An Exploratory Study on Solidity Guards and Ether Exchange Constructs

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ABSTRACT

Ethereum is a blockchain platform that enables the use of smart contracts. Smart contracts will execute a set of instructions without an intermediary party when called upon. The possibility to make calls to another contract or exchange cryptocurrency allows for potential exploits to occur, most notable reentrancy. The Solidity language for coding smart contracts has syntactic constructs created to be safer alternatives, and guards to aid in securing code against exploits. In this paper, we collect a total of 26,799 verified Solidity smart contracts from Etherscan, to analyze the language constructs used in calling another contract or exchanging ether. We also analyze the usage of guards to make the code more secure. For instance, even though call is the unsafest function, it is still used by 50% of the contracts in our dataset. The safe method transfer is used by approximately one-third of contracts, and send is rarely used. We noticed that contracts using call have a higher average and median size in Lines of Code than normal. We also found an increased percentage of call contracts using more guards. Moreover, 97% of all contracts are using the require guard, with 23 uses of require on average per contract. This may be an indication that Solidity developers are using more guards to prevent exploits in their contracts

KEYWORDS

Ethereum, Smart Contracts, Solidity, Call, Guards.

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1 INTRODUCTION

A blockchain is an append-only transactional database where the information is structured together in groups, also known as blocks [4, 11]. Each block has certain storage capacities and is chained onto the previous filled block, thus forming a blockchain. Another way to define it is a shared, immutable ledger that records transactions that can be used to track different assets. The most notable uses of this blockchain technology are the cryptocurrencies Bitcoin[13] and Ether [8, 20] on the Ethereum network. One important difference between these two blockchain platforms is that Ethereum enables the deployment of smart contracts.

A smart contract is a contract that executes automatically when called upon where the terms between the two parties are written in code (on the blockchain). These contracts then run when a function is called and the conditions for that function are met and can be used to automate executions of agreements without any intermediary party [2, 9, 11]. In its simplest form, a contract is just a collection of functions. Interesting to note is that all smart contract transactions are traceable, transparent, and also irreversible [4, 11].

A common functionality of smart contracts is the possibility to make calls to another contract on the same blockchain platform. This however needs to be done with caution as untrusted contracts can not only introduce errors but also risks as the contract or call may execute malicious code and exploit vulnerabilities. Every call transfers execution control to the called contract.

One of these dangers when calling an external contract is called reentrancy and is one of the most well-known attacks due to the DAO Attack in June 2016 where around 3.6 million Ether was taken which equated to around $50 million dollar at the time [1]. The original version of this attack involved functions that would be called repeatedly before the first function was finished.

Solidity is one of the major programming languages for smart contracts on Ethereum. To avoid these exploits, there have been introduced more language constructs and recommended coding patterns. More specifically, the function call() was to be replaced by the safer functions transfer() and send(). However, recently there has been a switch back to the call() function with the introduction of EIP 1884 [16].

Other precautions instead must be taken to prevent reentrancy attacks, one recommendation is making use of safe code patterns and using guards.

In this paper, we conduct an exploratory research investigating how these calling functions are used in practice and if they are still commonly used for the current smart contracts being deployed in the Ethereum network. For this study, we collected a dataset of 26,799 unique open-source verified smart contracts from Etherscan (from 2012-07-07 to 2022-01-06). We present different characteristics for the contracts and the Solidity language constructs being used.

The remainder of the paper is organized as follows. In Section 2, we explain some important concepts about Solidity, its language constructs, and Reentrancy attack. In Section 3, we describe our dataset and our research method. Section 4 presents the results from our exploratory study and a general analysis of them. Section 5 discusses the related work. Finally, in Section 6, we present our final remarks and outline future work ideas.

2 BACKGROUND

2.1 Solidity

Solidity [5] is one of the main languages to code smart contracts in the Ethereum platform. Solidity is an object-oriented, high-level language that has syntax comparable to C++.

2.1.1 Solidity Ether Exchange. We like to highlight the language constructs used to exchange cryptocurrency among contracts: call, send, and transfer (Table 1).

Table 1: Solidity Functions to Exchange Ether

Function	Gas Limit	Error Handling
call	Custom	Returns false on failure
transfer	2300	Throws exception on failure
send	2300	Returns false on failure

The call function is a low-level interface for sending a message to a contract and it is also a way to send Ether to another address. The call function transfers the execution control to the called contract and the caller can forward any amount of gas. Therefore, the call function has the potential to introduce vulnerabilities, most notably reentrancy.

