Designing Layer-2 based solutions to tackle the blockchain trilemma

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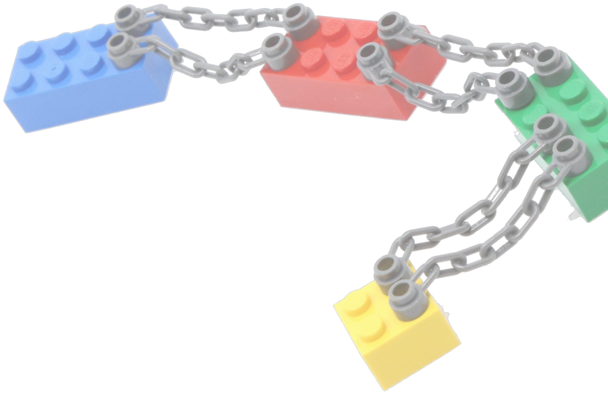
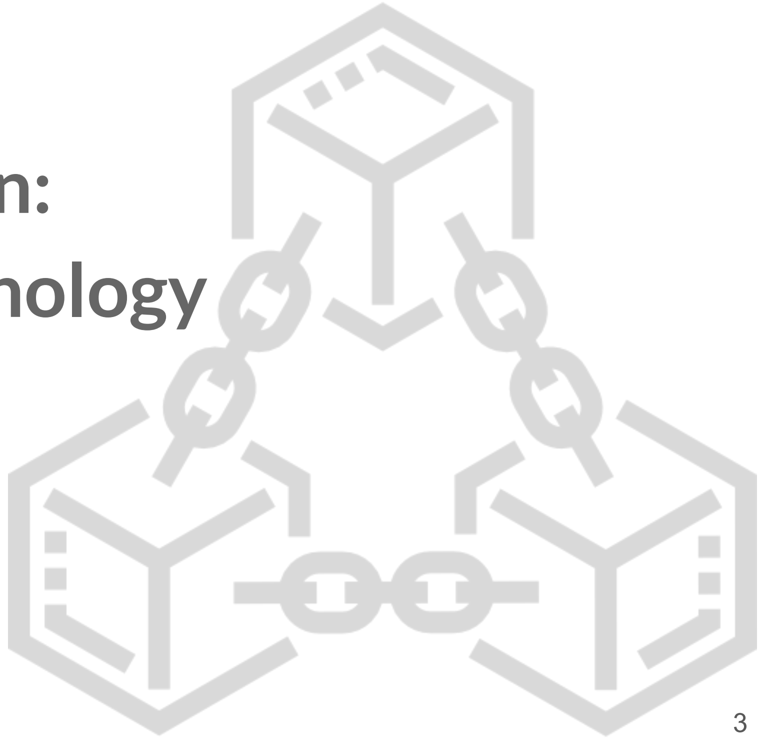


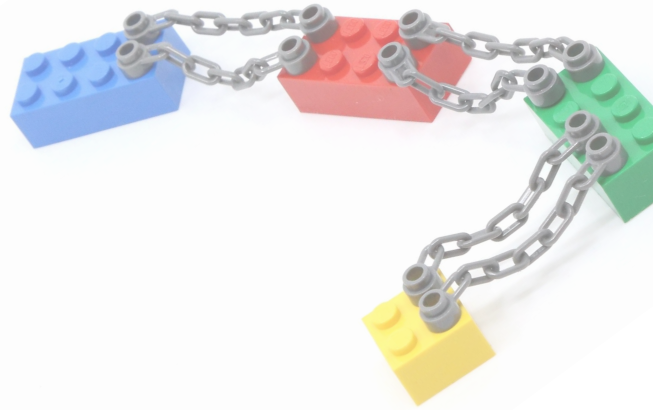
Roadmap

1. Introduction: Blockchain technology
2. State of the Art: Layer-2 technology
3. Proposal
4. Conclusions

Introduction:
Blockchain technology

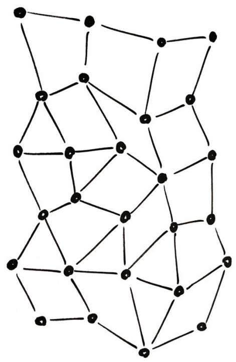


Blockchain technology



A data structure **replicated** by all the peers of a P2P network

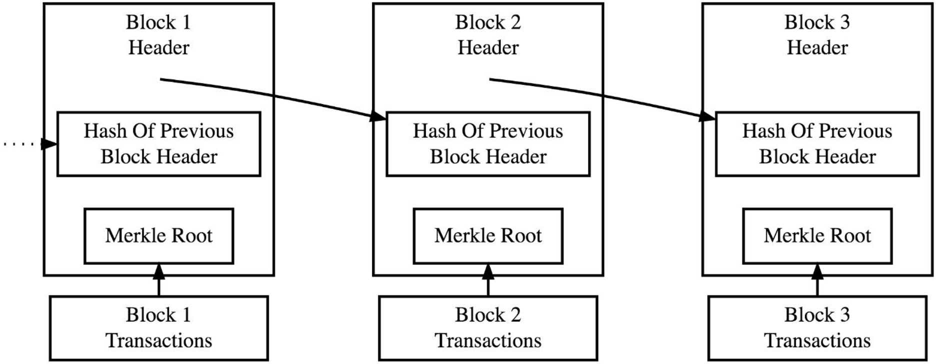
- The peers store the same data
- The peers agree on upgrades
  - This redundancy guarantees **immutability**
- Typically, freedom of connection
  - This guarantees **transparency**



Blockchain technology

The blockchain is composed by

- A list of blocks hash-linked together
- Each block is composed by
    - An Header
    - A body



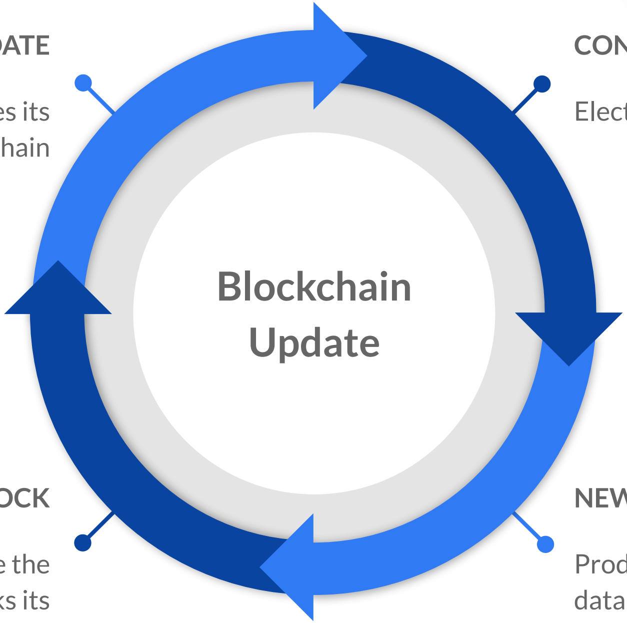
Blockchain technology

UPDATE

Each peer updates its local blockchain

CONSENSUS

Elect a block proposer

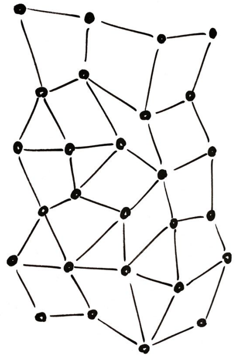


RECEIVE THE BLOCK

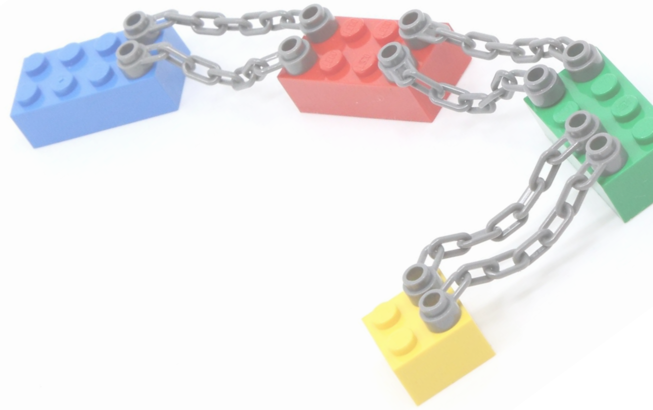
Each peer receive the block, and checks its correctness

NEW BLOCK

Produce a new block of data, and broadcast it



Bitcoin and Ethereum



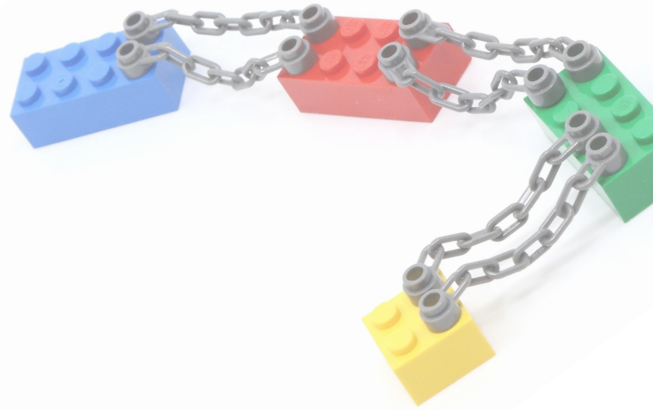
(1st Gen) Bitcoin implements the first decentralized digital currency, known as cryptocurrency, called bitcoin (BTC)

- The block body is composed by monetary **transactions**

(2nd Gen) Ethereum implements a platform for the execution of Decentralized Applications

- Execute Turing-complete programs called **smart contracts** on the Ethereum Virtual Machine

Architectural variations



Writer: A node that contributes to update the blockchain
Reader: A node that can read the blockchain and send transactions

If there are **NO** restrictions on the

- Writers => **Permissionless** / Readers => **Public**

Real world scenarios however might have different requirements

- Limit the peers to trusted ones (**Permissioned**)
- The state is not fully available (**Private**)

