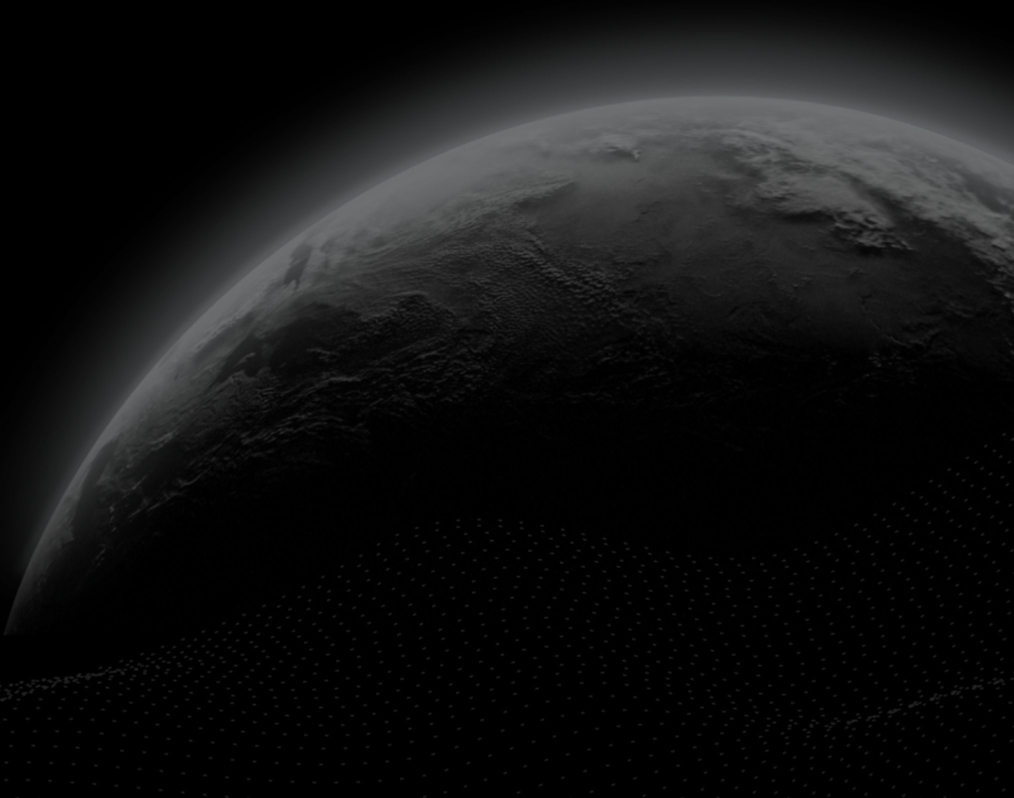
Security Assessment

STFIL

CertiK Verified on Apr 4th, 2023



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STFIL

The security assessment was prepared by CertiK, the leader in Web3.0 security.

Executive Summary

TYPES	ECOSYSTEM	METHODS
DeFi, Lending, Staking	Filecoin	Formal Verification, Static Analysis

LANGUAGE	TIMELINE	KEY COMPONENTS
Solidity	Delivered on 04/04/2023	N/A

CODEBASE	COMMITS
https://github.com/stfil-io/protocol ...View All	ccbf4f76ae66680881b0a2e1ee5530704c5386a5 ...View All

Vulnerability Summary

7	6	0	0	1	0	0
Total Findings	Resolved	Mitigated	Partially Resolved	Acknowledged	Declined	Unresolved

0	Critical		Critical risks are those that impact the safe functioning of a platform and must be addressed before launch. Users should not invest in any project with outstanding critical risks.
0	Major		Major risks can include centralization issues and logical errors. Under specific circumstances, these major risks can lead to loss of funds and/or control of the project.
2	Medium	2 Resolved	Medium risks may not pose a direct risk to users' funds, but they can affect the overall functioning of a platform.
2	Minor	2 Resolved	Minor risks can be any of the above, but on a smaller scale. They generally do not compromise the overall integrity of the project, but they may be less efficient than other solutions.
3	Informational	2 Resolved, 1 Acknowledged	Informational errors are often recommendations to improve the style of the code or certain operations to fall within industry best practices. They usually do not affect the overall functioning of the code.

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CODEBASE | STFIL

Repository

https://github.com/stfil-io/protocol

Commit

ccbf4f76ae66680881b0a2e1ee5530704c5386a5

AUDIT SCOPE | STFIL

24 files audited ● 1 file with Acknowledged findings ● 6 files with Resolved findings ● 17 files without findings

ID	File	SHA256 Checksum
SPU	contracts/protocol/stakingpool/StakingPool.sol	097394024adb828d2882c84f1ca39f65333a512918fc9dd2ff8539e139a3d7ed
INT	contracts/protocol/configuration/InterestRateStrategy.sol	6727344e6260f964cef5dd2f941609238879e3d71b7a623db23b6b3cfd476e22
STK	contracts/protocol/configuration/StakingPoolConfigurator.sol	f8b583cd6966564958214a7d34333636faf129f81c371a5befb4832868841816
GLU	contracts/protocol/libraries/logic/GenericLogic.sol	9c5cc05e38185a6d90031f993acdbf5d3a557ffbb56bcd14b01a5f3cf9806e46
STL	contracts/protocol/tokenization/STFILToken.sol	b40b94b4257ccf24985b2e7235d18048c3d143a13ea26b11d717b05277efbe78
STB	contracts/protocol/tokenization/StableDebtToken.sol	33a6ae29b5cde4e019ad17f01648e6b40403e81b3ec2e9079f2e0b50a803c0ee
VAR	contracts/protocol/tokenization/VariableDebtToken.sol	38ad2dce632a482d4e0088313c57971758c67e27462b472b379cfac3aeb6fb01
SPP	contracts/protocol/configuration/StakingPoolAddressesProvider.sol	379ef55d933b06eedc52e1db86e627ac3cd5489945a49f6e21d99e1aa8ce20dc
NCU	contracts/protocol/libraries/configuration/NodeConfiguration.sol	ffe43a6d241d44e7270acae53ba325bbd6162f1e9102003916f61c604886c8d8
PCU	contracts/protocol/libraries/configuration/PoolConfiguration.sol	4d1e1d4c1138c719c03b71b5d8cdc953ee02935fd656f2d830f06cc919700eeb
WRA	contracts/protocol/libraries/filecoin/contracts/utils/WrapActorAddresses.sol	39e75a0ecd277d502a2f17782f8614e39083203ec96dd66739ed1a56fda1ab19
WRP	contracts/protocol/libraries/filecoin/contracts/utils/WrapFilAddresses.sol	26fd75684c5761101a5fe9512f054ac5330589150faf7882621729d3d6c4a50e
WMP	contracts/protocol/libraries/filecoin/contracts/WrapMinerAPI.sol	4f2fa36e6da0cb57a18e0e01eb9ac3e16dcd829661e375b75ac551ba5344109a

