Dynamic Ad Hoc Clock Synchronization

Eurocrypt 2021

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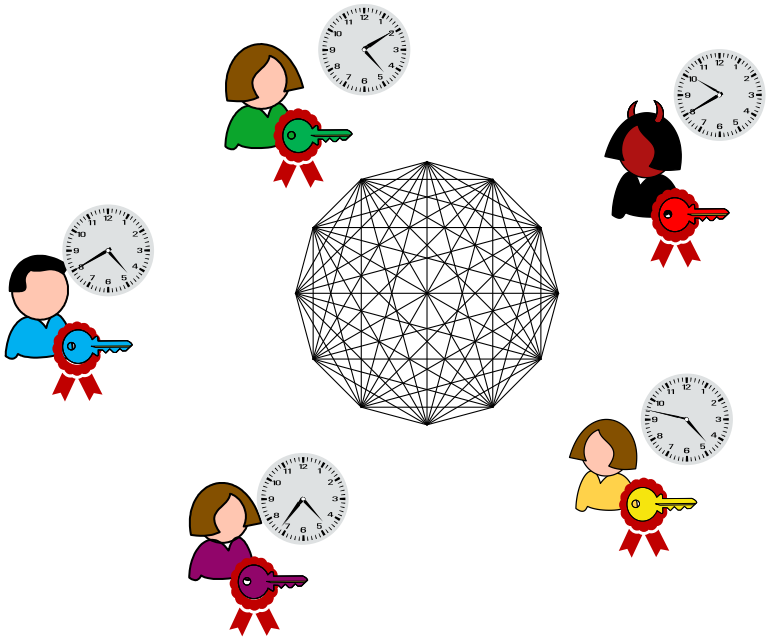
https://ia.cr/2019/838

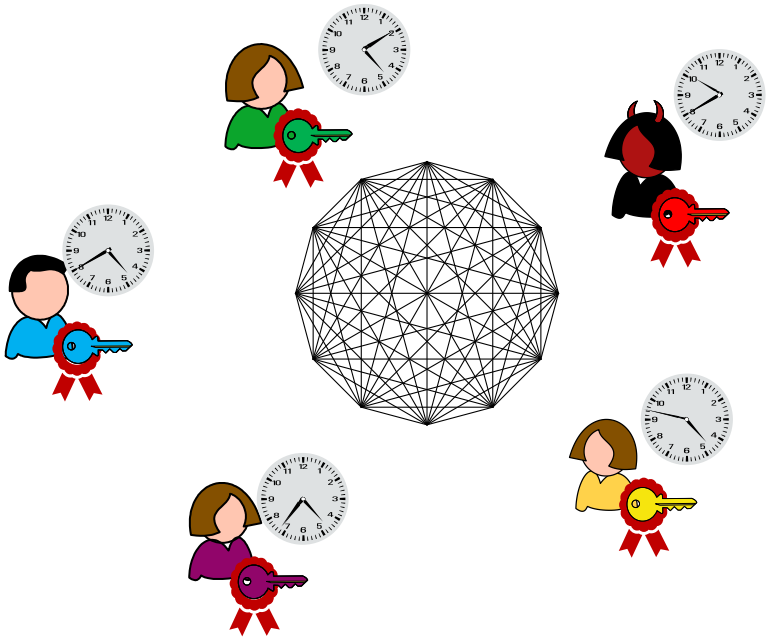
Clock Synchronization



Basic setup:

- **Local clocks** (duration timer) which run at approx. same speed
- PKI / CRS
- Bounded-delay network
- Majority of parties honest

Clock Synchronization



Goal:

Emulate “a global clock”, i.e., compute time values that satisfy:

- Approximate **synchrony**
- **Liveness**
- **Monotonicity** & limited “jumps”

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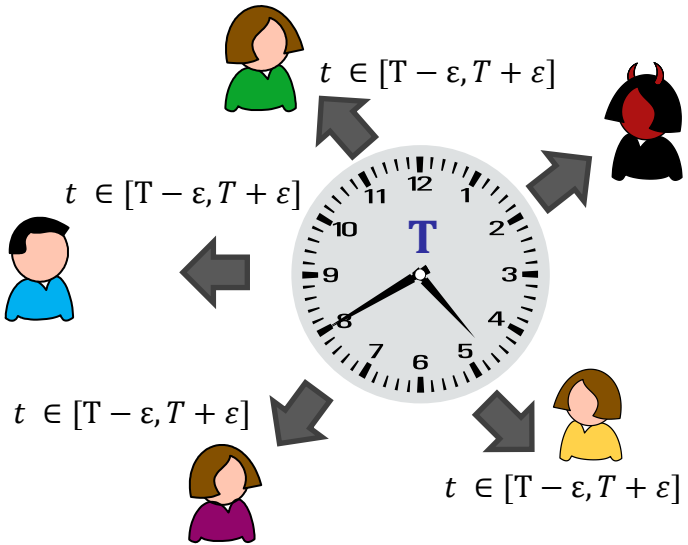


Realization of a **Global Clock Functionality** (with ε-synchrony)

Clock Synchronization – Models

Prior models:

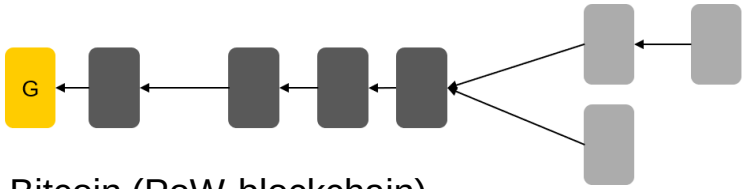
- **Fixed** set of parties in the protocol.
- **All parties active** except for byzantine nodes.
- Relaxation: **“ad hoc” model:** an unknown subset remains inactive
- **Security threshold** relative to size of **active party set.**

Dynamic ad hoc model:

- Number of online/offline parties changes over time.
- No a priori knowledge of participation levels.
- Unannounced disappearance.
- Newcomers need to be bootstrapped.
- **Security threshold** relative to **dynamic participation level.**

Ad hoc model:
Amos Beimel, Yuval Ishai, and Eyal Kushilevitz. Ad hoc PSM protocols: Secure computation without coordination. Eurocrypt 2017

Ideas for Novel Clock Synchronization



Bitcoin (PoW-blockchain)

- **Consistency**
- **Liveness**

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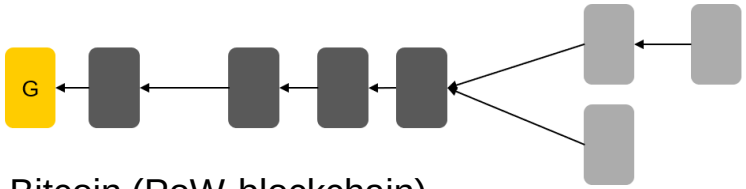

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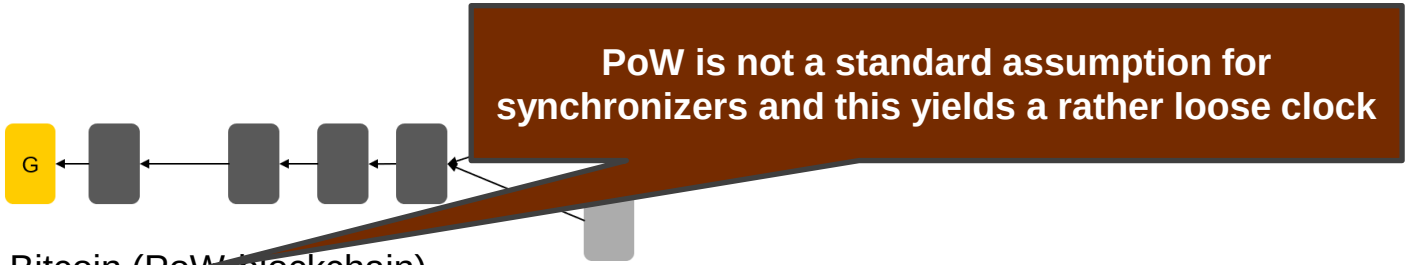