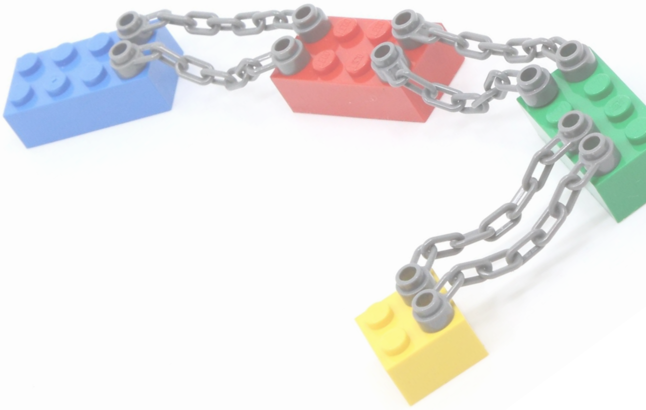
[Wüst]

Taxonomy

Restrictions on Readers

Private Permissionless Not realistic	**Private Permissioned** Required permission to participate Known identities, trusted nodes Non verifiable state Simple consensus, high scalability
Public Permissionless Can participate freely, decentralized (Pseudo) Anonymity Fully verifiable state Complex consensus, low scalability	**Public Permissioned** EOS Required permission to participate Known identities, trusted nodes Fully verifiable state Simple consensus, high scalability

Restrictions on Writers



Taxonomy

Restrictions on Readers ↑ / Restrictions on Writers →		
	Private Permissionless Not realistic	**Private Permissioned** Required permission to participate Known identities, trusted nodes Non verifiable state Simple consensus, high scalability
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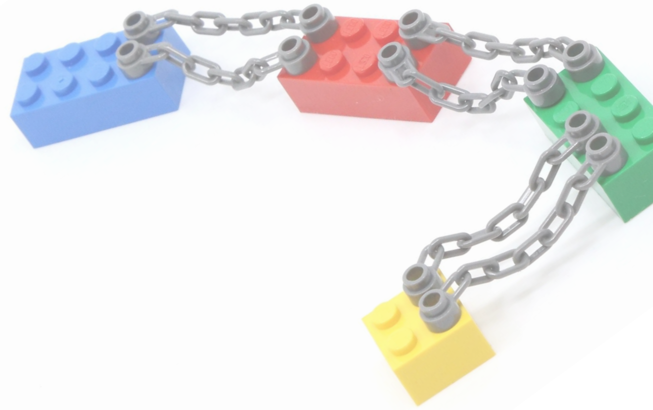
Restrictions on Readers

Restrictions on Writers

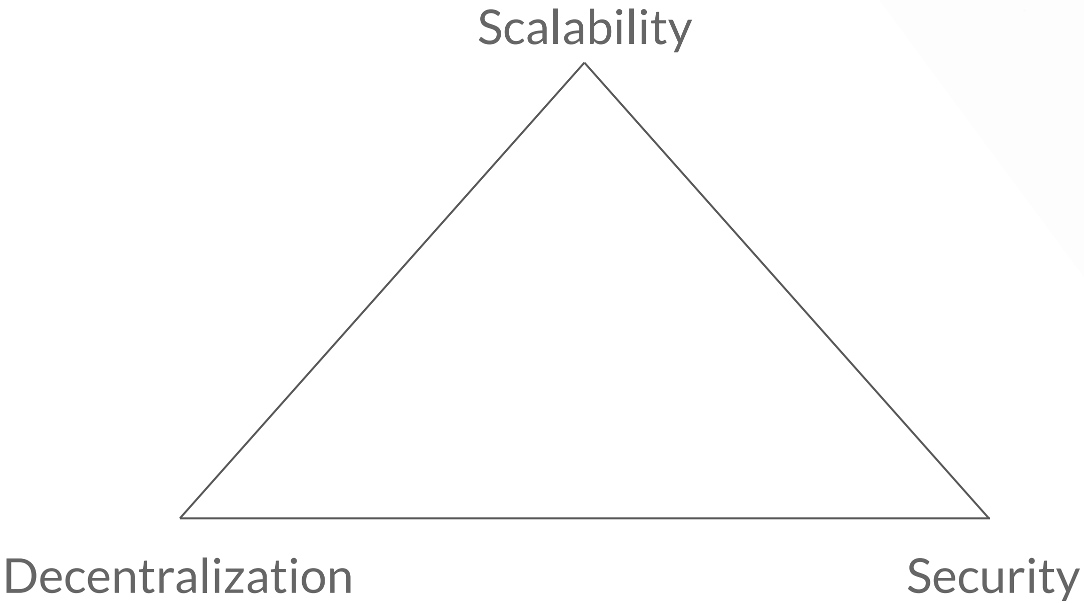


Scalability

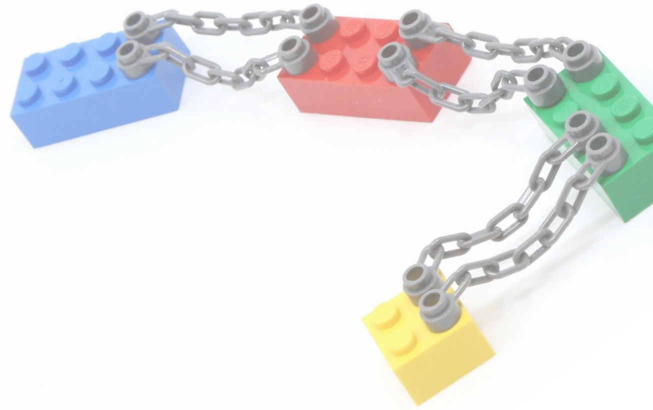
Scalability is typically connected with the permissionless / permissioned axis

- As a consequence, the consensus protocol
- An "open" consensus improves **decentralization**
    - Anybody can participate
- It improves **security**
    - There are strong cryptographic countermeasures
- But it does not **scale**
    - More the participants does not mean more the performance

Scalability



[Trilemma]

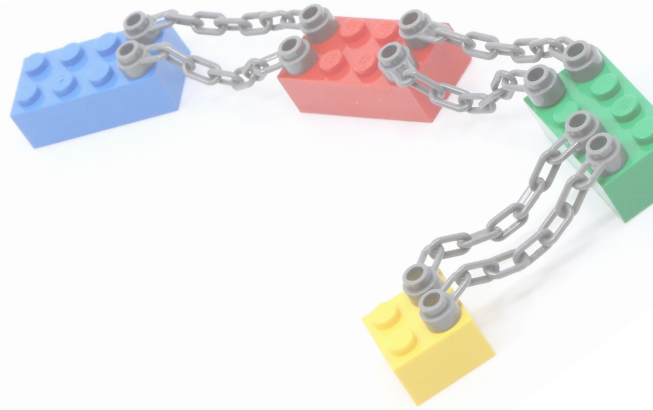


Scalability

			EOS	
Scalability	★½	★½	★★★★½	★★★★½
Decentralization	★★★★★	★★★½	★★½	★
Security	★★★★	★★★★	★★★½	★★½

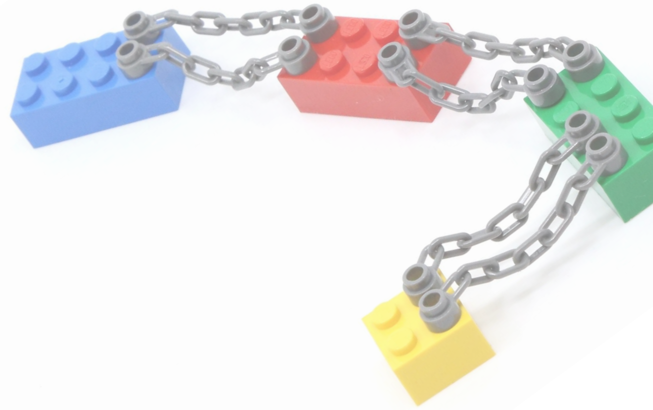
[Garriga]

Privacy



Privacy is typically connected with the public / private axis

- In a public network data have not privacy
  - So GDPR-sensitive data should not be stored
- Such data can be encrypted
  - But verifiability will be lost, that is a key feature of integrating the blockchain in a process

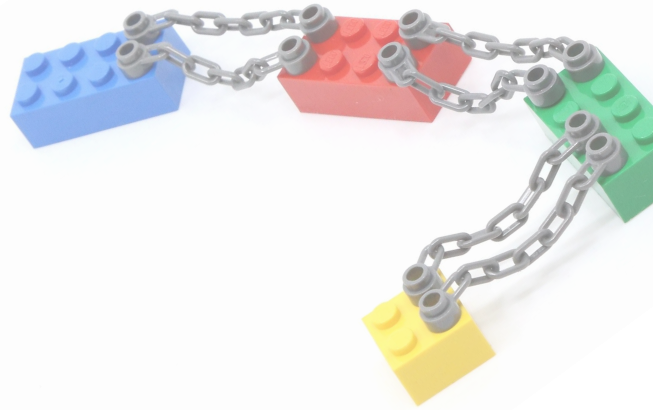


Privacy

			EOS	
Scalability	★½	★½	★★★★½	★★★★½
Decentralization	★★★★★	★★★½	★★½	★
Security	★★★★	★★★★	★★★½	★★½
Privacy	★★	★★	★★	★★★★

[Garriga]

Towards Layer-2



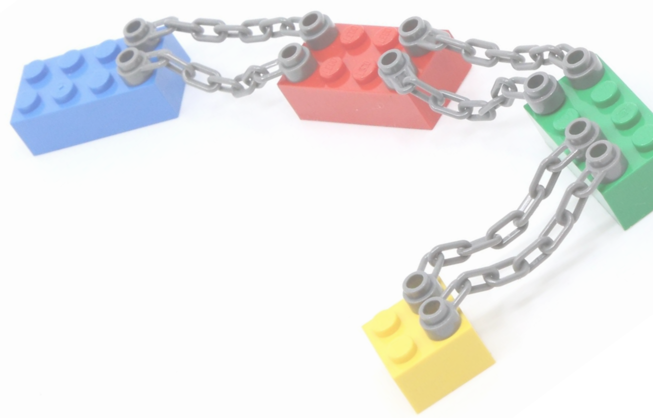
Trade-off within the blockchain trilemma

How can we improve scalability and privacy of public permissionless compositions?