The transfer method was first introduced in version 0.4.10 (May 2017) of the Solidity language. It provides a safe-by-design method to transfer cryptocurrency. Even though this method also transfers the execution control to the caller, it has a gas limit that prevents abuse. If the transfer fails, an exception is raised, which also adds to the security of this method as the exception reverts the transaction. Due to automatically reverting in case of errors, the transfer function is recommended in most cases.

The send function can be seen as a lower-level implementation of transfer. Similar to transfer, it provides a safe-by-design function to transfer cryptocurrency, with a gas limit to prevent exploits. The major difference between send and transfer, is that send returns false if it fails, delegating the error handling to the developer.

2.1.2 Solidity Guards. Guards are language constructs to prevent access or revert a transaction. In Solidity, *Require* and *Assert* have been introduced to the language in the version 0.4.10 (May 2017); *Revert* was introduced in version 0.4.12 (Ago 2017).

Both require and assert, check for a condition and raise an exception if such condition is not met. Any exception in a smart contract execution will cancel the transaction. Assert is supposed to be a check for internal errors and bugs. Assert will consume all remaining gas. On the other hand, require intent is to be used as much as possible for developers to check for conditions. Require refunds remaining gas if it raises an exception.

Revert raises an exception while refunding the remaining gas. It is similar to a "throws new Exception()" in Java.

Those three methods (assert, require, and revert) are guards to stop a transaction and prevent possible exploits in a smart contract. The usage of these constructs may indicate that developers are concerned with the security of the contract.

2.2 Reentrancy attack

The call function has some vulnerabilities. Every call to another contract transfers execution control to the called contract. Untrusted contracts may introduce and execute malicious code or exploit vulnerabilities. One of these major vulnerabilities is called the reentrancy attack, which takes advantage of the transfer of execution control by making recursive calls back to the original contract, repeating executions, and creating new transactions.

The two main types of reentrancy attacks are Single function, and Cross-function.

2.2.1 Single function reentrancy attack. This version repeatedly calls the involved function before the first invocation of the function is finished. Listing 1 shows a code snipped with this exploit.

```
1  mapping (address => uint) private userBalances;
2  function withdrawBalance() public {
3    uint amountToWithdraw = userBalances[msg.sender];
4    (bool succes, ) = msg.sender.call.value(
       amountToWithdraw)("");
5    require(success);
6    userBalances[msg.sender] = 0;
7  }
8  function () public payable { //fallback function
9    withdrawBalance();
10 }
```

Listing 1: Single function reentrancy attack

In this example, an attacker can recursively call the `withdrawBalance()` function and drain the whole contract as the user's balance is only set to 0 at the very end of the function.

2.2.2 Cross-function reentrancy attack. When a function shares a state with another function there is a possibility of a cross-function reentrancy attack. Listing 2 shows a code snipped with a cross-function reentrancy vulnerability.

```
mapping (address => uint) private userBalances;

function transfer(address to, uint amount) {
  if(userBalances[msg.sender] >= amount) {
     userBalances[to] += amount;
     userBalances[msg.sender] -= amount;
  }
}
function withdrawBalance() public {
  uint amountToWithdraw = userBalances[msg.sender];
  (bool succes, ) = msg.sender.call.value(
     amountToWithdraw)("");
  require(success);
  userBalances[msg.sender] = 0;
}
```

Listing 2: Cross-function reentrancy attack

Here the attacker will call the transfer function when the code is executed on an external call in `withdrawBalance()`, again the user's balance is not yet set to 0 and thus they will be able to transfer tokens again. A simple solution to both these types of attacks is updating the balance before transferring control to another function or contract. Another simple solution would be to use transfer or send (the safer-by-design constructs) instead of call.

3 STUDY DESIGN

3.1 Dataset

We collected verified smart contracts from Etherscan[1] which is a block explorer and analytic platform for Ethereum. Etherscan verified contracts allows the public to audit and read contracts as it has to be made publicly available to be granted the verified status. Etherscan does not give access to a complete dataset of verified smart contracts but rather has an open-source database of the latest 10,000-5,000 smart contracts that were verified. Therefore, we gathered the latest contracts from time to time, over a period of six months (2021-07-07 to 2022-01-06) to build our dataset.

