Security Review Report
NM-0074 PWN

NETHERMIND

(Mar 27, 2023)

Contents

1 Executive Summary

This document presents the security review performed by Nethermind on the PWN Contracts. PWN Finance is a DeFi solution for lending and borrowing tokens following `ERC20`, `ERC721`, `ERC1155`, and `CryptoKitties` standard. The protocol has an offer/request mechanism created off-chain to be fulfilled by a borrower/lender. PWN solves the possibility of under-collateralizing assets through a fixed amount of return of assets specified when the offer/request is created. PWN uses the `MultiToken` to interact with multiple types of assets in a single interface, providing functionalities such as transferring assets, approving allowance, and checking balances of a particular asset based on a certain category.

The audited code consists of 1,037 lines of Solidity with code coverage of 92.3%. The PWN team provided the developer docs, which contains most of the info required for understanding the system. **The audit was performed using** (a) manual analysis of the codebase, (b) automated analysis tools, and (c) simulation of the smart contracts. **Along this document, we report** 14 points of attention, where two are classified as `High`, five are classified as `Medium`, four are classified as `Low`, and three are classified as `Informational` or `Best Practices`. The issues are summarized in Fig. 1.

This document is organized as follows. Section 2 presents the files in the scope of this audit. Section 3 presents the assumptions for this audit. Section 4 summarizes the issues. Section 5 presents the system overview. Section 6 discusses the risk rating methodology adopted for this audit. Section 7 details the issues. Section 8 discusses the documentation provided by the client for this audit. Section 9 presents the compilation, tests, coverage, and automated tests. Section 10 concludes the document.

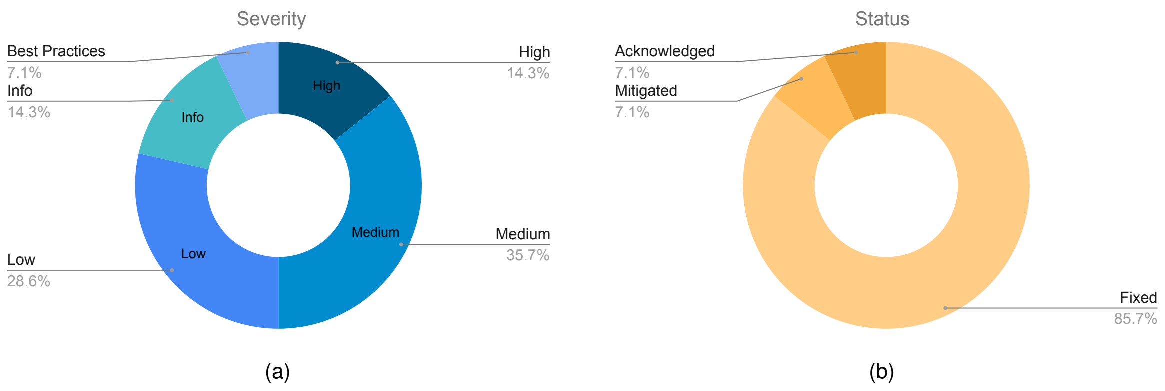


Fig. 1: Distribution of issues: Critical (0), **High** (2), **Medium** (5), **Low** (4), **Undetermined** (0), **Informational** (2), **Best Practices** (1).
Distribution of status: Fixed (12), **Acknowledged** (1), **Mitigated** (1), **Unresolved** (0)

Summary of the Audit

Audit Type	Security Review
Initial Report	Mar. 13, 2023
Response from Client	Mar. 20, 2023
Final Report	Mar. 27, 2023
Methods	Manual Review, Automated Analysis
Repository	PWN
Commit Hash (Initial Audit)	455e8f7d5ab9d284eeb3f9207c6021c389a794e2
Commit Hash (Reaudit)	13c67a5c743e50c30f97c540111fdfd67692d7eb
Documentation	PWN Developer Docs
Documentation Assessment	Medium
Test Suite Assessment	High

2 Audited Files

	Contract	LoC	Comments	Ratio	Blank	Total
1	lib/MultiToken/MultiToken.sol	154	134	87.0%	51	339
2	src/PWNErrors.sol	21	11	52.4%	11	43
3	src/hub/PWNHub.sol	25	46	184.0%	22	93
4	src/hub/PWNHubTags.sol	8	5	62.5%	6	19
5	src/hub/PWNHubAccessControl.sol	20	14	70.0%	13	47
6	src/loan/PWNVault.sol	63	94	149.2%	28	185
7	src/loan/lib/PWNFeeCalculator.sol	11	12	109.1%	6	29
8	src/loan/lib/PWNSignatureChecker.sol	46	19	41.3%	11	76
9	src/loan/token/IERC5646.sol	4	9	225.0%	3	16
10	src/loan/token/IPWNLoanMetadataProvider.sol	4	10	250.0%	3	17
11	src/loan/token/PWNLOAN.sol	41	63	153.7%	33	137
12	src/loan/terms/PWNLOANTerms.sol	13	12	92.3%	5	30
13	src/loan/terms/simple/loan/PWNSimpleLoan.sol	159	133	83.6%	74	366
14	src/loan/terms/simple/factory/IPWNSimpleLoanTermsFactory.sol	9	13	144.4%	5	27
15	src/loan/terms/simple/factory/request/PWNSimpleLoanSimpleRequest.sol	95	65	68.4%	33	193
16	src/loan/terms/simple/factory/request/base/PWNSimpleLoanRequest.sol	22	33	150.0%	18	73
17	src/loan/terms/simple/factory/offer/PWNSimpleLoanListOffer.sol	111	78	70.3%	37	226
18	src/loan/terms/simple/factory/offer/PWNSimpleLoanSimpleOffer.sol	97	67	69.1%	33	197
19	src/loan/terms/simple/factory/offer/base/PWNSimpleLoanOffer.sol	22	33	150.0%	18	73
20	src/nonce/PWNRevokedNonce.sol	35	66	188.6%	31	132
21	src/deployer/PWNDeployer.sol	18	35	194.4%	13	66
22	src/deployer/PWNContractDeployerSalt.sol	14	5	35.7%	8	27
23	src/config/PWNConfig.sol	45	65	144.4%	31	141
	Total	**1037**	**1022**	**98.6%**	**493**	**2552**

3 Assumptions

The prepared security review is based on the following assumptions:

- Only limited functionality of the library `MultiToken.sol` is used within the protocol;
- Offers and Request made off-chain by the Lenders and Borrowers have not been tampered with;
- The Merkle tree inclusion data is stored in a backend.

4 Summary of Issues

	Finding	Severity	Update
1	"No Revert on Failure" tokens can be used to steal from lender	High	Fixed
2	Borrower can steal lender's assets by using `WETH` as collateral	High	Fixed
3	Borrower can prevent the lender from receiving collateral during a claim	Medium	Fixed
4	Fee-on-transfer tokens can be locked in the vault	Medium	Fixed
5	Late repayment feature could be abused by lenders to trick borrowers into losing their collateral	Medium	Fixed
6	Some common ERC20 tokens can't be used in the protocol	Medium	Fixed
7	`CryptoKitties` token is locked when using it as ERC721 type collateral	Medium	Fixed
8	Function `calculateFeeAmount(...)` has unnecessary loss of precision	Low	Fixed
9	Malicious owner can arbitrarily change the fee to any value	Low	Mitigated
10	Ownable contracts	Low	Fixed
11	`offer.duration` can be set to zero	Low	Fixed
12	Fee Collector can be set to `address(0x0)` in function `setFeeCollector(...)`	Info	Fixed
13	Token that reverts on zero-value transfers can cause `createLoan(...)` to fail when transferring fees	Info	Fixed
14	Unlocked Pragma	Best Practices	Acknowledged

5 System Overview

PWN is a hub for peer-to-peer (P2P) loans backed by digital assets (DAI, LINK, APE, NFTs, and others) as collateral, and receive any `ERC20` assets for the same. The borrower has the flexibility to provide any standard `ERC20`, `ERC721`, `ERC1155` and `CryptoKitties` token. The lender can earn interest on the asset provided. The codebase is organized in the folders, as shown in Fig. 2.

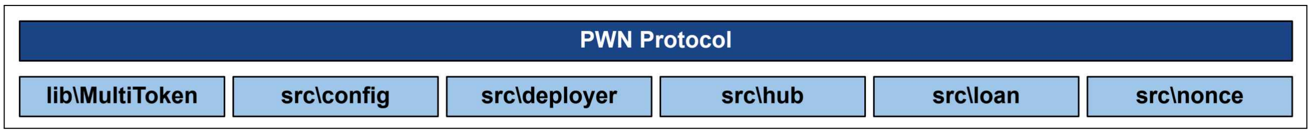


Fig. 2: Folders composing the protocol

5.1 `lib/MultiToken/MultiToken.sol`

This library provides functionalities for transferring assets of different categories. The library has the following imports.

```
import "openzeppelin-contracts/contracts/interfaces/IERC20.sol";
import "openzeppelin-contracts/contracts/interfaces/IERC721.sol";
import "openzeppelin-contracts/contracts/interfaces/IERC1155.sol";
import "openzeppelin-contracts/contracts/token/ERC20/extensions/draft-IERC20Permit.sol";
import "./interfaces/ICryptoKitties.sol";
```

Thus, we can notice that the protocol supports `ERC20, ERC721, ERC1155 and CryptoKitties` tokens, as illustrated in the `enum Category` reproduced below.

```
enum Category {
    ERC20,
    ERC721,
    ERC1155,
    CryptoKitties
}
```

Each asset is stored in the structure `Asset` reproduced below. The field `category` indicates the asset category according to the `enum Category`. The field `assetAddress` indicates the contract address defining the asset. The field `id` indicates the `TokenID` when the asset is an NFT. The field `amount` indicates the number of fungible tokens.

```
struct Asset {
    Category category;
    address assetAddress;
    uint256 id;
    uint256 amount;
}
```

The transfer functionalities are implemented using the six functions listed below.

```
function transferAssetFrom(Asset memory asset, address source, address dest) internal;

function safeTransferAssetFrom(Asset memory asset, address source, address dest) internal;

function _transferAssetFrom(Asset memory asset, address source, address dest, bool isSafe) internal;

function transferAssetFromCalldata(Asset memory asset, address source, address dest, bool fromSender) pure internal
↪   returns (bytes memory);

function safeTransferAssetFromCalldata(Asset memory asset, address source, address dest, bool fromSender) pure internal
↪   returns (bytes memory);

function _transferAssetFromCalldata(Asset memory asset, address source, address dest, bool fromSender, bool isSafe)
↪   pure private returns (bytes memory);
```

The library also implements one function for granting approval via permit signature, which can be standard (65 bytes) or compact (64 bytes) defined in the `EIP-2098`.

```
function permit(Asset memory asset, address owner, address spender, bytes memory permitData) internal;
```

The balance on various token interfaces can be queried using the function `balanceOf(...)`.

```
function balanceOf(Asset memory asset, address target) internal view returns (uint256);
```

The tokens' approval can be performed using the function `approveAsset(...)`.

```
function approveAsset(Asset memory asset, address target) internal;
```

Finally, the library also has two helper functions. The function `isValid(...)` returns if a given structure `Asset` is valid or not, while the function `isSameAs(...)` returns if two assets are equal.

```
function isValid(Asset memory asset) internal pure returns (bool);

function isSameAs(Asset memory asset, Asset memory otherAsset) internal pure returns (bool);
```

5.2 Folder `src/config`

This folder holds the contract `PWNConfig.sol`, which provides configurable values for the PWN protocol. The contract has the following imports.

```
import "openzeppelin-contracts/contracts/access/Ownable.sol";
import "openzeppelin-contracts/contracts/proxy/utils/Initializable.sol";
```

The contract has three state variables. The `fee` is stored as an `uint16` having the precision of two decimal digits, i.e., the value 100 indicates 1% of `fee`. All the fees collected by the protocol are sent to the `feeCollector` address. The contract also stores one mapping that relates the `loan contract address` to the `loan token metadata uri`. These state variables are reproduced below.

```
uint16 public fee;
address public feeCollector;
mapping (address => string) public loanMetadataUri;
```

The contract provides initialization and re-initialization functionalities. Fees management is performed using the function `setFee(...)`, while the fees collector is set using the function `setFeeCollector(...)`. Both functions can only be called by the contract owner.

```
function setFee(uint16 _fee) external onlyOwner;

function _setFee(uint16 _fee) private;

function setFeeCollector(address _feeCollector) external onlyOwner;

function _setFeeCollector(address _feeCollector) private;
```

The contract also has the function `setLoanMetadataUri(...)`, which assigns a `metadataUri` to a `loanContract`, only callable by the contract owner.

```
function setLoanMetadataUri(address loanContract, string memory metadataUri) external onlyOwner;
```

5.3 Folder `src/deployer`

This folder has two contracts: a) `PWNContractDeployerSalt.sol`; and, b) `PWNDeployer.sol`. The contract `PWNContractDeployerSalt.sol` is only a placeholder for constants used by the PWN protocol, while the contract `PWNDeployer.sol` presents the logic for deploying a release of the protocol. The contract `PWNDeployer.sol` has the following imports.

```
import "openzeppelin-contracts/contracts/access/Ownable.sol";
import "openzeppelin-contracts/contracts/utils/Create2.sol";
```

The contract offers three functions. The function `deploy(...)` receives the bytecode and the salt for deploying a new contract at a deterministic address. The address where the contract will be deployed can be queried using the function `computeAddress(...)`. In addition, the contract also offers the function `deployAndTransferOwnership(...)` that performs the deployment and transfers the ownership to the owner.

```
function deploy(bytes32 salt, bytes memory bytecode) external onlyOwner returns (address);

function deployAndTransferOwnership(bytes32 salt, address owner, bytes memory bytecode) external onlyOwner returns
    ↪ (address deployedContract);

function computeAddress(bytes32 salt, bytes32 bytecodeHash) external view returns (address);
```

5.4 Folder src/hub

This folder has three contracts. The contract PWNHubTags.sol is just a placeholder for constants. The contract PWNHub.sol connects the PWN contracts into the protocol. The contract PWNHubAccessControl.sol is an abstract contract that implements access control modifiers for the PWN Hub.

