Vyper: A Security Comparison with Solidity Based on Common Vulnerabilities

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Abstract—Vyper has been proposed as a new high-level language for Ethereum smart contract development due to numerous security vulnerabilities and attacks witnessed on contracts written in Solidity since the system's inception. Vyper aims to address these vulnerabilities by providing a language that focuses on simplicity, auditability and security. We present a survey where we study how well-known and commonly-encountered vulnerabilities in Solidity feature in Vyper's development environment. We analyze all such vulnerabilities individually and classify them into five groups based on their status in Vyper. To the best of our knowledge, our survey is the first attempt to study security vulnerabilities in Vyper.

I. INTRODUCTION

Since the inception of Ethereum, Solidity [1] has been the most popular high level language for writing smart contracts. Developed by the contributors of the Ethereum project, Solidity continues to be the most popular tool for writing Ethereum smart contracts today. However, smart contracts written in Solidity are riddled with security vulnerabilities, which have been exploited in many highly publicized attacks on various Ethereum based projects [2]. Although Solidity has undergone many revisions and updates in order to address these vulnerabilities, multiple improvements can still be made.

Recently, an alternate to Solidity, Vyper [3] has been developed to offer a better medium for writing smart contracts that are easier to understand. Vyper aims to make it harder for developers to intentionally write misleading or malicious code and also protects developers from unintentionally leaving vulnerabilities in their contract code. We offer a comparison between Vyper’s latest beta version i.e. 0.1.0-beta.15 and Solidity’s latest release i.e., v0.6.2, both at the time of writing. It is worth mentioning that Vyper does not claim to be a replacement for Solidity. It actually claims to strive towards goals of auditability, simplicity and security. To achieve these goals, it sacrifices various features and functionalities found in Solidity while introducing additional features to support security and readability. If any of the more complex features, which Vyper does not adapt, is required by the programmer then they will have to revert to using Solidity.

This paper presents a comparison of how various vulnerabilities, which are known to exist in the domain of smart contract development in Solidity, feature in Vyper’s environment. The paper targets smart contract developers, users, and researchers who can use this resource to get up to speed with Vyper’s current standing on known security issues. In Section II, the paper first outlines Vyper’s principles and design goals. In Section III, we present a taxonomy of the known vulnerabilities in smart contract development in Solidity and compare how Vyper features in each of those vulnerabilities. We provide more detailed background and analysis in the online version of our paper [4].

II. VYPER PRINCIPLES AND FEATURES

Vyper, according to its official documentation, is a contract-oriented, pythonic programming language targeting the Ethereum virtual machine. Although Vyper is still in development, we do not expect there to be major design changes once a stable version comes out or once the Vyper project migrates from its current Python based compiler to a Rust based compiler [5]. Vyper claims to be designed towards achieving the following three design goals or principles:

- **Language and compiler simplicity**: Vyper aims to keep the language and the compiler implementation as simple as possible.
- **Security**: Vyper aims to provide the programmer the ability to write smart contracts without any undesired vulnerabilities or loopholes.
- **Auditability**: Vyper is aimed at making smart contracts easy to read for the users, especially those with insignificant prior experience. Vyper claims to give user readability preference over even the development experience.

In order to achieve these desired goals, Vyper provides additional features not found in Solidity while omitting some features found in Solidity. The reader may refer to the Vyper official documentation [3] for a list of these features.

III. COMPARISON OF VYPER WITH SOLIDITY’S VULNERABILITIES

In this section we provide a detailed taxonomy of commonly known vulnerabilities in Solidity smart contracts and compare how each one fares in Vyper. Although numerous resources list the known vulnerabilities and attacks on smart contracts developed in Solidity, we use the vulnerabilities listed in Chen et al. [2] as our base reference since we believe that this paper’s list is the most comprehensive. Chen et al. attribute 19 vulnerabilities in Ethereum security either to smart contract programming or to the Solidity language and toolchain. We analyze each of these vulnerabilities in Vyper’s context and
present our findings. Vyper may introduce additional vulnerabilities of its own which have not been observed in Solidity. However, given that Vyper is still in development and due to inadequate resources and test cases we shall not study those in the present survey.

