A Blockchain Consensus Protocol with Horizontal Scalability

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Outline

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The dangers of centralisation

- Technological advancements give us convenience
- But it puts central authorities in control
- Many are motivated by profit or the goals of the local government
- The interest of the authorities do not align with the users

Blockchain: a new hope?

- Blockchains are distributed (replicated) ledgers with no central control
- They enable internet-scale consensus for the first time
- Some initial applications include:
  - Digital cash (e.g., Bitcoin, Litecoin)
  - Domain name system (e.g., Namecoin)
  - Storage rental (e.g., Filecoin)
  - General purpose (e.g., Ethereum)

Blockchain: not there yet

- All blockchain systems have a consensus algorithm
- Early consensus algorithms do not scale
- Bitcoin is limited to 7 transactions per second
- 100,000 transaction backlog in May 2017
- We require horizontal scalability for ubiquitous use
- More users → more transactions per second globally

Related work

- Off-chain solution
  - Lightning Network[1]
  - Perun[2]
  - Easy to deploy but application specific
- On-chain solution
  - Parameter tuning
  - BFT consensus (e.g. Tendermint[3], ByzCoin[4])
  - Sharding (e.g. Elastico[5], OmniLedger[6])

[1] https://lightning.network/
[2] https://perun.network
[3] https://www.tendermint.com/
[4] KJGKGF, USENIXSecurity16
[5] LNZBGS, CCS16
[6] KJGGSF, S&P18

Related work

State-of-the-art—Sharding:

- Split state into multiple shards
- Shards run consensus algorithm in parallel

Challenges:

- Choosing and evolving the shard size
- Perform atomic inter-shard transactions
- Parameter choice highly depends on the application

Research question

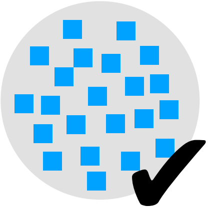
How can we design a *blockchain consensus protocol* that is *fault-tolerant*, *horizontally scalable*, and able to reach *global consensus?*

- Blockchain consensus protocol—application neutral
- Fault-tolerant—tolerate a number of malicious nodes
- Horizontal scalability—more nodes in the network leads to higher transaction throughput
- Global consensus—all node should agree on a global state

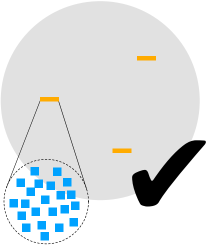
Outline

Intuition and idea explored in this thesis

- It is expensive to verify and reach consensus on all transactions
- Our idea: we decouple consensus and validation
- A single digest represents an arbitrarily large number of transactions
- Reach consensus on the small digest
- Nodes then independently check the validity of the transactions of interest



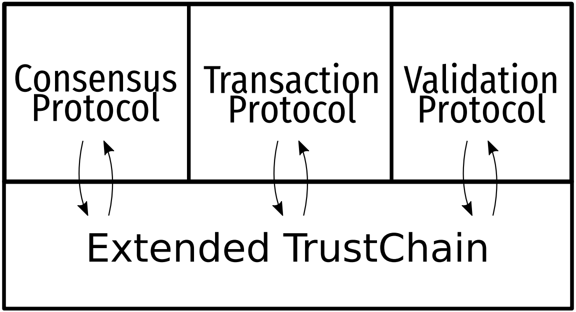
Early blockchains



Our idea

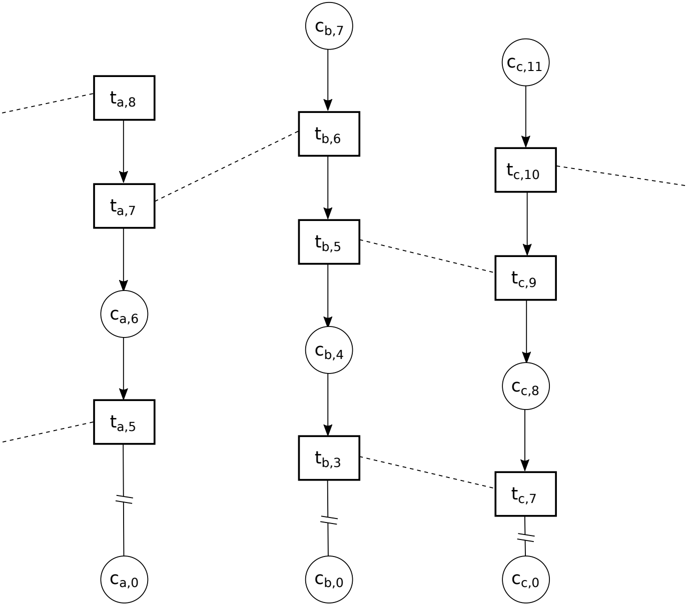
Architecture overview

The four components of CHECO[7]