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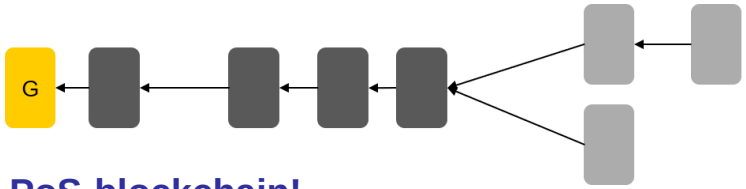
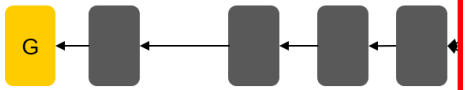


PoS-blockchain!

- **Consistency**
- **Liveness**

Source of trust: Genesis block

Ideas for Novel Clock Synchronization



PoS-b[illegible]chain!

- **Cons[illegible]ncy**
- **Liveness**

- Require a lower bound on or accurate estimate of participation…
- …or have to assume a reliable timing service!

But maybe we can still use some ideas from those protocols?

Source of trust: Genesis block

Clock Synchronization – Dynamic Ad Hoc Setting

Prior models:

- **Fixed** set of parties in the protocol.
- **All parties active** except for byzantine nodes. **Honest majority.**
- Relaxation: **Ad hoc:** active subset of parties fixed but not known.
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Is Clock Synchronization possible in this setting?

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YES - and even more…

Main Result

We design **the first PoS-blockchain** protocol with the following features:

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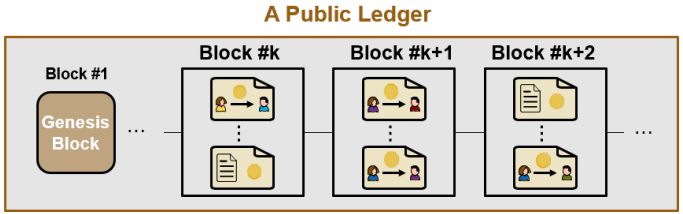
Main Result

We design **the first PoS-blockchain** protocol with the following features:

1) **It is secure in the dynamic ad hoc setting** (bounded delays, honest majority of stake) and does **not need a global clock** (instead: the weaker assumption of approx. same-speed clocks/timers).

2) **It is a clock synchronizer** and allows parties (and in fact any external observer) to compute time values that are only a bounded distance apart.

Chronos =



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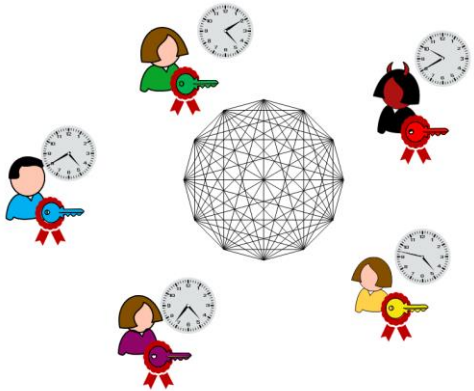
Informal Idea of The Solution



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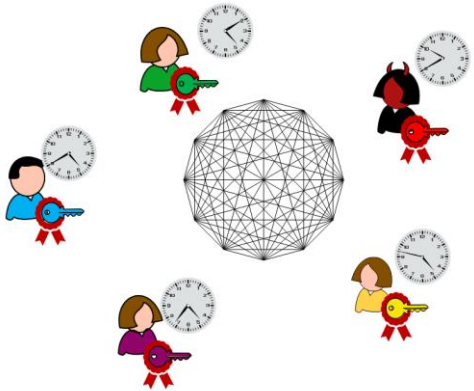

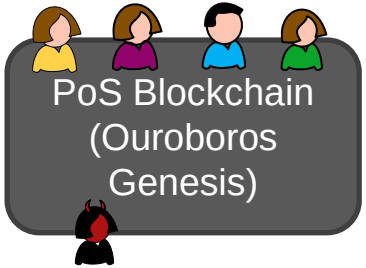

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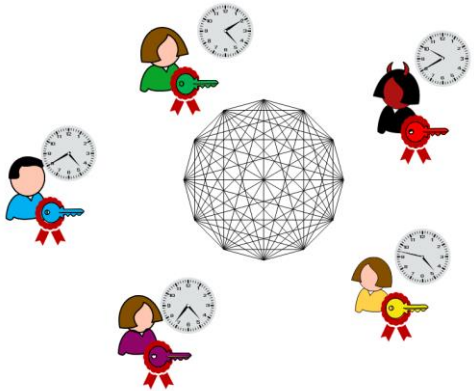
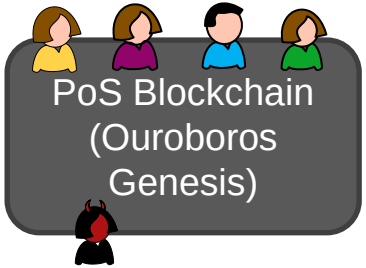


1 **Exchange** authenticated **sync-messages** containing local time stamps (restricted by the PoS lottery).



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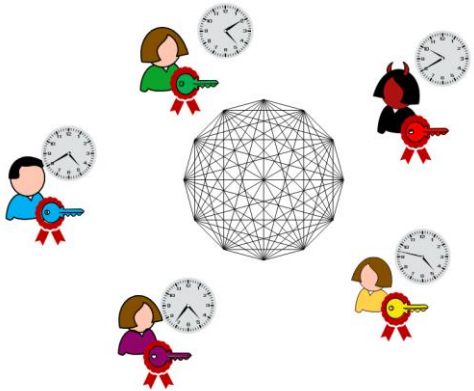

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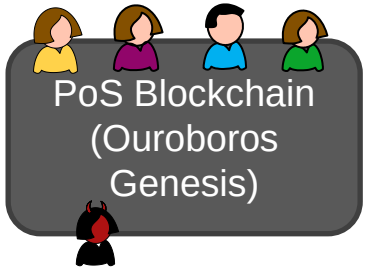
2 **Reach consensus** over the set of sync-messages using the blockchain.



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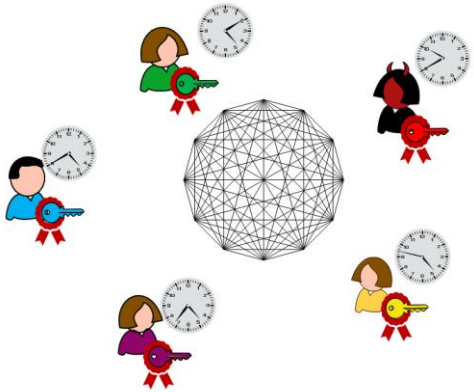

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PoS Blockchain (Ouroboros Genesis)

3 **Adjust time value** based on agreed set and observed “delays”.