We divide these 19 known vulnerabilities into five groups shown in Table I. The first group consists of currently existing vulnerabilities in Solidity that have been addressed in Vyper by providing an additional function or feature or disallowing specific features. These vulnerabilities can be completely avoided in Vyper. The second group consists of vulnerabilities which have been partially addressed by Vyper but still may exist if proper development practices are not followed by the developer. The third group consists of vulnerabilities that still exist both in Solidity and Vyper if the best programming practices and recommendations are not followed. The fourth group consists of historical vulnerabilities in the Solidity environment that were mitigated through later Solidity releases and do not exist in Solidity anymore and are also not present in Vyper. The fifth group consists of those vulnerabilities that have been listed by Chen et al [2] as being caused by smart contract programming or the underlying Solidity language and toolchain. However, in the context of this survey, we argue that these vulnerabilities can only be avoided through proper understanding of the underlying Ethereum system on part of the programmer and following the best programming practices and security recommendations. For this group of vulnerabilities, Vyper or any other high level language is not a candidate to address them. However, these vulnerabilities may be addressed by design and verification tools for smart contracts [6]. We now proceed to describe each of these 19 vulnerabilities in Vyper’s context and provide reasoning for the classification of each of these into their respective group.

### A. Vulnerabilities addressed by Vyper

1) **Integer overflow and underflow:** This vulnerability occurs due to the fact that both Solidity and the EVM do not enforce integer overflow / underflow detection. This can lead to attacks which make unauthorized or unintended manipulation to a contract’s state variables if proper measures were not taken during development. Libraries such as SafeMath [7] do provide mechanisms for protecting against over/underflows in Solidity but Vyper has this feature built-in. In Vyper, the contract execution will revert if an over/underflow is detected [8].

2) **DoS with unbounded operations:** This vulnerability occurs when the operations required in the execution of a function exceed the block gas limit due to unbounded operations either in the contract itself or in one of the called contracts. Vyper solves this problem by having a precise upper bound for the gas consumption of any function call. This is possible because infinite length loops and recursive function calling are not allowed in Vyper [3].

3) **Unchecked call return value:** This vulnerability exists due to the discrepancy in Solidity’s handling of exceptions occurring in callee contracts. Solidity handles exceptions when calling another contract in two ways: (1) when directly referencing the callee’s contract instance or using the `transfer()` function; (2) when using one of the four low level methods (`call`, `staticcall`, `delegatecall`, and `send`). In the first instance, the exception is “bubbled up” and the entire transaction is reverted whereas in the second case only a `false` is returned to the calling contract. The uninitiated developer can be misled to think that any call(s) to other contracts were successful because no exception was thrown in the latter case. Solidity does not enforce any checks on the return values. In comparison, Vyper only provides two ways to call another contract in addition to the direct reference, i.e., the functions `send()` and `raw_call()`. The current Vyper compiler has built-in asserts for both of these functions [9], so that in case of failure the entire transaction will be reverted.

### B. Vulnerabilities partially addressed by Vyper

1) **Reentrancy:** The reentrancy vulnerability occurs when a contract calls an external contract, handing it over the execution control, which allows the callee to call back to the calling contract and then be able to perform some malicious steps. A contract is particularly vulnerable to reentrancy attacks if it does not make the necessary state changes before calling the external contract or if the code does not protect against multi-contract access situations. Vyper provides the functionality to the programmer to protect a contract against multi-contract access situations by providing a `nonreentrant` decorator which places a lock on the current function and all functions with the same key value. Fig. I provides an example of how to use this feature (for function `sendFunc`). If any external callee tries to callback into such functions, it will result in a revert call. Solidity did not provide such functionality and the developer had to implement locks or mutexes themselves or through some third party libraries [10]. However, even in