5.4.1 PWNHubAccessControl.sol

The abstract contract PWNHubAccessControl.sol has the following imports.

```
import "@pwn/hub/PWNHub.sol";
import "@pwn/hub/PWNHubTags.sol";
import "@pwn/PWNErrors.sol";
```

The contract has only one storage variable, which is immutable. This variable is set in the constructor(...) to the address of the contract PWNHub.sol.

```
PWNHub immutable internal hub;

constructor(address pwnHub) {
    hub = PWNHub(pwnHub);
}
```

The contract also has two modifiers. The modifier onlyActiveLoan() checks if msg.sender has the tag PWNHubTags.ACTIVE_LOAN, while the modifier onlyWithTag(bytes32 tag) checks if msg.sender has the tag specified as an argument. Both modifiers are presented below.

```
modifier onlyActiveLoan() {
    if (hub.hasTag(msg.sender, PWNHubTags.ACTIVE_LOAN) == false)
        revert CallerMissingHubTag(PWNHubTags.ACTIVE_LOAN);
    _;
}
```

```
modifier onlyWithTag(bytes32 tag) {
    if (hub.hasTag(msg.sender, tag) == false)
        revert CallerMissingHubTag(tag);
    _;
}
```

5.4.2 PWNHubTags.sol

The list of tags can be found in the library PWNHubTags.sol. The tags are: ACTIVE_LOAN, SIMPLE_LOAN_TERMS_FACTORY, LOAN_REQUEST, LOAN_OFFER, as reproduced below.

```
library PWNHubTags {
    string internal constant VERSION = "1.0";

    /// @dev Address can mint LOAN tokens and create LOANs via loan factory contracts.
    bytes32 internal constant ACTIVE_LOAN = keccak256("PWN_ACTIVE_LOAN");

    /// @dev Address can be used as a loan terms factory for creating simple loans.
    bytes32 internal constant SIMPLE_LOAN_TERMS_FACTORY = keccak256("PWN_SIMPLE_LOAN_TERMS_FACTORY");

    /// @dev Address can revoke loan request nonces.
    bytes32 internal constant LOAN_REQUEST = keccak256("PWN_LOAN_REQUEST");
    /// @dev Address can revoke loan offer nonces.
    bytes32 internal constant LOAN_OFFER = keccak256("PWN_LOAN_OFFER");
}
```

5.4.3 PWNHub.sol

The contract PWNHub.sol has the following imports:

```
import "openzeppelin-contracts/contracts/access/Ownable.sol";
import "@pwn/PWNErrors.sol";
```

The contract has only one storage variable that maps the contract address and a tag to a boolean value indicating if the tag is true or false.

```
mapping (address => mapping (bytes32 => bool)) private tags;
```

The contract has only three functions: a) `setTag(...)`; b) `setTags(...)`; and, c) `hasTag(...)`. The function `setTag(address _address, bytes32 tag, bool _hasTag)` receives as arguments the `_address`, the `tag`, and the Boolean `_hasTag`value indicating if that given address has the tag or not. The function can only be called by the contract `owner`.

```
function setTag(address _address, bytes32 tag, bool _hasTag) public onlyOwner {}
```

The function `setTags(...)` iterates over an array of addresses and tags, calling the function `setTag(...)`.

```
function setTags(address[] memory _addresses, bytes32[] memory _tags, bool _hasTag) external onlyOwner {}
```

Finally, the contract also has the function `hasTag(...)`, which is a standard getter function.

```
function hasTag(address _address, bytes32 tag) external view returns (bool) {}
```

5.5 Folder `src/loan`

5.5.1 `PWNVault.sol`

This is implemented as an abstract contract that is the basis for transferring and managing collateral and loan assets in the PWN protocol. It contains transfer functions, hooks, and interface checks. The transfer functions rely on the `MultiToken.sol` implementation.

```
using MultiToken for MultiToken.Asset;
```

The internal function `_pull(...)` transfers the assets into the vault.

```
function _pull(MultiToken.Asset memory asset, address origin) internal {}
```

The function `_push(...)` pushes the asset from the vault to a given recipient.

```
function _push(MultiToken.Asset memory asset, address beneficiary) internal {}
```

The function `_pushFrom(...)` transfers an asset from a lender to a borrower.

```
function _pushFrom(MultiToken.Asset memory asset, address origin, address beneficiary) internal {}
```

The function `_permit(...)` sets the vault allowance for an asset using a signed permit.

```
function _permit(MultiToken.Asset memory asset, address origin, bytes memory permit) internal {}
```

The contract also implements `receive hooks` for the `ERC721` and `ERC1155`.

```
function onERC721Received(
    address operator,
    address /*from*/,
    uint256 /*tokenId*/,
    bytes calldata /*data*/
) override external view returns (bytes4) {}
```

```
function onERC1155Received(
    address operator,
    address /*from*/,
    uint256 /*id*/,
    uint256 /*value*/,
    bytes calldata /*data*/
) override external view returns (bytes4) {}
```

The function `onERC1155BatchReceived(...)` is not supported in this version of Vault and is reverted, as shown below.

```
function onERC1155BatchReceived(
    address /*operator*/,
    address /*from*/,
    uint256[] calldata /*ids*/,
    uint256[] calldata /*values*/,
    bytes calldata /*data*/
) override external pure returns (bytes4) {
    revert UnsupportedTransferFunction();
}
```

Finally, the contract implements the function `supportsInterface(...)` to return the supported interfaces

```
function supportsInterface(bytes4 interfaceId) external pure virtual override returns (bool) {}
```

5.5.2 lib/PWNFeeCalculator.sol

The library has only one function responsible for computing the fee amount. The function is shown below.

```
function calculateFeeAmount(uint16 fee, uint256 loanAmount) internal pure returns (uint256 feeAmount, uint256
↪ newLoanAmount) {}
```

5.5.3 lib/PWNSignatureChecker.sol

The library has only one function responsible for checking the signature using the standard (65 bytes) or compact (64 bytes) defined by `EIP-2098`.

```
function isValidSignatureNow( address signer, bytes32 hash, bytes memory signature ) internal view returns (bool) {}
```

5.5.4 token/PWNLOAN.sol

The contract `PWNLOAN.sol` inherits from `PWNHubAccessControl, IERC5646 and ERC721`, and has the following imports:

```
import "openzeppelin-contracts/contracts/token/ERC721/ERC721.sol";
import "@pwn/hub/PWNHubAccessControl.sol";
import "@pwn/loan/token/IERC5646.sol";
import "@pwn/loan/token/IPWNLoanMetadataProvider.sol";
import "@pwn/PWNErrors.sol";
```

The contract has two storage variables that track the last loan id, and the mapping from the loan id to the loan contract.

```
uint256 public lastLoanId;
mapping (uint256 => address) public loanContract;
```

The contract has five functions: a) `mint(...)`; b) `burn(...)`; c) `tokenURI(...)`; d) `getStateFingerPrint(...)`; and e) `supportsInterface(...)`. The function `mint(...)` and `burn(...)` are used to create and delete `LOAN` Tokens for a particular `owner` based on a certain `loanId`.

```
function mint(address owner) external onlyActiveLoan returns (uint256 loanId) {}

function burn(uint256 loanId) external {}
```

The function `tokenURI(...)` returns the `LOAN` Token Metadata URI.

```
function tokenURI(uint256 tokenId) public view virtual override returns (string memory) {}
```

The function `getStateFingerprint(...)` is used to return the current token state fingerprint defined by `EIP-5646`.

```
function getStateFingerprint(uint256 tokenId) external view virtual override returns (bytes32) {}
```

And the final function `supportsInterface(...)` which checks if the provided `interfaceId` is valid, along with if the `interfaceId` is the same interface id of `ERC5646`.

```
function supportsInterface(bytes4 interfaceId) public view virtual override returns (bool) {}
```

5.5.5 `terms/PWNLOANTerms.sol`

The library has only one structure `Simple` which defines the terms of a simple loan.

```
struct Simple {
    address lender;
    address borrower;
    uint40 expiration;
    bool lateRepaymentEnabled;
    MultiToken.Asset collateral;
    MultiToken.Asset asset;
    uint256 loanRepayAmount;
}
```

5.5.6 `terms/simple/loan/PWNSimpleLoan.sol`

The contract `PWNSimpleLoan.sol` inherits from `PWNVault, IERC5646 IPWNLoanMetadataProvider`, and has the following imports:

```
import "MultiToken/MultiToken.sol";
import "@pwn/config/PWNConfig.sol";
import "@pwn/hub/PWNHub.sol";
import "@pwn/hub/PWNHubTags.sol";
import "@pwn/loan/lib/PWNFeeCalculator.sol";
import "@pwn/loan/terms/PWNLOANTerms.sol";
import "@pwn/loan/terms/simple/factory/IPWNSimpleLoanTermsFactory.sol";
import "@pwn/loan/token/IERC5646.sol";
import "@pwn/loan/token/PWNLOAN.sol";
import "@pwn/loan/PWNVault.sol";
import "@pwn/PWNErrors.sol";
```

The contract has three `immutable` storage and a `mapping`. The `mapping` stores all the data of a Loan based on a loan id.

```
PWNHub immutable internal hub;
PWNLOAN immutable internal loanToken;
PWNConfig immutable internal config;
mapping (uint256 => LOAN) private LOANs;
```

It also contains a structure `LOAN`, which defines a simple loan.

```
struct LOAN {
    uint8 status;
    address borrower;
    uint40 expiration;
    bool lateRepaymentEnabled;
    address loanAssetAddress;
    uint256 loanRepayAmount;
    MultiToken.Asset collateral;
}
```

The contract has mainly four state-changing `external` functions: a) `createLOAN(...)`; b) `repayLOAN(...)`; c) `claimLOAN(...)`; and d) `enableLOANLateRepayment(...)`.

The function `createLOAN(...)` is used to create a Loan with particular collateral and asset. `loanTerms` are taken from a `loanTermsFactoryContract` specified in the calldata. Collateral is checked for validity, and then `LOAN` Token is minted to the lender. Collateral is transferred to the Loan Contract, the fee is read from `config`, and the corresponding fee is transferred to the `feeCollector`, and the rest of the amount is transferred to the `borrower`.

```
function createLOAN(
    address loanTermsFactoryContract,
    bytes calldata loanTermsFactoryData,
    bytes calldata signature,
    bytes calldata loanAssetPermit,
    bytes calldata collateralPermit
) external returns (uint256 loanId) {}
```

The function `repayLOAN` is used by the `borrower` to repay the LOAN with a particular `loanId`. `loanId` is checked for existence and invalid loan status. It is ensured that the loan has not expired, and if it has expired, it is checked if later repayment is enabled. If all conditions are satisfied, the loan is repaid to the Loan Contract, and the collateral from Loan Contract is returned to the `borrower`.

```
function repayLOAN(
    uint256 loanId,
    bytes calldata loanAssetPermit
) external {}
```

The function `claimLOAN` is used by the `lender` to claim the loan proceeds with a particular `loanId`. Only the owner of the `LOAN` Token with the same `loanId` passed as calldata can call this function. The loan status is checked for mainly three cases: (a) Existence; (b) Repaid Loan; and (c) Expired Loan. In case (a), the call reverts. In case (b), the `LOAN` Token is burned from the `caller`, and the asset, along with interest, is paid back to the `caller`. In case (c), the `LOAN` Token is burned from the `caller`, and the collateral is sent to the `caller`.

```
function claimLOAN(uint256 loanId) external {}
```

The function `enableLOANLateRepayment` is used by the `lender` to allow late payment for a particular `loanId`. Only the owner of the `LOAN` Token with the same `loanId` passed as calldata can call this function. The call will revert if late repayment is already enabled. The loan has to be ongoing for this call to succeed.

```
function enableLOANLateRepayment(uint256 loanId) external {}
```

5.5.7 `terms/simple/factory/request/PWNSimpleLoanSimpleRequest.sol`

The contract `PWNSimpleLoanSimpleRequest.sol` inherits from `PWNSimpleLoanRequest`, and has the following imports:

```
import "MultiToken/MultiToken.sol";
import "@pwn/loan/lib/PWNSignatureChecker.sol";
import "@pwn/loan/terms/simple/factory/request/base/PWNSimpleLoanRequest.sol";
import "@pwn/loan/terms/PWNLOANTerms.sol";
import "@pwn/PWNErrors.sol";
```

