TKH Coventry University

Faculty of Computing

Ethical Hacking and Cybersecurity

Automated Fuzzer (Code Healer)

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Declaration of Originality/Statement of Copyright/Ethics

I hereby declare that this dissertation, Code Healer: A revolutionary Approach to Automated Software testing Using ChatGPT and Google Gemini, is an original work and has been conducted and executed solely by me, Ramy Naiem, in fulfillment of the requirements for the degree of Ethical Hacking at TKH Coventry University.

Every effort has been made to ensure that the content of this dissertation is accurate and plagiarism free. Any Contributions or citations from the work of others has been referenced in accordance with the academic standards and ethical guidelines provided by the University.

I have ensured that all sources of information like journal articles and online resources have been properly credited.

In conclusion, I confirm that this dissertation represents a genuine and original contribution to the field of software testing and cybersecurity. I sincerely hope that the findings and innovations presented will contribute to the knowledge and practice in this domain.

Introduction

Background

The idea of the Code Healer project can be traced back to the presentation that was held by intel at our university, focusing on the concept of fuzzing. This presentation shined a light on the significance of fuzzing in software development and cybersecurity. Intrigued by the potential of fuzzing tools, I engaged with the speaker to gain more information about how AI is employed in the fuzzing process. Surprisingly, AI was not yet a component of their fuzzing process which ignited the idea for my project. With the passion for AI and its potential to enhance the daily workflows, I envisioned an innovative approach to software development / testing that integrates AI to automate the fuzzing process.

Problem statement

Traditional fuzzing tools / methods despite their advancements remain challenging for many users. The complexity of the tools often deters developers from utilizing them, resulting in a lack of widespread adoption. The manual debugging methods associated with traditional fuzzing are time consuming and prone to overlooking vulnerabilities. This project addresses these challenges by making fuzzers more accessible and user friendly, transforming them into a standard tool to be used by all software developers. Integrating AI specifically ChatGPT and Gemini into the projects to streamline the process of identifying and providing solutions on how to resolve software vulnerabilities. This enhances the overall efficiency and reliability of software development.

Objectives

The primary objective of the code healer project is to develop a solution that automates error handling, vulnerability detection and resolution suggestion using AI. The integration of

ChatGPT and Gemini is designed to assist the user in identifying and addressing issues that have been discovered during the fuzzing process. This not only aims to enhance the security and stability of the code but also to reduce the time and resources required for debugging. By providing software developers with solutions on how to fix issues, the project aspires to save valuable time and allow them to focus on more important tasks.

Significance

The integration of AI into the fuzzing workflow represents a significant advancement in the field of software testing and cybersecurity. By automating the process of detection of vulnerabilities and generating potential solutions. The project aims to improve the traditional software testing process. The anticipated impact on the industry includes the increased adaptation of fuzzing tools, improved code security and more efficient way to the debugging process. Developers can leverage the automated fuzzers to identify vulnerabilities and potential fixes. This accelerates the development cycle and enhancing the overall quality of the software.

Personal Contribution

The unique perspective and skills in AI and software development have been important in shaping the project. This project aligns with my career goals of integrating AI into practical applications to solve real world problems. By focusing on providing actionable solutions rather than just identifying an issue. The project sets itself apart in the landscape of automated testing tools. My commitment to advancing software security drives the innovation behind code healer, with the goal of contributing to the industry standards and best practices.

Literature Review

Tradition Software Testing Methods

Software testing is a critical phase in the software development lifecycle, ensuring the reliability and security of applications. Traditional testing methods include unit testing, system testing, integration testing and acceptance testing. All the mentioned methods have their strengths and limitations.

- Myers, G. J., Sandler, C., & Badgett, T. (2011). The Art of Software Testing (3rd ed.). Wiley.
- Bertolino, A. (2007). Software Testing Research: Achievements, Challenges, Dreams. Future of Software Engineering, 85-103.

Fuzzing Tools and Techniques

Fuzzing is a software testing technique that involves providing invalid, unexpected and random data to a program to discover vulnerabilities and bugs. Over the years fuzzing has improved into a powerful tool to identifying flaws in a code. However traditional fuzzing tools are often complex and require expertise to operate them effectively.

- Sutton, M., Greene, A., & Amini, P. (2007). Fuzzing: Brute Force Vulnerability Discovery. Addison-Wesley.
- Godefroid, P., Levin, M. Y., & Molnar, D. (2012). SAGE: Whitebox Fuzzing for Security Testing. Communications of the ACM, 55(3), 40-44.

AI in Software Testing

The integration of AI in software testing has opened new ways for automating and enhancing the testing process. AI driven tools can analyze vas amounts of data and predict potential issues. Machine learning algorithms can learn from past tests and improve future testing processes, making AI a very valuable technology to use in software testing / development.

- Ammann, P., & Offutt, J. (2016). Introduction to Software Testing (2nd ed.). Cambridge University Press.
- Grechanik, M., & Xie, T. (2010). Automated Software Testing: Emerging Techniques and Applications. IGI Global.

ChatGPT

ChatGPT is a AI that has been developed by OpenAI and it is a state of the art language model that uses natural language processing also called NLP to generate human like test based on the input it receives. The ability to understand the context and generate a coherent response makes it a perfect candidate for integration into an automated testing tool. By leveraging the capabilities of ChatGPT in my project Code Healer, my project aims to automate the debugging process and provide developers with solutions.

- Brown, T. B., Mann, B., Ryder, N., Subbiah, M., Kaplan, J. D., Dhariwal, P., ... & Amodei, D. (2020). Language Models are Few-Shot Learners. arXiv preprint arXiv:2005.14165.
- Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., ... & Polosukhin, I. (2017). Attention is All You Need. Advances in Neural Information Processing Systems, 30.

Gaps in Current Research

While significant progress / research has been made in both AI and fuzzing technology, there are still gaps that my project aims to address. Existing fuzzing tools are often complex and not user-friendly, deterring widespread adoption. While AI has been integrated into various aspects of software development its application in fuzzing remains limited. The code healer projects seek to bridge these gaps by developing a user-Friendly Ai integrated fuzzing tools that provides potential solutions to developers.

- Padhy, S., Panigrahi, P. K., & Rath, S. K. (2020). Artificial Intelligence in Software Engineering: Current Developments and Future Prospects. Journal of King Saud University-Computer and Information Sciences.
- Pastore, F., & Mariani, L. (2015). Automatic Detection of Software Failures: The Fuzz Testing Perspective. ACM Computing Surveys, 48(3), 44.

Methodology

Objective:

To understand current fuzzing techniques and how AI can enhance the automated testing process.

Steps:

1) Literature Review and Market Research: Analyze existing fuzzing tools and identify gaps.
2) ChatGPT and Gemini API exploration: Evaluate the capabilities and limitations of the ChatGPT API
3) Reporting: Compile findings into a detailed report

Timeline 1 month

Phase 2: Development of a Basic Fuzzer Framework

Objective: Create a scalable and robust fuzzer framework

1) Design Framework Architecture: Define the key components.
2) Implementation: Develop core components of the fuzzer
3) Initial Testing: Validate the functionality.

Timeline 1 month

Phase 3 integration of ChatGPT API

Objective:

Integration of the ChatGPT Api

Steps:

1) API Integration: Develop a python code to interface with the ChatGPT API
2) Enhancement of the Fuzzer: Incorporate AI-driven suggestions.
3) Testing and Evaluation: Conduct integration tests and analyze the AI suggestions.

Timeline: 2 months

Phase 4: Enhancement and report Generation

Objective:

Refine capabilities and develop a report generating feature using python.

Steps:

1) Feedback analysis: Collect and analyze Feedback.
2) Enhancement: Implement improvements and develop features
3) Report generation: Automate the documentation of the findings.

Timeline 3 months

Phase 5 Final testing, evaluation and report compilation

Objective:

Validate the final framework and compile a comprehensive project report.

Steps:

1) Comprehensive Testing: Conduct extensive tests using various codes to test the robustness of the framework.
2) Performance evaluation: Evaluate the system against performance metrics.
3) Project report compilation: Summarize the development process, testing process and recommendations.

Tools and techniques

1) Programming languages that were used: Python for developing the fuzzer framework and integrating the ChatGPT and Gemini API.
2) API: OpenAI's ChatGPT API and Google Gemini's API
3) Version control: GitHub for version control and collaboration

Challenges and mitigation

1) Accuracy of the language models: Regular validation of the AI generated solutions.
2) False positives: Algorithms to filter out false positives.
3) Privacy concerns: Anonymizing data and secure communication channels

Implementation

Framework development and Core components

The implementation of integrating AI into my project code healer involves a meticulous approach. Using the AFL ++ fuzzer automating various processes. This chapter provides an in-depth introduction to the development and integration phases while highlighting key components, methodologies and the challenges that were encountered along the way.

