An Efficient Framework for Optimistic Concurrent Execution of Smart Contracts[a]

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Presented by:

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[a] The initial idea has been presented in Doctoral Symposium, ICDCN 2019, and awarded with **'Best Poster Award'**.

Team of this Research Work

Parwat Singh Anjana | Sweta Kumari | Sathya Peri | Sachin Rathor | Archit Somani

Outline of the Talk

Introduction

- Blockchain
- Smart Contracts

Introduction

Blockchain

- Blockchain is a decentralized, distributed database or ledger of records.

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- Each block is a collection of transactions and has a pointer to its previous block.
- By design these blocks are immutable but publicly readable.
- Example: Bitcoin[b], Ethereum[c], and Hyperledger[d] etc.

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- Client requests are directed to scripts, called *smart contracts*. Examples are Ballot, coin, simple auction etc.
- Smart contracts are similar to a legal contract in which terms are recorded in a legal language.
- **Advantages:**
  1. No need for a trusted third party to validate the contract.
  2. Low contracting enforcement.
  3. Compliance costs.

Current Blockchain Design

Ethereum High Level Design

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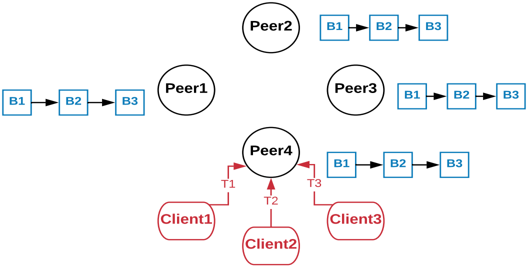

Figure: Clients send Transaction T1, T2 and T3 to Miner (Peer4)

Ethereum High Level Design

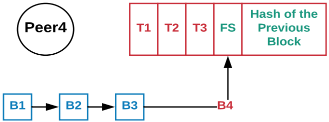

Figure: Miner forms a block B4 and computes final state (FS) sequentially

Ethereum High Level Design

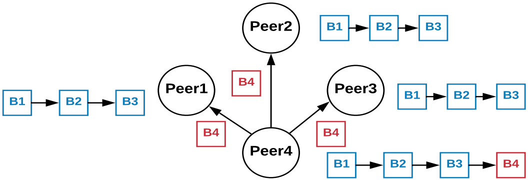

Figure: Miner broadcasts the block B4

Ethereum High Level Design

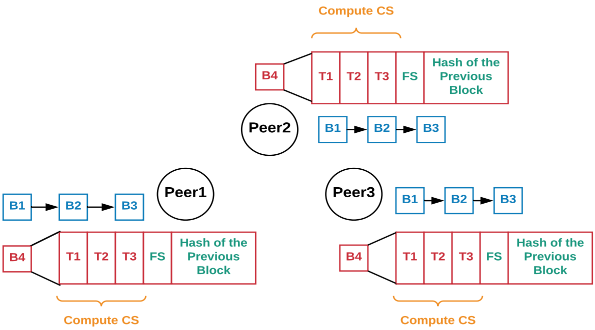

Figure: Validators (Peer 1, 2 and 3) compute current state (CS) sequentially

Ethereum High Level Design

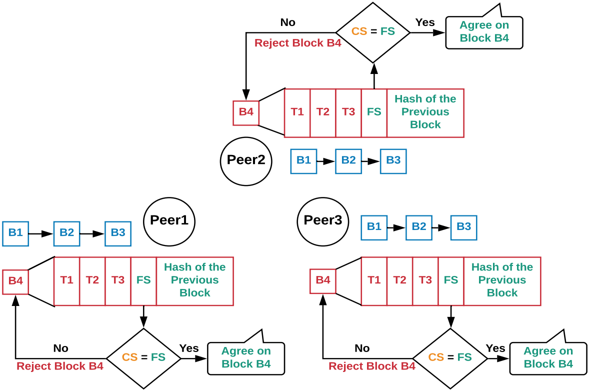

Figure: Validators verify the FS and reach the consensus protocol

Ethereum High Level Design

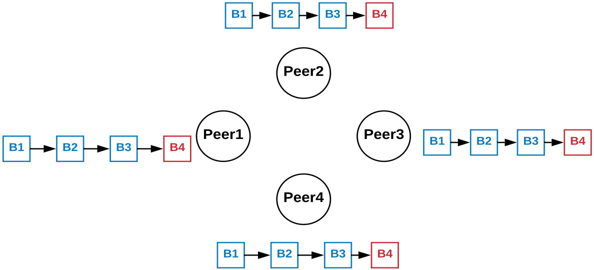

Figure: Block B4 successfully added to the blockchain

Bottleneck in Existing Blockchain

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Ethereum

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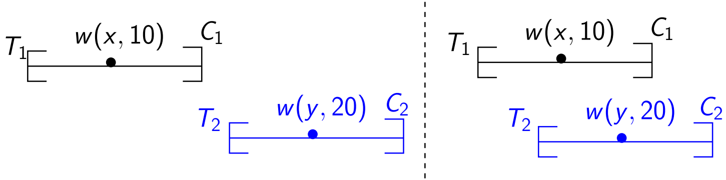