The contract has two `constant` and one `immutable` storage, which stores the version, request typehash, and domain separator.

```
string internal constant VERSION = "1.0";
bytes32 constant internal REQUEST_TYPEHASH = keccak256(
    "Request(uint8 collateralCategory,address collateralAddress,uint256 collateralId,uint256 collateralAmount,address
 ↪  loanAssetAddress,uint256 loanAmount,uint256 loanYield,uint32 duration,uint40 expiration,address borrower,address
 ↪  lender,bool lateRepaymentEnabled,uint256 nonce)"
);
bytes32 immutable internal DOMAIN_SEPARATOR;
```

It also contains a structure `Request`, which defines a simple request.

```
struct Request {
    MultiToken.Category collateralCategory;
    address collateralAddress;
    uint256 collateralId;
    uint256 collateralAmount;
    address loanAssetAddress;
    uint256 loanAmount;
    uint256 loanYield;
    uint32 duration;
    uint40 expiration;
    address borrower;
    address lender;
    bool lateRepaymentEnabled;
    uint256 nonce;
}
```

The contract has mainly two state-changing `external` functions: a) `makeRequest(...)`; b) `createLOANTerms(...)`. The function `makeRequest()` creates an on-chain request. It has a calldata `request` which contains all the details of the loan request as a structure parameter. The function `createLOANTerms(...)` creates a simple loan term from the provided info as calldata. The `request` data is decoded from `factoryData`, and the `signature` is checked for validity, ensuring that the request is not expired already and no revoke is initiated for the particular `request`. As this is a `request`, the lender cannot be a zero address. If every check is passed, a `loanTerms` is created and returned with this function call.

```
function makeRequest(Request calldata request) external {}

function createLOANTerms(
    address caller,
    bytes calldata factoryData,
    bytes calldata signature
) external override onlyActiveLoan returns (PWNLOANTerms.Simple memory loanTerms) {}
```

5.5.8 `terms/simple/factory/request/base/PWNSimpleLoanRequest.sol`

The abstract contract `PWNSimpleLoanRequest.sol` inherits from `IPWNSimpleLoanTermsFactory` and `PWNHubAccessControl`, and has the following imports:

```
import "@pwn/hub/PWNHubAccessControl.sol";
import "@pwn/loan/terms/simple/factory/IPWNSimpleLoanTermsFactory.sol";
import "@pwn/nonce/PWNRevokedNonce.sol";
import "@pwn/PWNErrors.sol";
```

The contract has one `immutable` storage and mapping, which stores the revoked request nonces and `bool` status of requests made.

```
PWNRevokedNonce immutable internal revokedRequestNonce;
mapping (bytes32 => bool) public requestsMade;
```

The contract has mainly one state-changing `external` function `revokeRequestNonce(...)`. The function `revokeRequestNonce(...)` revokes the nonce of the caller.

```
function revokeRequestNonce(uint256 requestNonce) external {}
```

5.5.9 `terms/simple/factory/offer/PWNSimpleLoanListOffer.sol`

The contract `PWNSimpleLoanListOffer.sol` inherits from `PWNSimpleLoanOffer`, and has the following imports:

```
import "MultiToken/MultiToken.sol";
import "openzeppelin-contracts/contracts/utils/cryptography/MerkleProof.sol";
import "@pwn/loan/lib/PWNSignatureChecker.sol";
import "@pwn/loan/terms/simple/factory/offer/base/PWNSimpleLoanOffer.sol";
import "@pwn/loan/terms/PWNLOANTerms.sol";
import "@pwn/PWNErrors.sol";
```

The contract has two `constant` and one `immutable` storage, which stores the version, and offers typehash and domain separator.

```
string internal constant VERSION = "1.0";
bytes32 constant internal OFFER_TYPEHASH = keccak256(
    "Offer(uint8 collateralCategory,address collateralAddress,bytes32 collateralIdsWhitelistMerkleRoot,uint256
↪   collateralAmount,address loanAssetAddress,uint256 loanAmount,uint256 loanYield,uint32 duration,uint40
↪   expiration,address borrower,address lender,bool isPersistent,bool lateRepaymentEnabled,uint256 nonce)"
);
bytes32 immutable internal DOMAIN_SEPARATOR;
```

It also contains the structure `Request`, which defines a simple list offer.

```
struct Offer {
    MultiToken.Category collateralCategory;
    address collateralAddress;
    bytes32 collateralIdsWhitelistMerkleRoot;
    uint256 collateralAmount;
    address loanAssetAddress;
    uint256 loanAmount;
    uint256 loanYield;
    uint32 duration;
    uint40 expiration;
    address borrower;
    address lender;
    bool isPersistent;
    bool lateRepaymentEnabled;
    uint256 nonce;
}
```

And another structure `OfferValues`, which defines Offer values.

```
struct OfferValues {
    uint256 collateralId;
    bytes32[] merkleInclusionProof;
}
```

The contract has mainly two state-changing `external` functions: a) `makeOffer(...)`; b) `createLOANTerms(...)`. The function `makeOffer(...)` creates an on-chain offer. It has a calldata `offer`, which contains all the details of the loan offer as a structure parameter. The function `createLOANTerms(...)` creates a simple loan term from the provided info as calldata. The `offer and offerValues` data is decoded from `factoryData`, and the `signature` is checked for validity, ensuring that the offer is not expired already. No revoke is initiated for the particular `offer`, and in this case, it is also checked that the collateral is verified. As this is a `offer`, the borrower cannot be a zero address. If every check is passed, a `loanTerms` is created and returned with this function call.

```
function makeOffer(Offer calldata offer) external {}

function createLOANTerms(
    address caller,
    bytes calldata factoryData,
    bytes calldata signature
) external override onlyActiveLoan returns (PWNLOANTerms.Simple memory loanTerms) {}
```

5.5.10 `terms/simple/factory/offer/PWNSimpleLoanSimpleOffer.sol`

The contract `PWNSimpleLoanSimpleOffer.sol` inherits from `PWNSimpleLoanOffer`, and has the following imports:

```
import "MultiToken/MultiToken.sol";
import "@pwn/loan/lib/PWNSignatureChecker.sol";
import "@pwn/loan/terms/simple/factory/offer/base/PWNSimpleLoanOffer.sol";
import "@pwn/loan/terms/PWNLOANTerms.sol";
import "@pwn/PWNErrors.sol";
```

The contract has two `constant` and one `immutable` storage, which stores the version, offer typehash and domain separator.

```
string internal constant VERSION = "1.0";
bytes32 constant internal OFFER_TYPEHASH = keccak256(
    "Offer(uint8 collateralCategory,address collateralAddress,uint256 collateralId,uint256 collateralAmount,address
↪   loanAssetAddress,uint256 loanAmount,uint256 loanYield,uint32 duration,uint40 expiration,address borrower,address
↪   lender,bool isPersistent,bool lateRepaymentEnabled,uint256 nonce)"
);
bytes32 immutable internal DOMAIN_SEPARATOR;
```

It also contains a structure `Request`, which defines a simple list offer.

```
struct Offer {
    MultiToken.Category collateralCategory;
    address collateralAddress;
    uint256 collateralId;
    uint256 collateralAmount;
    address loanAssetAddress;
    uint256 loanAmount;
    uint256 loanYield;
    uint32 duration;
    uint40 expiration;
    address borrower;
    address lender;
    bool isPersistent;
    bool lateRepaymentEnabled;
    uint256 nonce;
}
```

The contract has mainly two state-changing `external` functions: a) `makeOffer(...)`; b) `createLOANTerms(...)`. The function `makeOffer(...)` creates an on-chain offer. It has a calldata `offer`, which contains all the details of the loan offer as a struct parameter. The function `createLOANTerms(...)` creates a simple loan term from the provided info as calldata. The `offer and offerValues` data is decoded from `factoryData`, the `signature` is checked for validity, ensured that the offer is not expired already and no revoke is initiated for the particular `offer`. As this is a `offer`, the borrower cannot be a zero address. If every check is passed, a `loanTerms` is created and returned with this function call.

```
function makeOffer(Offer calldata offer) external {}

function createLOANTerms(
    address caller,
    bytes calldata factoryData,
    bytes calldata signature
) external override onlyActiveLoan returns (PWNLOANTerms.Simple memory loanTerms) {}
```

5.5.11 `terms/simple/factory/offer/base/PWNSimpleLoanOffer.sol`

The abstract contract `PWNSimpleLoanOffer.sol` inherits from `IPWNSimpleLoanTermsFactory and PWNHubAccessControl`, and has the following imports:

```
import "@pwn/hub/PWNHubAccessControl.sol";
import "@pwn/loan/terms/simple/factory/IPWNSimpleLoanTermsFactory.sol";
import "@pwn/nonce/PWNRevokedNonce.sol";
import "@pwn/PWNErrors.sol";
```

The contract has one `immutable` storage and mapping, which stores the revoked offer nonces and `bool` status of offers made.

```
PWNRevokedNonce immutable internal revokedOfferNonce;
mapping (bytes32 => bool) public offersMade;
```

The contract has mainly one state-changing `external` function `revokeOfferNonce(...)`. The function `revokeOfferNonce(...)` revokes the nonce of the caller.

```
function revokeOfferNonce(uint256 offerNonce) external {}
```

5.6 Folder `src/nonce`

This folder has only the contract `PWNRevokedNonce.sol` which inherits `PWNHubAccessControl`. This contract has the following imports.

```
import "@pwn/hub/PWNHubAccessControl.sol";
import "@pwn/PWNErrors.sol";
```

The contract has three storage variables: a) `accessTag`; b) `revokedNonces`; c) `minNonces`, which stores the tag, revoked nonces and minimum nonce value for a particular address.

```
bytes32 immutable internal accessTag;
mapping (address => mapping (uint256 => bool)) private revokedNonces;
mapping (address => uint256) private minNonces;
```

The contract has mainly three state-changing `external` functions: a)`revokeNonce(...)`; b)`revokeNonce(...)` (Different parameters); c)`setMinNonce(...)`. Both the function `revokeNonce(...)` is used to revoke a particular nonce of a certain owner. In the first function, it can be used by any caller to revoke the nonce of itself, and in the second function, it can be used by any caller, which has the required `accessTag`. The function `setMinNonce(...)` is used to set a minimum nonce value for that particular caller. Any `nonce` smaller than the `minNonce` is considered revoked.

```
function revokeNonce(uint256 nonce) external {}
function revokeNonce(address owner, uint256 nonce) external onlyWithTag(accessTag) {}
function setMinNonce(uint256 minNonce) external {}
```

Fig. 3 shows the structural diagram of the protocol, highlighting the borrow and lend use cases.

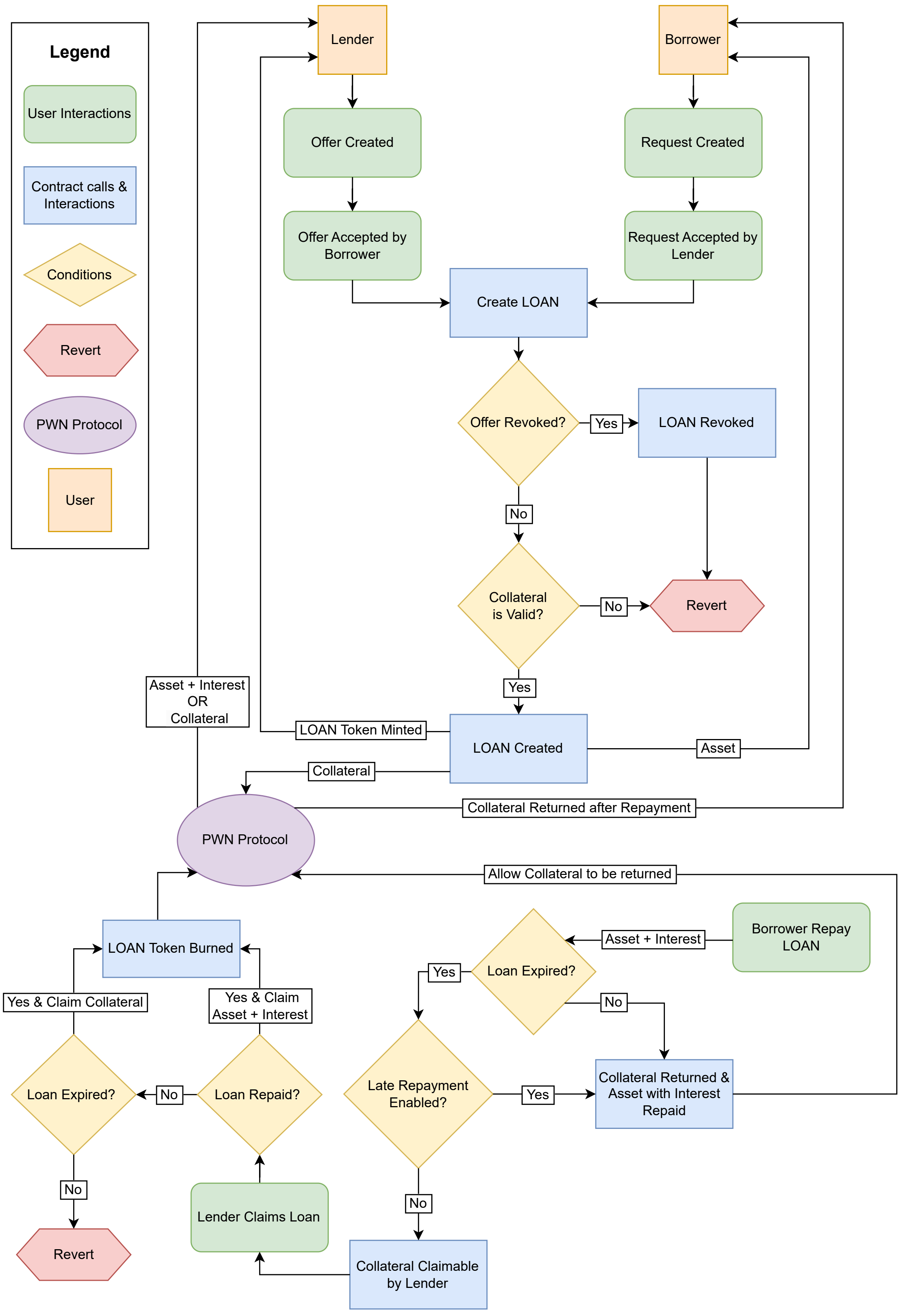


Fig. 3: Borrow and Lend protocol flow

6 Risk Rating Methodology

The risk rating methodology used by Nethermind follows the principles established by the OWASP Foundation. The severity of each finding is determined by two factors: **Likelihood** and **Impact**.

