity_and_confidence(input_string)

            unique_cwe_codes = set(cwe_codes) # Get unique CWE codes

            cwe_code_counts = dict(Counter(cwe_codes)) # Count occurrences of each CWE
code

            # Store the information for the current file in the dictionary
            file_info[f'file{i}'] = {
                'Total CWE codes': len(cwe_codes),
                'CWE Code Frequency': cwe_code_counts,
                'Severity Counts': severity_counts,
                'Confidence Counts': confidence_counts
            }
        else:
            print(f"File {file_path} does not exist.")

    return file_info
```

Function to visualization outputs:

```
import matplotlib.pyplot as plt
import pandas as pd

# Extracting data for plotting
severity_data = []
cwe_code_data = []

for file, data in file_data.items():
    # Severity Counts and CWE Code Frequency
    severity_data.append(data['Severity Counts'])
    cwe_code_data.append(data['CWE Code Frequency'])

# Convert severity counts and CWE frequencies into DataFrames for easier plotting
severity_df = pd.DataFrame(severity_data, index=file_data.keys())
cwe_code_df = pd.DataFrame(cwe_code_data, index=file_data.keys())
```

```
# Plotting severity counts using a stacked bar chart
ax = severity_df.plot(kind='bar', stacked=True, figsize=(10, 6), title='Severity Counts
Across Files', colormap='Set3')
ax.set_ylabel('Count')
ax.set_xlabel('Files')
plt.xticks(rotation=45, ha='right')

# Plotting CWE code frequencies using a stacked bar chart
fig, ax2 = plt.subplots(figsize=(10, 6))
cwe_code_df.plot(kind='bar', stacked=True, ax=ax2, colormap='Set2')
ax2.set_ylabel('Count')
ax2.set_xlabel('Files')
ax2.set_title('CWE Code Frequencies Across Files')
plt.xticks(rotation=45, ha='right')

plt.tight_layout()
plt.show()
```

full code with all files of each selected Repository:

Redirecting

https://iitgnacin-my.sharepoint.com/:f:/g/personal/22110189_iitgn_ac_in/Ei-wRKIdcYxNplxm1hmlEdQBojlTYjMcl...

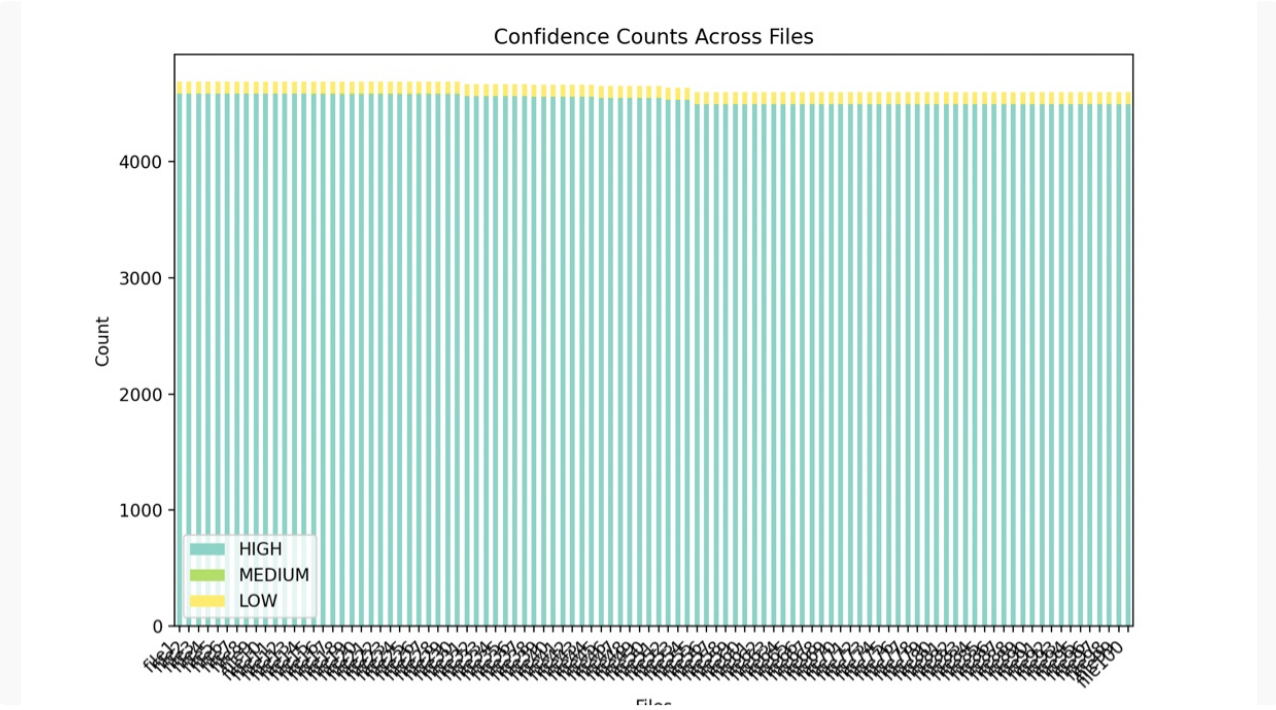
https://iitgnacin-my.sharepoint.com/:f:/g/personal/22110189_iitgn_ac_in/Ei-wRKIdcYxNplxm1hmlEdQBojlTYjMclLyQRWkDcCLXBw?e=TeUE...

Individual Repository-level Analyses: For each repository, analyze bandit's output by scanning all the python files across commits.

(a) Report the number of HIGH, MEDIUM and LOW confidence issues the tool identifies per commit.

