Smashing Smart Contracts

IT-SECX 2019

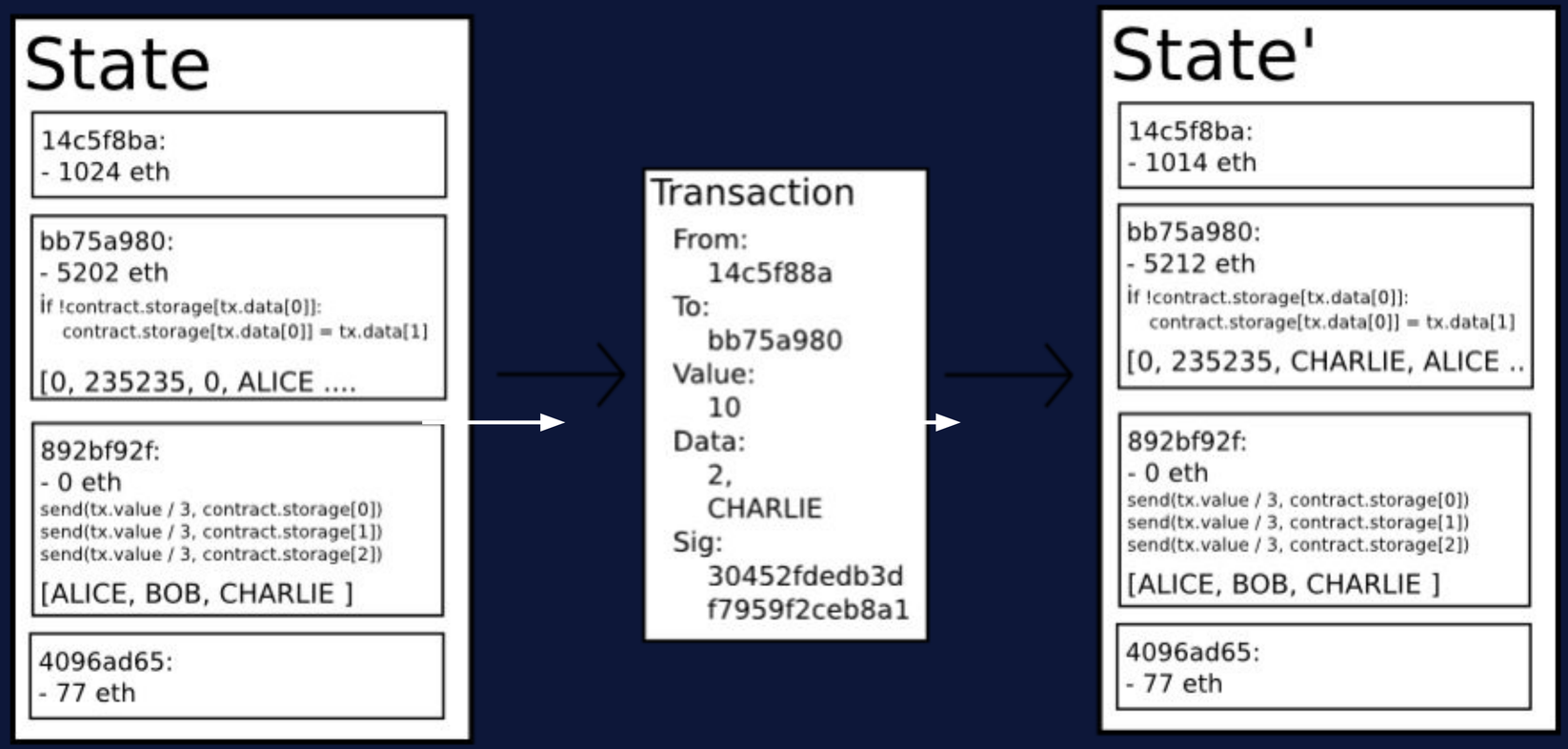
In this talk

- Ethereum intro
- Fast bug detection using symbolic execution of EVM bytecode (Mythril)
- Exploit automation (Scrooge McEtherface)
- Warfare on the Ethereum blockchain

What’s Ethereum?

- **It’s a blockchain like Bitcoin, but programmable**
- A platform for developing money protocols
- We can now send digital assets P2P
  - Tokens, stable coins, securities, bonds, kitties
- Create “money protocols” for payments, lending, fund allocation, decentralized organizations,...

Ethereum state machine



Smart contracts

- Mostly written in Solidity -> Compiles to Ethereum VM (EVM) bytecode

```
pragma solidity ^0.5.0;

contract Bausparvertrag {

    address payable sparefroh;
    uint256 reifedatum;

    constructor(address payable _addr) public payable {
        reifedatum = block.timestamp + 31556952;
        sparefroh = _addr;
    }

    function withdraw() public {
        require(block.timestamp > reifedatum);
        sparefroh.transfer(address(this).balance);
    }

}
```

A new meme is born!

($300 million destroyed forever)

m_numOwners is initially zero

Initialization function

Kill function

```
// throw unless the contract is not yet initialized.
modifier only_uninitialized { if (m_numOwners > 0) throw; _; }

// constructor - just pass on the owner array to the multiowned and
// the limit to daylimit
function initWallet(address[] _owners, uint _required, uint _daylimit) only_uninitialized {
  initDaylimit(_daylimit);
  initMultiowned(_owners, _required);
}

  // constructor is given number of sigs required to do protected "onlymanyowners" transactions
// as well as the selection of addresses capable of confirming them.
function initMultiowned(address[] _owners, uint _required) only_uninitialized {
  m_numOwners = _owners.length + 1;
  m_owners[1] = uint(msg.sender);
  m_ownerIndex[uint(msg.sender)] = 1;
  for (uint i = 0; i < _owners.length; ++i)
  {
    m_owners[2 + i] = uint(_owners[i]);
    m_ownerIndex[uint(_owners[i])] = 2 + i;
  }
      m_required = _required;
}

// METHODS

// gets called when no other function matches
function() payable {
  // just being sent some cash?
  if (msg.value > 0)
    Deposit(msg.sender, msg.value);
}

function isOwner(address _addr) view returns (bool) {
  return m_ownerIndex[uint(_addr)] > 0;
}

// kills the contract sending everything to `_to`.
function kill(address _to) onlyowner external {
  suicide(_to);
}
```