Likelihood measures how likely the finding is to be uncovered and exploited by an attacker. This factor will be one of the following values:

a) **High**: The issue is trivial to exploit and has no specific conditions that need to be met;

b) **Medium**: The issue is moderately complex and may have some conditions that need to be met;

c) **Low**: The issue is very complex and requires very specific conditions to be met.

When defining the likelihood of a finding other factors are also considered. These can include but are not limited to: Motive, opportunity, exploit accessibility, ease of discovery, and ease of exploit.

Impact is a measure of the damage that may be caused if the finding were to be exploited by an attacker. This factor will be one of the following values:

a) **High**: The issue can cause significant damage such as loss of funds or the protocol entering an unrecoverable state;

b) **Medium**: The issue can cause moderate damage such as impacts that only affect a small group of users or only a particular part of the protocol;

c) **Low**: The issue can cause little to no damage such as bugs that are easily recoverable or cause unexpected interactions that cause minor inconveniences.

When defining the impact of a finding other factors are also considered. These can include but are not limited to Data/state integrity, loss of availability, financial loss, and reputation damage. After defining the likelihood and impact of an issue, the severity can be determined according to the table below.

		Severity Risk		
Impact	**High**	Medium	High	Critical
	Medium	Low	Medium	High
	Low	Info/Best Practices	Low	Medium
	Undetermined	Undetermined	Undetermined	Undetermined
		Low	**Medium**	**High**
		Likelihood		

To address issues that do not fit a High/Medium/Low severity, Nethermind also uses three more finding severities: **Informational**, **Best Practices**, and **Undetermined**.

a) **Informational** findings do not pose any risk to the application, but they carry some information that the audit team intends to pass to the client formally;

b) **Best Practice** findings are used when some piece of code does not conform with smart contract development best practices;

c) **Undetermined** findings are used when we cannot predict the impact or likelihood of the issue.

7 Issues

7.1 [High] "No Revert on Failure" tokens can be used to steal from lender

File(s): pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol

Description: Some ERC20 tokens don't revert on failure but return false instead. Posting a request with such a token as collateral but with an incorrect asset type (ERC721 or CryptoKitties) may be used to create a loan for which no collateral is transferred. A good example of such a token is ZRX: Etherscan code.

Exploit Scenario:

– Alice posts a loan request with ZRX as collateral, but with ERC721 type. Alice does not have any ZRX tokens;
– Bob creates a loan from Alice's request;
– On loan creation, Bob's loan assets are transferred to Alice. However, Alice's collateral is not transferred since Alice has no ZRX token. The ZRX.transferFrom(...) does not revert but returns false;
– The function _transferAssetFrom(...) does not check the return value for the CryptoKitties type, so the failed transfer ICryptoKitties(ZRX).transferFrom(...) will silently return;
– Bob lent assets to Alice, but Alice did not provide any collateral.

The function is shown below.

```
function transferFrom(address _from, address _to, uint _value) returns (bool) {
    if (balances[_from] >= _value && allowed[_from][msg.sender] >= _value && balances[_to] + _value >= balances[_to]) {
        balances[_to] += _value;
        balances[_from] -= _value;
        allowed[_from][msg.sender] -= _value;
        Transfer(_from, _to, _value);
        return true;
    } else { return false; }
}
```

Recommendation(s): Check asset balance differences before and after each transfer.

Status: Fixed

Update from the client: Fixed by checking asset category in the isValid function of the MultiToken library.

Relevant commits:

– 3139c5745edd73313e7b7381378209f6f134b21d (category check);
– e5078eff465c2b53d0da0428ed46ebf1d102ff52 (gas optimisation).

Update from Nethermind: We agree with the checks added to the function isValid(...) in commit e5078ef. However, it does not consider tokens that support ERC165 but are not ERC721, ERC1155, or CryptoKitties. In the future, such tokens may become popular and be used with assert.category = ERC20. To address this issue, we recommend verifying that the asset interface id is ERC20 if it supports the ERC165 standard. This solution would resolve the aforementioned problem while also allowing potential ERC20 assets that implement ERC165.

Update from the client after Reaudit: Fixed by checking for support of IERC20 interface id (0x36372b07) in case where ERC20 asset implements ERC165.

Relevant commits:

– a2971be1ee44a4cd49c2d9f5a88830cce9560a6b.

7.2 [High] Borrower can steal lender's assets by using WETH as collateral

File(s): pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol

Description: The borrower can create a request with the correct amount of the WETH token as collateral but with collateralCategory = ERC1155 to steal the lender's funds. The types of collateral are checked with isValid(...), but the ERC1155 is not checked in that function, which effectively allows the creation of an object with an asset of category ERC1155 but with a WETH token. When the collateral is sent from the borrower to the contract PWNSimpleLoan, the ERC1155 interface is used. However, the WETH token doesn't contain the function safeTransferFrom(...) implemented, and its fallback function will ignore any unknown function. We present the WETH fallback function below.

```
function() public payable {
    deposit();
}

function deposit() public payable {
    balanceOf[msg.sender] += msg.value;
    Deposit(msg.sender, msg.value);
}
```

Pulling collateral from the borrower will silently return with no WETH tokens transferred. Next, the loan funds from the lender will be sent to the borrower. At this point, the borrower has no incentive to return the loan since no collateral is kept in the contract.

Recommendation(s): Check the balances after transfers. Checking balances for each token type mitigates using incorrect types and ensures the transfer of correct amounts.

Status: Fixed

Update from the client: Fixed by checking asset category in the function `isValid(...)` of the MultiToken library.

Relevant commits:

- 3139c5745edd73313e7b7381378209f6f134b21d (category check);
- e5078eff465c2b53d0da0428ed46ebf1d102ff52 (gas optimisation).

Update from Nethermind: We agree with the checks added to the function `isValid(...)` in commit e5078ef. However, it does not consider tokens that support `ERC165` but are not `ERC721`, `ERC1155`, or `CryptoKitties`. In the future, such tokens may become popular and be used with `assert.category = ERC20`. To address this issue, we recommend verifying that the asset interface id is `ERC20` if it supports the `ERC165` standard. This solution would resolve the problem above while allowing potential `ERC20` assets that implement `ERC165`.

Update from the client after Reaudit: Fixed by checking for support of `IERC20` interface id (`0x36372b07`) in case where `ERC20` asset implements `ERC165`.

Relevant commits:

- a2971be1ee44a4cd49c2d9f5a88830cce9560a6b.

7.3 [Medium] Borrower can prevent the lender from receiving collateral during a claim

File(s): `pwn/src/loan/terms/simple/loan/PWNSimpleLoan.sol`

Description: During the creation, repayment, or claiming of a loan, the `MultiToken` library handles token transfers through the `_pull`, `_push`, and `_pushFrom` functions. For ERC721 token transfers, the `MultiToken` library will use `transferFrom(...)` during a token "pull" since moving tokens to itself implicitly implies that it has ERC721 support and therefore does not need to check for `onERC721Received`. During a token "push" the `safeTransferFrom` functionality is used since the recipient may not support ERC721 tokens.

```
function() public payable {
    deposit();
}

function deposit() public payable {
    balanceOf[msg.sender] += msg.value;
    Deposit(msg.sender, msg.value);
}
```

A borrower could create an order with `WETH` as collateral and specify it as an ERC721 asset type. Upon a lender accepting the loan, the `WETH` would successfully transfer to the vault, since it uses a "pull" which uses `transferFrom`. However, if the borrower decides not to repay the loan, when the lender attempts to claim the collateral, a `safeTransferFrom` is used, which will not transfer tokens. In this case, both parties will lose out on their collateral. However, the borrower will have kept the collateral, so the borrower's losses are less than the lender's. For example, with collateral of $1000 and a borrowed amount of $800, the attack would cost the borrower $200, i.e., $1000 - $800), to inflict an $800 loss (the borrowed amount) onto the lender.

Recommendation(s): Check balances after transfers. Checking balances for each token type will mitigate using incorrect types and will ensure the transfer of correct amounts.

Status: Fixed

Update from the client: Fixed by checking asset category in the `isValid` function of the MultiToken library.

Relevant commits:

- 3139c5745edd73313e7b7381378209f6f134b21d (category check);
- e5078eff465c2b53d0da0428ed46ebf1d102ff52 (gas optimisation).

Update from Nethermind: We agree with the checks added to the function `isValid(...)` in commit e5078ef. However, it does not consider tokens that support `ERC165` but are not `ERC721`, `ERC1155`, or `CryptoKitties`. In the future, such tokens may become popular and be used with `assert.category = ERC20`. To address this issue, we recommend verifying that the asset interface id is `ERC20` if it supports the `ERC165` standard. This solution would resolve the aforementioned problem while also allowing potential `ERC20` assets that implement `ERC165`.

Update from the client after Reaudit: Fixed by checking for support of `IERC20` interface id (`0x36372b07`) in case where `ERC20` asset implements `ERC165`.

Relevant commits:

- a2971be1ee44a4cd49c2d9f5a88830cce9560a6b.

7.4 [Medium] Fee-on-transfer tokens can be locked in the vault

File(s): `pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol`

Description: The loan can be created for any pair of tokens. Some tokens (e.g., `STA`, `PAX`) deduce fees during a transfer. If such tokens are used as collateral, the collateral amount registered in the object `loan` would be greater than the actual amount of tokens in the vault, which would fail while trying to withdraw the collateral. There is a second scenario where two users use the same fee-on-transfer Token as collateral, and the first one who repays the loan has a better chance of getting the entire collateral back. In contrast, the second user will not be able to recover the collateral.

Recommendation(s): Consider checking balances before and after transfers to ensure the amount of the transferred tokens is correct. This solution would, however, make fee-on-transfer tokens unusable in this protocol.

Status: Fixed

Update from the client: Fixed by checking balances before and after a transfer.

Relevant commits:

- 5d601c37b77b3eaed57903340c5e20f1d29e1b8f (new auxiliary transfer amount function);
- 0f0b2968dd5e581cdd0d18296bc01b170422767d (check invalid transfer).

7.5 [Medium] Late repayment feature could be abused by lenders to trick borrowers into losing their collateral

File(s): `pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol`

Description: In `PWNSimpleLoan`, lenders can enable late repayment to allow borrowers to repay after the loan has expired. However, this feature can also be used by lenders to trick borrowers into giving up their collateral.

Exploit Scenario:

- Alice (the lender) and Bob (the borrower) agreed on a loan Alice offered. Usually, the value of the collateral Bob deposited must be higher than the loan amount;
- Alice told Bob that she would allow him to repay the loan late by calling the function `enableLOANLateRepayment(...)`. Bob saw this and thought that Alice was being friendly and that he could repay the loan a little bit late;
- However, as soon as the loan expired, Alice called the function `claimLOAN(...)` to get all the collateral. Since the collateral value was higher than the loan, Alice made a profit;

Recommendation(s): Extend the duration of the loan to a fixed value in case the lender enables late repayment and does not allow the lender to claim the collateral before the new expiration.

Status: Fixed

Update from the client: Fixed by removing `enableLOANLateRepayment` functionality and implementing `extendLOANExpirationDate` conditions:

- extended date cannot be before the current expiration date;
- extended date cannot be before current `block.timestamp`;
- extended date cannot be further than `block.timestamp` + 30 days to protect the lender;

Relevant commits:

- 598f84ad5abfa56377bfc0a3b6d2791b16f3031b.

Update from Nethermind: In commit 598f84a, the comment regarding `loanRepayAmount` was mistakenly deleted instead of the comment about `lateRepaymentEnabled`, in the contract `PWNSimpleLoan`.

7.6 [Medium] Some common ERC20 tokens can't be used in the protocol

File(s): `MultiToken/src/MultiToken.sol`

Description: The function `_transferAssetFrom(...)` checks the return value from the `ERC20` token transfer. The code snippet is reproduced below.

```
if (asset.category == Category.ERC20) {
    if (source == address(this))
        require(IERC20(asset.assetAddress).transfer(dest, asset.amount), "MultiToken: ERC20 transfer failed");
    else
        require(IERC20(asset.assetAddress).transferFrom(source, dest, asset.amount), "MultiToken: ERC20 transferFrom
↪   failed");

}
```

That makes a problem for transferring tokens that do not return a success value. Some tokens as USDT may not be usable in the protocol, since the `require` statement would fail when no `boolean` value is returned, even if the transfer would be successful. Others as BNB, may make lenders lose their funds, below we present an exploit scenario.