(a) Serial Execution of transactions (b) Concurrent Execution

Figure: Motivation towards concurrent execution over serial

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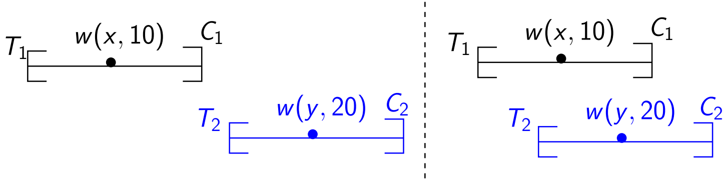

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Figure: Motivation towards concurrent execution over serial

- By adding concurrency to smart contracts execution, we can achieve better efficiency and higher throughput.

Challenges to Execute the Smart Contracts Concurrently

Challenges (1/2)

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- Identifying the conflicts at run-time is not straightforward.
- Improper use of locks may lead to deadlock.
- Discovering an equivalent serial schedule of concurrent execution of smart contract transactions is difficult.

Challenges (2/2)

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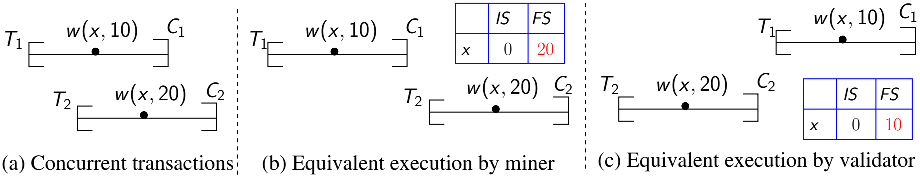

Figure: Concurrent execution of transactions by miner and validator

Proposed Methodology: Concurrent Miner and Validator

Proposed Methodology

Concurrent Miner

- We develop an efficient framework to execute the smart contract transactions concurrently by miner using optimistic Software Transactional Memory systems (STMs).

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- STMs are a convenient programming interface for a programmer to access shared memory using concurrent threads without worrying about concurrency issues.

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- STMs are a convenient programming interface for a programmer to access shared memory using concurrent threads without worrying about concurrency issues.
- Traditionally, STMs export the following methods:
  - t_begin()
  - t_read()
  - t_write()
  - tryC() and tryA()

A thread safe concurrent linked-list(LL) using STM

Algorithm 1 Insert(LL, e): Invoked by a thread to insert an element e into a linked-list LL. This method is implemented using transactions.

```
retry = 0;
while (true) do
    id = t_begin(retry);
    ...
    ...
    v = t_read(id, x); // reads the value of x as v
    ...
    ...
    t_write(id, x, v'); // writes a value v' to x
    ...
    ...
    ret = tryC(id); // tryC can return commit or abort
    if (ret == commit) then
        break;
    else
        retry++;
```

IITH-STM Library

- We have used two protocols implemented in IITH-STM library for concurrent execution of the smart contracts by miner.
    1. Basic Time-stamp Ordering (BTO) Protocol.
    2. Multi-Version Time-stamp Ordering (MVTO) Protocol.

Basic Time-stamp Ordering (BTO) Protocol [e]

- If $p_i(x)$ and $q_j(x)$, i $\neq$ j, are operations in conflict, the following has to hold:
  - $p_i(x)$ is executed before $q_j(x)$ iff $ts(t_i) < ts(t_j)$.

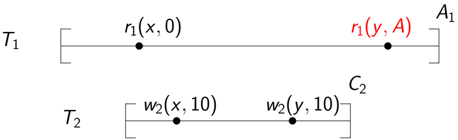
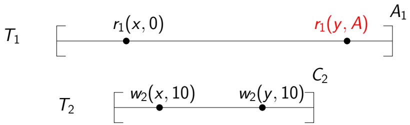


Figure: BTO

[e] Gerhard Weikum and Gottfried Vossen. Transactional Information Systems: Theory, Algorithms, and the Practice of Concurrency Control and Recovery, 2002.

Multi-Version Time-stamp Ordering (MVTO) Protocol [f]

- MVTO maintains multiple versions corresponding to each shared data-objects.
- It reduces the number of aborts and improves the throughput.



