



Security Assessment

# Tatum - Audit

CertiK Verified on Sept 16th, 2022





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## Tatum - Audit

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

### Executive Summary

#### TYPES

Platform

#### ECOSYSTEM

Ethereum (ETH)

#### METHODS

Manual Review, Static Analysis

#### LANGUAGE

Solidity

#### TIMELINE

Delivered on 09/16/2022

#### KEY COMPONENTS

N/A

#### CODEBASE

<https://github.com/tatumio/smart-contracts/blob/master/contracts/tatum/custodial>  
[...View All](#)

#### COMMITTS

477bb3937beb49c27fa66651238d7880d510ba2f  
8cff275c500acdcda7ff0c947fb698b980747b7  
[...View All](#)

### Vulnerability Summary



6

Total Findings

5

Resolved

0

Mitigated

0

Partially Resolved

1

Acknowledged

0

Declined

0

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.

■ 1 Major

1 Acknowledged



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.

■ 0 Medium

Medium risks may not pose a direct risk to users' funds, but they can affect the overall functioning of a platform.

■ 4 Minor

4 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.

■ 1 Informational

1 Resolved



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 | TATUM - AUDIT

## Repository

<https://github.com/tatumio/smart-contracts/blob/master/contracts/tatum/custodial>

## Commit

477bb3937beb49c27fa66651238d7880d510ba2f 8cff275c500acdcdca7ff0c947fb698b980747b7

# AUDIT SCOPE | TATUM - AUDIT

2 files audited ● 1 file with Acknowledged findings ● 1 file with Resolved findings

ID	File	SHA256 Checksum
● CWC	 tatum/custodial/CustodialWallet.sol	7157a2856e0bdaa2e8bd70ae8ccc9843da2e6a45d73d22e9cc6300e77738c897
● CWF	 tatum/custodial/CustodialWalletFactoryV2.sol	fcd1866cdf0424f0251bf19cb74ec3614f056ec1a879caf83bafeb2967f88e77

## APPROACH & METHODS | TATUM - AUDIT

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

## FINDINGS | TATUM - AUDIT



6

Total Findings

0

Critical

1

Major

0

Medium

4

Minor

1

Informational

This report has been prepared to discover issues and vulnerabilities for Tatum - Audit. Through this audit, we have uncovered 6 issues ranging from different severity levels. Utilizing Static Analysis techniques to complement rigorous manual code reviews, we discovered the following findings:

ID	Title	Category	Severity	Status
<u>CWC-01</u>	Centralization Related Risks	Centralization / Privilege	Major	● Acknowledged
<u>CWC-02</u>	Unused Return Value	Volatile Code	Minor	● Resolved
<u>CWC-03</u>	Usage Of <code>transfer</code> / <code>send</code> For Sending Ether	Volatile Code	Minor	● Resolved
<u>CWC-04</u>	Missing Zero Address Validation	Volatile Code	Minor	● Resolved
<u>CWC-05</u>	Missing Error Messages	Coding Style	Informational	● Resolved
<u>CWF-01</u>	Potential Gas Exhaustion	Volatile Code	Minor	● Resolved

## CWC-01 | FINDING DETAILS

### Finding Title

Centralization Related Risks

Category	Severity	Location	Status
Centralization / Privilege	● Major	tatum/custodial/CustodialWallet.sol: 48, 75, 107	● Acknowledged

### Description

In the contract `CustodialWallet`, the role `owner` has authority over the following functions:

- function transfer()
- function transferBatch()
- function approve()

Any compromise to the `owner` account may allow a hacker to take advantage of this authority and withdraw tokens from `CustodialWallet`.

### 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 (2/3, 3/5) 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.

*Noted: Recommend considering the long-term solution or the permanent solution. The project team shall make a decision based on the current state of their project, timeline, and project resources.*

**I Alleviation**

[Tatum Team]: Issue acknowledged. I will fix the issue in the future, which will not be included in this audit engagement. In the current version of the contract, this is not possible from the timeline perspective to achieve. We are aware of this risk, and we are informing our customers how to behave with their private keys and what security things they must do.