ID	File	SHA256 Checksum
WPP	contracts/protocol/libraries/filecoin/contracts/WrapPrecompilesAPI.sol	fcc9bda59d729b140f4bb6bee014d232418cd38d8a5cfe4e62a3017b9be380dd
WSP	contracts/protocol/libraries/filecoin/contracts/WrapSendAPI.sol	4390ba4483012cc765310d85591a01acfe7845eebdd848d2ce8bd46e5fa82d22
ERO	contracts/protocol/libraries/helpers/Errors.sol	9f5b67490a414ed01f60080f4481ad1604b279e85d54321302bd3598fbd69d7b
HER	contracts/protocol/libraries/helpers/Helpers.sol	a6c83b93ccf3a99bb788df4839c94c01f874058bfc7d3552426c1789d742f09b
POO	contracts/protocol/libraries/logic/PoolReserveLogic.sol	bd9956b4d73f0431f3c2da2a74fdbdfcf788bf80aa4db01d02b53fed1206df7d
DTU	contracts/protocol/libraries/types/DataTypes.sol	dda7055b57a0d978e136163fbd58ba0a960c38233e93b76b967596a6b8c87a2c
PKU	contracts/protocol/libraries/types/ProxyKey.sol	610c90c5610c72ae0953bc94d6e8a505920137f27c02f6c54ec4bf79bbd9e125
ROE	contracts/protocol/libraries/types/Role.sol	2eb7beaae4760fad4cca1b87952b4649b9a1acf604c4b0e9b0e25ce43b397456
NOU	contracts/protocol/stakingpool/base/NodeOperation.sol	fde62f74f431b07f7fb4e540a012dbe680063702c7c87e41fdc7d0ea3ad4ae2e
STN	contracts/protocol/stakingpool/base/StakingPoolStorage.sol	0e89a38d4a42579762d2b3238555e0432493328a057953e96d896e736fd867d0
DET	contracts/protocol/tokenization/base/DebtTokenBase.sol	a3ad8d37e0d427a7a91f029841824b1c3d1fa2c31343d2c781b418a04f6f135c

APPROACH & METHODS | STFIL

This report has been prepared for STFIL to discover issues and vulnerabilities in the source code of the STFIL project as well as any contract dependencies that were not part of an officially recognized library. A comprehensive examination has been performed, utilizing Static Analysis and Formal Verification techniques.

The auditing process pays special attention to the following considerations:

- Testing the smart contracts against both common and uncommon attack vectors.
- Assessing the codebase to ensure compliance with current best practices and industry standards.
- Ensuring contract logic meets the specifications and intentions of the client.
- Cross referencing contract structure and implementation against similar smart contracts produced by industry leaders.
- Thorough line-by-line manual review of the entire codebase by industry experts.

The security assessment resulted in findings that ranged from critical to informational. We recommend addressing these findings to ensure a high level of security standards and industry practices. We suggest recommendations that could better serve the project from the security perspective:

- Testing the smart contracts against both common and uncommon attack vectors;
- Enhance general coding practices for better structures of source codes;
- Add enough unit tests to cover the possible use cases;
- Provide more comments per each function for readability, especially contracts that are verified in public;
- Provide more transparency on privileged activities once the protocol is live.

REVIEW NOTES | STFIL

Proghub is a pledge & lending system based on the FileCoin ecosystem, where FIL holders earn revenue by pledging FIL in StakingPool, and SPs expand their business by borrowing FIL from StakingPool, paying a certain amount of interest. This helps to increase the liquidity of the FIL and through that liquidity to provide a better storage service, a win-win option for both parties.

Third-Party Dependencies

The contract serves as the underlying entity to interact with third-party protocols like `FileCoin`. The scope of the audit treats 3rd party entities as black boxes and assumes their functional correctness. However, in the real world, 3rd parties can be compromised and this may lead to lost or stolen assets. In addition, upgrades of 3rd parties can possibly create severe impacts, such as increasing fees of 3rd parties, migrating to new LP pools, etc.

We understand that business logic requires interaction with `FileCoin`, etc. We encourage the team to constantly monitor the statuses of 3rd parties to mitigate the side effects when unexpected activities are observed.

DECENTRALIZATION EFFORTS | STFIL

Description

In the contract `StakingPoolConfigurator` the role `POOL_ADMIN` has authority over the functions shown in the lists below. Any compromise to the `POOL_ADMIN` account may allow the hacker to take advantage of this authority.

- enableStableRate: Enable stable rate borrowing on the staking pool
- disableStableRate: Disable stable rate borrowing on the staking pool
- setFee: Updates the fee of the pool
- setLiquidationFactor: Updates the liquidation factor of the pool
- disabledBorrowing: Disable node borrowing
- enabledBorrowing: Enabled node borrowing
- setNodeLeverage: Sets the maximum leverage and liquidation threshold of the node

In the contract `StakingPoolConfigurator` the role `EMERGENCY_ADMIN` has authority over the function `setPoolPause` . Any compromise to the `EMERGENCY_ADMIN` account may allow the hacker to take advantage of this authority and disable the staking pool.

In the contract `StakingPoolAddressesProvider` the role `CONTRACTS_ADMIN` has authority over the function in the lists below. Any compromise to the `CONTRACTS_ADMIN` account may allow the hacker to take advantage of this authority.

- setProxy: Sets an address for a proxy key replacing the address saved in the addresses map
- upgrade: Upgrades `proxy` to `implementation` .
- upgradeAndCall: Upgrades `proxy` to `implementation` and calls a function on the new implementation.

In the contract `InterestRateStrategy` the role `POOL_ADMIN` has authority over the function `setStrategyParams` . Any compromise to the `POOL_ADMIN` account may allow the hacker to take advantage of this authority.

Recommendation

The risk describes the current project design and potentially makes iterations to improve in the security operation and level of decentralization, which in most cases cannot be resolved entirely at the present stage. We advise the client to carefully manage the privileged account's private key to avoid any potential risks of being hacked. In general, we strongly recommend centralized privileges or roles in the protocol be improved via a decentralized mechanism or smart-contract-based accounts with enhanced security practices, e.g., multi-signature wallets. Indicatively, here are some feasible suggestions that would also mitigate the potential risk at a different level in terms of short-term, long-term and permanent:

Short Term:

Timelock and Multi sign (⅔, ⅗) combination *mitigate* by delaying the sensitive operation and avoiding a single point of key management failure.

