Smart Contracts Verification (89400)

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Seminar

Outline

Seminar Goals

- Learn how to read a paper in CS
  - Focus on the important results
  - Cover necessary background
- Learn how to present
  - Who are you presenting to
  - What is the important message
  - Keep audience engaged
- Discover interesting research and tools
  - Active field of research
  - Many new techniques and tools

And many more institutions and startups

Technical Details

- 10:00 – 11:30
- Present one paper (80%)
- Attend and Participate (20%)
- https://u.cs.biu.ac.il/~zoharyo1/sc-seminar/index.html

Guidelines

- Make enough time for reading the paper
  - Read background material
  - Be prepared to answer questions from audience
  - Presenting a demo of the tools themselves is recommended
- Make enough time for preparing the slides
  - Slides should be clear
  - Practice the time frame
- When there are difficulties:
  - Ask me questions
  - Meet with me
  - Start early

Motivation

Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
satoshin@gmx.com
www.bitcoin.org

Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of

- Transfer money between parties directly
- Not going through a bank
- Retain security without a trusted verifying third-party

Blockchain

What is a blockchain?

- Linked list
- Elements are called blocks
- Each block has:
  - ID
  - data (set of transactions)
  - Pointer to previous block
  - Hash of previous block
- Allowed operations: append

Main Property

- Data remains forever
- Blocks are cryptographically immutable
- If A changes a block, B can (easily) notice it
  - Hash function
  - Remember the pointer and hash to the head

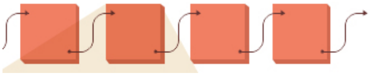
Bitcoin

Bitcoin

- Bitcoin is a currency
- Distributed
- Operated through the bitcoin p2p network
- Uses the bitcoin blockchain

The Bitcoin Blockchain

- Decentralized
- Public
- Used as a ledger
- The blocks data consists of transactions
  - Optimization: Several transactions in each block



Bitcoin Transactions

Transfer Transaction

- Transfer = destroy and create
- Address and signature of sender
- Address of recipient
- Coins to be used
- Pointer to creation of coins

Creation Transaction

- Data:
  - Address of recipient
  - Value
- When are these issued?
  - Genesis block
  - Every addition of a block

Bitcoin Transactions

Submitting a Transaction

1. A wants to send n coins to B
2. A broadcasts the transaction details to the entire bitcoin network
3. A waits for the transaction to be completed.

Completing a Transaction

- The network decides: Include it in a block on the blockchain?
- Each node makes its own decision
- Honest nodes:
  - Only include valid transactions in their blocks
  - Always add blocks to the longest valid branch
- Assumption: Most nodes are honest

Is the transaction then completed?

Bitcoin Transactions

What does it even mean?

I own a coin

=

I am able to spend a coin

=

When I submit a transaction with this coin
the transaction will be added to the blockchain

Bitcoin Transactions

What does it even mean?

I own a coin

=

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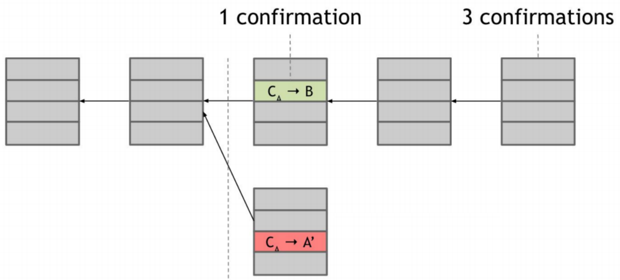
=

When I submit a transaction with this coin
the transaction will be added to the longest valid branch in the blockchain

Pizza

Example

- I broadcast a transaction where I transfer money to Amici's Pizza
- My transaction is added to the longest valid branch
- Should Amici's start preparing my pizza?
  - Will this transaction stay on the longest valid branch?
- The more Amici's wait, the better
- 6 blocks should be enough (≈ 1 hour)



Consensus

Consensus

- Transactions are broadcasted to the entire network
- Each node maintains a block with all the new transactions
- A hopefully random node gets to add its block to the chain
- Where? hopefully appending to the longest valid branch
  - Adding to a branch = confirming validity

Hope

- How to fulfill hopes?
- How to choose a random node?
- How to encourage nodes to being honest?

Achieving Honesty: Incentives

Block Creation Fee

- Every block includes a special transaction to its creator.
- Fixed amount
- Nodes want their blocks to appear in the longest valid branch
- Otherwise, the reward is useless

Transaction Fee

- Transactions may add a transaction fee to the block creator
- Fee is useless unless on the longest valid branch

Achieving Randomness: Mining

You Gotta Work For It!

