CROSS-CONTRACT OBFUSCATION AND GAS OPTIMIZATION FRAMEWORK FOR SOLIDITY SMART CONTRACT

A Project Report

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<u>BONAFIDE CERTIFICATE</u>

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ABSTRACT

In a digital world increasingly driven by decentralized systems, the need for robust, secure and efficient smart contracts is more critical than ever. This project introduces a Cross-Contract Obfuscation and Gas Optimization Framework for Solidity smart contracts, focusing on securing not just individual contracts, but the interactions between them. By manually analyzing and transforming different types of contract interactions—such as high-level interface calls, low-level calls, factory-based deployments, and proxy contracts—the framework applies tailored obfuscation techniques including opaque predicates, dynamic function dispatch, and computed deployment paths. These transformations enhance resistance to reverse engineering tools while preserving the original functionality. Post-obfuscation, gas optimization techniques are applied to ensure cost-effective on-chain execution. The technical implementation is backed by Solidity development tools and frameworks, with testing conducted on the Ethereum testnet to ensure compatibility and functionality. Challenges such as preserving contract behavior while transforming its structure were met through iterative design and detailed validation. The outcome is a secure, obfuscated, and gas-optimized contract system suitable for real-world decentralized applications. This project represents a forward-thinking step toward securing the next generation of smart contract systems and contributes to improving the security, efficiency, and deployability of smart contracts in complex Ethereum-based ecosystems.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The Cross-Contract Obfuscation and Gas Optimization Framework is an advanced solution designed to enhance the security and efficiency of Solidity-based smart contracts, especially those used in decentralized ecosystems like DeFi and DEX platforms. Unlike traditional obfuscation methods that focus solely on individual contracts, this framework addresses vulnerabilities in cross-contract interactions, which are critical in modular contract architectures. The primary aim of this project is to make smart contracts significantly harder to reverse engineer, while simultaneously minimizing gas costs and preserving their intended behavior.

Built through a manually guided approach, the framework analyzes smart contract interactions at the source-code level and applies tailored obfuscation techniques based on the type of call—such as high-level interface calls, low-level calls, factory-based deployments, and proxy contract routing. These techniques include the use of opaque predicates, dynamic dispatching, low-level call transformation, and randomized routing..

In addition to security enhancements, the framework also includes a gas optimization layer that applies techniques like dead code elimination, inline assembly improvements, and storage layout refinements to reduce on-chain computation costs. All transformations are performed in a way that ensures functional equivalence of the contract, thereby maintaining operational correctness and compatibility with the Ethereum network.

Overall, this project represents a strategic advancement in smart contract engineering, combining security, cost-efficiency, and practical deployability to support the next generation of secure and scalable decentralized applications.

1.2 PROBLEM STATEMENT

Smart contracts have revolutionized blockchain ecosystems by automating transactions and eliminating the need for intermediaries. However, as adoption grows, new challenges have emerged—particularly around code security, reverse engineering threats, and high gas consumption during execution.

Most available obfuscation tools focus only on individual contract logic and fail to address vulnerabilities that exist in inter-contract communications, which are central to real-world decentralized applications.

Furthermore, widely used decompilers are still capable of analyzing obfuscated contracts, especially when interaction logic remains unchanged or predictable. Existing solutions often introduce additional gas usage, rendering them impractical for live blockchain environments. The lack of tools that both secure smart contracts at the interaction level and maintain or reduce gas costs leaves developers exposed to intellectual property theft, logic manipulation, and economic inefficiency.

Thus, there is a need for a dedicated framework that obfuscates cross-contract interactions while optimizing gas, to ensure both robustness and cost-effectiveness in Solidity-based deployments.

1.3 SMART CONTRACT AND BLOCKCHAIN

Smart Contracts are self-executing programs written in languages like Solidity that run on blockchain platforms such as Ethereum. These contracts automatically enforce rules and logic once predefined conditions are met. Deployed in decentralized networks, smart contracts eliminate trust issues by offering transparency, immutability, and automation without relying on third parties.

In the Ethereum ecosystem, smart contracts enable use cases like DeFi, NFTs, and DAOs, where multiple contracts often interact across modules. These interactions—be it through function calls, delegatecalls, or factory deployments—form a network of trustless operations.

Blockchain, the underlying technology, ensures that smart contract transactions are tamper-proof and chronologically ordered across distributed nodes. However, since all deployed contract code is public and immutable, attackers can analyze interactions to understand and exploit contract logic. This makes obfuscation and gas efficiency essential components of secure blockchain application development.

Our project strengthens this environment by enhancing the security of smart contract interactions while optimizing execution costs, contributing to a safer and more scalable blockchain ecosystem.

1.4 AIM AND OBJECTIVE

The aim of this project is to secure and optimize smart contract systems by developing a framework that performs cross-contract interaction obfuscation and gas usage optimization for Solidity-based applications.

Objectives:

- To manually analyze different types of cross-contract interactions and identify security vulnerabilities.
- To implement interaction-specific obfuscation techniques such as opaque predicates, dynamic function dispatching, proxy routing, and low-level call rewriting.
- To maintain the original functionality of the contracts after transformation.
- To apply gas optimization strategies like dead code elimination, inline assembly tuning, and storage layout enhancements.
- To output secure, obfuscated, and gas-efficient smart contracts suitable for deployment on public blockchains.
- To improve resistance against static and dynamic analysis tools such as Vandal, Slither, and decompilers.

1.5 SCOPE OF THE PROJECT

The scope of this project extends across two critical areas of smart contract development: interaction-level security and gas performance optimization. While most traditional obfuscators focus only on a single contract's structure, this project addresses cross-contract interaction flows, which are essential in modern decentralized applications.

The project covers:

- High-level and Interface-based Calls: Transforming standard interface calls (like IERC20.transfer) into low-level .call() structures with encoded function signatures and computed selectors.

- Low-level External Calls: Obfuscating direct call, delegatecall, and staticcall operations using dynamic selector generation and opaque execution flows.

- Factory-based Deployments: Converting simple new keyword deployment into randomized CREATE2 deployments via factory contracts with path shuffling and salt computation.

- Proxy Contract Routing: Hiding fallback-based routing logic with nested proxies and selector-based implementation switching.

This approach enables developers to safeguard proprietary logic, reduce risks of exploitation, and meet the performance standards expected in large-scale blockchain deployments.

CHAPTER 2

LITERATURE SURVEY

2.1. **Title:** BiAn: Smart Contract Source Code Obfuscation

Authors: Zhang, Y., Li, Y., Wang, S., & Liu, Y.

Year: 2023

Statement: It introduces a semantic-preserving obfuscation system that transforms smart contract source code while maintaining the original functionality, increasing resistance to analysis tools.

Limitation: The focus is on individual contract logic; it does not support obfuscation of cross-contract calls or factory/proxy patterns commonly seen in modular smart contract systems.

Reference: Zhang, Y., Li, Y., Wang, S., & Liu, Y. (2023). BiAn: Smart Contract Source Code Obfuscation. IEEE Transactions on Software Engineering.

2.2. Title: A Dynamic Dispatch-based Obfuscation Technique to Hide Function Signatures in Smart Contracts

Authors: Yao, H., Wang, S., et al.

Year: 2022

Statement: Proposed a dynamic dispatch mechanism that replaces function selectors with computed selectors to enhance privacy and control flow hiding.

Limitation: Limited to hiding function-level intent; does not cover cross-contract flows or interaction-aware obfuscation.

Reference: Yao, H., Wang, S., et al. (2022). A Dynamic Dispatch-based Obfuscation Technique to Hide Function Signatures in Smart Contracts. IEEE Access. DOI: 10.1109/ACCESS.2022.3148281

2.3. Title: Cross-Contract Static Analysis for Detecting Practical Reentrancy Vulnerabilities in Smart Contracts

Authors: Xue, R, Zhang, L., & Lu, X.

Year: 2020

Statement: Performs static analysis across contracts to identify and classify reentrancy vulnerabilities in real-world smart contracts.

Limitation: Detects but does not mitigate or obfuscate the vulnerabilities.