Then, we did the following pre-processing steps in our dataset: (i) remove all duplicated[2] contracts; (ii) remove contracts not written in Solidity; (iii) removed contracts which we could not process using cloc.[3] After removing those contracts, we had a total of 26,799 unique verified solidity smart contracts. This dataset is publicly available.[4]

3.2 Method

We use the Etherscan API [6] to retrieve the source codes for each contract in our dataset. Listing 3 shows an example of the API call used to acquire the contract source code.

```
api.etherscan.io/api?module=contract
&action=getsourcecode
&address=0xb4e32b964f6ae78 //The contract address
&apikey=YourApiKeyToken // Your API key
```

Listing 3: Etherscan API call

Then, we used the cloc tool on the contracts to discover how many source lines of code[5] are in each one. We removed from this study the contracts that cloc were not able to process. Moreover, we used a Python script on the contracts to locate specific methods used in the contracts related to Ether exchange functions (call, send, and transfer) and guards (require, assert, and revert).

4 ANALYSIS AND RESULTS

4.1 Overall Analysis

First, we show some general characteristics of our dataset. Table 2 shows the general statistics considering the lines of code on the contract. We can see that the contracts in our dataset are small in lines of codes, with a median of 256 LoC and an average of 356 LoC. That is expected, as smart contract code tends to be smaller when compared to software code in other domains. The smallest contracts have only 2 LoC. For example, the contract *BlackHole*[6] only has two lines, a pragma definition for the solidity version, and an empty contract definition. The biggest contract is *RewardControl*[7] with 6,461 LoC.

Table 2: Source Lines of Code (LoC)

Min	Median	Average	Std. Dev.	Max
2	256	359	335	6,461

Now, we investigate how many Ether exchange methods and guards are being used in the contracts. Table 3 shows how many contracts in our dataset have at least one of the methods, the overall count of the method, the average and median number in all contracts. We also calculated the average and median of contracts that have a non-zero

[1] etherscan.io/contractsVerified

[2] We removed contracts with the same address in the Ethereum blockchain. We did not verify whether the contracts with the same name have the same source code. Since these contracts have different addresses, they are considered separate entities in the blockchain platform.

[3] cloc is a tool to count source lines of code available at <https://github.com/AlDanial/cloc>.

[4] https://github.com/DarinVerheijke/vulnerabilities_catalog/tree/main/wetseb/dataset

[5] In this paper, we always use Source Lines of Code (SLoC), because that is how the tool we employed counts it. However, during the paper, we may refer to it as just lines of code (LoC) for brevity.

[6] https://etherscan.io/address/0x727E9A3067DeEaF031916fA0fC53B02cf44F8731#code

[7] https://etherscan.io/address/0xcf8Fe5bB819359Ea02DF65E50B6194D12b69aB88#code

Table 3: Ether Exchange and Guards Usage

			Average		Median	
Method	Contracts	Count	All	!0	All	!0
Call	13,443 (50%)	32,236	1.20	2.40	1	2
Transfer	9,176 (34%)	17,814	0.66	1.94	0	1
Send	647 (02%)	1,059	0.04	1.64	0	1
Require	26,190 (97%)	622,679	23.24	23.78	18	19
Assert	7,279 (27%)	10,507	0.39	1.44	0	1
Revert	13,819 (51%)	41,502	1.55	3.00	1	2

number of constructs (in the !0 columns). Even though call is the unsafest method for Ether exchange, it is used by 50% of the contracts in the dataset. On average, there are 1.2 call uses considering all contracts, or 2.4 when considering only contracts with at least one call. Any contract using call has the potential to have a reentrancy vulnerability. On the other hand, send is a safer method and it is the least used (2%). Transfer is the safest method, and it is used by roughly one-third of contracts.

On the guard methods shown in Table 3, require is used by the great majority of all contracts (97%). On average, there are 23.24 uses of require in the contracts. The great usage of this guard may be to counteract the vulnerabilities of call. Revert is also commonly used by more than half of the contracts in our dataset. Finally, Assert is the least used guard in our analysis.

4.2 Contracts by Version

Table 4 shows the contracts categorized by their major Solidity version, and the average and median size in lines of code (LoC). Most contracts are from the latest Solidity version, 0.8.x. The oldest Solidity version to appear in our dataset is 0.4.x which has fewer amount of contracts. The biggest average and median LoC size are from contracts of version 0.6.x.

Table 4: Solidity Major Versions

Version	Contracts	Average LoC	Median LoC
0.8.x	14,869 (55%)	355	285
0.7.x	2,454 (09%)	432	321
0.6.x	5,838 (21%)	433	330
0.5.x	2,954 (11%)	200	121
0.4.x	684 (02%)	225	108

Figure 1 shows the top-10 solidity versions (major and minor) in our contracts. The versions with most contracts are 0.8.4 (18.7%), 0.6.12 (17.1%), and 0.8.7 (15.3%). Together these three versions compose over 50% of the contracts in our dataset.

