Efficient Smart Contracts on UTXO platforms

Smart contract efficienti su piattaforme UTXO

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SERICS SECURITY AND RIGHTS IN THE CYBERSPACE

Overview: two main results

Improving smart contracts on UTXO platforms (e.g. Cardano)

- Off-chain UTXO smart contracts execution

  How To Save Fees in Bitcoin Smart Contracts: a Simple Optimistic Off-chain Protocol

  Blockchain: Research and Applications 2025

- Distributing the state for UTXO smart contracts

  Scalable UTXO Smart Contracts via Fine-Grained Distributed State

  Future Generation Computer Systems 2026

Off-chain execution of UTXO smart contracts

Summary: off-chain UTXO smart contracts

- Contract trees: a significant class of smart contracts
- State of the art:
  - On chain execution cost: 1+N transaction fees

    where N = number of smart contract operations
- Our contribution:
  - Optimistic execution protocol: *hope for the best, prepare for the worst*
  - Off-chain execution cost: (3+N-H) transaction fees

    where H = number of protocol steps where all participants behave honestly

    $(0 \leq H \leq N)$

Contract trees

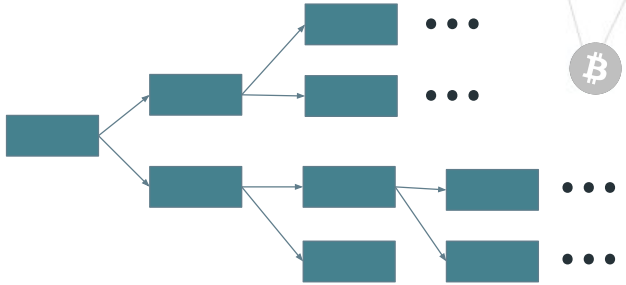
Assumption: all the possible executions of a smart contract can be described by a finite tree of state updates

Examples:

- tracing the production process of some goods
- gambling games
- ...

State updates can require conditions to become enabled:

- authorizations by participants
- time constraints
- ...



On-chain execution

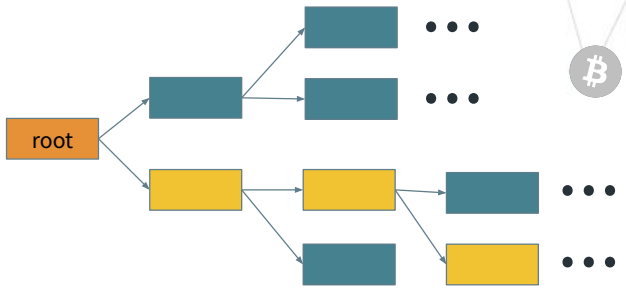
Contract stipulation:

exchange signatures, append root Tx on the blockchain

Contract execution:

choose one enabled Tx, append it, repeat

The chosen tree path forms a contract run



Assumption: at least one contract participant is honest

Off-chain execution

Floating transactions!

Our off-chain execution protocol exploits floating transactions (like the Lightning Network)

Most state updates are now executed off-chain, by exchanging messages (= no fees!)

Security:

- Same assumptions as for the on-chain case
- The contract tree logic is still enforced (no unexpected state updates)
- No deadlocks: in the presence of attacks, we can fall back to on-chain execution
- No state rollbacks: off-chain steps are final

Efficiency:

- Best case: 3 transaction fees (was 1+N in the on-chain case), can be lowered to 2
- Worst case: 3+N transaction fees

Distributing the smart contract state:

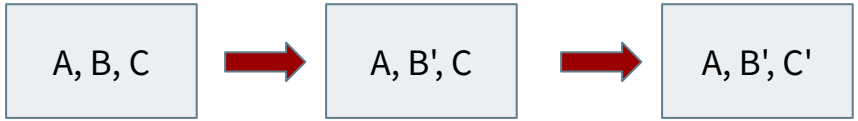
the hUTXO blockchain model

Summary: the hUTXO blockchain model

- State of the art:

  In the eUTXO model (Cardano) a transaction stores the whole contract state

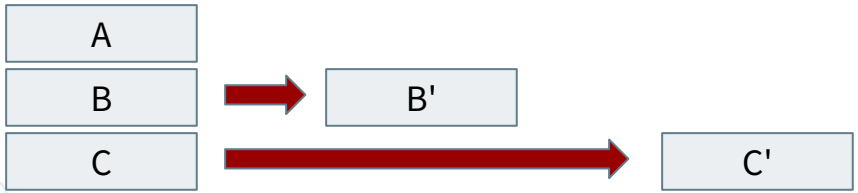
  Any contract operation must store the whole new state, again



- Our contribution:

  Our hUTXO model distribution of the state over several UTXOs

  - Contract operations only affect a part of the state, improving space and time efficiency



On distributing the contract state

A simple idea, yet requires some careful design to make it practical.

- Protecting from new attack vectors
- Storing the contract balance (we used a hybrid account/UTXO-based approach)
- Improving usability (addressed by our HURF smart contract language)

Advantages of hUTXO over eUTXO:

- Better time and space efficiency
- Enables parallel execution / validation on multi-code nodes
- Mitigates so-called "UTXO congestion" issues

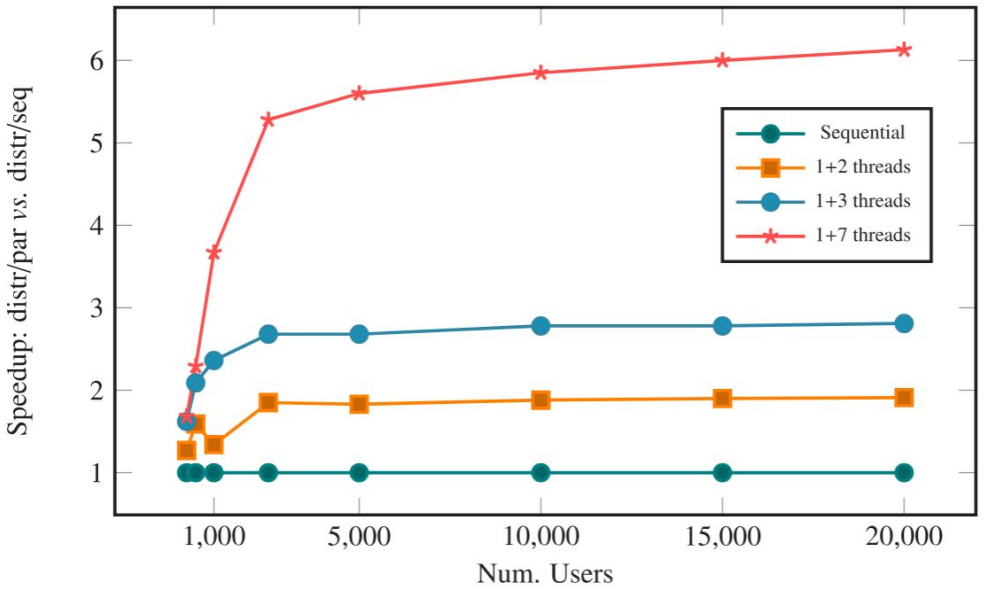
hUTXO implementation and experiments

We implemented a hUTXO simulator

(DiSCo_sim: ~7000 LoC of Rust)

Experiments show near-optimal scalability

on multi-core validator nodes



Thank you!

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