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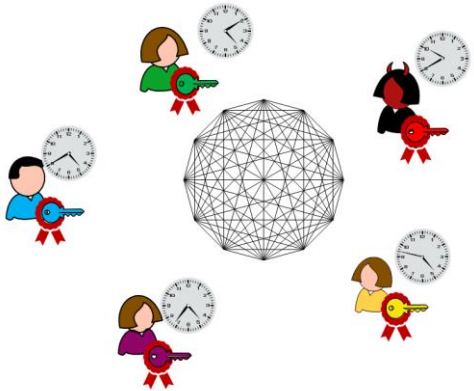

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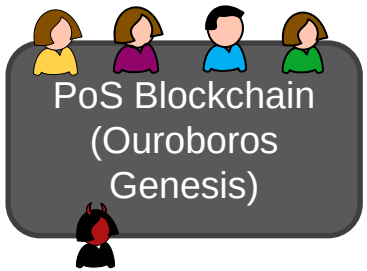
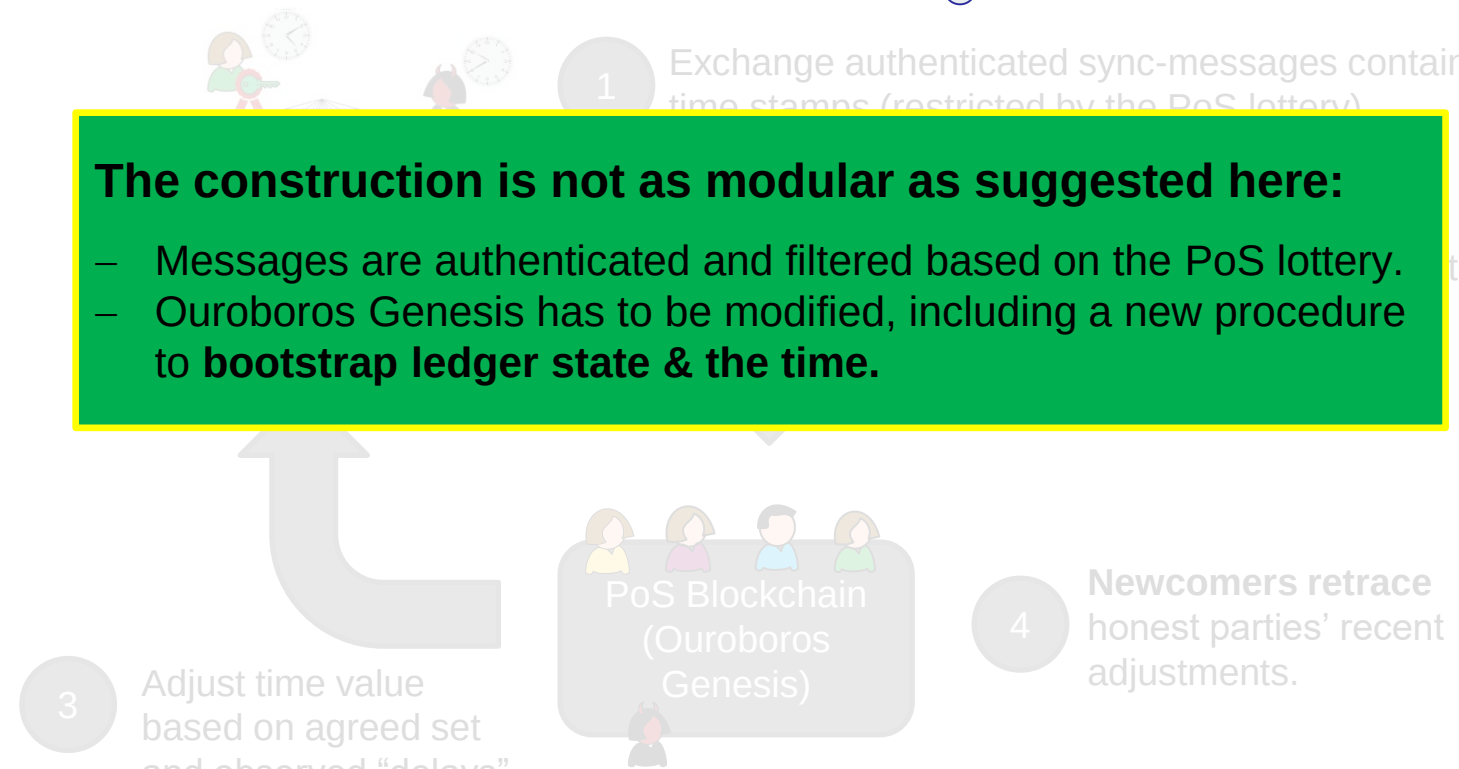


3 Adjust time value based on agreed set and observed “delays”.

4 **Newcomers retrace** honest parties’ recent adjustments.

Informal Idea of The Solution



The construction is not as modular as suggested here:

- Messages are authenticated and filtered based on the PoS lottery.
- Ouroboros Genesis has to be modified, including a new procedure to **bootstrap ledger state & the time.**

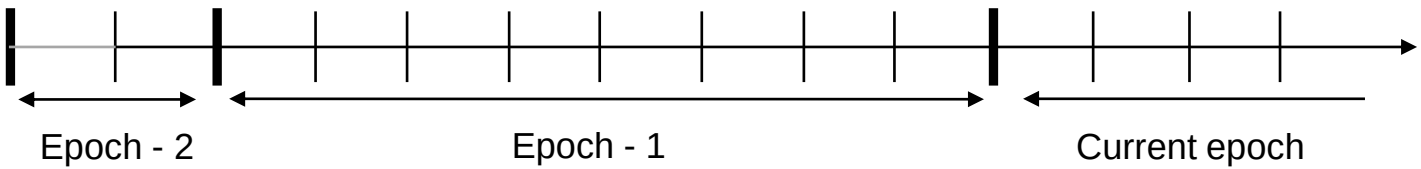
Outline of this Talk

1. Recap of Ouroboros Genesis

2. We see what happens to Genesis when we have local clocks/timers instead of a global clock

3. Presentation of Chronos

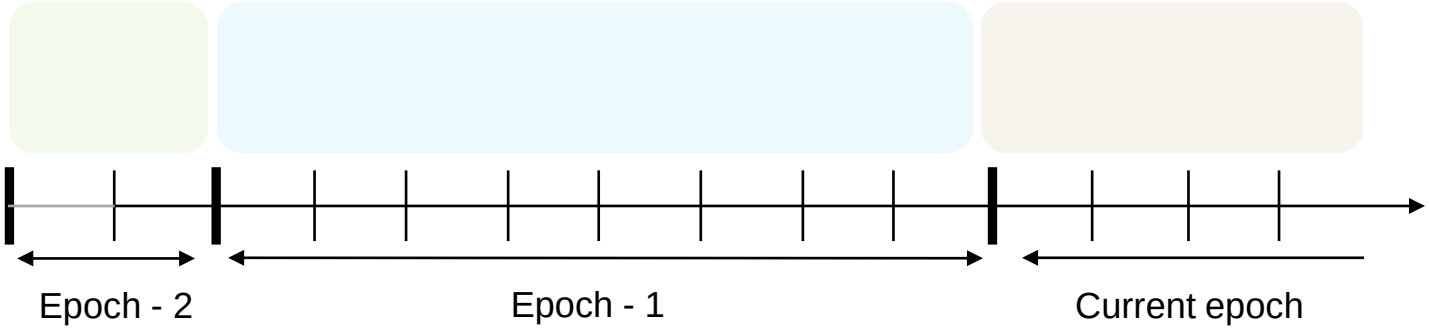
Ouroboros Genesis



Ouroboros Genesis

- In each slot, each party evaluates slot-leadership.
  Private election, proportional to stake, including recent randomness from the chain

- A slot leader extends its most preferred chain by creating the block for this slot.