This is where **Layer-2 technology** comes in

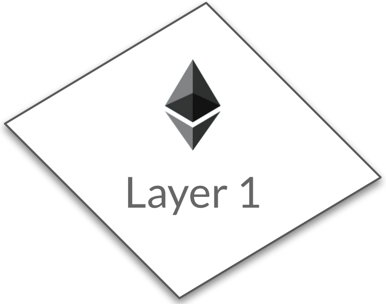
Layer-2 technology

Layer-2 technology (1)

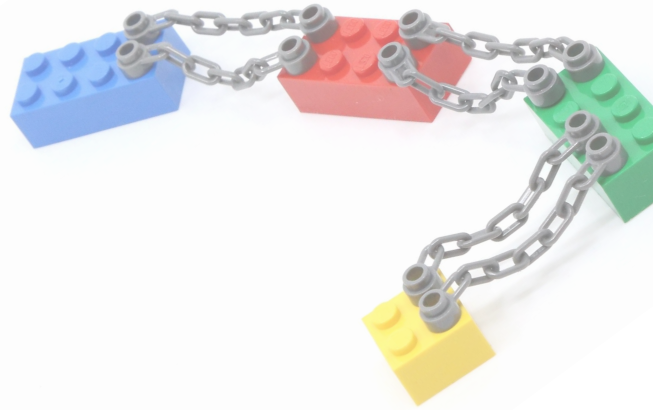


Any change to the blockchain protocol is labeled as **Layer-1**

- Block size, consensus algorithm…[Zhou]
- Any change is an important point of debate within the community
- And the impact on the scalability is relatively small
- Unless the overall architecture and protocol is drastically different

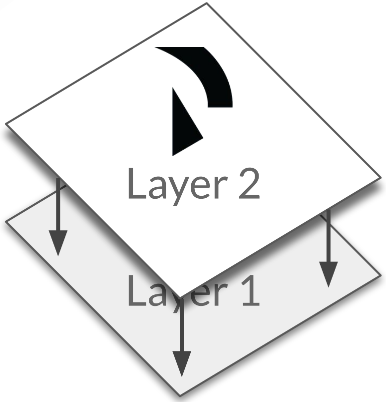


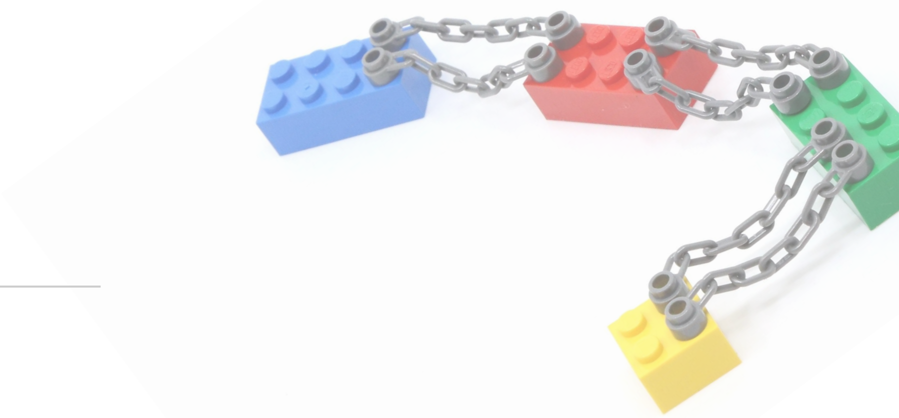
Layer-2 technology (2)



Layer-2 are those technologies improving a blockchain, e.g. scalability or privacy, with off-chain operations <u>bound to the blockchain</u>

- Operations are not subjected to consensus latencies
- Are not recorded
- But the link with the blockchain ensures auditability





Layer-2 technology (3)

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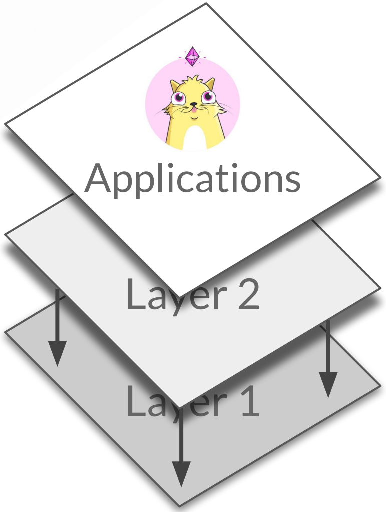
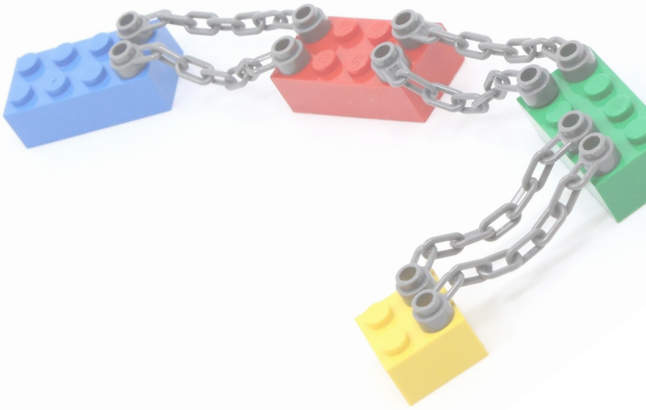
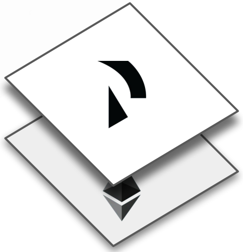


Layer-2 technology



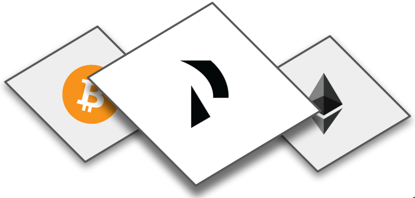
There are 3 Layer-2 high level models:

- State Channel
- Sidechains
- Off-chain computation and/or storage

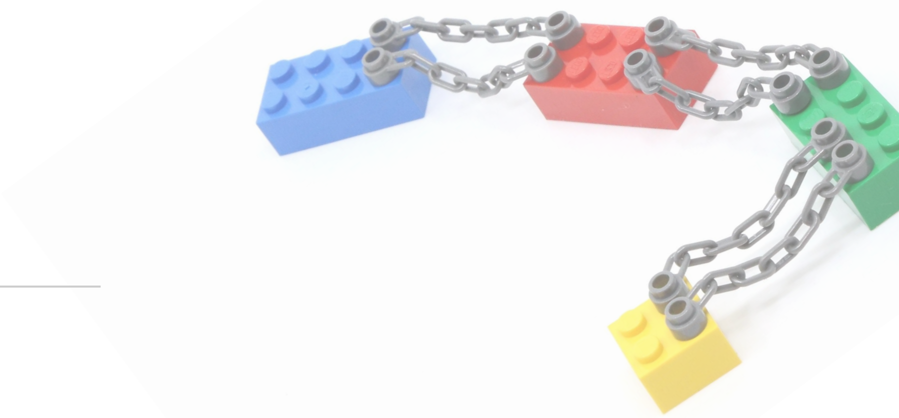


All of these models can

- Work on top of a blockchain protocol, **Single-chain**
- Connect more blockchains, **Multi-chain**

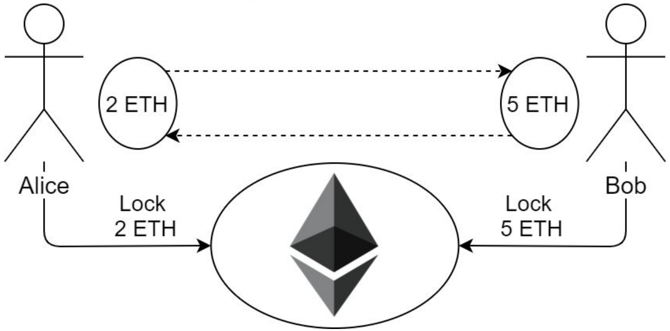


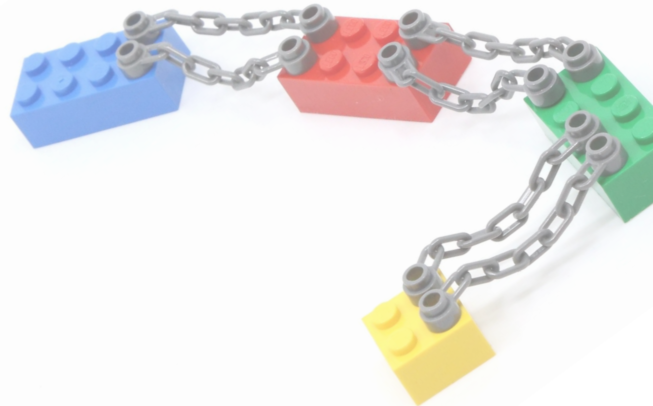
State channels



A state channel is a virtual connection between two peers

- The peers create a channel to share a state
  - The operation is **bound** with a transaction
- Each peer can update the state
  - The update happens off-chain
- Either peer can close the connection
  - **Bound** with a transaction