Reference: Xue, R., Zhang, L., & Lu, X. (2020). Cross-Contract Static Analysis for Detecting Practical Reentrancy Vulnerabilities in Smart Contracts. IEEE Transactions on Dependable and Secure Computing.

2.4. Title: Smart Contracts Obfuscation from Blockchain-based One-time Program

Authors: Kondo, Y., Nakamura, T., & Tanaka, K.

Year: 2022

Statement: Presents one-time program logic embedded in blockchain to provide strong security guarantees for smart contract execution.

Limitation: Complex implementation and lacks practical scalability for large systems.

Reference: Kondo, Y., Nakamura, T., & Tanaka, K. (2022). Smart Contracts Obfuscation from Blockchain-based One-time Program. IACR Cryptology ePrint Archive.

CHAPTER 3

SYSTEM ANALYSIS

3.1 EXISTING SYSTEM

In the current ecosystem of Ethereum smart contract development, security through obfuscation is still in its early stages. Most existing obfuscation techniques focus on individual contract-level transformations, aiming to make the code more difficult to reverse engineer or understand. These methods typically involve renaming variables, flattening control flows, inserting no-op statements, or encoding values and operations. While they may confuse casual analysis, they fail to offer protection against deeper analysis tools.

One significant drawback of these systems is that they do not address interactions between contracts, which are common in real-world decentralized applications (DApps), especially in domains like DeFi, DAOs, and modular contract-based systems. Contracts frequently interact through interfaces, delegate calls, external function invocations, and even dynamic deployments using factory patterns. However, these interaction pathways remain unprotected and transparent in most current solutions.

Furthermore, tools like Vandal, Gigahorse, and Mythril continue to perform well even on obfuscated code by reconstructing bytecode to identify logic and vulnerabilities. Another major issue with many obfuscation methods is that they lead to significant gas cost overhead, making the protected smart contracts inefficient and expensive to deploy on the Ethereum blockchain.

DISADVANTAGE

- Only protects individual contracts, leaving cross-contract interactions exposed.
- Obfuscation often increases gas cost, affecting deployment viability.
- Vulnerable to reverse engineering by advanced static analysis tools.
- Limited interaction-awareness—external calls and factory-based deployments are not obfuscated.
- Poor scalability for large contract ecosystems or production DApps.

3.2 PROPOSED SYSTEM

The proposed system introduces a Cross-Contract Obfuscation and Gas Optimization Framework that redefines how smart contract security is approached on the Ethereum platform. Unlike traditional single-contract techniques, this system emphasizes protecting inter-contract communication, dynamic execution flows, and deployment behaviors, which are often exploited during reverse engineering and static analysis.

At its core, the framework performs a static and semantic analysis of Solidity contracts to extract a map of all critical interactions—such as external calls, low-level operations (call, delegatecall), proxy routing, and contract creation via factories. Once identified, each interaction is transformed using a dedicated obfuscation strategy tailored to its type.

ADVANTAGE

- Provides end-to-end interaction obfuscation, not just local code scrambling.
- Uses control flow obfuscation (opaque predicates) to break static analysis.
- Reduces pattern matching effectiveness in decompilers like Vandal and Gigahorse.
- Obfuscates not only execution but deployment paths and function entrypoints.
- Highly customizable and scalable, works with real-world DApps and contract ecosystems.
- Maintains functional correctness while offering improved security and efficiency.

CHAPTER 4

SYSTEM REQUIREMENT

4.1 INTRODUCTION

The development of a Cross-Contract Obfuscation and Gas Optimization Framework for Solidity Smart Contracts involves the integration of multiple components, including static analysis, smart contract compilation, transformation logic, and gas efficiency evaluation. To support this development cycle, a well-equipped hardware and software setup is essential.

Given the decentralized nature of Ethereum and the complexity of modern smart contract systems, the project must simulate real-world blockchain behaviors, apply transformation logic on multiple contracts, and evaluate gas consumption post-obfuscation. Furthermore, since the project involves interaction-level analysis and dynamic obfuscation, tools must be capable of parsing, transforming, and redeploying Solidity code seamlessly.

The system requirements are divided into hardware and software, each playing a crucial role in ensuring that the framework operates efficiently, remains scalable, and produces reliable results during development, testing, and deployment.

4.2 HARDWARE REQUIREMENTS

- Processor (Intel Core i5 / AMD Ryzen 5 (or better))
- RAM (8 GB minimum (16 GB recommended))
- Storage (256 GB SSD or higher)
- GPU (Not mandatory (optional for UI simulation tools))
- Network (Stable internet connection for npm and testnets)

Hardware Description

- **Processor (CPU):**

  A multi-core processor is essential for tasks such as contract compilation (solc), Python-based script execution, and running Ethereum node simulators like Hardhat or Geth. These processes benefit from parallel execution, reducing analysis and test time.

- **RAM (Memory):**

  Static analysis tools such as Slither or Mythril load large abstract syntax trees (ASTs) and control flow graphs (CFGs) into memory. While 8 GB is the minimum, 16 GB is recommended to support simultaneous execution of analysis, transformation, and deployment scripts.

- **Storage:**

  A solid-state drive (SSD) offers faster read/write speeds, especially beneficial when compiling multiple contracts, installing npm packages, or working with testnet data. It also improves performance for local blockchain simulations (like Hardhat nodes).

- **GPU (Optional):**

  Not necessary for this project unless running graphical UI simulations or using Remix IDE in a browser with heavy debugging. It can slightly improve visual responsiveness in VS Code or contract visualization tools.

- **Network Connection:**

  Required for installing packages, interacting with public Ethereum testnets (like Goerli or Sepolia), and pushing/pulling dependencies.

4.3 SOFTWARE REQUIREMENTS

- Solidity (solc / py-solc-x)[Compiling smart contracts]
- Visual Studio Code [Code editing and script development]
- Node.js & npm [Hardhat and package management]
- Static tools [Complexity analysis]
- Python, web3.py [CLI automation, transformation logic]
- Remix IDE [Functionality Verification]
- Ethereum Testnets [For deployment and real-world simulation]

Software Description

- **Solidity Compiler (solc, py-solc-x):**

  Converts .sol files into bytecode and ABI formats. Required for compiling both original and obfuscated contracts before deployment and testing.

- **Visual Studio Code:**

  A robust IDE used to write, manage, and debug Solidity and Python scripts. Extensions like Solidity plugin and Python linter are used for productivity and error detection.

- **Node.js and npm:**

  The backbone of JavaScript-based development. Used to install and run Hardhat, a critical framework for Ethereum testing, and gas profiling tools.

- **Static tools:**

  Perform static analysis to detect vulnerabilities like reentrancy, unchecked calls, and cross-contract misuse. Used during the Security & Logic Analysis phase.

- **Python (3.x) + Libraries (web3.py, json, os):**

All CLI tools, JSON mapping, interaction transformations, and obfuscation automation scripts are written in Python. web3.py handles ABI encoding, function selector computation, and contract communication.

- **Remix IDE :**

Useful for testing bytecode behavior and analyzing contract behavior visually. Especially helpful during debugging or fine-tuning transformations.

- **Ethereum Testnets :**

Deployed obfuscated contracts are tested in public testnets to ensure correctness and evaluate real-world gas usage and behavior under Ethereum's actual consensus and transaction model.