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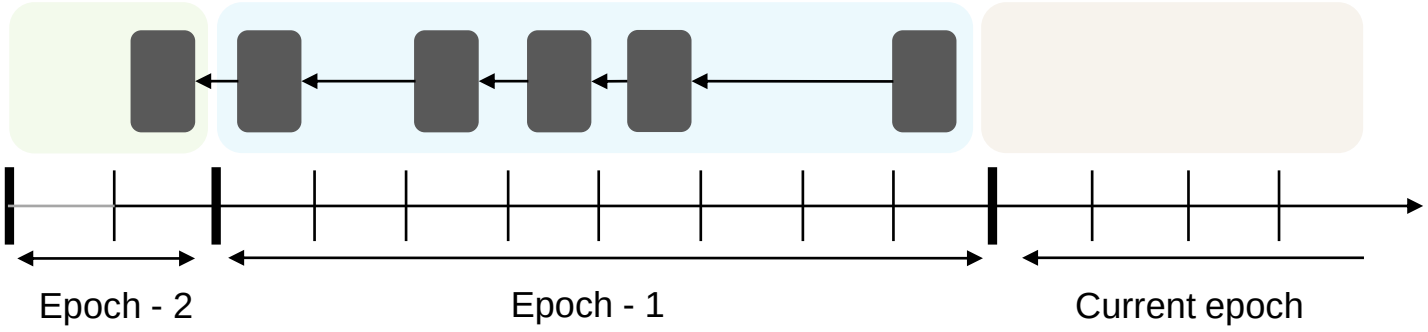

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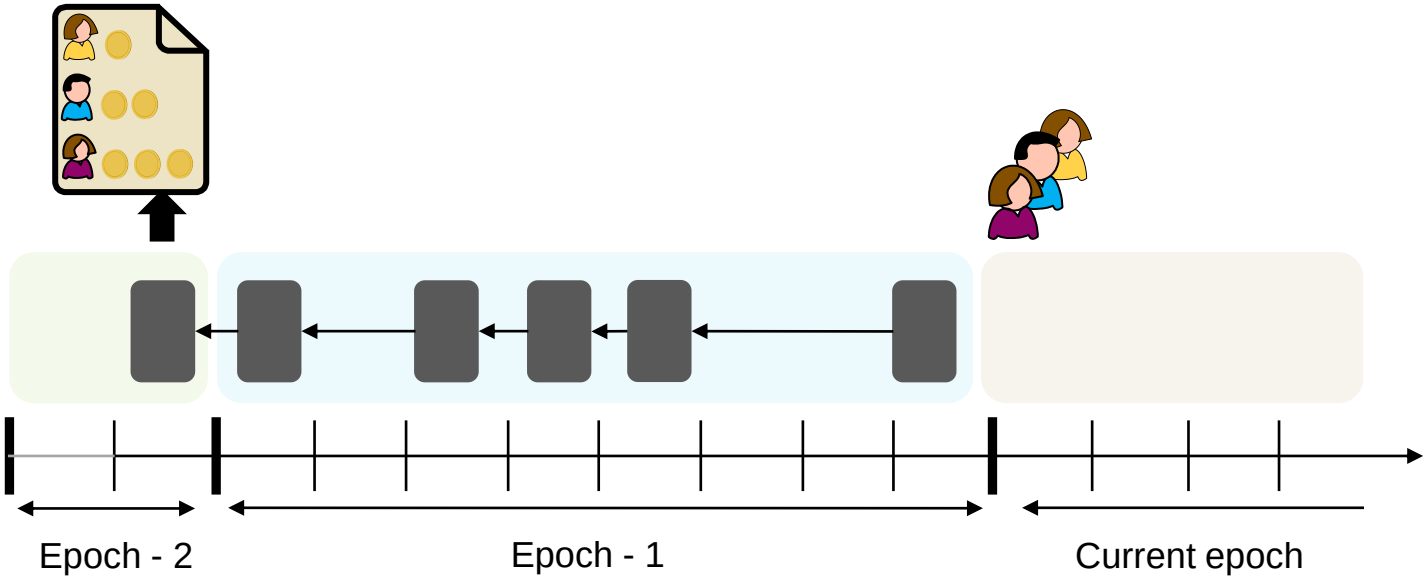

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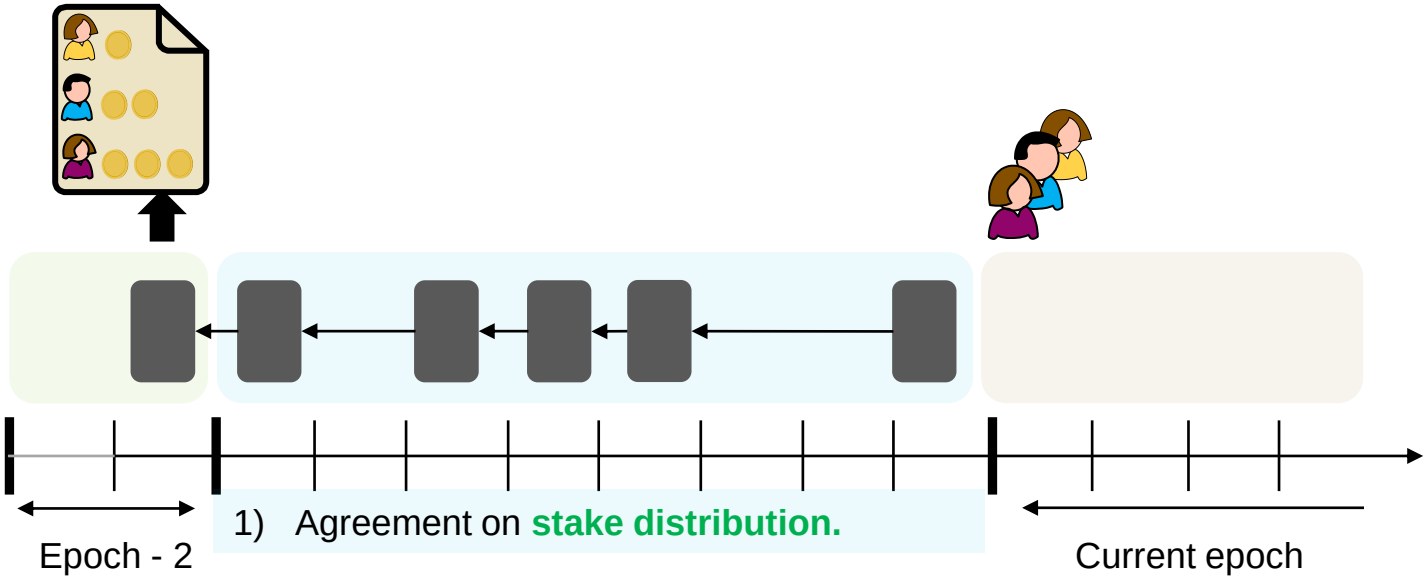