- Nodes (miners) compete for the right to create blocks
- They need to prove that they worked for it
  - Look for a number x such that $hash(x \# txs) < \epsilon$ and put it in the block
  - Assumption: the hash function is secure
  - No way other than exhaust the search space
  - Ensures randomness of block creator
- Searching for x = mining
- A node that searches for x: miner

The Need for Altcoins

"Script": The Language of Transactions

- Transactions are written in "Script"
- limited scripting language
- Stack-based, no loops
- Allows for limited variants of the above two transaction types

- These are not "Smart Contracts" yet
- "Turing-complete"-blockchain

Bitcoin Recap

- Public, distributed blockchain
- Relies of honest majority
- Never 100%, but exponentially reliable over time

- Transactions are broadcasted
- Written to blocks
- Blocks are added to the blockchain

- Miners create blocks
- Achieves randomness
- They get coins for it

- Transactions are written in scripts
- Limited language

Ethereum

Ethereum

- Like bitcoin, but with a Turing-complete scripting language
- Also has a blockchain
- Scripts = smart contracts
  - Code = meaning of contract
  - Execution = enforcement of contract
- Contracts are added to the blockchain via transactions
- Contracts are assigned with an address and a balance

Ether and Beyond

- Ether = The Ethereum currency
- General-purpose blockchain
- Other currencies
- Other purposes

Smart Contracts

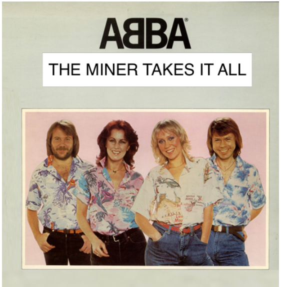
Smart Contracts

- Deployed as bytecode
- Run by Ethereum Virtual Machine (EVM)
- Usually written in a high-level language: Solidity
- Stateful
- Other high-level languages are considered

```
pragma solidity 0.4.8;
contract ControlStructure {
    address public a;
    function ControlStructure(uint input1) {
        while(input1 >= 0){
            if(input1 == 5)
                input1 = input1 - 1;
                a++;
        }
    }
}
```

Gas

- Preventing contracts from running forever: Gas
- Each VM instruction has a fixed cost in gas units
- When publishing a transaction to the network, the sender specifies:
  - how much (s)he will pay per gas unit
  - gas limit
- If gas limit is hit, the execution is reverted
- The miner gets the gas value



Challenges

- Blockchain Technology, and in particular the Ethereum blockchain are (relatively) new fields
- A lot of research subjects naturally arise
- To name a few:
  - Cryptographic protocols
  - Consensus Protocols
  - Incentives

    ⋮
  - Estimation of gas costs
    - Decide whether to submit a transaction
    - Decide what gas limit to put
  - Verification of smart contracts
    - Find bugs
    - Know what the contract does

Reasoning about Smart Contracts

- Solidity is a programming language
- We would like to verify some properties of smart contracts
- Examples:
  - Safety w.r.t. particular attacks
  - Termination
  - Not running out of gas
  - Specification by examples
- Challenges:
  - Non-standard control flow
    - Contracts are called by other contracts whose code is unknown
    - Need for modularity
  - Need to reason about second-order concepts
  - Sum, count,...
  - Is gas an internal or external notion to the contract?

Example 1: Tokens

Tokens

- The Ethereum blockchain is used not only for Ether
- It is a general-purpose blockchain
- Many currencies are created within it, they are called *tokens*
- Tokens may differ in their logic / rules / functionality.

ERC20 Standard

- A standard for tokens
- Tokens should include several functions, e.g.:
  - totalSupply()
  - balanceOf(address)
  - transfer(to, tokens)

  ⋮

Example 1: Tokens

```
contract SimpleToken {
  def ts : uint //total supply
  def b : address -> uint //balances
  method burn(a : uint, s : address) { //amount, sender
    ts = ts - a
    if (b[s] >= a) {
      b[s] = b[s] - a
    }
  }
}
```

We would like to prove an invariant: $Sum(balances) = totalSupply$

$$(\Sigma b = ts \Rightarrow (ts' = ts - a \wedge (b[s] \geq a \Rightarrow b' = b[s \leftarrow [s] - a]) \wedge (b[s] < a \Rightarrow b' = b))) \Rightarrow \Sigma b' = ts'$$

Not Valid!