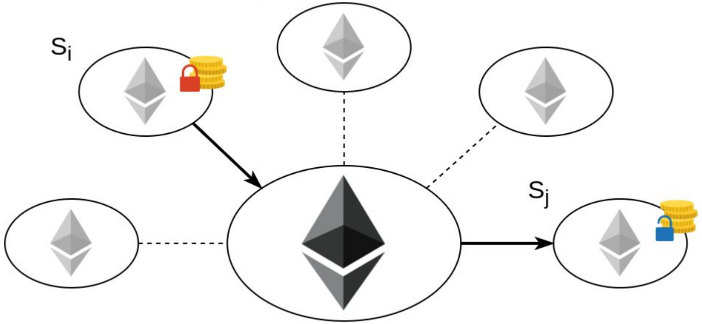




Sidechains

In a sidechain model the state is split among different chains

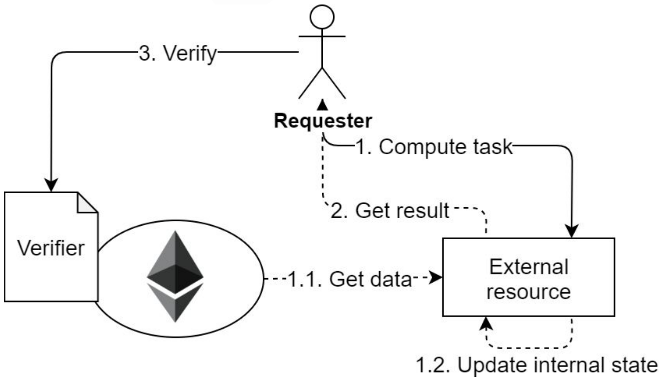
- Each sidechain S_i store a portion of a state (e.g. a subset of transactions)
- Its block headers are **bound** to a Main Chain
  - A Main Chain for many sidechains
- Hierarchy of validators
- Asset may go from S_i to S_j
  - Locked in S_i, unlocked in S_j



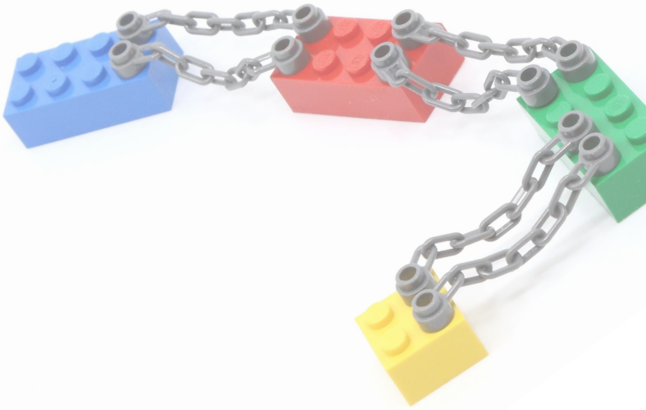
Off-chain computation

The off-chain computation model is based on relief the smart contracts from heavy computation

- A computation is performed “outside”
- A smart contract has to verify the outcome
  - Or a “proof”
- The verification has to be cheaper
  - **Binds** the outcome on the blockchain
- Similar approach for the storage

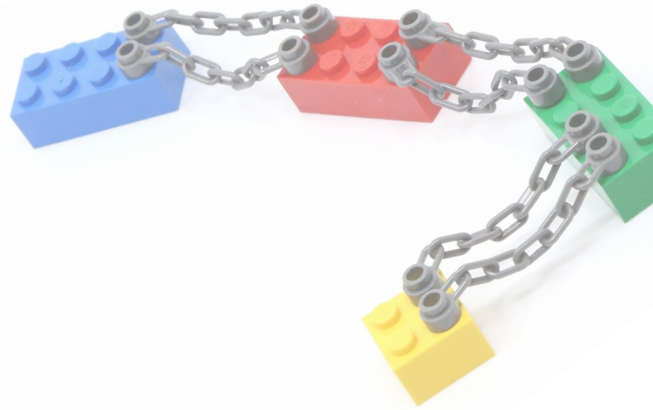


Lightning Network



The Lightning Network[Poon] is a layer-2 solution for Bitcoin based on state channels

- Known as payment channels
- Two users, A and B, lock funds in the channel
- Exchange funds within the channel
  - An exchange is known as **commitment**
  - No fees, fast time, no public record
- Either user can close the channel at any time



Lightning Network

Commitments

S0

Comm-1

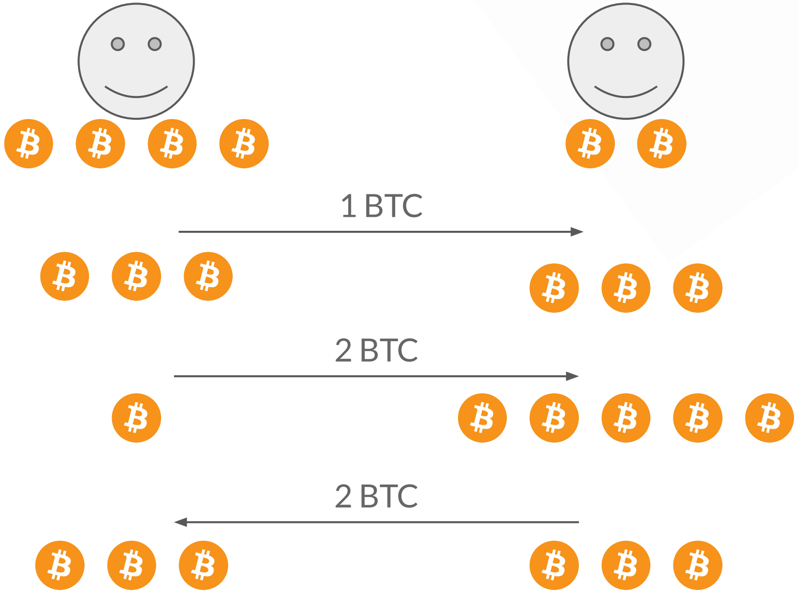
S1

Comm-2

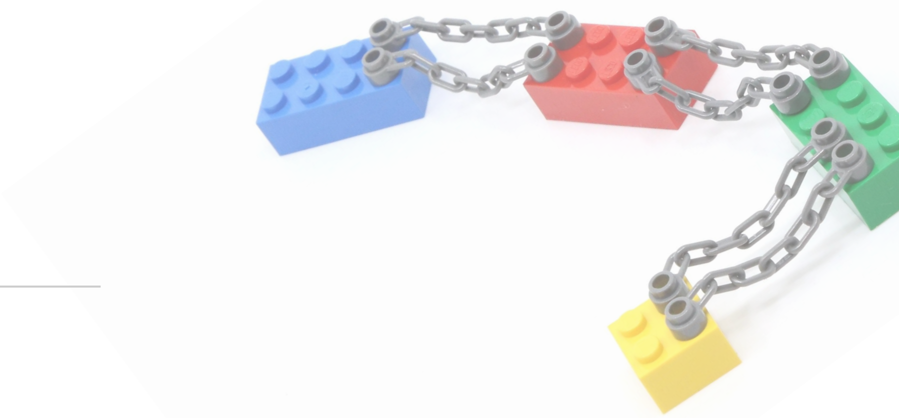
S2

Comm-3

S3

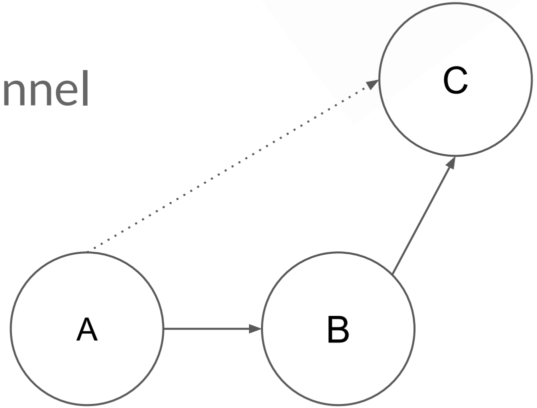


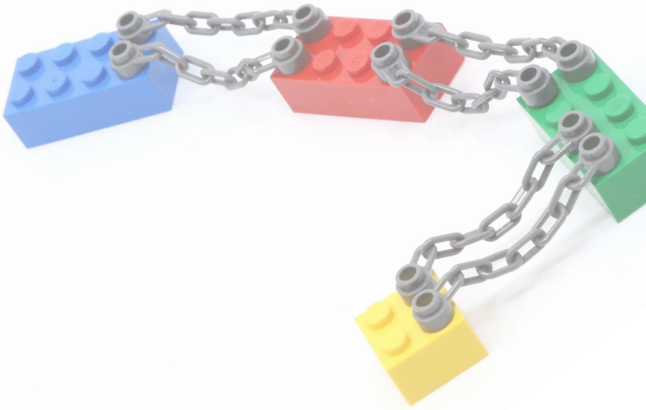
Lightning Network



If A wants to send BTC to C

- A and C need to open a new channel
    - A may not have enough funds
        - A needs to close another channel
- B and C are connected
    - A can exploit that connection

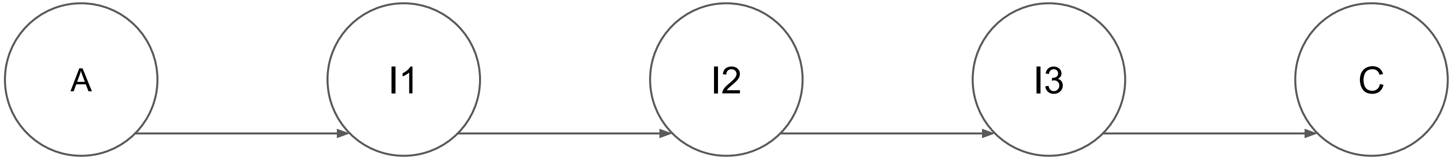




Lightning Network

A needs to find a path to C

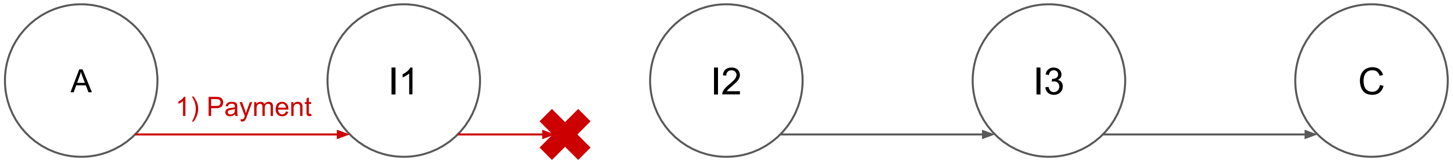
- Assuming the path A, I1, I2, I3, C

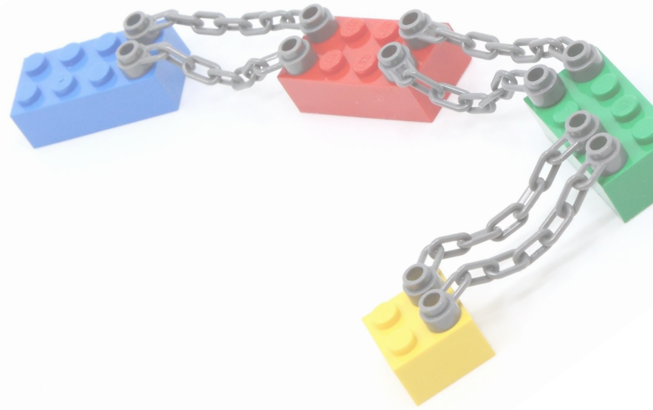


Lightning Network

A needs to find a path to C

- Assuming the path A, I1, I2, I3, C
- If A pays I1
  - I1 may not forward the payment

