Towards Finding Accounting Errors in Smart Contracts

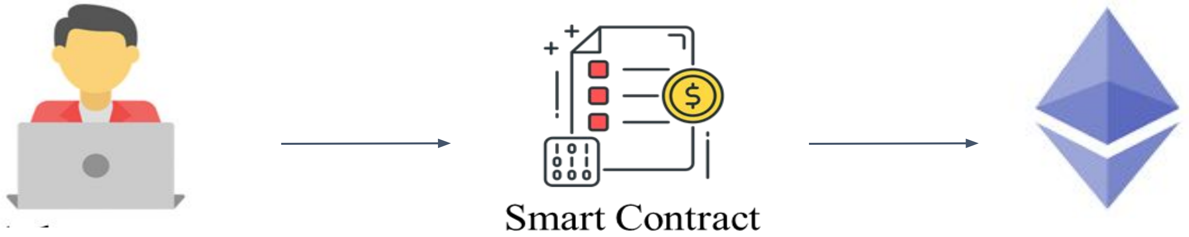
Brian Zhang

Reusable v1.1

Available v1.1

Smart Contracts

- **Blockchain-based application**
- Provide a wide variety of services:



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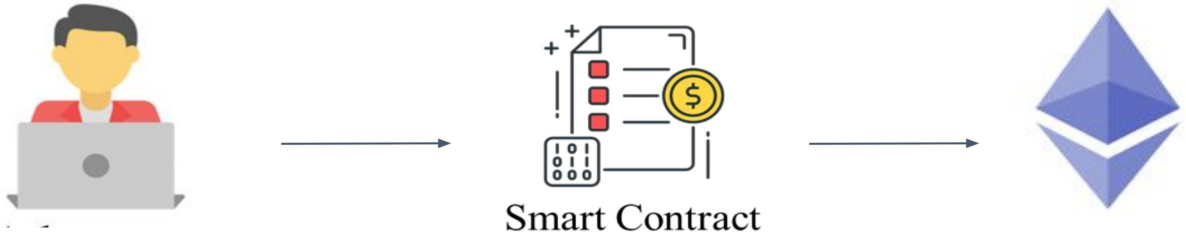

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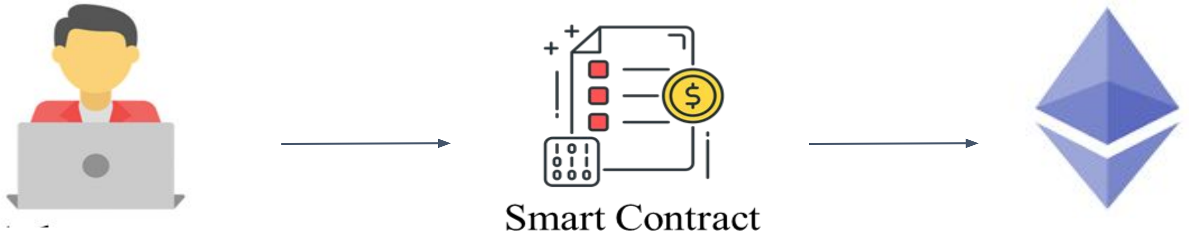
  - Tokens (WETH) are used instead of direct real money (USD)



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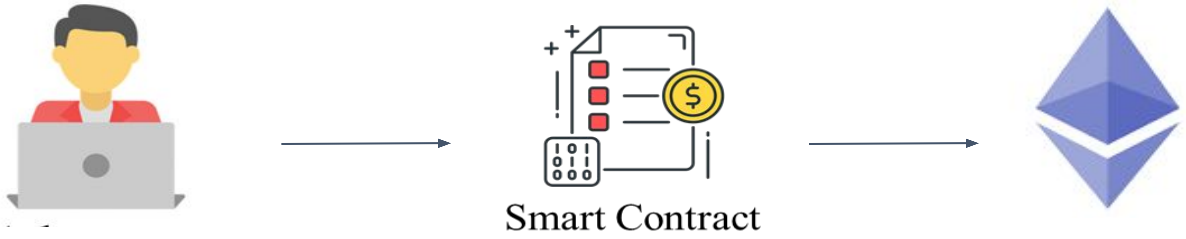
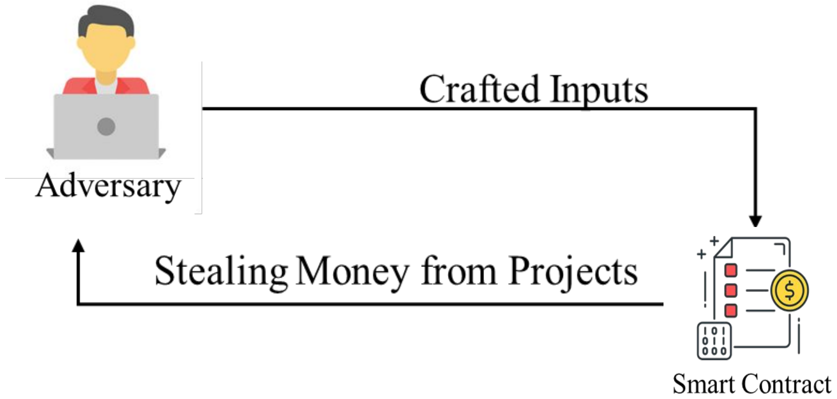
- They rely on the Decentralized Finance (DeFi) principle



Smart Contract Exploits

- Smart contracts are developed by humans, and thus inevitably contain **vulnerabilities**



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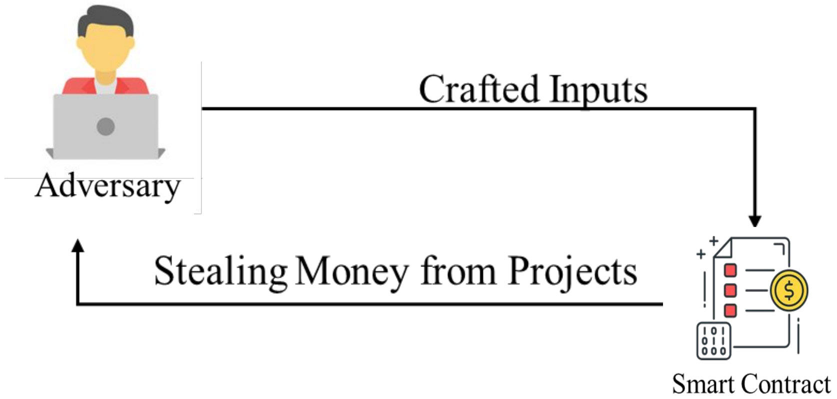

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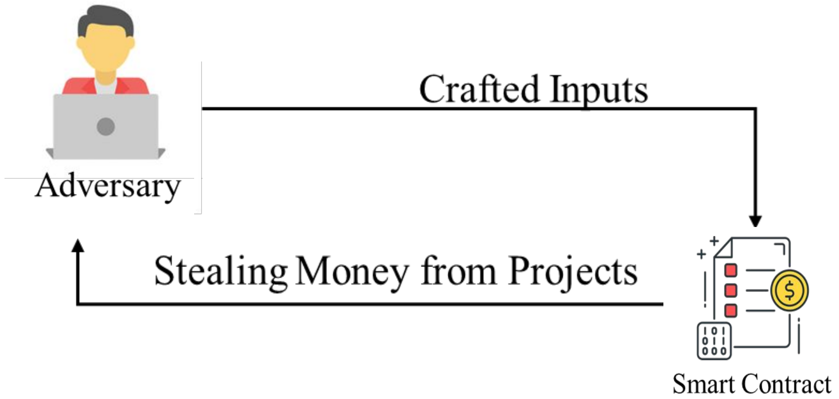

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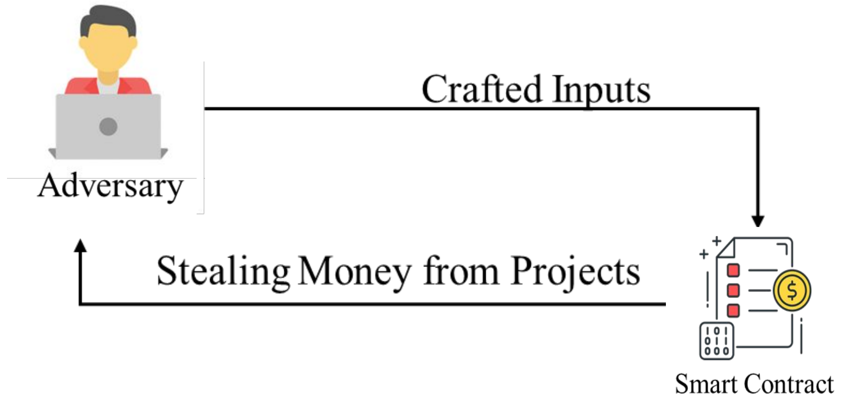
- Smart contracts are **lucrative targets** for malicious actors
- In Q2 of 2023, **212 exploits caused $300 million in damages**
- Researchers have developed many techniques to prevent such exploits



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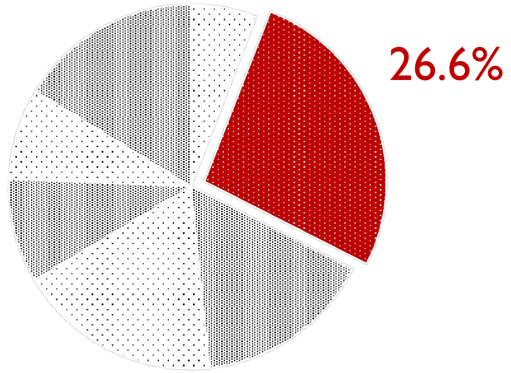

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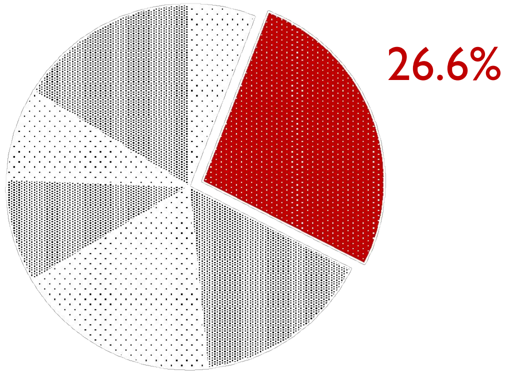

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- *Accounting errors are incorrect implementations of domain-specific business models*
- Uranium finance exploit caused **$87 million dollars** of damages due to two extra zeros
  - The bug survived multiple rounds of pre-deployment auditing