Programing languages that were used and their libraries:

I have used python as the primary programming language due to tis versatility and the extensive range of libraries for various use cases. The Main Libraries that were used in my project include:

- requests: For making HTTP requests to APIs.
- Path (from pathlib): For handling file paths.
- base64: For encoding and decoding data.
- subprocess: For running external processes.
- move (from shutil): For moving files.
- clang.cindex: For interacting with C/C++ code using Clang.
- re: For regular expression operations.
- os: For interacting with the operating system.
- shutil: For file operations.
- datetime: For handling date and time operations.
- google.generativeai (genai): For interacting with the Gemini API.
- openai: For interacting with the ChatGPT API.
- fpdf: For generating PDF reports.
- date (from datetime): For date operations.
- difflib: For comparing sequences.

These libraries support the diverse requirements of my project, this includes file handling and subprocess management to API request and report generation.

Framework Architecture:

The fuzzer framework is designed to the very modular and scalable depending on the different requirements. Ensuring that each component can be developed, tested and modified independently. The main components of my project are the following:

1. Downloader.py

- The downloader module is to automate the process of retrieving the code from GitHub repositories. It uses the requests library to make a http request and download the code from GitHub. This module ensures that always the newest code is used for the fuzzing process.

2. Auto compiler:

- This component is for compiling the downloaded code using gcc. The subprocess library is utilized to execute the compilation commands in the terminal. The auto compiler handles both C and C++ codes. This is a very important process for the fuzzing process.

3. Seed Generator:

- This module creates an initial input (Seed) for the fuzzer. The seeds are one of the most crucial steps for starting the fuzzing process and are designed to cover a wide range of different inputs to detect potential vulnerabilities.

4. mover

- The mover module organizes and moves files around in the work environment. It uses the shutil and os libraries, it ensures that the files are moved to the correct folders to continue the workflow.

5. Fuzzer starter:

- This component automates the execution of the AFL fuzzer. It automatically configures the setting and sets up already the predefined seed, settings and monitors its progress. The sub process library is used to manage the execution of the fuzzer.

6. API Integrator:

- The API integrator interacts with ChatGPT and Gemini API to analyze the crash output from AFL fuzzer to provide potential solutions in a txt file. This module formats the data so it can be sent to the AI API's.

7. Report Generator

- The report module combines the outputs from both APIs into a nice comprehensive PDF file. Using the FPDF library, it formats the data into a readable and professional looking document that developers can use to address the potential solution.

Development Process:

The process of the Code Healer project was carried out in several phases, each focusing on a different aspect of the system. This approach ensures functionality and compatibility with different fuzzers or programming languages. This approach ensured that each component was tested and validated before moving on to the next phase.

Detailed Technical summary of the modules

Downloader.py

This code is designed to automate the process of downloading the latest code from the specified GitHub repository. This module is essential to always fuzz the newest version of the code.

Code Breakdown:

```
import requests
from pathlib import Path
import base64
```

- Requests: This library is to make HTTP request to the GitHub API
- Path (Pathlib): This is for an object-oriented approach to handle the file system paths.
- Base64: This is used to decode base64 content, because the GitHub API sends the contents in a base 64 format.

```
repo_url = "https://api.github.com/repos/username/repository/contents/"
save_dir = Path("/path/to/save/directory")
```

- Repo_url: This is the API endpoint for the GitHub Repo
- Save_dir: This is the local directory where the file should be saved.

```
def download_file(file_path, save_path):
    response = requests.get(file_path)
    if response.status_code == 200:
        content = base64.b64decode(response.json()['content'])
        save_path.write_bytes(content)
    else:
        print(f"Failed to download {file_path}")
```

Parameters:

- File_path: URL of the file to be downloaded.

- Save_path: This is the local path where the file should be saved.

Functionality:

- File_path receives a HTTP get request
- It checks if the response status is ok with 200 OK
- Decodes the base 64 content and write it to the save_path
- Prints an error message if the request can't be queried.

```python
def download_repo(repo_url, save_dir):
    response = requests.get(repo_url)
    if response.status_code == 200:
        for item in response.json():
            if item['type'] == 'file':
                file_url = item['download_url']
                file_path = save_dir / item['path']
                file_path.parent.mkdir(parents=True, exist_ok=True)
                download_file(file_url, file_path)
            elif item['type'] == 'dir':
                download_repo(item['url'], save_dir)
    else:
        print(f"Failed to access {repo_url}")

```

Parameters:

- repo_url: URL of the repository to download
- save_dir : The local directory where the contents will be saved

Functionality:

- Sends a HTTP request to the repo_url
- Checks if the response is 200
- Iterates through each code in the repository.
- If the found item is a file:
  Constructs the download URL with file_url and local save path file_path
  - Creates needed directories with (file_path.parent.mkdir(parents=True, exist_ok=True)).
  - Calls download_file to download the file

- If the item is in a directory
    - It calls it recursively download_repo with the directory URL
- Prints an error message if the request fails.

Starting the download process:

```
download_repo(repo_url, save_dir)
```

Calls download_repo with the repo URL and saves the directory to start the download process.

Autocompiler.py

```
import subprocess
from pathlib import Path
import os
```

- Subprocess: this is used to run external process in our case we used it for the GCC compiler.
- Path (pathlib): This is for an object-oriented approach to handle the file system paths.
- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.

```
source_dir = Path("/home/ramy/Desktop/folda/waiting")
compiled_dir = Path("/home/ramy/Desktop/folda/compiled")
new_dir = Path("/home/ramy/Desktop/folda/new")
```

- Source_dir: Directory that contains the source file that is going to be compiled.
- Compiled_dir: Directory where the compiled code will be saved.
- New_dir: Direcotry where the latest source file will be moved after compilation.

```python
def compile_latest_source():
    # Get the list of source files in the source directory
    source_files = sorted(source_dir.glob("*.c") + source_dir.glob("*.cpp"),
key=os.path.getmtime)

    # Check if there are any source files
    if not source_files:
        print("No source files found.")
        return

    # Get the latest source file
    latest_source = source_files[-1]
    compiled_path = compiled_dir / latest_source.name.replace(".c",
"").replace(".cpp", "")

    # Determine the compiler to use
    compiler = "gcc" if latest_source.suffix == ".c" else "g++"

    # Compile the source file
    compile_cmd = [compiler, latest_source, "-o", compiled_path]
    result = subprocess.run(compile_cmd, capture_output=True, text=True)

    # Check if the compilation was successful
    if result.returncode == 0:
        print(f"Compiled {latest_source} successfully.")
        # Move the compiled file to the new directory
        new_file_path = new_dir / latest_source.name
        os.rename(latest_source, new_file_path)
    else:
        print(f"Failed to compile {latest_source}.\n{result.stderr}")
```

Parameters: Doesn't use any parameters because it uses globally defined directories.

Functionality:

- Retrieves a sorted list of the c code and the cpp files in the source_dir that are ordered by the modification time.

- Checks if any codes are found, if there a re none it will print an error message and exit
- Identifies the latest source file and determines based on that if it is a c code or a cpp code and will choose the appropriate compiler to compile the file.
- Automatically creates the command and runs it using subprocess.run
- When the compilation is successful it will print a success message and move the file to the new_dir and rename the source file. If the compilation fails it will print an error with the compiler's output.

```
compiled_dir.mkdir(parents=True, exist_ok=True)
new_dir.mkdir(parents=True, exist_ok=True)
```

Ensures that the compild_dir and the new_dir exist and if they aren't it will create them.

```
compile_latest_source()
```

Calls compile_latest_source to start the compilation process.

Analyzer.py

```
import clang.cindex
from clang.cindex import Index, TokenKind
import re
import os
```

- Clang.cindex: this is used for parsing the c and the C++ code and also for the tokens for using the Clangs AST.
- Re: utilizes regular expression operations
- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.

