Smart Contracts Verification (89400)

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Seminar

Outline

Outline

Schedule

Schedule

- Seminar web-page:
  - https://u.cs.biu.ac.il/~zoharyo1/sc-seminar/2024-2025/index.html
- Please send me your paper/date requests in order of preference
- The more options given, the more likely you get one of them
- Until next meeting
- Speaking of next meeting: who wants to present?

Requirements

Presenting (80%)

- Slides in English, talk in English
- IN ENGLISH
- Presentation in pairs, ~ 75 minutes excluding questions
- No GPTs.

Participating (20%)

- Attend (physically/virtually), ask questions, get involved
- Send me an email after each lecture with:
  - Your name and ID
  - A paragraph about the lecture that you've heard (~ 100) words.
  - No GPTs.

Presentation criteria

- complete: includes all the main material from the paper
- engaging: interesting, makes me want to listen
- knowledgable: show that you understood the paper in a deep manner
- clear:
  - everything is explained properly
  - no knowledge assumed (beyond being a 3rd year CS student)
  - no skipping key definitions
- past reference: refer to previous relevant talks
- IKAR vs. TAFEL: focus on what's important
- coordination: one presentation by two students $\neq$ two presentations
- demo: very important, engaging and interesting

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

Outline

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

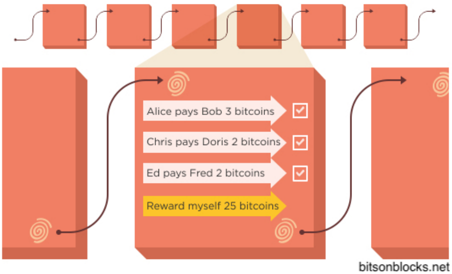
Blockchain

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



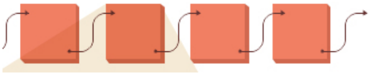
Bitcoin

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

What does it 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 mean?

I own a coin

=

I am able to spend a coin

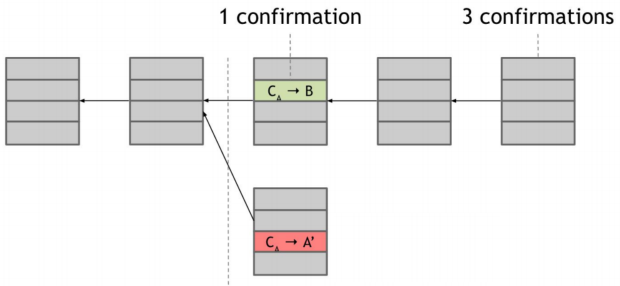
=

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



Achieving Randomness: Mining

You Gotta Work For It!

- Nodes 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

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

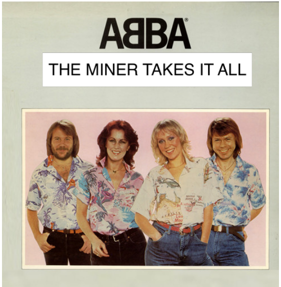
Smart Contracts

- 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



Outline

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) {
      b[s] = b[s] - a
      ts = ts - a
    }
  }
}
```

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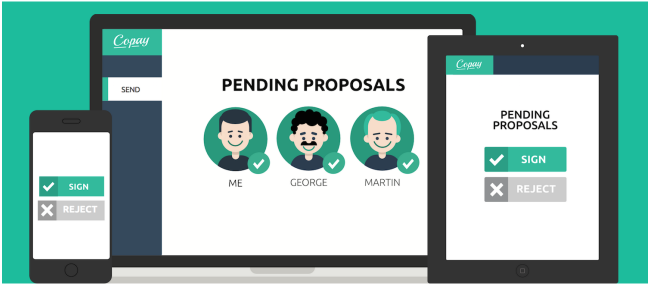
Valid!

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!

Outline

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

Let's look at the papers

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)
- ...

Outline

Reading Papers

Tips – 1

- **Start early**
- Read background material
- Papers are rarely fully self-contained
- Ask for help, via email or a meeting
- **Start early**

Tips – 2

- Look for references in the paper
  - for background material
- Look for references of the paper
  - for a more general understanding
  - google scholar

The Three Pass Approach

Read more than once

- https://web.stanford.edu/class/ee384m/Handouts/HowtoReadPaper.pdf
- Reading once from start to finish often does not work
- Ideas need to be absorbed
- Understanding requires time

Three Passes

Three Passes

- First Pass:
  - title, abstract
  - section titles
  - references
  - contributions
- Second Pass:
  - "normal" reading
  - write notes
  - mark notions, questions, important parts
  - ignore proofs / low level details
  - summarize
- Third Pass:
  - critical thinking
  - trying to "re-create" the details
  - deeper understanding
  - low-level details

Outline

Presenting a Paper

Technicalities

- Let me know by next class your preferences
- Pairs
- Partition your presentation equally
- Not necessarilly equal grading
- English

Presenting a Paper

Tips 1

- Start after or during the reading of the paper
- What would you / your partner have asked?
- What might be unclear?
- Keep it simple (effects)
- Go deep (content)

Tips 2

- Many examples
- Examples may come before definitions
- presentation $\neq$ handout
  - Short bullets
  - Do not include long summaries
  - Graphs, plots, illustrations
  - Demos

Preparing a Presentation

Preparing Slides

- https://homes.cs.washington.edu/~mernst/advice/giving-talk.html
- Know the paper well
- Remember the audience
- What are the key takeaways?
- Rely on previous lectures
  - Copy / Screenshot
  - Don't ignore
  - Acknowledge

Structure Your Talk

Structure

- Intro/Background:
  - What is the paper about?
  - Motivation
  - Terminology and notions from previous presentations
  - Main Contribution
- Body
  - Main results
  - Significance
  - Methods / Tools / Techniques
  - Examples and Demos
  - Advanced material
- Conclusion
  - Repeat the main message
  - What was done
  - What is left to do

Presenting

Presenting Slides

- Practice
- Writing $\neq$ Speaking
- Time yourself
- Not too fast, not too slow
- Engage

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/2024-2025/index.html