CHAPTER 5

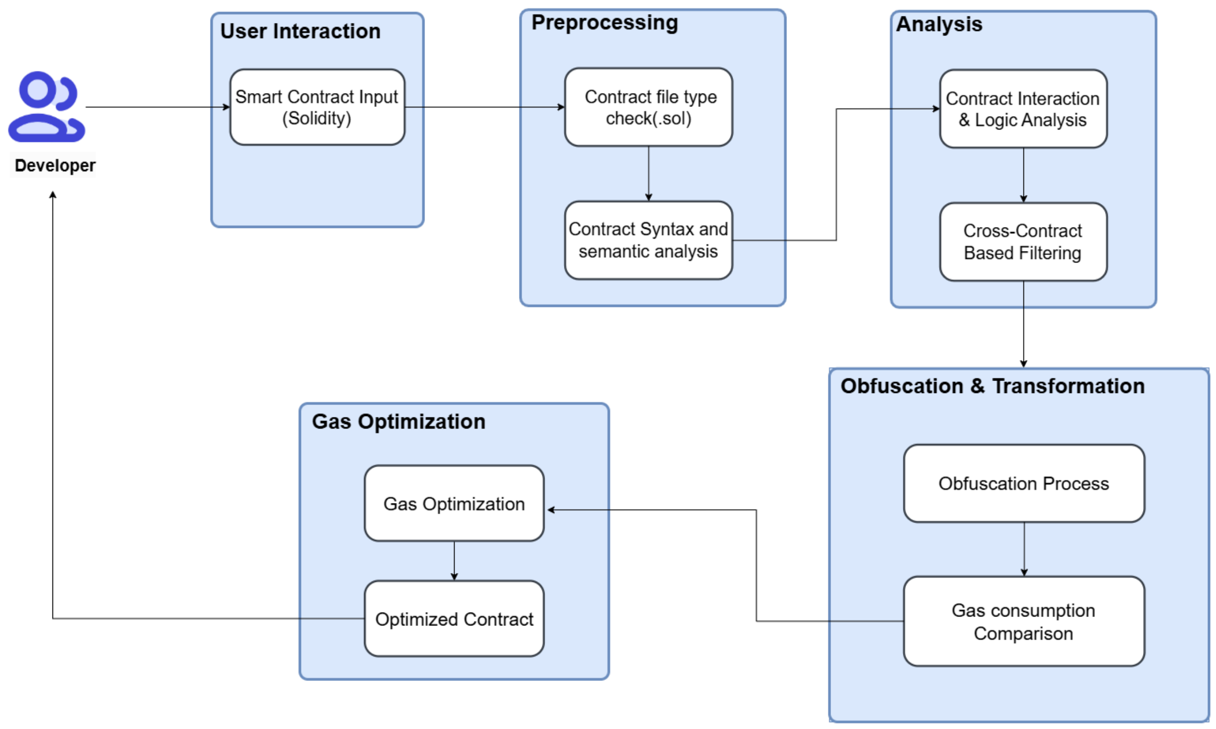
SYSTEM DESIGN

5.1 SYSTEM ARCHITECTURE

The architecture of the proposed Cross-Contract Obfuscation and Gas Optimization Framework is designed as a modular pipeline, starting with the developer uploading Solidity (.sol) files. The system performs syntax and semantic validation using solcjs, followed by interaction analysis through a combination of static and regex-based methods.

Detected interactions—such as high-level calls, low-level calls, proxy routes, and factory deployments—are mapped into a structured JSON. Based on this map, the Obfuscation Engine applies one of four custom transformation techniques that enhance security without breaking functionality.

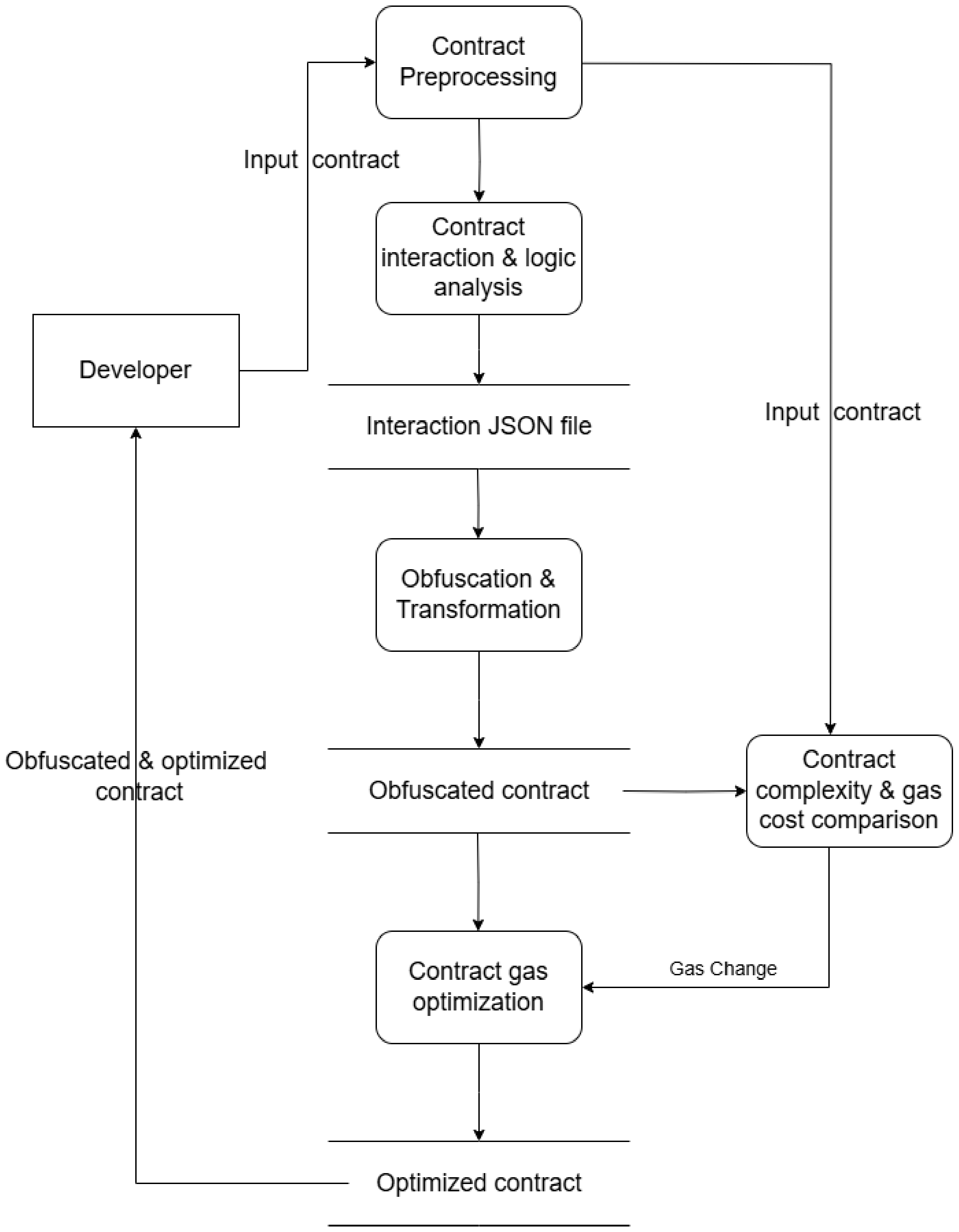
The transformed contracts are then passed to a Gas Optimization module that minimizes deployment and execution costs through bytecode refinements. Finally, the system generates obfuscated contracts, gas reports, and logs for the developer, ensuring a complete and secure transformation workflow.


Developer
User Interaction
Smart Contract Input (Solidity)
Preprocessing
Contract file type check(.sol)
Contract Syntax and semantic analysis
Analysis
Contract Interaction & Logic Analysis
Cross-Contract Based Filtering
Obfuscation & Transformation
Obfuscation Process
Gas consumption Comparison
Gas Optimization
Gas Optimization
Optimized Contract

FIG(1): ARCHITECTURE DIAGRAM

5.2 Data Flow Diagram

The data flow diagram outlines how information moves through the system, beginning with the developer submitting a smart contract. The contract first passes through a preprocessing module that ensures it is syntactically and semantically valid. Valid contracts are forwarded to the Contract interaction & logic analysis module, which generates a JSON map of key interaction types. This data flows into the Contract obfuscation, where context-specific transformations are applied. The resulting code is passed to the gas optimizer, which enhances efficiency while preserving security. Finally, the optimized and obfuscated contract, along with gas reports and logs, is delivered back to the developer. This stepwise data transformation ensures accuracy, scalability, and security at every stage of the process.