Motivating Example (from the *Tracer* Project)

- Performs an exchange from USD to WETH

```
uint256 wethContractReserve ;
mapping(address => uint256) public wethUserBalances ;
function exchange ( address user, uint256 usdcBalance, uint256 wethPrice, uint256 exg_fee) ... {

        uint256 wethBalance = usdcBalance * wethPrice ;

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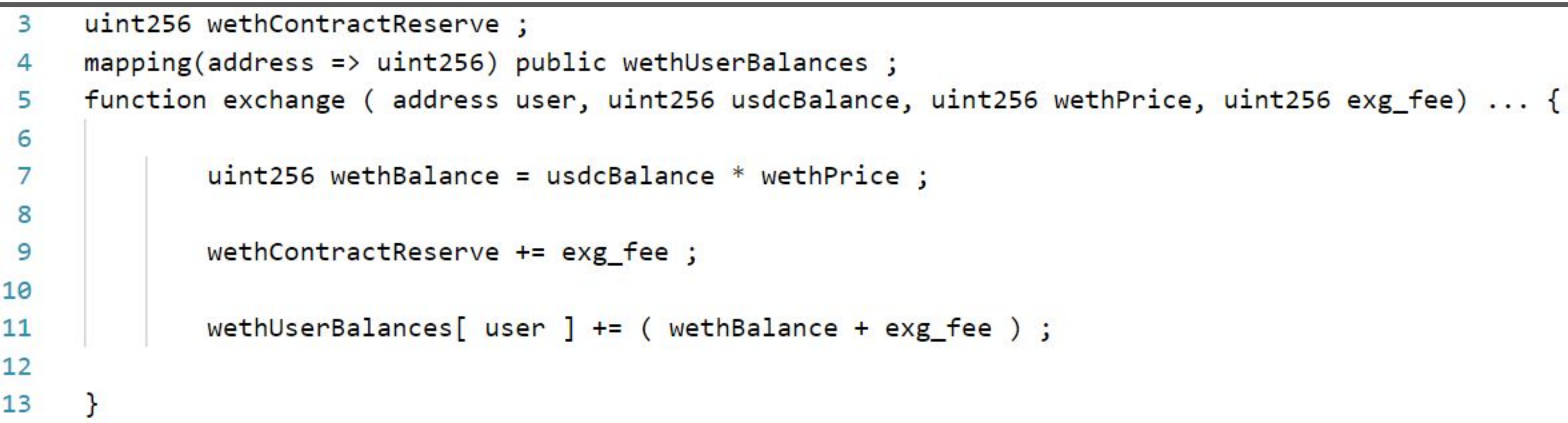

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- Performs an exchange from USD to WETH
- Collects an exchange fee
- Analogous to converting money at an ATM

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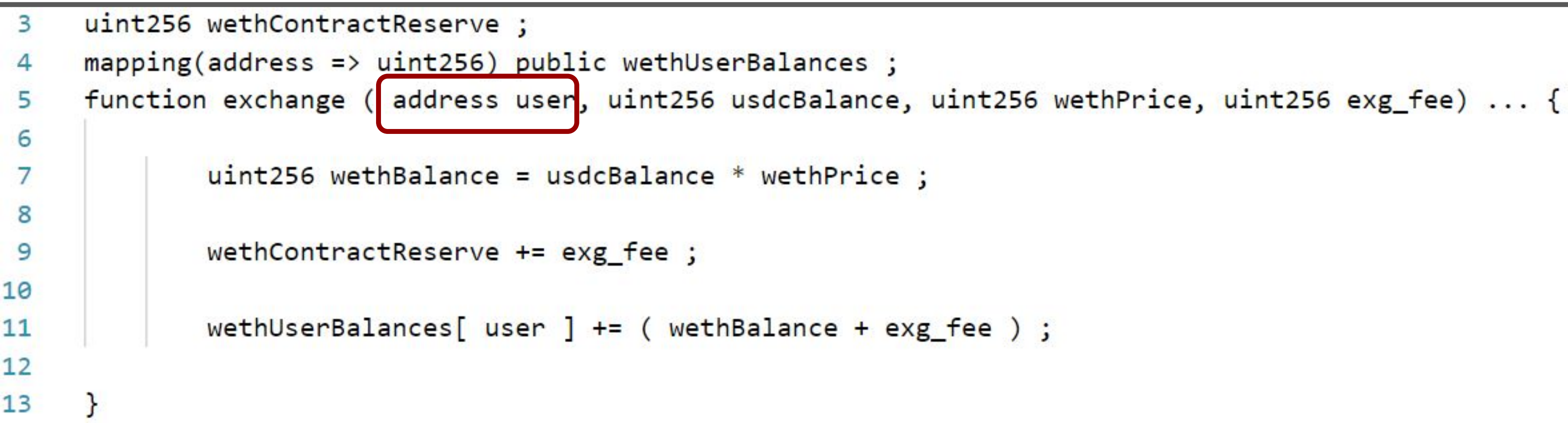
Motivating Example - Variables

- "*user*" is the address for a user
  - Analogous to credentials stored on a credit card



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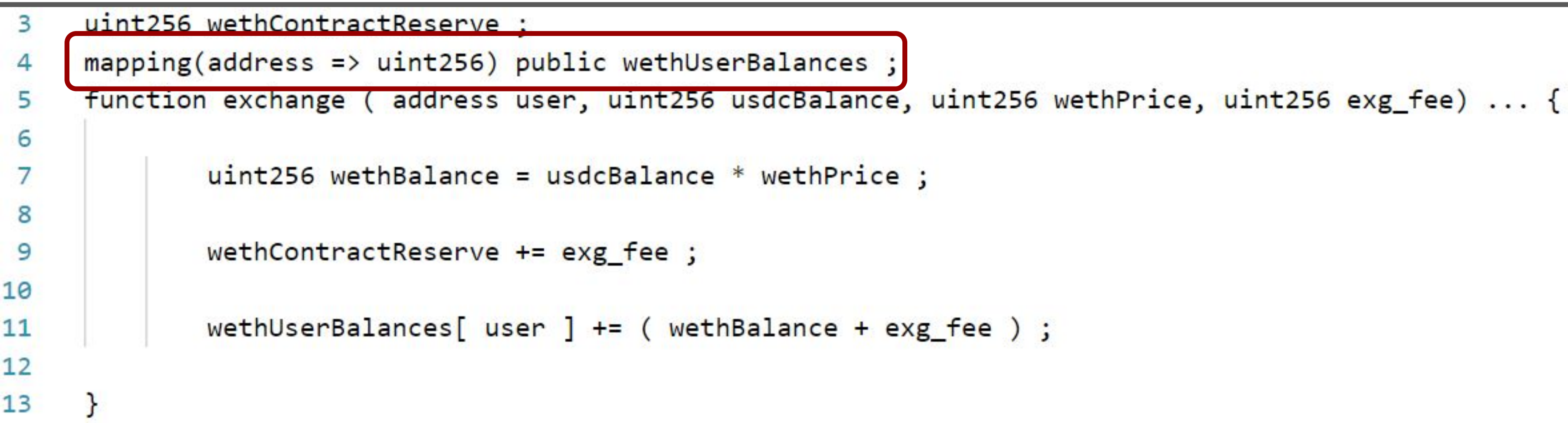
    - Analogous to bank accounts



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- "*wethUserBalances*" is an array storing the accounts of all users (in WETH)
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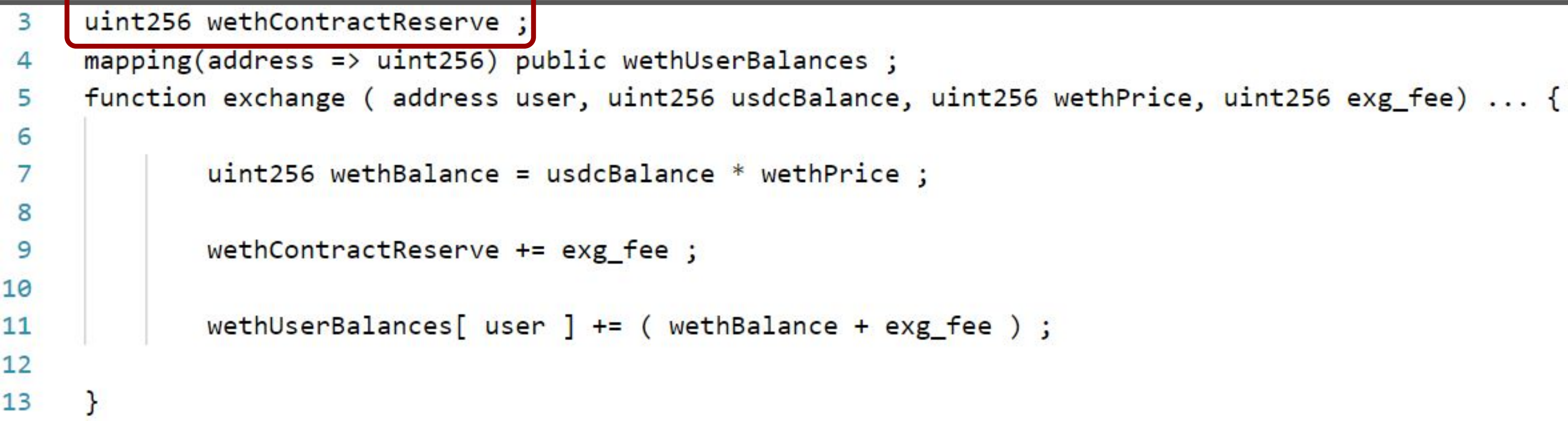
- "*wethContractReserve*" is the reserve/account of the smart contract (in WETH)
    - Analogous to ATM reserves