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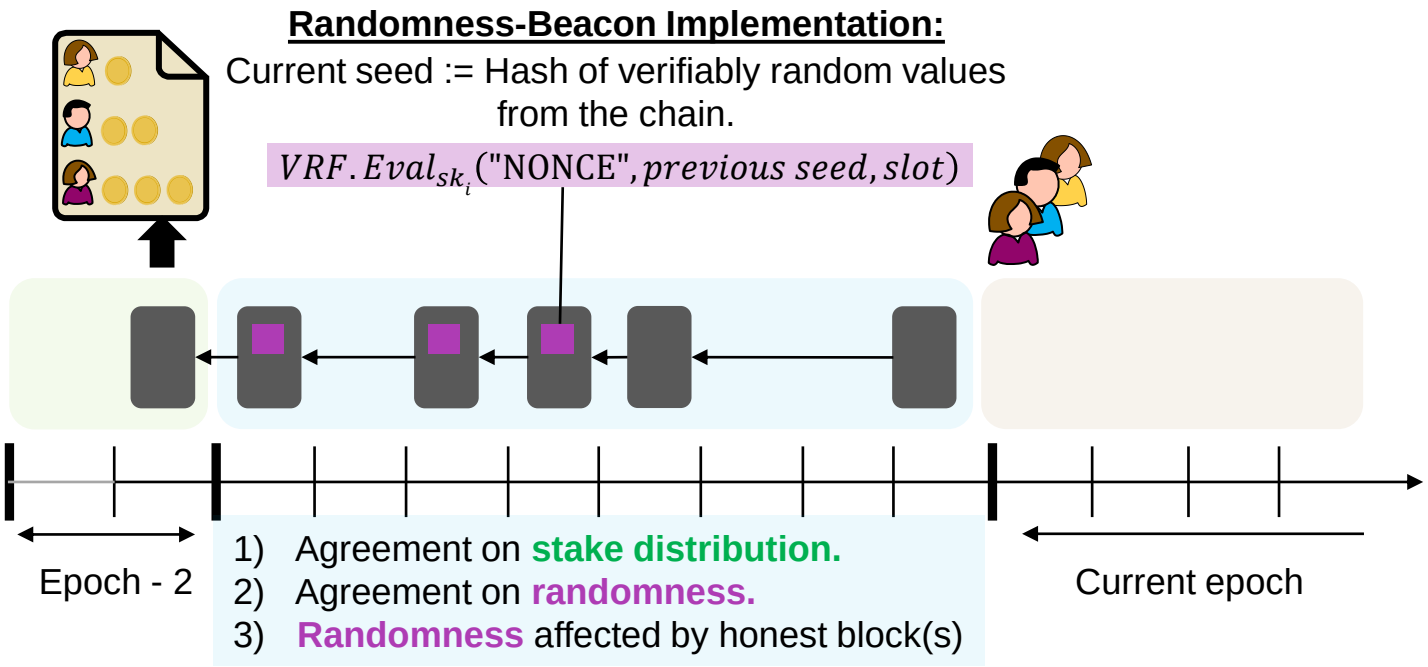
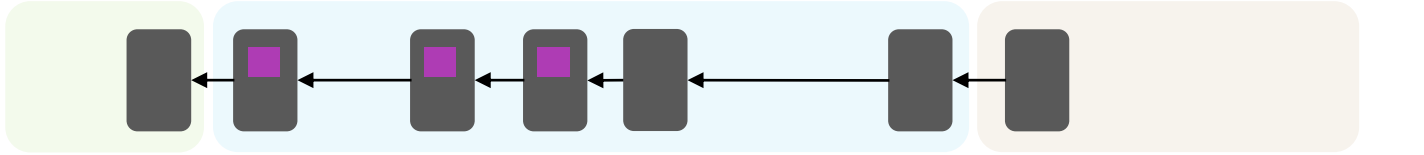


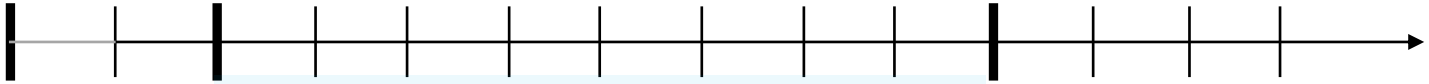
Ouroboros Genesis

Lottery in each slot:

A party i is leader if and only if $VRF.Eval_{sk_i}(\text{"TEST"}, \boldsymbol{seed}, slot) < T(\boldsymbol{stake_i})$

- Empty slots possible
- Multiple leaders possible
- Leadership proof from VRF.



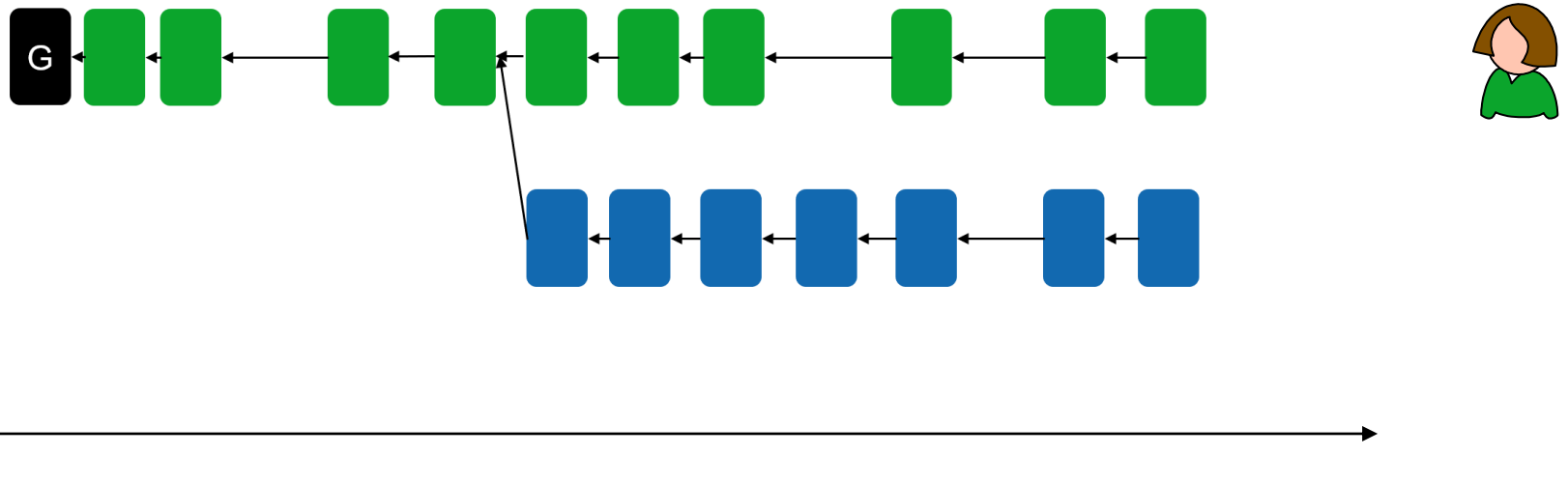


Epoch - 2

1) Agreement on **stake distribution.**
2) Agreement on **randomness.**
3) **Randomness** affected by honest block(s)