## CWC-02 | FINDING DETAILS

### Finding Title

Unused Return Value

Category	Severity	Location	Status
Volatile Code	● Minor	tatum/custodial/CustodialWallet.sol: 109, 111, 113	● Resolved

### Description

The return value of an external call is not stored in a local or state variable.

```
109 IERC20(tokenAddress).approve(spender, amount);
```

### Recommendation

We recommend checking or using the return values of all external function calls.

### Alleviation

The team heeded the advice and resolved the finding in the commit hash `8cfff275c500acdcdca7ff0c947fb698b980747b7`.

## CWC-03 | FINDING DETAILS

### Finding Title

Usage Of `transfer` / `send` For Sending Ether

Category	Severity	Location	Status
Volatile Code	● Minor	tatum/custodial/CustodialWallet.sol: 56, 88	● Resolved

### Description

It is not recommended to use Solidity's `transfer()` and `send()` functions for transferring Ether, since some contracts may not be able to receive the funds. Those functions forward only a fixed amount of gas (2300 specifically) and the receiving contracts may run out of gas before finishing the transfer. Also, EVM instructions' gas costs may increase in the future. Thus, some contracts that can receive now may stop working in the future due to the gas limitation.

```
56 payable(recipient).transfer(amount);
```

- `CustodialWallet.transfer` uses `transfer()`.

### Recommendation

We recommend using the `Address.sendValue()` function from OpenZeppelin.

Since `Address.sendValue()` may allow reentrancy, we also recommend guarding against reentrancy attacks by utilizing the [Checks-Effects-Interactions Pattern](#) or applying OpenZeppelin [ReentrancyGuard](#).

### Alleviation

The team heeded the advice and resolved the finding in the commit hash `8cfff275c500acdcdca7ff0c947fb698b980747b7`.

## CWC-04 | FINDING DETAILS

### Finding Title

Missing Zero Address Validation

Category	Severity	Location	Status
Volatile Code	● Minor	tatum/custodial/CustodialWallet.sol: 56, 88	● Resolved

### Description

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

```
56 payable(recipient).transfer(amount);
```

- `recipient` 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 the finding in the commit hash `8cff275c500acdcdca7ff0c947fb698b980747b7`.

## CWC-05 | FINDING DETAILS

### Finding Title

Missing Error Messages

Category	Severity	Location	Status
Coding Style	● Informational	tatum/custodial/CustodialWallet.sol: 76, 77, 78, 79	● Resolved

### Description

The **require** can be used to check for conditions and throw an exception if the condition is not met. It is better to provide a string message containing details about the error that will be passed back to the caller.

### Recommendation

We advise adding error messages to the linked **require** statements.

### Alleviation

The team heeded the advice and resolved the finding in the commit hash `8cfff275c500acdcda7ff0c947fb698b980747b7` .

## CWF-01 | FINDING DETAILS

### Finding Title

Potential Gas Exhaustion

Category	Severity	Location	Status
Volatile Code	● Minor	tatum/custodial/CustodialWalletFactoryV2.sol: 44	● Resolved

### Description

The `for` loop within the function `getWallets()` and `createBatch()` takes unbounded arrays' lengths as the maximum iteration times. If the size of the array `index` grows large, iterating through the entire array could be an expensive operation. Even worse, if the computation for each iteration is extremely complex, it could exceed the gas limit per block.

### Recommendation

We recommend setting constraints to the length of the array `index`.

### Alleviation

The team heeded the advice and resolved the finding in the commit hash `8cfff275c500acdcdca7ff0c947fb698b980747b7`.

## OPTIMIZATIONS | TATUM - AUDIT

ID	Title	Category	Severity	Status
<u>CKP-01</u>	Function Should Be Declared External	Gas Optimization	Optimization	● Resolved

## CKP-01 | FINDING DETAILS

### Finding Title

Function Should Be Declared External

Category	Severity	Location	Status
Gas Optimization	● Optimization	tatum/custodial/CustodialWallet.sol: 75; tatum/custodial/CustodialWalletFactoryV2.sol: 30, 43	● Resolved

### Description

The functions which are never called internally within the contract should have external visibility for gas optimization.

```
75     function transferBatch(address[] memory tokenAddress, uint256[] memory
contractType, address[] memory recipient, uint256[] memory amount, uint256[] memory
tokenId) public payable onlyOwner {
```

```
30     function getWallets(address owner, uint256[] memory index) public view
returns (address[] memory, bool[] memory, bytes32[] memory) {
```

```
43     function createBatch(address owner, uint256[] memory index) public {
```

### Recommendation

It is recommended to change the visibility of the aforementioned functions to `external` for gas optimization.