Parity WalletLibrary

Attacker’s goals

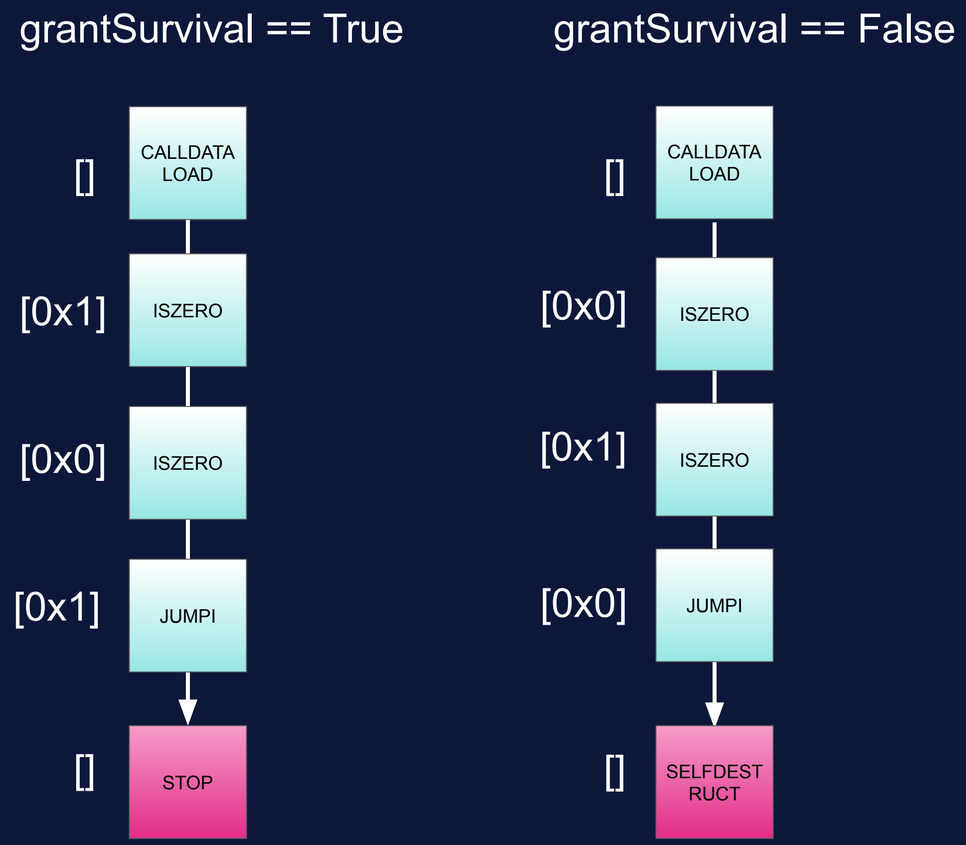
- Gain ownership of assets
  - Steal Ether (the native currency)
  - Steal tokens
  - Mint new tokens out for themselves
  - ....

Some tools we made

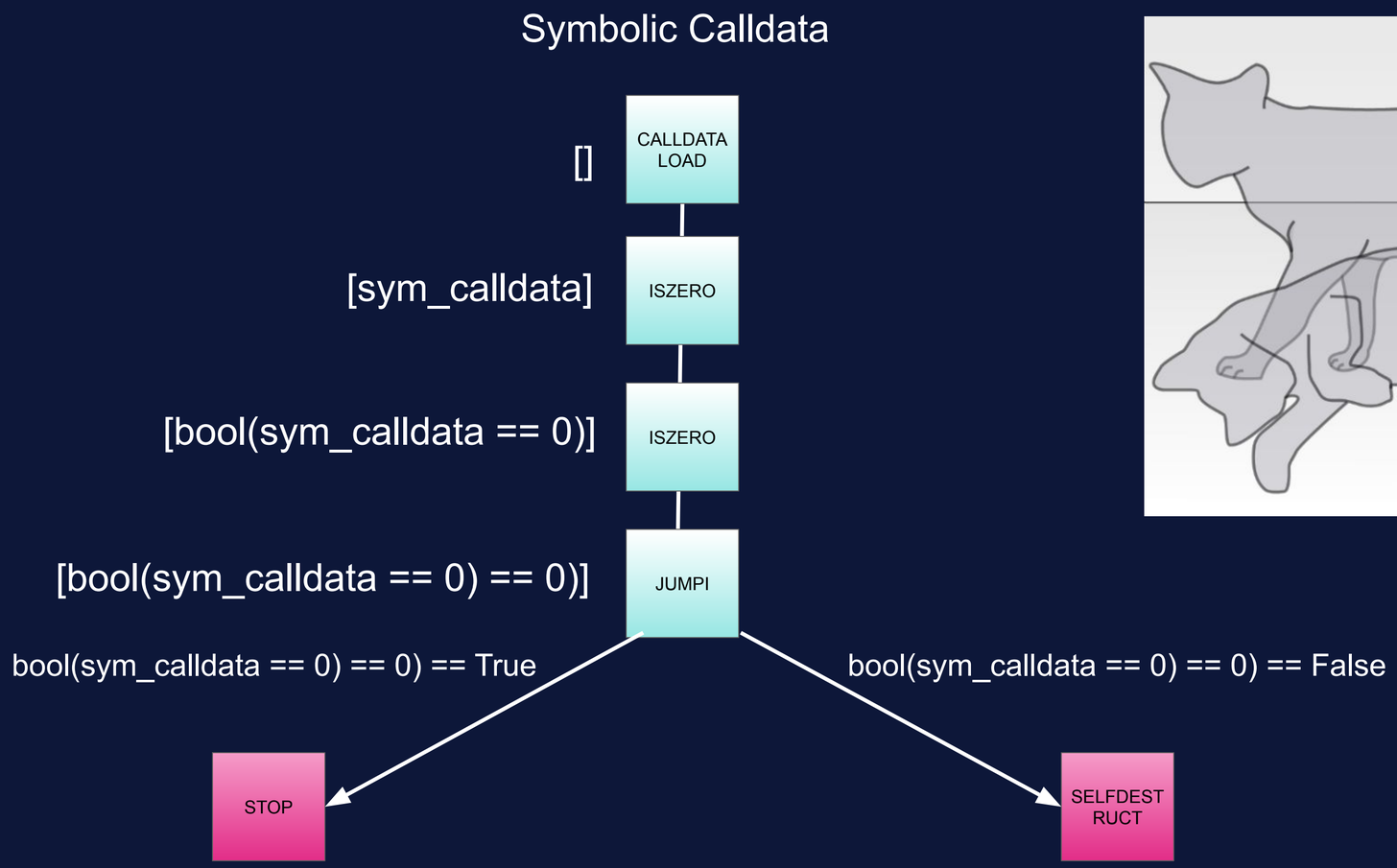
- Mythril: Symbolic Analyzer
  - https://github.com/ConsenSys/mythril
- Scrooge McEtherface: Auto-Exploiter
  - https://github.com/b-mueller/scrooge-mcetherface
- Karl: Blockchain Monitor
  - https://github.com/cleanunicorn/karl
- Theo: Frontrunning Tool
  - https://github.com/cleanunicorn/theo