Contract Preprocessing
Input contract
Contract interaction & logic analysis
Developer
Interaction JSON file
Input contract
Obfuscation & Transformation
Obfuscated & optimized contract
Obfuscated contract
Contract complexity & gas cost comparison
Gas Change
Contract gas optimization
Optimized contract

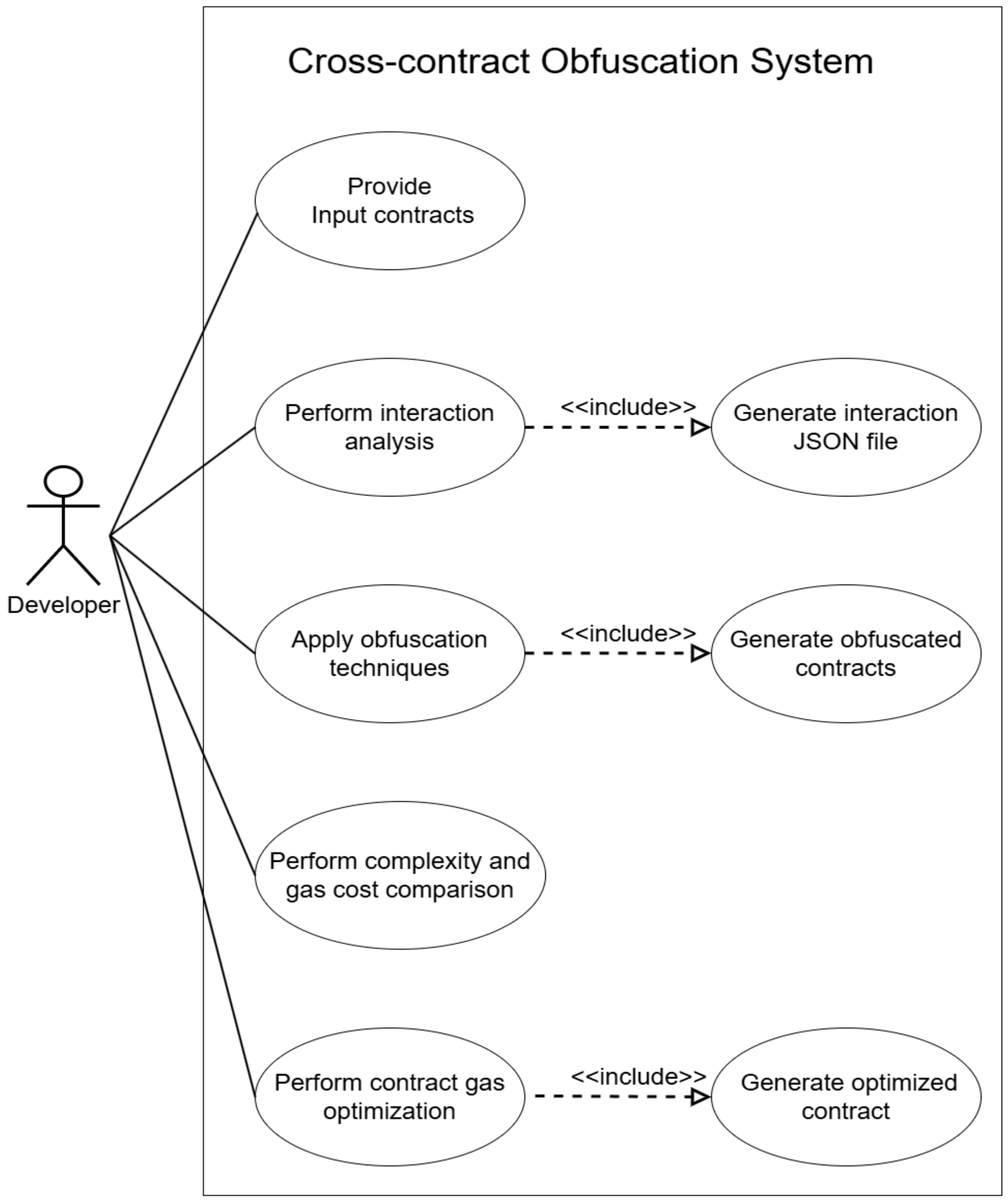
FIG(2): DATA FLOW DIAGRAM

5.3 Use Case Diagram

The use case diagram for this project illustrates how a developer interacts with the obfuscation framework to secure Solidity smart contracts. The main actor, the developer, performs tasks such as provide Solidity files, initiating syntax and semantic checks, detecting interaction types, and generating a structured interaction report. The developer can then apply interaction-specific obfuscation techniques, run gas optimization to enhance cost-efficiency, validate the transformed contract through functional testing (e.g., Remix IDE), and finally export the secure obfuscated version of the contract. This use case flow represents a comprehensive and user-driven security enhancement lifecycle for multi-contract Ethereum applications.

Advantages

- Clear Visualization of System Functionality
- Improves Communication Between Stakeholders
- Defines System Boundaries and Scope
- Simplifies Requirement Gathering and Analysis
- Supports Modular System Design
- Enhances Test Planning


Cross-contract Obfuscation System
Provide Input contracts
Perform interaction analysis
<<include>>
Generate interaction JSON file
Developer
Apply obfuscation techniques
<<include>>
Generate obfuscated contracts
Perform complexity and gas cost comparison
Perform contract gas optimization
<<include>>
Generate optimized contract

FIG(3): USECASE DIAGRAM

CHAPTER 6

SYSTEM IMPLEMENTATION

6.1 MODULE

1. **Smart Contract Preprocessing**
   - Accepts Solidity contracts and perform syntax and semantic analysis.

2. **Interaction & Logic Analysis**
   - Detects contract interaction type using static analysis methods.
   - Filters cross-contract interactions.

3. **Obfuscation & Transformation**
   - Applies obfuscation techniques .
   - Analyzes gas consumption before and after transformation.

4. **Gas Optimization**
   - Refines obfuscated code to reduce gas costs while maintaining security.
   - Outputs a secure, obfuscated, and gas-optimized smart contract.

6.2 MODULE DESCRIPTION

1. **Smart Contract Preprocessing**

   This module is the first step in the pipeline. It is responsible for validating and preparing smart contracts for analysis. The system accepts user-input Solidity files and performs file format checks, followed by basic syntax and semantic validation.

   What it does:

   - Checks if uploaded files are of .sol extension.
   - Ensures contracts are syntactically correct using the Solidity compiler (solc or py-solc-x).
   - Performs semantic checks to ensure constructs (like inheritance, modifiers, fallback functions, etc.) are valid for further processing.
   - Filters out incomplete or broken contracts before deeper analysis.

2. **Interaction & Logic Analysis**

   This module detects different types of contract interactions, which are the targets for transformation in later stages. It uses a hybrid of static parsing and regex-based analysis to find and classify key interaction patterns.

   What it does:

   - Parses contract code using regular expressions to match:
     - ➢ High-level calls: IERC20(...).transfer(...)

    - Low-level calls: .call(...), .delegatecall(...)
    - Factory deployments: new Contract(...)
    - Proxy patterns: delegatecall routing or implementation()
- Maps each interaction to:
    - Its type (high-level, low-level, proxy, factory)
    - Caller and callee of the interaction
    - Funcion name and signature
- This forms the basis for the JSON-based interaction mapping used in the next module.

3. Obfuscation & Transformation

This is the core module of your system. It applies your custom obfuscation techniques to interaction points detected earlier. The goal is to make the contract behavior difficult to reverse engineer while maintaining full functional correctness.

What it does:

- For each interaction type, applies one of the four custom obfuscation strategies:
    - High-Level → Low-Level Call + Selector Encoding + Opaque Predicate
    - Low-Level → Selector Computation + Memory Obfuscation
    - Factory → CREATE2 Deployment + Randomized Salt/Args
    - Proxy → Dynamic Fallback Selector + Nested Routing
- Inserts the transformed logic directly into the contract source code.
- Before and after transformation, records gas usage for target functions to measure performance impact.

4. Gas Optimization

After transformation, this module focuses on refining the obfuscated code to reduce gas usage without compromising obfuscation logic or functionality.