Current epoch

Ouroboros Genesis – Chain Selection



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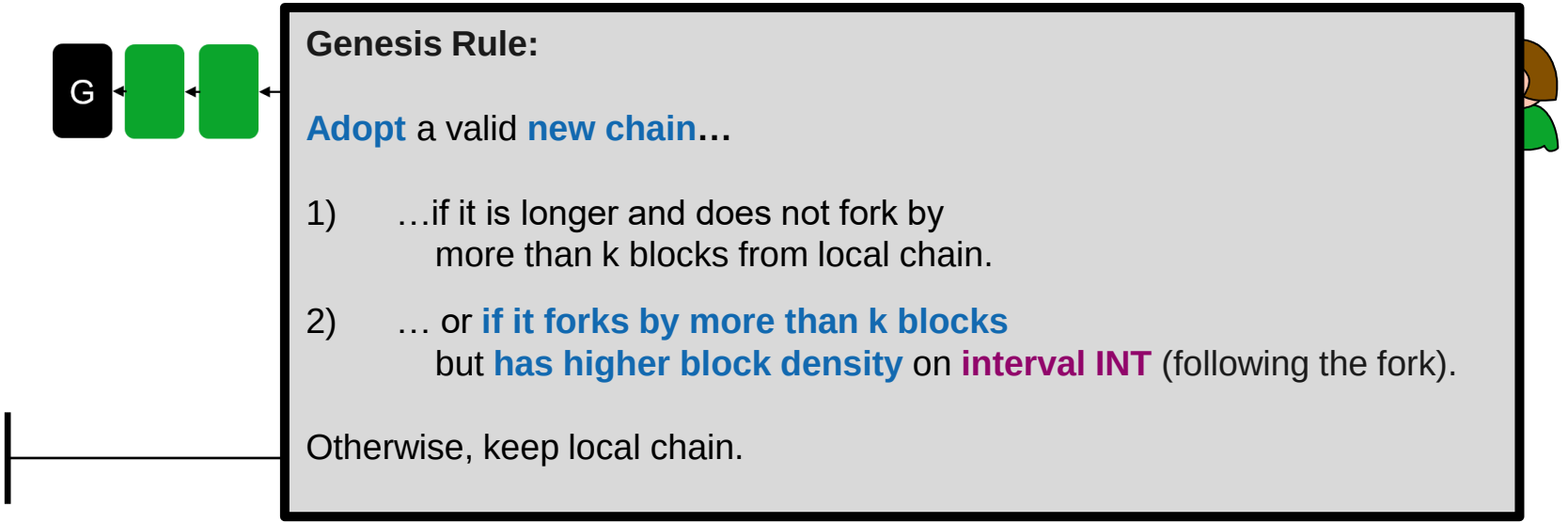

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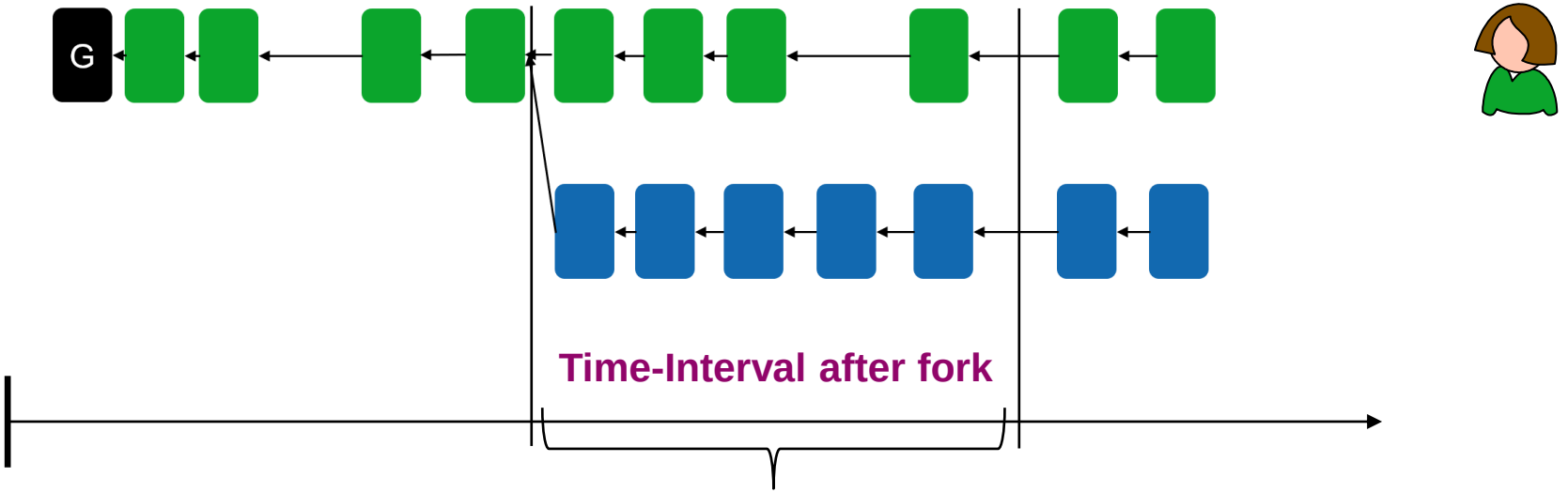

(Protocol parameter: **size** of INT)

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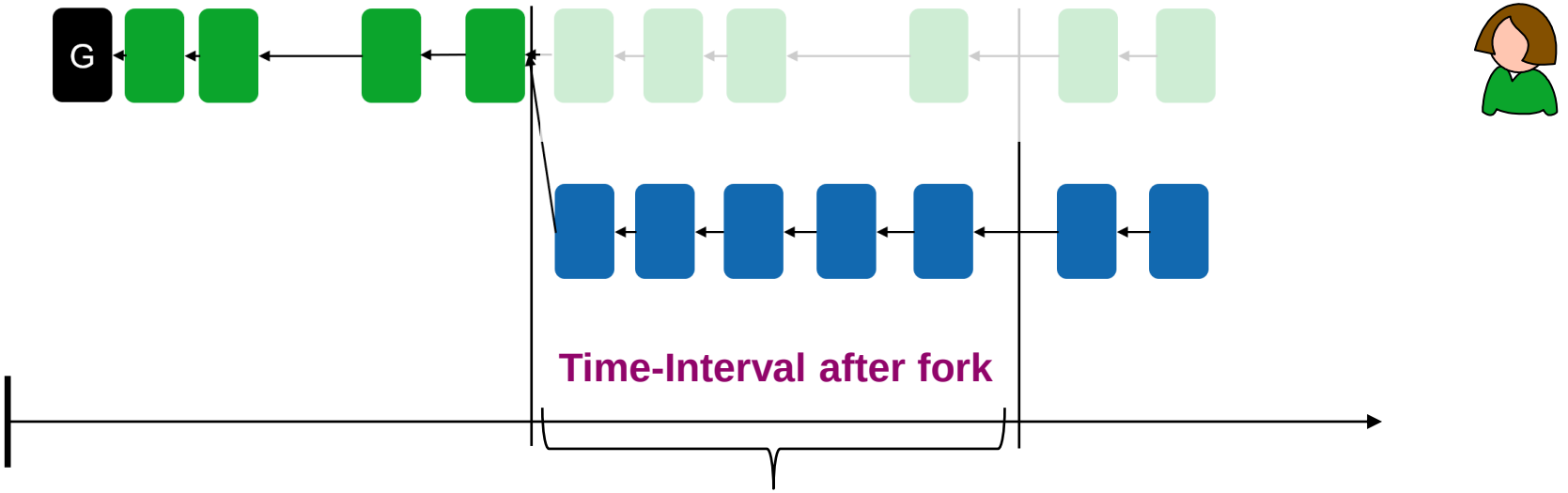