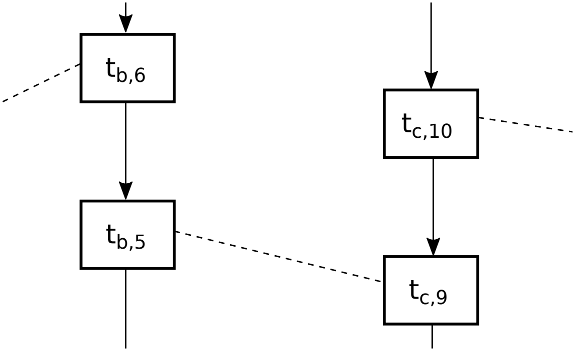
[7] CHEckpoint COnsensus

Extended TrustChain



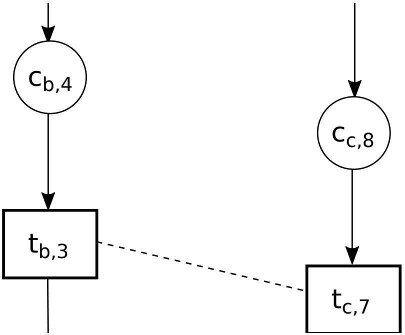
Extended TrustChain: Transaction (TX) block

- Goal: record transactions
- A transaction is an agreement on a piece of data, i.e. digitally signed by both parties
- It is represented by a pair of TX blocks

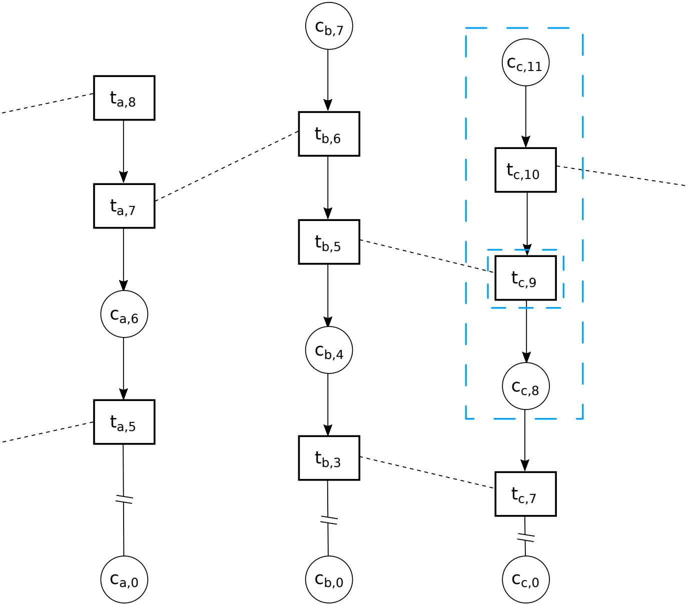


Extended TrustChain: Checkpoint (CP) block

- Goal: represent the state of the chain using a single digest
- A collection of CP blocks from all the nodes represent the state of the system
- Nodes become aware of the system state by running our consensus protocol