- Time-lock with reasonable latency, e.g., 48 hours, for awareness on privileged operations; AND
- Assignment of privileged roles to multi-signature wallets to prevent a single point of failure due to the private key compromised; AND
- A medium/blog link for sharing the timelock contract and multi-signers addresses information with the public audience.

Long Term:

Timelock and DAO, the combination, *mitigate* by applying decentralization and transparency.

- Time-lock with reasonable latency, e.g., 48 hours, for awareness on privileged operations; AND
- Introduction of a DAO/governance/voting module to increase transparency and user involvement. AND
- A medium/blog link for sharing the timelock contract, multi-signers addresses, and DAO information with the public audience.

Permanent:

Renouncing the ownership or removing the function can be considered *fully resolved*.

- Renounce the ownership and never claim back the privileged roles. OR
- Remove the risky functionality.

Alleviation

The team acknowledged the description and recommendations

FINDINGS | STFIL

7	0	0	2	2	3
Total Findings	Critical	Major	Medium	Minor	Informational

This report has been prepared to discover issues and vulnerabilities for STFIL. Through this audit, we have uncovered 7 issues ranging from different severity levels. Utilizing the techniques of Static Analysis & Formal Verification to complement rigorous manual code reviews, we discovered the following findings:

ID	Title	Category	Severity	Status
DTB-01	Lack Of Storage Gap In Upgradeable Contract	Logical Issue	Medium	Resolved
SPU-01	Logic Issue In `liquidation()`	Logical Issue	Medium	Resolved
PRO-01	Unprotected Initializer	Coding Style	Minor	Resolved
STF-01	Missing Zero Address Validation	Volatile Code	Minor	Resolved
GLU-01	Incorrect Comments	Coding Style	Informational	Resolved
INT-01	Lack Of Event Emitting	Coding Style	Informational	Resolved
SPU-02	Discussions On `Liquidation`	Volatile Code	Informational	Acknowledged

DTB-01 | LACK OF STORAGE GAP IN UPGRADEABLE CONTRACT

Category	Severity	Location	Status
Logical Issue	Medium	DebtTokenBase.sol (93ca5d5): 14	Resolved

Description

There is no storage gap preserved in the logic contract. Any logic contract that acts as a base contract that needs to be inherited by other upgradeable child should have a reasonable size of storage gap preserved for the new state variable introduced by the future upgrades.

Recommendation

We recommend having a storage gap of a reasonable size preserved in the logic contract in case that new state variables are introduced in future upgrades. For more information, please refer to: https://docs.openzeppelin.com/contracts/3.x/upgradeable#storage_gaps.

Alleviation

The team heeded the advice and resolved this issue in commit `bb44ace604ac56b420ae7c99cccab6b09f0a9cc8`.

SPU-01 | LOGIC ISSUE IN `liquidation()`

Category	Severity	Location	Status
Logical Issue	Medium	contracts/protocol/stakingpool/StakingPool.sol: 326	Resolved

Description

The node's `safetyBuffer` variable represents the maximum amount of debt already held by the node. However, during the liquidation process, the `safetyBuffer` variable should be updated to reflect any changes in the node's debt level. Failure to update the `safetyBuffer` variable will result in inaccurate calculations and may put the node at risk of insolvency.

Recommendation

We propose to update the `safetyBuffer` synchronously when the debt of the node changes during the liquidation process.

Alleviation

The team heeded the advice and resolved this issue in commit `0b7356eac09efdcd2953a3d1451d8251481bf4fc`.

PRO-01 | UNPROTECTED INITIALIZER

Category	Severity	Location	Status
Coding Style	Minor	contracts/protocol/configuration/StakingPoolConfigurator.sol: 39; contracts/protocol/tokenization/STFILToken.sol: 50; contracts/protocol/tokenization/StableDebtToken.sol: 34; contracts/protocol/tokenization/VariableDebtToken.sol: 28	Resolved

Description

One or more logic contracts do not protect their initializers. An attacker can call the initializer and assume ownership of the logic contract, whereby she can perform privileged operations that trick unsuspecting users into believing that she is the owner of the upgradeable contract.

```
21  contract StakingPoolConfigurator is Initializable, IStakingPoolConfigurator {
```

- `StakingPoolConfigurator` is an upgradeable contract that does not protect its initializer.

```
39    function initialize(IStakingPoolAddressesProvider provider) public initializer
{
```

- `initialize` is an unprotected initializer function.

```
18  contract STFILToken is ISTFILToken, ERC20Upgradeable, IERC2612 {
```

- `STFILToken` is an upgradeable contract that does not protect its initializer.

```
50    function initialize(IStakingPool pool, address treasury) external initializer
{
```

- `initialize` is an unprotected initializer function.

```
17  contract StableDebtToken is IStableDebtToken, DebtTokenBase {
```

- `StableDebtToken` is an upgradeable contract that does not protect its initializer.

```
34     function initialize(IStakingPool pool) public initializer {
```

- `initialize` is an unprotected initializer function.

```
16  contract VariableDebtToken is DebtTokenBase, IVariableDebtToken {
```

- `VariableDebtToken` is an upgradeable contract that does not protect its initializer.

```
28     function initialize(IStakingPool pool) public initializer {
```

- `initialize` is an unprotected initializer function.

Recommendation

We advise calling `_disableInitializers` in the constructor or giving the constructor the `initializer` modifier to prevent the intializer from being called on the logic contract.

Reference: https://docs.openzeppelin.com/upgrades-plugins/1.x/writing-upgradeable#initializing_the_implementation_contract

Alleviation

The team heeded the advice and resolved this issue in commit `fe9d776c2e36643e9eb06b1f498eb4a98c3491be`.

STF-01 | MISSING ZERO ADDRESS VALIDATION

Category	Severity	Location	Status
Volatile Code	Minor	STFILToken.sol (93ca5d5): 70	Resolved

Description

The address should be checked before assignment or external call to make sure they are not zero addresses.

```
70      _treasury = treasury;
```

- `treasury` is not zero-checked before being used.

Recommendation

We advise adding a zero-check for the passed-in address value to prevent unexpected errors.

Alleviation

The team heeded the advice and resolved this issue in commit `776eb758117dc5e57c844228679b25dd50f07dbf`.

GLU-01 | INCORRECT COMMENTS

Category	Severity	Location	Status
Coding Style	Informational	contracts/protocol/libraries/logic/GenericLogic.sol: 69	Resolved

Description

```
/**
 *
 * @return The liquidation position and award
 **/
function calcPaybackAfterLiquidation(uint256 position, uint256 availablePosition,
uint256 maxLeverage, uint256 liquidationThreshold) internal pure returns (uint256){
```

The comment of the function `calcPaybackAfterLiquidation` is incorrect, there is only one return argument.

