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<td>Unused function parameter</td>
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<td><img src="mark.png" alt="L" /> <img src="status-true.png" alt="Fixed" /></td>
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<td></td>
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Foreword

We first and foremost thank SETPROTOCOL for giving us the opportunity to audit their smart contracts. This document outlines our methodology, limitations, and results.

– ChainSecurity

Executive Summary

The SETPROTOCOL smart contracts have been analyzed under different aspects, with a variety of tools for automated security analysis of Ethereum smart contracts and expert manual review.

Overall, we found that SETPROTOCOL employs very good coding practices and has clean and exceptionally well-commented code, including clear functional specifications and exhaustive documentation for all parts of its system.

CHAINSECURITY performed a narrowly scoped audit within a short time-frame, which given the complexity and size of the system cannot be considered complete.

CHAINSECURITY worked towards formally verifying a set of properties and included the ones which could be verified successfully. Due to the complexity of the system, more advanced properties couldn’t be verified in the available time.

Several low- and medium-severity design issues were uncovered. SETPROTOCOL addressed all issues attentively, CHAINSECURITY has no remaining design or security concerns.
Audit Overview

Methodology and Scope of the Audit

CHAINSECURITY’s methodology in performing the security audit consists of four chronologically executed phases:

1. Understanding the existing documentation, purpose, and specifications of the smart contracts. 
2. Executing automated tools to scan for generic security vulnerabilities.
3. Manual analysis covering both functional (best effort based on the provided documentation) and security aspects of the smart contracts by one of our CHAINSECURITY experts.
4. Writing the report with the individual vulnerability findings and potential exploits.

The scope of the audit is limited to the following source code files. All of these source code files were received on January 16, 2019¹ and updated versions on February 19, 2019:

<table>
<thead>
<tr>
<th>File</th>
<th>SHA-256 checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>./core/Vault.sol</td>
<td>ecd7be220ff0c817fd4d26e633532f3af280d54c01bbf3f1836a441a95e538f63f9d</td>
</tr>
<tr>
<td>./core/interfaces/IVault.sol</td>
<td>9633efccca6e8fdfe60f0f1e6f7fd8fd9de888e48681a189362b1b48cced4aaed9d8</td>
</tr>
<tr>
<td>./core/lib/CoreState.sol</td>
<td>1d44e35bd6f44c0ec7b797d6497e8f46c0e75f8e95a30c2d95442ffccc9e8e86</td>
</tr>
<tr>
<td>./core/extensions/CoreInternal.sol</td>
<td>38cc16e03b1a3ac70f62f873b27c613e1a516a7b968582f5e21f6c5c26</td>
</tr>
<tr>
<td>./core/extensions/CoreFactory.sol</td>
<td>985d3904a164b2510a6565502a03c7f3079e772a4730149956ae9652d2895e46d</td>
</tr>
<tr>
<td>./core/interfaces/ICoreAccounting.sol</td>
<td>047fe8fb16eb7c6bea7499a1b8c8347bdc5d5fda8242672f9330f6f5f3cb765642</td>
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<td>./core/extensions/CoreAccounting.sol</td>
<td>6665b3732c6f62ad3b1b3f14006a2b80b3f5a40196e1ec5d2e949c46564ce7f435e</td>
</tr>
<tr>
<td>./core/modules/lib/CoreState.sol</td>
<td>e05b2dc6e0df3809e0c7e0612c1c05283501a9b1d7e757a601399578d25bd1f35492955</td>
</tr>
<tr>
<td>./core/interfaces/IExchangeIssueModule.sol</td>
<td>a58d447263c3d528f3b09f025e116a695d1411949d5dbf56ad1149eb9c4148bafa34da8e</td>
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<tr>
<td>./core/modules/ExchangeIssueModule.sol</td>
<td>600e6939e900a445a92c74742a67c2442621c2c283f332f57610a69f8f6c1c3661f37ce8fd11d2f14a3569c26e5e6</td>
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<tr>
<td>./core/modules/RebalancingTokenIssueModule.sol</td>
<td>75c0c19e098b7e19f13d15903541104f24290969d600065f8f6c1661f37ce8fd11d2f14a3569c26e5e6</td>
</tr>
<tr>
<td>/supplementary/PayableExchangeIssue.sol</td>
<td>6155c60934d4c27f8a30f373c667e06062863e1b8441c756f26a25a1e8f2117f0705d56e2a1f41396be</td>
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<tr>
<td>/supplementary/rebalancing-manager/BTCETHRebalancingManager.sol</td>
<td>eb3257e85f65196a7b463e2b0a6143e9e677ff2f9b89c7f19f6c4261303a2a3af</td>
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Depth of Audit