Extended TrustChain: Fragment of a TX block

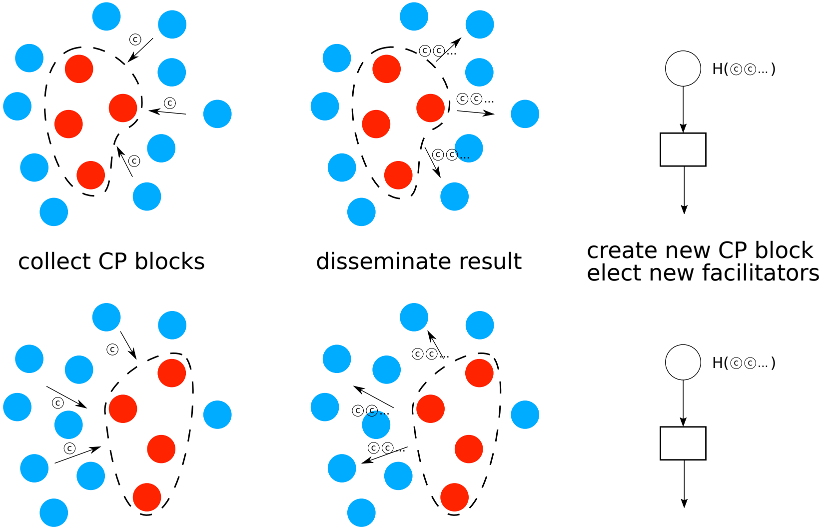


Consensus protocol

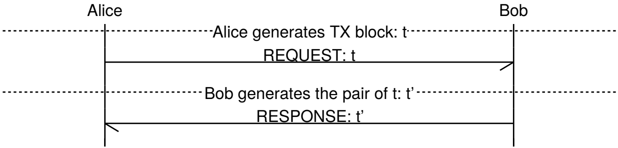
- Goal 1: reach consensus on a collection of CP blocks amongst all the nodes
- Goal 2: create new CP blocks at the end of the protocol
- Uses an existing fault-tolerant consensus algorithm (HoneyBadgerBFT[8]) as the building block
- But it cannot be used in a large network due to high communication complexity
- We overcome this limitation by selecting a small number of *facilitators* from the network to run HoneyBadgerBFT

[8] MXCSS, CCS16

Consensus protocol

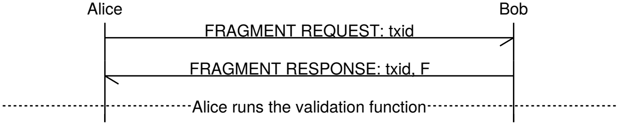


Transaction protocol



- Two TX blocks are generated on the chains of Alice and Bob
- No guarantee that nodes follow this protocol
- Contrary to early blockchain systems, we do not broadcast transactions

Validation protocol



- To check that the transaction protocol is correctly followed
- Alice needs the fragment of the TX on Bob's hash chain
- Validation function checks whether the fragment is OK and contain the transaction
- Can be generalised—any node may run the validation protocol on any transaction (does not need to be their own)

Validation protocol: properties

Consensus on CP blocks → consensus on transactions

- CP blocks of the fragments are "anchored" due to the consensus protocol
- It is difficult to modify the fragment once "anchored"
- Since the transaction protocol and the validation protocol only use point-to-point communication, we achieve horizontal scalability.