Directory setup:

```
DIRECTORY = "./new"
```

Directory: This specifies the directory in which the c codes files are located

Finding the newest c or c ++ code:

```python
def find_newest_c_or_cpp_file(directory):
    """Finds the newest .c or .cpp file in the specified directory."""
    newest_file = None
    newest_mtime = 0
    for filename in os.listdir(directory):
        if not filename.endswith(('.c', '.cpp')):
            continue
        filepath = os.path.join(directory, filename)
        mtime = os.path.getmtime(filepath)
        if mtime > newest_mtime:
            newest_file = filepath
            newest_mtime = mtime
    return newest_file
```

find_newest_c_or_cpp_file: this is the function that the searches for specified directory to find the newest modified c code file.

Extracting the regular expressions and literals:

```python
def extract_with_regex(file_path):
    """Extracts string and numerical literals from the file using regex."""
    regex_patterns = [
        r'"([^"\\]*(?:\\.[^"\\]*)*)"',  # String literals
        r'\b\d+\b'  # Numerical constants
    ]
    seeds = set()
    with open(file_path, 'r') as file:
        content = file.read()
        for pattern in regex_patterns:
            seeds.update(re.findall(pattern, content))
    return seeds
```

extract_with_regex: this function reads the content of the code and uses regular expressions to extract the strings and numerical constants. Then it returns a set of those literals.

Extracting Literals with Clang:

```
def extract_with_ast(file_path):
    """Extracts string literals from the file using the Clang AST."""
    index = Index.create()
    translation_unit = index.parse(file_path)
    seeds = set()
    for token in translation_unit.cursor.get_tokens():
        if token.kind == TokenKind.LITERAL and token.spelling.startswith('"'):
            seeds.add(token.spelling)
    return seeds
```

extract_with_ast this function uses the Clangs ast to parse the code and extract the string literals. It also returns these literals.

Generating exploit seeds:

```
def generate_exploit_seeds():
    """Generates a set of seeds designed to test common vulnerabilities."""
    buffer_size = 50  # Example buffer size based on typical vulnerable buffer
lengths
    return {
        "",  # Empty string
        "A" * (buffer_size - 1),  # Just below boundary
        "A" * buffer_size,  # At boundary
        "A" * (buffer_size + 1),  # Just over boundary
        "%s%p%x%d",  # Common format string exploits
        "AAAA" + "\x00" + "BBBB",  # Null byte injection
        ";\nls\n",  # Command injection
        "`id`",  # Command execution via backticks
        "admin\0"  # Null byte termination
    }
```

Generate_exploit_seeds: This function generates a fixed set of seeds to test the common vulnerabilities such as buffer overflows, format strings and command injections. Then it returns a set of these seeds.

Saving the seed to a file:

```python
def save_seeds(seeds, output_file="./ongoing/seed/seeds.txt"):
    """Saves the generated seeds to a file."""
    with open(output_file, "w") as file:
        for seed in sorted(seeds):  # Sort seeds for easier review
            file.write(f"{seed}\n")
    print(f"Seeds saved to {output_file}")

```

Save_seeds: This function saves the set of seeds to a specified output file. It sorts the seeds for a easier review and then prints a message indicating the file location.

Main function:

S

```python
def main():
    newest_file = find_newest_c_or_cpp_file(DIRECTORY)
    if newest_file:
        print(f"Analyzing the newest file: {newest_file}")
        regex_seeds = extract_with_regex(newest_file)
        ast_seeds = extract_with_ast(newest_file)
        exploit_seeds = generate_exploit_seeds()

        combined_seeds = regex_seeds.union(ast_seeds).union(exploit_seeds)

        save_seeds(combined_seeds)
    else:
        print("No .c or .cpp files found in the directory.")
```

Main: This function analyses the process. It then identifies the newest c code and extract the literals using both AST methods and regex then generates the exploit seeds and then combines all the seeds into one file.

Script execution:

```
if __name__ == "__main__":
    main()
```

This is to start the main function.

Mover.py

Import Statements:

```
import shutil
import os
from pathlib import Path
```

- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.
- Shutil: used for moving files
- Path (pathlib): This is for an object-oriented approach to handle the file system paths.

```python
def move_compiled_file_to_ongoing():
    compiled_dir = Path('compiled')
    target_dir = Path('ongoing/code')

    # Ensure the target directory exists
    target_dir.mkdir(parents=True, exist_ok=True)

    # Assuming there's at most one file to move from compiled each time this is run
    for file in compiled_dir.iterdir():
        if file.is_file():
            shutil.move(str(file), str(target_dir / file.name))
            print(f"Moved {file.name} to {target_dir}")
            break  # Assuming only one file is moved at a time
```

move_compiled_file_to_ongoing: This function is used to move the compiled files from compiled directory to the ongoing/code directory

Parameters: None because they are globally defined.

- Functionality:
    - Compiled_dir this function defines the directory that contains the compiled files
    - Target_dir: Defines the target directory where the file should be moved to
    - Directory Creation: Ensure that the targe directory exists and if it is not available it wil be created using: mkdir(parents=True, exist_ok=True)

    - File movement:
        - Iterates through the files that are in the compiled_dir
        - Moves the file to the target_dir using the shutil.move
        - Print the success message
        - Breaks the loop after moving one file.

Starter.py

Import Statements

```
import subprocess
import os
from pathlib import Path
```

- Subprocess: this is used to run external process in our case we used it for the GCC compiler.
- Path (pathlib): This is for an object-oriented approach to handle the file system paths.
- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.

Finding the Executable File:

```
def find_executable_in_directory(directory):
    """Find the first file (considered executable) in the specified directory."""
    directory = Path(directory)  # Ensure directory is a Path object
    for file in directory.iterdir():
        if file.is_file() and not file.suffix:  # Assuming the executable has no
extension
            return file
    return None
```

find_executable_in_directory: this functions searches the specified directory to find the first file without an extension. It returns the path to this file

Constructing the AFL++ Command:

```python
def construct_afl_fuzz_command(input_dir, output_dir, executable):
    """Construct the afl-fuzz command using specified input and output directories, and the executable."""
    # Ensuring absolute paths are used for AFL++ command
    input_dir_abs = os.path.abspath(input_dir)
    output_dir_abs = os.path.abspath(output_dir)
    executable_abs = os.path.abspath(executable)
    return f"afl-fuzz -i {input_dir_abs} -o {output_dir_abs} {executable_abs}"
```

construct_afl_fuzz_command: this function creates the afl-fuzz command using the specified the input directory, output directory, and executable. Then it converts it to a path to the absolute paths to ensure the command works correctly.

Script Execution:

```python
if __name__ == "__main__":
    # Define the paths using pathlib for consistency
    ongoing_path = Path('ongoing')
    seed_dir = ongoing_path / 'seed'
    output_dir = ongoing_path / 'output'
    code_dir = ongoing_path / 'code'

    os.makedirs(output_dir, exist_ok=True)  # Ensure output directory exists

    executable_file = find_executable_in_directory(code_dir)
    if executable_file:
        afl_fuzz_command = construct_afl_fuzz_command(seed_dir, output_dir,
executable_file)

        # Debugging: Print the command before executing
        print(f"Command to be executed: {afl_fuzz_command}")

        run_afl_fuzz_in_konsole(afl_fuzz_command)
    else:
        print("Required executable not found.")
```

The script starts by defining the path to the ongoing, seed, output and the code directory.

It ensures that the output directory exists by creating it if necessary.

Identifies the executable file in the code directory using find_executable_in_directory

If the executable file is found it creates the afl command using construct_afl_fuzz_command and runs the command in a new Konsole windows using run_afl_fuzz_in_konsole

If the executable is not found it will print an error message

Finished_mover.py

Import statements:

```
import os
import shutil
```

- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.
- Shutil: this is used to move directories and their contents

Creating a New Fuzz Folder:

```
def create_and_get_fuzz_folder(finished_path):
    """Create a new Fuzz folder based on existing ones to avoid name
conflicts."""
    i = 1
    while True:
        fuzz_folder_name = f"Fuzz{i}"
        fuzz_folder_path = os.path.join(finished_path, fuzz_folder_name)
        if not os.path.exists(fuzz_folder_path):
            os.makedirs(fuzz_folder_path)
            return fuzz_folder_path
        i += 1
```

create_and_get_fuzz_folder: this function creates a new folder called Fuzz within the finished_path. It also increments the folder name so if a folder called Fuzz1 already exist it will create a folder called Fuzz2 until it finds a unique name that doesn’t conflict with an existing folder name. After it created the folder, it returns the path to the new folder.

Moving Contents from Source to Destination:

```python
def move_contents(source_path, destination_path):
    """Move all contents from source to destination."""
    for item in os.listdir(source_path):
        item_path = os.path.join(source_path, item)
        shutil.move(item_path, destination_path)
```

Move_contents: This function is used to move all the files and the direcotries from the source_path to the destination_path then it iterates through the items in the source directory and then uses shutil.move to move them.

