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Automated Inference on Financial Security of Ethereum Smart Contracts

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Background

Wide usage

- financial industry
- Internet of Things
- …

High value

- managing assets
- market cap of ethers keeps growing

Attractive for attackers

- June 2016, DAO, $150M
- July 2017, Parity wallet, $30M
- August 2021, Poly Network, $27M

It is necessary to guarantee the financial security of Ethereum smart contracts

Existing Security Analyzers

- Automated bug-finding tools
  - ➢ support automated analysis on a great amount of smart contracts
  - ➢ based on pre-defined patterns and not accurate enough
- Semi-automated verification frameworks
- Automated verifiers

Existing Security Analyzers

- Automated bug-finding tools
- Semi-automated verification frameworks
  - ➢ formally verify the correctness or security of smart contracts
  - ➢ require manually-defined properties
- Automated verifiers

Existing Security Analyzers

- Automated bug-finding tools
- Semi-automated verification frameworks
- Automated verifiers
  - try to provide sound and automated verification of pre-defined properties for smart contracts
  - eThor does not aim for the financial security of smart contracts
  - SECURIFY does not support solving numerical constraints
  - ZEUS has soundness issues in transforming contracts into IR

Example1

```
contract Ex1{
    mapping(address=>uint) balances;
    constructor() public{
        balances[0x12] = 100;
    }
    function transfer (address to,uint value) public{
        uint val1 = balances[msg.sender] - value;
        uint val2 = balances[to] + value;
        balances[msg.sender] = val1;
        balances[to] = val2;
        return;
    }
}
```

- **Normal case**:

  balances[msg.sender]-=value, balances[to]+=value

Example1

```
1   contract Ex1{
2       mapping(address=>uint) balances;
3       constructor() public{
4           balances[0x12] = 100;
5       }
6       function transfer (address to,uint value) public{
7           uint val1 = balances[msg.sender] - value;
8           uint val2 = balances[to] + value;
9           balances[msg.sender] = val1;
10          balances[to] = val2;
11          return;
12      }
13  }
```

overwrite the result of line 9

- **Abnormal case**:

  msg.sender=to, balances[to]+=value

Questions

- How to generate properties automatically?
- How to translate contracts into models automatically?
- How to verify the properties against the models automatically?

Automated Property Generation

Challenge

- There is no uniform standard for the security requirements of contracts

- Most existing automated tools define patterns or properties according to known vulnerabilities
  - ➢ The vulnerabilities that can be covered are limited to known ones
  - ➢ Even a variant of a known vulnerability may evade their detection

Automated Property Generation

Observation

- Most of the contracts are finance-related

(related to ethers or tokens)

Our goal

- Analyze the financial security of smart contracts

↓

Focus on

- ethers and tokens

Automated Property Generation

Method

- Categories
  - ether-related
  - token-related
  - indirect-related
  - non-finance-related

Automated Property Generation

Method

- Identification
  - ether-related : *transfer, send, call, payable*
  - token-related : *balances, ownedTokenCount*

  (most token contracts use similar variable names to denote token balances)

Automated Property Generation

Method

- Property generation
  - Invariant property (token-related) :

$$\sum_{a \in A_1} balances = C_1$$

Automated Property Generation

Method

- Property generation
  - Equivalence property (ether-related, token-related):

given two sequences A and B consisting of the same transactions

$$balances_A(adv) = balances_B(adv)$$
$$\land$$
$$balance_A(adv) = balance_B(adv)$$

Example: invariant property

```
contract Ex1{
    mapping(address=>uint) balances;
    constructor() public{
        balances[0x12] = 100;
    }
    function transfer (address to,uint value) public{
        uint val1 = balances[msg.sender] - value;
        uint val2 = balances[to] + value;
        balances[msg.sender] = val1;
        balances[to] = val2;
        return;
    }
}
```

- **Abnormal case**:

msg.sender=to, balances[to]+=value

Example: invariant property

```
contract Ex1{
    mapping(address=>uint) balances;
    constructor() public{
        balances[0x12] = 100;
    }
    function transfer (address to,uint value) public{
        uint val1 = balances[msg.sender] - value;
        uint val2 = balances[to] + value;
        balances[msg.sender] = val1;
        balances[to] = val2;
        return;
    }
}
```

The invariant property is violated

- **Abnormal case**:

$$\sum balances += value$$

Automated Property Generation

Advantage of our properties

- Cover 6 types of vulnerabilities
  - Invariant property: overflow/underflow, transferMint
  - Equivalence property: reentrancy, gasless send, TD, TOD
- Not limited to known vulnerabilities
  - transferMint (not supported by automated tools in our evaluation)

Automated Modeling and Verification

2-step modeling

- Generates different models according to different properties
  - Invariant property: 1-safety
  - Equivalence property: 2-safety

- Independent modeling module generates partial models of smart contracts (Written in Solidity language)