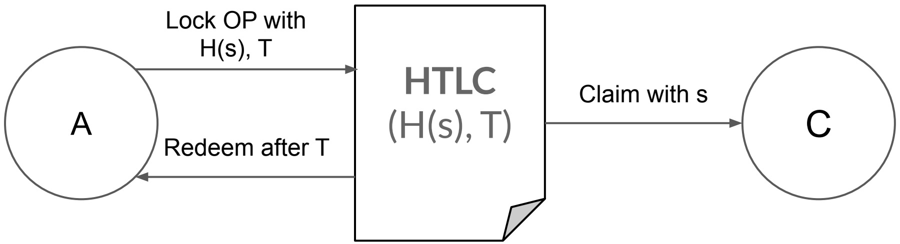




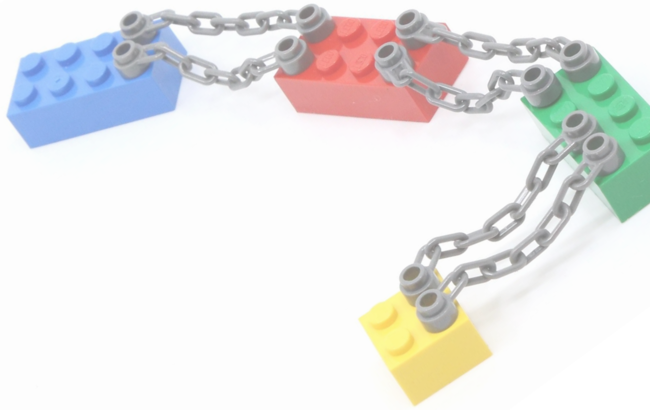
Lightning Network

Hash Time Lock Contracts (HTLC), contracts that exploit

- **Hashlock:** lock an operation unless the preimage of a hash value is revealed
- **Timelock:** lock an operation within a deadline



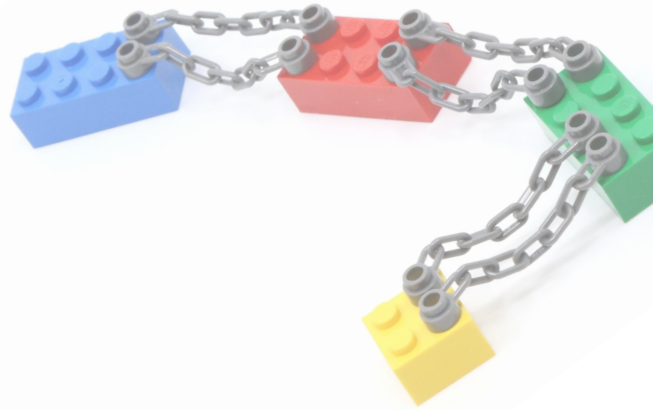
Lightning Network

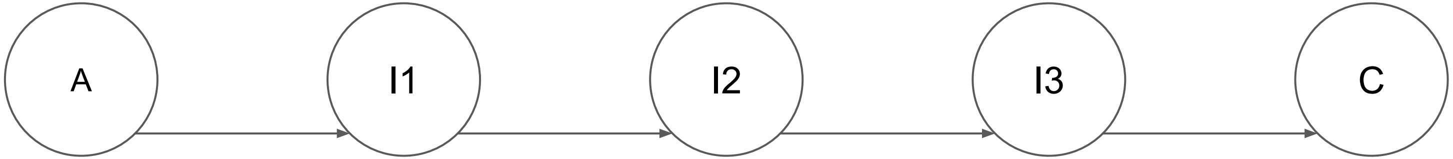


A needs to find a path to C

- Assuming the path A, I1, I2, I3, C
    a. Generation of secret and hashlock
    b. Hashlock communication
    c. HTLC setup route
    d. Secret revelation and payment route

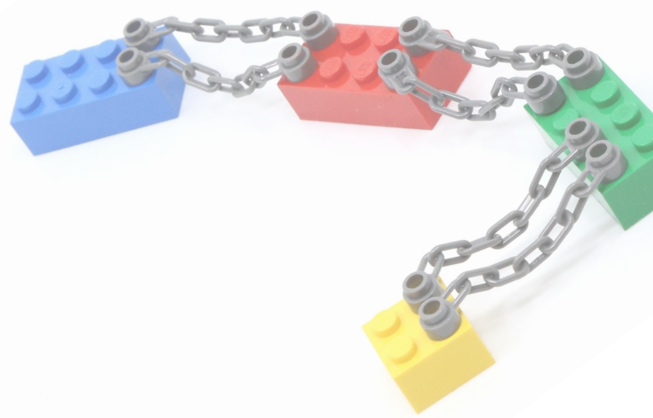
Lightning Network

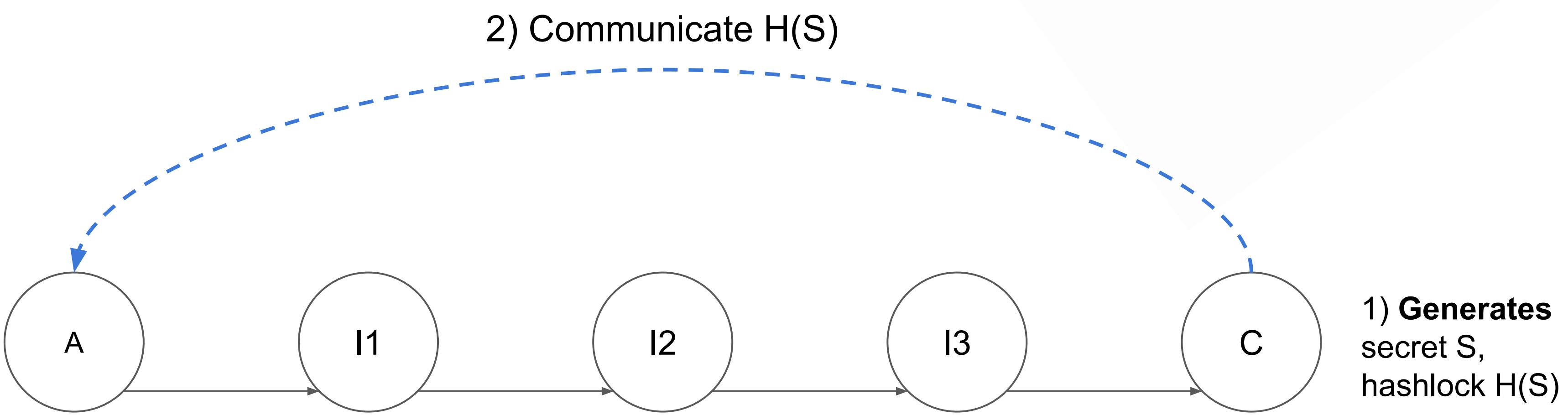




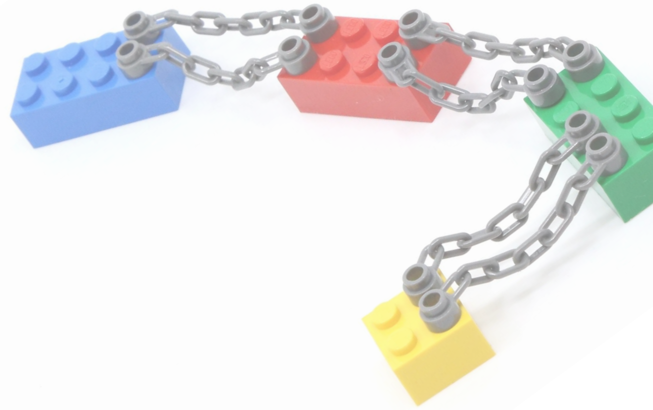
1) **Generate** secret S, hashlock H(S)