Moving New Files to Fuzz Folder:

```python
def move_new_files_to_fuzz(new_folder_path, destination_path):
    """Move files from 'new' folder to the newest Fuzz folder."""
    move_contents(new_folder_path, destination_path)
```

Move_new_files_t_fuzz: This function handles moving files from the new folder to the newly created fuzz folder. It the uses move_contents function to move them.

Main Function:

```python
def main():
    ongoing_path = 'ongoing'
    finished_path = 'Finished'
    code_path = os.path.join(ongoing_path, 'code')
    seed_path = os.path.join(ongoing_path, 'seed')
    output_path = os.path.join(ongoing_path, 'output')
    new_path = 'new'  # Path to the 'new' folder

    # Ensure the Finished folder exists
    if not os.path.exists(finished_path):
        os.makedirs(finished_path)

    # Handle the output folder and rename to avoid conflicts
    fuzz_folder_path = create_and_get_fuzz_folder(finished_path)
    shutil.move(output_path, fuzz_folder_path)  # Move and rename output to FuzzX

    # Move contents of code, seed, and new to the new Fuzz folder
    move_contents(code_path, fuzz_folder_path)
    move_contents(seed_path, fuzz_folder_path)
    move_new_files_to_fuzz(new_path, fuzz_folder_path)
```

main: the main function executes the entire process. It defines the path for the ongoing, finished, code, seed, output and the new directories. It ensures that the Finished directory exists and creates a new fuzz folder and then moves the output directory to this folder and then moves the contents of the code, seed and the new folder to the new Fuzz folder.

Readme_move.py

Function to move and rename files:

```
def move_and_rename_readme_and_crash():
    finished_dir = Path('/home/ramy/Desktop/folda/Finished')
    # Identify the newest Fuzz folder
    newest_fuzz_folder = max((folder for folder in finished_dir.iterdir() if
folder.is_dir() and 'Fuzz' in folder.name),
                             key=lambda x: x.stat().st_mtime, default=None)

    if newest_fuzz_folder is None:
        print("No Fuzz folder found.")
        return

    # Define the crashes directory path
    crashes_dir = newest_fuzz_folder / 'output' / 'default' / 'crashes'

    # Move README.txt if it exists
    readme_file = crashes_dir / 'README.txt'
    if readme_file.exists():
        destination_path = newest_fuzz_folder / 'README.txt'
        shutil.move(str(readme_file), str(destination_path))
        print(f"README file moved to {destination_path}")
    else:
        print("No README file located in the crashes folder.")

    # Find and rename the crash file
    crash_files = list(crashes_dir.glob('*'))
    if crash_files:
        crash_file = crash_files[0]
        new_name = datetime.now().strftime("%Y%m%d%H%M%S") + '.txt'
        new_crash_file_path = crash_file.parent / new_name
        crash_file.rename(new_crash_file_path)
        print(f"Crash file renamed to {new_crash_file_path}")
    else:
        print("No crash files found in the crashes folder.")
```

Move_and_rename_readme_and_crash: This function handles the identify the newest Fuzz folder and moves the README.txt file and renames the crash file. This had to be done because I couldn't parse the content of the crash output because the crash file didn't have a .txt extension.

Identifying the newest fuzz folder:

```
finished_dir = Path('/home/ramy/Desktop/folda/Finished')
newest_fuzz_folder = max((folder for folder in finished_dir.iterdir() if 
folder.is_dir() and 'Fuzz' in folder.name),
                         key=lambda x: x.stat().st_mtime, default=None)

if newest_fuzz_folder is None:
    print("No Fuzz folder found.")
    return
```

Identify newest folder: The script searches in the Finished directory to find the most recently modified Fuzz folder. It uses the max with a lambda function that check the for the modification time using st_mtime.

Defining the crashes directory path:

```
crashes_dir = newest_fuzz_folder / 'output' / 'default' / 'crashes'
```

Crashes_dir: it defines the path to the crashes the directory within the newest Fuzz folder.

Moving the README file:

```
readme_file = crashes_dir / 'README.txt'
if readme_file.exists():
    destination_path = newest_fuzz_folder / 'README.txt'
    shutil.move(str(readme_file), str(destination_path))
    print(f"README file moved to {destination_path}")
else:
    print("No README file located in the crashes folder.")
```

Move README File: Checks if the Readme.txt file exists in the crashes directory. If it does it moves the file to the root of the newest Fuzz folder using shutil.move

Renaming Crash Files:

```
crash_files = list(crashes_dir.glob('*'))
if crash_files:
    crash_file = crash_files[0]
    new_name = datetime.now().strftime("%Y%m%d%H%M%S") + '.txt'
    new_crash_file_path = crash_file.parent / new_name
    crash_file.rename(new_crash_file_path)
    print(f"Crash file renamed to {new_crash_file_path}")
else:
    print("No crash files found in the crashes folder.")
```

Rename Crash files: List all files in the crashes directory and if any files are found the first is renamed using a timestamp. The timestamp is generated using datetime.now().strftime("%Y%m%d%H%M%S.

Gemini.py

Import Statements:

```python
import google.generativeai as genai
import os
from google.generativeai import GenerativeModel
from pathlib import Path
```

Genai and GenrativeModel: Used to interact with the Gemini AI model.

API Key configuration:

```python
# Set the API key directly in the script
api_key = ""
genai.configure(api_key=api_key)
```

Api Key: This is to configure the Gemini API with the provided API key.

Directory and File Setup:

```python
# Absolute path to the 'Finished' directory
finished_dir = Path('/home/ramy/Desktop/folda/Finished')

# Ensure the 'Finished' directory exists and is not empty
if not finished_dir.exists() or not any(finished_dir.iterdir()):
    print("No 'Finished' directory or it is empty.")
    exit()
```

Finished_dir: Defines the path to the Finished folder.

Directory Check: Checks if the Finished directory exists and is not empty. If it does not exist, then the script will print an error message and quit.

Finding the code File:

```python
# Find the first .c or .cpp file in the newest folder
code_files = list(newest_folder.glob('*.c')) + list(newest_folder.glob('*.cpp'))
if not code_files:
    print("No code files found in the newest folder.")
    exit(1)
code_file = code_files[0]
```

Code_files: It searches for a c code inside the newest folder. If no folder is found in the script it will print an error message.

Reading the Code File:

```python
# Read the content of the code file
with open(code_file, 'r') as file:
    code_content = file.read()
```

Code_content: Reads the content of a code.

Setting up the crashes Directory:

```
# Path to the 'crashes' directory in the newest folder
crashes_dir = newest_folder / 'output' / 'default' / 'crashes'

# Ensure the 'crashes' directory exists and contains files
if crashes_dir.exists() and any(crashes_dir.iterdir()):
    # Find the newest file in the 'crashes' directory
    newest_file = max(crashes_dir.iterdir(), key=lambda x: x.stat().st_mtime if
x.is_file() else float('-inf'))
```

Crashes_dir: It defines the path to the crashes directory with the newest fuzz folder.

Directory Check: Ensures the crashes directory exists and contains files, if not the code prints an error message.

Reading the Crash File:

```
    # Read the content of the newest crash file in binary mode
    with open(newest_file, 'rb') as file:
        binary_content = file.read()

    # Convert binary content to a hexadecimal string (as an example)
    crash_content = binary_content.hex()
```

Binary_content: Reads the content of the newest crash file.

Crash_content: Converts the binary content to hexadecimal strings.

Using the Gemini Model:

```
    # Use the content in the AI model
    model = genai.GenerativeModel('gemini-1.0-pro-latest')
    prompt = (
        f"This is my code:\n{code_content}\n\n"
        f"And this is the input that made it crash:\nCrash Data (hex):
{crash_content}\n\n"
        "Suggest me a solution to fix my code using the crash input and the
original code."
    )
    response = model.generate_content(prompt)
```

Model: Initialize the model.

Prompt: Creates a prompt that combines the code content and the crash content

Response: sends a prompt to the Gemini model and stores the response.

Saving the AI response:

```
   # Save the AI's response
   response_path = newest_folder / 'Ai_response.txt'
   with open(response_path, 'w') as file:
       file.write(response.text)
   print(f"AI Response saved to {response_path}")
```

Response_path: Defines the path to save the AI response into.

Saving response: Write the AI response into a txt file.