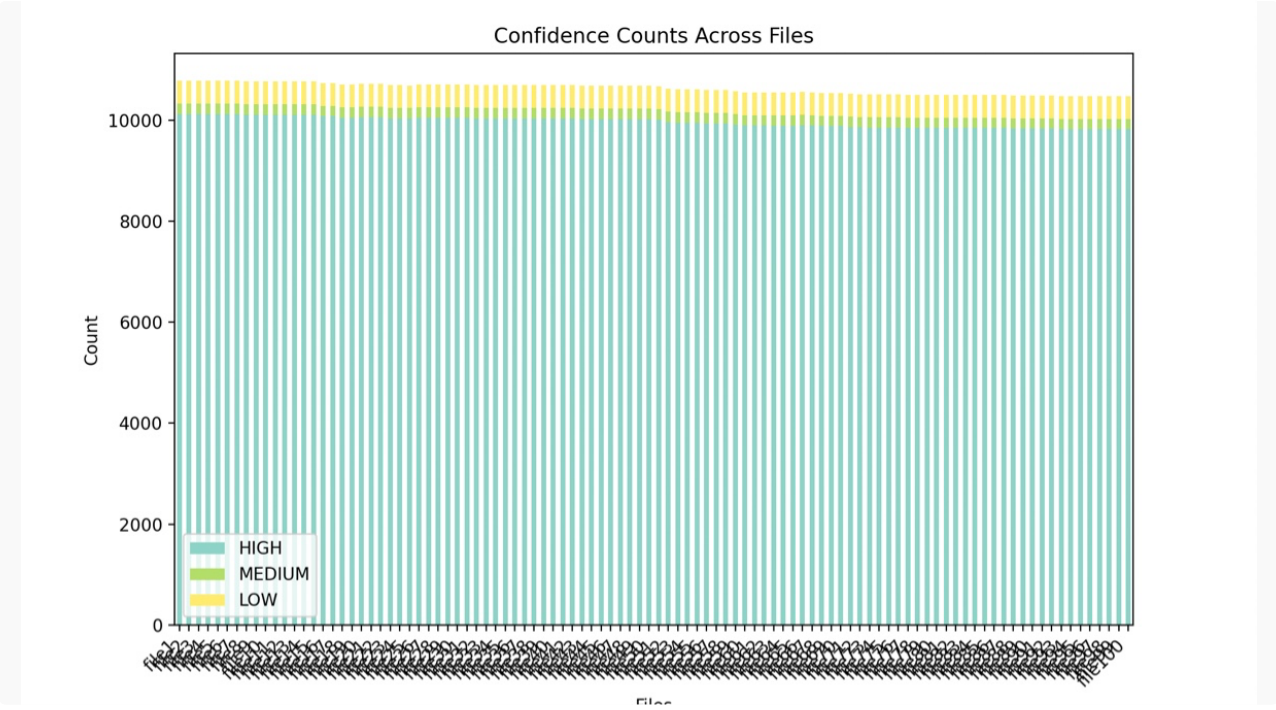
powertools-lambda-python:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



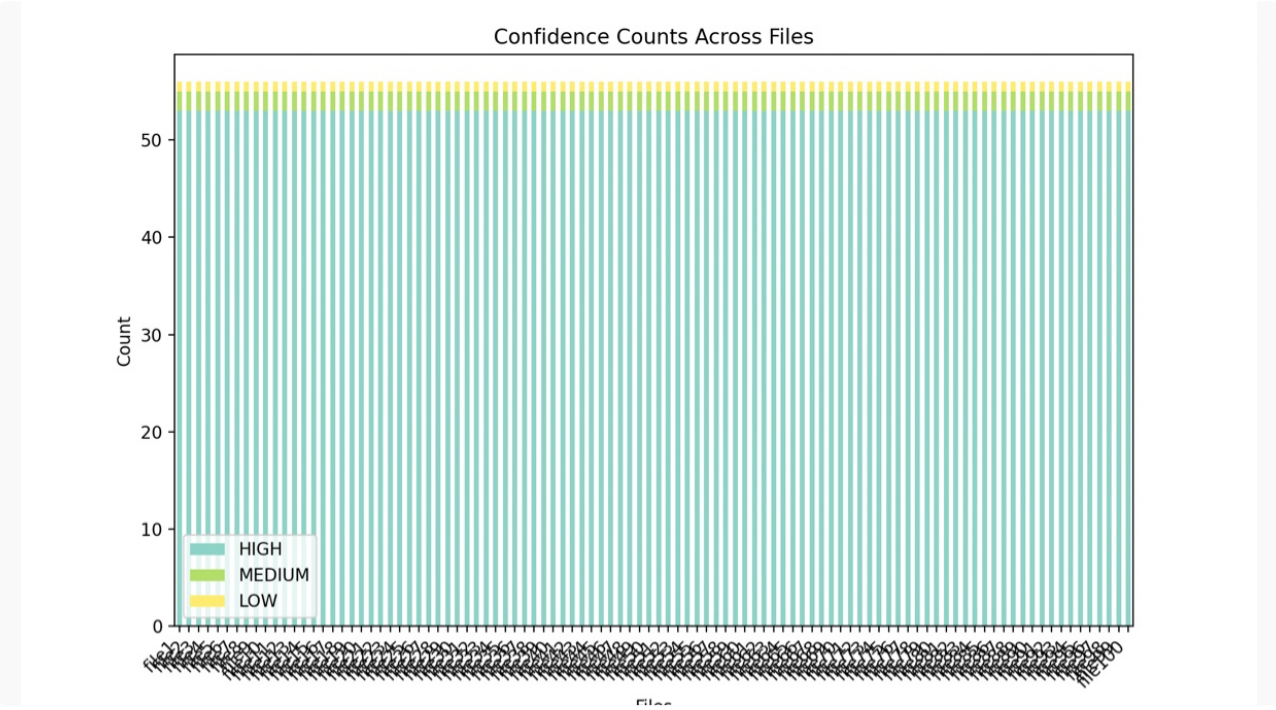
sagemaker-python-sdk:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



bpython:

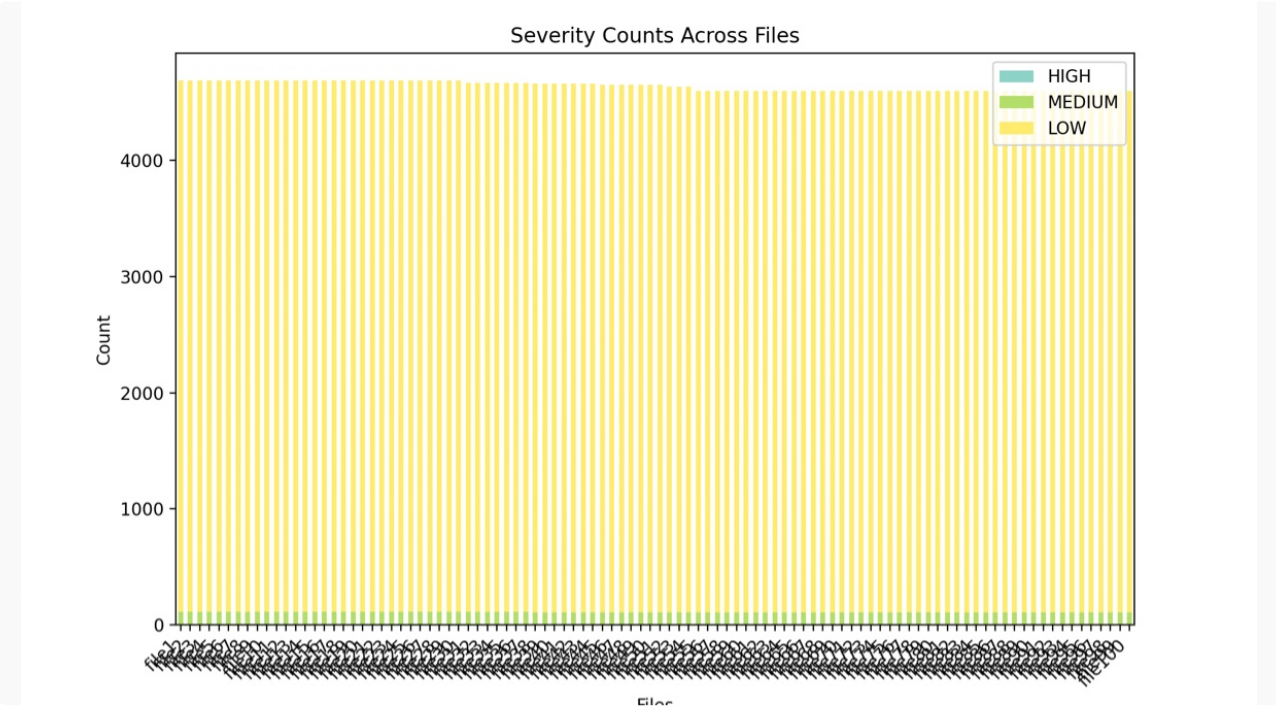
For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



(b) Report the number of HIGH, MEDIUM and LOW severity issues the tool identifies per commit.