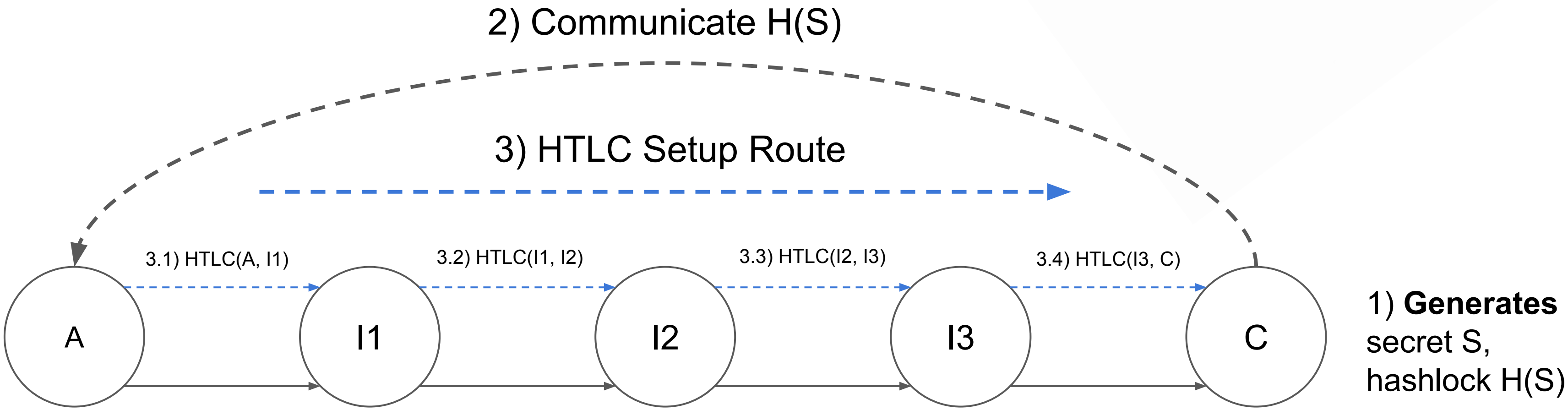
Lightning Network





Lightning Network





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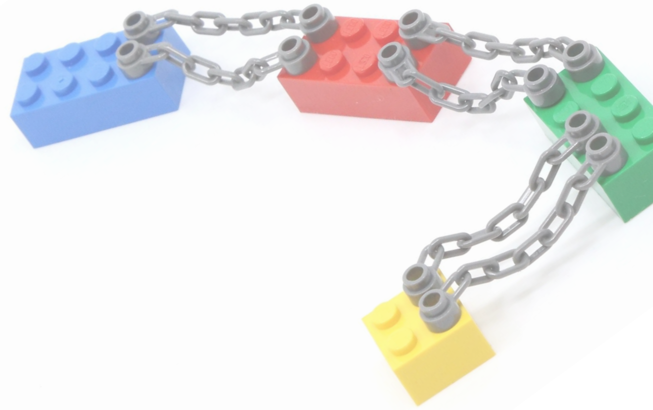
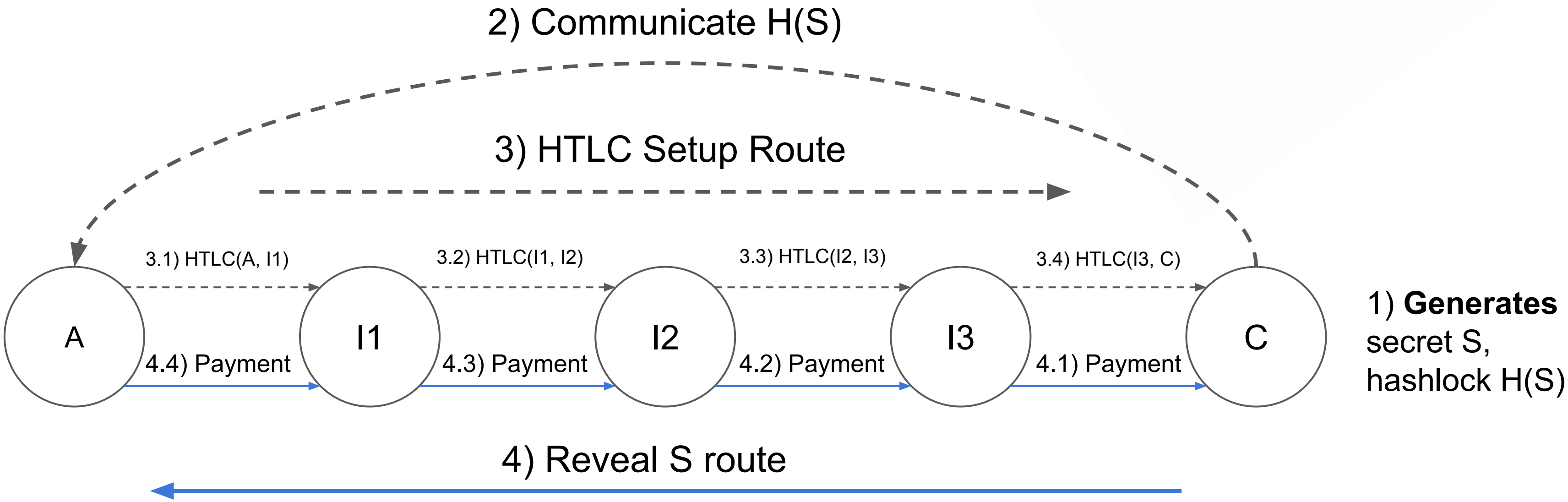
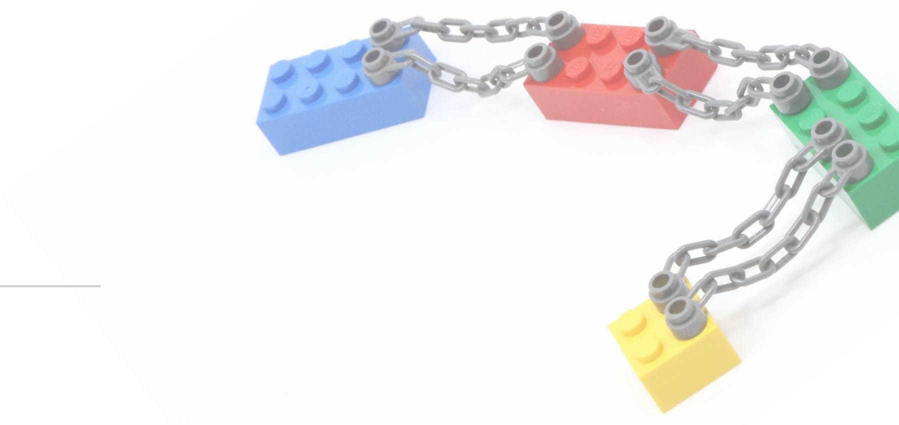






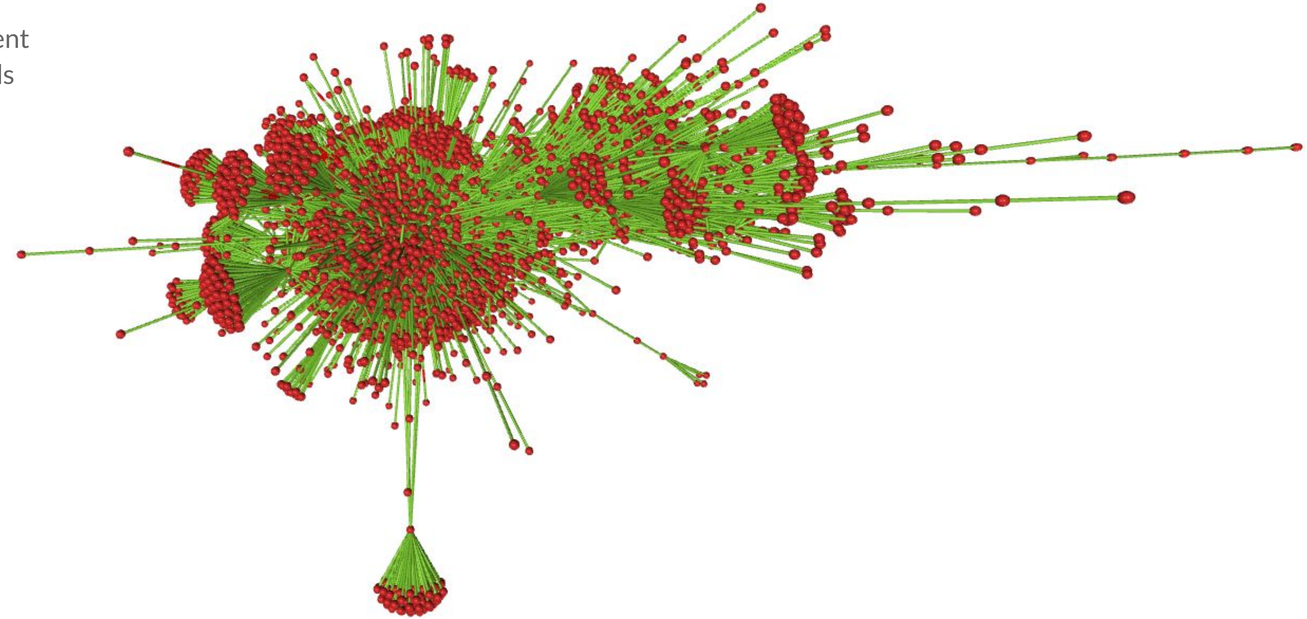
Lightning Network

Snapshot September 2020

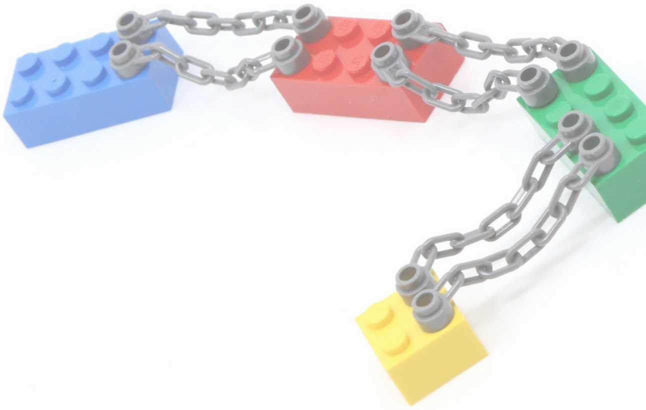
14K nodes, 37K channels
Biggest connected component
90% of the network channels