Recommendation

We recommend revising the comments.

Alleviation

The team heeded the advice and resolved this issue in commit `5a422058a9ee074ab3f619223266883583fb6ccb`.

INT-01 | LACK OF EVENT EMITTING

Category	Severity	Location	Status
Coding Style	Informational	contracts/protocol/configuration/InterestRateStrategy.sol: 58~62	Resolved

Description

Functions that affect the status of sensitive variables should emit events as notifications to customers.

Recommendation

We advise adding events for sensitive actions in the aforementioned functions, and emit them in the functions.

Alleviation

The team heeded the advice and resolved this issue in commit `a99517fe7fb2d32418ac03ccf99b89b60122c650`.

SPU-02 | DISCUSSIONS ON `Liquidation`

Category	Severity	Location	Status
Volatile Code	Informational	contracts/protocol/stakingpool/StakingPool.sol: 452	Acknowledged

Description

With regard to the debt repayment part of the liquidation, we have a question to confirm with you:

During the liquidation process, the debt to be settled is divided into two parts.

1. The first part represents the debt that is liquidated when the current debt rate is reduced to the liquidation threshold. This portion of the debt, as well as the liquidation reward, is paid for using the risk margin.
2. The second part refers to the debt that is liquidated between the liquidation threshold and the maximum debt rate. This part of the debt is deducted from the available positions of the node.

Would it not be more reasonable to utilize the available positions of the liquidated node to settle all debts first, and then use the risk margin to pay off any remaining debt?

Recommendation

We recommend reviewing the logic again and ensuring it is as intended.

Alleviation

[Proghub Team]: In liquidation, liquidators can receive rewards while only paying for the gas fees, so liquidation should be timely and small in amount (reward > gas fee). If timely liquidation can be ensured, I believe that the order of liquidation and repayment operations should not have significant issues. However, if the assets of a node are less than its debt due to delayed liquidation, repaying before liquidation can cause all assets of the node to belong to the STFIL protocol, which may cause storage providers to abandon the node and maximize the losses of the protocol.

Unlike AAVE, where collateral can be liquidated to pay off debt, allowing debt to be satisfied. in the STFIL protocol, most of the storage provider's assets are locked in the network's collateral and cannot be liquidated.

However, in the event of a major incident(disk damage, data loss), if the collateral of the storage provider is insufficient to cover all losses, they may lose the motivation to recover the remaining value, which could cause greater losses to the protocol. To encourage storage providers to maintain their nodes actively at all times, we must ensure that there is always a certain proportion of residual value in the nodes, generally equal to 1-liquidationFactor.

OPTIMIZATIONS | STFIL

ID	Title	Category	Severity	Status
COT-01	Unused State Variable	Gas Optimization	Optimization	Resolved

COT-01 | UNUSED STATE VARIABLE

Category	Severity	Location	Status
Gas Optimization	Optimization	WrapPrecompilesAPI.sol (93ca5d5): 8; WrapFilAddresses.sol (93ca5d5): 13	Resolved

Description

One or more state variables are never used in the codebase.

Variable `LOOKUP_DELEGATED_ADDRESS_PRECOMPILE_ADDR` in `WrapPrecompilesAPI` is never used in `WrapPrecompilesAPI`.

```
 8      address constant LOOKUP_DELEGATED_ADDRESS_PRECOMPILE_ADDR =
0xfE00000000000000000000000000000000000002;
```

Variable `InvalidAddress` in `WrapFilAddresses` is never used in `WrapFilAddresses`.

```
    error InvalidAddress();
```

Recommendation

We advise removing the unused variables.

Alleviation

The team heeded the advice and resolved this issue in commit `60f65c626c502d2bf9d865d819813d02d9be1d69`.

FORMAL VERIFICATION | STFIL

Formal guarantees about the behavior of smart contracts can be obtained by reasoning about properties relating to the entire contract (e.g. contract invariants) or to specific functions of the contract. Once such properties are proven to be valid, they guarantee that the contract behaves as specified by the property. As part of this audit, we applied automated formal verification (symbolic model checking) to prove that well-known functions in the smart contracts adhere to their expected behavior.

Considered Functions And Scope

In the following, we provide a description of the properties that have been used in this audit. They are grouped according to the type of contract they apply to.

Verification of ERC-20 Compliance

We verified properties of the public interface of those token contracts that implement the ERC-20 interface. This covers

- Functions `transfer` and `transferFrom` that are widely used for token transfers,
- functions `approve` and `allowance` that enable the owner of an account to delegate a certain subset of her tokens to another account (i.e. to grant an allowance), and
- the functions `balanceOf` and `totalSupply` , which are verified to correctly reflect the internal state of the contract.

The properties that were considered within the scope of this audit are as follows:

Property Name	Title
erc20-transfer-revert-zero	`transfer` Prevents Transfers to the Zero Address
erc20-transfer-correct-amount	`transfer` Transfers the Correct Amount in Non-self Transfers
erc20-transfer-correct-amount-self	`transfer` Transfers the Correct Amount in Self Transfers
erc20-transfer-change-state	`transfer` Has No Unexpected State Changes
erc20-transfer-exceed-balance	`transfer` Fails if Requested Amount Exceeds Available Balance
erc20-transfer-recipient-overflow	`transfer` Prevents Overflows in the Recipient's Balance
erc20-transfer-false	If `transfer` Returns `false` , the Contract State Is Not Changed
erc20-transfer-never-return-false	`transfer` Never Returns `false`
erc20-transferfrom-revert-from-zero	`transferFrom` Fails for Transfers From the Zero Address
erc20-transferfrom-revert-to-zero	`transferFrom` Fails for Transfers To the Zero Address