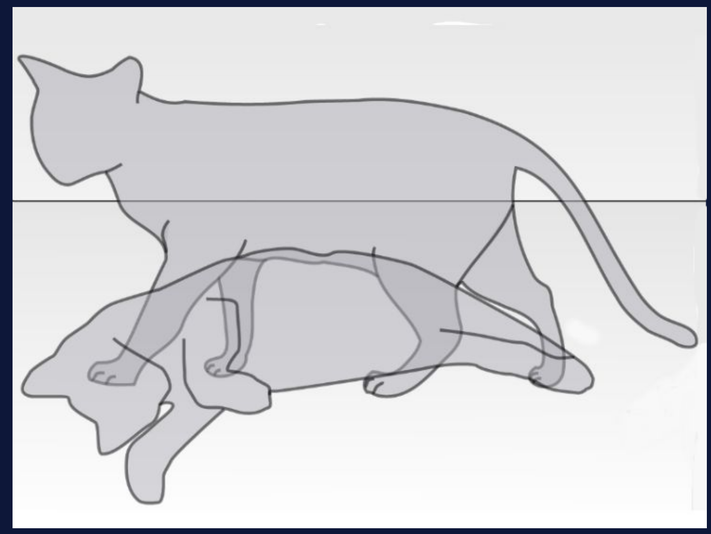
Symbolic execution (1)

```
contract Cat {

    function extend_life(bool grantSurvival) public {
        if (!grantSurvival) {
            selfdestruct(address(0x0));
        }
    }
}
```

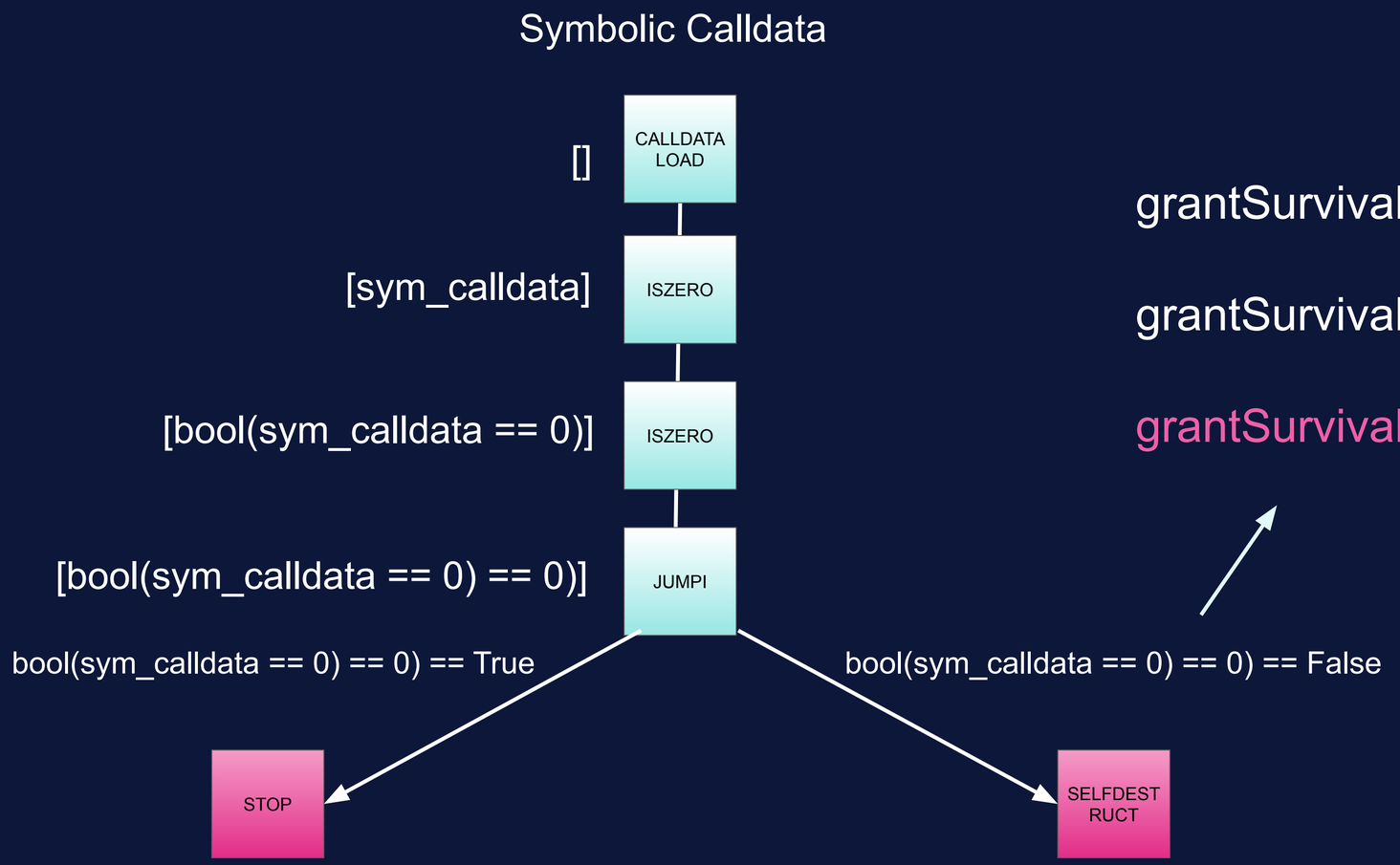


Symbolic execution (2)





How to kill the cat?



grantSurvival = ((0 == 0) == 0) == True

grantSurvival = (True == False) == True

grantSurvival = False

Further reading

- Introduction to Mythril and Symbolic Execution (Joran Honig)
  - https://medium.com/@joran.honig/introduction-to-mythril-classic-and-symbolic-execution-ef59339f259b
- Smashing Smart Contracts (B. Mueller, HITB GSEC 2018)
  - https://github.com/b-mueller/smashing-smart-contracts
- Advances in Smart Contract Vulnerability Detection (B. Mueller & D. Luca, DEFCON 2019)
  - ADD LINK