Chatgpt.py

```
import os
import re
import json
import requests
from datetime import datetime

# Define the path to the crash files
crash_directory =
'/home/ramy/Desktop/folda/Finished/Fuzz5/output/default/crashes'
output_directory = '/home/ramy/Desktop/folda/Finished/Fuzz5/output'
```

.

- os: this is used for the code to interact with the operating system, we used it here for moving files and receiving the modification times.
- Re: utilizes the regular expression operations
- Json: for using Json data.
- Requests: To make a http request
- Datetime: handling date and time

```
def get_latest_crash_file(directory):
    files = [os.path.join(directory, f) for f in os.listdir(directory) if
os.path.isfile(os.path.join(directory, f))]
    latest_file = max(files, key=os.path.getctime)
    return latest_file

latest_crash_file = get_latest_crash_file(crash_directory)
```

Get_latest_crash_file: This function is to retrieve the most recent file in the directory. This is to ensure that always the latest file is analyzed.

```python
with open(latest_crash_file, 'r') as file:
    crash_data = file.read()
```

Open: the file is being opend in read mode and the content of it is stored in the variable crash_data

```python
data = {
    "model": "gpt-3.5-turbo",
    "messages": [
        {"role": "system", "content": "You are an intelligent assistant."},
        {"role": "user", "content": f"Analyze the following crash data and 
provide a solution: {crash_data}"}
    ]
}
```

Data: a new dictionary is created containing the model type and the formatted messages for the ChatGPT API. The system message sets the context, and the user message includes the crash data.

```python
response = requests.post(
    'https://api.openai.com/v1/chat/completions',
    headers={'Authorization': f'Bearer YOUR_API_KEY'},
    json=data
)

response_data = response.json()
solution = response_data['choices'][0]['message']['content']
```

Requests.post: sends a POST request to the API with the headers and data.

Response_data: The JSON response from the API is parsed and extracted.

```
output_file_path = os.path.join(output_directory, 'chatgpt_response.txt')
with open(output_file_path, 'w') as output_file:
    output_file.write(solution)
```

Output_file_path: The path for the output is created.

Open: the file is saved with the ChatGPT API solution.

Pdfmaker.py

Import statements:

```
from fpdf import FPDF
from datetime import date
from pathlib import Path
import difflib
```

FPDF: This is a library to create a PDF document.

Date: This is for handling time, and this is used to add the current date to the report

Difflib: this is to compare sequences and to calculate the similarity score.

PDF class Definition:

```python
class PDF(FPDF):
    def header(self):
        self.set_font('Arial', 'B', 12)
        self.cell(0, 10, 'Code Healer Report', 0, 1, 'L')

    def footer(self):
        self.set_y(-15)
        self.set_font('Arial', 'I', 8)
        self.cell(0, 10, f'Page {self.page_no()}', 0, 0, 'C')
```

Header: This is to define the header for each page. Code healer was used to be the header for all the pages.

Footer: This is to define the footer for each page with the corresponding page number

Function to calculate the similarity:

```python
def calculate_similarity(text1, text2):
    if text1 and text2:  # Only calculate similarity if both texts are available
        return difflib.SequenceMatcher(None, text1, text2).ratio()
    return 0
```

Calculate_similarity: this is used to calculate the similarity score for the two texts using difflib.SequenceMatcher

Setting up the file paths and the read files:

```
finished_dir = Path('/home/ramy/Desktop/folda/Finished')
newest_folder = max(finished_dir.iterdir(), key=lambda x: x.stat().st_mtime if
x.is_dir() else float('-inf'))
crashes_dir = newest_folder / 'output' / 'default' / 'crashes'
newest_file = max(crashes_dir.iterdir(), key=lambda x: x.stat().st_mtime if
x.is_file() else float('-inf'))
```

Finished_dir: defines the path for the Finished directory.

Newest_folder: Identifies the most recently modified folder that is located inside the Finished directory.

Crashes Dir: Defines the path to the crashes directory that is in the newest Fuzz folder.

Newest_file: Identifies the most recently modified file that is located in the crashes directory.

```
crash_content = ''
response_gpt = ''
response_gemini = ''

if newest_file.exists():
    with open(newest_file, 'r') as file:
        crash_content = file.read()

chat_response_path = newest_folder / 'chatgpt_response.txt'
ai_response_path = newest_folder / 'Ai_response.txt'

if chat_response_path.exists():
    with open(chat_response_path, 'r') as file:
        response_gpt = file.read()

if ai_response_path.exists():
    with open(ai_response_path, 'r') as file:
        response_gemini = file.read()
```

Crash_content: this reads the content of the newest crash txt file.

Response_gpt: reads the content that has been saved from the ChatGPT response.

Response_gemini: Reads the content of the Gemini response file

```
similarity_score = calculate_similarity(response_gpt, response_gemini)
similarity_desc = f"Similarity score: {similarity_score:.2f}/1.00"
```

Similarity_score: calculates the similarity score based on the ChatGPT and Gemini response.

Similarity_desc: formats the similarity score so it can be put on the pdf.

Creating the PDF:

```
pdf = PDF()
pdf.add_page()
pdf.set_font("Arial", 'B', 16)
pdf.cell(200, 10, 'CODE HEALER', 0, 1, 'L')
pdf.set_font("Arial", size=12)
pdf.cell(200, 10, str(date.today()), 0, 1, 'L')
pdf.set_font("Arial", 'B', 12)
pdf.cell(200, 10, "Crash reason:", 0, 1)
pdf.set_font("Arial", size=12)
pdf.multi_cell(0, 10, crash_content)
if response_gpt:
    pdf.set_font("Arial", 'B', 12)
    pdf.cell(200, 10, 'ChatGPT Solution:', 0, 1)
    pdf.set_font("Arial", size=12)
    pdf.multi_cell(0, 10, f'{similarity_desc}\n{response_gpt}')
if response_gemini:
    pdf.set_font("Arial", 'B', 12)
    pdf.cell(200, 10, 'Gemini Solution:', 0, 1)
    pdf.set_font("Arial", size=12)
    pdf.multi_cell(0, 10, f'{similarity_desc}\n{response_gemini}')
```

PDF Content: This adds all the content to the PDF. This includes the : title,date,crash reason, and the generated solution from both AI's alongside the similarity score.

Saving the PDF:

```
pdf_output_path = newest_folder / 'CODE_HEALER.pdf'
pdf.output(str(pdf_output_path))
print(f"PDF saved to {pdf_output_path}")
```

Pdf_output_path: Defines where the PDF file is saved.

Saving PDF: Saves the generated PDF to the predefined path.

Benefits of a modular Design in the Code Healer

The decision to structure the project into multiple modules is one of the main strengths of this project, its offering numerous advantages in terms of flexibility, maintainability and its scalability. The modular approach is not to only enhance the versatility of the fuzzer but also make it a lot easier to integrate it with different fuzzing tools. Here are the specific benefits of this modular approach:

1. Flexibility in the integration of the fuzzer

One of the benefits of having a modular architecture is the ease with which different tools can be integrated. Each module in the project is designed to perform one specific task such as downloading, compiling, generating seeds or running the fuzzer. This separation of concerns means that changing one module out like the fuzzer, does not necessitate changes to the other modules like:

- Easy substitution: To switch from the AFL fuzzer to another one like libFuzzer, you only need to go and modify the starter.py module. This change is very easy, just certain commands and parameters for the new fuzzer have to be changed without affecting the rest of the system.

- Interchangeable components: The modular approach allows the user to tailor the fuzzer for different applications by providing the flexibility to choose the best tool for each task. This adaptability is very important in his field where new tools or techniques arise.

2. Enhanced Maintainability

The modular design improves the maintainability of the project. Each module can be changed, tested developed and debugged. This makes it easier to fix issues, this modularity has several practical advantages like:

- Simplified Debugging: When a issue arises the user can just isolate it and narrow it down to one module rather than going through one big code. This target debugging reduces the downtime in the event of a failure.

- Focused updates: Updates or improvements to each module can be implemented without disrupting the entire project. For instance, if somebody decide to change the analyzer.py to improve the seed generation this can be don't without affecting the compilation process or the execution of the project.

- Clear Responsibilities: Each module has a pre-defined purpose and scope, making it easier for the end user to understand and change the code. This reduces the learning curve for a new user.