Property Name	Title
erc20-transferfrom-correct-amount	`transferFrom` Transfers the Correct Amount in Non-self Transfers
erc20-transferfrom-correct-amount-self	`transferFrom` Performs Self Transfers Correctly
erc20-transferfrom-correct-allowance	`transferFrom` Updated the Allowance Correctly
erc20-transferfrom-change-state	`transferFrom` Has No Unexpected State Changes
erc20-transferfrom-fail-exceed-balance	`transferFrom` Fails if the Requested Amount Exceeds the Available Balance
erc20-transferfrom-fail-exceed-allowance	`transferFrom` Fails if the Requested Amount Exceeds the Available Allowance
erc20-transferfrom-fail-recipient-overflow	`transferFrom` Prevents Overflows in the Recipient's Balance
erc20-transferfrom-false	If `transferFrom` Returns `false` , the Contract's State Is Unchanged
erc20-transferfrom-never-return-false	`transferFrom` Never Returns `false`
erc20-totalsupply-change-state	`totalSupply` Does Not Change the Contract's State
erc20-balanceof-change-state	`balanceOf` Does Not Change the Contract's State
erc20-allowance-correct-value	`allowance` Returns Correct Value
erc20-allowance-change-state	`allowance` Does Not Change the Contract's State
erc20-approve-revert-zero	`approve` Prevents Approvals For the Zero Address
erc20-approve-correct-amount	`approve` Updates the Approval Mapping Correctly
erc20-approve-change-state	`approve` Has No Unexpected State Changes
erc20-approve-false	If `approve` Returns `false` , the Contract's State Is Unchanged
erc20-approve-never-return-false	`approve` Never Returns `false`

Verification Results

For the following contracts, model checking established that each of the properties that were in scope of this audit (see scope) are valid:

Detailed Results For Contract StableDebtToken (contracts/protocol/tokenization/StableDebtToken.sol) In Commit ccbf4f76ae66680881b0a2e1ee5530704c5386a5

Verification of ERC-20 Compliance

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-revert-zero	True	
erc20-transfer-correct-amount	True	
erc20-transfer-correct-amount-self	True	
erc20-transfer-change-state	True	
erc20-transfer-exceed-balance	True	
erc20-transfer-recipient-overflow	True	
erc20-transfer-false	True	
erc20-transfer-never-return-false	True	

Detailed results for function `transferFrom`

Property Name	Final Result	Remarks
erc20-transferfrom-revert-from-zero	True	
erc20-transferfrom-revert-to-zero	True	
erc20-transferfrom-correct-amount	True	
erc20-transferfrom-correct-amount-self	True	
erc20-transferfrom-correct-allowance	True	
erc20-transferfrom-change-state	True	
erc20-transferfrom-fail-exceed-balance	True	
erc20-transferfrom-fail-exceed-allowance	True	
erc20-transferfrom-fail-recipient-overflow	True	
erc20-transferfrom-false	True	
erc20-transferfrom-never-return-false	True	

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-change-state	● True	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-change-state	● True	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-correct-value	● True	
erc20-allowance-change-state	● True	

Detailed results for function `approve`

Property Name	Final Result	Remarks
erc20-approve-revert-zero	● True	
erc20-approve-correct-amount	● True	
erc20-approve-change-state	● True	
erc20-approve-false	● True	
erc20-approve-never-return-false	● True	

Detailed Results For Contract VariableDebtToken (contracts/protocol/tokenization/VariableDebtToken.sol) In Commit ccbf4f76ae66680881b0a2e1ee5530704c5386a5

Verification of ERC-20 Compliance

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-revert-zero	True	
erc20-transfer-correct-amount	True	
erc20-transfer-correct-amount-self	True	
erc20-transfer-change-state	True	
erc20-transfer-exceed-balance	True	
erc20-transfer-recipient-overflow	True	
erc20-transfer-false	True	
erc20-transfer-never-return-false	True	

Detailed results for function `transferFrom`

Property Name	Final Result	Remarks
erc20-transferfrom-revert-from-zero	True	
erc20-transferfrom-revert-to-zero	True	
erc20-transferfrom-correct-amount	True	
erc20-transferfrom-correct-amount-self	True	
erc20-transferfrom-correct-allowance	True	
erc20-transferfrom-change-state	True	
erc20-transferfrom-fail-exceed-balance	True	
erc20-transferfrom-fail-exceed-allowance	True	
erc20-transferfrom-fail-recipient-overflow	True	
erc20-transferfrom-false	True	
erc20-transferfrom-never-return-false	True	

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-change-state	● True	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-change-state	● True	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-correct-value	● True	
erc20-allowance-change-state	● True	

Detailed results for function `approve`

Property Name	Final Result	Remarks
erc20-approve-revert-zero	● True	
erc20-approve-correct-amount	● True	
erc20-approve-change-state	● True	
erc20-approve-false	● True	
erc20-approve-never-return-false	● True	

APPENDIX | STFIL

Finding Categories

Categories	Description
Gas Optimization	Gas Optimization findings do not affect the functionality of the code but generate different, more optimal EVM opcodes resulting in a reduction on the total gas cost of a transaction.
Logical Issue	Logical Issue findings detail a fault in the logic of the linked code, such as an incorrect notion on how block.timestamp works.
Volatile Code	Volatile Code findings refer to segments of code that behave unexpectedly on certain edge cases that may result in a vulnerability.
Coding Style	Coding Style findings usually do not affect the generated byte-code but rather comment on how to make the codebase more legible and, as a result, easily maintainable.

Checksum Calculation Method

The "Checksum" field in the "Audit Scope" section is calculated as the SHA-256 (Secure Hash Algorithm 2 with digest size of 256 bits) digest of the content of each file hosted in the listed source repository under the specified commit.

The result is hexadecimal encoded and is the same as the output of the Linux "sha256sum" command against the target file.

Details on Formal Verification

Some Solidity smart contracts from this project have been formally verified using symbolic model checking. Each such contract was compiled into a mathematical model which reflects all its possible behaviors with respect to the property. The model takes into account the semantics of the Solidity instructions found in the contract. All verification results that we report are based on that model.

Technical Description

The model also formalizes a simplified execution environment of the Ethereum blockchain and a verification harness that performs the initialization of the contract and all possible interactions with the contract. Initially, the contract state is initialized non-deterministically (i.e. by arbitrary values) and over-approximates the reachable state space of the contract throughout any actual deployment on chain. All valid results thus carry over to the contract's behavior in arbitrary states after it has been deployed.

Assumptions and Simplifications

The following assumptions and simplifications apply to our model:

- Gas consumption is not taken into account, i.e. we assume that executions do not terminate prematurely because they run out of gas.
- The contract's state variables are non-deterministically initialized before invocation of any function. That ignores contract invariants and may lead to false positives. It is, however, a safe over-approximation.
- The verification engine reasons about unbounded integers. Machine arithmetic is modeled using modular arithmetic based on the bit-width of the underlying numeric Solidity type. This ensures that over- and underflow characteristics are faithfully represented.
- Certain low-level calls and inline assembly are not supported and may lead to a contract not being formally verified.
- We model the semantics of the Solidity source code and not the semantics of the EVM bytecode in a compiled contract.

Formalism for Property Specification

All properties are expressed in linear temporal logic (LTL). For that matter, we treat each invocation of and each return from a public or an external function as a discrete time step. Our analysis reasons about the contract's state upon entering and upon leaving public or external functions.