### Alleviation

The team heeded the advice and resolved the finding in the commit hash `8cff275c500acdcdca7ff0c947fb698b980747b7`.



# FORMAL-VERIFICATION | TATUM - AUDIT

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

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



erc20-transferfrom-succeed-self

Function

transferFrom

Succeeds on Admissible Self Transfers

erc20-transferfrom-correct-allowance

Function

transferFrom

Updated the Allowance Correctly

erc20-transferfrom-change-state

Function

transferFrom

Has No Unexpected State Changes

erc20-transferfrom-fail-exceed-balance

Function

transferFrom

Fails if the Requested Amount Exceeds the Available Balance

erc20-transferfrom-fail-exceed-allowance

Function

transferFrom

Fails if the Requested Amount Exceeds the Available Allowance

erc20-transferfrom-false

If Function

transferFrom

Returns false , the Contract's State Has Not Been Changed

erc20-totalsupply-succeed-always

Function

totalSupply

Always Succeeds

erc20-totalsupply-correct-value

Function

totalSupply

Returns the Value of the Corresponding State Variable

erc20-totalsupply-change-state

Function

totalSupply

Does Not Change the Contract's State

erc20-balanceof-succeed-always

Function

balanceOf

Always Succeeds

erc20-transferfrom-fail-recipient-overflow

Function

transferFrom

Prevents Overflows in the Recipient's Balance

erc20-balanceof-correct-value

Function

balanceOf

Returns the Correct Value

erc20-balanceof-change-state

Function

balanceOf

Does Not Change the Contract's State

erc20-allowance-succeed-always

Function

allowance

Always Succeeds

erc20-allowance-correct-value

Function

allowance

Returns Correct Value

erc20-allowance-change-state

Function

allowance

Does Not Change the Contract's State

erc20-transferfrom-never-return-false

Function

transferFrom

Never Returns false

erc20-approve-revert-zero

Function

approve

Prevents Giving Approvals For the Zero Address

erc20-approve-succeed-normal

Function

approve

Succeeds for Admissible Inputs

erc20-approve-correct-amount

Function

approve

Updates the Approval Mapping Correctly

erc20-approve-false

If Function

approve

Returns false , the Contract's State Has Not Been Changed

erc20-approve-change-state

Function

approve

Has No Unexpected State Changes

erc20-approve-never-return-false

Function

approve

Never Returns false

erc20-transfer-revert-zero

Function

transfer

Prevents Transfers to the Zero Address

erc20-transfer-correct-amount

Function

transfer

Transfers the Correct Amount in Non-self Transfers

For the following contracts, model checking established that each of the 38 properties that were in scope of this audit (see scope) are valid:

**Contract ERC20 (Source File**  
**projects/tatum/contracts/token/ERC20/presets/ERC20PresetMinterPauser.sol)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20 (Source File `projects/tatum/contracts/ProassetzToken.sol`)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20PausableMock (Source File**  
**projects/tatum/contracts/mocks/ERC20PausableMock.sol)**



Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-change-state	● Valid	
erc20-transfer-exceed-balance	● Valid	
erc20-transfer-recipient-overflow	● Valid	
erc20-transfer-false	● Valid	

Detailed results for function `allowance`

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

Detailed results for function `approve`

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

**Contract ERC20PermitMock (Source File `projects/tatum/contracts/mocks/ERC20PermitMock.sol`)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20PresetFixedSupply (Source File**  
**projects/tatum/contracts/token/ERC20/presets/ERC20PresetFixedSupply.sol)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20BurnableMock (Source File**  
**projects/tatum/contracts/mocks/ERC20BurnableMock.sol)**

Detailed results for function `transfer`

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



Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20CappedMock (Source File**  
**projects/tatum/contracts/mocks/ERC20CappedMock.sol)**

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-false	● Valid	
erc20-transfer-never-return-false	● Valid	