Mythril usage

$ pip install mythril

$ myth analyze <solidity_file>[:contract_name]

$ myth analyze -a <address>

Some flags:

$ myth -v4 analyze -t3 --execution-timeout 3600 <solidity_file>

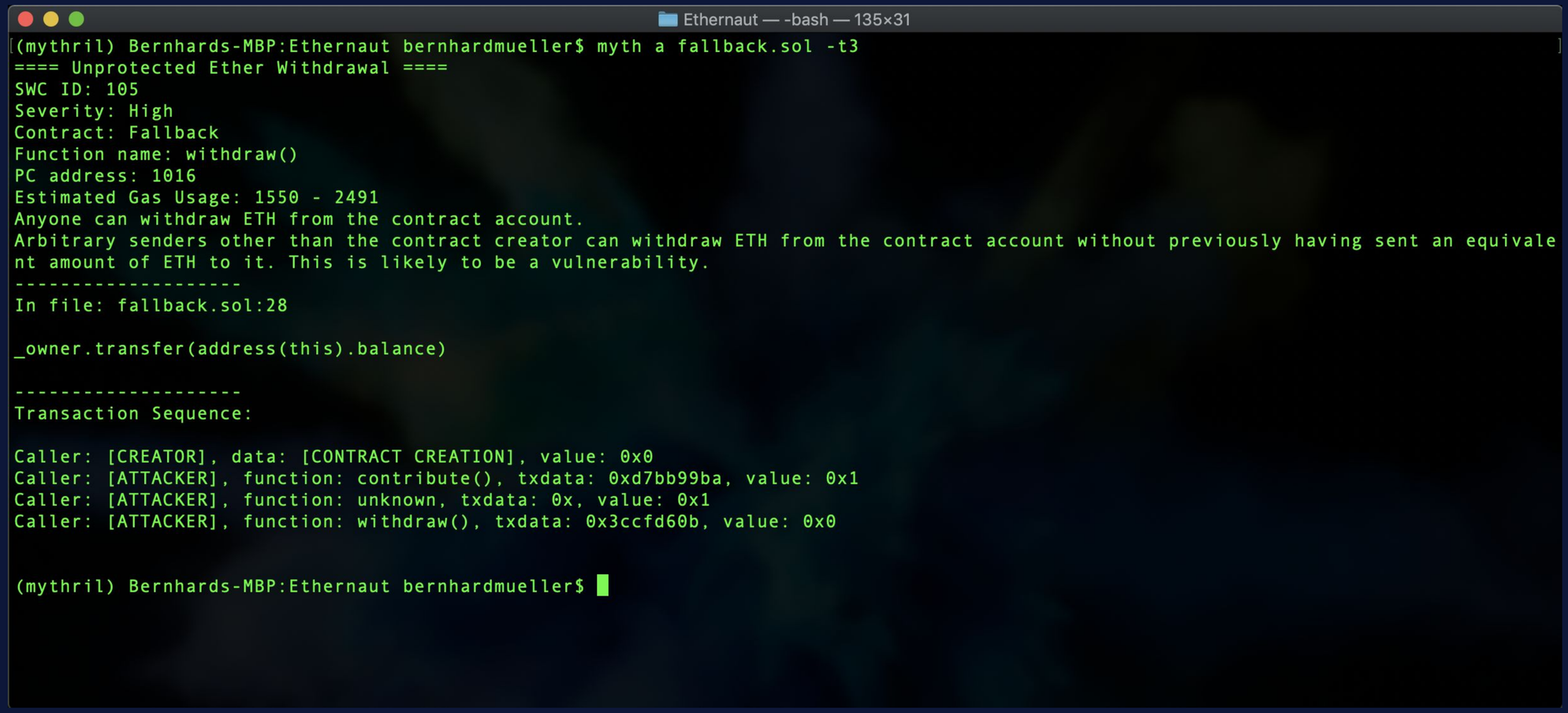
Example

- Level 1 of the Ethernaut Challenge
- To practice smart contract hacking check out these awesome pages:

https://ethernaut.openzeppelin.com
https://capturetheether.com
https://blockchain-ctf.securityinnovation.com

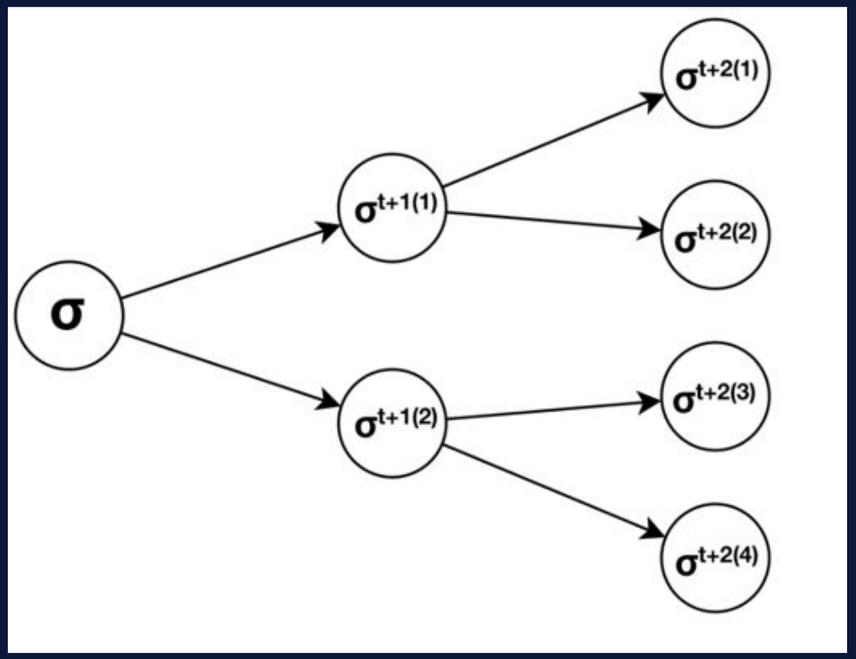
```
pragma solidity ^0.5.0;

import 'Ownable.sol';
import 'SafeMath.sol';

contract Fallback is Ownable {

  using SafeMath for uint256;
  mapping(address => uint) public contributions;

  constructor() public {
    contributions[msg.sender] = 1000 * (1 ether);
  }

  function contribute() public payable {
    require(msg.value < 0.001 ether);
    contributions[msg.sender] = contributions[msg.sender].add(msg.value);
    if(contributions[msg.sender] > contributions[_owner]) {
      _owner = msg.sender;
    }
  }

  function getContribution() public view returns (uint) {
    return contributions[msg.sender];
  }

  function withdraw() public onlyOwner {
    _owner.transfer(address(this).balance);
  }

  function() payable external {
    require(msg.value > 0 && contributions[msg.sender] > 0);
    _owner = msg.sender;
  }
}
```