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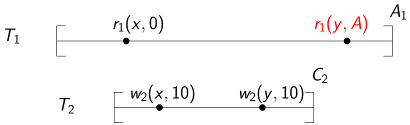

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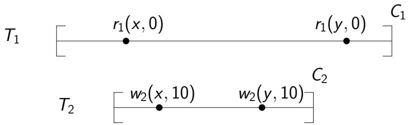

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Block Graph (1/6)

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- BG used by validator to execute smart contract transactions concurrently.
- Two transactions which do not have a path should be able to execute concurrently.

Block Graph Components (2/6)

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- The edges of the block graph depends on the STM protocol.
- For BTO:
  - Uses single version and satisfies co-opacity (similar to CSR).
  - Hence, conflict graph is same as block graph.
  - If T_i, T_j are conflicting and $i < j$ then add an edge from T_i to T_j in the graph.

Block Graph Edges (3/6)

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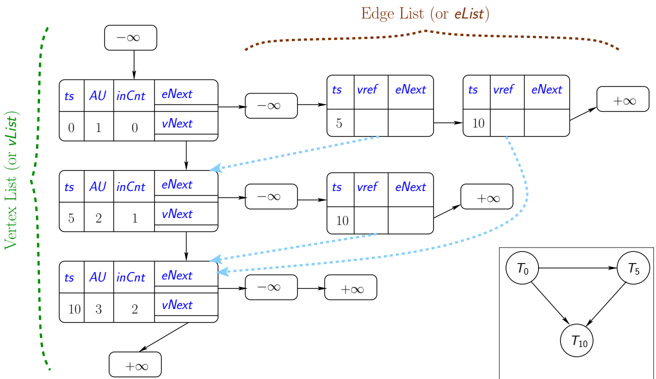
  - *Version Order Edge:* It captures the multiversion relations among the transactions and form the edges.

Block Graph (4/6)

Data Structure of Lock-free Concurrent Block Graph



(a) Underlying representation of Block Graph

(b) Block Graph

Figure: Pictorial representation of Block Graph

Block Graph (5/6)

Lock-Free Concurrent BG Methods

Concurrent Miner Methods: addVert(), addEdge()

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- searchGlobal(): Searches for a vertex with no incoming edges & claims it.
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- EVM doesn't supports multi-threading.
- We converted smart contracts from solidity to **C++** language for concurrent execution.

Experimental Evaluation (2/3)

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- Ballot: It implements an electronic voting contract in which voters cast their vote to the proposal.
- Mixed: Combination of above three contracts in equal proportion.

Experimental Evaluation (3/3)

- We run our experiment for two workloads:
  1. The number of transactions (or atomic-units) varies from 50 to 400, while threads and shared data-objects are fixed to 50 and 40 respectively.
  2. The number of threads varies from 10 to 60 while atomic-units are fixed to 400 and shared data-objects to 40.

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  2. The number of threads varies from 10 to 60 while atomic-units are fixed to 400 and shared data-objects to 40.
- Concurrent Validator used two approaches: 1) Fork-Join Approach and 2) Decentralized Approach.

Simple Auction Contracts

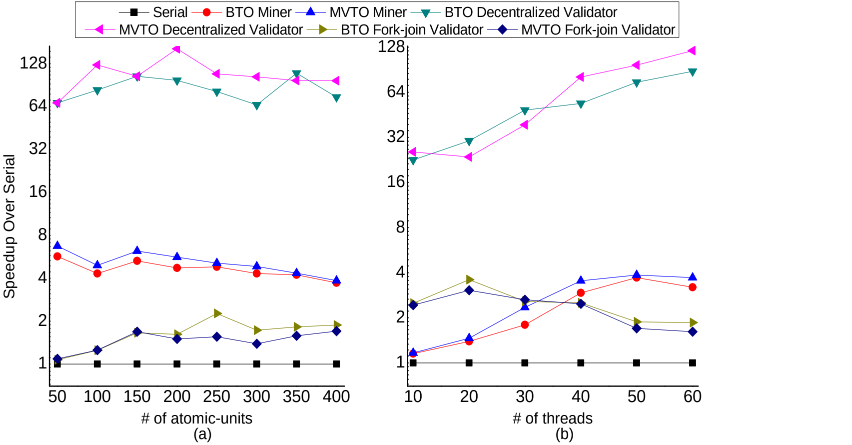

Figure: Simple Auction Contracts

- It achieve 3.9x and 4.45x average speedups for concurrent miner using BTO and MVTO STM protocol respectively. Along with BTO and MVTO validator outperform average 35.8x and 43.1x than serial validator respectively.