Detailed results for function `balanceOf`

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

Detailed results for function `approve`

Property Name	Final Result	Remarks
erc20-approve-correct-amount	● Valid	
erc20-approve-succeed-normal	● Valid	
erc20-approve-change-state	● Valid	
erc20-approve-false	● Valid	
erc20-approve-never-return-false	● Valid	

**Contract ERC20DecimalsMock (Source File**  
**projects/tatum/contracts/mocks/ERC20DecimalsMock.sol)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20Mock (Source File `projects/tatum/contracts/mocks/ERC20Mock.sol`)**

Detailed results for function `transfer`

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

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	



Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

In the remainder of this section, we list all contracts where model checking of at least one property was not successful. There are several reasons why this could happen:

- Model checking reports a counterexample that violates the property. Depending on the counterexample, this occurs if
  - The specification of the property is too generic and does not accurately capture the intended behavior of the smart contract. In that case, the counterexample does not indicate a problem in the underlying smart contract. We report such instances as being "inapplicable".

- The property is applicable to the smart contract. In that case, the counterexample showcases a problem in the smart contract and a correspond finding is reported separately in the Findings section of this report. In the following tables, we report such instances as "invalid". The distinction between spurious and actual counterexamples is done manually by the auditors.
- The model checking result is inconclusive. Such a result does not indicate a problem in the underlying smart contract. An inconclusive result may occur if
  - The model checking engine fails to construct a proof. This can happen if the logical deductions necessary are beyond the capabilities of the automated reasoning tool. It is a technical limitation of all proof engines and cannot be avoided in general.
  - The model checking engine runs out of time or memory and did not produce a result. This can happen if automatic abstraction techniques are ineffective or of the state space is too big.

### Contract ERC20PresetMinterPauser (Source File `projects/tatum/contracts/token/ERC20/presets/ERC20PresetMinterPauser.sol`)

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-revert-zero	● Valid	
erc20-transfer-correct-amount	● Valid	
erc20-transfer-succeed-normal	● Invalid	
erc20-transfer-succeed-self	● Invalid	
erc20-transfer-correct-amount-self	● Valid	
erc20-transfer-exceed-balance	● Valid	
erc20-transfer-recipient-overflow	● Valid	
erc20-transfer-change-state	● Valid	
erc20-transfer-false	● Valid	
erc20-transfer-never-return-false	● Valid	

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	● Valid	
erc20-totalsupply-correct-value	● Valid	
erc20-totalsupply-change-state	● Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ProassetzToken (Source File `projects/tatum/contracts/ProassetzToken.sol`)**

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-revert-zero	● Valid	
erc20-transfer-succeed-self	● Invalid	
erc20-transfer-succeed-normal	● Invalid	
erc20-transfer-correct-amount	● Valid	
erc20-transfer-correct-amount-self	● Valid	
erc20-transfer-change-state	● Valid	
erc20-transfer-exceed-balance	● Valid	
erc20-transfer-recipient-overflow	● Valid	
erc20-transfer-false	● Valid	
erc20-transfer-never-return-false	● Valid	

Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

**Contract ERC20SnapshotMock (Source File**  
**projects/tatum/contracts/mocks/ERC20SnapshotMock.sol)**

Detailed results for function `transfer`

Property Name	Final Result	Remarks
erc20-transfer-revert-zero	● Valid	
erc20-transfer-correct-amount	● Valid	
erc20-transfer-succeed-normal	● Invalid	
erc20-transfer-succeed-self	● Invalid	
erc20-transfer-correct-amount-self	● Valid	
erc20-transfer-false	● Valid	
erc20-transfer-change-state	● Valid	
erc20-transfer-exceed-balance	● Valid	
erc20-transfer-recipient-overflow	● Valid	
erc20-transfer-never-return-false	● Valid	



Detailed results for function `transferFrom`

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

Detailed results for function `totalSupply`

Property Name	Final Result	Remarks
erc20-totalsupply-succeed-always	Valid	
erc20-totalsupply-correct-value	Valid	
erc20-totalsupply-change-state	Valid	

Detailed results for function `balanceOf`

Property Name	Final Result	Remarks
erc20-balanceof-succeed-always	● Valid	
erc20-balanceof-correct-value	● Valid	
erc20-balanceof-change-state	● Valid	