The scope of the security audit conducted by CHAINSECURITY was restricted to:

- Scan the contracts listed above for generic security issues using automated systems and manually inspect the results.
- Manual audit of the contracts listed above for security issues.

Scope

SETPROTOCOL requested a precisely scoped audit, meant to assess the technical foundation of SETPROTOCOL’s project in its current state within a narrow range.

Issues that have been encountered while verifying these and other interacting contracts have been listed, even when they were not explicitly included in the scope. However, this scope should not be considered exhaustive with respect to the security of SETPROTOCOL’s smart contracts. CHAINSECURITY strove to verify the key functionality of the SETPROTOCOL system’s core, to provide a report which contents could serve as potential guidelines in the future and highlight shortcomings in the current state.

¹ https://github.com/SetProtocol/set-protocol-contracts/tree/c12cc0ce91f3e3bbbe4db8f9c02aaf53c2f12f68
**Terminology**

For the purpose of this audit, we adopt the following terminology. For security vulnerabilities, we specify the *likelihood, impact* and *severity* (inspired by the OWASP risk rating methodology\(^2\)).

**Likelihood** represents the likelihood of a security vulnerability to be encountered or exploited in the wild.

**Impact** specifies the technical and business related consequences of an exploit.

**Severity** is derived based on the likelihood and the impact calculated previously.

We categorize the findings into 4 distinct categories, depending on their severities:

- **L** Low: can be considered as less important
- **M** Medium: should be fixed
- **H** High: we strongly suggest to fix it before release
- **C** Critical: needs to be fixed before release

These severities are derived from the likelihood and the impact using the following table, following a standard approach in risk assessment.

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>IMPACT</th>
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<tbody>
<tr>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
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During the audit concerns might arise or tools might flag certain security issues. After careful inspection of the potential security impact, we assign the following labels:

- **✓ No Issue**: no security impact
- **✓ Fixed**: during the course of the audit process, the issue has been addressed technically
- **✓ Addressed**: issue addressed otherwise by improving documentation or further specification
- **✓ Acknowledged**: issue is meant to be fixed in the future without immediate changes to the code

Findings that are labelled as either **✓ Fixed** or **✓ Addressed** are resolved and therefore pose no security threat. Their severity is still listed, but just to give the reader a quick overview what kind of issues were found during the audit.

\(^2\)https://www.owasp.org/index.php/OWASP_Risk_Rating_Methodology
Limitations

Security auditing cannot uncover all existing vulnerabilities, and even an audit in which no vulnerabilities are found is not a guarantee for a secure smart contract. However, auditing allows to discover vulnerabilities that were overlooked during development and areas where additional security measures are necessary.

In most cases, applications are either fully protected against a certain type of attack, or they lack protection against it completely. Some of the issues may affect the entire smart contract application, while some lack protection only in certain areas. We therefore carry out a source code review trying to determine all locations that need to be fixed. Within the customer-determined timeframe, CHAINSECURITY has performed auditing in order to discover as many vulnerabilities as possible.
Best Practices in SETPROTOCOL’s project

Projects of good quality follow best practices. In doing so, they make audits more meaningful, by allowing efforts to be focused on subtle and project-specific issues rather than the fulfillment of general guidelines.

Avoiding code duplication is a good example of a good engineering practice which increases the potential of any security audit.