Apart from the Boolean connectives and the modal operators "always" (written `[]`) and "eventually" (written `<>`), we use the following predicates as atomic propositions. They are evaluated on the contract's state whenever a discrete time step occurs:

- `started(f, [cond])` Indicates an invocation of contract function `f` within a state satisfying formula `cond`.
- `willSucceed(f, [cond])` Indicates an invocation of contract function `f` within a state satisfying formula `cond` and considers only those executions that do not revert.
- `finished(f, [cond])` Indicates that execution returns from contract function `f` in a state satisfying formula `cond`. Here, formula `cond` may refer to the contract's state variables and to the value they had upon entering the function (using the `old` function).
- `reverted(f, [cond])` Indicates that execution of contract function `f` was interrupted by an exception in a contract state satisfying formula `cond`.

The verification performed in this audit operates on a harness that non-deterministically invokes a function of the contract's public or external interface. All formulas are analyzed w.r.t. the trace that corresponds to this function invocation.

Description of the Analyzed ERC-20 Properties

The specifications are designed such that they capture the desired and admissible behaviors of the ERC-20 functions `transfer`, `transferFrom`, `approve`, `allowance`, `balanceOf`, and `totalSupply`. In the following, we list those property specifications.

Properties related to function `transfer`

erc20-transfer-revert-zero

`transfer` Prevents Transfers to the Zero Address. Any call of the form `transfer(recipient, amount)` must fail if the recipient address is the zero address. Specification:

```
[](started(contract.transfer(to, value), to == address(0)) ==>
  <>(reverted(contract.transfer) || finished(contract.transfer(to, value), return
    == false)))
```

erc20-transfer-succeed-normal

`transfer` Succeeds on Admissible Non-self Transfers. All invocations of the form `transfer(recipient, amount)` must succeed and return `true` if

- the `recipient` address is not the zero address,
- `amount` does not exceed the balance of address `msg.sender`,
- transferring `amount` to the `recipient` address does not lead to an overflow of the recipient's balance, and
- the supplied gas suffices to complete the call. Specification:

```
[](started(contract.transfer(to, value), to != address(0) && to != msg.sender &&
    value >= 0 && value <= _balances[msg.sender] && _balances[to] + value <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[to] >= 0 && _balances[msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transfer(to, value), return == true)))
```

erc20-transfer-succeed-self

`transfer` Succeeds on Admissible Self Transfers. All self-transfers, i.e. invocations of the form `transfer(recipient, amount)` where the `recipient` address equals the address in `msg.sender` must succeed and return `true` if

- the value in `amount` does not exceed the balance of `msg.sender` and
- the supplied gas suffices to complete the call. Specification:

```
[](started(contract.transfer(to, value), to != address(0) && to == msg.sender &&
    value >= 0 && value <= _balances[msg.sender] && _balances[msg.sender] >= 0 &&
    _balances[msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transfer(to, value), return == true)))
```

erc20-transfer-correct-amount

`transfer` Transfers the Correct Amount in Non-self Transfers. All non-reverting invocations of `transfer(recipient, amount)` that return `true` must subtract the value in `amount` from the balance of `msg.sender` and add the same value to the balance of the `recipient` address. Specification:

```
[](willSucceed(contract.transfer(to, value), to != msg.sender && _balances[to] >= 0
    && value >= 0 && _balances[to] + value <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[msg.sender] >= 0 && _balances[msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transfer(to, value), return == true ==>
      _balances[msg.sender] == old(_balances[msg.sender]) - value && _balances[to]
      == old(_balances[to]) + value)))
```

erc20-transfer-correct-amount-self

`transfer` Transfers the Correct Amount in Self Transfers. All non-reverting invocations of `transfer(recipient, amount)` that return `true` and where the `recipient` address equals `msg.sender` (i.e. self-transfers) must not change the balance of address `msg.sender`. Specification:

```
[](willSucceed(contract.transfer(to, value), to == msg.sender && _balances[to] >= 0
    && _balances[to] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transfer(to, value), return == true ==> _balances[to] ==
      old(_balances[to]))))
```

erc20-transfer-change-state

`transfer` Has No Unexpected State Changes. All non-reverting invocations of `transfer(recipient, amount)` that return `true` must only modify the balance entries of the `msg.sender` and the `recipient` addresses. Specification:

```
[](willSucceed(contract.transfer(to, value), p1 != msg.sender && p1 != to) ==>
  <>(finished(contract.transfer(to, value), return == true ==> (_totalSupply ==
        old(_totalSupply) && _allowances == old(_allowances) && _balances[p1] ==
        old(_balances[p1]) && other_state_variables ==
        old(other_state_variables)))))
```

erc20-transfer-exceed-balance

`transfer` Fails if Requested Amount Exceeds Available Balance. Any transfer of an amount of tokens that exceeds the balance of `msg.sender` must fail. Specification:

```
[](started(contract.transfer(to, value), value > _balances[msg.sender] &&
    _balances[msg.sender] >= 0 && value <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(reverted(contract.transfer) || finished(contract.transfer(to, value), return
      == false)))
```

erc20-transfer-recipient-overflow

`transfer` Prevents Overflows in the Recipient's Balance. Any invocation of `transfer(recipient, amount)` must fail if it causes the balance of the `recipient` address to overflow. Specification:

```
[](started(contract.transfer(to, value), to != msg.sender && _balances[to] + value
    >= 0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[to] >= 0 && _balances[to] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000 && value >
    0 && value <= _balances[msg.sender]) ==> <>(reverted(contract.transfer) ||
    finished(contract.transfer(to, value), return == false) ||
    finished(contract.transfer(to, value), _balances[to] > old(_balances[to]) +
      value -
      0x10000000000000000000000000000000000000000000000000000000000000000)))
```

erc20-transfer-false

If `transfer` Returns `false`, the Contract State Is Not Changed. If the `transfer` function in contract `contract` fails by returning `false`, it must undo all state changes it incurred before returning to the caller. Specification:

```
[](willSucceed(contract.transfer(to, value)) ==> <>(finished(contract.transfer(to,
        value), return == false ==> (_balances == old(_balances) && _totalSupply ==
        old(_totalSupply) && _allowances == old(_allowances) &&
        other_state_variables == old(other_state_variables)))))
```

erc20-transfer-never-return-false

`transfer` Never Returns `false`. The transfer function must never return `false` to signal a failure. Specification:

```
[](!(finished(contract.transfer, return == false)))
```