Mythril output



State space explosion :(

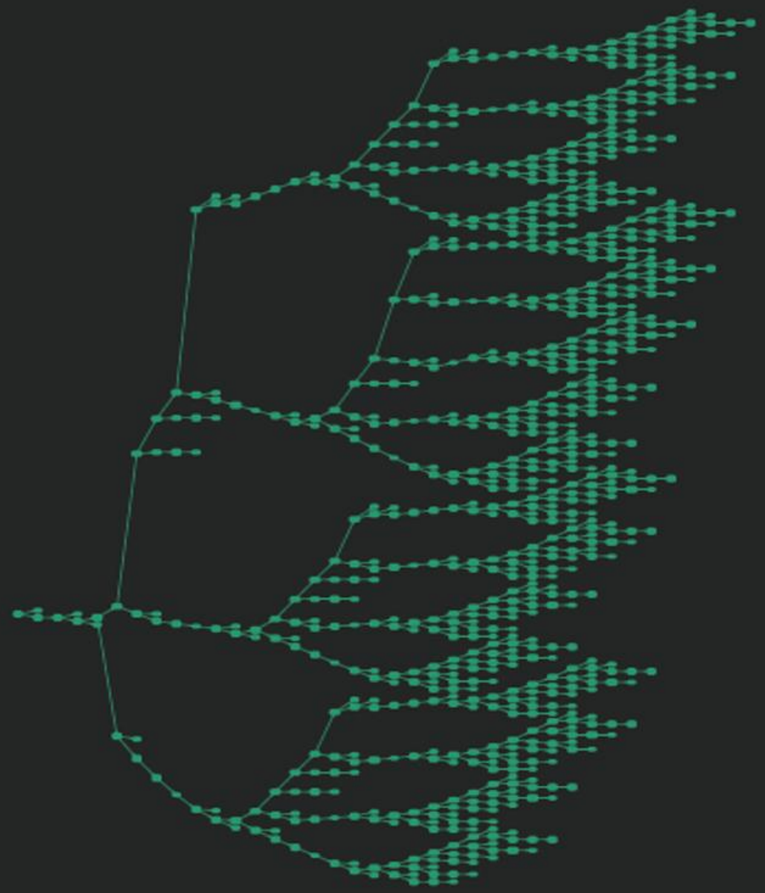
```
pragma solidity ^0.5.7;

contract KillBilly {
    uint256 private is_killable;
    uint256 private completelyrelevant;

    mapping (address => bool) public approved_killers;

    function engage_fluxcompensator(uint256 a, uint256 b) public {
        completelyrelevant = a * b;
    }

    function vaporize_btc_maximalists(uint256 a, uint256 b) public {
        completelyrelevant = a + b;
    }

    function killerize(address addr) public {
        approved_killers[addr] = true;
    }

    function activatekillability() public {
        require(approved_killers[msg.sender] == true);
        is_killable -= 1;
    }

    function commencekilling() public {
        require(is_killable > 0);
        selfdestruct(msg.sender);
    }

}
```



Mythril pruning algorithm

- Prune unreachable paths given concrete initial state
- Prune pure functions (STOP state == initial state)
- Dynamic pruning. Execute a path only if:
  - It is newly discovered
  - A state variable that was modified in the previous transaction is read somewhere along the path
  - Somewhere along this path, a state variable is written to that we know is being read elsewhere

teEther uses a similar method: https://www.usenix.org/node/217465



no pruning
8,807 states

prune pure functions
5,636 states (-36%)

dynamic pruning
3,355 states (-62%)

Mythril v0.21.12
State space graph for 3 transactions
killbilly.sol - https://gist.github.com/b-mueller/8fcf3b8a2c0f0b691ecc0ef3e245c1c7

Pruning effectiveness

Fully execute 63 samples from the smart contract weakness registry
https://smartcontractsecurity.github.io/SWC-registry/

	Base	**Prune Pure Funcs**	**Dynamic Pruning**	**Speedup**
1 TX	297s	N/A	N/A	N/A
2 TX	2,346s	1,919s	1,152s	103.5%
3 TX	9,943s	6,072s	2,242s	343.49%
4 TX	too long	13,312s	7,440s	> 400%

Coming soon™

- Function summaries
  - Store constraints imposed on state when executing paths (“summary”)
  - In subsequent runs, apply summary via conjunction instead of re-executing the same code
  - Pakala uses a comparable approach
- Multithreading :)