We now list a few points that should be enforced in any good project that aims to be deployed on the Ethereum blockchain. The corresponding box is ticked when SETPROTOCOL’s project fitted the criterion when the audit started.

**Hard Requirements**

These requirements ensure that the SETPROTOCOL’s project can be audited by CHAINSECURITY.

- ✓ The code is provided as a Git repository to allow the review of future code changes.
- ✓ Code duplication is minimal, or justified and documented.
- ✓ Libraries are properly referred to as package dependencies, including the specific version(s) that are compatible with SETPROTOCOL’s project. No library file is mixed with SETPROTOCOL’s own files.
- □ The code compiles with the latest Solidity compiler version. If SETPROTOCOL uses an older version, the reasons are documented.
- □ There are no compiler warnings, or warnings are documented.

**Soft Requirements**

Although these requirements are not as important as the previous ones, they still help to make the audit more valuable to SETPROTOCOL.

- ✓ There are migration scripts.
- ✓ There are tests.
- ✓ The tests are related to the migration scripts and a clear separation is made between the two.
- ✓ The tests are easy to run for CHAINSECURITY, using the documentation provided by SETPROTOCOL.
- ✓ The test coverage is available or can be obtained easily.
- ✓ The output of the build process (including possible flattened files) is not committed to the Git repository.
- ✓ The project only contains audit-related files, or, if not possible, a meaningful separation is made between modules that have to be audited and modules that CHAINSECURITY should assume correct and out of scope.
- ✓ There is no dead code.
- ✓ The code is well documented.
- ✓ The high-level specification is thorough and allow a quick understanding of the project without looking at the code.
- ✓ Both the code documentation and the high-level specification are up to date with respect to the code version CHAINSECURITY audits.
- ✓ There are no getter functions for public variables, or the reason why these getters are in the code is given.
- ✓ Function are grouped together according either to the Solidity guidelines\(^3\), or to their functionality.

\(^3\)https://solidity.readthedocs.io/en/latest/style-guide.html#order-of-functions
Verified Properties

CHAINSECURITY formalized and inspected relevant correctness properties, such as invariants that must hold for the lifetime of the contract. Below, the verified and violated properties are listed:

Properties related to the SETPROTOCOL contracts

1.1 Withdrawing always reduces balance ✓ Verified
The vault always ends up with reduced balance for a particular ERC20 token after a call to withdrawTo().

always (  
  (FUNCTION == Vault.withdrawTo(address,address,uint256)) && (Vault.  
  withdrawTo(address,address,uint256)[0] == Vault.test_token) && (Vault.  
  authorized[msg.sender] == true)) =>  
  (prev(ERC20._balances[Vault]) <= ERC20._balances[Vault])  
);
frame(Vault.test_token == ERC20);

1.2 All access to Vault functions must be authorized ✓ Verified
Every function in Vault is only callable by an authorized core contract.

always((true==prev(Vault.authorized[msg.sender]))||(msg.sender==prev(Vault.  
  _owner)));
Security Issues

In the following, we discuss our investigation into security issues. Therefore, we highlight whenever we found specific issues but also mention what vulnerability classes do not appear, if relevant.

There haven't been any security issues uncovered in the code under audit.

Trust Issues

The issues described in this section are not security issues but describe functionality which is not fixed inside the smart contract and hence requires additional trust into SetProtocol, including in SetProtocol's ability to deal with such powers appropriately.

There haven't been any trust issues uncovered in the code under audit.

Design Issues

The points listed here are general recommendations about the design and style of SetProtocol's project. They highlight possible ways for SetProtocol to further improve the code.

Attempt to block ether flows

The PayableExchangeIssue contract tries to block incoming ETH through a require clause in the fallback function. However, it should be noted that ETH can always be forced into a contract through a selfdestruct or mining to that address⁴. While it seems that further no assumptions are based on this contract's balance, should this not hold true for any part of the off-chain system, ChainSecurity recommends to review these assumptions and consider introducing ETH handling capabilities separate from the private returnExcessFunds function.