Exploit Scenario:

– A loan is created with BNB as collateral;
– The lender sends loan assets to the borrower, and the borrower successfully provides BNB as collateral (`BNB.transferFrom(...)` returns `bool`);
– When the loan is repaid or expired, the collateral can't be withdrawn from the vault since the function `BNB.transfer(...)` does not return a `bool` value, and the `require` statement in `_transferAssetFrom(...)` will always fail, effectively locking `BNB` in the vault;

Recommendation(s): Consider using the `SafeERC20` library to allow transfers of `ERC20` tokens that do not return on a successful transfer.

Status: Fixed

Update from the client: Fixed by using OZ `SafeERC20` library and checking loan asset validity by the `isValid` function.

Relevant commits:

– 53205a29c572a66c60b93dc13ea4463d8d5dc52b (SafeERC20);
– bcfa846cad13682f9d4581a1bb0e2defc303c5ec (loan asset check).

7.7 [Medium] `CryptoKitties` token is locked when using it as ERC721 type collateral

File(s): `pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol`

Description: When creating a loan, the collateral token is not checked to match its category. Since `CryptoKitties` and `ERC721` share the same function `transferFrom(...)`, if the collateral token is `CryptoKitties` but the user signs it as `ERC721` category, it will successfully transfer in. However, when transferring out, `ERC721` category uses the function `safeTransferFrom(...)`, which does not exist in `CryptoKitties`. As a result, this `CryptoKitties` collateral is locked in `PWNVault`. Below we present part of the function `_transferAssetFrom(...)`, which is responsible for transferring `ERC721` assets:

```
function _transferAssetFrom(Asset memory asset, address source, address dest, bool isSafe) private {
...
    } else if (asset.category == Category.ERC721) {
        if (!isSafe)
            IERC721(asset.assetAddress).transferFrom(source, dest, asset.id);
        else
            IERC721(asset.assetAddress).safeTransferFrom(source, dest, asset.id, "");
...
}
```

Recommendation(s): We recommend to use the `ERC165` interface to verify the type of asset, as both `CryptoKitties` and `ERC721` support different interfaces.

Status: Fixed

Update from the client: Fixed by checking asset category in the `isValid` function of the MultiToken library.

Relevant commits:

- 3139c5745edd73313e7b7381378209f6f134b21d (category check);
- e5078eff465c2b53d0da0428ed46ebf1d102ff52 (gas optimisation).

Update from Nethermind: We agree with the checks added to the function `isValid(...)` in commit e5078ef. However, it does not consider tokens that support `ERC165` but are not `ERC721`, `ERC1155`, or `CryptoKitties`. In the future, such tokens may become popular and be used with `assert.category = ERC20`. To address this issue, we recommend verifying that the asset interface id is `ERC20` if it supports the `ERC165` standard. This solution would resolve the problem above, while also allowing potential `ERC20` assets that implement `ERC165`.

Update from the client after Reaudit: Fixed by checking for support of `IERC20` interface id (`0x36372b07`) in case where `ERC20` asset implements `ERC165`.

Relevant commits:

- a2971be1ee44a4cd49c2d9f5a88830cce9560a6b.

7.8 [Low] Function `calculateFeeAmount(...)` has unnecessary loss of precision

File(s): `pwn_contracts/src/loan/lib/PWNFeeCalculator.sol`

Description: The function `calculateFeeAmount(...)` is used to compute the fee amount given the loan amount and fees value in basis points. Currently in the codebase, if `loanAmount >= 1e4`, to avoid overflow in an edge-case, it does the division before the multiplication and accepts the precision loss. However, the overflow only happens when `loanAmount*fee` overflows, i.e., `loanAmount >= 1e73` in case `fee = 1e4`, which is much less likely to happen compared to `loanAmount >= 1e4` in the current codebase.

```
function calculateFeeAmount(uint16 fee, uint256 loanAmount) internal pure returns (uint256 feeAmount, uint256
↪ newLoanAmount) {
    if (loanAmount < 1e4)
        feeAmount = loanAmount * uint256(fee) / 1e4;
    else
        feeAmount = loanAmount / 1e4 * uint256(fee);

    newLoanAmount = loanAmount - feeAmount;
}
```

Recommendation(s): Consider changing the check to reduce loss of precision. For example, `(loanAmount * fee) / fee == loanAmount`. With this check, in case `loanAmount * fee` overflows, it cannot get the same `loanAmount` if divided by `fee`. Or consider only using the first formula since no token is not malicious but has `1e73` tokens in the circulating supply.

```
function calculateFeeAmount(uint16 fee, uint256 loanAmount) internal pure returns (uint256 feeAmount, uint256
↪ newLoanAmount) {
    unchecked {
        if ((loanAmount * fee) / fee == loanAmount)
            feeAmount = loanAmount * uint256(fee) / 1e4;
        else
            feeAmount = loanAmount / 1e4 * uint256(fee);
    }
    newLoanAmount = loanAmount - feeAmount;
}
```

Status: Fixed

Update from the client: Fixed by changing the check according to recommendations.

Relevant commits:

- 506e5e04076f28502eb7d2a7d9b63d448e9ff44f.

7.9 [Low] Malicious owner can arbitrarily change the fee to any value

File(s): `pwn_contracts/src/config/PWNConfig.sol`

Description: PWN protocol charges fees when users create loans on the platform. However, a malicious/lost private key owner can arbitrarily change the fee to any value without a timelock for users to react. Consider the scenario when a user creates a large loan with 0.1% fees. The owner can front-run to change fees to 100% right before the user's transaction is executed and steals all the assets.

```
function setFee(uint16 _fee) external onlyOwner {
    _setFee(_fee);
}

function _setFee(uint16 _fee) private {
    uint16 oldFee = fee;
    fee = _fee;
    emit FeeUpdated(oldFee, _fee);
}
```

Recommendation(s): Add an upper threshold for fees that the owner can update. You can also consider a time lock so users can have enough time to react to owner actions.

Status: Mitigated

Update from the client: `PWNConfig` will be deployed as a proxy, so any hardcoded value can be updated anytime. Nevertheless, we set the max value to 10% in combination with `TimelockController` set as a `PWNConfig` owner to make it harder for a malicious owner to execute such an attack.

Relevant commits:

– fb8561111ef7116cfa5834e67839e37a95d050d2.

7.10 [Low] Ownable contracts

File(s): `pwn_contracts/src/hub/PWNHub.sol`, `pwn_contracts/src/config/PWNConfig.sol`, `pwn_contracts/src/deployer/PWNDeployer.sol`

Description: The contracts `PWNHub`, `PWNConfig`, and `PWNDeployer` inherit from OpenZeppelin's `Ownable` contract, which provides a one-step ownership transfer. Transferring ownership in a single step is error-prone and can severely harm the protocol if a mistake happens. Additionally, those contracts inherit the function `renounceOwnership(...)`. If this function were called, those essential contracts would be unusable.

Recommendation(s): We recommend implementing a two-step process for transferring ownership, such as the propose-accept scheme. Check the `Ownable2Step.sol` contract from OpenZeppelin. Consider also disabling the function `renounceOwnership(...)` to ensure it's never called.

Status: Fixed

Update from the client: Fixed by inheriting from `Ownable2Step` in `PWNHub` and `PWNConfig`. Decided to keep simple `Ownable` for `PWNDeployer` and keep the `renounceOwnership` function active.

Relevant commits:

– f7977c1183731b3995fd1b42c84b00079ff90646 (PWNConfig update);
– 4fe0ced7e979ea57649437e16eeb75910d1e555e (PWNHub update).

7.11 [Low] `offer.duration` can be set to zero

File(s): `pwn_contracts/src/loan/terms/simple/factory/offer/PWNSimpleLoanListOffer.sol`, `pwn_contracts/src/loan/terms/simple/factory/offer/PWNSimpleLoanSimpleOffer.sol`, `pwn/src/loan/terms/simple/factory/request/PWNSimpleLoanSimpleRequest.sol`

Description: The `loanTerms.expiration` can be set to the current timestamp if the `offer.duration` is zero. This will allow the lender to force claim the collateral after fulfilling the request. The code snippet is reproduced below.

```
...
expiration: uint40(block.timestamp) + offer.duration,
...
```

Recommendation(s): Ensure that `offer.duration` exceeds zero. The lowest value could be around one block time.

Status: Fixed

Update from the client: Set min loan duration to 10 min.

Relevant commits:

– 5c712e486411615ec3ac133a8a5591cd302beaad (revert on 0);
– 53786f804ed4641eae96dc5ef1e376491a9a4f16 (set min 10 min duration).

7.12 [Info] Fee Collector can be set to `address(0x0)` in function `setFeeCollector(...)`

File(s): `pwn_contracts/src/config/PWNConfig.sol`

Description: The function `setFeeCollector(...)` is designed to set a new address for the fee collector. However, the function does not check the new address for `address(0x0)`, which can lead to asset loss. The function is reproduced below.

```
function setFeeCollector(address _feeCollector) external onlyOwner {
    _setFeeCollector(_feeCollector);
}

function _setFeeCollector(address _feeCollector) private {
    ////////////////////////////////////////////////////////////
    // @audit Not checking "_feeCollector" for "address(0x0)".
    ////////////////////////////////////////////////////////////
    address oldFeeCollector = feeCollector;
    feeCollector = _feeCollector;
    emit FeeCollectorUpdated(oldFeeCollector, _feeCollector);
}
```

Recommendation(s): Although the function is `onlyOwner`, checking the `_feeCollector` for `address(0x0)` can prevent typos and fund losses.

Status: Fixed

Update from the client: Check for the zero address before setting the new fee collector address.

Relevant commits:

– 1a55bd8e36ed9e2b9b6ceb81143d4eaa3bf29c99.

7.13 [Info] Token that reverts on zero-value transfers can cause `createLoan(...)` to fail when transferring fees

File(s): `pwn_contracts/src/loan/terms/simple/loan/PWNSimpleLoan.sol`

Description: Some tokens (e.g., `LEND`) revert when transferring a zero-value amount. If `feeAmount` is rounded to zero for a small loan, it can cause `createLoan(...)` to fail, meaning users cannot create loans with some tokens.

```
// Transfer fee amount to fee collector
////////////////////////////////////////////////////////////
// @audit Transferring a zero amount can fail for some tokens
////////////////////////////////////////////////////////////
loanTerms.asset.amount = feeAmount;
_pushFrom(loanTerms.asset, loanTerms.lender, config.feeCollector());
```

Recommendation(s): Only perform transfers when the amount is larger than zero.

Status: Fixed

Update from the client: Fixed by only transferring the fee when the amount is >0.

Relevant commits:

– adcdd70167db89a95c9f73655bec8b1fc36a17fb;

7.14 [Best Practices] Unlocked Pragma

File(s): `MultiToken/src/MultiToken.sol`

Description: The contract uses unlocked pragma `^0.8.0`. A better approach is to stick to a single Solidity version, ensuring the protocol works in that context. The solidity compiler frequently has new versions, and using an old version prevents access to new Solidity security checks. Also, notice that some versions are more stable than others.

Recommendation(s): Lock the pragma to version `0.8.16` and use this version for deploying the contract. For more information, please check this reference.

Status: Acknowledged

Update from the client: Acknowledged. Nevertheless, the MultiToken lib is used in more projects which do not share the same pragma version. We've decided to keep the unlocked pragma.

8 Documentation Evaluation

Technical documentation is created to explain what the software product does. This way, developers and stakeholders can easily follow the purpose and the underlying functionality of each file/function/line. Documentation can come not only in the form of a `README.md`, but also using code as documentation (to write clear code), diagrams, websites, research papers, videos, and external documentation. Besides being a good programming practice, proper technical documentation improves the efficiency of audits. Less time can be spent understanding the protocol and more time can be put towards auditing which improves the efficiency and overall output of the audit.

The `PWN` team provided developer documents to assist the audit process, describing `MultiToken` library, the `PWN Vault` and `PWN Loan` contracts and a diagram describing the protocol flow. These documents covered the most common terms used in the source code, explanations for the core business logic, and functions flow. By reading the whole developer documentation, we could get a proper understanding of how *PWN Vault* and *PWN Loan* contracts should operate. **The provided documentation is a complete source of resources for developers and auditors, and we are satisfied with it. The codebase has sufficient inline comments, helping the audit team to understand the function flow and to detect some issues**.

8.1 Documentation inconsistencies

Along this investigation, we noticed some areas in the code where the implementation differs from the specification and/or inline comments. Consider updating either the implementation or the documentation to match each other based on the correct business logic.

8.1.1 Documentation about `ERC721` does not match implementation

The function `isValid(...)` in the contract library `MultiToken` assures that the amount of the `ERC721` token must be `0`. However, in the developer documentation it is stated that the `collateralAmount` for `ERC721` asset must be `1`.