In Table 5, we assess the percentage of contracts using at least one of the methods (Call, Send, Transfer, Require, Assert, and Revert) per major version of Solidity. We also included the percentage considering all contracts for comparison. As we can see, the major version appears to have an impact on the usage of call, transfer, assert, and revert. For instance, versions 0.7.x and 0.6.x have a higher percentage of contracts using call than the normal, and versions 0.5.x and 0.4.x have a lower percentage. Considering the transfer method, version 0.7.x and 0.4.x show a higher percentage of contracts using transfer.

For the guards in Table 5, versions 0.8.x and 0.5.x show lower percentages for asserts and reverts. On the other hand, versions 0.7.x and 0.6.x show a higher percentage than normal for the same guard methods. Version 0.4.x shows an increase in contracts using assert but a decrease in contracts using revert.

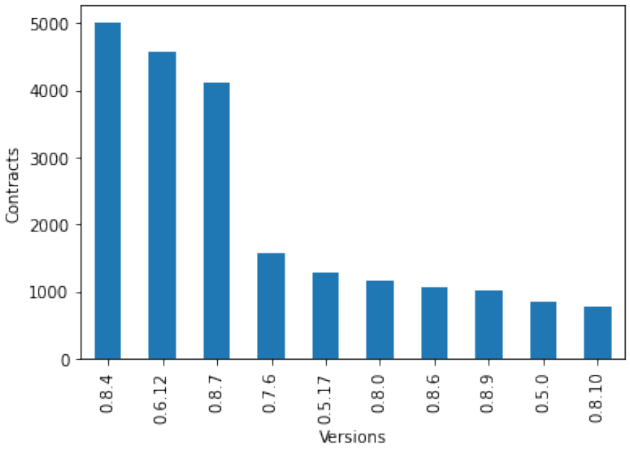

Figure 1: Top-10 Solidity versions in the database.

Table 5: Contracts using Ether Exchange & Guards by Major Version

	Call	Send	Transfer	Require	Assert	Revert
all	50%	2%	34%	97%	27%	51%
0.8.x	44%	3%	33%	98%	8%	45%
0.7.x	67%	1%	42%	98%	32%	66%
0.6.x	79%	<1%	32%	98%	68%	79%
0.5.x	16%	<1%	29%	96%	32%	20%
0.4.x	8%	3%	48%	92%	51%	39%

4.3 Contracts using Call

We focus only on the contracts that contain a call function. Since call is a very unsafe function, there is the possibility for the contracts using it to suffer from a reentrancy vulnerability. For this reason, such contracts may have different characteristics. Table 6 shows the lines of code considering only the contracts that contain a call function. The average and median LoC values are higher than the ones for all contracts. Therefore, the contract with call in our dataset

Table 6: Contracts using Call - Lines of Code

Min	Median	Average	Std. Dev.	Max
6	530	511	367	5,572

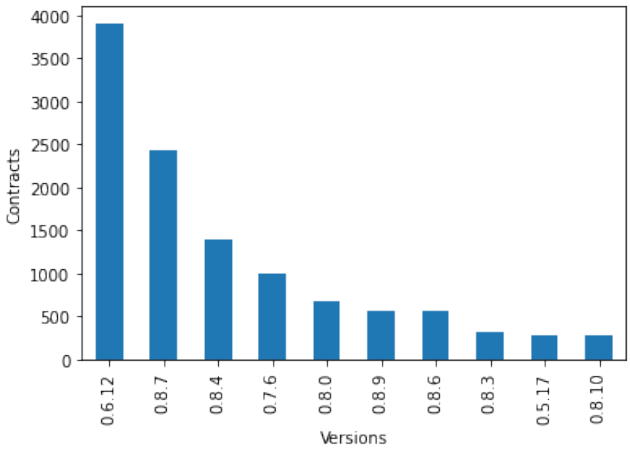

Figure 2: Top-10 Solidity versions on Contracts using Call.

usually has more lines of code. The call contract with the least lines of code is called *FlashBotLowGas*.[8]

Figure 2 shows the Solidity versions for contracts with call. The version with most contracts using call is 0.6.12. The top-3 versions for all contracts are also the top-3 for contracts with call but in different positions.