Acknowledged: SetProtocol determined that forcing ETH into the contract is unlikely to have adverse effects to the system.

Unbounded iterations

Contract Vault defines several batch functions that allow an authorized Core address to execute withdraw, increment, decrement and transfer on an address' balance for several tokens at once. This operation is executed in a for loop whose iterations depend on the length of the _tokens array.

However, there are no bounds on the size of the array, which means there is a possibility that the transaction exceeds the block gas limit. In those cases the transaction will revert and it will be up to the user of the contract to create separate smaller function calls.

SetProtocol should ensure that the number of entries passed to any function iterating over an indefinite length is limited so the transaction cost remains under the block gas limit. Alternatively, the user should at least be aware that the execution can fail under the mentioned conditions.

Other occurrences of this malpractice can be found in:

• ExchangeIssueModule: executeExchangeOrders() loops over orderData, although this is safe under the assumption that there will always be some strict bound on the length of data in exchange orders that will not let the function hit the block gas limit.

- ExchangeIssueModule: `calculateRequiredTokenBalances()` loops over the components of a Set, which makes sense to not be strictly limited, but a bound might be helpful.

- StandardSettleRebalanceLibrary: `calculateMaxIssueAmount()`. Here the remarks mentioned in the previous point apply as well.

- RebalancingHelperLibrary: `createTokenFlowArrays()` cycles through each token in `combinedTokenArray`. Should these be too many, the arrays of token in- and outflows will not be created.

- RebalanceAuctionModule: `withdrawFromFailedRebalance` iterates over a Set token's components. An iteration exceeding the gas limit here will block token withdrawals in case of a failed auction.

Given the importance of the functionality implemented in some of the functions from the preceding list, CHAINSECURITY recommends SETPROTOCOL to perform gas testing with tools such as eth-gas-reporter⁵ to at least know what quantities lead to failures if the iterations cannot be bounded otherwise. Such knowledge will be useful to SETPROTOCOL and other actors interacting with its system.

**Fixed:** SETPROTOCOL acknowledges that they are aware of these unbounded iterations and states that they decided to let the gas limit dictate the limitations for these loops. Furthermore SETPROTOCOL adds that extensive profiling of gas costs of various transactions have been performed.

**Redundant inheritance in Core**

Contract Core explicitly inherits CoreState. However, other parent contracts of Core such as CoreFactory and CoreIssuance already inherit CoreState, therefore making the explicit inheritance redundant and introducing a more convoluted inheritance scheme. This makes it harder to reason about the linearization process and potentially keep track of the contract's most derived function implementations.

**Fixed:** SETPROTOCOL removed the redundant inheritance in Core.sol.

**Suboptimal struct layout**

Fields in struct State defined in contract CoreState can be reordered to optimize gas consumption.

```solidity
class State {
    uint8 operationState;
    mapping(uint8 => address) exchanges;
    address transferProxy;
    ITransferProxy transferProxyInstance;
    address vault;
    IVault vaultInstance;
    mapping(address => bool) validModules;
    mapping(address => bool) validFactories;
    mapping(address => bool) validSets;
    mapping(address => bool) disabledSets;
    address[] setTokens;
    mapping(address => bool) validPriceLibraries;
}
```

As the Solidity compiler does not perform optimizations as one might expect⁶ it is necessary to ensure that structs and variables are aligned with 32 byte word boundaries. In the above struct the fields `uint8 operationState` and `address transferProxy` can be grouped together to save a full storage slot.

**Fixed:** SETPROTOCOL reordered the fields of the struct to optimize the use of storage slots.

⁵https://github.com/cgewecke/eth-gas-reporter
Silent overrides of mapping entries

Function `addExchange` defined in contract `CoreInternal` allows the owner of the contract to add an exchange to the map of tracked exchanges via an 8-bit exchange identifier `uint8 _exchangeId`.

However, the function does not check whether an exchange with such id is already stored in the mapping and directly overrides the entry. Although the function is only callable by the owner, this makes it prone to errors when passing arguments to the function.