Example 1: Tokens

```
contract SimpleToken {
  def ts : uint  //total supply
  def b : address -> uint  //balances
  method burn(a : uint, s : address) { //amount, sender
    if (b[s] >= a) {
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      ts = ts - a
    }
  }
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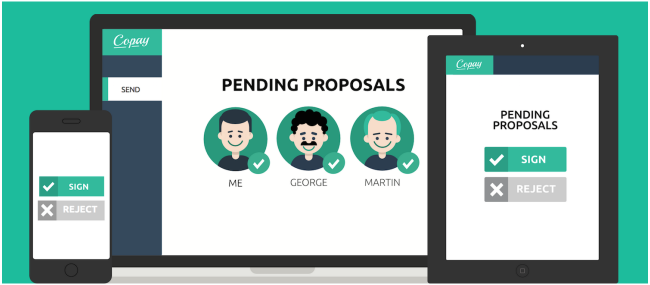
Valid!

Example 2: Wallets

Multi-signature Wallets

- In some cases, it makes sense to have a shared wallet
- n owners, at least m must sign for each transaction
- Examples:
  - Spouse joint account
  - Company board of directors
  - Buyer, seller, trustee



Example 2: Wallets

```
contract Wallet {
  def req : uint //number of required signatures
  def os : address -> bool //owners
  method removeOwner(o: address) {
    os[o] = false
  }
}
```

We would like to prove an invariant: $Count(os) \geq req$

$$CountTrue(os) \geq req \Rightarrow (\ os' = os[o \leftarrow false] \Rightarrow Count(os') \geq req\ )$$

Not Valid!

Example 2: Wallets

```
contract Wallet {
  def req : uint //number of required signatures
  def n: uint //number of owners
  def os : address -> bool //owners
  method removeOwner(o: address) {
    if n > req {
      os[o] = false
      n = n-1
    }
  }
}
```

We would like to prove an invariant: $n \geq req \wedge n = Count(os)$

$$(n \geq req \wedge n = Count(os)) \Rightarrow ((n > req \Rightarrow (os' = os[o \leftarrow false] \wedge n' = n - 1)) \Rightarrow (n' \geq req \wedge n' = Count(os')))$$

Valid!

Background Recap

We have seen:

- The Blockchain data structure
- Bitcoin
- Ethereum & Solidity
- Verification

We have not seen:

- Cryptography
- Consensus
- Low-level details
- ...

Resources:

- Princeton Bitcoin book
- Stanford course
- Tons of other resources

Thanks:

- Shelly Grossman
- Mooly Sagiv
- You

Topics

High Level Topic

Verification of Smart Contracts

Sub-topics

- Smart Contract Languages and their vulnerability
- General-purpose Verification Techniques
- Specific Verification Techniques for Smart Contracts

Smart Contract Languages and Vulnerabilities

Languages

- Script
- Solidity and Ethereum Bytecode
- Move
- Michelson (Tezos)
- ...

Vulnerabilities

- Real assets are transferred
- No safety net
- Private contract storage vs. shared blockchain storage
- Callbacks and interactions between contracts
- ...

Verification

Verification, Testing, Auditing

- Verification: 100% correctness, non-terminating
- Testing: Low coverage, terminating
- Auditing: Mostly manual
- Combinations: e.g., verification techniques for test generation

Rice's Theorem

- It is undecidable to determine whether a given program satisfies a certain (semantic, non-trivial) property
- Verification is impossible?
- Heuristics, incompleteness, application-guided research

Verification Despite Rice's Theorem

Satisfiability Modulo Theories (SMT)

- Core Technique: Translating programs into a logical formula
- SMT-solvers: general-purpose logical solvers
- Translation is straight-forward without (unbounded) loops
- Loops require dedicated techniques

Verification of Smart Contracts

Specific Challenges and Techniques

- Gas
- Special vulnerabilities
- Basic SW verification techniques work to a certain extent
- Specific techniques are developed for Smart Contracts

Tools

- solc-verify (SRI)
- Verisol (Microsoft Research)
- The Move Prover (Facebook, Stanford)
- Solidity's internal checker (Ethereum Foundation)
- . . .

Demos

- The Move Prover
- cvc5: https://cvc4.github.io/app/

Summary

- Diverse and Interesting topic: Practical tools + deep theory
- Please email me by next lecture your preferred papers
- Seminar Website:
  https://u.cs.biu.ac.il/~zoharyo1/sc-seminar/index.html