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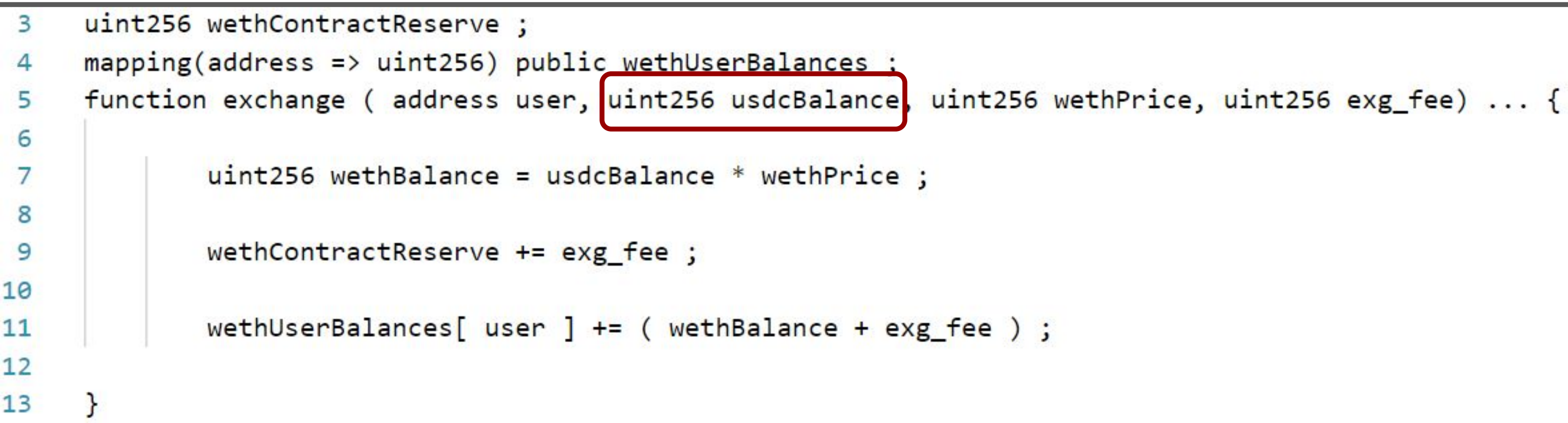

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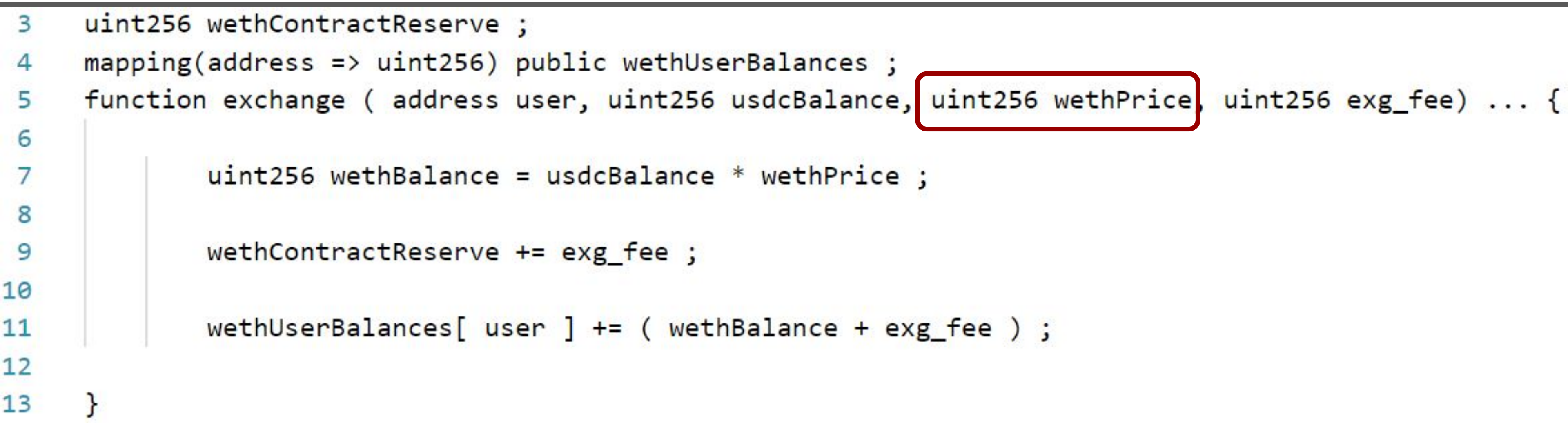
- “*usdcBalance*” is the amount of USD to be exchanged
- “*wethPrice*” is the conversion price of USD to WETH
    - Around $3,600



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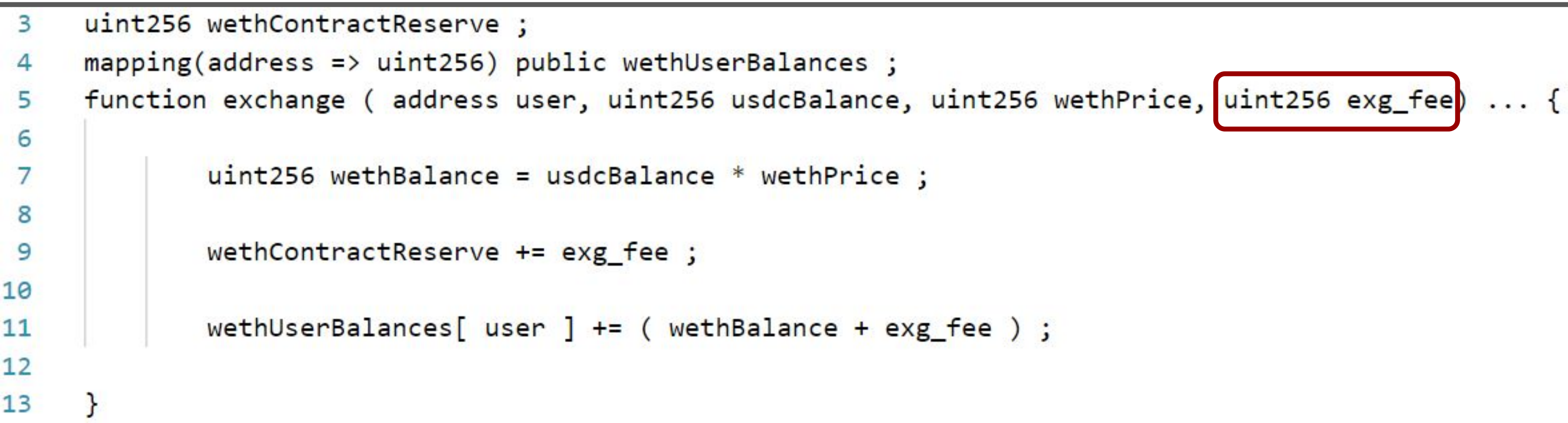
- "*wethPrice*" is the conversion price of USD to WETH
    - Around $3,600 = 1 WETH
- "*exg_fee*" is the fee to be collected during the exchange



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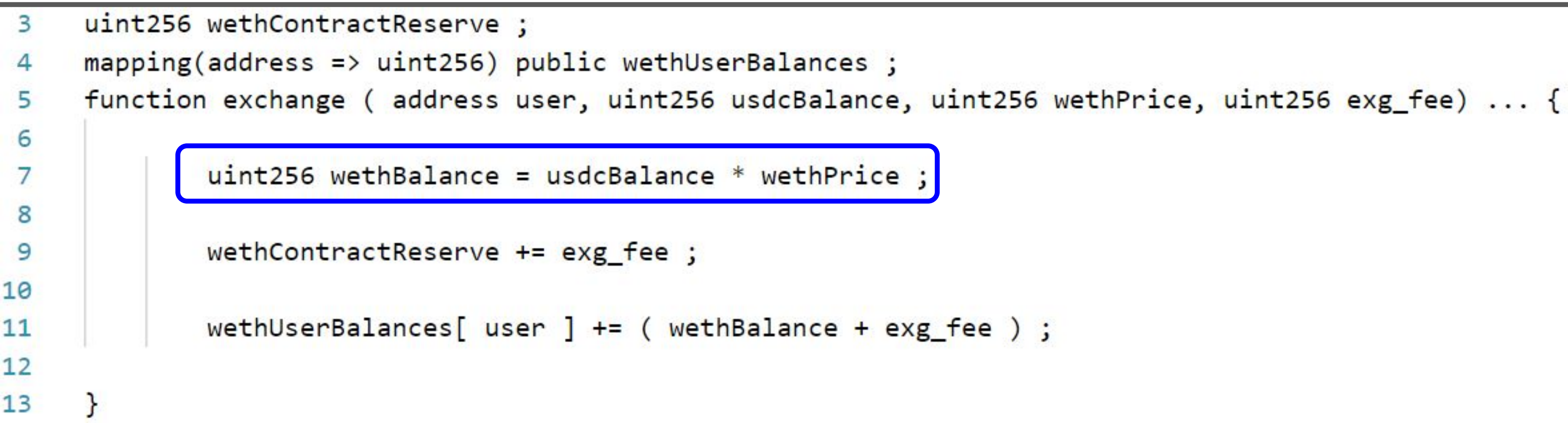

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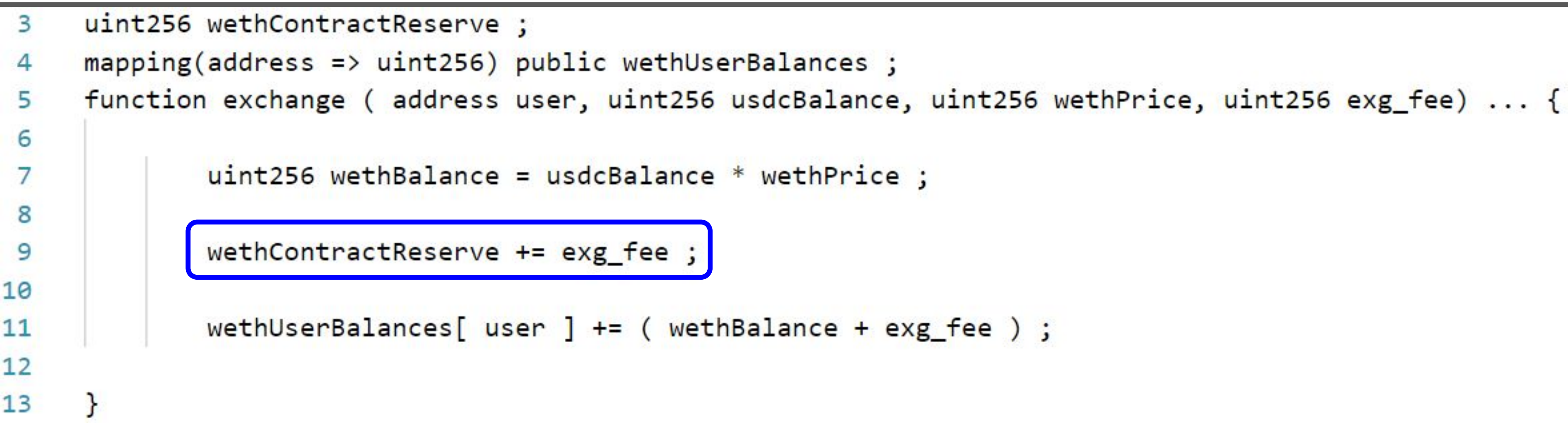
  - Multiplies the amount of USD by the conversion price to WETH
- Adds the exchange fee to the contract reserves on line **9**



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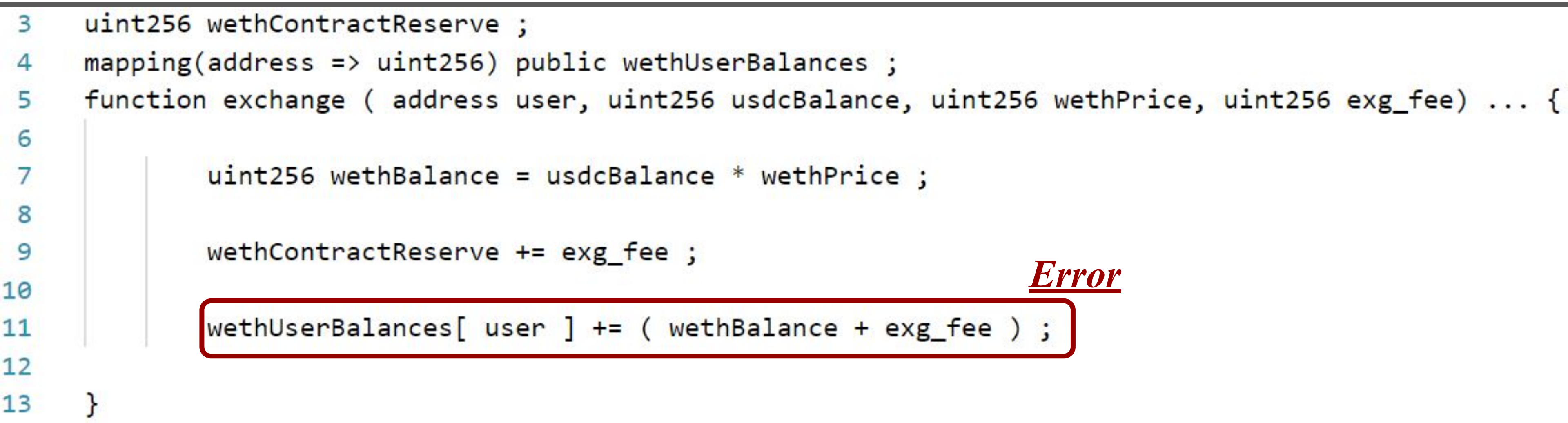

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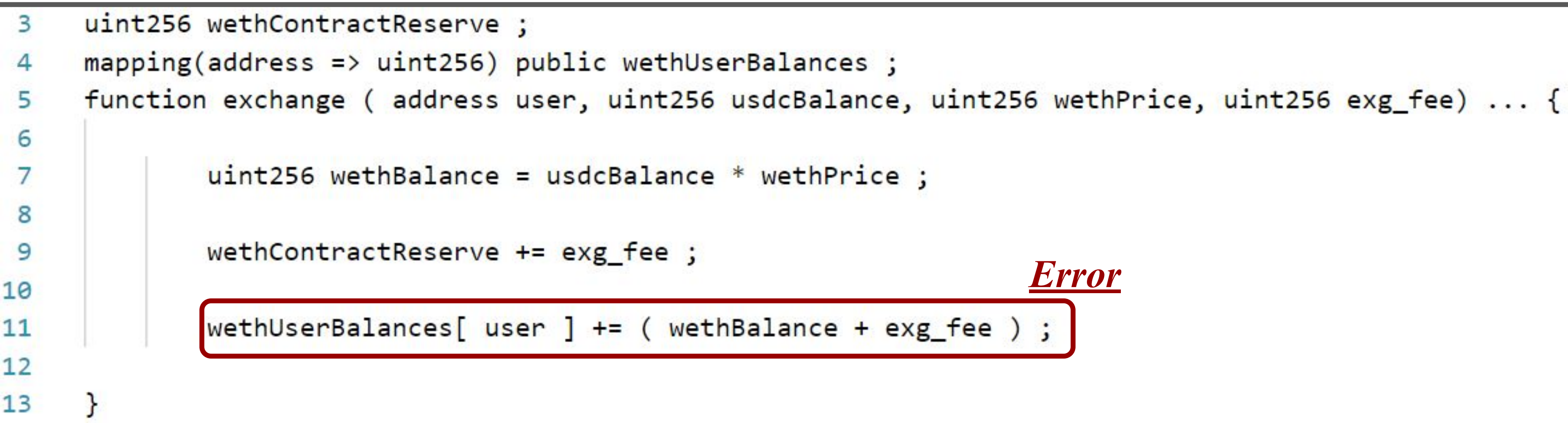

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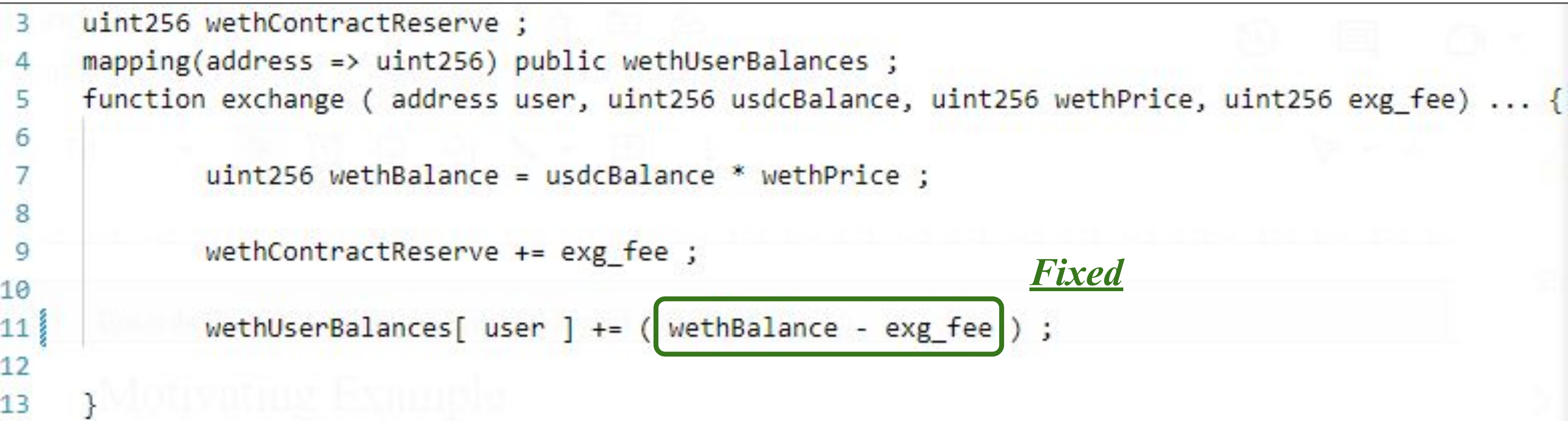

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Challenges to detecting Accounting Errors

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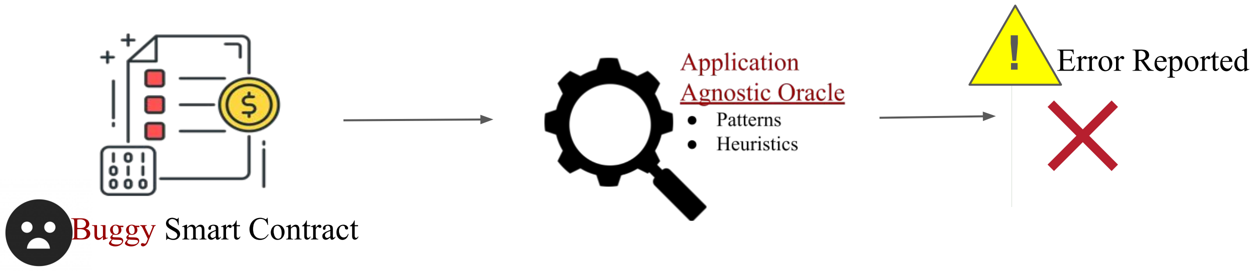
