Blockchain Abstract Data Type

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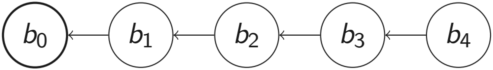
Blockchain day, @LINCS

July 12th, 2019

Blockchain: a distributed public ledger

Ideally, the Blockchain is an append-only (immutable) chain of blocks.

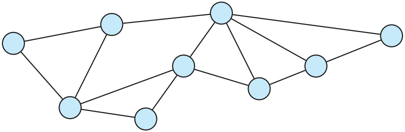


Each **block** contains the hash of the previous block and other application dependent information (as transactions).

Few Important points

Blockchain runs on a distributed system: different nodes are involved

Nodes communicate exchanging messages.



Each node has a local copy of the Blockchain

Append a new block

When there is a new block, who appends it?

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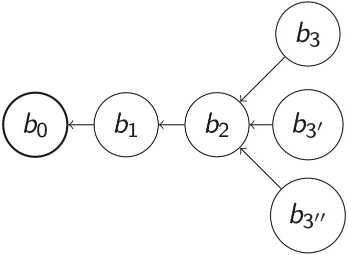
We want to preserve a chain shape, so we do not want to have multiple writers per time:



Two main approaches to append

We want one writer per block height.

- Proof-of-Work: a peer in order to append a new block has to provide as a proof the solution of a cryptographic puzzle.
  - it may happen to have more than one peer writing concurrently.

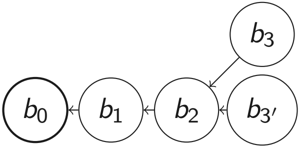
Two main approaches to append

We want one writer per block height.

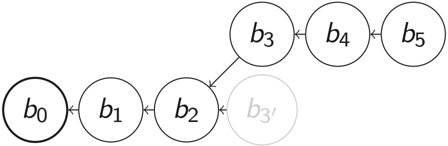
- Proof-of-Work: a peer in order to append a new block has to provide as a proof the solution of a cryptographic puzzle.
  - it may happen to have more than one peer writing concurrently.
- Consensus: peers agree on the next block to append.
  - Consensus does not scale;

Fork

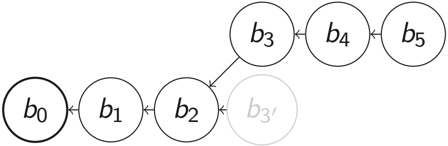
There can be more than one peer that appends, i.e., solves the PoW to append at the same block, in such case we have a **fork**.



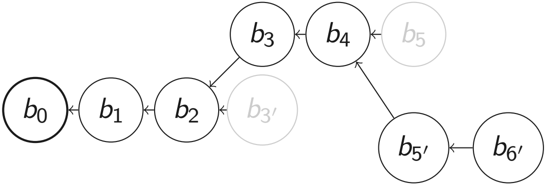
Fork Resolution: the longest chain is the main chain.



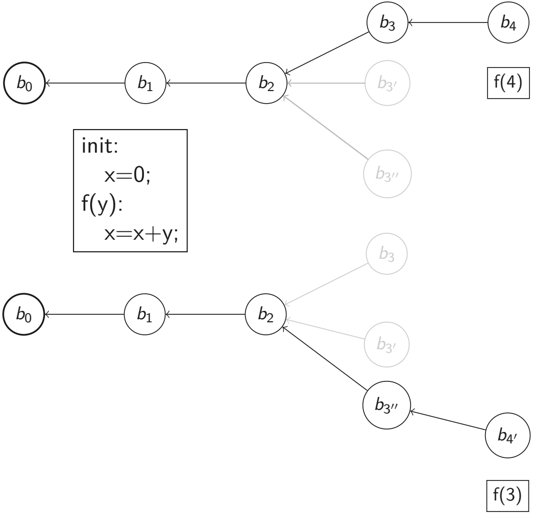
What do we read?