3. Scalability

The modular approach for Code Healer also improves scalability and extensibility. If the project grows or new requirements emerge, additional modules can be added without changing up the entire project. Examples are:

- Adding new features: If the end user decides to add a new feature, he just has to add a new module to perform that one task, for example if he decides to perform static code analysis before fuzzing. The developer can add this new module and integrate it to the existing pipeline without any hiccups.

- Handling larger workloads: As the volume of codes that must be fuzzed increases, the user can just scale the project by running multiple instances of the code healer software. Or add a module to add a feature for parallel fuzzing like adding a pipeline for just analyzing the code to distribute the workload effectively.

4. Versatility in different use cases

The versatility of the code healer project is to greatly enhance its modularity. Each module can be adapted or changed to be used in a different context. For instance:

- Custom Workflows: Developers can customize the workflow by changing the modules to fit their specific testing requirements. This allows them to tailor code healer to their specific use case.

- Integration with CI/CD pipelines: This modular approach makes it easier to integrate Code Healer with continuous integration. Individual modules can be triggered at different stages of the pipeline to provide real time feedback.

5. Improved Code Quality

- Reusable Components: Modules can be reused in other projects or for a different purpose. For example, if somebody decides to change up the downloader.py module which handles the download of codes from GitHub it can be used to download the code from different sources for example.

- Consistent Quality: Each module can be tested and validated to ensure that the system maintains a standard of quality.

Detailed Technical Explanation:

To showcase the benefits of this approach lets showcase some technical aspect:

- Downloader.py
    - Integrity and security: The downloader.py module ensures the integrity of the download process by a checksum verification and the use of HTTPS connection to prevent any third-party tampering.

- Auto compiler improvements:
    - Compiler configurations: The autocompiler.py module can be adjusted to compile flags based on project configuration and for optimization for different build environments.

    - Cross compilation support: Support for different coding languages making it possible to test more software's. This is very crucial to have one tool that can fuzz many different coding languages.

Phases

Phase 1: Analysis of existing tools and the Capabilities of ChatGPT

The phase involved a detailed analysis of the existing fuzzing tools and their capabilities. Different Language models were also considered in this phase. This phase aimed to understand the strengths and weaknesses of the current solutions.

- Literature review

  A review of the existing fuzzing tools was made to mainly understand their capabilities, strengths and weaknesses. This involved looking at fuzzers like AFL, libFuzzer and Syzkaller.

- ChatGPT API

  The strengths and limitations of the ChatGPT API were evaluated through different experiments. These were aimed to determine how well the API could understand and generate potential solutions based on the code and the crash output.

Phase 2: Development of a Basic Fuzzer

The next step was to develop a fuzzer framework. This framework is a crucial part because it’s the backbone for the subsequent AI integration.

- Framework Architecture:

  The Architecture of the fuzzer was carefully designed to ensure flexibility. The main components are input generators, mutations engine (AFL Fuzzer), mover and the other modules. Each module was made to do one task, to ensure that the project is modular.

- Implementation

  The core components of the fuzzer were coded using Python. This includes all the modules such as the downloader, auto compiler and the seed generator.

- Initial Testing:

  Tests were performed to validate the functionality of the fuzzer. The tests involved running the fuzzer using various codes to ensure it could download, compile and fuzz different codes effectively.

Phase 3: Integrating ChatGPT and Geminis API

Using a functional fuzzer in place, the next phase focused on implementing ChatGPT and Geminis API into the framework.

- Integration of the API's

  Different modules were developed to interface with ChatGPT and Geminis API. These modules used the crash data and the source code and formatted them into a format that both APIs understand. The request to the APIS and the processed response is extracted and saved as a txt file in the directory of the currently fuzzed code.

- Enhancing the Fuzzer Framework

The frameworks were modified to include the Ai driven suggestions. This process involved updating how the fuzzer framework saves the crash report.

- Testing and Evaluation

  The integration was tested on how accurate the provided solutions are. The tests also assessed the quality and relevance of the generated solutions.

Phase 4: Enhancing the report Generation and the feature development.

The next phase focused on refining the fuzzing process and the initial feedback and developing a report generation feature.

- Feedback

  Initial tests were conducted and analyzed. The feedback highlighted areas for improvement and additional features that could enhance the fuzzing process.

- Enhancements made to the framework.

  Based on the feedback, several enhancements were made to improve the performance and the usage of the fuzzer. This included improving the data handling process, enhancing error handling and refining the API integration.

  Report Generation

  A module was made to automate the generation of creating a report based on the AI suggestions. Using the FPDF library, this python library creates PDF reports that were clear concise and useful for the developers.

Phase 5. Initial Testing and Validation

With the API integration completed the fuzzer underwent initial testing to validate its functionality

- Testing of the Functionality: The framework was tested to ensure that it could send data to the APIS and receive the appropriate suggestions and save them into a txt file.

- Performance Testing: Tests were conducted to evaluate the responsiveness. This involved testing the fuzzer with varying codes to assess its ability to correctly fuzz larger codes.

- Integration: Tests were performed to verify the integration of the APIS with the fuzzer. This included testing the functionality of the framework, from code download to report generation.

Result Analysis and Discussion

The code healer project aims to revolutionize the software testing and debugging process, by integrating AI solutions to automate the error handling and the creation of potential solutions. This section focuses on the results of the project and discusses its implications for software development.

Automated Solution generation:

One key outcome of the project is the ability to automate the generation of solutions. By integrating ChatGPT and Geminis API the framework can analyze crash outputs and source code that is provided by the framework automatically. This automated approach simplifies and reduces the time and effort required to address certain coding flaws, enabling developers to focus on more important tasks.

Impact on Security and Stability:

The integration of AI has made a profound impact on security and stability. By providing developers with solutions, the frame works helps prevent potential security vulnerabilities. This approach to code analysis and debugging enhances the overall security posture of the software application, making it more robust.

Time and resource Efficiency:

The primary objective of this framework is to save time for developers and resources by automating the debugging task. This approach streamlines the identification process and resolution creation process. The framework enables developers to work more effectively. This Efficiency is seen to accelerate the development process.

Challenges and limitations:

Despite the many benefits AI offers the project also faces several challenges. One of the main challenges I the accuracy of the AI suggestions. While both APIs provide valuable information there is still room for improvement. Additionally, the system reliance on AI introduces complexity and potential risks such as false positive and incorrect solutions. The seed Generation also faced a lot of limitations due to the nature of different codes that were provided to the framework. The Seed generation process is a crucial part of the fuzzing process maybe even the most important process from them all. A good Seed can accelerate the time taken to fuzz a code by 10x compared to a weak or simple seed.

Future Directions:

The project has several areas where improvements must be made. One future research is the enhancement of AI models to improve the accuracy and relevance of the provided solutions. Integrating more APIs into the reporting process is also a valuable opportunity to gain more insight on more perspectives of different AI models. If a company also decides not to use any APIs to provide solutions to their framework options, this is also possible in this framework. By simply changing the API codes to run local Language models on the local machine to provide solutions.

Project Management

Project Planning

Effective Project Management is a very important process. This section outlines detailed planning and initiation phases, focusing on defining the scope of the project, setting, objectives, identifying and establishing a timeline.

Scope and Objectives:

The first step in managing any project is to clearly define its scope and objectives. The goal is to develop a software solution that integrates AI into a fuzzing tool to automate the error handling and vulnerability detection. The objective are as follows:

- Developing a robust fuzzer framework
- Integrating ChatGPT and Gemini to analyze the crash output and provide a solution.
- Automating the workflow to eliminate any kind of human interaction.
- Generating a report that is based on the AI generated solutions.

These objectives help establish a clear direction for the project to follow.

Resource Identification

Identifying the necessary resources is a very critical step of the planning process. This involved determining the human resources, tools and technologies required to complete the project. The resources are as the following:

- Human resources: Team consisting of software developers and testers. Each member has a role and his responsibilities that were clearly defined to ensure efficient collaboration.

- Tools and Technologies: The essential tools are as the following: Python, AFL, ChatGPT API, Gemini API and the various python libraries installed. These tools were chosen to meet the project technical requirements.

Timeline and Milestones:

Creating a timeline with well defined milestones was crucial for tracking progress and ensuring timely completion of the project and meeting the deadlines. The timeline was divided into phases, each with their deliverables. The phases were:

- Phase 1: Analysis of Existing tools and ChatGPT API
- Phase 2: Development of a basic fuzzer
- Phase 3: Integration of ChatGPT API with the Fuzzer
- Phase 4: Enhancement and report generation Feature
- Phase 5: Final Testing and finishing the Project report.