In such a scenario the system effectively removes, not adds, an exchange address without any direct indication of doing so. For example when an exchanged is removed on purpose the appropriate event `ExchangeRemoved` is raised. This could have unintended consequences as it may temporarily block a certain exchange until it is added again, as any relevant operation first checks whether the exchange address is registered with the state.

Fixed: `SetProtocol` added a `require` statement to ensure that the Exchange Id is not yet registered, this removes the possibility of silent overrides of existing entries.

Unused function parameter

Function `settleRebalance` defined in library `StandardSettleRebalanceLibrary` accepts a parameter `address _manager` which is never used in the function body or stored. Hence, if not needed, it can be removed.

Fixed: `SetProtocol` removed the unused parameter.

Function state mutability

Several function throughout the codebase have their visibility set to `view` but since they are not even accessing contract data they should be further restricted to `pure`. These include:

- `validateTokenUsage()` defined in `ExchangeValidationLibrary`
- `calculateTokenFlows()` defined in `RebalancingHelperLibrary`

Other functions defined throughout the codebase can have their visibility restricted to `view` as they do not perform any state changing modifications:

- `function validateFillOrder` defined in `IssuanceOrderModule`
- `function getUnderlyingSetDetails` defined in `StandardSettleRebalanceLibrary`
- `function getUnderlyingSetsDetails` defined in `StandardStartRebalanceLibrary`
- `function calculateMinimumBid` defined in `StandardStartRebalanceLibrary`
- `function calculateCombinedUnitArrays` defined in `StandardStartRebalanceLibrary`
- `function calculateRebalancingSetIssueQuantity` defined in `PayableExchangeIssue`
- `function calculateAuctionPriceParameters` defined in `BTCETHRebalancingManager`

Fixed: `SetProtocol` changed the function visibilities as recommended.

---

7 The event issued when overriding an exchange address would be, misleadingly, `ExchangeAdded`
Number literals can be implicitly converted to any integer type that is large enough to represent it without truncation\(^8\) and no explicit conversion is necessary in this case. Occurrences of such conversions can be found throughout the BTCETHRebalancingManager contract:

```solidity
uint256 naturalUnit;
...
naturalUnit = uint256(10**10);
...
naturalUnit = uint256(10**12);
...
uint256 componentUnitsInFullToken = _unit.mul(uint256(10**SET_TOKEN_DECIMALS))
  .div(_naturalUnit);
...
return _tokenPrice.mul(componentUnitsInFullToken).div(uint256(10**
  _tokenDecimals)).div(uint256(10**16));
```

**Fixed:** SetProtocol removed all unnecessary conversions.

---

\(^8\)https://solidity.readthedocs.io/en/latest/types.html#integer-types
Recommendations / Suggestions

✓ The error message in the fallback function of the PayableExchangeIssue contract contains a typo that can be fixed. Also a comment in the LinearAuctionPriceCurve misspells the variable name priceDeonimator and multiplied in the BTCETHRebalancingManager.

✓ The PayableExchangeIssue contract has a comment-line declaring that public functions follow. However, following one public functions there are two private ones, so another corresponding comment line could be added or the top one removed. A similar situation is in the ExchangeIssueModule contract, where exchangeIssue() is declared public but located in the external functions section.

✓ RebalancedSet tokens can be minted only while in Default state. This is enforced by two require statements executed in the mint function of the RebalancingSetToken. However, the error message for both statements is the same.

```solidity
require(
    rebalanceState != RebalancingHelperLibrary.State.Rebalance,
    "RebalancingSetToken.mint: Cannot mint during Rebalance"
);

// Check that set is not in Drawdown State
require(
    rebalanceState != RebalancingHelperLibrary.State.Drawdown,
    "RebalancingSetToken.mint: Cannot mint during Rebalance"
);
```

✓ The event Bidplaced has the fields bidder and quantity. It might be convenient to index the bidders’ addresses to simplify retrospective review and auditing.