Different peers can have a different version of the Blockchain (due to network delays). **Which kind of consistency is provided?**



Example: Smart Contracts on Blockchain



```
init:
   x=0;
f(y):
   x=x+y;
```

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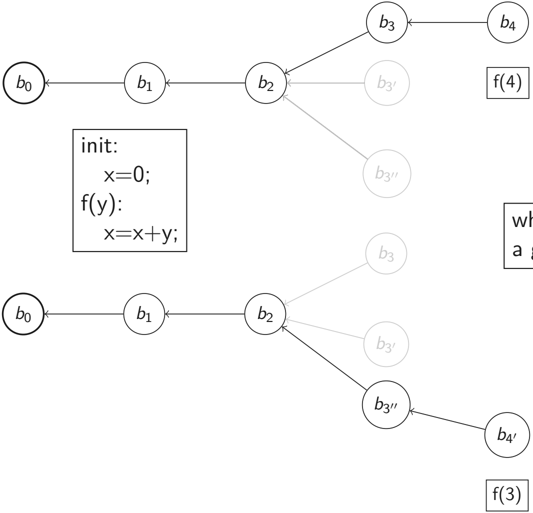

```
init:
    x=0;
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what is the value of x at
a generic time t at the two sites?

Blockchain, from the origin to nowadays

2008, ₿ S. Nakamoto. Bitcoin: A Peer-to-Peer Electronic Cash System

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Our contribution:

A unified construction providing formal specifications capturing forkable and non-forkable blockchains

E. Anceaume et al. *Blockchain Abstract Data Type*. In SPAA 2019

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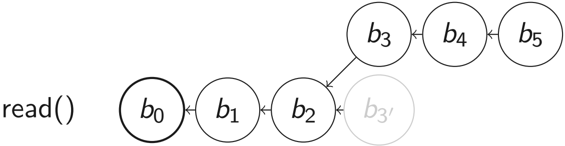
Abstract Data Type

Our approach:

- Blockchain formalized as a **tree** of blocks: BlockTree Abstract Data Type;
- the block generation process is formalized as an Oracle compoundable with the BlockTree: Θ Token Oracle Abstract Data Type.



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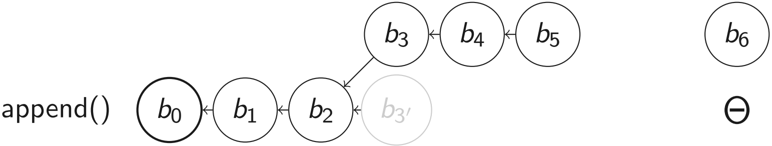

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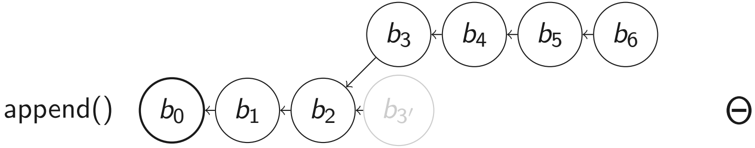

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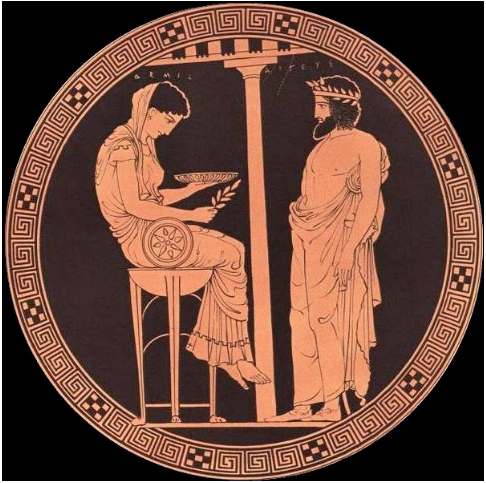
BlockTree Abstract Data Type

The BlockTree Abstract Data Type exposes two operations:

- read(): selects a blockchain in the blocktree;

- append(b): appends the block b to the blocktree if such block is valid, i.e., it satisfies a predicate P.

Token Oracle

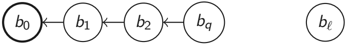


Any process that wants to append a block must call the oracle.

Token Oracle

The Token Oracle Θ_k Abstract Data Type exposes two operations:

- getToken(b_q, b_ℓ): returns or not the right to extend the block b_k with block b_ℓ.



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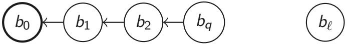
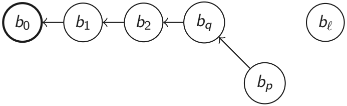
  

- consumeToken$(b_\ell^{b_q})$: allows a valid block to be appended or not, depending on how many blocks already extend b_q.