Every phase has its own detailed tasks and sub-tasks, with clearly defined start and end dates. Milestones were established at the end of each phase to track the progress and ensure that the project goals are met.

Risk Management:

- Risk management is a crucial part for mitigating potential issues that could negatively impact the project's success. A risk management plan was developed, to identify potential risks and their impact. Key risk included:

- Technical risks: Challenges related to integrating AI into the fuzzer. The API limitations and data handling, mitigation strategies involved thorough testing and regular reviews of the code.
- Schedule risks: Delays in project phases due to unforeseen issues. Strategies were implemented that included setting realistic timelines and regular progress monitoring.

Communication Plan:

Communication is vital for successful project management. A communication plan was established to ensure that a clear and concise communication among all stakeholders (Advisors). The plan included the following:

Regular meetings. Weekly project meetings to review progress. Discussing issues and planning upcoming tasks.

Collaboration tools: GitHub was used as a collaboration tool. It was used to facilitate real time communication and version control.

Project initiation:

With the planning phases completed the project could officially start. The steps coming were the following:

First meeting: A project "start" meeting was held to introduce the idea of the project, review the project plan and outline the next steps.

Resource allocation: Assigning tasks for each day. This ensured that each day had a clear milestone to meet the project objectives.

Setting up tools and Environments: Configuring the necessary development environments, installing all the libraries tools etc. Setting up version control systems such as (GitHub).

Development Phase

The development phase involves the creation of various modules to form the finished software. This phase was marked by iterative development, through testing and continuous improvements to ensure that each module worked as intended as expected the integration seamlessly worked with the other modules.

Core Components:

The focus is on developing modules for the fuzzer. These modules are a essential part of the fuzzing process and serve as a solid foundation for the enhancements and integrations.

Risk Management and Mitigation Strategies:

Risk management were a cornerstone of the code healer project, ensuring that potential issues were identified. This section is to outline the risks encountered during the project development and the strategies that were implemented.

Identification of potential risks:

The first step was to identify potential risks that could impact the project success. These risks were categorized into different sections:

Technical Risks:

i. Challenges with integrating AI APIs.

ii. Bugs in the framework.

iii. Scalability issues

Resource Risks:

iv. Availability of skilled personnel.

v. Access to required tools and technologies.

Schedule Risks:

vi. Delays due to unforeseen technical challenges.

vii. Depending on a third-party service or APIs.

Operational Risks:

viii. Data privacy and security concerns.

ix. Reliability and availability of APIs.

2. Risk Assessment and Prioritization: Once potential risks are identified, they are assessed based on their likelihood and potential impact. This assessment can help prioritize risks and focus efforts on the most important ones. Each risk is evaluated using a risk matrix, categorizing them as high, medium, or low.

3. Mitigation Strategies: For each identified risk, a specific mitigation strategy is developed and implemented. Key strategies included:

Technical Risks:

i. **Regular Testing and Code Reviews:** Implementing continuous integration (CI) practices ensured that new code is regularly tested and reviewed. Automated tests are run to catch bugs early and maintain the code quality.

ii. **Scalability Planning:** Designing the system with scalability in mind, using a modular approach to allow for easy expansion and optimization.

iii. **Fallback Mechanisms:** Developing fallback mechanisms to handle API failures to ensure that the systems remain operational even if a external services is unavailable.

Resource Risks:

iv. **Cross-Training Team Members:** Ensuring that multiple team members are familiar with critical components of the project.

v. **Resource Allocation Planning:** Allocating resources efficiently and ensuring that all necessary tools and technologies are available when they are needed.

Schedule Risks:

vi. **Realistic Timelines:** Setting a realistic timeline for each project phase, with built-in buffers to account for potential delays.

vii. **Dependency Management:** Identifying dependencies early and planning for potential delays from third-party services or APIs.

Operational Risks:

viii. **Data Privacy Measures:** Implementing robust data privacy measures, such as anonymizing sensitive data before sending them to external APIs and using secure communication channels.

ix. **Service Level Agreements (SLAs):** Establishing SLAs with external API providers to ensure reliability and availability.

4. Risk Monitoring and Review: Risk management is an ongoing process throughout the project lifecycle. Regular reviews are conducted to monitor the status of identified risks and evaluate the effectiveness of mitigation strategies.:
5. Weekly Risk Meetings: Regular meetings are held to discuss current risks, new potential risks, and the effectiveness of mitigation strategies.
6. Risk Logs: Maintaining detailed logs of all identified risks, their status, and actions taken to mitigate them is crucial for effective risk management.
7. Stakeholder Communication: Keeping stakeholders informed about potential risks and the measures being taken to address them ensures transparency and collaboration.
8. Incident Response Planning: Despite the best mitigation efforts, some risks could still materialize. An incident response plan was developed to handle such situations effectively. This plan includes the following components:
9. Incident Response Team: Establishing a dedicated team responsible for managing incidents, with clear roles and responsibilities.

10. Communication Protocols: Defining communication protocols to ensure timely and accurate information sharing during an incident.
11. Recovery Procedures: Developing procedures to recover from incidents, such as rolling back to a previous stable state or deploying backup systems.
12. Case Study: Handling a Technical Risk During the integration of the ChatGPT API, the project team encountered several technical challenges, including compatibility issues with data formats and API rate limits. The following steps were taken to address these challenges:
13. Compatibility Issues: The team developed data preprocessing scripts to ensure that crash outputs and source code were formatted correctly before being sent to the API.
14. API Rate Limits: Implementing rate limiting strategies and using API keys with higher rate limits to manage the volume of requests.

What is a fuzzer specifically and how does it work?

Fuzzing is a software testing method that involves inputting various invalid or random data inputs into a code to discover software vulnerability and bugs. This method is a widely used and particularly effective way to identify security flaws and stability issues in software. Fuzzing has become a essential tool that is used by a lot of software developers and security professionals due to its ability to uncover software vulnerabilities.

Types of fuzzers:

Fuzzers can be put into 3 different types based on their method that they used to generate inputs:

Smart Fuzzers:

- Grammar based Fuzzers: These fuzzers generate inputs based on predefined set of rules or grammar specific to target a code. They are most effective than random fuzzers because they produce more accurate inputs that are more likely to find / trigger deeper code paths.

- Protocol-based Fuzzers: These generate inputs based on communication protocol to target a program. They are used to test network applications and they can uncover vulnerabilities based on how a code handles protocol specific data.

Dumb Fuzzers:

Random Fuzzers:

- These fuzzers generate a completely random input without any insight or knowledge about the target code. It doesn't know its program structure or even programming language. They are very easily implemented but they are not very effective in finding deep seated bugs because they can't generate a target specific seed.

Hybrid Fuzzers:

Coverage guided Fuzzers:

- These fuzzers use feedback from the code to change their seed and generate different inputs. Their main goal is to maximize the code coverage by focusing on the seed that can explore new code paths. The coverage guided approach is highly effective in finding deeper routed complex bugs.

How fuzzing works:

What are the steps to fuzz a code:

1. Preparation:

- Selecting the target: The first step is always to select the target program or a specific component of it that will be fuzzed. This could range from a specific function to an entire application.

- Defining the input space: The input space is the range of inputs that the fuzzer is allowed to generate in. They can range from a specific format, structure and their constraints of the inputs.

- Setting up the environment: The testing environment must be set up before we run the target program. We monitor its behavior and capture any crashes that occur during the process.   In this step its crucial to configure the fuzzer to log and monitor the specified code to ensure that the target is being correctly instrumented for the coverage analysis.

2. Input Generation:

- Generating inputs: The fuzzers generate a seed based on the defined input space. The Dumb fuzzers create random data that has nothing to do with the actual code. Smart fuzzers on the other hand use predefined rules to generate the seed.

- Monitoring and Logging: The fuzzers monitor the programs execution to detect crashes or any anomalies. This usually also contains any error message, stack trace or even memory dumps. The logs are a crucial part of the fuzzing process, it can be used to either debug potential problems with the fuzzing process or to analyze the behavior of the code.

3. Execution:

- Setting a input for the target: The generated input is fed to the target program. One input is being passed to the code at the time. The program is executed each time with the new input. The behavior is monitored for any crashes.

- Monitoring and logging: The fuzzers monitors the codes execution to detect any crashes or anomalies.

4. Analysis

- Identifying vulnerabilities: The logged crashes are analyzed to identify potential vulnerabilities.

- Prioritizing the findings: Not all the crashes are a sign of vulnerability. The findings are prioritized based on their severity and potential impact on the code.