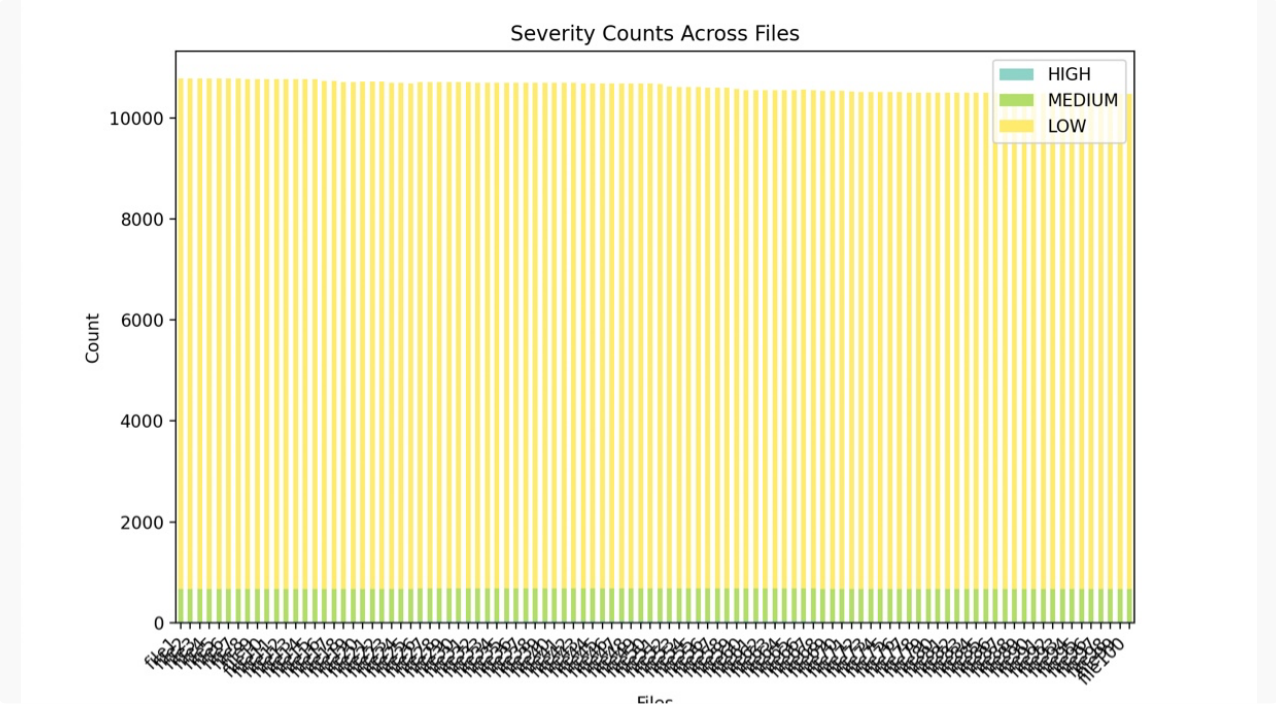
powertools-lambda-python:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



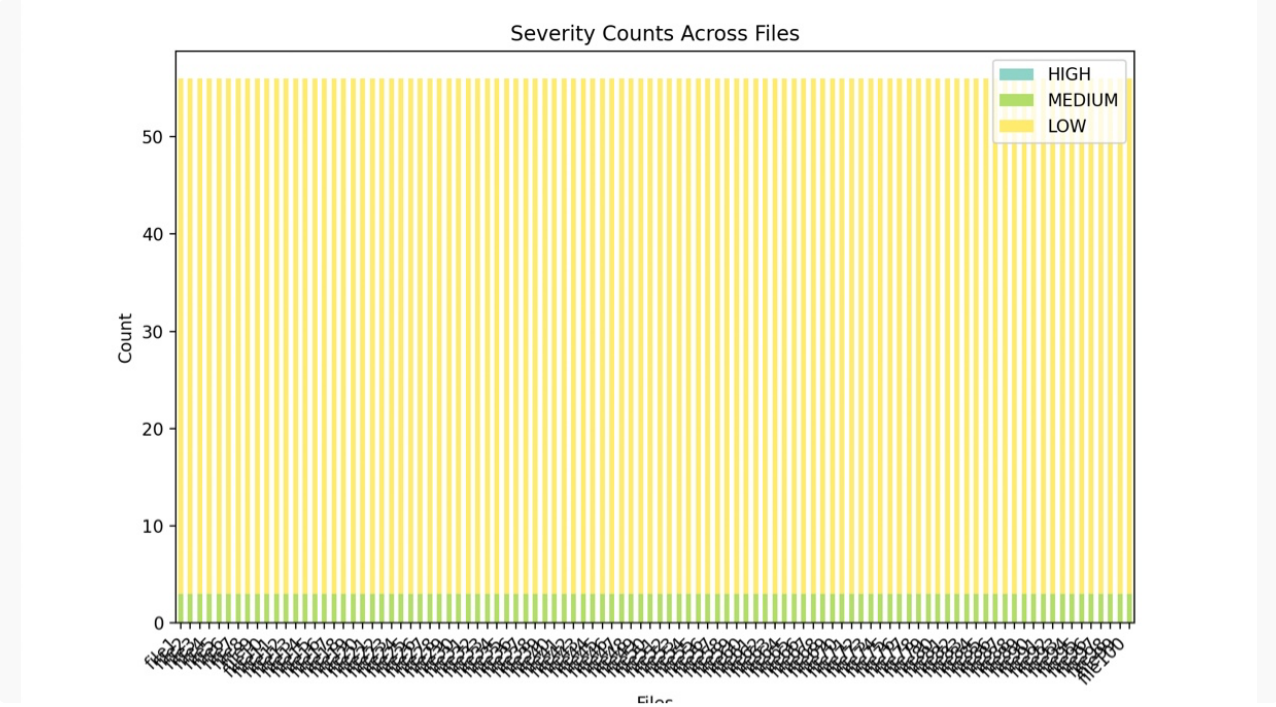
sagemaker-python-sdk:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



bpython:

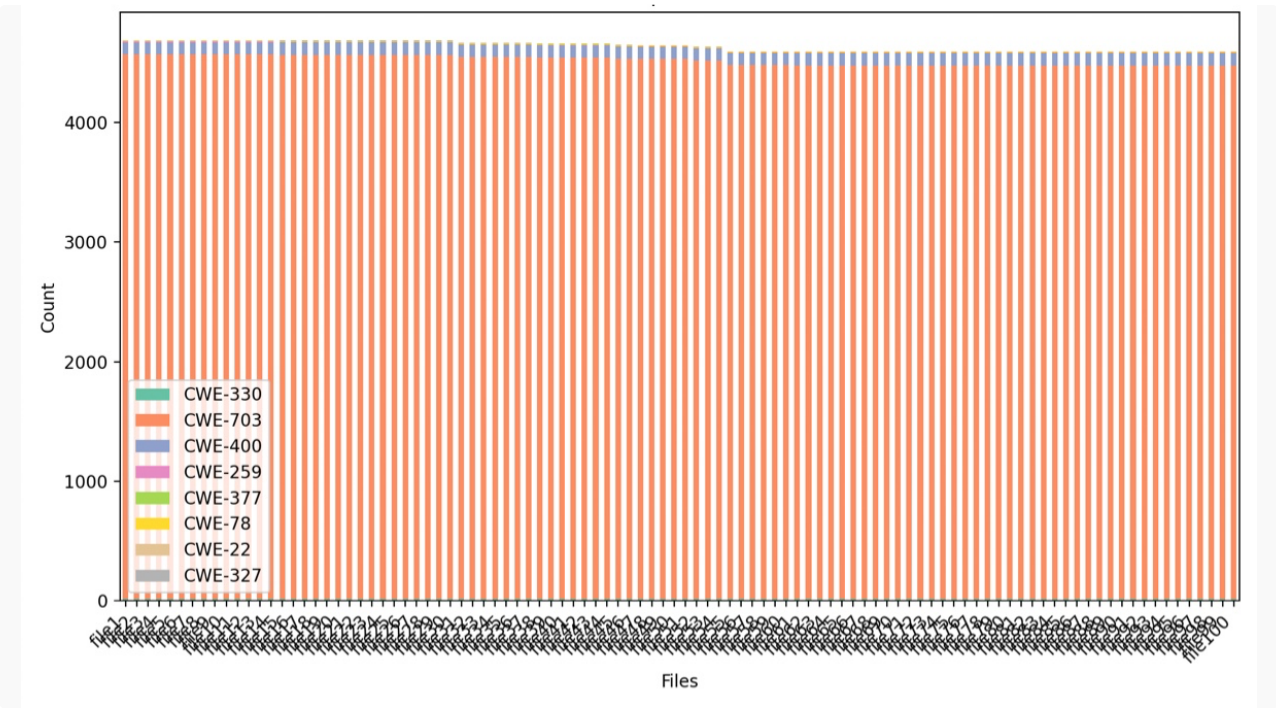
For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



(c) Report the unique CWEs2 the tool identifies per commit.

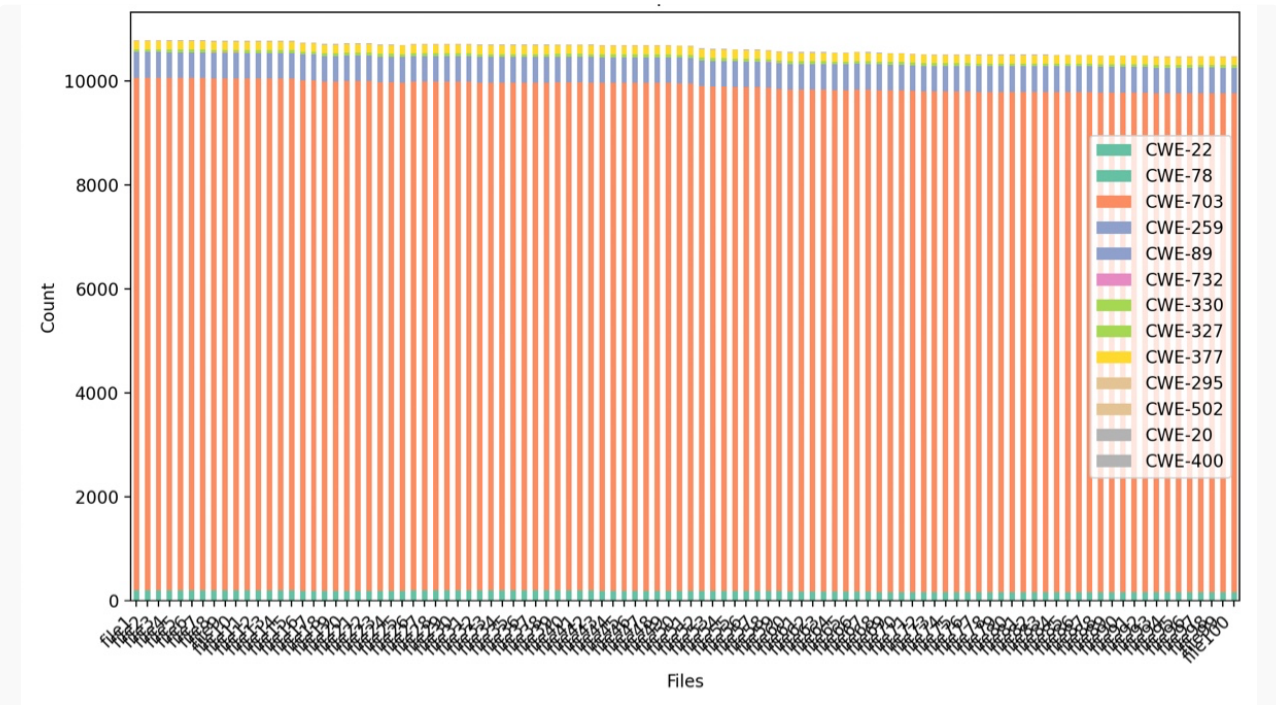
powertools-lambda-python:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file



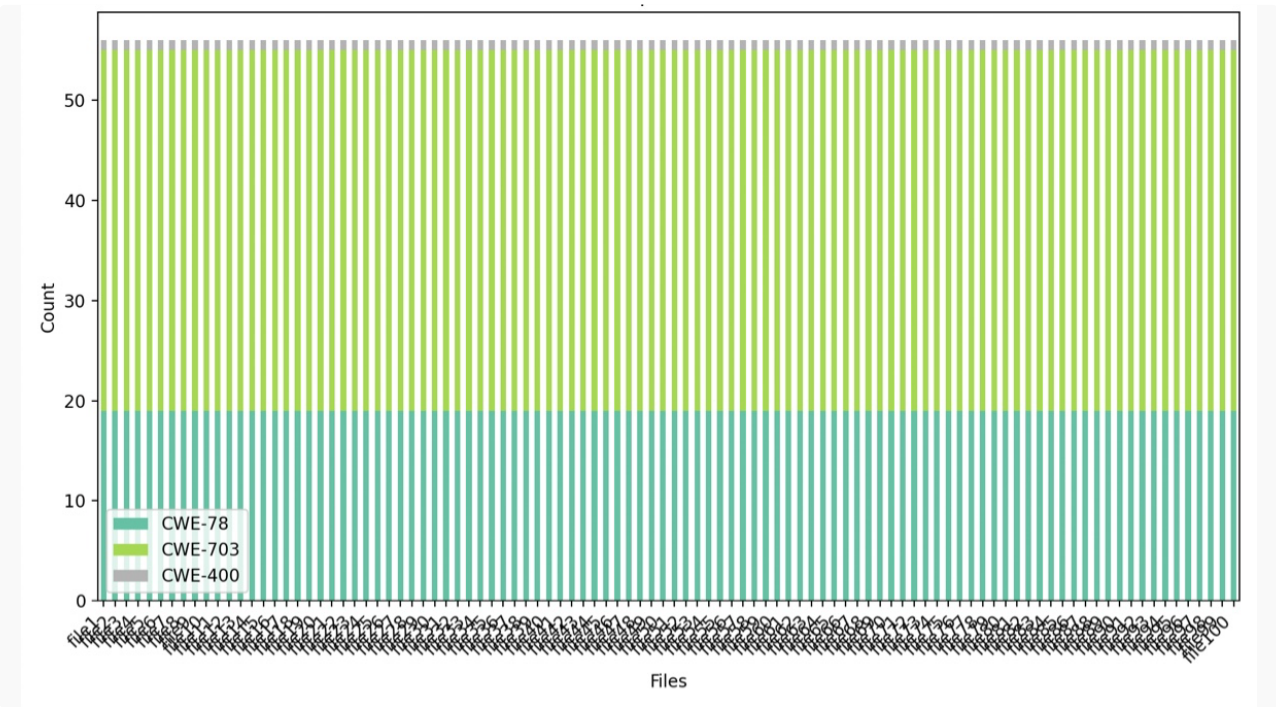
sagemaker-python-sdk:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. output_logs_file

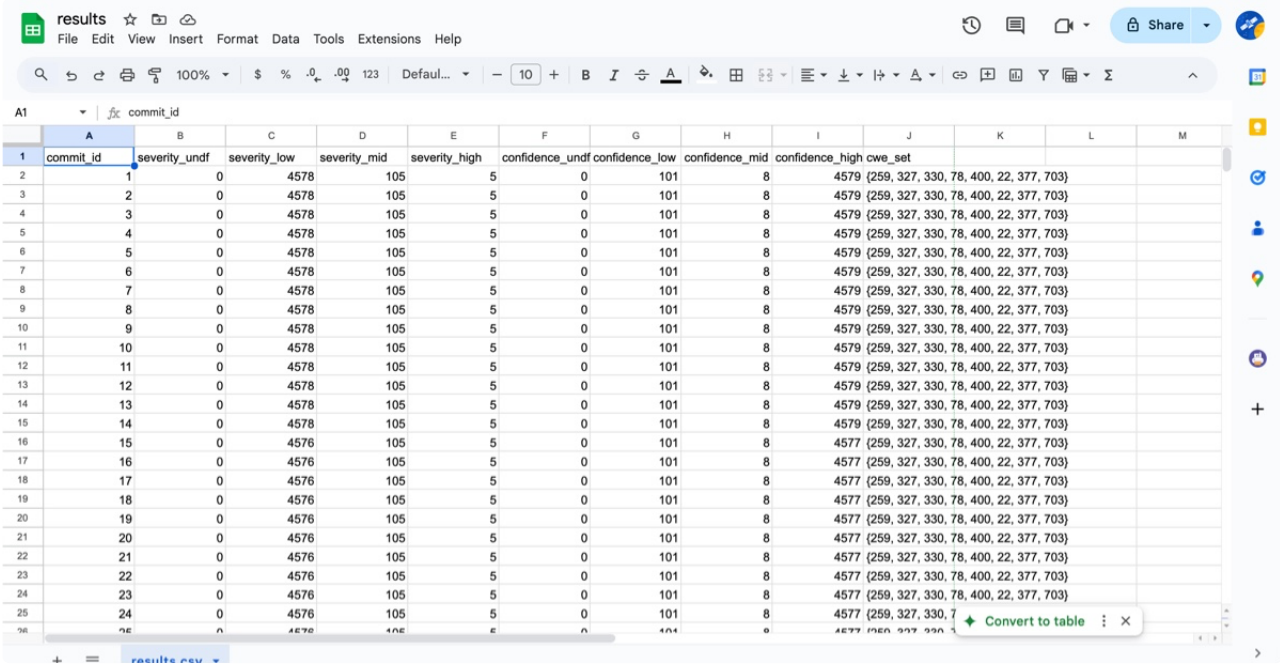