Table 7 show the Ether exchange and guard methods considering only the 13,443 contracts that contain at least one call method. We can see that approximately one-third of the contracts using call also use the send function. We also like to highlight that there is a greater number of contracts with call-using guards. For instance, 99% of the call contracts used Require compared to 97% of all contracts; 39% of the call contracts used Assert compared to 27% of all contracts; and 89% of the call contracts used Revert compared to 51% of all contracts. The higher usage of guards is probably to counter the vulnerabilities of call. This may be an indication that Solidity developers are concerned about the security of their contracts especially when using unsafe methods such as call.

4.4 Contracts using Transfer

Now, we focus only on the contracts that contain a transfer function. Transfer is a much safer alternative than call for Ether exchange. Therefore, we expect the contracts using transfer to have different characteristics than the ones using call.

[8]https://etherscan.io/address/0x90ab9a926a1593992547e0f9a0df6401f10421cd#code

Table 7: Solidity Methods of Contracts using Call

Method	Contracts	Count	Average	Median
Transfer	4,514 (33%)	8,789	0.65	0
Send	582 (04%)	920	0.07	2
Require	13,392 (99%)	456,461	33.96	31
Assert	5,348 (39%)	6,701	0.49	0
Revert	11,976 (89%)	38,273	2.84	2

Table 8: Contracts using Transfer - Lines of Code

Min	Median	Average	Std. Dev.	Max
6	345	452	373	6,461

Table 8 shows the lines of code only from contracts with a transfer function. The median, average, and standard deviation are higher than the ones when considering all contracts. However, the same statistics are lower when compared to the contracts with call. This means that contracts using transfer tend to have lower LoC than the contracts using call. The reason for this difference could be that call will need extra code to protect against vulnerabilities. Since transfer is a safe-by-design function, it will not need as much extra code as call for a more secure contract. The smallest LoC contract using transfer is *TransferValueToMinerCoinbase*[9] with 6 LoC.

Figure 3 shows the solidity versions for contracts that contain transfer. The top-5 versions for contracts using send are the same top-5 versions for all contracts in our dataset. This could indicate that the contracts with send may represent a general set similar to all contracts in our dataset.

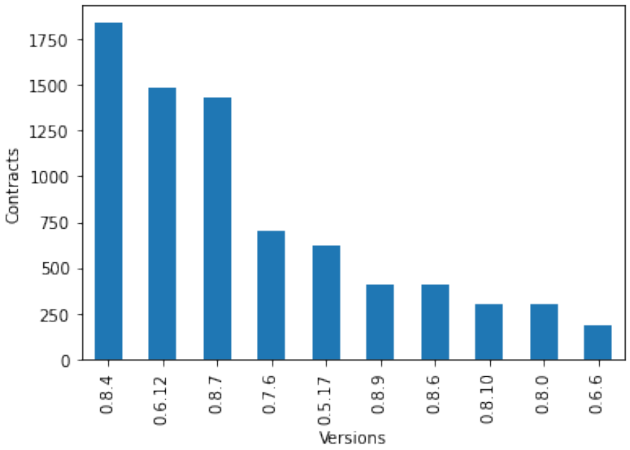

Figure 3: Top-10 Solidity versions on Contracts using Transfer.

[9]https://etherscan.io/address/0x8512a66d249e3b51000b772047c8545ad010f27c#code

Table 9: Solidity Methods of Contracts using Transfer

Methods	Contracts	Count	Average	Median
Call	4,514 (49%)	11,083	1.20	0
Send	107 (01%)	251	0.03	0
Require	9,060 (98%)	256,835	27.99	23
Assert	2,722 (29%)	4,789	0.52	0
Revert	4,876 (53%)	14,493	1.57	1

Table 9 shows the Ether exchange and guard methods considering only the 9,176 contracts that contain at least one transfer method. The percentage of contracts when looking at only contracts with transfer is similar (with a 1-2% difference) from the ones considering all contracts. This is different from the contracts with call where the guards' percentage increases by a noticeable amount for Assert and Revert.

4.5 Contracts with Send

We analyze only the contracts using at least one send method. In our dataset, send is the least used method, being present in only 647 (approximately 2%) of the contracts. Even though there are fewer contracts to analyze, we expect to obverse different characteristics.

Table 10 shows lines of code for contracts with send. The median, average, and standard deviation are the highest when compared to all contracts, contracts using call, and contracts using transfer. The contract *PaymentManager*[10] has 2 send functions and it is smallest contract with 15 LoC.

Table 10: Contracts using Send - Lines of Code

Min	Median	Average	Std. Dev.	Max
15	575	635	498	6,461

The most common Solidity versions for contracts using send were 0.8.7, 0.8.4, 0.8.0, 0.8.10, and 0.8.6. As we can see, the top-5 versions are all 0.8.x.