5. Reporting

- Generating the Report: The Framework automatically generates a detailed report of the findings, the report includes the input that caused the crash and other potential vulnerabilities. The report also heavily focuses on the suggestions that is provided by ChatGPT and Gemini.

What are the benefits of Fuzzing:

Fuzzing offers several benefits over traditional testing methods:

- Automation: Fuzzing can be automated to run all the time and at scale, covering a wide range of inputs and different scenarios.

- Effective in Finding bugs: Fuzzing is very good in uncovering hidden and unexpected bugs that may not be detected by a software developer.

- Adaptable to different Targets: Fuzzers can be change to test various types of applications that includes libraries, network protocols and operating systems.

Challenges of fuzzing:

Despite all the benefits of deploying a fuzzers there are also several challenges:

- High resource consumption: Fuzzing can be very resource intensive at times, requiring a significant amount of computing power.

- False positives: Fuzzers may also generate false positives where a simple issue is reported even though it’s not a security vulnerability. This requires human intervention to correctly filter out those results.

- Complex Setup: Setting up fuzzers is not as straightforward as people think. The environments can be very complex and involve different configurations of the fuzzers so that the target program can be correctly fuzzed.

Input generation:

1. Random Input Generation:

- Random Data: The simplest seed can be generated using completely random data. This method is very easy to implement. Most of the team it leads to invalid or useless triggers. This method is not very effective to explore any meaningful execution paths.

- Bit Flipping: Also, another well-known technique that involves flipping individual bits in the seed. This can be very helpful to identifying vulnerabilities that are related to boundary conditions and bit level operations.

2. Mutation Based inputs:

- Seed files: Mutation based fuzzers start with a valid seed. These files are represented as normal inputs that the code can expect.

- Byte Level Mutations: Mutation fuzzers use small changes to the seed to ass, remove or even modify bytes. Most mutations include bit flips, insertion of random bytes and removing bytes.

- Structure Mutations: Some inputs with specific formats like XML for example, can be fuzzed using structured mutations to maintain overall structure while changing the content. This validates that the seed remains valid, and this makes the seed more likely to be processed by the target code.

3. Generation based inputs:

- Grammar based generation: Programs that accept inputs with predefined grammar, fuzzers can generate seeds based on grammar rules. This technique is used to ensure that the seeds are correct and can trigger deeper code paths.

- Protocol Generation: This is very similar to the grammar-based generation. Protocol based fuzzers use inputs based on specific communication protocols. This is very effective because it can test network applications.

Execution and monitoring:

1. Input Feeding:

- Command line arguments: For each code that accepts various inputs via the command line, the fuzzers execute the code with each generated input as an argument.

- File inputs: When a program reads a input from a file the fuzzers is able to write each generated input into a file and can directly interact with the program.

- Network inputs: For network applications the fuzzers generate inputs that can be passed through the network to the targeted program.

2. Program Execution:

- Single run execution: This is the easiest execution method that involves running the program once for just one input. This can be used to process inputs very quickly.

- Persistent execution: This method is employed if a program has a high startup cost or processes multiple inputs in one run. Persistent execution can keep a program running without closing it and feed multiple inputs into the program.

3. Monitoring tool:

- Instrumentation: This method involves modifying the target program to collect data on its execution. This can be done at "Compile Time" also called source code instrumentation or at run time. The most common tool is the AFLs QEMU mode and intel PIN.

- Crash Detection: The fuzzers monitor the program for any crashes or anomalies. This method usually checks for abnormal termination, memory access violation or unhandled exceptions.

- Coverage Analysis: A coverage guided fuzzers tracks the code coverage closely, this is done by counting each input. This information is used to guide the new generation for new inputs. Tools like gcov and LLVM SanitzerCoverage are used for this exact purpose.

Post execution Analysis:

1. Crash analysis

Duplication: Fuzzers often encounter a lot of crashes that are caused by underlying issues. This technique combines multiples crashes together to avoid redundant analysis.

2 Bug minimization

- Input minimization: When a crash has been detected the fuzzers attempts to minimize the input that has caused the crash. One of the methods is to reduce the size or the complexity of an input while still retaining the ability to trigger a crash.

3. Root cause analysis:

- Static analysis: A static analysis tool analyzes a program source code without executing it. This can help identify the root cause of the crash by examining the code paths.

- Dynamic Analysis: Dynamic Analysis tools monitor how a program runs to gather the runtime information. This can help to identify the conditions and inputs that trigger the crash by providing insight on vulnerabilities.

Overview, Core components and Architecture of the AFL fuzzer.

AFL++ (American Fuzzy Lop Plus plus) this is a highly versatile fuzzing tool that build upon the original American Fuzzy Lop (AFL). Developed by Michal Zalewski, AFL was a groundbreaking tool in the fuzzing field with its unique approach to feedback driven fuzzing. This is also known as coverage guided fuzzing. AFL takes a step further by including numerous enhancements and features that were built by a community of developers.

Evolution from AFL to AFL++

- Compile-time: AFL instruments the target code at compilation time to insert lightweight instrumentation code that can be tracked for coverage. The "instrumentation" allows the fuzzers to gather detailed information about how to run the code and can explore different paths each time.

- Genetic Algorithms: AFL uses genetic algorithms to evolve inputs over time, focusing on those that maximize the code coverage to trigger new execution paths.

- Ease of use: The AFL fuzzers is very user friendly and it's designed to have a very comprehensive documentation that is easily accessible.

AFL ++ builds upon the mentioned core principles while still retaining the main functionality. The AFL ++ addresses some limitations by adding new features. The features are as the following:

- Improvements regarding Performance: The improvements were about reducing the overhead that was associated with the instrumentation and input processing, this resulted in faster fuzzing cycles.

- Extended Platform Support: AFL ++ has added support to Windows, MacOS and Unix systems.

- Enhancing instrumentation: AFL ++ has added support for more instrumentation modes such as QEMU that can be used for binary only targets and LLVM modes to improve the coverage tracking.

Core Components and Architecture:

AFL++ is split up into several components, each is responsible for a specific task of the fuzzing process. The Components work in conjunction to generate inputs, execute the target code and analyze the results for future inputs.

1. Instrumentation:

- Compile time Instrumentation: During the compilation process for the target program, AFL++ inserts different instrumentation code into the binary. This code is to track basic block transitions, allowing the fuzzer to gather a very detailed coverage information during the execution process.

- Run Instrumentation: For a case where the code is not available the AFL++ fuzzer provides runtime instrumentation options, like the QEMU mode. This mode uses a dynamic binary translation to instrument the code at the runtime.

2. Mutation Engine:

- Seed inputs: AFL++ needs to have a preset seed input, which are typically valid inputs for the targeted code. The base seed is for the initial population for the fuzzing process.

- Mutation Strategies: The fuzzer applies different mutation strategies to generate new inputs that originate from the seed input. The different mutation strategies are the following: bit flips, byte swaps, insertion of random data and removing data segments. This is to achieve different inputs to produce new triggers for the target program and uncover hidden bugs.

3. Execution Engine:

- Input feeding: The execution engine feeds the mutated inputs to the target code; it is done one at the time. This can also be done using the command line arguments, file inputs, network inputs and depending on the nature of the targeted program.

- Monitoring: During the execution the fuzzer monitors the targeted code for any crashes or anomalies. This involves checking if the program sends a termination signal, memory access violation or if it receives an unhandled exception.

4. Feedback Mechanism

- Coverage Feedback: The AFL fuzzer uses coverage information that was gathered during the execution process to guide future input generation. This input is to trigger new basic block transitions, or it can explore previously unexplored code paths.

- Fitness Function: Coverage feedback can be used to calculate a fitness score for each input, this can be used to determine the likelihood of being selected for another mutation. Inputs with higher scores are more likely to be kept for further mutation.

Interaction of components:

These are interactions between components that follow a iterative process:

1. Initialization: The fuzzer initializes by compiling the target program with the instrumentation and loads the initial seed inputs.

2. Input mutation: The mutation engine generates new inputs from the initial seed using different mutation strategies.

3. Program Execution: The execution engine feeds the newly modified seed into the target program and monitors its behavior.

4. Feedback collection: Using the coverage information that it collected during the execution and the fitness score of the inputs are updated.

5. Input Selection: Inputs with the higher fitness score are selected for further mutations and this process repeats repeatedly till the desired result is achieved.

This entire cycle is continuous with the AFL++ fuzzer to consistently refine the input to maximize the code coverage and discover new vulnerabilities.

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