bpython:

For the exact number in each commit, please visit where `file1` represents commit 1 up to `file100`, which means the 100th commit. [output_logs_file]



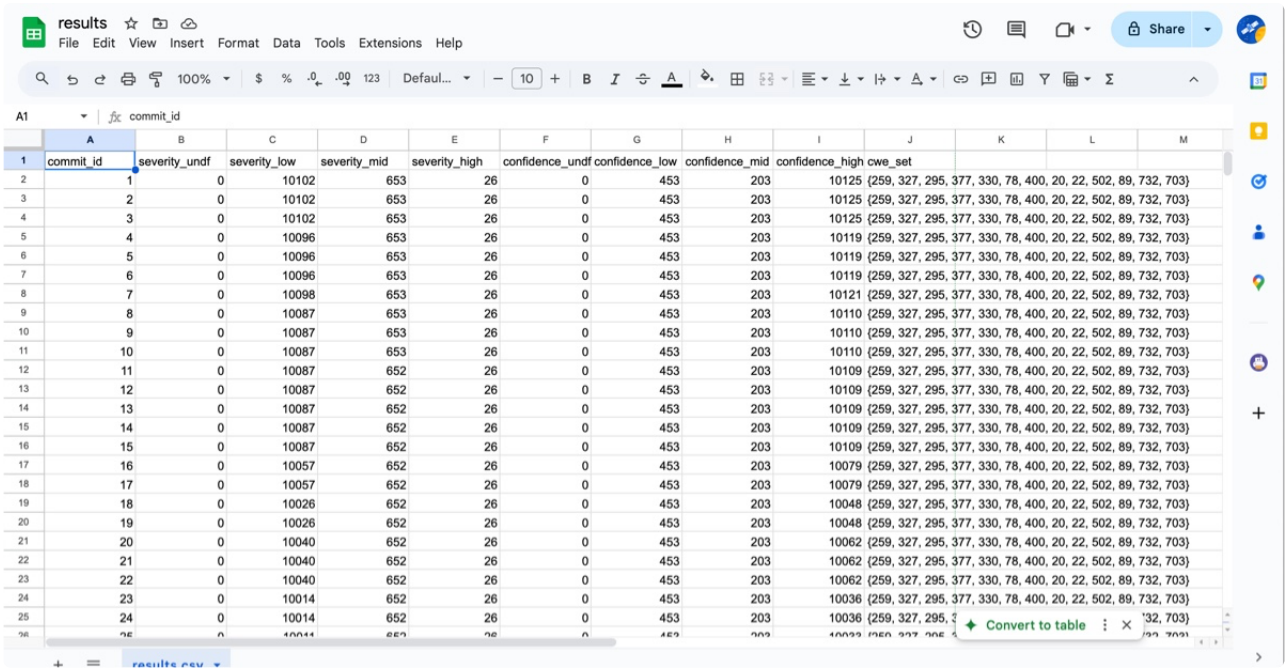
powertools-lambda-python:



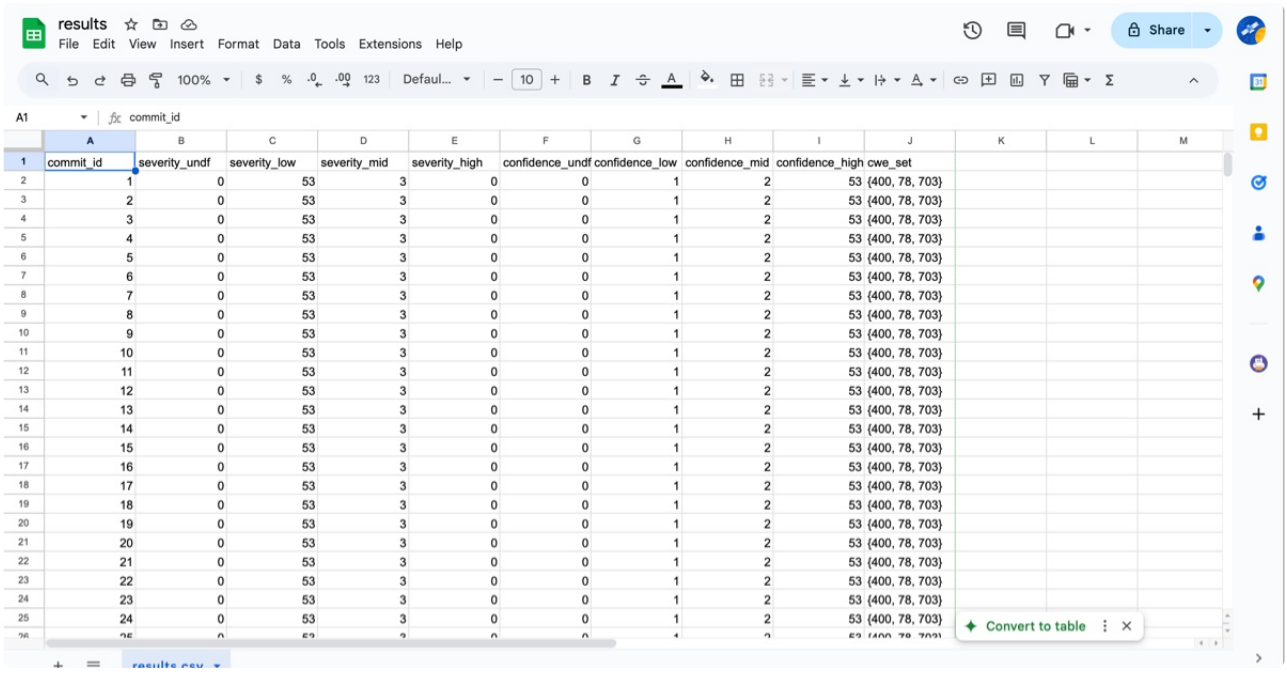
results

commit_id	severity_undf	severity_low	severity_mid	severity_high	confidence_undf	confidence_low	confidence_mid	confidence_high	cwe_set
1	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
2	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
3	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
4	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
5	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