Table 11 show the Ether exchange and guard methods considering only the 647 contracts that contain at least one send function. The contracts percentage are different when contrasted with all contracts. For instance, 89% of send contracts have a call function compared to 50% of all contracts; 90% of send contracts have at least one revert compared to 51% of all contracts; and in the opposite direction, 16% of send contracts have at least one transfer method compared to 34% of all contracts.

Table 11: Solidity Methods of Contracts using Send

Method	Contracts	Count	Average	Median
Call	582 (89%)	1,203	1.86	2
Transfer	107 (16%)	234	0.36	0
Require	647 (100%)	25,058	38.73	37
Assert	63 (09%)	166	0.26	0
Revert	588 (90%)	2304	3.56	4

5 RELATED WORK

Juels, Kosba and Shi [9] investigate the risk of smart contracts fueling new criminal ecosystems. They show how a Criminal Smart Contract can facilitate leakage of confidential information, theft of cryptographic keys, and more, showing the urgency of creating safeguards against these CSCs. They look at questions like how practical these new crimes will be, whether these CSCs enable a wider range of new crimes in comparison to earlier cryptocurrencies such as Bitcoin, and what advantages they offer to criminals in comparison with the conventional online systems.

Luu et al. [11] also investigate and introduce several security problems to manipulate smart contracts in an attempt to gain profit and propose ways to enhance the operational semantics of Ethereum. A focus is put on the semantic gap between the assumption contract writers make about the underlying execution semantics and the actual semantics of the contract are made as a reason for these security flaws. A tool OYENTE is also provided to detect bugs which is a symbolic execution tool. The model works directly with Ethereum virtual machine bytecode and thus does not need a higher level representation such as Solidity. An evaluation of OYENTE on 19,366 smart contracts is given where 8,333 contracts were documented with potential bugs.

Mense and Flatscher [12] summarize known vulnerabilities found by literature research and analysis such as external calls, gasless sends, mishandled exceptions, and reentrancy. They also compare code analysis tools for their ability to identify vulnerabilities in smart contracts based on a taxonomy for vulnerabilities. The results of their paper show that reentrancy ranks the highest among the vulnerabilities that they have discussed and is detected by most of the tools used. They then delve deeper into the DAO hack as well.

Liu et al. [10] present ReGuard which is a fuzzing-based analyzer to automatically detect reentrancy bugs in Ethereum smart contracts. They iteratively generate random (but diverse) transactions, this is called fuzz testing. Then based on the runtime they will identify reentrancy vulnerabilities in a contract. How the architecture works is they parse a smart contracts source or binary code to an intermediate representation which will then be transformed to C++, keeping the original behavior. Together with a runtime library, ReGuard executes the contract and runs an analysis of the operations for any reentrancy attacks.

SmartCheck [18] is an extensible static analysis tool to detect code issues in Solidity, where it translates Solidity

[10] https://etherscan.io/address/0xaddeb5dbdc1c62c2a2a8e04fddd42e3c3f19587b#code

into an XML-based representation and checks it against XPath patterns. The authors used a real-world dataset to evaluate their tool and also make a comparison to the earlier mentioned Oyente.

Samreen and Alalfi [15] explain eight vulnerabilities by looking at past exploitation case scenarios and reviewing some of the available tools and applications to detect these vulnerabilities. For each case they discuss the vulnerability exploited, the tactic used as well as the financial loss that happened. Coverage is given of some preventive techniques as protection against some of these exploits. The discussed tools adopt either a form of static analysis such as symbolic execution and control flow graph construction or dynamic analysis such as the fuzzing testing or tracing the sequence of instructions that are executed at run time.

Tantikul and Ngamsuriyaroj [17] investigate a more recent state of the vulnerabilities of smart contracts. Their research consists of going through a database of verified smart contracts and checking common occurrences as well as trends of vulnerabilities. An analysis is done using both Oyente and Smartcheck and common characteristics of vulnerable smart contracts are identified. A correlation computation is done via Pearson's correlation to detect how often any pair of vulnerabilities will be found on the same smart contract. Their results show that overflow and underflow have the highest correlation. Another relation found is the timestamp dependency and transaction order which might be caused by malicious miners.

Bragagnolo et al. [3] address the lack of inspectability of a deployed smart contract. They do this by analyzing the state of the contract using different decompilation techniques. Their solution SmartInspect is an inspector based on pluggable property reflection. Their approach of utilizing mirrors generated from an analysis of Solidity source code allows access to unstructured information from a deployed smart contract in a structured way. This can be done without a need to redeploy or develop additional code for decoding.

