Sereum: Protecting Existing Smart Contracts Against Re-Entrancy Attacks

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The DAO Hack
17 June 2016
3.6 Million Ether Stolen
worth $50 Million
5% of all available Ether
The DAO Aftermath

Hard-Fork

Ethereum ETH

Ethereum Classic ETC
The DAO Attack

Child DAO
Balance: 100

The DAO
splitDAO(...)
Check Attacker Balance
Transfer Amount
Update Attacker Balance

Attacker
Withdraw to Child DAO

Re-Entrancy Vulnerability

Attacker Balance: 100
Balance: 0
Can we automatically detect re-entrancy vulnerabilities?
Prior Research on
Bug Finding and Exploitation in Smart Contracts

Symbolic execution

- **Oyente** [Luu et al., CCS16]
- **Manticore** (Trail of Bits)
- **Mythril** (ConsenSys)

Runtime Checking

- **ECFChecker** [Grossman et al., POPL18]
- **MAIAN** [Nikolic et al., ACSAC18]
- **OSIRIS** [Torres et al., ACSAC18]

Verification

- **ZEUS** [Kalra et al., NDSS18]

**Static analysis**

- **Securify** [Tsankov et al., CCS18]
- **SmartCheck** [Tikhomirov et al., CCS18]
Current Bug Finding Tools

- Cover many vulnerability types
- No protection of deployed contracts
- Do not analyze combination of contracts
- Many false positives
Our Research Questions:

1. Do existing tools cover all re-entrancy bugs?
2. Can we protect deployed contracts?
Our Contributions

- Overlooked re-entrancy attack patterns
- Sereum – Hardened Ethereum Client
- Taint tracking engine for EVM bytecode
- Runtime detection of re-entrancy attacks
- Investigation of root causes for false positives
Overlooked re-entrancy problems
Attack 1: Cross-Function Re-Entrancy

Victim Contract

Attacker Contract

Malicious
Attack 2: Delegated Re-Entrancy

Victim Contract

Library Contract

Attacker Contract

Malicious

DELEGATECALL

A

B
Attack 3: Create-Based Re-Entrancy

- Victim Contract
- Attacker Contract
- Newly Created Contract
- Malicious

A
CREATE
Constructor
# Overview on Re-Entrancy Detection

<table>
<thead>
<tr>
<th>Tool</th>
<th>Same-Function</th>
<th>Cross-Function</th>
<th>Delegated</th>
<th>Create-based</th>
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</thead>
<tbody>
<tr>
<td><strong>Oyente</strong></td>
<td>✓</td>
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<tr>
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<td>✓</td>
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</table>

* Conservative policy with high number of false positives
Main Observation

Typically re-entrancy attacks exploit inconsistent state at the time the vulnerable contract decides whether to take a branch.
function withdraw(uint amount)

if (balance[msg.sender] >= amount)

msg.sender.call.value(amount)("");  
balance[msg.sender] -= amount;

return;

Mark variables that influence branching decisions as critical

Prevent further updates with write-locks
Sereum Architecture

Ethereum Virtual Machine (EVM)
go-ethereum

Transaction Manager
Bytecode Interpreter

Sereum

Attack Detector
Taint Engine

Enforcement:
Transaction roll-back on detected attack
Evaluation Results

Evaluation on first 4.5 Million Ethereum blocks

- Successful detection of The DAO incident
- Manual reverse-engineering and analysis of flagged transactions
- ~50k flagged transactions
- ~2k true attack transactions
- 14 distinct contracts result in false positive

New Finding:
The curios case of DSEthToken

- Developers hacked their own contract
- 7 days before The DAO incident

FP rate: 0.06%
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Questions?

github.com/uni-due-syssec/eth-reentrancy-attack-patterns
Backup Slides
Sereum Performance

* Benchmark: Execute 50 Blocks in Batch (10 000 repetitions)
  * Sereum – mean 2494.5 ms (σ = 174.8 ms)
  * Geth – mean 2277.0 ms (σ = 146.7 ms)
  * Mean overhead: 9.6 %
  * Average memory consumption: geth 9252MB, Sereum 9767MB

* Timings on newer blocks (around block ~6 700 000)
  * Average 5 sec to process block with Sereum (about 150 TX)
  * New block every ~15 sec
  * Sereum can keep up with network!
Evaluation of Sereum

1. We verified that Sereum successfully detects the new attack patterns

2. Evaluation on the Ethereum blockchain
   - We re-executed all blocks up until block number 4,500,000 (77,987,922 transactions)
   - We detected attacks related to “the DAO”
   - Sereum flagged 49,080 transactions as re-entrancy attacks

3. We manually reverse-engineered and analyzed detected contracts/attacks
   - We identified 2,337 true attack transactions
   - Sereum has an overall false positive rate as low as 0.06%
   - We identified 5 major classes of root-causes of false positives (see details in the paper)
False Positive Causes

I. Lack of field-sensitivity on the EVM level
   • Small types packed densely into one storage address

II. Storage Deallocation
    • Deallocation: overwrite with zero

III. Constructor Callbacks
    • Instead of passing data as argument, retrieved

IV. Tight Contract Coupling
    • Contract execution passes between two or more contracts

V. Manual Re-Entrancy Locking
    • Manual locking is identical to malicious re-entrancy pattern
Sereum Usage

• Detection mode
  • Developer continuously runs Sereum
  • Re-play all public Ethereum transactions, looking for attacks
  • Developer reacts to attacks

• Enforcement mode
  • Integrate Sereum into all Ethereum clients
  • For example: private blockchain based on Ethereum
References

- J. Krupp and C. Rossow, “TeEther: Gnawing at Ethereum to Automatically Exploit Smart Contracts,” USENIX Security 2018