Coin Contracts

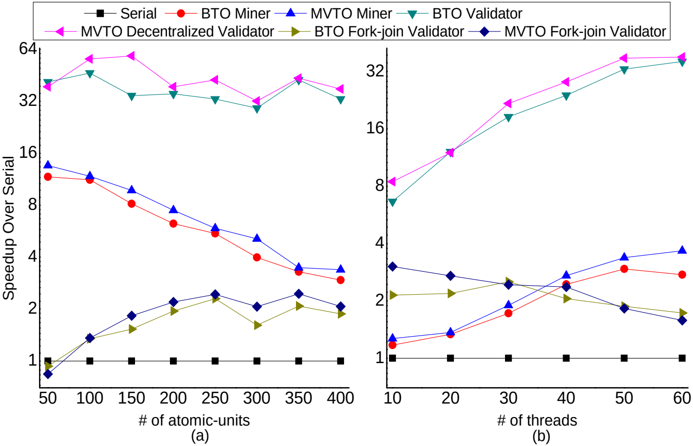

Figure: Coin Contracts

- It achieve 4.7x and 5.2x average speedups for concurrent miner using BTO and MVTO STM protocol respectively. Along with BTO and MVTO validator outperform average 25.6x and 31.3x than serial validator respectively.

Ballot Contracts

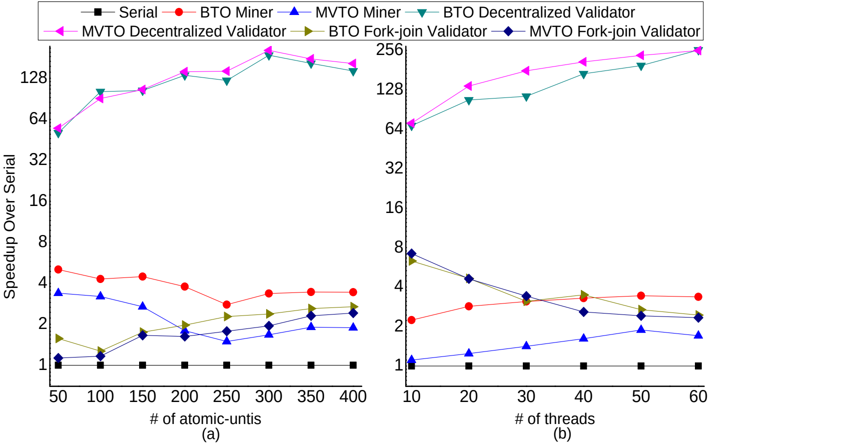

Figure: Ballot Contract

- It achieve 3.1x and 2.8x average speedups for concurrent miner using BTO and MVTO STM protocol respectively. Along with BTO and MVTO validator outperform average 55.9x and 62.9x than serial validator respectively.

Mixed Contracts

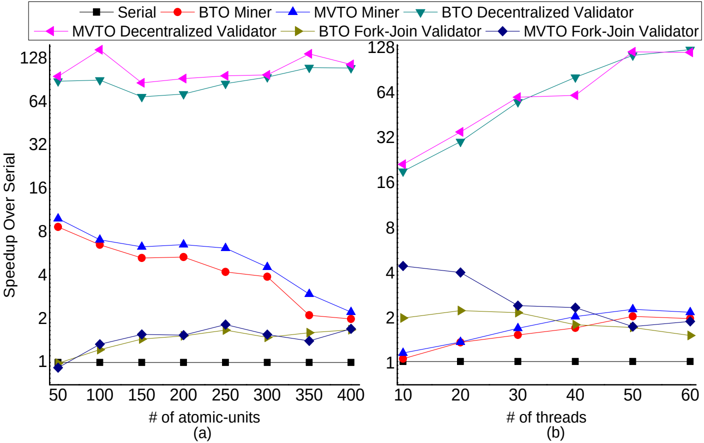

Figure: Mixed Contract

- It achieve 3.0x and 3.7x average speedups for concurrent miner using BTO and MVTO STM protocol respectively. Along with BTO and MVTO validator outperform average 52.3x and 59.1x than serial validator respectively.

Conclusion and Future Work

Conclusion [g]

- Introduced a novel way to execute the smart contract concurrently by miner using optimistic STMs.

[g] Technical report: `https://arxiv.org/abs/1809.01326`

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- We proposed concurrent validator that re-executes the smart contract transactions deterministically and efficiently with the help of block graph given by concurrent miner.

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- We proposed a lock-free graph library to generate the block graph.
- We proposed concurrent validator that re-executes the smart contract transactions deterministically and efficiently with the help of block graph given by concurrent miner.
- Proposed protocol shows significant performance gain as compare to serial miner and validator.

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Future Work

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- This idea can be applied to other blockchains such as Hyperledger, Ripple, Quorum etc as well.

Thanks &
Questions Please!!