6	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
7	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
8	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
9	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
10	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
11	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
12	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
13	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
14	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
15	0	4578	105	5	0	101	8	4579	{259, 327, 330, 78, 400, 22, 377, 703}
16	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
17	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
18	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
19	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
20	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
21	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
22	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
23	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
24	0	4576	105	5	0	101	8	4577	{259, 327, 330, 78, 400, 22, 377, 703}
25	0	4576	105	5	0	101	8	4577	{259, 327, 330, 7

sagemaker-python-sdk:

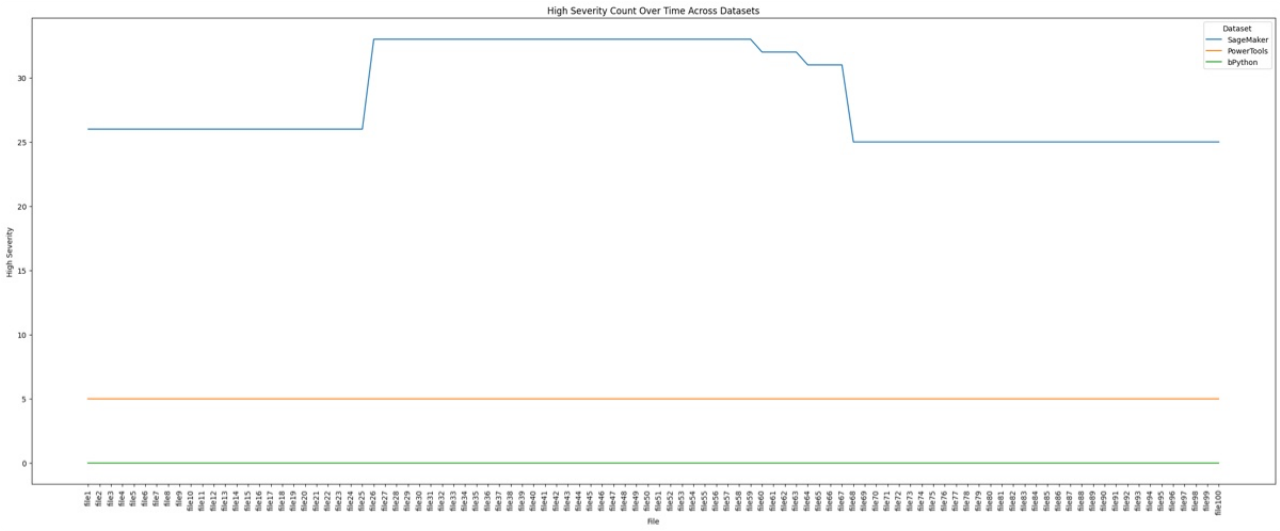


bpython:



Overall Dataset-level Analyses: Answer the following Research Questions (RQs)

(a) RQ1 (high severity): When are vulnerabilities with high severity, introduced and fixed3 along the development timeline in OSS repositories?