- Complementary modeling module modifies the models according to different properties

Automated Modeling and Verification

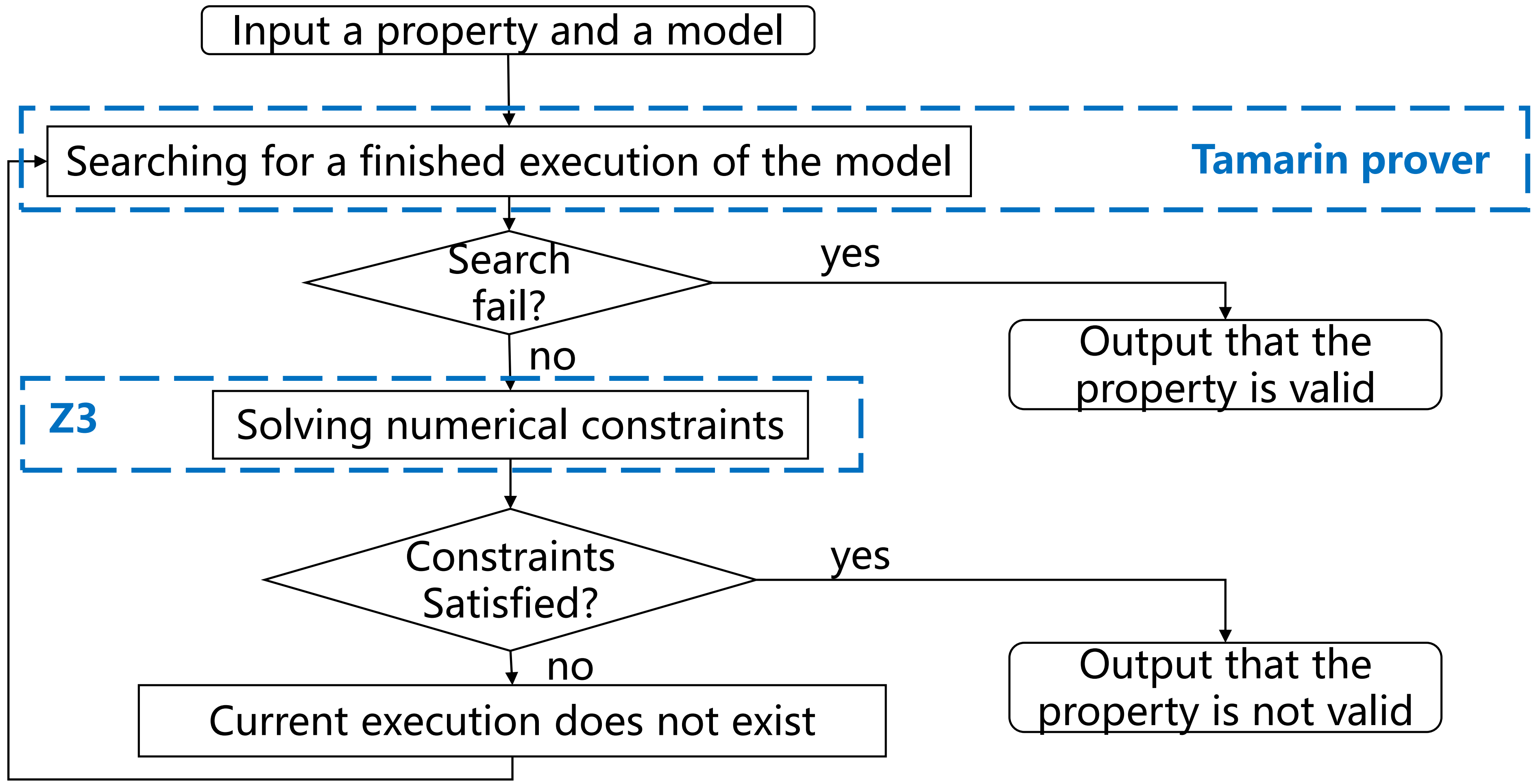
2-step modeling

- We prove the soundness of translation from Solidity language to our models based on KSolidity (a custom semantics of Solidity, IEEE S&P 2022)

Theorem 1 (Soundness). If an invariant property (or equivalence property) holds in the complementary model of FASVERIF, it holds in real-world transactions interpreted by KSolidity semantics.