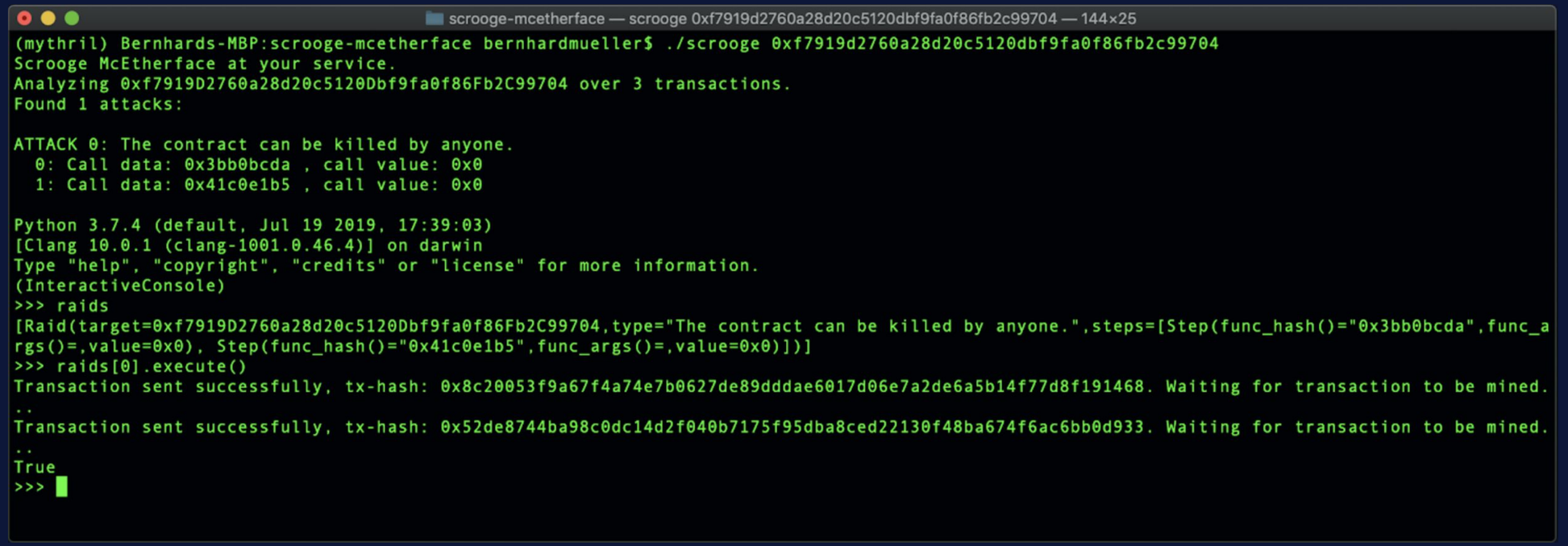
Scrooge McEtherface

Auto-exploits bugs detected by Mythril

DEMO!

https://github.com/b-mueller/scrooge-mcetherface

Scrooge McEtherface



Situation on the Mainnet

Frontrunning Bot

Fake Exploitable Contract

You

Actually Vulnerable

Honeypots!

```
contract SharedWallet is Ownable {

    uint256 min_initial_deposit = 0.1 ether;
    mapping(address => uint256) public balances;
    address payable public _owner;

    constructor() public payable {
        _init();
    }

    function _init() public payable {
        require(msg.value >= min_initial_deposit);
        _owner = msg.sender;
    }

    function deposit() public payable {
        balances[msg.sender] += msg.value;
    }

    function withdraw(uint256 amount) public {
        require(balances[msg.sender] >= amount);

        balances[msg.sender] -= amount;
        msg.sender.transfer(amount);
    }

    function ownerWithdraw() public onlyOwner {
        _owner.transfer(address(this).balance);
    }
}
```

Honeypots!

```
contract SharedWallet is Ownable {

    uint256 min_initial_deposit = 0.1 ether;
    mapping(address => uint256) public balances;
    address payable public _owner;

    constructor() public payable {
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    function _init() public payable {
        require(msg.value >= min_initial_deposit);
        _owner = msg.sender;
    }

    function deposit() public payable {
        balances[msg.sender] += msg.value;
    }

    function withdraw(uint256 amount) public {
        require(balances[msg.sender] >= amount);

        balances[msg.sender] -= amount;
        msg.sender.transfer(amount);
    }

    function ownerWithdraw() public onlyOwner {
        _owner.transfer(address(this).balance);
    }
}
```

```
contract Ownable {
    address payable private _owner;

    event OwnershipTransferred(address indexed previousOwner, address indexed newOwner);

    constructor () internal {
        _owner = msg.sender;
        emit OwnershipTransferred(address(0), _owner);
    }

    modifier onlyOwner() {
        require(isOwner(), "Ownable: caller is not the owner");
        _;
    }
```

The real owner

Tricking tools (1)

```
function ownerWithdraw() public onlyOwner {
    _owner.transfer(address(this).balance);

    logger.log('OwnerWithdrawal', address(this).balance, msg.sender);
}
```

Tricking tools (2)