8.1.2 Documentation about `onERC1155BatchReceived(...)` does not match implementation

The documentation in contract `PWNVault` mentions that in order for the batch transfer to be accepted, the `onERC1155BatchReceived(...)` should return its own function selector. But it reverts directly with a custom error message.

```
/**
 * @dev Handles the receipt of a multiple ERC1155 token types. This function
 * is called at the end of a `safeBatchTransferFrom` after the balances have
 * been updated. To accept the transfer(s), this must return
 * `bytes4(keccak256("onERC1155BatchReceived(address,address,uint256[],uint256[],bytes)"))`
 * (i.e. 0xbc197c81, or its own function selector).
 * @return `bytes4(keccak256("onERC1155BatchReceived(address,address,uint256[],uint256[],bytes)"))` if transfer is
 ↪  allowed
 */
function onERC1155BatchReceived(
    address /*operator*/,
    address /*from*/,
    uint256[] calldata /*ids*/,
    uint256[] calldata /*values*/,
    bytes calldata /*data*/
) override external pure returns (bytes4) {
    revert UnsupportedTransferFunction();
}
```

9 Test Suite Evaluation

9.1 Contracts Compilation Output

```
pwn_contracts % forge build
[] Compiling...
[] Compiling 96 files with 0.8.16
[] Solc 0.8.16 finished in 27.70s
Compiler run successful
```

9.2 Tests Output

```
pwn_contracts % forge test
[] Compiling...
No files changed, compilation skipped

Running 1 test for test/unit/PWNSimpleLoanSimpleOffer.t.sol:PWNSimpleLoanSimpleOffer_EncodeLoanTermsFactoryData_Test
[PASS] test_shouldReturnEncodedLoanTermsFactoryData() (gas: 153472)
Test result: ok. 1 passed; 0 failed; finished in 7.50ms

Running 6 tests for test/unit/PWNHub.t.sol:PWNHub_SetTags_Test
[PASS] test_shouldAddTagsToAddress() (gas: 80019)
[PASS] test_shouldEmitEvent_TagSet_forEverySet() (gas: 82528)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 25714)
[PASS] test_shouldFail_whenDiffInputLengths() (gas: 22214)
[PASS] test_shouldNotFail_whenEmptyList() (gas: 13944)
[PASS] test_shouldRemoveTagsFromAddress() (gas: 25684)
Test result: ok. 6 passed; 0 failed; finished in 7.18ms

Running 6 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_EnableLOANLateRepayment_Test
[PASS] test_shouldEmitEvent_LOANLateRepaymentEnabled() (gas: 35224)
[PASS] test_shouldFail_whenCallerIsNotLOANTokenHolder() (gas: 32608)
[PASS] test_shouldFail_whenLateRepaymentIsAlreadyEnabled() (gas: 35808)
[PASS] test_shouldFail_whenLoanIsNotRunning() (gas: 36236)
[PASS] test_shouldPass_whenLoanIsExpired() (gas: 33987)
[PASS] test_shouldStoreThatLateRepaymentIsEnabled() (gas: 34464)
Test result: ok. 6 passed; 0 failed; finished in 9.15ms

Running 3 tests for test/unit/PWNConfig.t.sol:PWNConfig_Initialize_Test
[PASS] test_shouldFail_whenCalledSecondTime() (gas: 20795)
[PASS] test_shouldFail_whenOwnerIsZeroAddress() (gas: 14165)
[PASS] test_shouldSetOwner() (gas: 19573)
Test result: ok. 3 passed; 0 failed; finished in 9.54ms

Running 6 tests for test/unit/PWNConfig.t.sol:PWNConfig_Reinitialize_Test
[PASS] test_shouldFail_whenCalledSecondTime() (gas: 48758)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 20611)
[PASS] test_shouldFail_whenFeeCollectorIsZeroAddress() (gas: 20459)
[PASS] test_shouldFail_whenInitializeCalledAfterReinitialize() (gas: 48517)
[PASS] test_shouldFail_whenOwnerIsZeroAddress() (gas: 16519)
[PASS] test_shouldSetParameters() (gas: 48180)
Test result: ok. 6 passed; 0 failed; finished in 10.04ms

Running 5 tests for test/integration/PWNProtocolIntegrity.t.sol:PWNProtocolIntegrityTest
[PASS] test_shouldClaimRepaidLOANWithNotActiveLoanContract() (gas: 572100)
[PASS] test_shouldFailCreatingLOANOnNotActiveLoanContract() (gas: 210666)
[PASS] test_shouldFail_whenCallerIsNotActiveLoan() (gas: 29414)
[PASS] test_shouldFail_whenPassingInvalidTermsFactoryContract() (gas: 205572)
[PASS] test_shouldRepayLOANWithNotActiveLoanContract() (gas: 556549)
Test result: ok. 5 passed; 0 failed; finished in 22.59ms

Running 3 tests for test/unit/PWNConfig.t.sol:PWNConfig_SetFeeCollector_Test
[PASS] test_shouldEmitEvent_FeeCollectorUpdated() (gas: 25149)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 12686)
[PASS] test_shouldSetFeeCollectorAddress() (gas: 21826)
Test result: ok. 3 passed; 0 failed; finished in 476.42µs
```

```
Running 1 test for test/unit/PWNSimpleLoanListOffer.t.sol:PWNSimpleLoanListOffer_EncodeLoanTermsFactoryData_Test
[PASS] test_shouldReturnEncodedLoanTermsFactoryData() (gas: 194733)
Test result: ok. 1 passed; 0 failed; finished in 1.46ms

Running 1 test for test/unit/PWNSimpleLoanSimpleOffer.t.sol:PWNSimpleLoanSimpleOffer_GetOfferHash_Test
[PASS] test_shouldReturnOfferHash() (gas: 32572)
Test result: ok. 1 passed; 0 failed; finished in 611.63µs

Running 4 tests for test/unit/PWNLOAN.t.sol:PWNLOAN_Burn_Test
[PASS] test_shouldBurnLOANToken() (gas: 24323)
[PASS] test_shouldDeleteStoredLoanContract() (gas: 23738)
[PASS] test_shouldEmitEvent_LOANBurned() (gas: 24354)
[PASS] test_shouldFail_whenCallerIsNotStoredLoanContractForGivenLoanId() (gas: 15595)
Test result: ok. 4 passed; 0 failed; finished in 3.21ms

Running 1 test for test/unit/PWNDeployer.t.sol:PWNDeployer_ComputeAddress_Test
[PASS] test_shouldComputeAddress(bytes32,bytes32) (runs: 256, : 6181, ~: 6181)
Test result: ok. 1 passed; 0 failed; finished in 28.01ms

Running 5 tests for test/unit/PWNFeeCalculator.t.sol:PWNFeeCalculator_CalculateFeeAmount_Test
[PASS] testFuzz_feeAndNewLoanAmountAreEqToOriginalLoanAmount(uint16,uint256) (runs: 256, : 3662, ~: 3658)
[PASS] test_shouldHandleSmallAmount() (gas: 632)
[PASS] test_shouldHandleZeroAmount() (gas: 633)
[PASS] test_shouldReturnCorrectValue_forNonZeroFee() (gas: 611)
[PASS] test_shouldReturnCorrectValue_forZeroFee() (gas: 655)
Test result: ok. 5 passed; 0 failed; finished in 27.27ms

Running 2 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_GetLOAN_Test
[PASS] test_shouldReturnEmptyLOANDataForNonExistingLoan() (gas: 36715)
[PASS] test_shouldReturnLOANData() (gas: 31240)
Test result: ok. 2 passed; 0 failed; finished in 2.76ms

Running 3 tests for test/unit/PWNConfig.t.sol:PWNConfig_SetFee_Test
[PASS] test_shouldEmitEvent_FeeUpdated() (gas: 18875)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 10657)
[PASS] test_shouldSetFeeValue() (gas: 17762)
Test result: ok. 3 passed; 0 failed; finished in 1.53ms

Running 1 test for test/unit/PWNSimpleLoanSimpleOffer.t.sol:PWNSimpleLoanSimpleOffer_MakeOffer_Test
[PASS] test_shouldMakeOffer() (gas: 62261)
Test result: ok. 1 passed; 0 failed; finished in 663.29µs

Running 1 test for test/unit/PWNSimpleLoanListOffer.t.sol:PWNSimpleLoanListOffer_GetOfferHash_Test
[PASS] test_shouldReturnOfferHash() (gas: 32641)
Test result: ok. 1 passed; 0 failed; finished in 631.42µs

Running 3 tests for test/unit/PWNRevokedNonce.t.sol:PWNRevokedNonce_IsNonceRevoked_Test
[PASS] test_shouldReturnFalse_whenNonceIsNotRevoked() (gas: 14378)
[PASS] test_shouldReturnTrue_whenNonceIsRevoked() (gas: 13524)
[PASS] test_shouldReturnTrue_whenNonceIsSmallerThanMinNonce() (gas: 11063)
Test result: ok. 3 passed; 0 failed; finished in 390.13µs

Running 1 test for test/unit/PWNLOAN.t.sol:PWNLOAN_Constructor_Test
[PASS] test_shouldHaveCorrectNameAndSymbol() (gas: 13878)
Test result: ok. 1 passed; 0 failed; finished in 1.45ms

Running 2 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_GetStateFingerprint_Test
[PASS] test_shouldReturnCorrectStateFingerprint() (gas: 50636)
[PASS] test_shouldReturnZeroIfLoanDoesNotExist() (gas: 21042)
Test result: ok. 2 passed; 0 failed; finished in 2.89ms

Running 1 test for test/unit/PWNHub.t.sol:PWNHub_Constructor_Test
[PASS] test_shouldSetHubOwner() (gas: 366545)
Test result: ok. 1 passed; 0 failed; finished in 300.21µs

Running 1 test for test/integration/PWNSimpleLoanSimpleOfferIntegration.t.sol:PWNSimpleLoanSimpleOfferIntegrationTest
[PASS] test_shouldRevokeOffersInGroup_whenAcceptingOneFromGroup() (gas: 565110)
Test result: ok. 1 passed; 0 failed; finished in 4.86ms
```