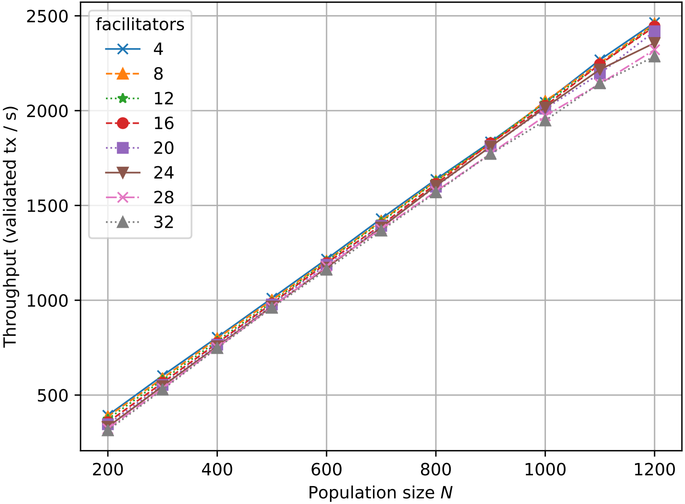
Outline

Implementation and experiment setup

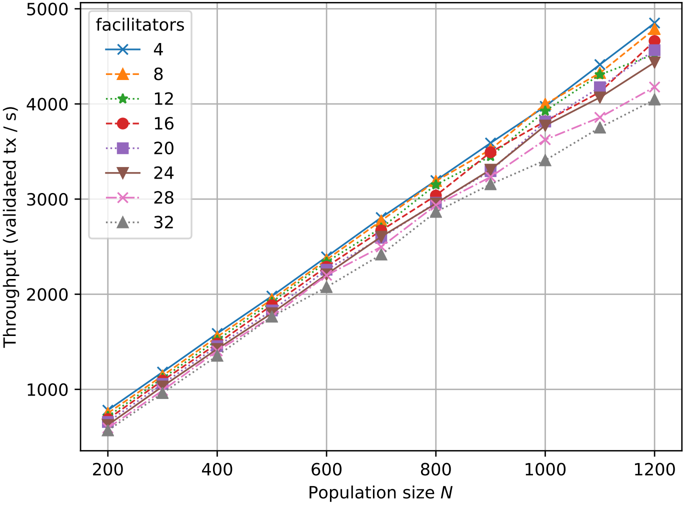
- Free and open source implementation on Github: `https://github.com/kc1212/checo`
- SHA256 for hash functions and Ed25519 for digital signature
- Experiment on the DAS-5[9]
- Up to 1200 nodes
- A third of the facilitators are malicious

[9] `http://www.cs.vu.nl/das5/`

Validated transaction throughput (random node)



Validated transaction throughput (fixed neighbour)



Outline

Conclusion

Our contribution:

- We design a blockchain consensus protocol—CHECO with horizontal scalability
- We formally analyse CHECO to ensure correctness
- Our experimental evaluation show strong evidence of our claim.

Future perspective:

- Improve fault-tolerance using ByzCoinX from OmniLedger
- Design and evaluate UTXO-style transactions (new paper to appear in Crypto Valley Conference)
- Assume a permissionless model

TX block

1. Hash pointer to the previous block
2. Sequence number
3. Transaction ID
4. Public key of the counterparty
5. Transaction message m
6. Signature the five items above

A transaction is represented by a *pair* of TX blocks

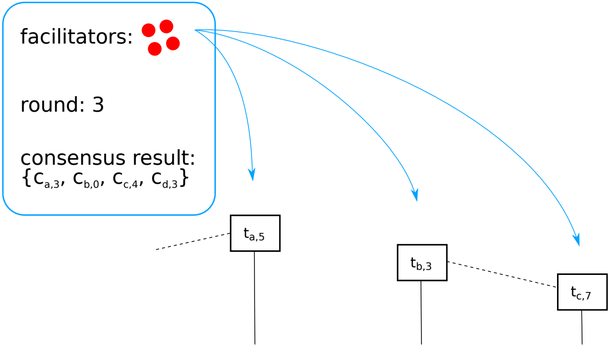
CP block

1. Hash pointer to the previous block
2. Sequence number
3. Digest of consensus result, i.e. a set of CP blocks
4. Round number r
5. Signature on the four items above

Background on ACS

- Asynchronous common subset
- A simplification of HoneyBadgerBFT
- n nodes
- t nodes may be malicious
- Input: every node proposes a set of values, e.g., $\{A, B\}, \{B, C\}, \ldots$
- Output: set union of the majority, e.g., $\{A, B, C, \ldots\}$

Consensus protocol: part 1

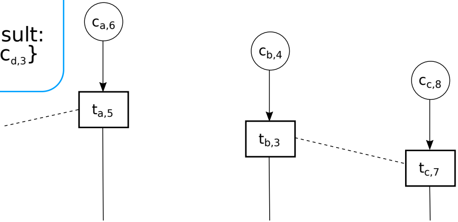


Consensus protocol: part 2

facilitators:

round: 3

consensus result:
$\{c_{a,3}, c_{b,0}, c_{c,4}, c_{d,3}\}$

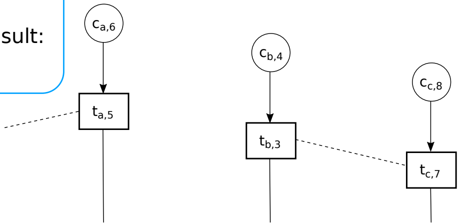


Consensus protocol: part 3

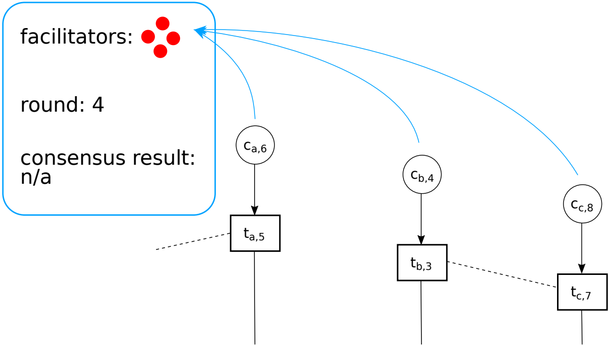
facilitators: lottery
$\{c_{a,3}, c_{b,0}, c_{c,4}, c_{d,3}\}$