Wang et al. [19] evaluate a set of real-world smart contracts with ContractWard which uses machine learning techniques to detect vulnerabilities in smart contracts. Their idea was proposed due to existing detection methods being mainly based on symbolic execution or analysis which are very time-consuming. The system extracts dimensional bigram features from simplified operation codes to construct a feature space and can get a predictive recall and precision of over 96% based on their dataset of 49502 smart contracts on 6 vulnerabilities.

A deep-learning-based approach is used by Qian et al. [14]. The aim is to precisely detect reentrancy bugs using a bidirectional long-short term memory with an attention mechanism. They also propose using a contract snippet as another way to represent a smart contract only capturing key semantic sentences which contain related and critical information such as control flow and data dependencies. These are then used as input to the sequential models. They show that this deep-learning approach outperforms other state-of-the-art smart contract vulnerability tools.

Slither by Feist et al. [7] is a static analysis framework that converts Solidity smart contracts into an intermediate representation which they call SlithIR. Static Single Assignment forms are used as well as a reduced instruction set for ease of implementation. Their framework has use cases in automated detection of vulnerabilities, detection of code optimization opportunities, improvement of clarity, and ease of understanding of the contracts. An evaluation of the capabilities of the proposed framework is done using a set of real-world smart contracts.

6 FINAL REMARKS

In this paper, we conducted an exploratory study on the usage of specific Solidity language constructs in a dataset of 26,799 contracts. Even though, call is the unsafest method for Ether exchange it is the most popular method being used by 50% of contracts. Perhaps because call can be used to transfer the execution control to another contract, and not only for ether exchange, is the reason for its popularity despite the fact that it is unsafe. The other methods for ether exchange, transfer is used by 34% of contracts, and send is rarely used (2% of the contracts).

In our analysis on guards, require is the most popular one being used in 97% of all contracts. On average, each contract uses 23 instances of require. The high number of require usage combined with other guards, is anecdotal evidence that Solidity developers are concerned with the security of their contracts by using guards to prevent possible exploits.

The most popular Solidity versions in our dataset were 0.8.4 (18.7% of the contracts), 0.6.12 (17.1% of the contracts), and 0.8.7 (15.3% of the contracts). We also saw that the usage of call, transfer, assert, and revert can vary a lot from different versions of the contract.

When we focused on only contracts using call, the average and median size in LoC of the contracts are higher than normal. We also noticed an increased percentage of call contracts using more guard methods. This may be an indication that Solidity developers are concerned about the security of their contracts especially when using unsafe methods such as call.

As future work, we plan to execute vulnerability detection tools to further investigate the characteristics of the contracts in our dataset. We also plan to contrast different code metrics besides Lines of Code.

REFERENCES

[1] Nicola Atzei, Massimo Bartoletti, and Tiziana Cimoli. 2017. A Survey of Attacks on Ethereum Smart Contracts (SoK). In *Principles of Security and Trust*, Matteo Maffei and Mark Ryan (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 164–186.

[2] Karthikeyan Bhargavan, Antoine Delignat-Lavaud, Cédric Fournet, Anitha Gollamudi, Georges Gonthier, Nadim Kobeissi, Natalia Kulatova, Aseem Rastogi, Thomas Sibut-Pinote, Nikhil Swamy, and Santiago Zanella-Béguelin. 2016. Formal Verification of Smart Contracts: Short Paper. In *Proceedings of the 2016 ACM Workshop on Programming Languages and Analysis for Security* (Vienna, Austria) *(PLAS '16)*. Association for Computing Machinery, New York, NY, USA, 91–96. https://doi.org/10.1145/2993600.2993611

[3] Santiago Bragagnolo, Henrique Rocha, Marcus Denker, and Stephane Ducasse. 2018. SmartInspect: solidity smart contract inspector. In *2018 International Workshop on Blockchain Oriented Software Engineering (IWBOSE)*. 9–18. https://doi.org/10.1109/IWBOSE.2018.8327566

[4] Santiago Bragagnolo, Henrique S C Rocha, Marcus Denker, and Stéphane Ducasse. 2018. SmartInspect: Solidity Smart Contract Inspector. In *IWBOSE 2018 - 1st International Workshop on Blockchain Oriented Software Engineering*. IEEE, Campobasso, Italy. https://doi.org/10.1109/IWBOSE.2018.8327566