  - Oracles have made bugs such as **Reentrancy** and **Integer Overflow** obsolete



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- **Challenge 1:** No existing general-testing oracles
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- **Challenge 2:** Requires understanding the complex business logic of Smart Contracts

Key insights to ScType

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- **Insight 2:** All smart contracts can be instantiated as banks
    - Many basic operations are analogous
    - I.e. Depositing, Withdrawing, Loaning …

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  - It is implemented on the Slither static analysis tool
- It introduces an abstract type for Solidity variables, ExtendedType:
  - **Financial Meaning**
  - **Token Unit**
  - **Scaling Factor**
- Allows for type rules to be created that check **consistency** and **correctness** of Smart Contract operations

ExtendedType - Financial Meaning

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  - “Raw Balance” - An amount of a currency owned by a user (that has not had fee applied to it)
  - “Price” - The ratio representing the transfer of one currency to another
  - “Reserve” - An amount of currency owned by the Smart Contract
  - …

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Raw Balance	Raw Balance	🚫	Reserve	🚫
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Reserve	Reserve	🚫	Reserve	Reserve
Fee	🚫	🚫	Reserve	Fee

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- Provided is a table for "+" operations (Left Column + Top Row = Cell)
  - **"Raw Balance" + "Reserve" = "Reserve"**
  - **"Raw Balance" + "Price" = Error**
  - The complete table can be found in our paper

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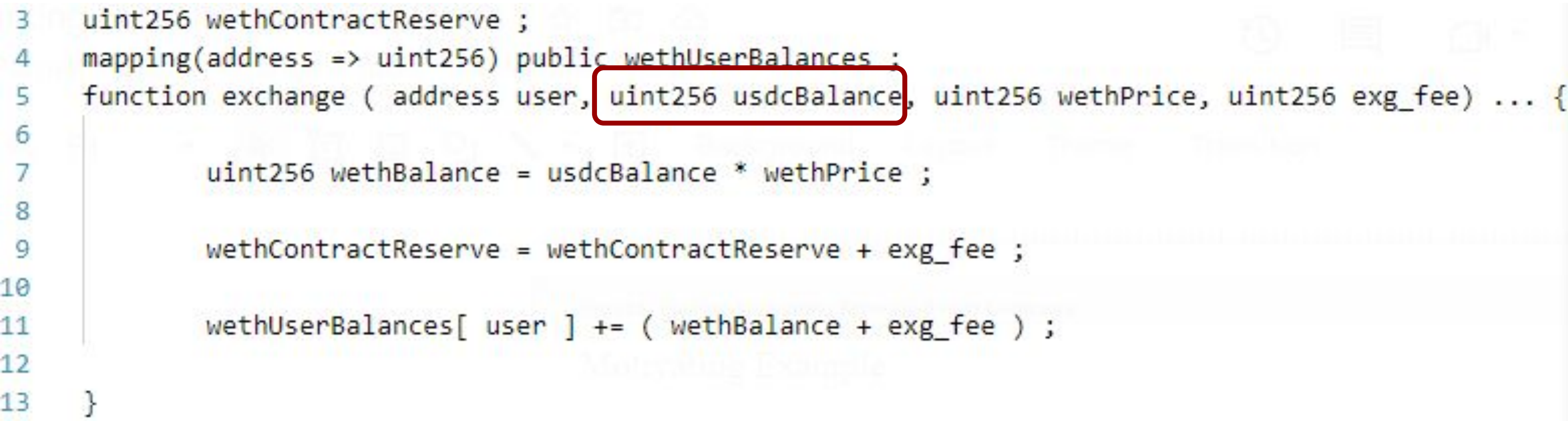
Motivating Example

- "*usdcBalance*" has financial meaning "Raw Balance"
  - "Raw Balance": An amount of tokens owned by users



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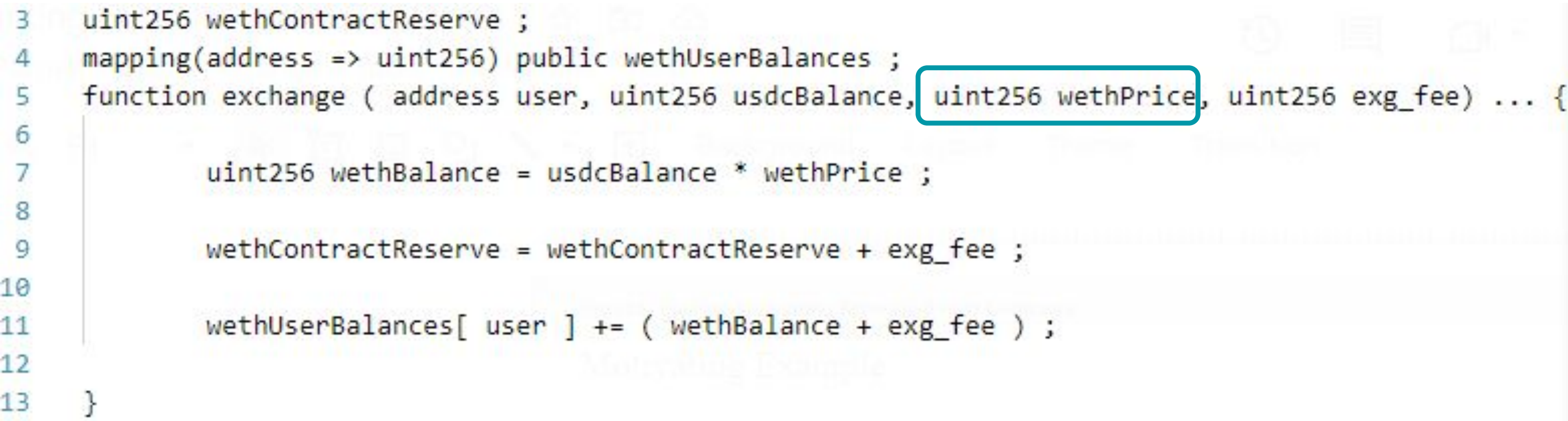
  - "Raw Balance": An amount of tokens owned by users
- "*wethPrice*" has financial meaning "Price"
  - "Price": An exchange rate from one token to another



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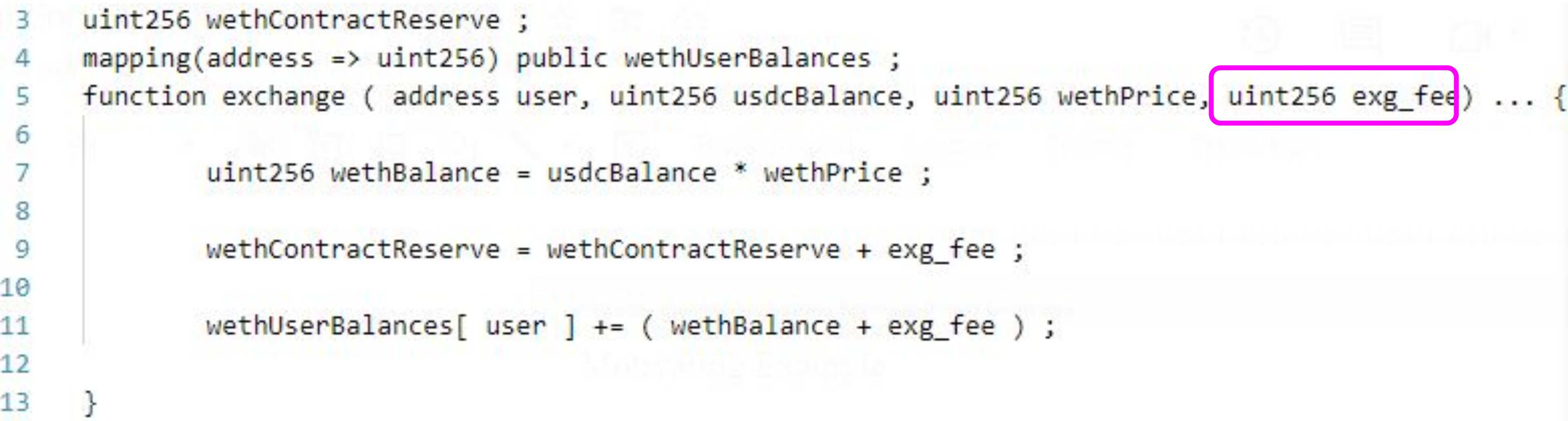

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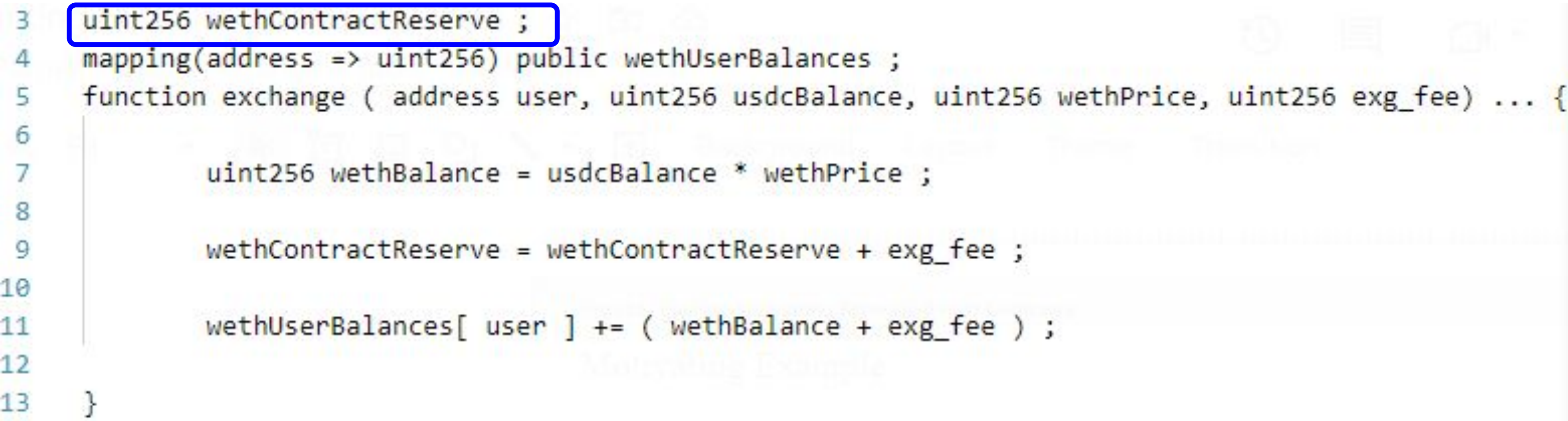
Motivating Example

- "*exg_fee*" has financial meaning "Fee"
  - "Fee": An amount of tokens that are taken as fee for an operation
- "wethContractReserve" has financial meaning "Reserve"
  - "Reserve": An amount of tokens that are owned by the smart contract, not user