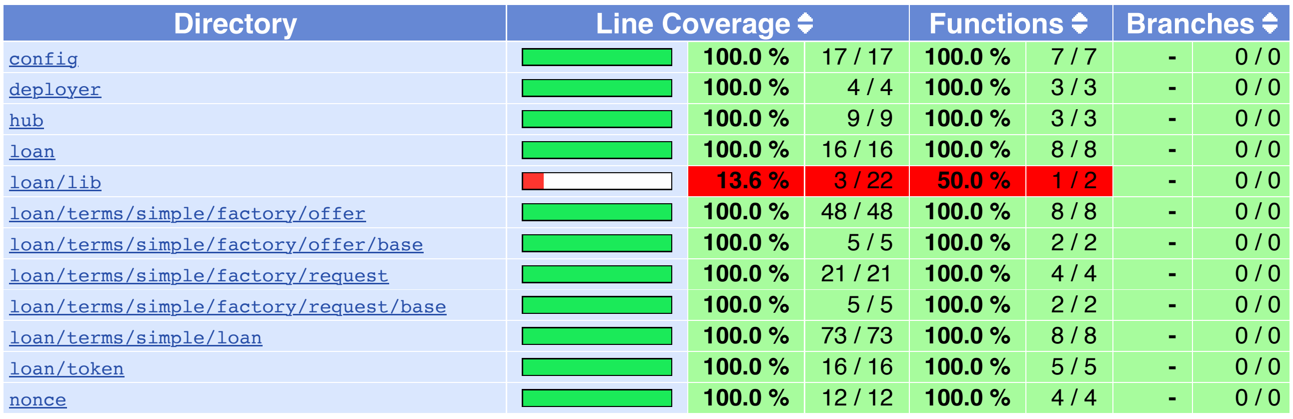
```
Running 3 tests for test/unit/PWNConfig.t.sol:PWNConfig_SetLoanMetadataUri_Test
[PASS] test_shouldEmitEvent_LoanMetadataUriUpdated() (gas: 45263)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 15552)
[PASS] test_shouldSetLoanMetadataUriToLoanContract() (gas: 44244)
Test result: ok. 3 passed; 0 failed; finished in 557.25µs

Running 2 tests for test/unit/PWNRevokedNonce.t.sol:PWNRevokedNonce_RevokeNonceByOwner_Test
[PASS] test_shouldEmitEvent_NonceRevoked() (gas: 38416)
[PASS] test_shouldStoreNonceAsRevoked() (gas: 37414)
Test result: ok. 2 passed; 0 failed; finished in 313.75µs

Running 1 test for test/unit/PWNSimpleLoanListOffer.t.sol:PWNSimpleLoanListOffer_MakeOffer_Test
[PASS] test_shouldMakeOffer() (gas: 62396)
Test result: ok. 1 passed; 0 failed; finished in 669.29µs

Running 2 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_LoanMetadataUri_Test
[PASS] test_shouldCallConfig() (gas: 15060)
[PASS] test_shouldReturnCorrectValue() (gas: 12818)
Test result: ok. 2 passed; 0 failed; finished in 814.88µs

Running 3 tests for test/unit/PWNRevokedNonce.t.sol:PWNRevokedNonce_RevokeNonceWithOwner_Test
[PASS] test_shouldEmitEvent_NonceRevoked() (gas: 43586)
[PASS] test_shouldFail_whenCallerIsDoesNotHaveAccessTag() (gas: 18695)
[PASS] test_shouldStoreNonceAsRevoked() (gas: 42571)
Test result: ok. 3 passed; 0 failed; finished in 447.21µs

Running 2 tests for test/unit/PWNLOAN.t.sol:PWNLOAN_GetStateFingerprint_Test
[PASS] test_shouldCallLoanContract() (gas: 13647)
[PASS] test_shouldReturnZeroIfLoanDoesNotExist() (gas: 9919)
Test result: ok. 2 passed; 0 failed; finished in 559.21µs

Running 2 tests for test/unit/PWNHub.t.sol:PWNHub_HasTag_Test
[PASS] test_shouldReturnFalse_whenAddressDoesNotHaveTag() (gas: 11289)
[PASS] test_shouldReturnTrue_whenAddressDoesHaveTag() (gas: 11301)
Test result: ok. 2 passed; 0 failed; finished in 1.56ms

Running 3 tests for test/unit/PWNRevokedNonce.t.sol:PWNRevokedNonce_SetMinNonceByOwner_Test
[PASS] test_shouldEmitEvent_MinNonceSet() (gas: 38432)
[PASS] test_shouldFail_whenNewValueIsSmallerThanCurrent() (gas: 11916)
[PASS] test_shouldStoreNewMinNonce() (gas: 37313)
Test result: ok. 3 passed; 0 failed; finished in 414.54µs

Running 6 tests for test/unit/PWNLOAN.t.sol:PWNLOAN_Mint_Test
[PASS] test_shouldEmitEvent_LOANMinted() (gas: 87671)
[PASS] test_shouldFail_whenCallerIsNotActiveLoanContract() (gas: 14481)
[PASS] test_shouldIncreaseLastLoanId() (gas: 85707)
[PASS] test_shouldMintLOANToken() (gas: 110110)
[PASS] test_shouldReturnLoanId() (gas: 85169)
[PASS] test_shouldStoreLoanContractUnderLoanId() (gas: 109805)
Test result: ok. 6 passed; 0 failed; finished in 907.42µs

Running 3 tests for test/unit/PWNSimpleLoanOffer.t.sol:PWNSimpleLoanOffer_MakeOffer_Test
[PASS] test_shouldEmitEvent_OfferMade() (gas: 38675)
[PASS] test_shouldFail_whenCallerIsNotLender() (gas: 13382)
[PASS] test_shouldMarkOfferAsMade() (gas: 37356)
Test result: ok. 3 passed; 0 failed; finished in 442.75µs

Running 15 tests for test/unit/PWNSimpleLoanSimpleRequest.t.sol:PWNSimpleLoanSimpleRequest_CreateLOANTerms_Test
[PASS] test_shouldFail_whenCallerIsNotActiveLoan() (gas: 39164)
[PASS] test_shouldFail_whenCallerIsNotLender_whenSetLender() (gas: 149699)
[PASS] test_shouldFail_whenInvalidSignature_whenContractAccount() (gas: 51430)
[PASS] test_shouldFail_whenInvalidSignature_whenEOA() (gas: 146164)
[PASS] test_shouldFail_whenPassingInvalidRequestData() (gas: 21481)
[PASS] test_shouldFail_whenRequestIsExpired() (gas: 129540)
[PASS] test_shouldFail_whenRequestIsRevoked() (gas: 131262)
[PASS] test_shouldPass_whenRequestHasBeenMadeOnchain() (gas: 51552)
[PASS] test_shouldPass_whenRequestHasNoExpiration() (gas: 130904)
[PASS] test_shouldPass_whenRequestIsNotExpired() (gas: 133716)
[PASS] test_shouldPass_whenValidSignature_whenContractAccount() (gas: 57085)
[PASS] test_shouldPass_withValidSignature_whenEOA_whenCompactEIP2098Signature() (gas: 130289)
```

```
[PASS] test_shouldPass_withValidSignature_whenEOA_whenStandardSignature() (gas: 152458)
[PASS] test_shouldReturnCorrectValues() (gas: 133213)
[PASS] test_shouldRevokeRequest() (gas: 133654)
Test result: ok. 15 passed; 0 failed; finished in 17.95ms

Running 8 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_RepayLOAN_Test
[PASS] test_shouldEmitEvent_LOANPaidBack() (gas: 42446)
[PASS] test_shouldFail_whenLoanDoesNotExist() (gas: 32912)
[PASS] test_shouldFail_whenLoanIsExpired_whenLateRepaymentDisable() (gas: 31134)
[PASS] test_shouldFail_whenLoanIsNotRunning() (gas: 33111)
[PASS] test_shouldMoveLoanToRepaidState() (gas: 41721)
[PASS] test_shouldPass_whenLoanIsExpired_whenLateRepaymentEnable() (gas: 44334)
[PASS] test_shouldTransferCollateralToBorrower() (gas: 42349)
[PASS] test_shouldTransferRepaidAmountToVault() (gas: 159614)
Test result: ok. 8 passed; 0 failed; finished in 15.26ms

Running 4 tests for test/unit/PWNHub.t.sol:PWNHub_SetTag_Test
[PASS] test_shouldAddTagToAddress() (gas: 42388)
[PASS] test_shouldEmitEvent_TagSet() (gas: 43622)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 15495)
[PASS] test_shouldRemoveTagFromAddress() (gas: 11108)
Test result: ok. 4 passed; 0 failed; finished in 591.88µs

Running 1 test for test/unit/PWNLOAN.t.sol:PWNLOAN_SupportsInterface_Test
[PASS] test_shouldSupportERC5646() (gas: 5838)
Test result: ok. 1 passed; 0 failed; finished in 982.88µs

Running 1 test for test/unit/PWNSimpleLoanOffer.t.sol:PWNSimpleLoanOffer_RevokeOfferNonce_Test
[PASS] test_shouldCallRevokeOfferNonce() (gas: 16469)
Test result: ok. 1 passed; 0 failed; finished in 902.83µs

Running 1 test for
 →  test/unit/PWNSimpleLoanSimpleRequest.t.sol:PWNSimpleLoanSimpleRequest_EncodeLoanTermsFactoryData_Test
[PASS] test_shouldReturnEncodedLoanTermsFactoryData() (gas: 144353)
Test result: ok. 1 passed; 0 failed; finished in 1.17ms

Running 9 tests for test/unit/PWNSignatureChecker.t.sol:PWNSignatureChecker_isValidSignatureNow_Test
[PASS] testFail_shouldFail_whenSignerIsEOA_whenInvalidSignature() (gas: 101168)
[PASS] test_shouldCallEIP1271Function_whenSignerIsContractAccount() (gas: 11704)
[PASS] test_shouldFail_whenSignerIsContractAccount_whenEIP1271FunctionNotReturnsCorrectValue() (gas: 10423)
[PASS] test_shouldFail_whenSignerIsContractAccount_whenEIP1271FunctionReturnsWrongDataLength() (gas: 10258)
[PASS] test_shouldFail_whenSignerIsEOA_whenSignatureHasWrongLength() (gas: 100949)
[PASS] test_shouldReturnFalse_whenSignerIsEOA_whenSignerIsNotRecoveredAddressOfSignature() (gas: 104484)
[PASS] test_shouldReturnTrue_whenSignerIsContractAccount_whenEIP1271FunctionReturnsCorrectValue() (gas: 10339)
[PASS] test_shouldReturnTrue_whenSignerIsEOA_whenSignerIsRecoveredAddressOfSignature() (gas: 106574)
[PASS] test_shouldSupportCompactEIP2098Signatures_whenSignerIsEOA() (gas: 84411)
Test result: ok. 9 passed; 0 failed; finished in 3.19ms

Running 1 test for test/unit/PWNSimpleLoanSimpleRequest.t.sol:PWNSimpleLoanSimpleRequest_MakeRequest_Test
[PASS] test_shouldMakeRequest() (gas: 61870)
Test result: ok. 1 passed; 0 failed; finished in 668.67µs

Running 1 test for test/unit/PWNSimpleLoanSimpleRequest.t.sol:PWNSimpleLoanSimpleRequest_GetRequestHash_Test
[PASS] test_shouldReturnRequestHash() (gas: 32157)
Test result: ok. 1 passed; 0 failed; finished in 616.71µs

Running 2 tests for test/unit/PWNLOAN.t.sol:PWNLOAN_TokenUri_Test
[PASS] test_shouldCallLoanContract() (gas: 19018)
[PASS] test_shouldReturnCorrectValue() (gas: 17015)
Test result: ok. 2 passed; 0 failed; finished in 632.13µs

Running 19 tests for test/unit/PWNSimpleLoanListOffer.t.sol:PWNSimpleLoanListOffer_CreateLOANTerms_Test
[PASS] testFail_shouldNotRevokeOffer_whenIsPersistent() (gas: 142201)
[PASS] test_shouldAcceptAnyCollateralId_whenMerkleRootIsZero() (gas: 139509)
[PASS] test_shouldFail_whenCallerIsNotActiveLoan() (gas: 44035)
[PASS] test_shouldFail_whenCallerIsNotBorrower_whenSetBorrower() (gas: 138552)
[PASS] test_shouldFail_whenGivenCollateralIdIsNotWhitelisted() (gas: 202601)
[PASS] test_shouldFail_whenInvalidSignature_whenContractAccount() (gas: 57197)
[PASS] test_shouldFail_whenInvalidSignature_whenEOA() (gas: 152068)
```

```
[PASS] test_shouldFail_whenOfferIsExpired() (gas: 135554)
[PASS] test_shouldFail_whenOfferIsRevoked() (gas: 137258)
[PASS] test_shouldFail_whenPassingInvalidOfferData() (gas: 21443)
[PASS] test_shouldPass_whenGivenCollateralIdIsWhitelisted() (gas: 203788)
[PASS] test_shouldPass_whenOfferHasBeenMadeOnchain() (gas: 57628)
[PASS] test_shouldPass_whenOfferHasNoExpiration() (gas: 136847)
[PASS] test_shouldPass_whenOfferIsNotExpired() (gas: 139747)
[PASS] test_shouldPass_whenValidSignature_whenContractAccount() (gas: 62945)
[PASS] test_shouldPass_withValidSignature_whenEOA_whenCompactEIP2098Signature() (gas: 136276)
[PASS] test_shouldPass_withValidSignature_whenEOA_whenStandardSignature() (gas: 158467)
[PASS] test_shouldReturnCorrectValues() (gas: 139294)
[PASS] test_shouldRevokeOffer_whenIsNotPersistent() (gas: 139863)
Test result: ok. 19 passed; 0 failed; finished in 16.27ms

Running 3 tests for test/unit/PWNSimpleLoanRequest.t.sol:PWNSimpleLoanRequest_MakeRequest_Test
[PASS] test_shouldEmitEvent_RequestMade() (gas: 38697)
[PASS] test_shouldFail_whenCallerIsNotBorrower() (gas: 13404)
[PASS] test_shouldMarkRequestAsMade() (gas: 37356)
Test result: ok. 3 passed; 0 failed; finished in 497.83µs

Running 1 test for test/unit/PWNDeployer.t.sol:PWNDeployer_Constructor_Test
[PASS] test_shouldSetParameters(address) (runs: 256, : 364397, ~: 364397)
Test result: ok. 1 passed; 0 failed; finished in 71.47ms

Running 3 tests for test/unit/PWNDeployer.t.sol:PWNDeployer_DeployAndTransferOwnership_Test
[PASS] test_shouldDeployContract() (gas: 386056)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 17807)
[PASS] test_shouldTransferOwnerhsip() (gas: 386215)
Test result: ok. 3 passed; 0 failed; finished in 899.17µs

Running 1 test for test/unit/PWNSimpleLoanRequest.t.sol:PWNSimpleLoanRequest_RevokeRequestNonce_Test
[PASS] test_shouldCallRevokeRequestNonce() (gas: 16469)
Test result: ok. 1 passed; 0 failed; finished in 344.83µs

Running 5 tests for test/unit/PWNVault.t.sol:PWNVault_ReceivedHooks_Test
[PASS] test_shouldFail_whenOnERC1155BatchReceived() (gas: 10019)
[PASS] test_shouldFail_whenOperatorIsNotVault_onERC1155Received() (gas: 9415)
[PASS] test_shouldFail_whenOperatorIsNotVault_onERC721Received() (gas: 9271)
[PASS] test_shouldReturnCorrectValue_whenOperatorIsVault_onERC1155Received() (gas: 6343)
[PASS] test_shouldReturnCorrectValue_whenOperatorIsVault_onERC721Received() (gas: 6224)
Test result: ok. 5 passed; 0 failed; finished in 622.38µs

Running 2 tests for test/unit/PWNVault.t.sol:PWNVault_PushFrom_Test
[PASS] test_shouldCallSafeTransferFrom_fromOrigin_toBeneficiary() (gas: 22785)
[PASS] test_shouldEmitEvent_VaultPushFrom() (gas: 24603)
Test result: ok. 2 passed; 0 failed; finished in 2.59ms

Running 12 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_ClaimLOAN_Test
[PASS] test_shouldBurnLOANToken() (gas: 31248)
[PASS] test_shouldDeleteLoanData() (gas: 86714)
[PASS] test_shouldEmitEvent_LOANClaimed_whenDefaulted() (gas: 33584)
[PASS] test_shouldEmitEvent_LOANClaimed_whenRepaid() (gas: 30391)
[PASS] test_shouldFail_whenCallerIsNotLOANTokenHolder() (gas: 32729)
[PASS] test_shouldFail_whenLoanDoesNotExist() (gas: 18566)
[PASS] test_shouldFail_whenLoanIsNotRepaidNorExpired() (gas: 36524)
[PASS] test_shouldPass_whenLoanIsExpired_whenLateRepaymentDisable() (gas: 31899)
[PASS] test_shouldPass_whenLoanIsExpired_whenLateRepaymentEnable() (gas: 31924)
[PASS] test_shouldPass_whenLoanIsRepaid() (gas: 28759)
[PASS] test_shouldTransferCollateralToLender_whenLoanIsExpired() (gas: 53677)
[PASS] test_shouldTransferRepaidAmountToLender_whenLoanIsRepaid() (gas: 32173)
Test result: ok. 12 passed; 0 failed; finished in 2.56ms

Running 2 tests for test/unit/PWNDeployer.t.sol:PWNDeployer_Deploy_Test
[PASS] test_shouldDeployContract() (gas: 381024)
[PASS] test_shouldFail_whenCallerIsNotOwner() (gas: 15545)
Test result: ok. 2 passed; 0 failed; finished in 509.58µs

Running 3 tests for test/unit/PWNVault.t.sol:PWNVault_SupportsInterface_Test
[PASS] test_shouldReturnTrue_whenIERC1155Receiver() (gas: 5736)
[PASS] test_shouldReturnTrue_whenIERC165() (gas: 5632)
```

```
[PASS] test_shouldReturnTrue_whenIERC721Receiver() (gas: 5643)
Test result: ok. 3 passed; 0 failed; finished in 419.96µs

Running 16 tests for test/unit/PWNSimpleLoanSimpleOffer.t.sol:PWNSimpleLoanSimpleOffer_CreateLOANTerms_Test
[PASS] testFail_shouldNotRevokeOffer_whenIsPersistent() (gas: 136747)
[PASS] test_shouldFail_whenCallerIsNotActiveLoan() (gas: 39282)
[PASS] test_shouldFail_whenCallerIsNotBorrower_whenSetBorrower() (gas: 133128)
[PASS] test_shouldFail_whenInvalidSignature_whenContractAccount() (gas: 51774)
[PASS] test_shouldFail_whenInvalidSignature_whenEOA() (gas: 146633)
[PASS] test_shouldFail_whenOfferIsExpired() (gas: 130130)
[PASS] test_shouldFail_whenOfferIsRevoked() (gas: 131812)
[PASS] test_shouldFail_whenPassingInvalidOfferData() (gas: 21437)
[PASS] test_shouldPass_whenOfferHasBeenMadeOnchain() (gas: 52173)
[PASS] test_shouldPass_whenOfferHasNoExpiration() (gas: 131392)
[PASS] test_shouldPass_whenOfferIsNotExpired() (gas: 134292)
[PASS] test_shouldPass_whenValidSignature_whenContractAccount() (gas: 57482)
[PASS] test_shouldPass_withValidSignature_whenEOA_whenCompactEIP2098Signature() (gas: 130821)
[PASS] test_shouldPass_withValidSignature_whenEOA_whenStandardSignature() (gas: 152979)
[PASS] test_shouldReturnCorrectValues() (gas: 133839)
[PASS] test_shouldRevokeOffer_whenIsNotPersistent() (gas: 134387)
Test result: ok. 16 passed; 0 failed; finished in 7.55ms

Running 2 tests for test/unit/PWNVault.t.sol:PWNVault_Permit_Test
[PASS] testFail_shouldNotCallPermit_whenPermitIsZero() (gas: 14337)
[PASS] test_shouldCallPermit_whenPermitNonZero() (gas: 19081)
Test result: ok. 2 passed; 0 failed; finished in 560.79µs

Running 2 tests for test/unit/PWNVault.t.sol:PWNVault_Pull_Test
[PASS] test_shouldCallTransferFrom_fromOrigin_toVault() (gas: 19966)
[PASS] test_shouldEmitEvent_VaultPull() (gas: 21451)
Test result: ok. 2 passed; 0 failed; finished in 578.71µs

Running 10 tests for test/unit/PWNSimpleLoan.t.sol:PWNSimpleLoan_CreateLoan_Test
[PASS] test_shouldEmitEvent_LOANCreated() (gas: 189324)
[PASS] test_shouldFailWhenCollateralAssetIsInvalid() (gas: 73618)
[PASS] test_shouldFail_whenLoanFactoryContractIsNotTaggerInPWNHub() (gas: 22683)
[PASS] test_shouldGetLOANTermsStructFromGivenFactoryContract() (gas: 478016)
[PASS] test_shouldMintLOANToken() (gas: 167980)
[PASS] test_shouldReturnCreatedLoanId() (gas: 162441)
[PASS] test_shouldStoreLoanData() (gas: 262096)
[PASS] test_shouldTransferCollateral_fromBorrower_toVault() (gas: 320792)
[PASS] test_shouldTransferLoanAsset_fromLender_toBorrowerAndFeeCollector_whenNonZeroFee() (gas: 314992)
[PASS] test_shouldTransferLoanAsset_fromLender_toBorrower_whenZeroFees() (gas: 306430)
Test result: ok. 10 passed; 0 failed; finished in 15.95ms

Running 12 tests for test/integration/PWNSimpleLoanIntegration.t.sol:PWNSimpleLoanIntegrationTest
[PASS] test_shouldClaimDefaultedLOAN() (gas: 491571)
[PASS] test_shouldClaimRepaidLOAN() (gas: 561866)
[PASS] test_shouldCreateLOAN_fromListOffer() (gas: 508982)
[PASS] test_shouldCreateLOAN_fromSimpleOffer() (gas: 504189)
[PASS] test_shouldCreateLOAN_fromSimpleRequest() (gas: 503119)
[PASS] test_shouldCreateLOAN_withCryptoKittiesCollateral() (gas: 165)
[PASS] test_shouldCreateLOAN_withERC1155Collateral() (gas: 521980)
[PASS] test_shouldCreateLOAN_withERC20Collateral() (gas: 499191)
[PASS] test_shouldCreateLOAN_withERC721Collateral() (gas: 497582)
[PASS] test_shouldFailToRepayLoan_whenLOANExpired() (gas: 534879)
[PASS] test_shouldRepayLoan_whenExpired_withLateRepaymentEnabled() (gas: 553307)
[PASS] test_shouldRepayLoan_whenNotExpired() (gas: 548438)
Test result: ok. 12 passed; 0 failed; finished in 79.93ms

Running 2 tests for test/unit/PWNVault.t.sol:PWNVault_Push_Test
[PASS] test_shouldCallSafeTransferFrom_fromVault_toBeneficiary() (gas: 20117)
[PASS] test_shouldEmitEvent_VaultPush() (gas: 21454)
Test result: ok. 2 passed; 0 failed; finished in 483.58µs

Running 1 test for
 ↪ test/integration/PWNSimpleLoanSimpleRequestIntegration.t.sol:PWNSimpleLoanSimpleRequestIntegrationTest
[PASS] test_shouldRevokeRequestsInGroup_whenAcceptingOneFromGroup() (gas: 563807)
Test result: ok. 1 passed; 0 failed; finished in 5.24ms
```