Frugal and Prodigal Token Oracles

A Frugal Oracle $\Theta_{F,k}$ allows to append at most k blocks to the same block.

A Prodigal Oracle Θ_P allows to append an unlimited number of blocks to any block.



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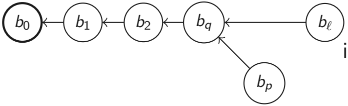

if $\Theta_{F,k>1}$ or Θ_P

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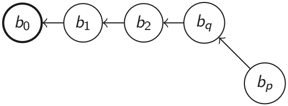


if $\Theta_{F,k=1}$

BlockTree Abstract Data Type

The BlockTree Abstract Data Type exposes two operations:

- read(): selects a blockchain in the blocktree;
- append(b): appends the block b to the blocktree if such block is valid, i.e., it satisfies a predicate P.

We establish two consistency criteria predicating on the result of the read() operations.

Blockchain Consistency Criteria

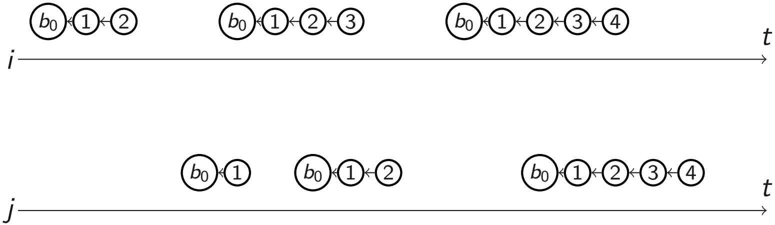
Eventual Consistency Criteria (EC):

- Local Monotonic Read;
- Validity;
- Ever Growing Tree;
- **Eventual Prefix** properties.

Strong Consistency Criteria (SC) :

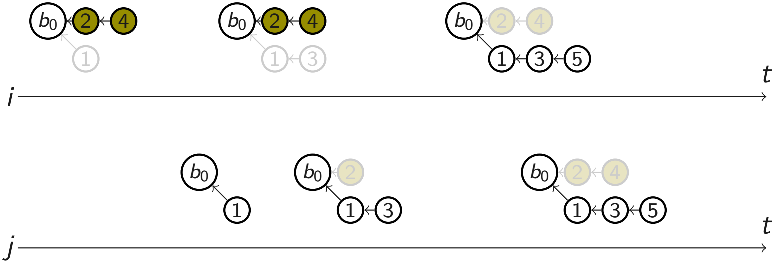
- Local Monotonic Read;
- Validity;
- Ever Growing Tree;
- **Strong Prefix** properties.

Strong Prefix Property



Strong prefix property: for each pair of read() operations, one returns a blockchain that is the prefix of the other or vice versa.

Eventual Prefix Property



Eventual prefix property: For each read blockchain with a score s, eventually all the subsequent read blockchains share a maximum common prefix with a score of at least s.

Blocktree and Oracle ADT hierarchy

$$\begin{tikzcd}
 & \boxed{\mathfrak{R}(\text{BT-ADT}_{SC}, \Theta_{F,k=1})} \arrow[dl] \arrow[dr] & \\
\boxed{\mathfrak{R}(\text{BT-ADT}_{SC}, \Theta_{F,k>1})} \arrow[d] & & \boxed{\mathfrak{R}(\text{BT-ADT}_{SC}, \Theta_{P})} \arrow[ddl] \\
\boxed{\mathfrak{R}(\text{BT-ADT}_{EC}, \Theta_{F,k>1})} \arrow[dr] & & \\
 & \boxed{\mathfrak{R}(\text{BT-ADT}_{EC}, \Theta_{P})} &
\end{tikzcd}$$

$\Theta_{F,k=1}$ has Consensus number ∞

Θ_P has Consensus number 1

We compose the BlockTree ADT and the Oracle ADT as $\mathfrak{R}(\text{BT-ADT}, \Theta)$ in a hierarchy.