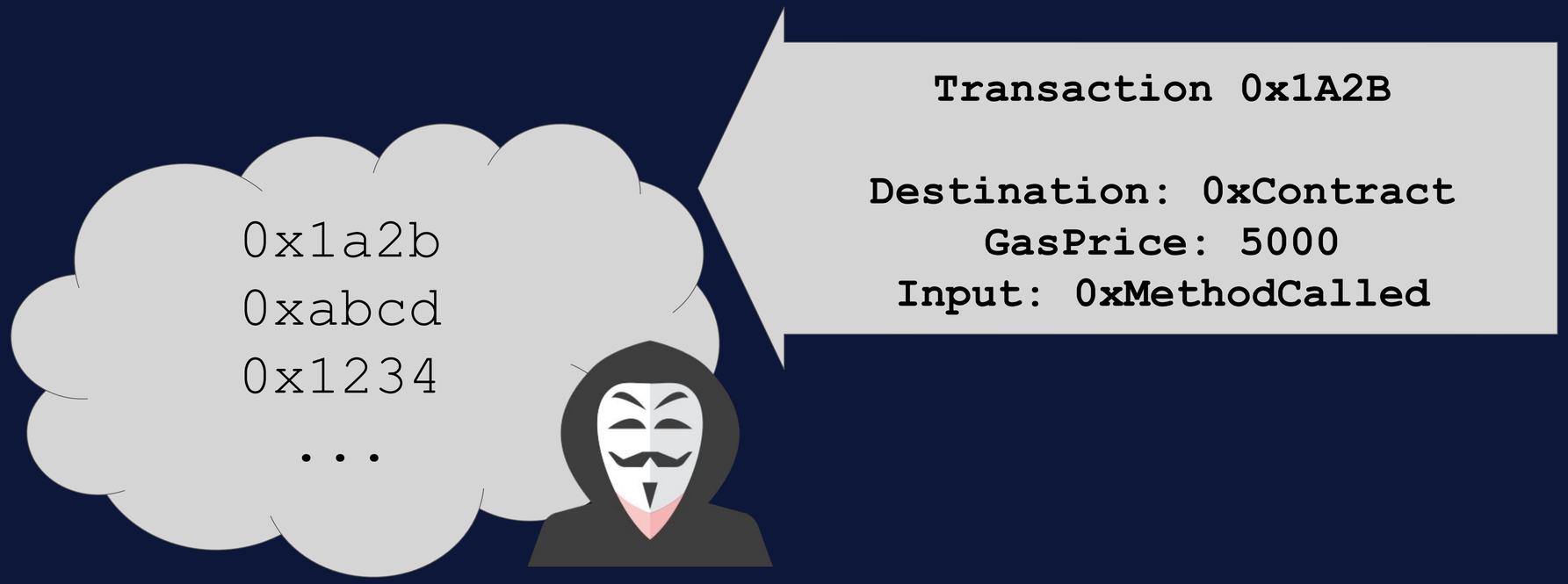
Transaction ordering

TxFee = Gas * GasPrice

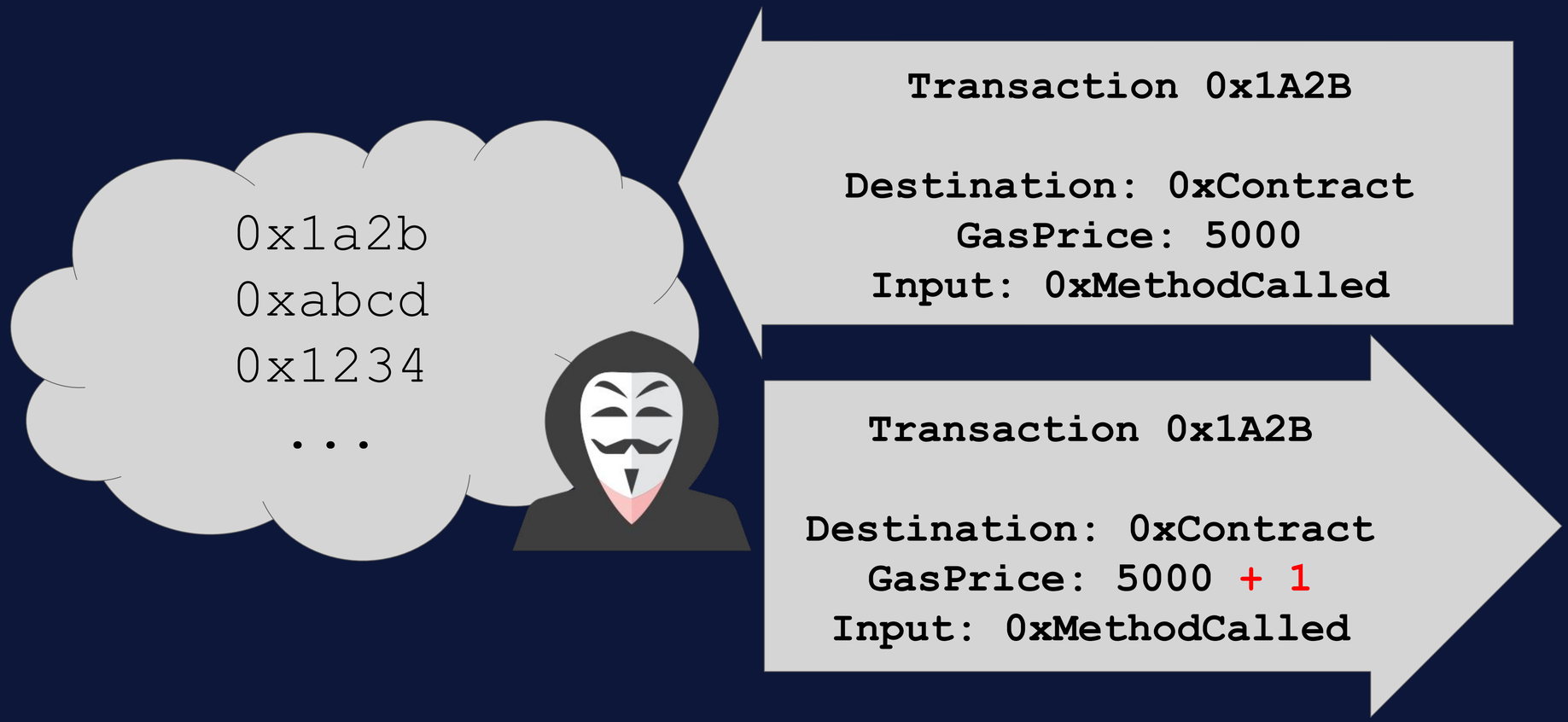
Block #100

```
#0 Tx: 0x123456 GasPrice: 5000
#1 Tx: 0xd1e2f3 GasPrice: 2001
#2 Tx: 0xf1d2e3 GasPrice: 2000
#3 Tx: 0xd1fe64 GasPrice: 1900
...
```