Node

Channel



Proposal



Proposal

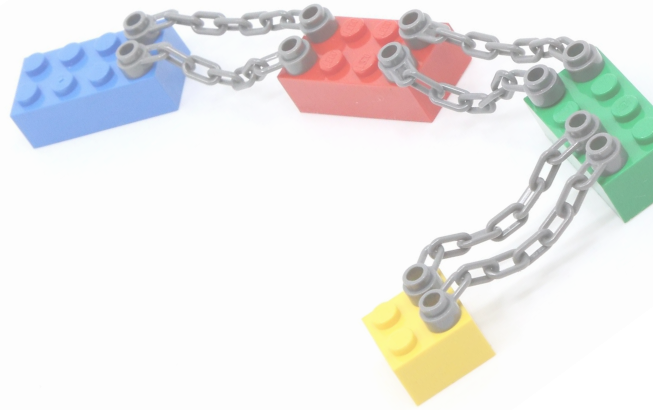
Idea

- Tackle the blockchain trilemma and privacy issues with Layer-2 technologies

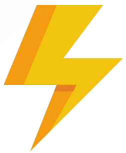
Goal

- Analyze the Layer-2 technology, and develop a framework for their adoption for blockchain applications

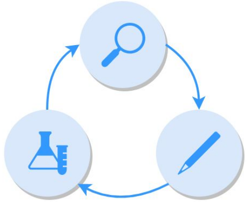
Proposal



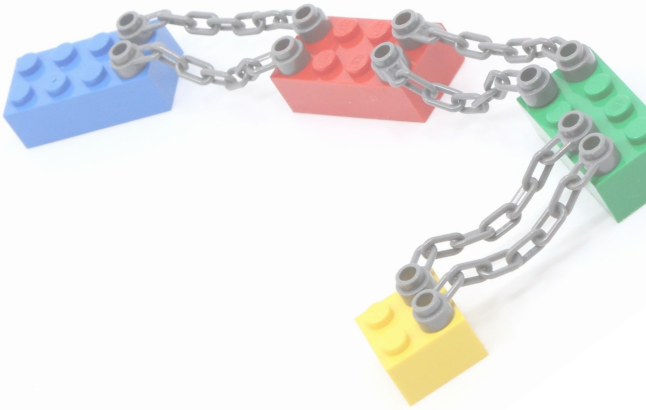
Two research directions



- Analysis of the Bitcoin Lightning Network
  - Graph analysis, security issues, routing protocol



- Development of a methodological framework for the adoption of Layer-2 models in applications
  - Use case analysis, prototyping, generalization



Proposal

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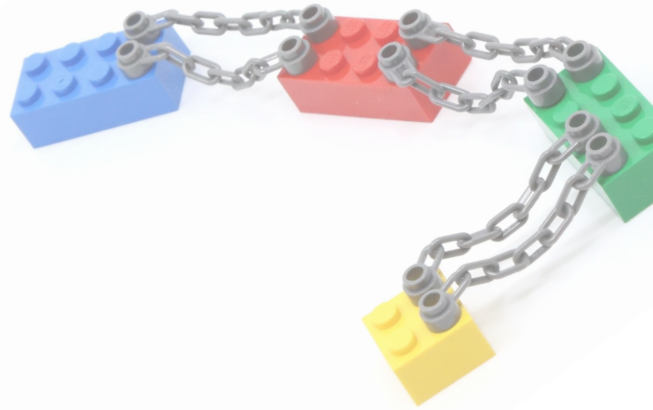
  - Graph analysis, security issues, routing protocol

- Development of a methodological framework for the adoption of Layer-2 models in applications
  - Use case analysis, prototyping, generalization

Analysis



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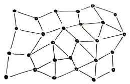

1 2 3 4

Crawling the Lightning Network

Download a snapshot of the network

Get an historical trace of snapshots

Analyze the network

Node degree distribution, topological properties

Temporal behavior and churn

Evaluate the security issues

Presence of payment hubs[Martinazzi], empty channels[Rohrer], privacy data disclosure[Joancomarti]

Design a routing protocol

Constraints close to a Flow optimization problem, plus properties to preserve[Gudgeon]

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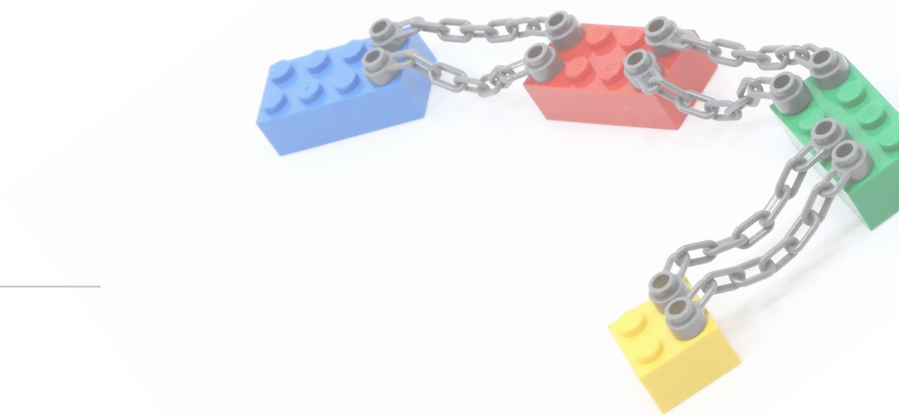

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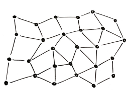

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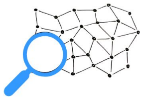

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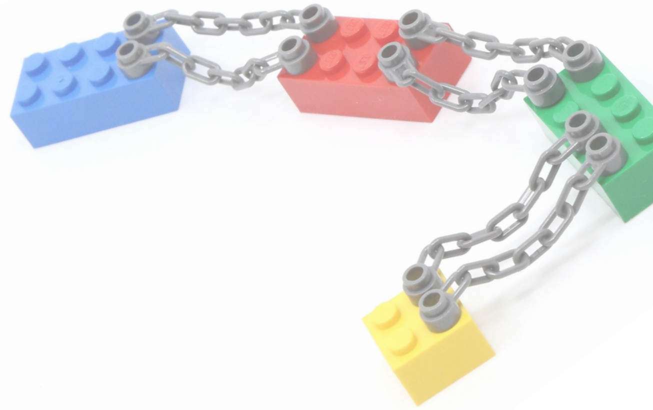

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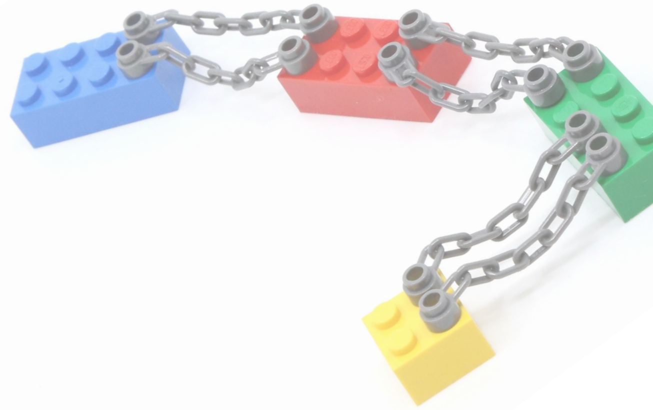

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Work in progress

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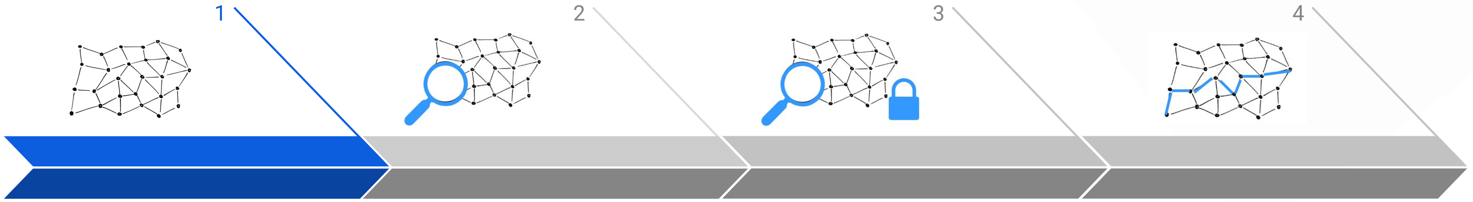
TO DO



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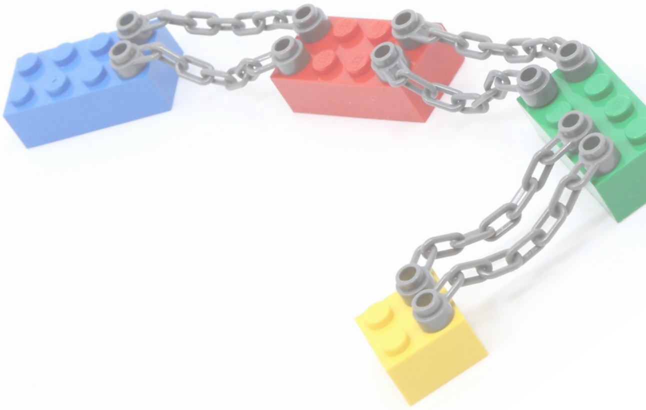
Proposal



Two research directions

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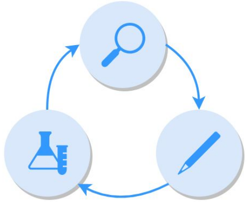
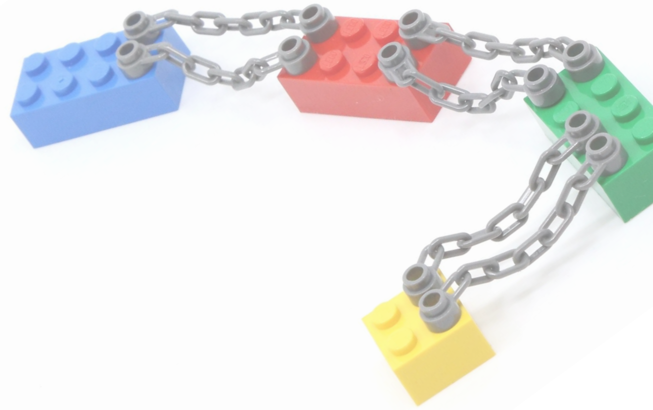
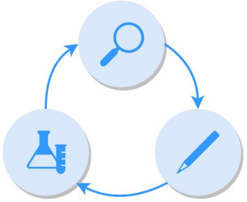