| Vulnerabilities in Solidity | FA | PA | NA | AA | NP |
|-----------------------------|----|----|----|----|----|
| Integer overflow and underflow | X |    |    |    |    |
| DoS with unbounded operation | X |    |    |    |    |
| Unchecked call return value | X |    |    |    |    |
| Reentrancy                  | X |    |    |    |    |
| Delegatecall injection      |   | X |    |    |    |
| Forced Ether to contract    |   | X |    |    |    |
| DoS with unexpected revert  |   | X |    |    |    |
| Erroneous visibility        |   | X |    |    |    |
| Uninitialized storage pointer|   | X |    |    |    |
| Erroneous constructor name  |   | X |    |    |    |
| Upgradeable contract        |   |   |   | X |    |
| Type casts                  |   |   |   | X |    |
| Insufficient signature information |   |   |   | X |    |
| Frozen Ether                |   |   |   | X |    |
| Authentication through tx.origin |   |   |   | X |    |
| Unprotected suicide         |   |   |   | X |    |
| Leaking Ether to arbitrary address |   |   |   | X |    |
| Secrecy failure             |   |   |   | X |    |
| Outdated compiler version   |   |   |   | X |    |

### TABLE I

SMART CONTRACT VULNERABILITIES IN VYPER AND SOLIDITY. FA, PA, AND NA STAND FOR "FULLY ADDRESSED", "PARTIALLY ADDRESSED", AND "NOT ADDRESSED" BY VYPER, RESPECTIVELY. SIMILARLY, AA AND NP STAND FOR "ALREADY ADDRESSED BY SOLIDITY/VYPER" AND "NOT ADDRE-SSABLE BY LANGUAGE OR TOOLCHAIN," RESPECTIVELY.
Vyper, the developer still has to identify the functions or blocks of code that might be susceptible to such a vulnerability and also has to ensure that all necessary state changes are made before making an external interaction. The current Vyper compiler does not warn the developer for such cases.

C. Vulnerabilities not addressed by Vyper

1) Delegatecall Injection: EVM provides the option of calling an external contract with the context of the caller contract using the DELEGATECALL opcode. This is achieved by using the delegatecall function in Solidity and using the raw_call function with the delegate_call keyword argument set to True in Vyper, e.g., raw_call(argAddress, example_bytes, outsize=0, gas=10000, value=1, delegate_call=True). However, if the contract being called is malicious, it can manipulate the state variables of caller contract. This vulnerability can be mitigated in Solidity by only using the DELEGATECALL with contracts that have been declared as libraries. In Vyper this vulnerability can similarly be avoided by only using DELEGATECALL with functions that are declared with the @constant decorator, which ensures that the functions will not mutate the state. However, like Solidity, this is not enforced in Vyper because there are legitimate cases, using the DELEGATECALL opcode, where the caller wants the callee to modify its state. Perhaps the best way to completely avoid this vulnerability is for the EVM to provide another opcode (just like DELEGATECALL) which retains the context of the caller contract but causes a revert if the callee tries to make any changes to the caller’s state (just like STATICCALL). Another possible solution at the language level could be to have the compiler place appropriate checks on state variables before and after the DELEGATECALL opcode is used and to give the user an option to enable to disable these checks.

2) Forced Ether to contract: This vulnerability occurs when the developer of the smart contract incorrectly assumes that the contracts fallback or payable function will be executed each time Ether is transferred to the contract. There are two situations in which Ether can be sent to a contract without invoking its fallback or payable functions. Firstly, when a contract that is self-destructing sends its remaining Ether to the contract or secondly, if Ether is transferred to an address even before the contract is loaded to that address. The second situation is possible because the contract addresses are deterministic and can be calculated before deploying them [11]. This vulnerability is due to the design of the underlying Ethereum protocol and the developer has to be aware of Ethereum’s design and functionality when writing smart contracts. This vulnerability can be avoided if the contract does not place checks on the exact values of the contract’s balance (self.balance). Currently, the Vyper compiler does not warn the developer if checks are placed on the self.balance variable in the contract code.