round: 4

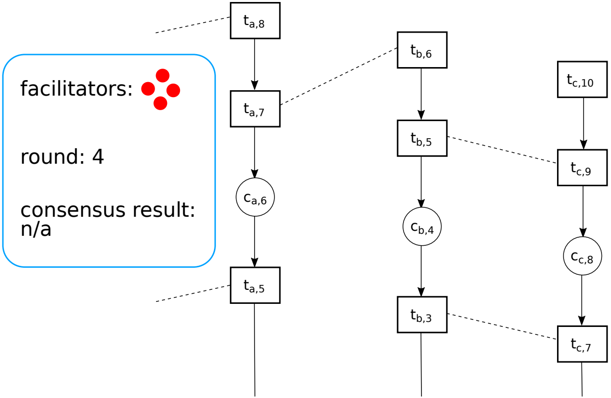
consensus result:
n/a



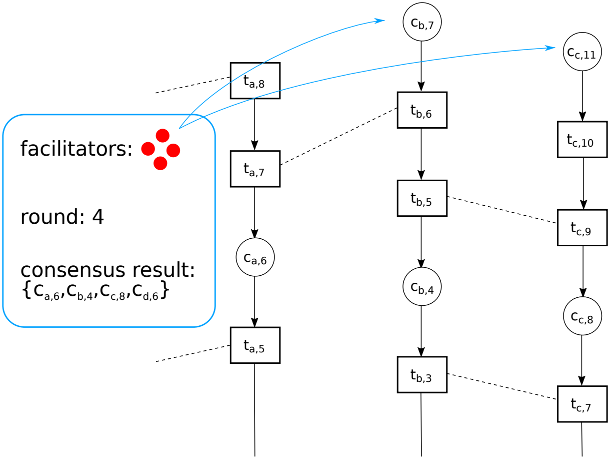
Consensus protocol: part 4



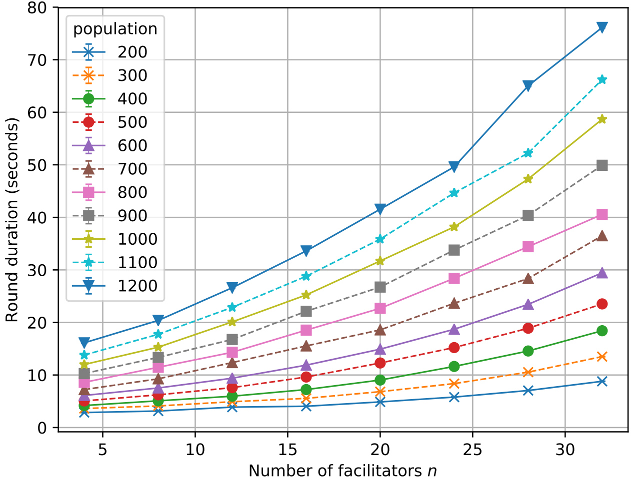
Consensus protocol: part 5



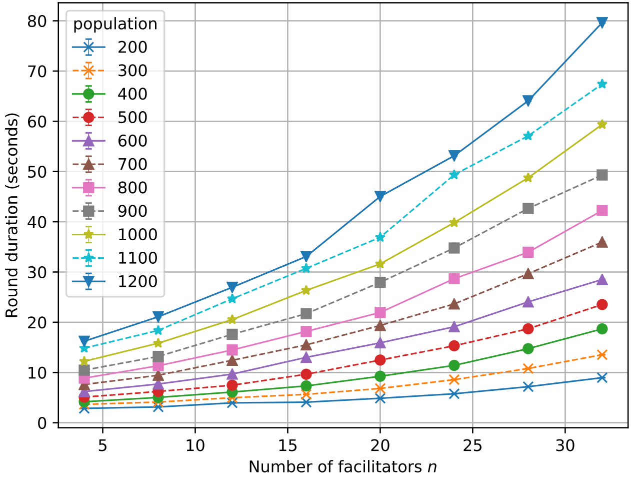
Consensus protocol: part 6



Effect of the number of facilitators (fixed neighbours)



Effect of the number of facilitators (random neighbours)



Stress test (fixed neighbour)