```
uint256 wethContractReserve ;
mapping(address => uint256) public wethUserBalances ;
function exchange ( address user, uint256 usdcBalance, uint256 wethPrice, uint256 exg_fee) ... {

        uint256 wethBalance = usdcBalance * wethPrice ;

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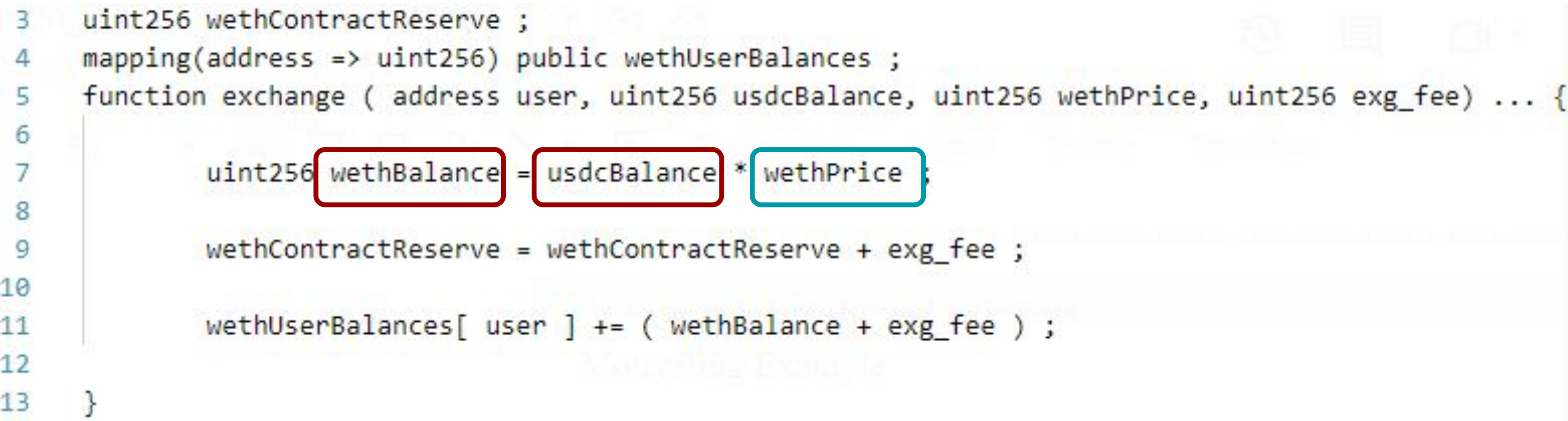
}
```

Motivating Example

- “*wethBalance*” has financial meaning “Raw Balance”



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}
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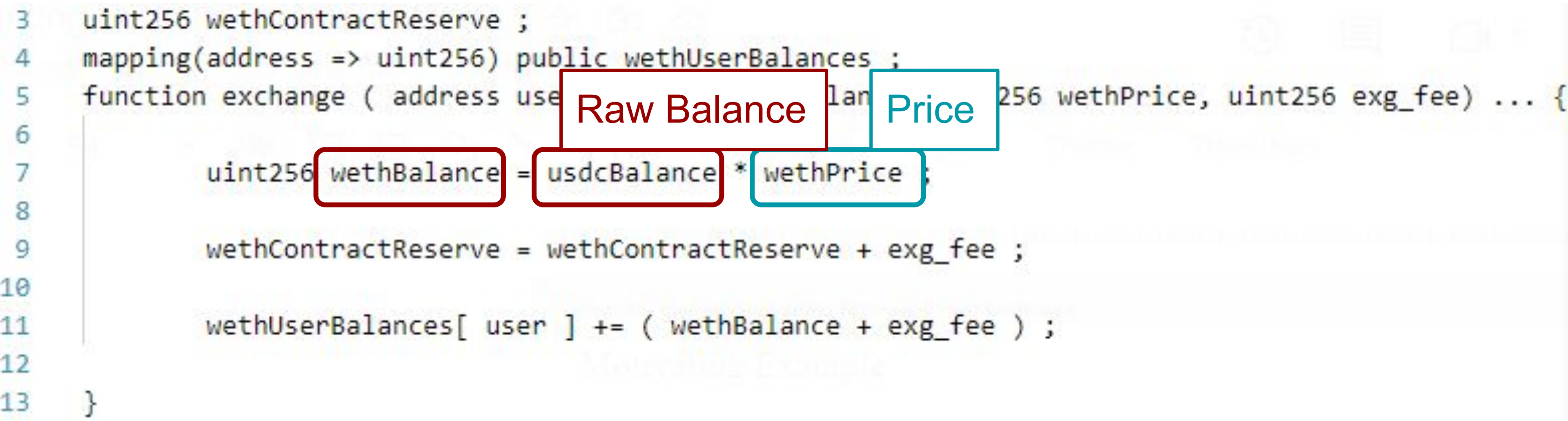
Motivating Example

- “*wethBalance*” has financial meaning “Raw Balance”
    - “*usdcBalance*” (Raw Balance) * “*wethPrice*” (Price) = “*wethBalance*” (Raw Balance)



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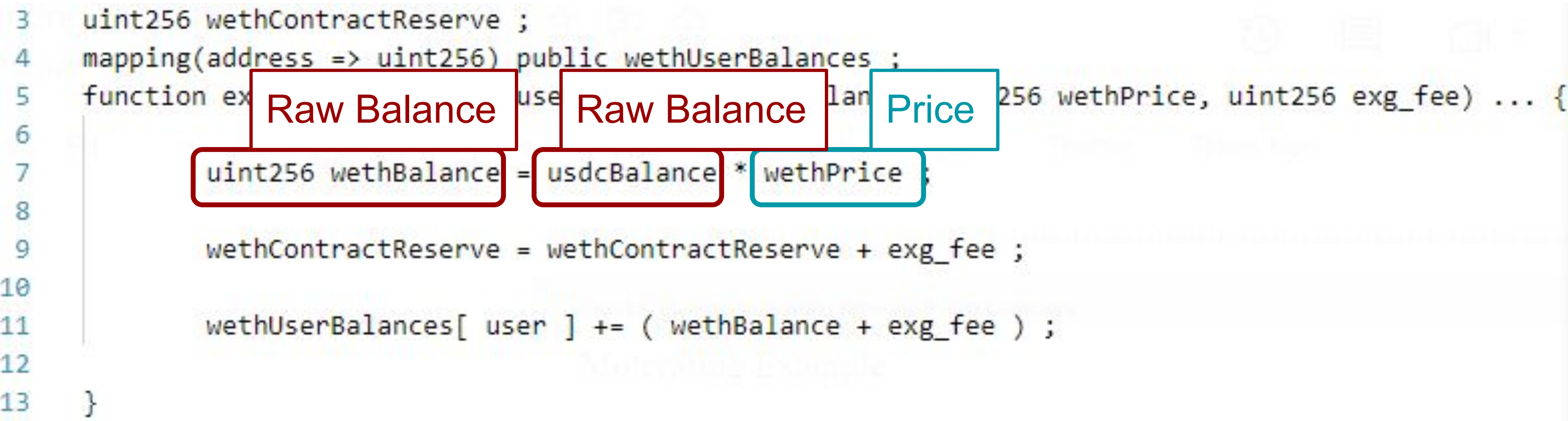
Motivating Example

- "*wethBalance*" has financial meaning "Raw Balance"
  - "*usdcBalance*" (Raw Balance) * "*wethPrice*" (Price) = "*wethBalance*" (Raw Balance)
  - Intuitively, multiply by price only changes the token unit, not the meaning



```
uint256 wethContractReserve ;
mapping(address => uint256) public wethUserBalances ;
function ex                  use                  lan           256 wethPrice, uint256 exg_fee) ... {