Development

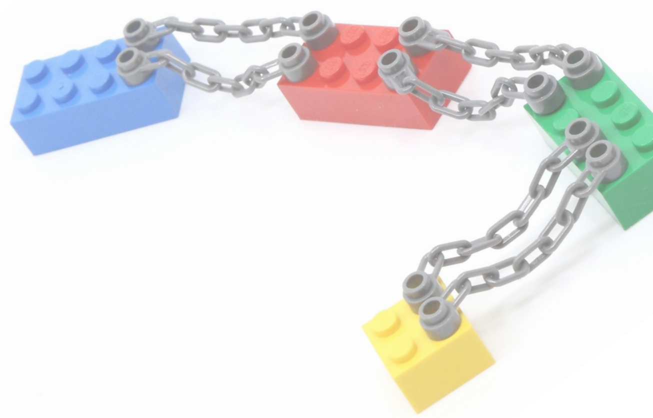
Work in progress | Done | TO DO



1. **Analyze requirements of test use cases**
   - Rating and Recommender Systems (RS)[Ricci]
   - Responsible Disclosure (RD)[Lagutin]
2. **Design a Layer-2 prototype**
   - Identify the model(s) best satisfying the requirements
   - Evaluate scalability and privacy
3. **Define a methodology**
   - Map requirements and constraints to Layer-2 models
4. **Design a general framework**
   - Output the best two-layered architecture for an input use case
   - Understand gains and losses in terms of scalability and privacy



Development



Work in progress — Done — TO DO

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Responsible Disclosure (RD)[Lagutin]

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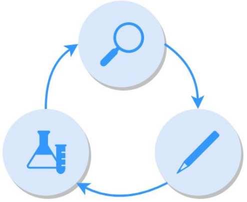

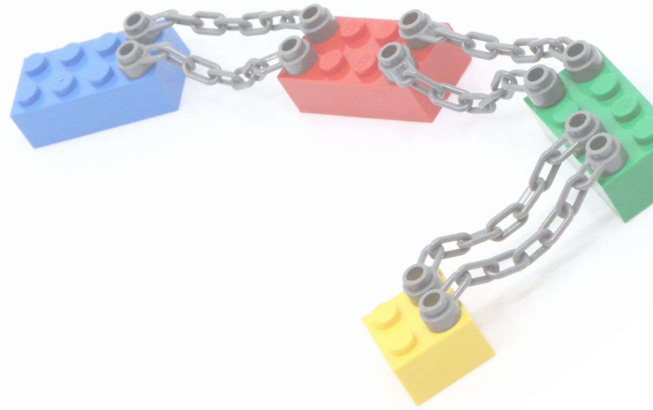

Development

Work in progress   Done   TO DO

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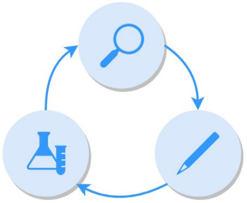

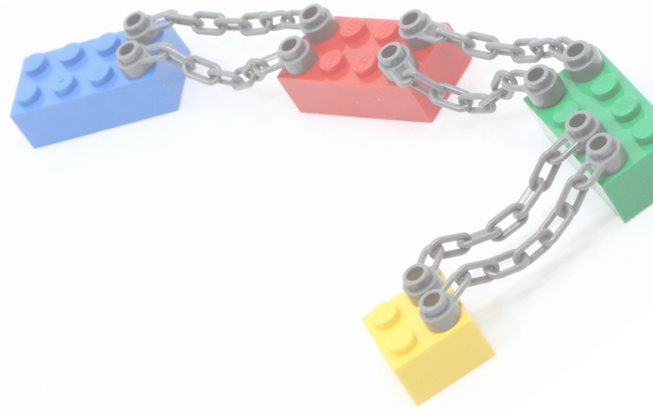

Development

Work in progress

Done

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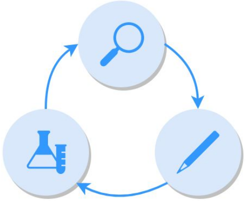
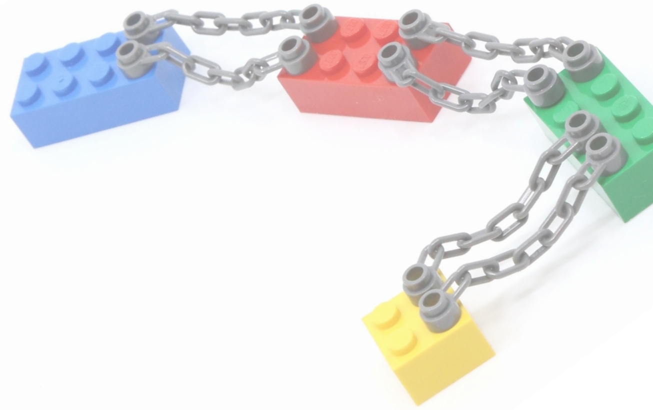


Conclusions



Conclusions

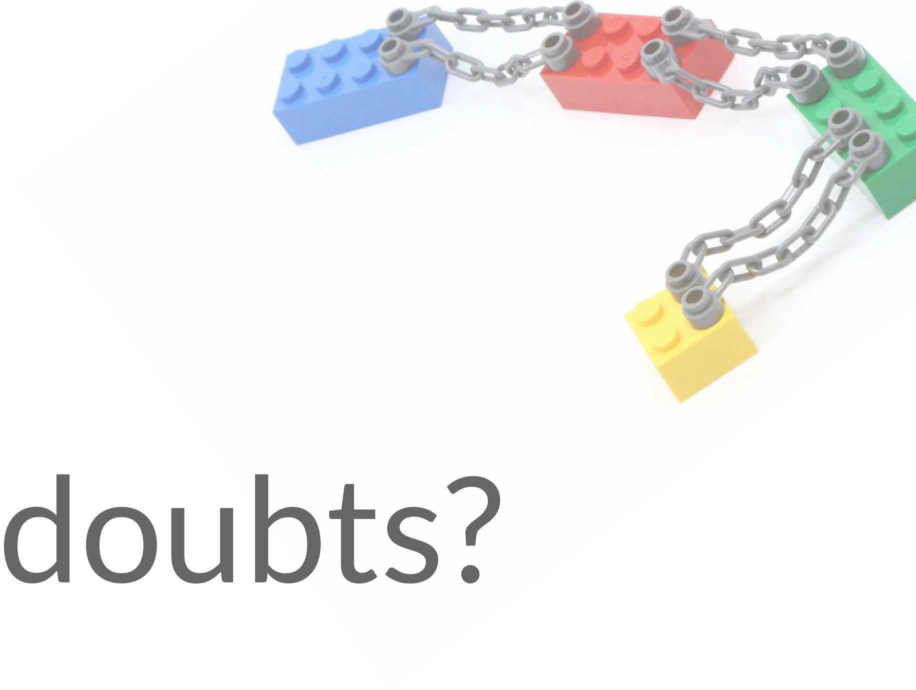
Blockchain-based applications suffer of the trilemma and privacy issues

- Layer-2 technologies try to solve them working on top of existing Layer-1 architectures

Goal

Study these technologies, and find a standard way to apply them to use-cases of research and industrial interest

Thank you!



Any doubts?

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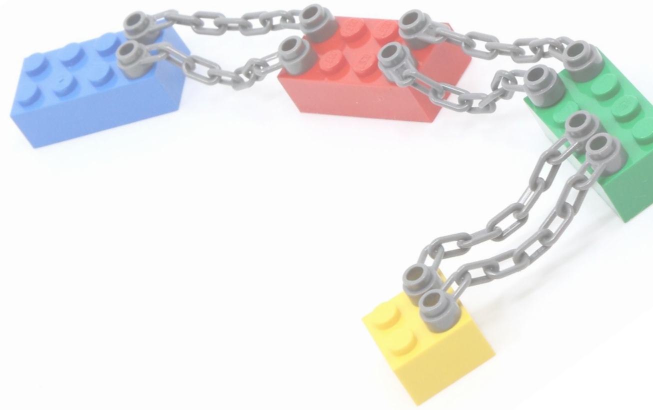

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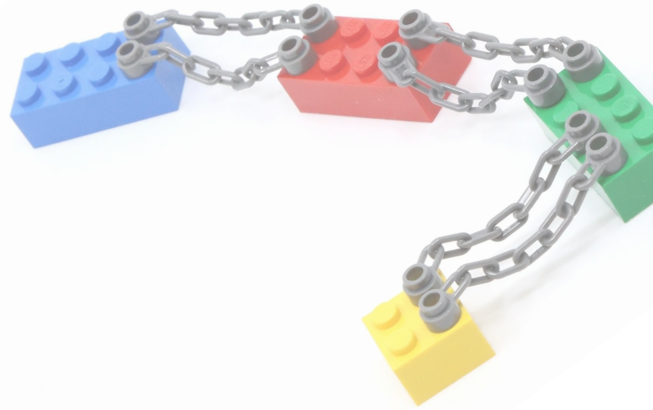

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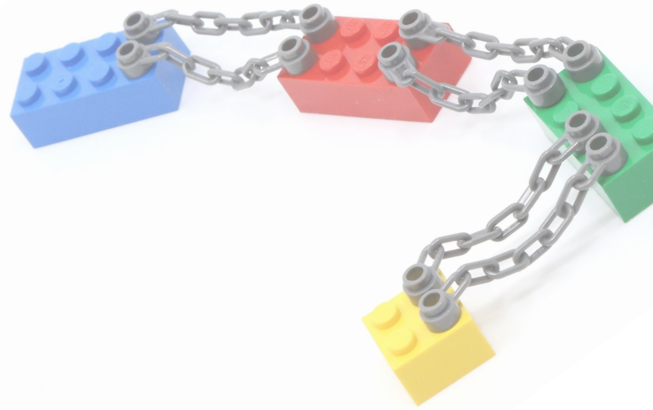

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[Lisi_FGCS] **Rewarding reviews with tokens: an Ethereum-based approach**, Lisi Andrea et al (SUBMITTED)