In this way, we can state implementability results on the weakest combination and propagate them above.

Impossibilities

- It is not possible to implement a Blockchain satisfying Eventual Consistency if an update message is lost;

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Impossibilities

- It is not possible to implement a Blockchain satisfying Eventual Consistency if an update message is lost;
- It is not possible to implement a Blockchain satisfying Strong Consistency if a fork occurs;
  - $\Theta_{F,k=1}$ is necessary;
    - Consensus is necessary;

The best we can have in presence of Forks is Eventual Consistency.

Mapping with existing solutions

References	Refinement
Bitcoin	$\mathfrak{R}(BT\text{-}ADT_{EC}, \Theta_P)$
Ethereum	$\mathfrak{R}(BT\text{-}ADT_{EC}, \Theta_P)$
Algorand	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$
ByzCoin	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$
PeerCensus	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$
Redbelly	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$
Hyperledger	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$
Tendermint	$\mathfrak{R}(BT\text{-}ADT_{SC}, \Theta_{F,k=1})$

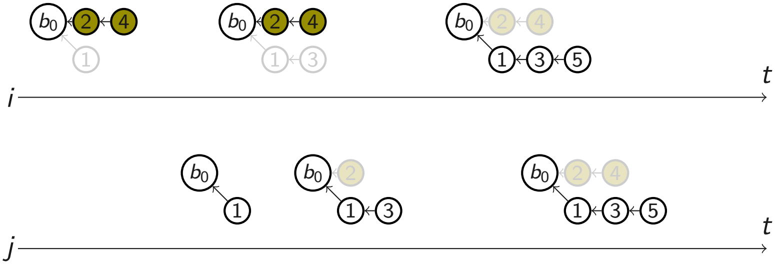
Conclusions and Future Work

- we presented a formal specification for characterizing blockchains;
- and derived conclusion on their implementability in a distributed system.

Future works.

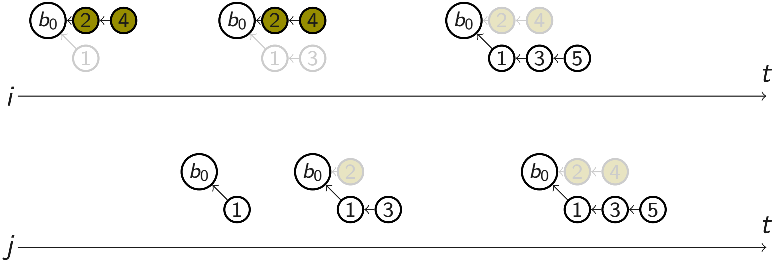
- solvability of Strong and Eventual Prefix in message-passing system;
- fairness properties for oracles;
- . . .

Validity Property



Validity property: all the block read are valid (w.r.t. the application level) and have been appended by some process.

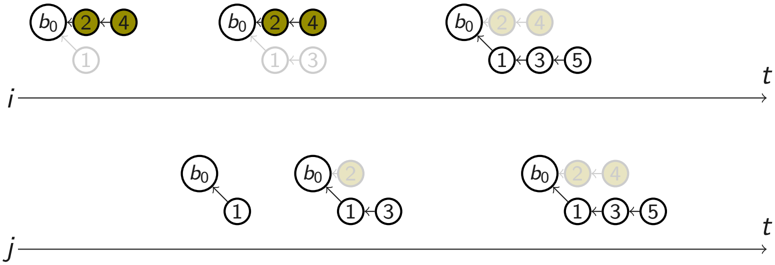
Local Monotonic Read Property



Local monotonic read property: the **score** of the sequence of blockchains read at the same peer never decreases.

score: it can be the length, the weight, etc.., it is a general way to measure and compare blockchains.

Ever Growing Tree Property



Ever growing tree property: the score of returned blockchains eventually grows.

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