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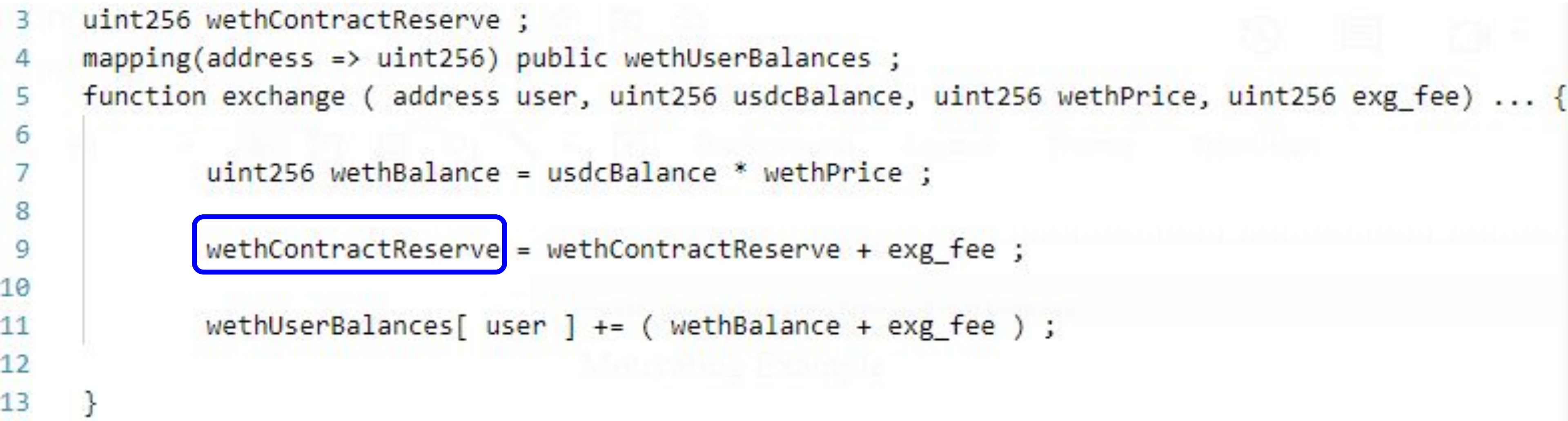
}
```

Motivating Example

- "*wethContractReserve*" has financial meaning "Reserve"
  - "*wethContractReserve*" (Reserve) + "*exg_fee*" (Fee) = "*wethContractReserve*" (Reserve)



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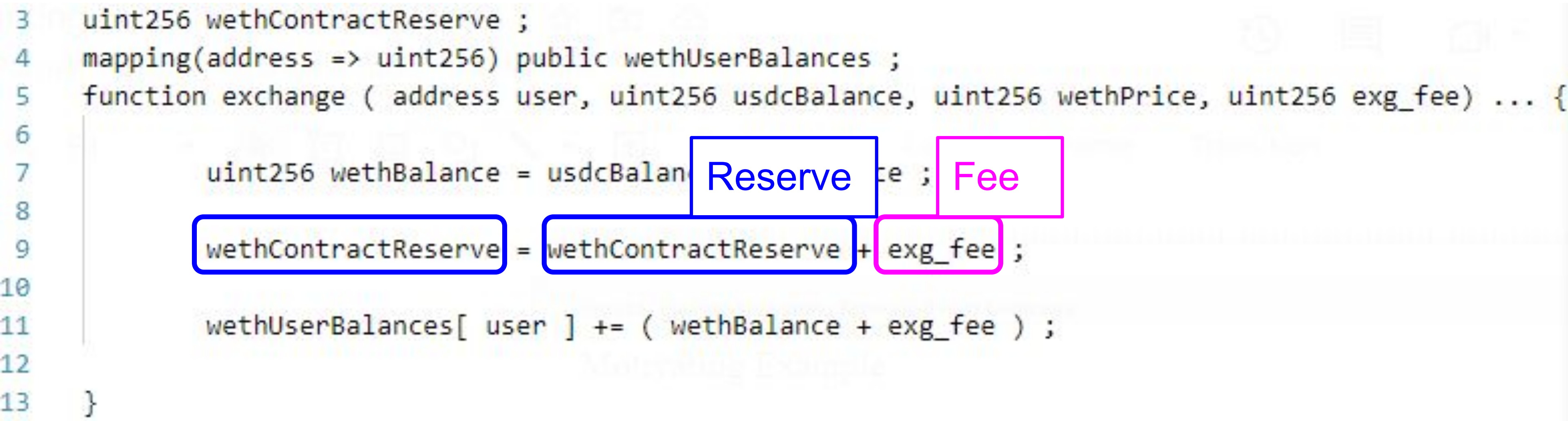

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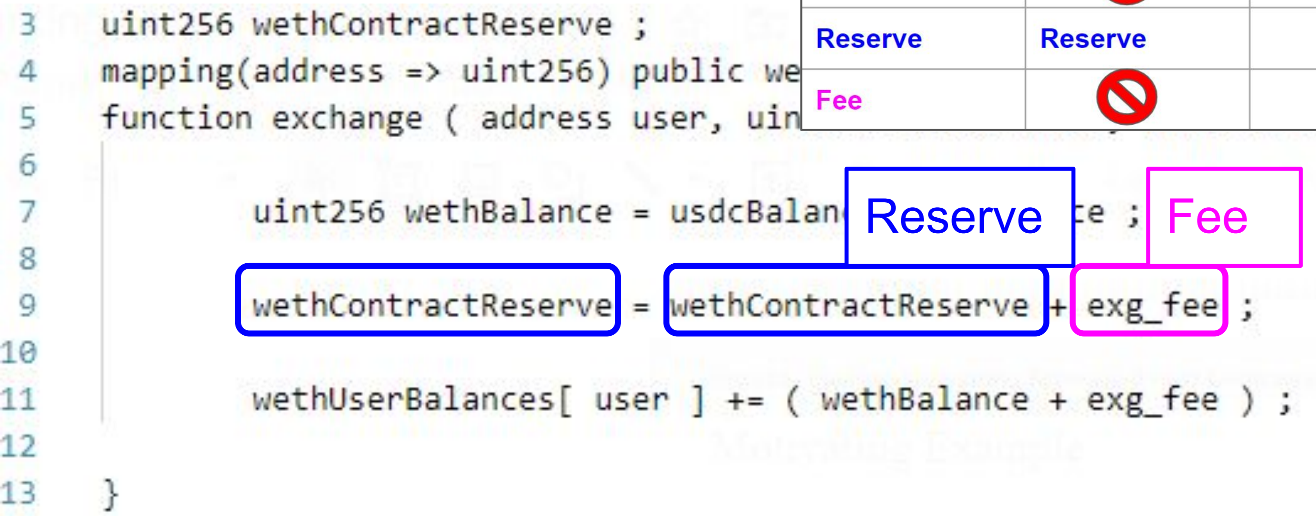
+	Raw Balance	Price	Reserve	Fee
Raw Balance	Raw Balance	🚫	Reserve	🚫
Price	🚫	Price	🚫	🚫
Reserve	Reserve	🚫	Reserve	Reserve
Fee	🚫	🚫	Reserve	Fee



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mapping(address => uint256) public we
function exchange ( address user, uin

        uint256 wethBalance = usdcBalan        te ;

        wethContractReserve = wethContractReserve + exg_fee ;

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- "*wethContractReserve*" has financial meaning "Reserve"
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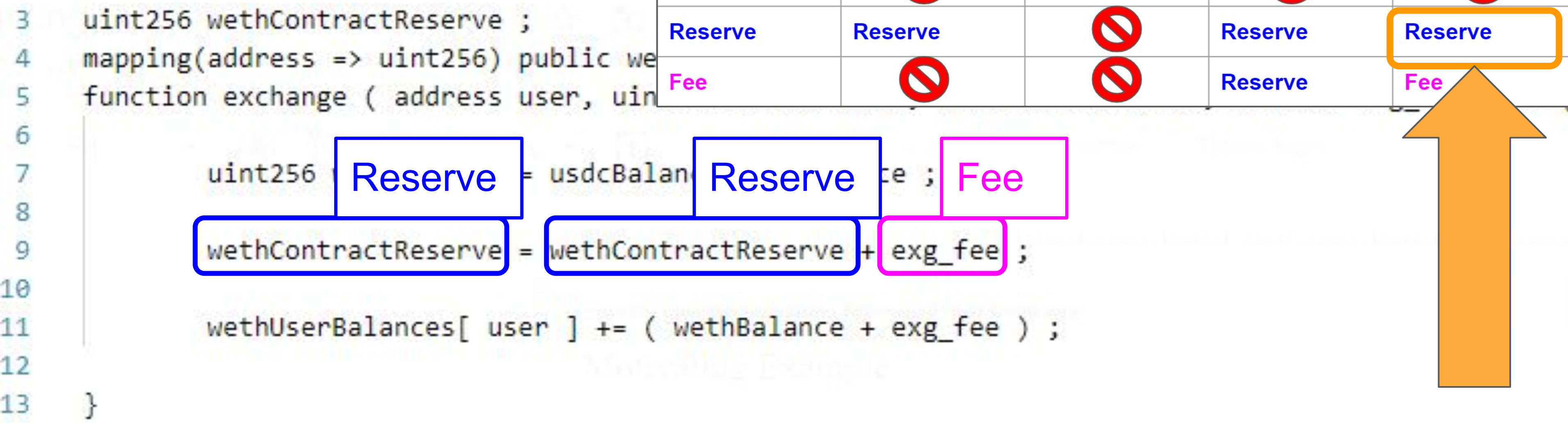
+	Raw Balance	Price	Reserve	Fee
Raw Balance	Raw Balance	🚫	Reserve	🚫
Price	🚫	Price	🚫	🚫
Reserve	Reserve	🚫	Reserve	Reserve
Fee	🚫	🚫	Reserve	Fee



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}
```
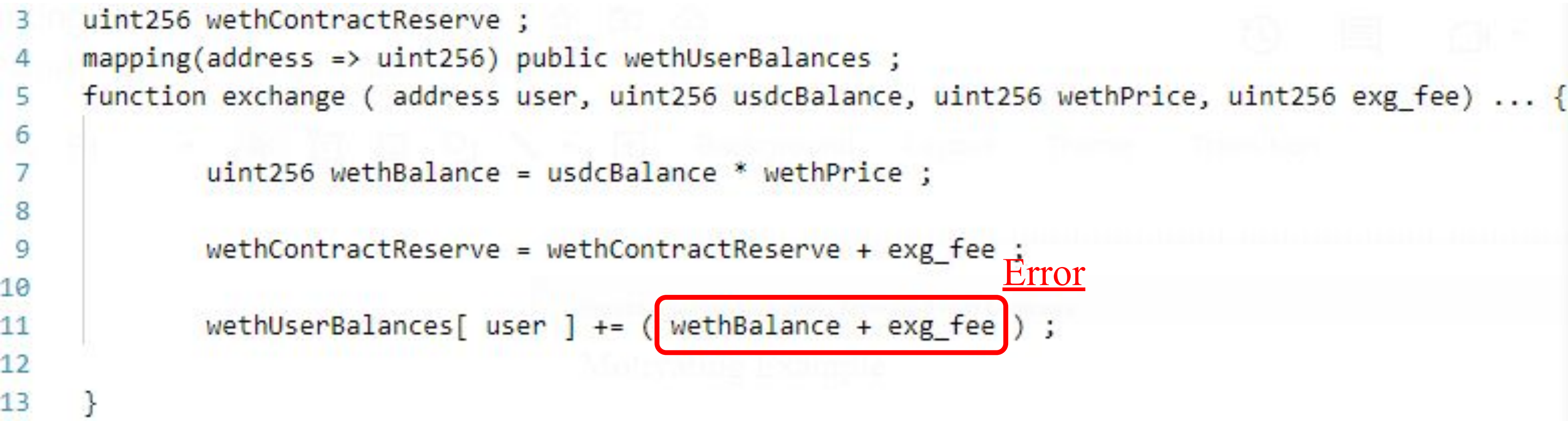

Motivating Example

- Error detected on line **11**
  - "*wethBalance*" (Raw Balance) + "*exg_fee*" (Fee) = Error
  - Intuitively, "Fee" should only be taken away from a user's "Raw Balance" and added to a contract's "Reserve"



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6
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8
9           wethContractReserve = wethContractReserve + exg_fee ;
10
11          wethUserBalances[ user ] += ( wethBalance + exg_fee ) ;
12
13  }
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+	Raw Balance	Price	Reserve	Fee
Raw Balance	Raw Balance	🚫	Reserve	🚫
Price	🚫	Price	🚫	🚫
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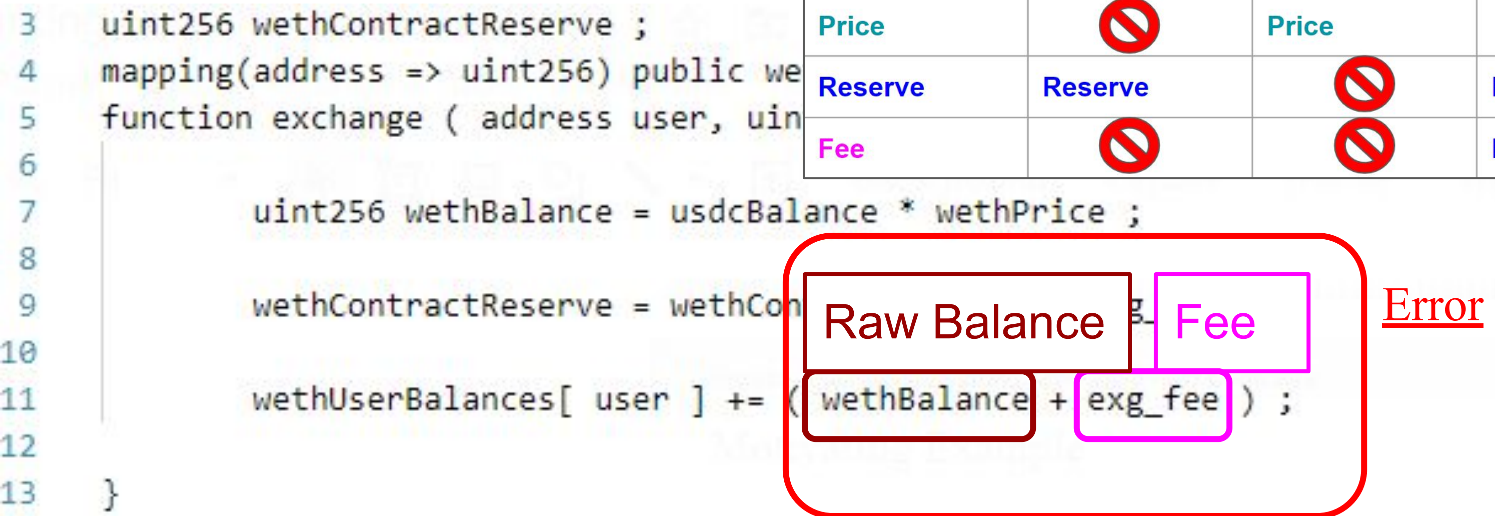
Fee	🚫	🚫	Reserve	Fee