Another possible workaround could be to have a built-in mechanism in contracts to run the payable or fallback functions if a contract is invoked and its balance is different from its last invocation (meaning Ether was forced to the contract in between the invocations).

3) DoS with unexpected revert: This vulnerability occurs when an external contract causes a revert resulting in disruption of execution of the caller contract before it has completed its function [12]. The most common scenario is when the developer fails to account for the case when a payment is made to an external contract whose fallback or payable function execution results in a revert. This vulnerability is addressed in Solidity and Vyper by making use of a pull rather that push based mechanism when making external payments [13]. Alternatively, contracts in Solidity can take measures to handle the cases in code where an external call might throw an exception. Vyper currently, does not allow the handling of exceptions.

D. Vulnerabilities addressed in Solidity or Ethereum

1) Erroneous Visibility: This vulnerability occurs when a contract’s visibility is incorrectly specified and thus permits unauthorized access. Solidity used to make functions public by default if the visibility was not specified. However, this was addressed with version 0.5.0 by making it compulsory to specify visibility when defining functions [14]. Vyper allows functions without visibility (v0.1.0beta15) but defaults them to being of private visibility instead of public.

2) Uninitialized storage pointer: This vulnerability occurs due to the fact that prior to Solidity 0.5.0, if a complicated local variable (e.g., struct, array or mapping) was not explicitly initialized at the time of declaration, then the local variable’s reference points to slot 0 in storage by default, possibly overwriting a state variable [15]. Since Solidity v0.5.0, the Solidity compiler reports an error to contracts that contain uninitialized storage pointers. Also, explicit data location (i.e., storage, memory, or calldata) for all variables of struct, array or mapping type is now mandatory in Solidity [14]. Vyper also mandates the initialization of local variables at the time of declaration and failure to do so results in a compile time error.

3) Erroneous constructor name: This vulnerability occurred due to the fact that prior to Solidity version 0.4.22, a function declared with the same name as the contract was considered to be the contract’s constructor function. A constructor function is called only once at the time of contract creation to perform initialization. If the programmer
accidentally misspelled this function name then it became a public function which allowed anyone to call it and possibly compromise the contract [16]. This vulnerability was mitigated in Solidity version 0.4.22 by introducing the usage of mandatory keyword constructor when defining the constructor function [17]. Similarly, Vyper uses the keyword __init__ for the constructor.

E. Vulnerabilities not addressable by language or toolchain

1) Upgradeable Contract: This vulnerability occurs when a contract relies on external contracts for critical functions and the external contracts can be dynamically updated [2]. This vulnerability cannot be avoided in Vyper either. The developers have to ensure that they do not outsource critical functions to untrusted external contracts which are built such that their functionality can be dynamically updated. In the future, tools and utilities may be developed that traverse the entire call hierarchy of the contract and its callees to identify functionality which is susceptible to being updated but we are not aware of any such software available at the time of writing.

2) Type casts: This vulnerability occurs due to the Solidity compiler flagging some type errors (e.g., assigning an integer value to a string type) but not all [2]. Types are also used in direct calls, where the caller must declare the callee’s interface and cast to it the callee’s address when performing the call. Having some type checks may mislead the programmer to believe that all type checks are made. If the function being called doesn’t exist in the callee contract then the callee contract’s fallback is executed without any exception being thrown to alert the programmer. The functionality is the same in Vyper. Fig. 2 shows an example of a smart contract which defines two contract interfaces (LibA and LibB) but will have no way of knowing if the argument address passed to function workerFunction is of type LibA and not LibB. Smart contract development tools such as VeriSolid [18] can be used to build and deploy smart contracts that are free from this vulnerability in Solidity.

3) Insufficient signature information: This vulnerability occurs in a contract that uses a signed message to authorize payments to participants (e.g., a micropayment channel contract and the signed message can be used by the participants to claim authorization for a second action (replay attack). This vulnerability can result in replay attacks in the same contract, across multiple contracts, or even across multiple blockchains. This vulnerability was exploited for cross-blockchain replay attacks after the Ethereum classic hard fork [19] and was addressed by the Ethereum Improvement Proposal (EIP) 155. To avoid this vulnerability within the same contract or across multiple contracts, the developer has to ensure that the contract’s signed message generation and authentication mechanism is properly implemented. This can be achieved by including the requisite information (e.g., nonce and contract address) in the message [20].