What it does:

- Performs bytecode-level and source-level optimizations:
    - ➢ Storage Packing (Optimized Slot Usage)
    - ➢ Precomputed Function Selector Dispatching
    - ➢ Optimized Memory Handling (Minimal Stack Moves)
- Uses static analysis to validate post-optimization gas usage.
- Outputs a final version of the contract that is:
    - ➢ Functionally correct
    - ➢ Security-preserved
    - ➢ Gas-efficient

6.3 MODULE IMPLEMENTATION

1. **Smart Contract Preprocessing**
    - Implemented in Python using os and glob modules.
    - Checks if each uploaded file has .sol extension.
    - Uses py-solc-x to compile the contract and validate for syntax/semantic errors.
    - Valid contracts are copied to a staging folder for analysis.

```
# Syntax Analysis - checks if Solidity code can compile to bytecode
result = subprocess.run(
    [r"C:\Users\WELCOME\AppData\Roaming\npm\npx.cmd",
"solcjs", "--bin", file_path],
    stdout=subprocess.PIPE,
    stderr=subprocess.PIPE,
    text=True
)
```

2. **Interaction & Logic Analysis**

    Interaction detection is performed in two stages:
    - Regex-based matching to identify patterns like:
      \.call\(|\.delegatecall\(|IERC20\(.+\)\.transfer\(|new\s+\w+\(
    - AST-based extraction using py-solc-x to identify function scopes and map interactions to their context.
    - Results are structured into a JSON mapping file, for example:

```
{
   "interactions": [
      {
         "caller": "High_level.sol",
         "callee": "freelancer",
         "function": "transfer",
         "interaction_type": "high_level",
         "interaction_role": "initiator",
         "function_signature": "transfer(amount)",
               }}
```

3. Obfuscation & Transformation

- Python scripts read the JSON mapping and transform each interaction based on its type.
- Obfuscation logic is applied using string rewriting and AST transformations.

- Transformations Include:
  - ➢ Replacing high-level calls: token.call(abi.encodeWithSignature("transfer(address,uint256)", to, amount));
  - ➢ Adding computed selectors: bytes4selector= bytes4(keccak256("transfer(address,uint256)"));

4. Gas Optimization

- Obfuscated contracts are tested using static analysis
- Bytecode optimizations done through:
  - Mentioning the handling of memory.
  - Simplification of logics.
- Results are logged in a comparison file

CHAPTER 7

TESTING

7.1 CONTRACT FUNCTIONALITY TESTING

The goal of contract functionality testing is to ensure that all functions in the obfuscated smart contracts behave identically to their original counterparts. This step verifies that obfuscation does not break business logic, state transitions, or contract interactions, which is crucial before deployment.

Testing Environment

- IDE Used: Remix Ethereum IDE (https://remix.ethereum.org)
- Environment: JavaScript VM (Local Ethereum simulation)
- Compiler Version: Solidity 0.8.x (same as used in implementation)
- Test Accounts: Auto-generated test wallets by Remix (with Ether)

Testing Approach

1. **Upload Original & Obfuscated Contracts:**

   Both versions (Original.sol and Obfuscated.sol) were uploaded into Remix IDE.

2. **Compile Each Contract:**
   - Compilation was performed with the same settings for both contracts
   - Ensured no syntax or bytecode errors during compilation.

3. **Deploy to Local Blockchain:**
    - ➢ Used the “Deploy” button to deploy each contract instance into the Remix JavaScript VM environment.
    - ➢ Multiple contracts were tested, including contracts using:
        - Factory deployment
        - Delegatecall-based proxy logic
        - ERC20 token transfers (high-level and low-level calls)

4. **Test Public & External Functions:**
    - ➢ Each public and external function in both versions was executed using the Remix interface.
    - ➢ Sample input values were passed to test:
        - Token transfers
        - Proxy delegation
        - Contract creation via factory
        - Fallback and routing behaviours

5. **Test Validate Output and State Changes:**
    - ➢ Compared return values, logs, and contract state variables before and after function execution.
    - ➢ Verified event logs and emit statements matched in both contract versions.
    - ➢ Checked that gas usage did not trigger out-of-gas errors.

7.2 COMPLEXITY AND GAS COST TESTING

This test focuses on analyzing the interaction complexity and estimated gas cost of original vs. obfuscated contracts.

Testing Method:

- A Python script was created using regex and static parsing techniques.
- It counts the occurrence of various interaction types:
    - ➢ High-level calls
    - ➢ Low-level calls
    - ➢ Opaque predicates
    - ➢ Proxy patterns
    - ➢ Factory deployments
- It estimates logical complexity and relative gas cost impact.
- Finally, it generates a visual comparison using matplotlib bar charts.

Metrics Compared:

- Total interaction-based Complexity Score
- Estimated Gas Cost Score
- % Change between original and obfuscated contracts

Extract interaction data from Solidity code:

```
def extract_interaction_data(filepath):
    high_calls = re.findall(r'\w+\.\w+\(', content)
    low_calls = re.findall(r'\.(call|delegatecall|staticcall)\b', content)
    opaque_preds=re.findall(r'if\s*\(.*(call|delegatecall|staticcall).*&&.*\)',
content)
```

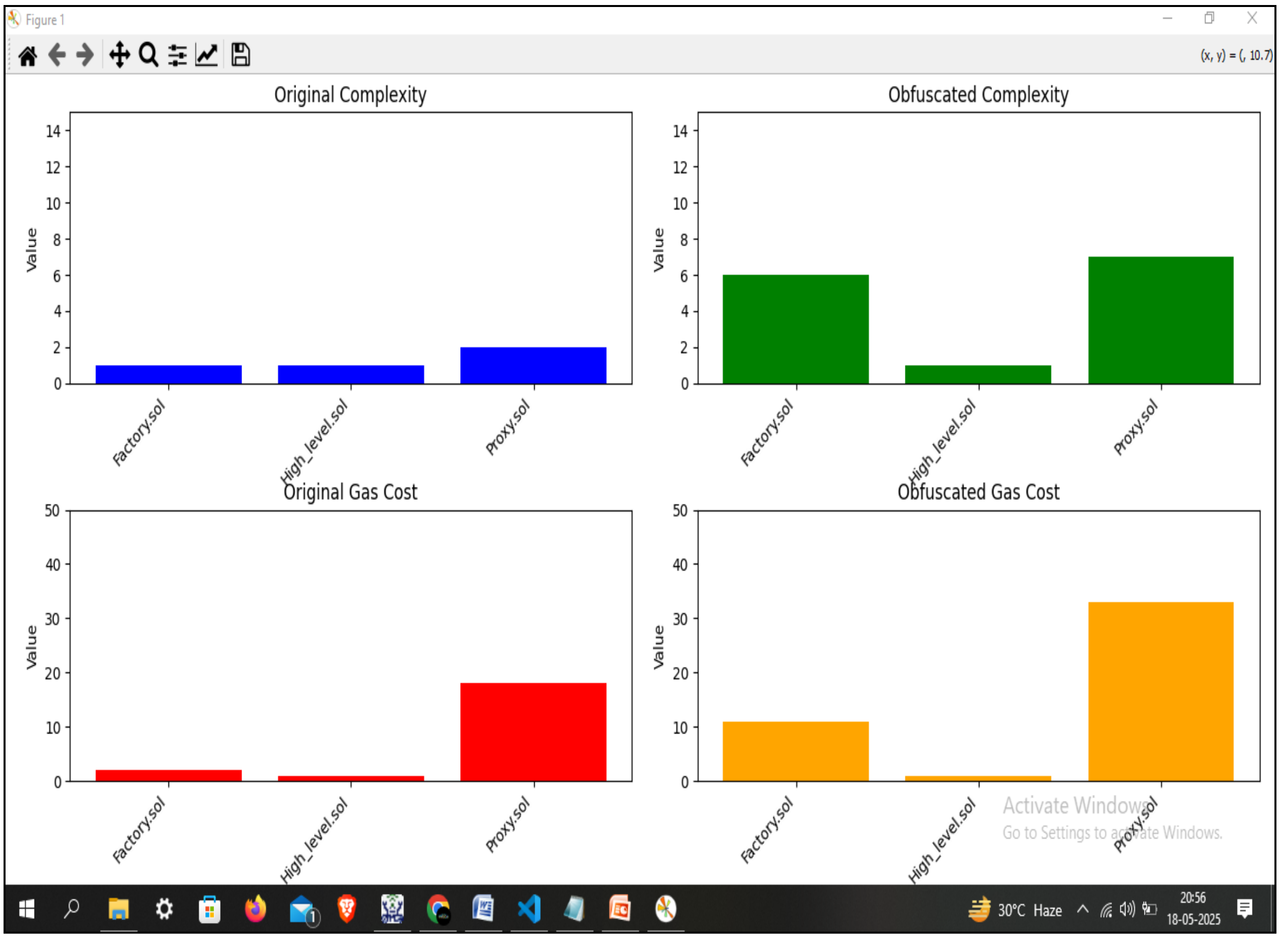
```
        factory_new = re.findall(r'new\s+[A-Z]\w+', content)
        factory_create2 = re.findall(r'create2', content, re.IGNORECASE)
```

Compare complexity and gas cost between original and obfuscated versions:

```
    def compare_files(orig_file, obf_file):
        orig_complexity, orig_gas = extract_interaction_data(orig_file)
        obf_complexity, obf_gas = extract_interaction_data(obf_file)
        return os.path.basename(orig_file), orig_complexity, obf_complexity,
    percent_change(orig_complexity, obf_complexity), orig_gas, obf_gas,
    percent_change(orig_gas, obf_gas)
```

7.3 TESTING RESULT

Comparison of complexity and gas cost between original and obfuscated versions.