Detailed results for function `allowance`

Property Name	Final Result	Remarks
erc20-allowance-succeed-always	● Valid	
erc20-allowance-correct-value	● Valid	
erc20-allowance-change-state	● Valid	

Detailed results for function `approve`

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

## APPENDIX | TATUM - AUDIT

### Finding Categories

Categories	Description
Centralization / Privilege	Centralization / Privilege findings refer to either feature logic or implementation of components that act against the nature of decentralization, such as explicit ownership or specialized access roles in combination with a mechanism to relocate funds.
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.
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

#### Technical description

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.

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 of those functions. 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 as operations on the congruence classes arising from the bit-width of the underlying numeric 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 an ERC-20 token 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 definitions

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 steps. 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  $\Box$ ) and "eventually" (written  $\Diamond$ ), we use the following predicates to reason about the validity of 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 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 for ERC-20 function `transfer`

#### `erc20-transfer-revert-zero`

Function `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)))
```

### erc20-transfer-succeed-normal

Function `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 <= type(uint256).max && _balances[to] >= 0
    && _balances[msg.sender] <= type(uint256).max)
    ==> <>(finished(contract.transfer(to, value), return)))
```

### erc20-transfer-succeed-self

Function `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] <= type(uint256).max)
    ==> <>(finished(contract.transfer(to, value), return)))
```

**erc20-transfer-correct-amount**

Function `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 <= type(uint256).max
  && _balances[msg.sender] >= 0 && _balances[msg.sender] <= type(uint256).max)
  ==> <>(finished(contract.transfer(to, value), return
    ==> _balances[msg.sender] == old(_balances[msg.sender]) - value
    && _balances[to] == old(_balances[to]) + value)))

```

**erc20-transfer-correct-amount-self**

Function `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] <= type(uint256).max)
  ==> <>(finished(contract.transfer(to, value), return
    ==> _balances[to] == old(_balances[to]))))

```

**erc20-transfer-change-state**

Function `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
    ==> (_totalSupply == old(_totalSupply) && _allowances == old(_allowances)
    && _balances[p1] == old(_balances[p1]))))

```

**erc20-transfer-exceed-balance**

Function `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 <= type(uint256).max)
  ==> <>(reverted(contract.transfer) || finished(contract.transfer(to, value),
    !return)))

```

### erc20-transfer-recipient-overflow

Function `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 > type(uint256).max
  && _balances[to] >= 0 && _balances[to] <= type(uint256).max
  && _balances[msg.sender] <= type(uint256).max
  && value > 0 && value <= _balances[msg.sender])
  ==> <>(reverted(contract.transfer) || finished(contract.transfer(to, value),
    !return) || finished(contract.transfer(to, value), _balances[to]
      > old(_balances[to]) + value - type(uint256).max - 1)))

```

### erc20-transfer-false

If Function `transfer` Returns `false`, the Contract State Has Not Been 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)
  ==> (_balances == old(_balances) && _totalSupply == old(_totalSupply)
    && _allowances == old(_allowances) )))

```

### erc20-transfer-never-return-false

Function `transfe` Never Returns `false`.

The transfer function must never return `false` to signal a failure.

Specification:

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

## Properties for ERC-20 function `transferFrom`

### erc20-transferfrom-revert-from-zero

Function `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)))
```

### erc20-transferfrom-revert-to-zero

Function `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)))
```

### erc20-transferfrom-succeed-normal

Function `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 <= type(uint256).max
  && value >= 0 && _balances[to] >= 0 && _balances[from] >= 0
  && _balances[from] <= type(uint256).max
  && _allowances[from][msg.sender] >= 0
  && _allowances[from][msg.sender] <= type(uint256).max)
  ==> <>(finished(contract.transferFrom(from, to, value), return)))

```

### erc20-transferfrom-succeed-self

Function `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] <= type(uint256).max
  && _allowances[from][msg.sender] <= type(uint256).max)
  ==> <>(finished(contract.transferFrom(from, to, value), return)))

```

### erc20-transferfrom-correct-amount

Function `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] <= type(uint256).max
  && _balances[to] >= 0 && _balances[to] + value <= type(uint256).max)
  ==> <>(finished(contract.transferFrom(from, to, value), return
    ==> _balances[from] == old(_balances[from]) - value
    && _balances[to] == old(_balances[to] + value))))