Automated Modeling and Verification

Verification



Evaluation

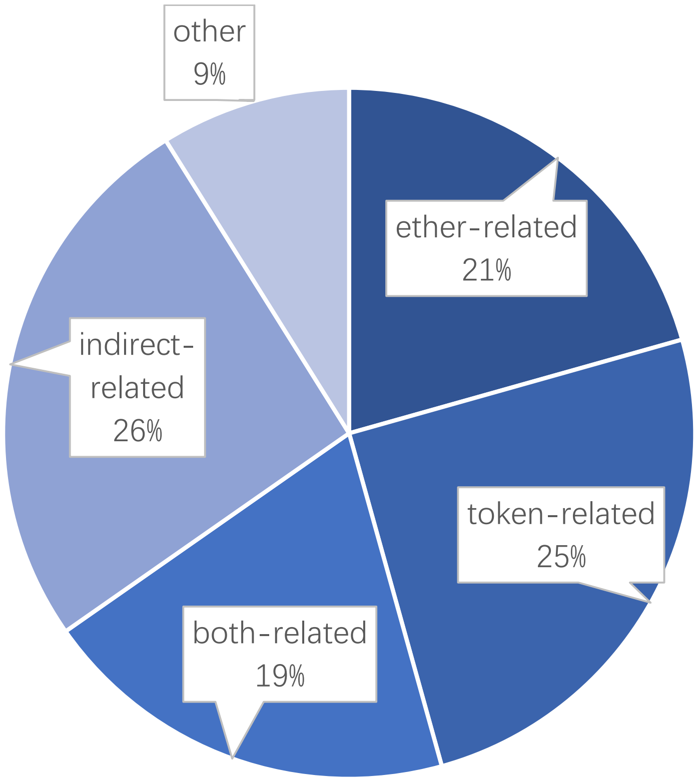
Dataset

- Vulnerability dataset: 549 contracts collected from public datasets of other works
  - transaction order dependency (TOD)
  - timestamp dependency(TD)
  - Reentrancy
  - gasless send
  - overflow/underflow
  - transferMint

- Real-world dataset: 30577 contracts crawled from Etherscan

Evaluation

Statistical analysis



threshold	70	75	80	85	90
Acc(%)	98.31	98.32	98.32	98.50	98.46
F1(%)	98.13	98.14	98.14	98.31	98.27

- the accuracy of our method to identify token contracts is higher than 98%

- 27858/30577 finance-related contracts

Evaluation

Comparison

Table 1: A comparison of representative automated analyzers for smart contracts. (Acc and F1 outside brackets correpsond to the finance-vulnerable contracts, while those inside brackets correpsond to the vulnerable contracts, * denote automated verifiers)

Types of Vulnerabilities	Osiris		SECURIFY*		Mythril		OYENTE		VERISMART		SmartCheck		Slither		Manticore		eThor*		FASVERIF *		
	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	Acc(%)	F1	U
TOD-eth	/	/	96.43	0.98	/	/	42.86	0.6	/	/	/	/	/	/	/	/	/	/	100	1	10
TOD-token	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	100	1	0
TD	71.60 (70.37)	0.83 (0.82)	/	/	45.68 (44.44)	0.62 (0.62)	76.54 (75.31)	0.87 (0.86)	/	/	/	/	16.05 (14.81)	0.26 (0.25)	24.69 (23.46)	0.38 (0.38)	/	/	95.06 (93.83)	0.97 (0.96)	33
reentrancy	66.67 (69.05)	0.79 (0.81)	78.57 (76.19)	0.85 (0.84)	71.42 (69.04)	0.81 (0.8)	73.81 (76.19)	0.85 (0.86)	/	/	73.81 (76.19)	0.85 (0.86)	85.71 (83.33)	0.91 (0.90)	38.09 (35.71)	0.41 (0.40)	83.72 (86.05)	0.92 (0.93)	90.48 (88.10)	0.94 (0.93)	2
gasless send	/	/	92.19	0.95	82.35	0.67	/	/	/	/	92.19	0.95	85.94	0.91	29.69	0.26	/	/	100	1	7
overflow/underflow	81.20 (81.20)	0.89 (0.89)	/	/	95.30 (95.30)	0.97 (0.97)	90.27 (90.27)	0.95 (0.95)	98.99 (98.99)	0.99 (0.99)	/	/	/	/	19.40 (19.40)	0.11 (0.11)	/	/	99.33 (99.33)	0.99 (0.99)	4
transferMint	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	100	1	0

- FASVERIF achieves higher accuracy and F1 values than other automated tools
- Only FASVERIF can detect all of the 6 types of vulnerabilities

Evaluation

Analysis of 1700 real-world contracts

```
contract Ex1{
    mapping(address=>uint) balances;
    constructor() public{
        balances[0x12] = 100;
    }
    function transfer(address to,uint value) public{
        uint val1 = balances[msg.sender] - value;
        uint val2 = balances[to] + value;
        balances[msg.sender] = val1;
        balances[to] = val2;
        return;
    }
}
```

- 10 contracts with transferMint, 3 contracts with TD

Limitations (Still working on them)

- The average time to analyze a contract using FASVERIF is longer than the one using other automated tools.
- There are still some financial security properties and financial vulnerabilities that are unsupported by FASVERIF
- Solidity language is not fully supported.
- …

Thank you for listening!

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