Properties related to function `transferFrom`

erc20-transferfrom-revert-from-zero

`transferFrom` Fails for Transfers From the Zero Address. All calls of the form `transferFrom(from, dest, amount)` where the `from` address is zero, must fail. Specification:

```
[](started(contract.transferFrom(from, to, value), from == address(0)) ==>
  <>(reverted(contract.transferFrom) || finished(contract.transferFrom, return ==
      false)))
```

erc20-transferfrom-revert-to-zero

`transferFrom` Fails for Transfers To the Zero Address. All calls of the form `transferFrom(from, dest, amount)` where the `dest` address is zero, must fail. Specification:

```
[](started(contract.transferFrom(from, to, value), to == address(0)) ==>
  <>(reverted(contract.transferFrom) || finished(contract.transferFrom, return ==
      false)))
```

erc20-transferfrom-succeed-normal

`transferFrom` Succeeds on Admissible Non-self Transfers. All invocations of `transferFrom(from, dest, amount)` must succeed and return `true` if

- the value of `amount` does not exceed the balance of address `from` ,
- the value of `amount` does not exceed the allowance of `msg.sender` for address `from` ,
- transferring a value of `amount` to the address in `dest` does not lead to an overflow of the recipient's balance, and
- the supplied gas suffices to complete the call. Specification:

```
[](started(contract.transferFrom(from, to, value), from != address(0) && to !=
    address(0) && from != to && value <= _balances[from] && value <=
    _allowances[from][msg.sender] && _balances[to] + value <
    0x10000000000000000000000000000000000000000000000000000000000000000 && value >=
    0 && _balances[to] >= 0 && _balances[from] >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _allowances[from][msg.sender] >= 0 && _allowances[from][msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transferFrom(from, to, value), return == true)))
```

erc20-transferfrom-succeed-self

`transferFrom` Succeeds on Admissible Self Transfers. All invocations of `transferFrom(from, dest, amount)` where the `dest` address equals the `from` address (i.e. self-transfers) must succeed and return `true` if:

- The value of `amount` does not exceed the balance of address `from` ,
- the value of `amount` does not exceed the allowance of `msg.sender` for address `from` , and
- the supplied gas suffices to complete the call. Specification:

```
[](started(contract.transferFrom(from, to, value), from != address(0) && from == to
    && value <= _balances[from] && value <= _allowances[from][msg.sender] && value
    >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _allowances[from][msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transferFrom(from, to, value), return == true)))
```

erc20-transferfrom-correct-amount

`transferFrom` Transfers the Correct Amount in Non-self Transfers. All invocations of `transferFrom(from, dest, amount)` that succeed and that return `true` subtract the value in `amount` from the balance of address `from` and add the same value to the balance of address `dest`. Specification:

```
[](willSucceed(contract.transferFrom(from, to, value), from != to && value >= 0 &&
    _balances[from] >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[to] >= 0 && _balances[to] + value <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transferFrom(from, to, value), return == true ==>
      _balances[from] == old(_balances[from]) - value && _balances[to] ==
      old(_balances[to] + value))))
```

erc20-transferfrom-correct-amount-self

`transferFrom` Performs Self Transfers Correctly. All non-reverting invocations of `transferFrom(from, dest, amount)` that return `true` and where the address in `from` equals the address in `dest` (i.e. self-transfers) do not change the balance entry of the `from` address (which equals `dest`). Specification:

```
[](willSucceed(contract.transferFrom(from, to, value), from == to && value >= 0 &&
    value < 0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[from] >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transferFrom(from, to, value), return == true ==>
      _balances[from] == old(_balances[from]))))
```

erc20-transferfrom-correct-allowance

`transferFrom` Updated the Allowance Correctly. All non-reverting invocations of `transferFrom(from, dest, amount)` that return `true` must decrease the allowance for address `msg.sender` over address `from` by the value in `amount`. Specification:

```
[](willSucceed(contract.transferFrom(from, to, value), value >= 0 && value <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[from] >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[to] >= 0 && _balances[to] <
    0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _allowances[from][msg.sender] >= 0 && _allowances[from][msg.sender] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.transferFrom(from, to, value), return == true ==>
      ((_allowances[from][msg.sender] == old(_allowances[from][msg.sender]) -
      value) || (_allowances[from][msg.sender] ==
      old(_allowances[from][msg.sender]) && (from == msg.sender ||
        old(_allowances[from][msg.sender]) ==
        0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF))))))
```

erc20-transferfrom-change-state

`transferFrom` Has No Unexpected State Changes. All non-reverting invocations of `transferFrom(from, dest, amount)` that return `true` may only modify the following state variables:

- The balance entry for the address in `dest` ,
- The balance entry for the address in `from` ,
- The allowance for the address in `msg.sender` for the address in `from` . Specification:

```
[](willSucceed(contract.transferFrom(from, to, amount), p1 != from && p1 != to &&
    (p2 != from || p3 != msg.sender)) ==> <>(finished(contract.transferFrom(from,
      to, amount), return == true ==> (_totalSupply == old(_totalSupply) &&
      _balances[p1] == old(_balances[p1]) && _allowances[p2][p3] ==
      old(_allowances[p2][p3]) && other_state_variables ==
      old(other_state_variables)))))
```

erc20-transferfrom-fail-exceed-balance

`transferFrom` Fails if the Requested Amount Exceeds the Available Balance. Any call of the form `transferFrom(from, dest, amount)` with a value for `amount` that exceeds the balance of address `from` must fail. Specification:

```
[](started(contract.transferFrom(from, to, value), value > _balances[from] &&
    _balances[from] >= 0 && _balances[from] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(reverted(contract.transferFrom) || finished(contract.transferFrom, return ==
      false)))
```

erc20-transferfrom-fail-exceed-allowance

`transferFrom` Fails if the Requested Amount Exceeds the Available Allowance. Any call of the form `transferFrom(from, dest, amount)` with a value for `amount` that exceeds the allowance of address `msg.sender` must fail. Specification:

```
[](started(contract.transferFrom(from, to, value), msg.sender != from && value >
    _allowances[from][msg.sender] && _allowances[from][msg.sender] >= 0 && value <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(reverted(contract.transferFrom) || finished(contract.transferFrom(from, to,
        value), return == false)))
```

erc20-transferfrom-fail-recipient-overflow

`transferFrom` Prevents Overflows in the Recipient's Balance. Any call of `transferFrom(from, dest, amount)` with a value in `amount` whose transfer would cause an overflow of the balance of address `dest` must fail. Specification:

```
[](started(contract.transferFrom(from, to, value), from != to && _balances[to] +
    value >= 0x10000000000000000000000000000000000000000000000000000000000000000 &&
    value < 0x10000000000000000000000000000000000000000000000000000000000000000 &&
    _balances[to] >= 0 && _balances[to] <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(reverted(contract.transferFrom) || finished(contract.transferFrom(from, to,
        value), return == false) || finished(contract.transferFrom(from, to,
        value), _balances[to] > old(_balances[to]) + value -
      0x10000000000000000000000000000000000000000000000000000000000000000)))
```

erc20-transferfrom-false

If `transferFrom` Returns `false`, the Contract's State Is Unchanged. If `transferFrom` returns `false` to signal a failure, it must undo all incurred state changes before returning to the caller. Specification:

```
[](willSucceed(contract.transferFrom(from, to, value)) ==>
  <>(finished(contract.transferFrom(from, to, value), return == false ==>
    (_balances == old(_balances) && _totalSupply == old(_totalSupply) &&
    _allowances == old(_allowances) && other_state_variables ==
    old(other_state_variables)))))
```

erc20-transferfrom-never-return-false

`transferFrom` Never Returns `false`. The `transferFrom` function must never return `false`. Specification:

```
[](!(finished(contract.transferFrom, return == false)))
```