CHAPTER 8

APPLICATION

The proposed system has practical applications in multiple areas of decentralized blockchain development. As smart contracts become increasingly modular and interdependent, protecting the integrity of cross-contract interactions while maintaining gas efficiency becomes vital.

1. Decentralized Finance (DeFi) Protocols

DeFi platforms like Uniswap, Aave, and Curve use complex contract ecosystems that interact across modules (liquidity pools, routers, oracles, etc.). These contracts are prime targets for reverse engineering and MEV (miner extractable value) attacks.

Application: The proposed system can be used to obfuscate sensitive logic in routers, liquidity pools, or arbitrage components, reducing the risk of strategy theft and front-running.

Benefit: Protects trade logic, automated market making strategies, and flash loan mechanics from malicious actors.

2. Smart Contract Wallets and Account Abstraction

Wallets like Argent, Gnosis Safe, or Safe Wallet often implement smart contract logic for secure multisig and programmable wallets. These involve multiple contracts interacting to handle authorization, upgradeability, and fallback mechanisms.

Application: This framework can obfuscate the control flow in proxy contracts and wallet execution logic, especially around fallback delegation and permission checks.

Benefit: Makes it harder for attackers to reverse engineer wallet internals or exploit upgradability patterns.

3. **Factory-Based DApp Deployment**

In many DApps, new contract instances are deployed dynamically using factory contracts. Examples include NFT marketplaces, staking platforms, and custom DEX pairs.

Application: By applying CREATE2-based obfuscation and randomized deployment paths, your system protects how and where these contracts are deployed.

Benefit: Prevents attackers from predicting contract addresses or replicating your deployment logic.

CHAPTER 9

CONCLUSION

The project successfully implements a robust and scalable framework for cross-contract obfuscation and gas optimization in Solidity smart contracts. By shifting the focus from traditional single-contract obfuscation to interaction-level protection, the system addresses key vulnerabilities found in complex decentralized applications such as DeFi platforms, DAOs, and smart wallets. Using static and regex-based analysis, the framework accurately detects contract interactions and applies four customized obfuscation strategies that target high-level calls, low-level calls, proxy routing, and factory-based deployments. Each obfuscation technique is designed to preserve contract functionality while introducing complexity for reverse engineering and static analysis tools. Functional testing using Remix IDE confirmed behavioral consistency, while a Python-based analysis tool measured the increase in logical complexity and the controlled impact on gas costs. Overall, the system proves that interaction-aware obfuscation, when combined with optimization, can enhance smart contract security without compromising performance or correctness.

CHAPTER 10

FUTURE ENHANCEMENT

One of the most impactful directions for future enhancement lies in extending the obfuscation capabilities to include dynamic external contract interactions, such as those involving oracles, ERC20/ERC721 tokens, and third-party smart contracts or services. These external dependencies are critical in production environments but were excluded from this project due to practical challenges in safely modifying standardized ABIs, ensuring compatibility, and avoiding unintended execution failures. Obfuscating external interactions would require advanced techniques such as interface wrapping, proxy adaptation layers, and dynamic ABI encoding, which introduce significant implementation complexity and integration risks if not handled precisely. However, achieving this in the future would significantly strengthen the system by preventing adversaries from analyzing interaction signatures with popular external protocols, thus enhancing defense against reverse engineering, MEV attacks, and strategy replication. This would make the obfuscation framework suitable for enterprise-grade decentralized applications that rely heavily on off-chain data feeds and shared standards.