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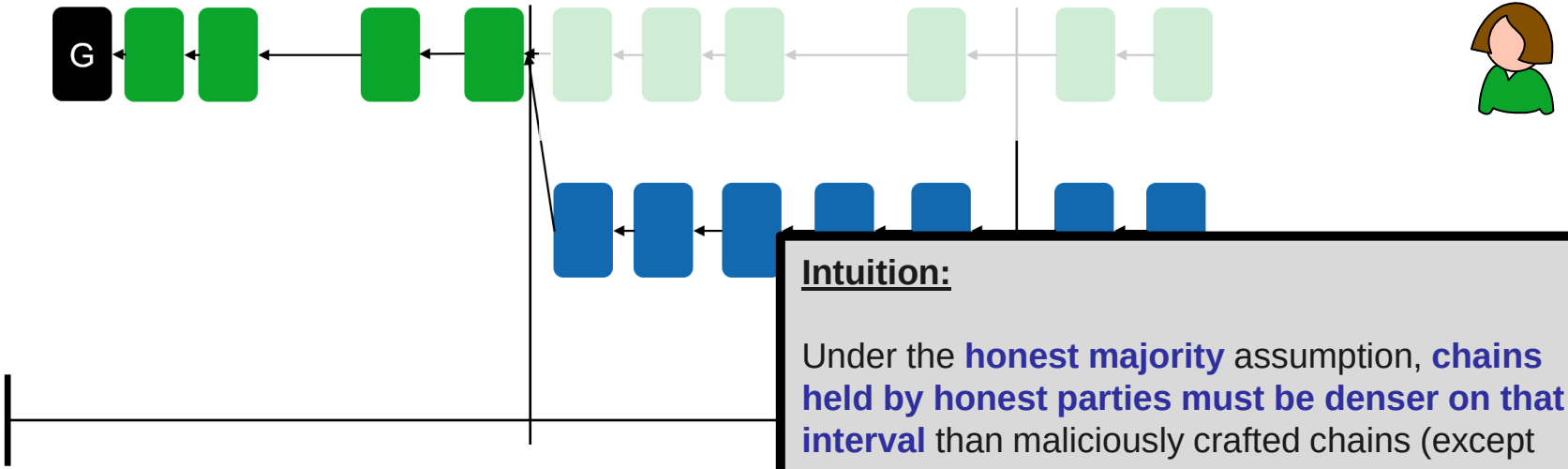

Intuition:

Under the **honest majority** assumption, **chains held by honest parties must be denser on that interval** than maliciously crafted chains (except with negligible probability).

Reference:
C. Badertscher, P. Gaži, A. Kiayias, A. Russell, V. Zikas.
Ouroboros Genesis: Composable Proof-of-Stake Blockchains with Dynamic Availability. CCS 18.

Ouroboros Genesis – Useful Property

Using the Genesis chain-selection rule, a newly **joining party** will **adopt a chain** with large common prefix w.r.t. honest parties. No other advice than **the genesis block** is needed.

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Reason:

- *The genesis rule establishes density as a proxy for honesty.*
- *Thus, all parties' chains contain the stable prefix held by alert parties, because that prefix wins any genesis (density) comparison.*

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This argument does not assume reliable time information!

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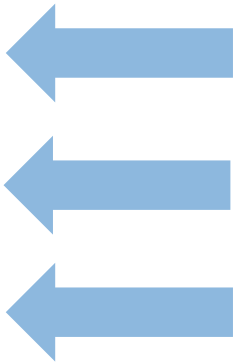
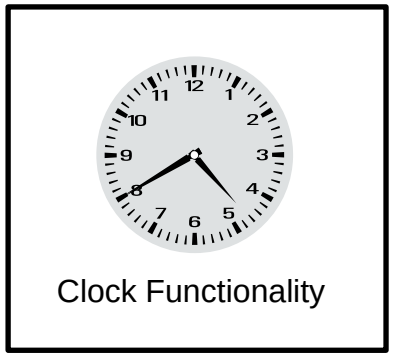
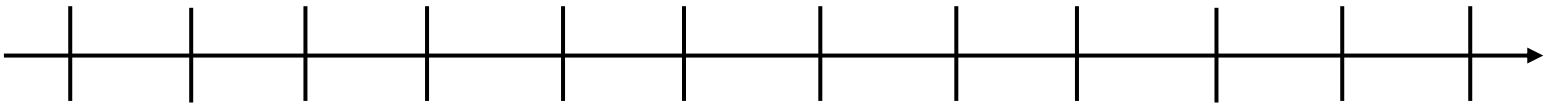




Time axis:



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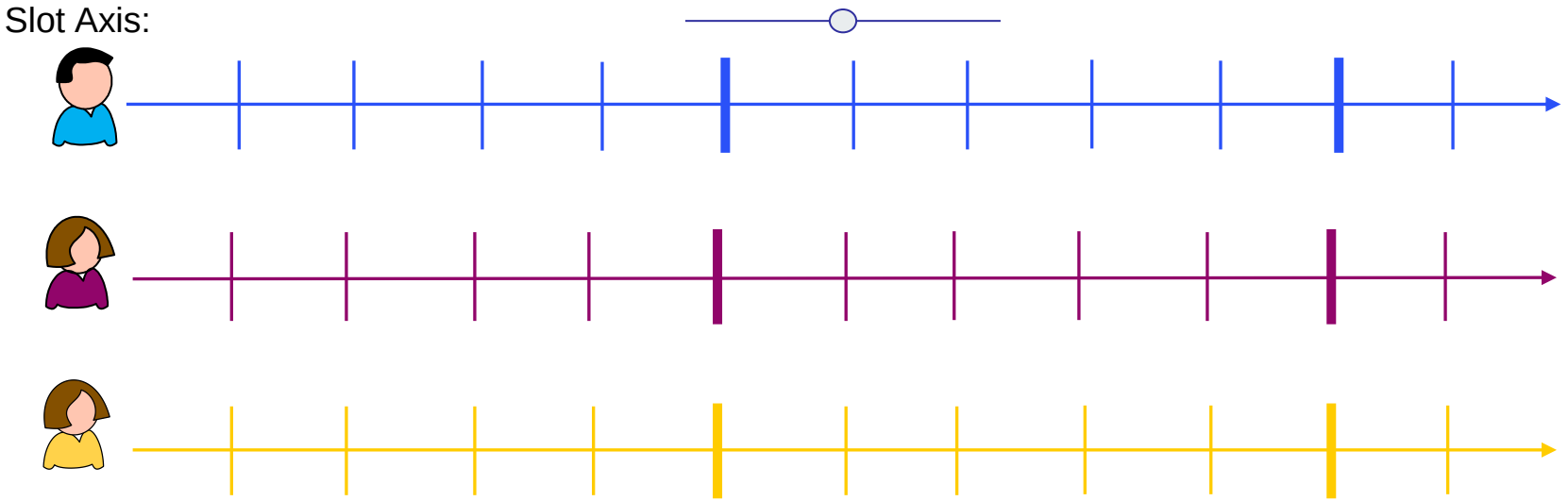