Properties related to function `totalSupply`

erc20-totalsupply-succeed-always

`totalSupply` Always Succeeds. The function `totalSupply` must always succeeds, assuming that its execution does not run out of gas. Specification:

```
[](started(contract.totalSupply) ==> <>(finished(contract.totalSupply)))
```

erc20-totalsupply-correct-value

`totalSupply` Returns the Value of the Corresponding State Variable. The `totalSupply` function must return the value that is held in the corresponding state variable of contract contract. Specification:

```
[](willSucceed(contract.totalSupply) ==> <>(finished(contract.totalSupply, return
      == _totalSupply)))
```

erc20-totalsupply-change-state

`totalSupply` Does Not Change the Contract's State. The `totalSupply` function in contract contract must not change any state variables. Specification:

```
[](willSucceed(contract.totalSupply) ==> <>(finished(contract.totalSupply,
      _totalSupply == old(_totalSupply) && _balances == old(_balances) &&
      _allowances == old(_allowances) && other_state_variables ==
      old(other_state_variables))))
```

Properties related to function `balanceOf`

erc20-balanceof-succeed-always

`balanceOf` Always Succeeds. Function `balanceOf` must always succeed if it does not run out of gas. Specification:

```
[](started(contract.balanceOf) ==> <>(finished(contract.balanceOf)))
```

erc20-balanceof-correct-value

`balanceOf` Returns the Correct Value. Invocations of `balanceOf(owner)` must return the value that is held in the contract's balance mapping for address `owner` . Specification:

```
[](willSucceed(contract.balanceOf) ==> <>(finished(contract.balanceOf(owner),
      return == _balances[owner])))
```

erc20-balanceof-change-state

`balanceOf` Does Not Change the Contract's State. Function `balanceOf` must not change any of the contract's state variables. Specification:

```
[](willSucceed(contract.balanceOf) ==> <>(finished(contract.balanceOf(owner),
      _totalSupply == old(_totalSupply) && _balances == old(_balances) &&
      _allowances == old(_allowances) && other_state_variables ==
      old(other_state_variables))))
```

Properties related to function `allowance`

erc20-allowance-succeed-always

`allowance` Always Succeeds. Function `allowance` must always succeed, assuming that its execution does not run out of gas. Specification:

```
[](started(contract.allowance) ==> <>(finished(contract.allowance)))
```

erc20-allowance-correct-value

`allowance` Returns Correct Value. Invocations of `allowance(owner, spender)` must return the allowance that address `spender` has over tokens held by address `owner`. Specification:

```
[](willSucceed(contract.allowance(owner, spender)) ==>
  <>(finished(contract.allowance(owner, spender), return ==
    _allowances[owner][spender])))
```

erc20-allowance-change-state

`allowance` Does Not Change the Contract's State. Function `allowance` must not change any of the contract's state variables. Specification:

```
[](willSucceed(contract.allowance(owner, spender)) ==>
  <>(finished(contract.allowance(owner, spender), _totalSupply == old(_totalSupply)
    && _balances == old(_balances) && _allowances == old(_allowances) &&
    other_state_variables == old(other_state_variables))))
```

Properties related to function `approve`

erc20-approve-revert-zero

`approve` Prevents Approvals For the Zero Address. All calls of the form `approve(spender, amount)` must fail if the address in `spender` is the zero address. Specification:

```
[](started(contract.approve(spender, value), spender == address(0)) ==>
  <>(reverted(contract.approve) || finished(contract.approve(spender, value),
    return == false)))
```

erc20-approve-succeed-normal

`approve` Succeeds for Admissible Inputs. All calls of the form `approve(spender, amount)` must succeed, if

- the address in `spender` is not the zero address and
- the execution does not run out of gas. Specification:

```
[](started(contract.approve(spender, value), spender != address(0)) ==>
  <>(finished(contract.approve(spender, value), return == true)))
```

erc20-approve-correct-amount

`approve` Updates the Approval Mapping Correctly. All non-reverting calls of the form `approve(spender, amount)` that return `true` must correctly update the allowance mapping according to the address `msg.sender` and the values of `spender` and `amount`. Specification:

```
[](willSucceed(contract.approve(spender, value), spender != address(0) && value >=
    0 && value <
    0x10000000000000000000000000000000000000000000000000000000000000000) ==>
  <>(finished(contract.approve(spender, value), return == true ==>
      _allowances[msg.sender][spender] == value)))
```

erc20-approve-change-state

`approve` Has No Unexpected State Changes. All calls of the form `approve(spender, amount)` must only update the allowance mapping according to the address `msg.sender` and the values of `spender` and `amount` and incur no other state changes. Specification:

```
[](willSucceed(contract.approve(spender, value), spender != address(0) && (p1 !=
      msg.sender || p2 != spender)) ==> <>(finished(contract.approve(spender,
        value), return == true ==> _totalSupply == old(_totalSupply) && _balances
      == old(_balances) && _allowances[p1][p2] == old(_allowances[p1][p2]) &&
      other_state_variables == old(other_state_variables))))
```

erc20-approve-false

If `approve` Returns `false`, the Contract's State Is Unchanged. If function `approve` returns `false` to signal a failure, it must undo all state changes that it incurred before returning to the caller. Specification:

```
[](willSucceed(contract.approve(spender, value)) ==>
  <>(finished(contract.approve(spender, value), return == false ==> (_balances ==
      old(_balances) && _totalSupply == old(_totalSupply) && _allowances ==
      old(_allowances) && other_state_variables == old(other_state_variables)))))
```

erc20-approve-never-return-false

`approve` Never Returns `false`. The function `approve` must never returns `false`. Specification:

```
[](!(finished(contract.approve, return == false)))
```

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