Frontrunning



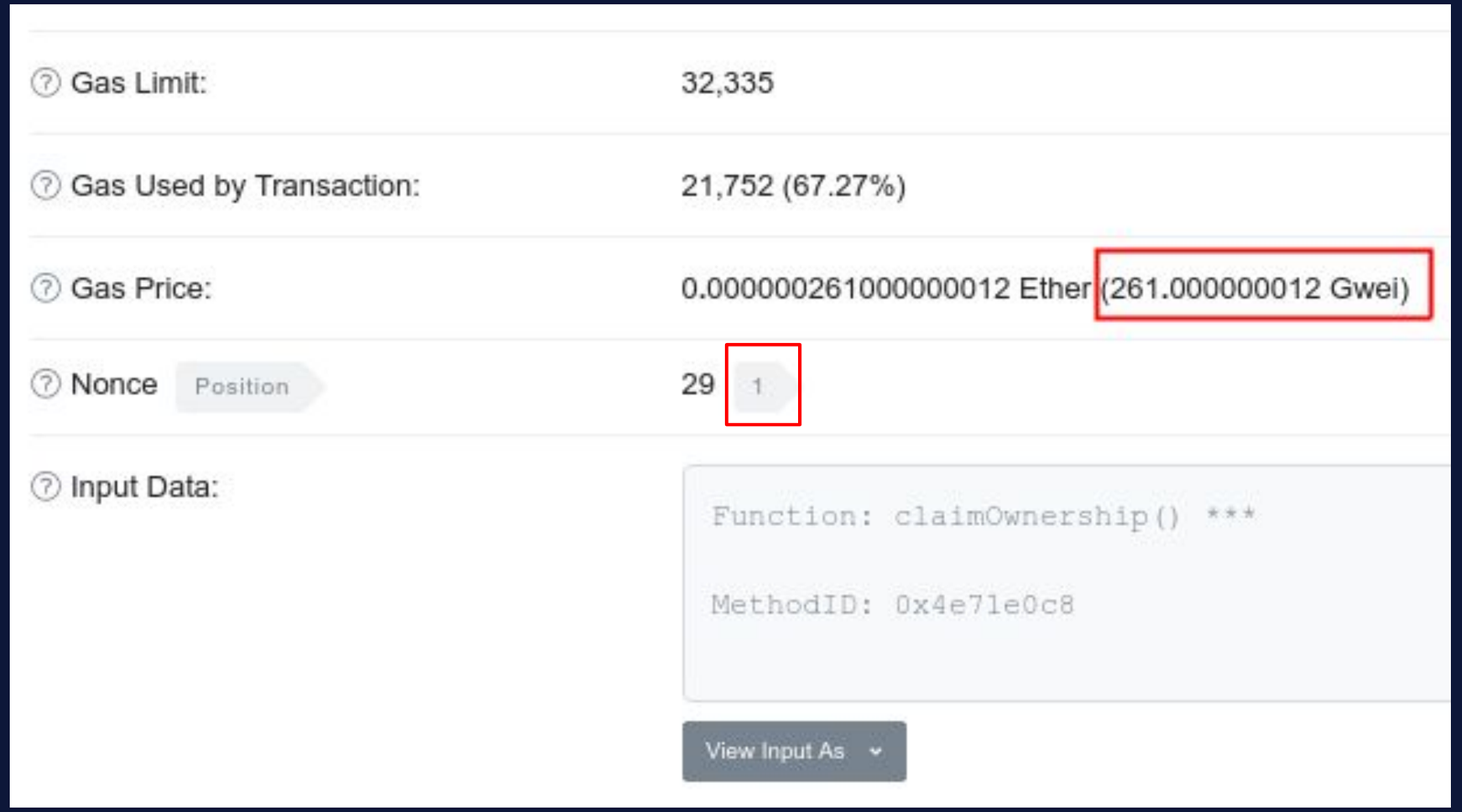
Frontrunning



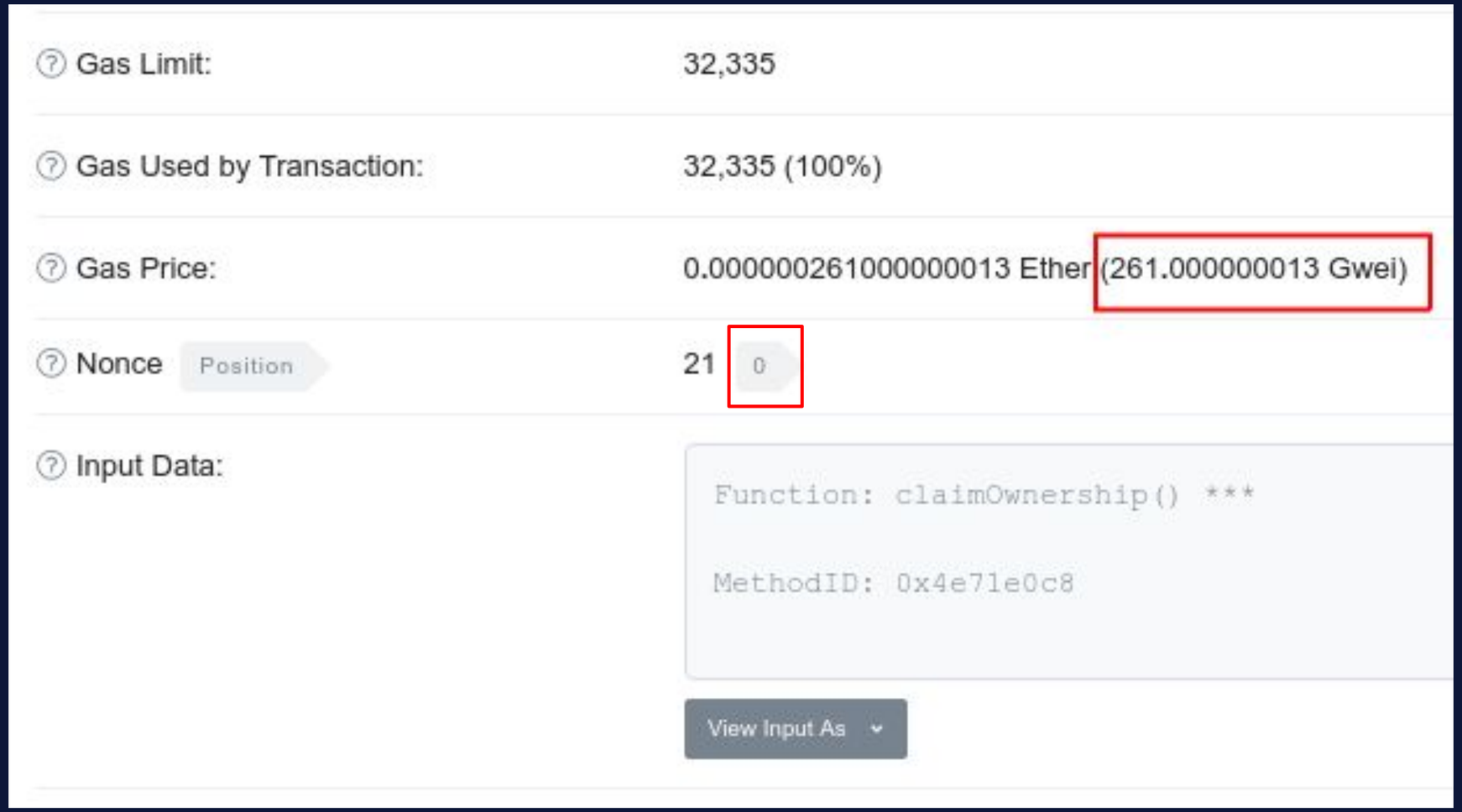
```
function claimOwnership() public payable {
    require(msg.value == 0.1 ether);

    if (claimed == false) {
        player = msg.sender;
        claimed = true;
    }
}

function retrieve() public {
    require(msg.sender == player);

    msg.sender.transfer(address(this).balance);

    player = address(0);
    claimed = false;
}
```

Does this work in the wild?

The victim’s transaction



Theo’s transaction



Defending against Theo

- Roll back transaction if the attack failed

```
contract Wrapper {

    _target = 0xaAaAaAaaAaAaAaaAaAAAAAAAAaaaAaAaAaaAaAa

    constructor(bytes memory _data) public payable {
        address proxy = address(this);
        uint256 start_balance = msg.sender.balance + proxy.balance;

        address(_target).call.value(msg.value)(_data);

        assert(msg.sender.balance + proxy.balance > start_balance);
        selfdestruct(msg.sender);
    }

    function() external payable {}
}
```

Get involved!

- War games / CTFs
  - https://capturetheether.com
  - https://ethernaut.openzeppelin.com
  - https://blockchain-ctf.securityinnovation.com/
- Bug bounties
  - https://bounty.ethereum.org
  - Many projects pay up to $100k/bug
  - Check out Sam Szun’s work: https://samczsun.com

Q & A