4) Frozen Ether: This vulnerability is observed when Ether is stuck in a contract with no way to send it to other contracts or external accounts. This can happen due to the contract having a faulty or nonexistent function for sending Ether. It can also occur due to the contract relying on another contract for its money-spending functions and the callee contract having been deleted or not being usable anymore. Since this can occur due to a wide range of reasons we believe it is best addressed by the required due diligence on the developer’s part and by not outsourcing critical spending functions to untrusted contracts. Third party development and verification tools such as VeriSolid [18] can be used to ensure that the appropriate withdrawal functions always remain reachable in the developed smart contracts.

5) Authentication through tx.origin: The tx.origin variable is used in Solidity as well as Vyper to refer to the original external account that initiated the transaction in question, whereas the msg.sender variable is used in both to refer to the sender of the message for the current call. This vulnerability occurs when an inexperienced developer mistakenly checks tx.origin for authentication purposes rather than msg.sender [21]. Fig. 3 provides an example of this vulnerability (Line 9) in function withdrawAll, which uses tx.origin to confirm the owner of the contract that is calling the function. This is an error on the developer’s part due to their inadequate understanding of the Ethereum system and the Solidity / Vyper language.

6) Unprotected suicide: This vulnerability occurs due to the fact that contract bytecode and storage can be deleted from the Ethereum network by using the SELFDESTRUCT keyword.
intended recipients are able to withdraw Ether because the proper authorization logic in code to ensure that only the owner and trusted third parties are able to self-destruct the contract. Developers must also ensure that their contracts do not depend on third party contracts that might be deleted in the future rendering their own contracts unusable. Development and verification tools such as VeriSolid [18] ensure that the suicide statement in smart contracts cannot be reached using an unintended execution trace.

7) Leaking Ether to arbitrary address: This vulnerability exists when a contract is able to send funds to a caller who is not an owner or investor or a legitimate payee of the contract. It occurs due to the contract not enforcing adequate authorization mechanisms before transferring funds or can occur as a result of the many other vulnerabilities mentioned in this survey. This vulnerability can be mitigated by the developer adapting proper authorization logic in code to ensure that only the intended recipients are able to withdraw Ether because the language is blind to the intentions of the developer.

8) Secrecy failure: This vulnerability occurs when developers incorrectly assume that restricting a variable / function’s visibility would make its value/functionality hidden from the participants of the Ethereum network. This is not the case due to the public nature of the blockchain. If a state variable is declared private, other contracts are not allowed to access it but participants can still see its value from transaction data. Similarly, the inner-workings of a private function are also visible to all. Hence, the vulnerability is only mitigated if the developer has an understanding of the underlying Ethereum system and cannot be addressed by the language or toolchain.

9) Outdated compiler version: This vulnerability occurs when a contract is compiled using an outdated compiler version which might contain unresolved bugs and vulnerabilities. This vulnerability is addressed by using the latest compiler version when compiling contracts in either Solidity or Vyper.

IV. CONCLUSION

We presented a detailed comparison of how the known vulnerabilities that exist in the Solidity smart contract development environment translate to the Vyper development environment (we provide detailed background in the online version of our paper [4]). We believe that most of the vulnerabilities listed in Chen et al. [2] are either not addressable at the language / toolchain level or have already been mitigated in Solidity through its subsequent releases and do not surface in Vyper’s environment. Based on this survey, Vyper addresses most of the remaining vulnerabilities, albeit at the cost of complex functionality. Vyper may introduce additional vulnerabilities of its own but those will only become evident once a stable version of Vyper is released and adapted by a larger developer community. Most of the current security risks occur because of developers not following the recommended development practices and safety precautions or due to them having insufficient knowledge of the underlying Ethereum system.

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