APPENDIX

SOURCE CODE

Main.py

```
import argparse
import os
import subprocess
import contract_analysis
import Obfuscated_contract_complexity_analysis  # Import comparison logic

from utils.file_handler import (
    get_latest_json, manage_intermediate_files, delete_intermediate_files,
write_final_output
)
from obfuscation_techniques.opaque_predicate_obfuscation.obfuscate import
process_files
fromobfuscation_techniques.factory_based_contract.factory_based_obfuscation
import apply_obfuscation
from obfuscation_techniques.proxy_contract.proxy_interaction_obfuscation
import process_proxy_files
from obfuscation_techniques.dynamic_function_dispatch.obfuscation import
process_obfuscation
from obfuscation_techniques.high_to_low_conversion import process_contracts

def print_separator(title):
    print("\n" + "=" * 50)
    print(f"=== {title} ===")
    print("=" * 50)

def get_files_from_input(input_path):
    if os.path.isfile(input_path):
        if input_path.endswith('.sol'):
            return [input_path]
        else:
            print(f"Error: {input_path} is not a Solidity (.sol) file.")
            return []
    elif os.path.isdir(input_path):
        files = [os.path.join(input_path, f) for f in os.listdir(input_path) if
f.endswith('.sol')]
        if not files:
            print("Error: No Solidity (.sol) files found in the folder.")
        return files
    else:
        print("Error: Invalid input path.")
        return []

def syntax_analysis(file_path):
    print_separator(f"Syntax Analysis for {file_path}")
    try:
        result = subprocess.run(
            [r"C:\Users\WELCOME\AppData\Roaming\npm\npx.cmd", "solcjs", "--
bin", file_path],
            stdout=subprocess.PIPE, stderr=subprocess.PIPE, text=True
        )
        if result.returncode != 0:
            print(f"Syntax Error:\n{result.stderr}")
            return False
        print(f"Syntax analysis passed.\n{result.stdout}")
        return True
    except FileNotFoundError:
        print("Error: Solidity compiler not found. Make sure it's installed.")
        return False

def semantic_analysis(file_path):
    print_separator(f"Semantic Analysis for {file_path}")
    try:
        result = subprocess.run(
            [r"C:\Users\WELCOME\AppData\Roaming\npm\npx.cmd", "solcjs", "--
abi", file_path],
            stdout=subprocess.PIPE, stderr=subprocess.PIPE, text=True
        )
        if result.returncode != 0:
            print(f"Semantic Error:\n{result.stderr}")
            return False
        print(f"Semantic analysis passed.\n{result.stdout}")
        return True
    except FileNotFoundError:
        print("Error: Solidity compiler not found. Make sure it's installed.")
        return False

def run_obfuscation(input_folder, intermediate_folder, output_folder,
json_folder):
    latest_json_file = get_latest_json(json_folder)
    print_separator(f"Obfuscation Process (JSON: {latest_json_file})")

    print("\n Step 1: Opaque Predicate Obfuscation")
    process_files(input_folder, intermediate_folder, latest_json_file)

    print("\n Step 2: Dynamic Dispatch Obfuscation")
    process_obfuscation(intermediate_folder, latest_json_file, output_folder)
    delete_intermediate_files(intermediate_folder)

    print("\n Step 3: Factory-Based Contract Obfuscation")
    process_contracts(output_folder, intermediate_folder, latest_json_file)
    delete_intermediate_files(output_folder)

    print("\n Step 4: Proxy-Based Contract Obfuscation")
    process_proxy_files(intermediate_folder, output_folder, latest_json_file)
    delete_intermediate_files(intermediate_folder)

    print("\n Step 5: High-to-Low Conversion Obfuscation")
    apply_obfuscation(output_folder, latest_json_file)

    print_separator("Obfuscation Completed ")

#  CLI COMMAND HANDLERS

def analyze_cmd(args):
    input_path = args.input
    files = get_files_from_input(input_path)
    if not files:
        print("No valid files found for analysis. Exiting.")
        return

    for file in files:
        print_separator(f"Processing File: {file}")

        if not syntax_analysis(file):
            print(f"Skipping further checks for {file} due to syntax errors.")
            continue

        if not semantic_analysis(file):
            print(f"Skipping further checks for {file} due to semantic errors.")
            continue

        print(f"\n {file} passed syntax and semantic analysis.")

    print_separator("Performing Interaction Analysis")
    contract_analysis.manual_analysis(os.path.dirname(files[0]))

def obfuscate_cmd(args):
    input_path = args.input
    output_path = "output/obfuscated_contracts"
    intermediate_folder = "utils/intermediate_contracts"

    print_separator("Starting Obfuscation Phase")
    run_obfuscation(input_path, intermediate_folder, output_path,
"output/analysis_results")

    print_separator("Obfuscation Finished ")
```

```
def compare_cmd(args):
    print_separator("Comparing Obfuscated Contracts")
    Obfuscated_contract_complexity_analysis.compare_folders(args.original, 
args.obfuscated)

# === MAIN CLI ENTRY ===

def main():
    parser = argparse.ArgumentParser(prog='main', description="Final Year 
Project: Solidity Obfuscation CLI")
    subparsers = parser.add_subparsers(dest='command', required=True)

    # analyze
    p_analyze = subparsers.add_parser('analyze', help='Syntax, semantic & 
interaction analysis')
    p_analyze.add_argument('input', help='Path to Solidity file or folder')
    p_analyze.set_defaults(func=analyze_cmd)

    # obfuscate
    p_obfuscate = subparsers.add_parser('obfuscate', help='Apply interaction-
specific obfuscation')
    p_obfuscate.add_argument('input', help='Path to Solidity file or folder')
    p_obfuscate.set_defaults(func=obfuscate_cmd)

    # compare
    p_compare = subparsers.add_parser('compare', help='Compare original vs 
obfuscated contracts')
    p_compare.add_argument('--original', required=True, help='Original 
contracts folder')
```

```
    p_compare.add_argument('--obfuscated', required=True, help='Obfuscated
contracts folder')
    p_compare.set_defaults(func=compare_cmd)

    args = parser.parse_args()
    args.func(args)

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

Obfuscated_contract_complexity_analysis.py

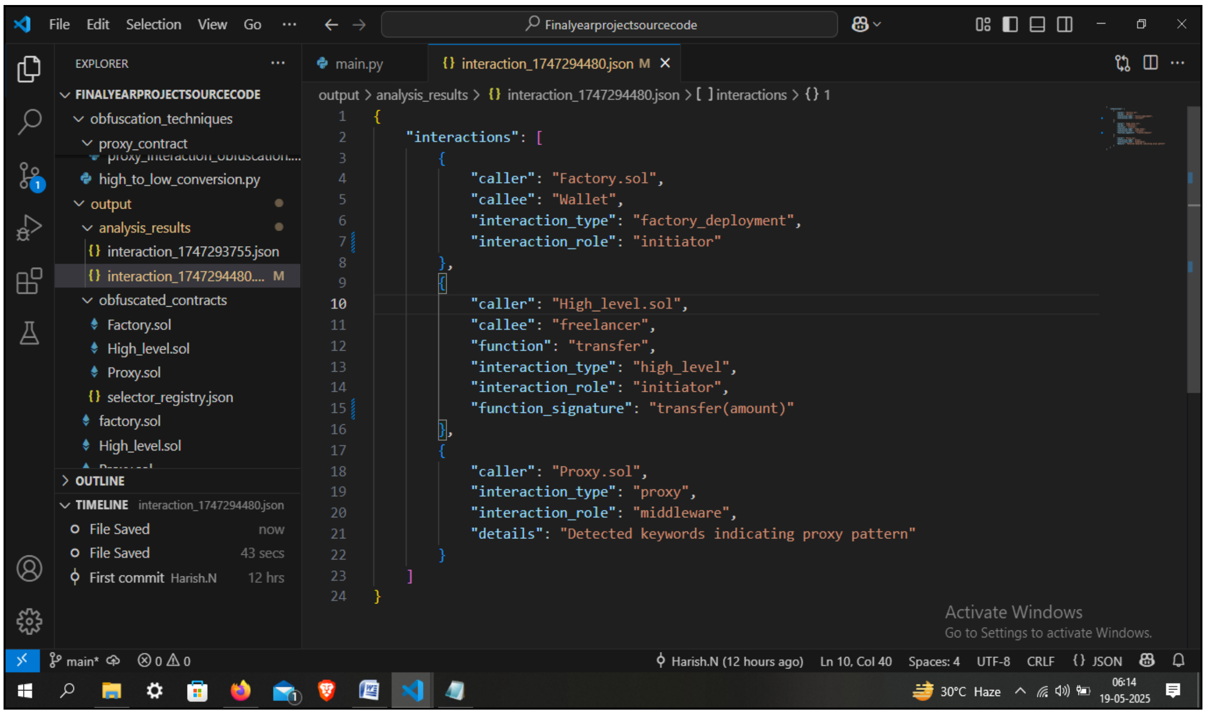
```
import os
import re
import argparse
import matplotlib.pyplot as plt

def extract_interaction_data(filepath):
    """Extract contract interaction complexity and gas cost using static
analysis."""
    with open(filepath, 'r', encoding='utf-8') as f:
        content = f.read()

    complexity = 0
    gas_cost = 0

    # High-level calls
    high_calls = re.findall(r'\w+\.\w+\(', content)
    complexity += len(high_calls)
    gas_cost += len(high_calls)

    # Low-level calls
    low_calls = re.findall(r'\.(call|delegatecall|staticcall)\b', content)
    low_conditions = re.findall(r'if\s*\(.*\.(call|delegatecall|staticcall)', content)
    complexity += len(low_conditions) + len(low_calls)
    gas_cost += len(low_calls) + len(low_conditions) * 2

    # Opaque predicates
    opaque_preds = re.findall(r'if\s*\(.*(call|delegatecall|staticcall).*&&.*\)',
content)
    complexity += len(opaque_preds)
    gas_cost += len(opaque_preds) * 2

    # Proxy patterns
    proxy_patterns =
re.findall(r'(fallback|delegateTo|implementation|forwardTo|functionSelector)',
content)
    complexity += len(set(proxy_patterns))
    gas_cost += len(proxy_patterns) * 2

    # Factory-related complexity
    factory_proxy = re.findall(r'new\s+Proxy\s*\(', content)
    complexity += len(factory_proxy)
    gas_cost += len(factory_proxy) * 4

    factory_new = re.findall(r'new\s+[A-Z]\w+', content)
    factory_create2 = re.findall(r'create2', content, re.IGNORECASE)
    complexity += len(factory_new)
    gas_cost += len(factory_new) * 2 + len(factory_create2) * 3

    return complexity, gas_cost

def percent_change(orig, obf):
    """Calculate percentage change."""
    if orig == 0 and obf > 0:
        return f"{(obf - orig) * 10:+.2f}%"
    elif orig == 0 and obf == 0:
        return "0%"
    else:
        return f"{(obf - orig) * 10:+.2f}%"

def compare_files(orig_file, obf_file):
    """Compare total complexity and gas cost between original and obfuscated
contracts."""
    orig_complexity, orig_gas = extract_interaction_data(orig_file)
    obf_complexity, obf_gas = extract_interaction_data(obf_file)

    comp_change = percent_change(orig_complexity, obf_complexity)
    gas_change = percent_change(orig_gas, obf_gas)

    return os.path.basename(orig_file), orig_complexity, obf_complexity,
comp_change, orig_gas, obf_gas, gas_change

def compare_folders(orig_folder, obf_folder):
    """Analyze complexity across multiple contract files and generate table &
charts."""
    results = []
    for file in os.listdir(orig_folder):
        if file.endswith('.sol'):
            orig_path = os.path.join(orig_folder, file)
            obf_path = os.path.join(obf_folder, file)

            if os.path.exists(obf_path):
                results.append(compare_files(orig_path, obf_path))

    print_table(results)
    plot_bar_charts(results)

def print_table(data):
    """Print the comparison table in structured format."""
    print("\n Solidity Contract Complexity & Gas Cost Comparison\n")
    print("-" * 120)
    print(f"{'File Name':<20} | {'Orig. Complex.':>5} | {'Obf. Complex.':>5} |
{'% Change':>10} | {'Orig. Gas':>5} | {'Obf. Gas':>5} | {'% Change':>10}")
    print("-" * 120)

    for entry in data:
        print(f"{entry[0]:<25} | {entry[1]:^10} | {entry[2]:^10} | {entry[3]:^10} |
{entry[4]:^10} | {entry[5]:^10} | {entry[6]:^10}")

    print("-" * 120)

def plot_bar_charts(data):
    """Generate four bar charts for complexity and gas cost comparison with
adjusted Y-axis ranges."""
```