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```

Extended Type - Token Unit

- **Token Unit** represents the token denomination of a variable
  - Tokens are cryptocurrencies (Example 1: USDC, WETH)
- Intuitively, it is analogous to the symbols: “$” and “¥”

Extended Type - Scaling Factor

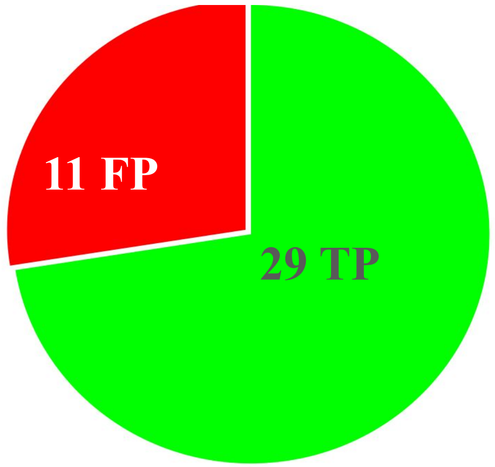
- Floating points are not supported in Solidity
  - Rely on scaling values by large factors (i.e. 1e18)
- Scaling Factor denotes how much a certain variable has been scaled

Research Questions

- **RQ1: How effective is ScType at disclosing accounting bugs?**
- **RQ2: How effective is ScType at disclosing zero-day vulnerabilities?**
- RQ3: How efficient is ScType?
- RQ4: What are the categories and distributions of accounting bugs?
- RQ5: What is the capacity of the type system?

RQ1: How effective is ScType at disclosing accounting bugs?

Ran ScType on **29 projects**, covering **57 accounting error bugs**



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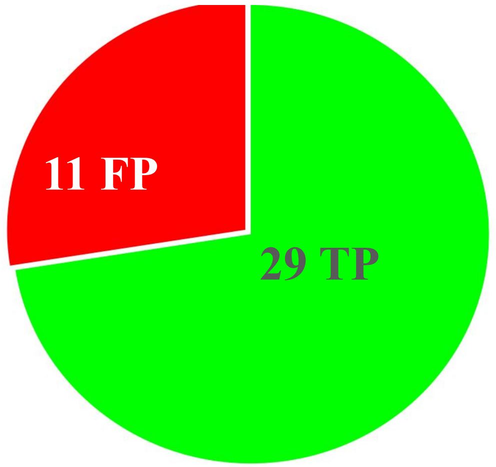

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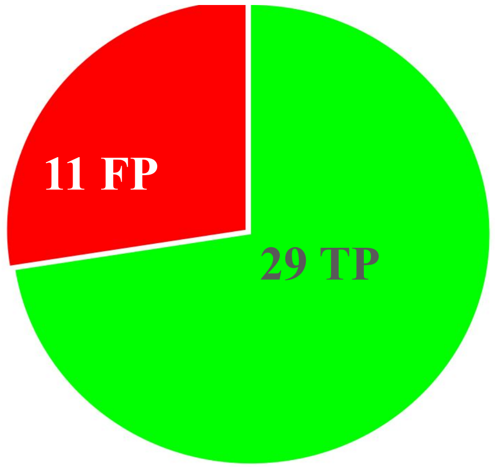
- 57 -24 = 33 accounting error bugs are in scope



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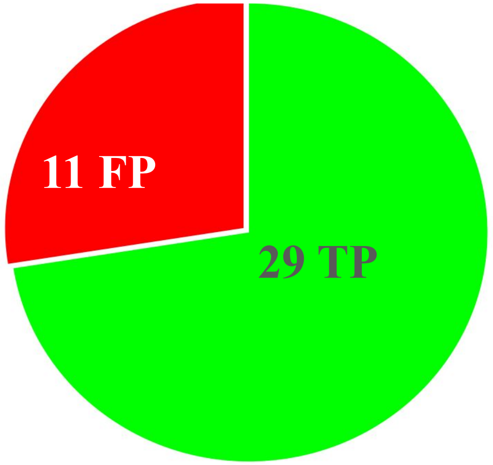

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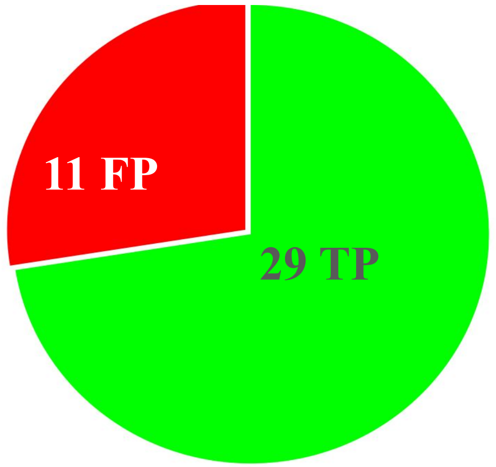
It achieves an accuracy of: 29/33 = <u>**87.8%**</u>



RQ2: Effectiveness at disclosing zero-day vulnerabilities?

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- Code4rena is a vendor for smart contract auditing competitions

ScType was run on 9 smart contracts

- Found **6 zero-day vulnerabilities**, 4 leading to direct fund loss
- Awarded **$6,000** as a result

Related Work

- **Liu and Y. Li, “Invcon: A dynamic invariant detector for ethereum smart contracts,” Proceedings of the 37th IEEE/ACM International Conference on Automated Software Engineering, 2022.**
- **Y. Liu, Y. Li, S.-W. Lin, and R.-R. Zhao, “Towards automated verification of smart contract fairness,” Proceedings of the 28th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering, 2020.**
- ***Smart Contract and DeFi Security Tools: Do They Meet the Needs of Practitioners?***

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- ExtendedType models Financial Meaning, Token Unit, and Scaling Factor
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- ExtendedType models Financial Meaning, Token Unit, and Scaling Factor
  - Capable of achieving 87% accuracy on the Benchmark
  - Caught 6 0-days with $6,000 in rewards

Thanks!

Reusable v1.1

Available v1.1

Github QRCode

Paper QRCode

Towards Finding Accounting Errors in Smart Contracts

- RQ2: How efficient is ScType?

TODO

Motivating Example 1

```
function getTotalBalance(address _user) external returns (uint256 total){
    uint256 USDCAmount = USDC.balanceOf(_user);
    uint256 WETHAmount = WETH.balanceOf(_user);
    uint256 totalAmount = USDCAmount + WETHAmount;
    USDC.transfer(_user, totalAmount);
}
```

Error should be reported here

[Corrected] Motivating Example 2

```
uint256 wethContractReserve ;
mapping(address => uint256) public wethUserBalances ;
function applyTrade ( address user, uint256 usdcBalance, uint256 usdcToWethPrice, uint256 feeRate ) internal pure returns ... {
        uint256 wethBalance = usdcBalance * usdcToWethPrice / 1e18 ;
        uint256 fee = wethBalance * feeRate / 1e18 ;
        wethContractReserve += fee ;
        wethUserBalances[ user ] += ( wethBalance - fee ) ;
}
```

Motivating Example 2

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uint256 wethContractReserve ;
mapping(address => uint256) public wethUserBalances ;
function applyTrade ( address user, uint256 usdcBalance, uint256 usdcToWethPrice, uint256 feeRate ) internal pure returns ... {

        uint256 wethBalance = usdcBalance * usdcToWethPrice / 1e18 ;

        uint256 fee = wethBalance * feeRate / 1e18 ;

        wethContractReserve += fee ;

        wethUserBalances[ user ] += ( wethBalance + fee ) ;

}
```

Error should be reported here

[ScType] Example 2

- RQ3: What are the categories and distributions of accounting bugs?

TODO

- RQ4: What is the capacity of the type system?

TODO

Towards Finding Accounting Errors in Smart Contracts

Slither?

Abstract typing?

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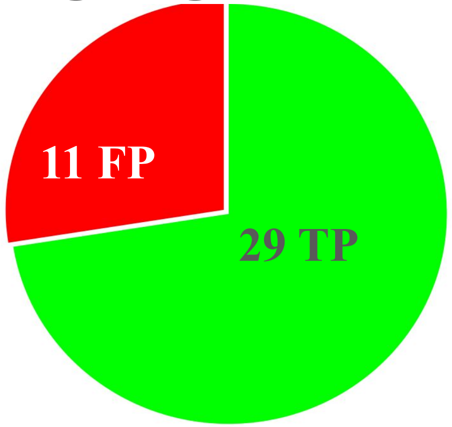
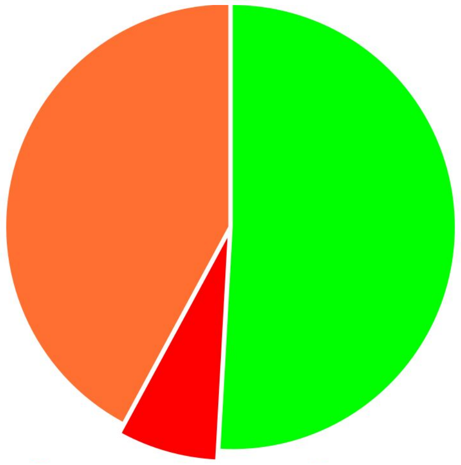
- ScType reports 29 True Positives and 11 False Positives

Of the 57 accounting error bugs, 24 are out of scope

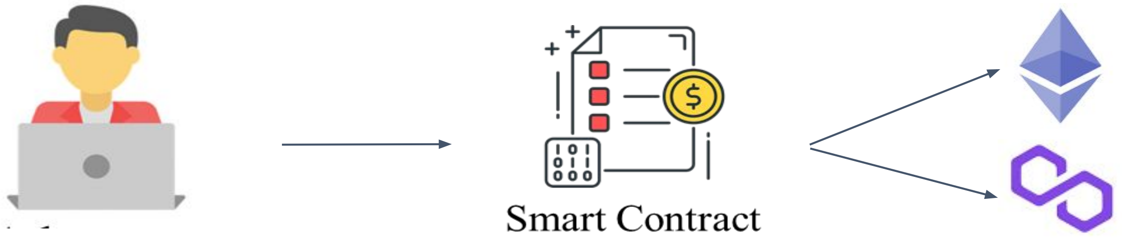
- Belong to other categories (i.e. Pure math errors)
- Hence, only 4 are not detected

ScType has an accuracy of 29/(29+4) = 87.9%





Spare pictures


Smart Contract