```

**erc20-transferfrom-correct-amount-self**

Function `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 <= type(uint256).max && _balances[from] >= 0
  && _balances[from] <= type(uint256).max)
  ==> <>(finished(contract.transferFrom(from, to, value), return
    ==> _balances[from] == old(_balances[from]))))

```

**erc20-transferfrom-correct-allowance**

Function `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 <= type(uint256).max && _balances[from] >= 0
  && _balances[from] <= type(uint256).max && _balances[to] >= 0
  && _balances[to] <= type(uint256).max && _allowances[from][msg.sender] >= 0
  && _allowances[from][msg.sender] <= type(uint256).max)
  ==> <>(finished(contract.transferFrom(from, to, value), return
    ==> ((_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])
            == type(uint256).max))))))

```

**erc20-transferfrom-change-state**

Function `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
    ==> (_totalSupply == old(_totalSupply) && _balances[p1] == old(_balances[p1])
      && _allowances[p2][p3] == old(_allowances[p2][p3])  ))))
```

### erc20-transferfrom-fail-exceed-balance

Function `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] <= type(uint256).max)
  ==> <>(reverted(contract.transferFrom)
    || finished(contract.transferFrom, !return)))
```

### erc20-transferfrom-fail-exceed-allowance

Function `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), value > _allowances[from]
[msg.sender]
  && _allowances[from][msg.sender] >= 0 && value <= type(uint256).max)
  ==> <>(reverted(contract.transferFrom)
    || finished(contract.transferFrom(from, to, value), !return)
    || finished(contract.transferFrom(from, to, value), return
      && (msg.sender == from
        || _allowances[from][msg.sender] == type(uint256).max))))
```

### erc20-transferfrom-fail-recipient-overflow

Function `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 > type(uint256).max && value <= type(uint256).max
  && _balances[to] >= 0 && _balances[to] <= type(uint256).max)
  ==> <>(reverted(contract.transferFrom)
    || finished(contract.transferFrom(from, to, value), !return)
    || finished(contract.transferFrom(from, to, value), _balances[to]
      > old(_balances[to]) + value - type(uint256).max - 1)))

```

### erc20-transferfrom-false

If Function `transferFrom` Returns `false`, the Contract's State Has Not Been Changed.

If `transferFrom` returns `false` to signal a failure, it must undo all incurred state changes before returning to the caller.

Specification:

```

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

```

### erc20-transferfrom-never-return-false

Function `transferFrom` Never Returns `false`.

The `transferFrom` function must never return `false`.

Specification:

```

[](!(finished(contract.transferFrom, !return)))

```

### Properties related to function `totalSupply`

#### erc20-totalsupply-succeed-always

Function `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

Function `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

Function `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) )))
```

#### Properties related to function `balanceOf`

##### erc20-balanceof-succeed-always

Function `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

Function `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

Function `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) )))

```

#### Properties related to function `allowance`

##### erc20-allowance-succeed-always

Function `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

Function `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

Function `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) )))

```

#### Properties related to function `approve`

##### erc20-approve-revert-zero

Function `approve` Prevents Giving 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)))
```

### erc20-approve-succeed-normal

Function `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)))
```

### erc20-approve-correct-amount

Function `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 <= type(uint256).max)
  ==> <>(finished(contract.approve(spender, value), return
    ==> _allowances[msg.sender][spender] == value)))
```

### erc20-approve-change-state

Function `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
        ==> _totalSupply == old(_totalSupply) && _balances == old(_balances)
            && _allowances[p1][p2] == old(_allowances[p1][p2]) )))

```

### erc20-approve-false

If Function `approve` Returns `false`, the Contract's State Has Not Been Changed.

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
        ==> (_balances == old(_balances) && _totalSupply == old(_totalSupply)
            && _allowances == old(_allowances) ))))

```

### erc20-approve-never-return-false

Function `approve` Never Returns `false`.

The function `approve` must never returns `false`.

Specification:

```

[] (! (finished(contract.approve, !return)))

```



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