```
filenames = [entry[0] for entry in data]
orig_complexity = [entry[1] for entry in data]
obf_complexity = [entry[2] for entry in data]
orig_gas = [entry[4] for entry in data]
obf_gas = [entry[5] for entry in data]

fig, axes = plt.subplots(2, 2, figsize=(12, 8))

# Set Y-axis limits for complexity charts (range: 15)
axes[0, 0].bar(filenames, orig_complexity, color='blue')
axes[0, 0].set_title("Original Complexity")
axes[0, 0].set_ylim(0, 15)

axes[0, 1].bar(filenames, obf_complexity, color='green')
axes[0, 1].set_title("Obfuscated Complexity")
axes[0, 1].set_ylim(0, 15)

# Set Y-axis limits for gas cost charts (range: 50)
axes[1, 0].bar(filenames, orig_gas, color='red')
axes[1, 0].set_title("Original Gas Cost")
axes[1, 0].set_ylim(0, 50)

axes[1, 1].bar(filenames, obf_gas, color='orange')
axes[1, 1].set_title("Obfuscated Gas Cost")
axes[1, 1].set_ylim(0, 50)

# Improve readability for X-axis labels
for ax in axes.flatten():
    ax.set_xticklabels(filenames, rotation=45, ha='right')
```

```
        ax.set_ylabel("Value")

    plt.tight_layout()
    plt.show()

if __name__ == "__main__":
    parser = argparse.ArgumentParser(description="Compare total contract
complexity and gas cost.")
    parser.add_argument('--original', required=True, help="Path to original
contract folder")
    parser.add_argument('--obfuscated', required=True, help="Path to obfuscated
contract folder")
    args = parser.parse_args()

    compare_folders(args.original, args.obfuscated)
```

OUTPUT:

Interaction.json



```json
{
    "interactions": [
        {
            "caller": "Factory.sol",
            "callee": "Wallet",
            "interaction_type": "factory_deployment",
            "interaction_role": "initiator"
        },
        {
            "caller": "High_level.sol",
            "callee": "freelancer",
            "function": "transfer",
            "interaction_type": "high_level",
            "interaction_role": "initiator",
            "function_signature": "transfer(amount)"
        },
        {
            "caller": "Proxy.sol",
            "interaction_type": "proxy",
            "interaction_role": "middleware",
            "details": "Detected keywords indicating proxy pattern"
        }
    ]
}
```

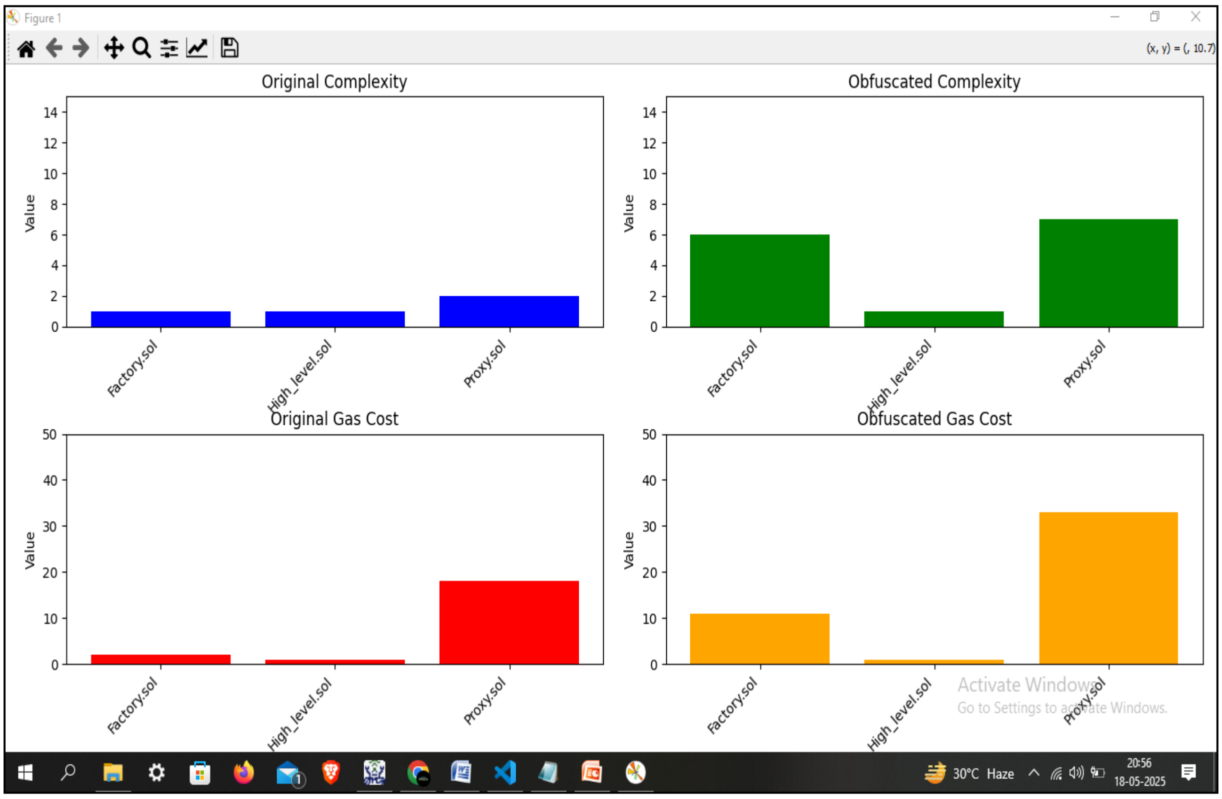
Original Contract

```solidity
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.20;

contract Wallet {
    address public owner;
    uint256 public unlockTime;

    constructor(address _owner, uint256 _unlockTime) {
        owner = _owner;
        unlockTime = _unlockTime;
    }
}
contract VaultDeployer {
    function deployWallet(address user, uint256 unlockAfter) public returns
(address) {
        Wallet newWallet = new Wallet(user, unlockAfter);
        return address(newWallet);
    }
}
```

Obfuscated contract

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.20;

contract Wallet {
    address public owner;
    uint256 public unlockTime;

    constructor(address _owner, uint256 _unlockTime) {
        owner = _owner;
        unlockTime = _unlockTime;
    }
}

contract VaultDeployer {
    function deployWallet(address user, uint256 unlockAfter) public returns
(address) {
        require(msg.sig == bytes4(keccak256('deployWallet(address user,
uint256 unlockAfter)')), 'Invalid function selector');
        Wallet newWallet = ObfuscatedFactory_Wallet().deploy(0,
keccak256(abi.encodePacked(block.timestamp, user, unlockAfter)), user,
unlockAfter, 59, "ObfuscatedParam");
        return address(newWallet);
    }
}



contract ObfuscatedFactory_Wallet {
    function deploy(uint256 route, bytes32 salt, address arg1, uint256 arg2,
uint256 dummyArg1, string memory dummyArg2) public returns (address) {
        if (route == 0) {
            return address(new Wallet(arg1, arg2));
        } else if (route == 1) {
            return address(new Wallet(arg1, arg2));
        } else {
            return Create2.deploy(salt,
abi.encodePacked(type(Wallet).creationCode, abi.encode(arg1, arg2)));
        }
    }
}
```

Complexity & Gas cost Analysis result



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