[5] Ethereum. 2021. *Solidity documentation*. https://docs.soliditylang.org/en/v0.8.11/#

[6] Etherscan. 2021. *Etherscan API Knowledge Base*. https://docs.etherscan.io/api-endpoints/contracts

[7] Josselin Feist, Gustavo Grieco, and Alex Groce. 2019. Slither: A Static Analysis Framework for Smart Contracts. In *2019 IEEE/ACM 2nd International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)*. 8–15. https://doi.org/10.1109/WETSEB.2019.00008

[8] Ethereum Foundation. 2014. Ethereum's white paper. (2014). https://ethereum.org/en/whitepaper/

[9] Ari Juels, Ahmed Kosba, and Elaine Shi. 2016. The Ring of Gyges: Investigating the Future of Criminal Smart Contracts. In *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security* (Vienna, Austria) *(CCS '16)*. Association for Computing Machinery, New York, NY, USA, 283–295. https://doi.org/10.1145/2976749.2978362

[10] Chao Liu, Han Liu, Zhao Cao, Zhong Chen, Bangdao Chen, and Bill Roscoe. 2018. ReGuard: Finding Reentrancy Bugs in Smart Contracts. In *Proceedings of the 40th International Conference on Software Engineering: Companion Proceeedings* (Gothenburg, Sweden) *(ICSE '18)*. Association for Computing Machinery, New York, NY, USA, 65–68. https://doi.org/10.1145/3183440.3183495

[11] Loi Luu, Duc-Hiep Chu, Hrishi Olickel, Prateek Saxena, and Aquinas Hobor. 2016. Making Smart Contracts Smarter. In *Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security* (Vienna, Austria) *(CCS '16)*. Association for Computing Machinery, New York, NY, USA, 254–269. https://doi.org/10.1145/2976749.2978309

[12] Alexander Mense and Markus Flatscher. 2018. Security Vulnerabilities in Ethereum Smart Contracts. In *Proceedings of the 20th International Conference on Information Integration and Web-Based Applications & Services* (Yogyakarta, Indonesia) *(iiWAS2018)*. Association for Computing Machinery, New York, NY, USA, 375–380. https://doi.org/10.1145/3282373.3282419

[13] Satoshi Nakamoto. 2008. (2008). https://bitcoin.org/bitcoin.pdf

[14] Peng Qian, Zhenguang Liu, Qinming He, Roger Zimmermann, and Xun Wang. 2020. Towards Automated Reentrancy Detection for Smart Contracts Based on Sequential Models. *IEEE Access* 8 (2020), 19685–19695. https://doi.org/10.1109/ACCESS.2020.2969429

[15] Noama Fatima Samreen and Manar H. Alalfi. 2020. A Survey of Security Vulnerabilities in Ethereum Smart Contracts. In *Proceedings of the 30th Annual International Conference on Computer Science and Software Engineering* (Toronto, Ontario, Canada) *(CASCON '20)*. IBM Corp., USA, 73–82.

[16] Martin Holst Swende. 2019. *EIP-1884: Repricing for trie-size-dependent opcodes*. https://eips.ethereum.org/EIPS/eip-1884

[17] Phitchayaphong Tantikul. and Sudsanguan Ngamsuriyaroj. 2020. Exploring Vulnerabilities in Solidity Smart Contract. In *Proceedings of the 6th International Conference on Information Systems Security and Privacy - ICISSP,*. INSTICC, SciTePress, 317–324. https://doi.org/10.5220/0008909803170324

[18] Sergei Tikhomirov, Ekaterina Voskresenskaya, Ivan Ivanitskiy, Ramil Takhaviev, Evgeny Marchenko, and Yaroslav Alexandrov. 2018. SmartCheck: Static Analysis of Ethereum Smart Contracts. In *Proceedings of the 1st International Workshop on Emerging Trends in Software Engineering for Blockchain* (Gothenburg, Sweden) *(WETSEB '18)*. Association for Computing Machinery, New York, NY, USA, 9–16. https://doi.org/10.1145/3194113.3194115

[19] Wei Wang, Jingjing Song, Guangquan Xu, Yidong Li, Hao Wang, and Chunhua Su. 2021. ContractWard: Automated Vulnerability Detection Models for Ethereum Smart Contracts. *IEEE Transactions on Network Science and Engineering* 8, 2 (2021), 1133–1144. https://doi.org/10.1109/TNSE.2020.2968505

[20] Gavin Wood. 2018. Ethereum: A secure decentralised generalised transaction ledger. (06 2018), 1–39.