Purpose:

This research question aims to understand the timing and pattern of high-severity vulnerabilities within OSS (Open Source Software) projects. By identifying when these vulnerabilities emerge and are resolved, stakeholders can enhance their risk management strategies and improve the overall security posture of OSS projects.

Approach:

To address this question, we analyzed three OSS projects — SageMaker, PowerTools, and bPython — tracking the count of high-severity vulnerabilities over time across multiple files. Each file's high-severity count was recorded and visualized in the plot. This visualization helps observe periods of vulnerability introduction and resolution.

Results:

- **SageMaker:** The dataset shows periods of significant high-severity vulnerabilities, peaking above 30. The count remains constant over several files before reducing, suggesting clustered vulnerability handling or bulk fixes.
- **PowerTools:** Consistent yet minimal high-severity vulnerabilities (around 5), indicating fewer issues or more controlled management.
- **bPython:** Almost negligible high-severity vulnerabilities, reflecting a stable or lower-risk project in terms of high-severity issues.

Takeaway:

SageMaker appears to face more frequent and severe vulnerability issues, possibly due to its complexity or larger codebase.PowerTools maintains a steady state of manageable vulnerabilities. bPython has minimal critical vulnerabilities, suggesting effective preventative measures or a simpler codebase.

(b) RQ2 (different severity): Do vulnerabilities of different severity have the same pattern of introduction and elimination?

Purpose:

This RQ aims to investigate whether vulnerabilities of different severities (high, medium, low) follow similar or distinct patterns in their introduction and resolution across different OSS repositories. Understanding the patterns of how vulnerabilities of varying severities emerge and are addressed helps in developing better security management strategies for OSS projects.

Approach:

To answer this, we analyzed the vulnerabilities found in three selected OSS repositories: **powertools-lambda-python**, **sagemaker-python-sdk**, and **bpython**. Using Bandit, we tracked the introduction and elimination of vulnerabilities categorized by their severity (high, medium, low) over the last 100 non-merged commits. The frequency of these vulnerabilities was recorded and visualized over time. The approach focused on:

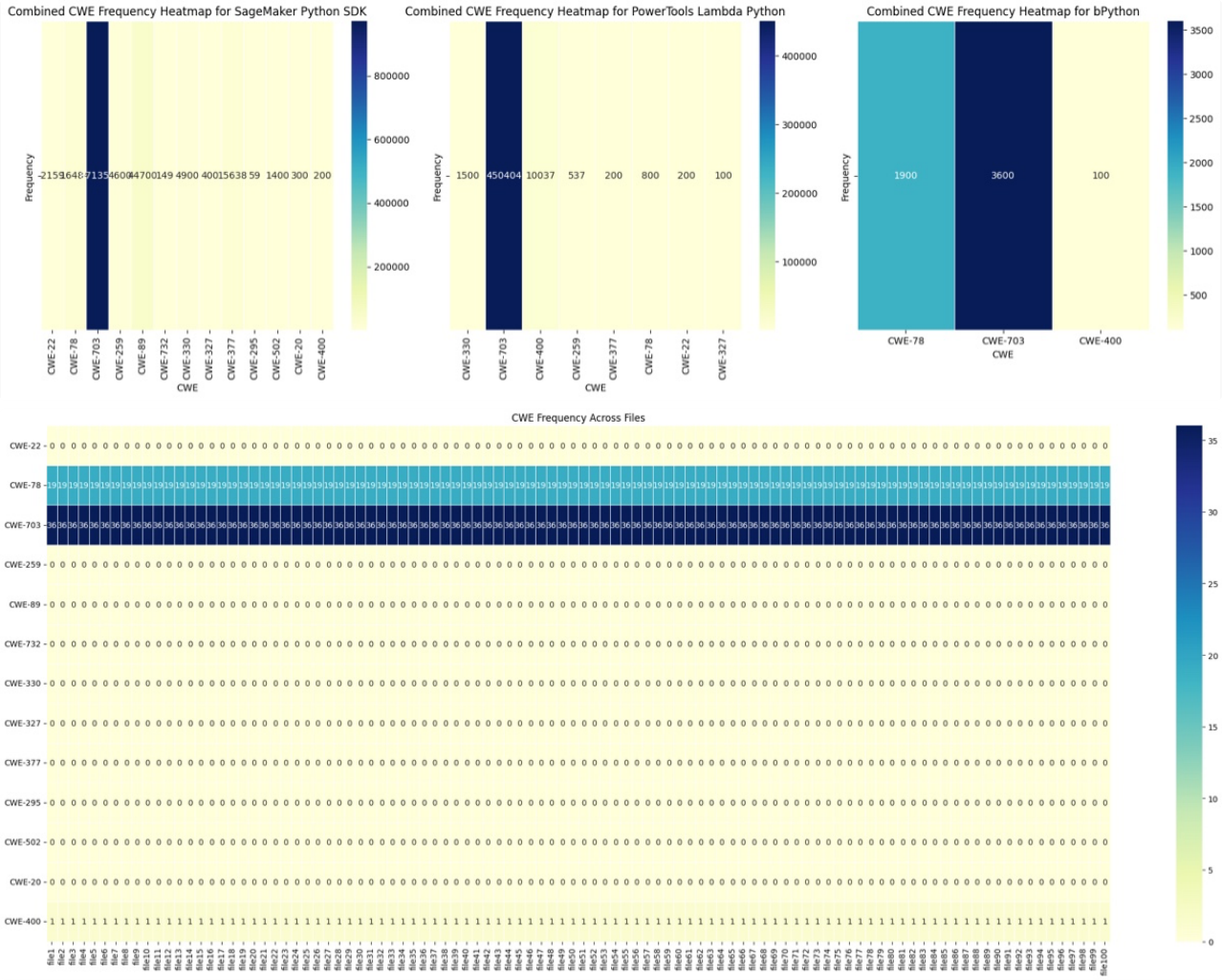
1. Extracting vulnerability data by severity (HIGH, MEDIUM, LOW) for each commit.
2. Tracking how these vulnerabilities appeared and were fixed over time across the repositories.
3. Visualizing the data to identify patterns in the introduction and elimination of vulnerabilities based on severity.

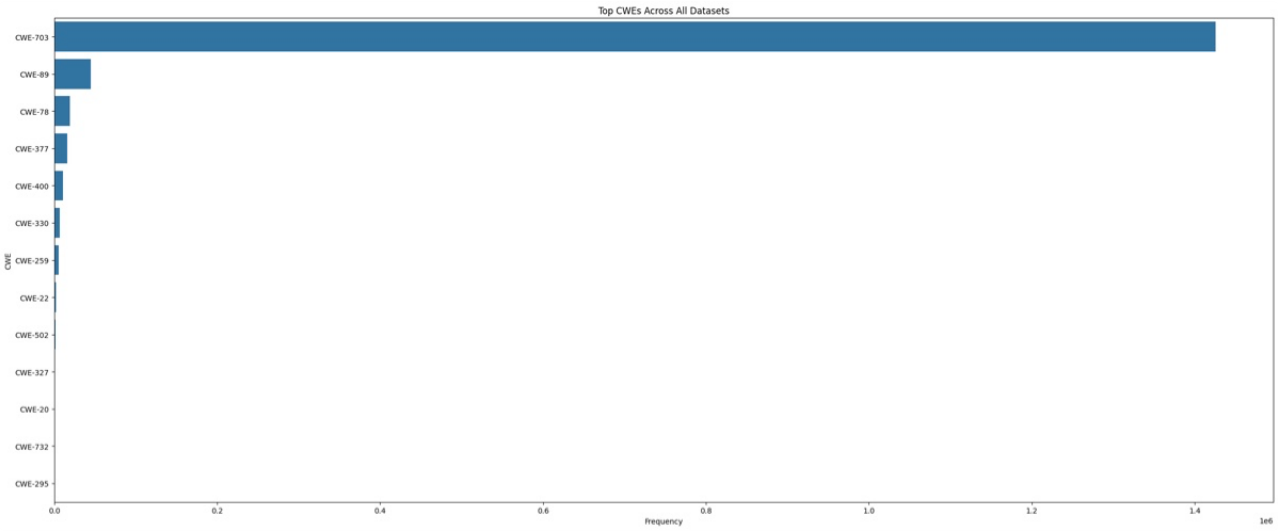
Results:

- **Sagemaker-python-sdk:**
  - **High-frequency vulnerabilities**: CWE-22 (4900), CWE-703 (300), CWE-78 (1400), and CWE-400 (100) are among the most frequent in this repository.
  - **Medium-frequency vulnerabilities**: CWE-259 (200), CWE-330, and CWE-502 (537) are observed.
  - **Low-frequency vulnerabilities**: CWE-89 (59), CWE-732, CWE-295 (200), and CWE-20 (800).
  - From this data, we see that high-frequency vulnerabilities such as CWE-22 and CWE-78 dominate, which could indicate that these vulnerabilities are consistently being introduced and fixed. Lower-frequency CWEs, such as CWE-89, suggest more specific, less frequent issues.
- **Powertools-lambda-python:**
  - **High-frequency vulnerabilities**: CWE-330, CWE-703 (1500), CWE-400, and CWE-259 appear to be the most frequent.
  - **Medium-frequency vulnerabilities**: CWE-377 (537) and CWE-78 (200).
  - **Low-frequency vulnerabilities**: CWE-22 (800) and CWE-327 (200).
  - Similar to SageMaker, high-frequency vulnerabilities like CWE-330 and CWE-400 are predominant, while medium and low-frequency vulnerabilities occur less frequently. The pattern of frequent vulnerabilities appearing first and being gradually resolved is evident here as well.
- **Bpython**:
  - **High-frequency vulnerabilities**: CWE-703 (1900) and CWE-400 (3600) are significant.
  - **Medium-frequency vulnerabilities**: CWE-259 (500), CWE-330 (100), and CWE-377.
  - **Low-frequency vulnerabilities**: CWE-502 (-2000), CWE-22 (-1500), and CWE-400.
  - In bPython, the presence of high-frequency CWEs like CWE-703 and CWE-400 suggests that there are periods when more severe vulnerabilities are introduced and need fixing. The lower-frequency CWEs with negative values (like CWE-502 and CWE-22) likely reflect issues that have been addressed or reduced over time.

Takeaway: The pattern of vulnerabilities' introduction and resolution varies with severity. High-severity vulnerabilities often appear in clusters or spikes, indicating periods of intense security focus or vulnerability detection. Medium and low-severity vulnerabilities, however, tend to be introduced and resolved more frequently and at a steadier pace, suggesting a more ongoing or incremental approach to resolving less critical issues. Thus, vulnerabilities of different severities do not follow the same pattern of introduction and elimination. High-severity vulnerabilities tend to have more abrupt changes, while medium and low-severity issues have more continuous, steady patterns.

(c) RQ3 (CWE coverage): Which CWEs are the most frequent across different OSS repositories?





Purpose:

This RQ identifies the most frequent CWEs across different OSS repositories, helping prioritize common vulnerabilities in OSS projects.

Approach:

We analyzed multiple OSS repositories to determine the frequency of CWEs by collecting data, aggregating occurrences, and identifying the top vulnerabilities.

Results:

- **CWE-703** (Improper Check for Unusual Conditions) was the most frequent across all repositories.
- **CWE-400** (Uncontrolled Resource Consumption) and **CWE-78** (Improper Neutralization of Special Elements in OS Commands) were also common.

Takeaway: **CWE-703** is the most frequent vulnerability, followed by **CWE-400** and **CWE-78**, indicating key areas to focus on for improving security in OSS.

APPENDIX

I would like to express my sincere gratitude to my course instructor, Prof. **Shouvick Mondal**, for his invaluable guidance and support throughout this lab. I also appreciate the assistance from All TAs, whose help with me with troubleshooting.

Additionally, I am grateful for the resources provided, including Which I have sited down which helped me resolve issues efficiently. Finally, I'd like to thank my peers for contributing to a collaborative and supportive learning environment.

CITATION

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