9.3 Code Coverage



Directory	Line Coverage			Functions		Branches	
config	🟩	100.0 %	17 / 17	100.0 %	7 / 7	-	0 / 0
deployer	🟩	100.0 %	4 / 4	100.0 %	3 / 3	-	0 / 0
hub	🟩	100.0 %	9 / 9	100.0 %	3 / 3	-	0 / 0
loan	🟩	100.0 %	16 / 16	100.0 %	8 / 8	-	0 / 0
loan/lib	🟥	13.6 %	3 / 22	50.0 %	1 / 2	-	0 / 0
loan/terms/simple/factory/offer	🟩	100.0 %	48 / 48	100.0 %	8 / 8	-	0 / 0
loan/terms/simple/factory/offer/base	🟩	100.0 %	5 / 5	100.0 %	2 / 2	-	0 / 0
loan/terms/simple/factory/request	🟩	100.0 %	21 / 21	100.0 %	4 / 4	-	0 / 0
loan/terms/simple/factory/request/base	🟩	100.0 %	5 / 5	100.0 %	2 / 2	-	0 / 0
loan/terms/simple/loan	🟩	100.0 %	73 / 73	100.0 %	8 / 8	-	0 / 0
loan/token	🟩	100.0 %	16 / 16	100.0 %	5 / 5	-	0 / 0
nonce	🟩	100.0 %	12 / 12	100.0 %	4 / 4	-	0 / 0

9.4 Slither

All the relevant issues raised by Slither have been incorporated into the issues described in this report.

10 About Nethermind

Nethermind is a Blockchain Research and Software Engineering company. Our work touches every part of the web3 ecosystem - from layer 1 and layer 2 engineering, cryptography research, and security to application-layer protocol development. We offer strategic support to our institutional and enterprise partners across the blockchain, digital assets, and DeFi sectors, guiding them through all stages of the research and development process, from initial concepts to successful implementation.

We offer security audits of projects built on EVM-compatible chains and Starknet. We are active builders of the Starknet ecosystem, delivering a node implementation, a block explorer, a Solidity-to-Cairo transpiler, and formal verification tooling. Nethermind also provides strategic support to our institutional and enterprise partners in blockchain, digital assets, and decentralized finance (DeFi). In the next paragraphs, we introduce the company in more detail.

Blockchain Security: At Nethermind, we believe security is vital to the health and longevity of the entire Web3 ecosystem. We provide security services related to Smart Contract Audits, Formal Verification, and Real-Time Monitoring. Our Security Team comprises blockchain security experts in each field, often collaborating to produce comprehensive and robust security solutions. The team has a strong academic background, can apply state-of-the-art techniques, and is experienced in analyzing cutting-edge Solidity and Cairo smart contracts, such as ArgentX and StarkGate (the bridge connecting Ethereum and StarkNet). Most team members hold a Ph.D. degree and actively participate in the research community, accounting for 240+ articles published and 1,450+ citations in Google Scholar. The security team adopts customer-oriented and interactive processes where clients are involved in all stages of the work.

Blockchain Core Development: Our core engineering team, consisting of over 20 developers, maintains, improves, and upgrades our flagship product - the Nethermind Ethereum Execution Client. The client has been successfully operating for several years, supporting both the Ethereum Mainnet and its testnets, and now accounts for nearly a quarter of all synced Mainnet nodes. Our unwavering commitment to Ethereum's growth and stability extends to sidechains and layer 2 solutions. Notably, we were the sole execution layer client to facilitate Gnosis Chain's Merge, transitioning from Aura to Proof of Stake (PoS), and we are actively developing a full-node client to bolster Starknet's decentralization efforts. Our core team equips partners with tools for seamless node set-up, using generated docker-compose scripts tailored to their chosen execution client and preferred configurations for various network types.

DevOps and Infrastructure Management: Our infrastructure team ensures our partners' systems operate securely, reliably, and efficiently. We provide infrastructure design, deployment, monitoring, maintenance, and troubleshooting support, allowing you to focus on your core business operations. Boasting extensive expertise in Blockchain as a Service, private blockchain implementations, and node management, our infrastructure and DevOps engineers are proficient with major cloud solution providers and can host applications in-house or on clients' premises. Our global in-house SRE teams offer 24/7 monitoring and alerts for both infrastructure and application levels. We manage over 5,000 public and private validators and maintain nodes on major public blockchains such as Polygon, Gnosis, Solana, Cosmos, Near, Avalanche, Polkadot, Aptos, and StarkWare L2. Sedge is an open-source tool developed by our infrastructure experts, designed to simplify the complex process of setting up a proof-of-stake (PoS) network or chain validator. Sedge generates docker-compose scripts for the entire validator set-up based on the chosen client, making the process easier and quicker while following best practices to avoid downtime and being slashed.

Cryptography Research: At Nethermind, our Cryptography Research team is dedicated to continuous internal research while fostering close collaboration with external partners. The team has expertise across a wide range of domains, including cryptography protocols, consensus design, decentralized identity, verifiable credentials, Sybil resistance, oracles, and credentials, distributed validator technology (DVT), and Zero-knowledge proofs. This diverse skill set, combined with strong collaboration between our engineering teams, enables us to deliver cutting-edge solutions to our partners and clients.

Smart Contract Development & DeFi Research: Our smart contract development and DeFi research team comprises 40+ world-class engineers who collaborate closely with partners to identify needs and work on value-adding projects. The team specializes in Solidity and Cairo development, architecture design, and DeFi solutions, including DEXs, AMMs, structured products, derivatives, and money market protocols, as well as ERC20, 721, and 1155 token design. Our research and data analytics focuses on three key areas: technical due diligence, market research, and DeFi research. Utilizing a data-driven approach, we offer in-depth insights and outlooks on various industry themes.

Our suite of L2 tooling: Warp is Starknet's approach to EVM compatibility. It allows developers to take their Solidity smart contracts and transpile them to Cairo, Starknet's smart contract language. In the short time since its inception, the project has accomplished many achievements, including successfully transpiling Uniswap v3 onto Starknet using Warp.

- **Voyager** is a user-friendly Starknet block explorer that offers comprehensive insights into the Starknet network. With its intuitive interface and powerful features, Voyager allows users to easily search for and examine transactions, addresses, and contract details. As an essential tool for navigating the Starknet ecosystem, Voyager is the go-to solution for users seeking in-depth information and analysis;
- **Horus** is an open-source formal verification tool for StarkNet smart contracts. It simplifies the process of formally verifying Starknet smart contracts, allowing developers to express various assertions about the behavior of their code using a simple assertion language;
- **Juno** is a full-node client implementation for Starknet, drawing on the expertise gained from developing the Nethermind Client. Written in Golang and open-sourced from the outset, Juno verifies the validity of the data received from Starknet by comparing it to proofs retrieved from Ethereum, thus maintaining the integrity and security of the entire ecosystem.

Learn more about us at nethermind.io.

Disclaimer