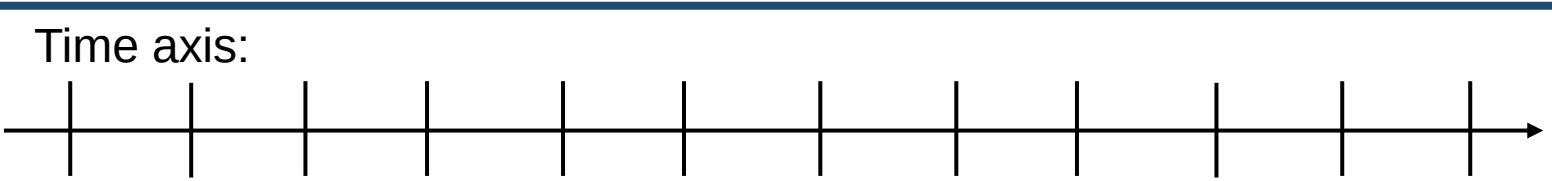

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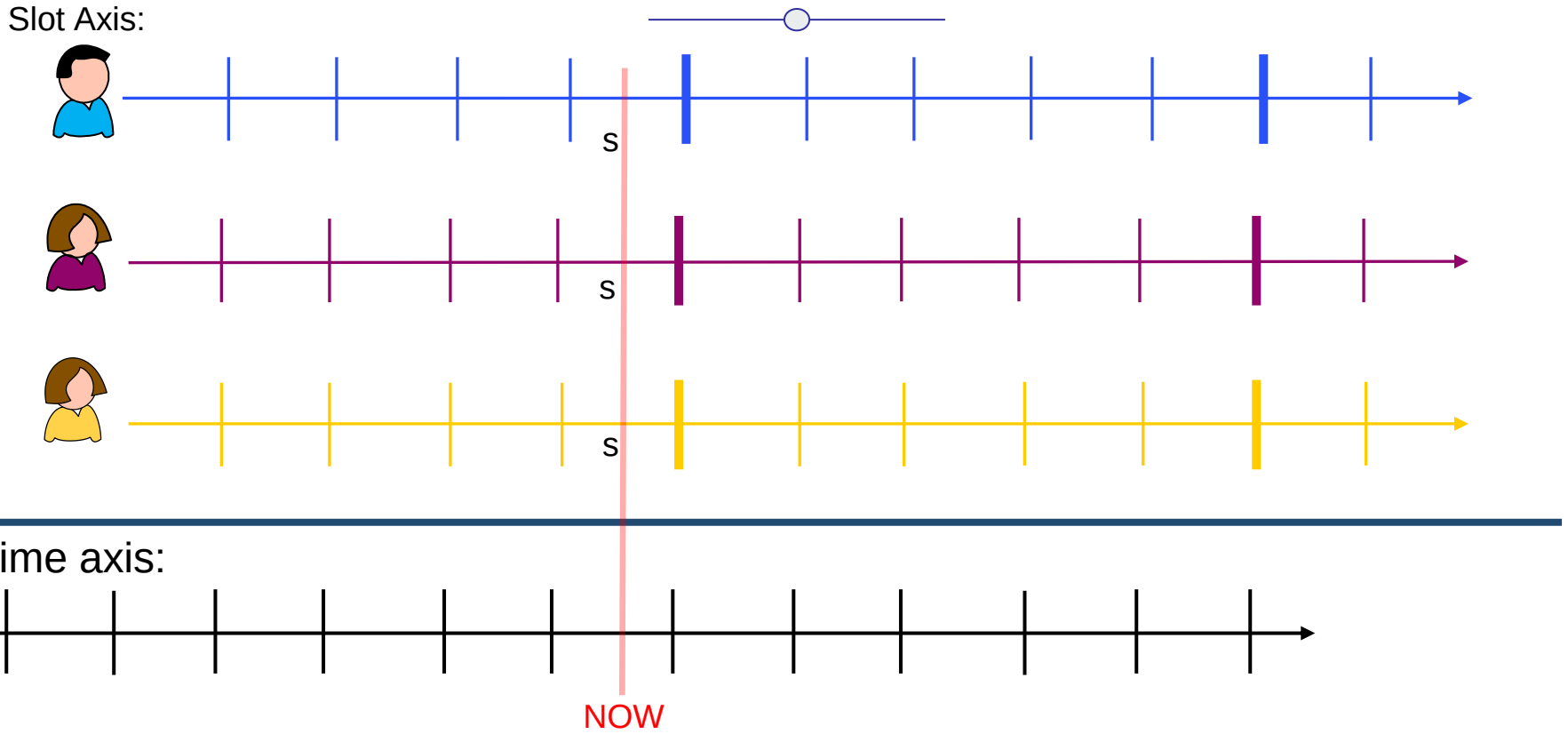
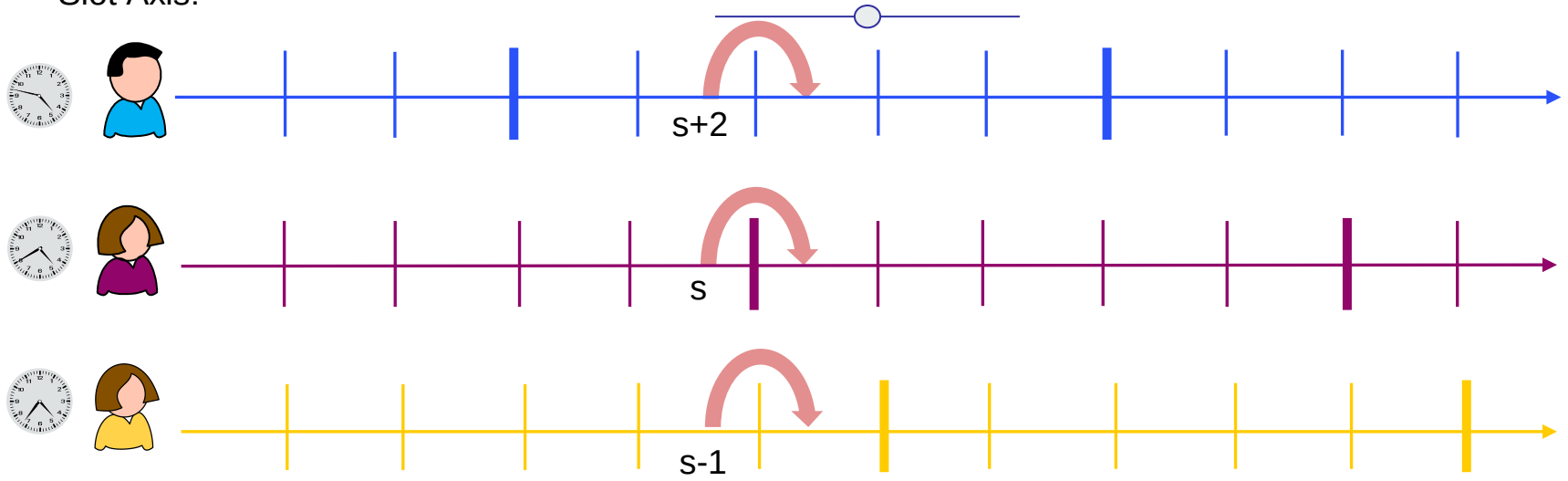


We want: Same-Speed Assumption

Slot Axis:



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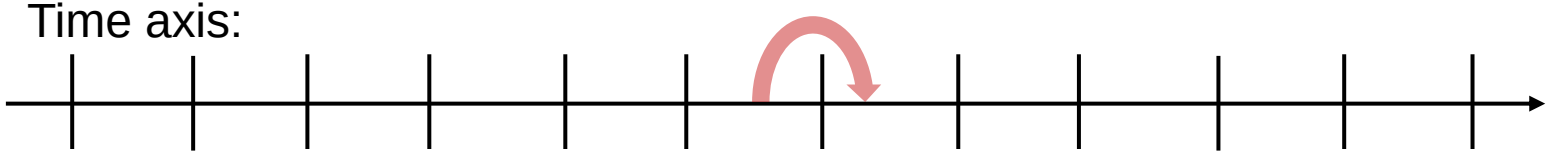

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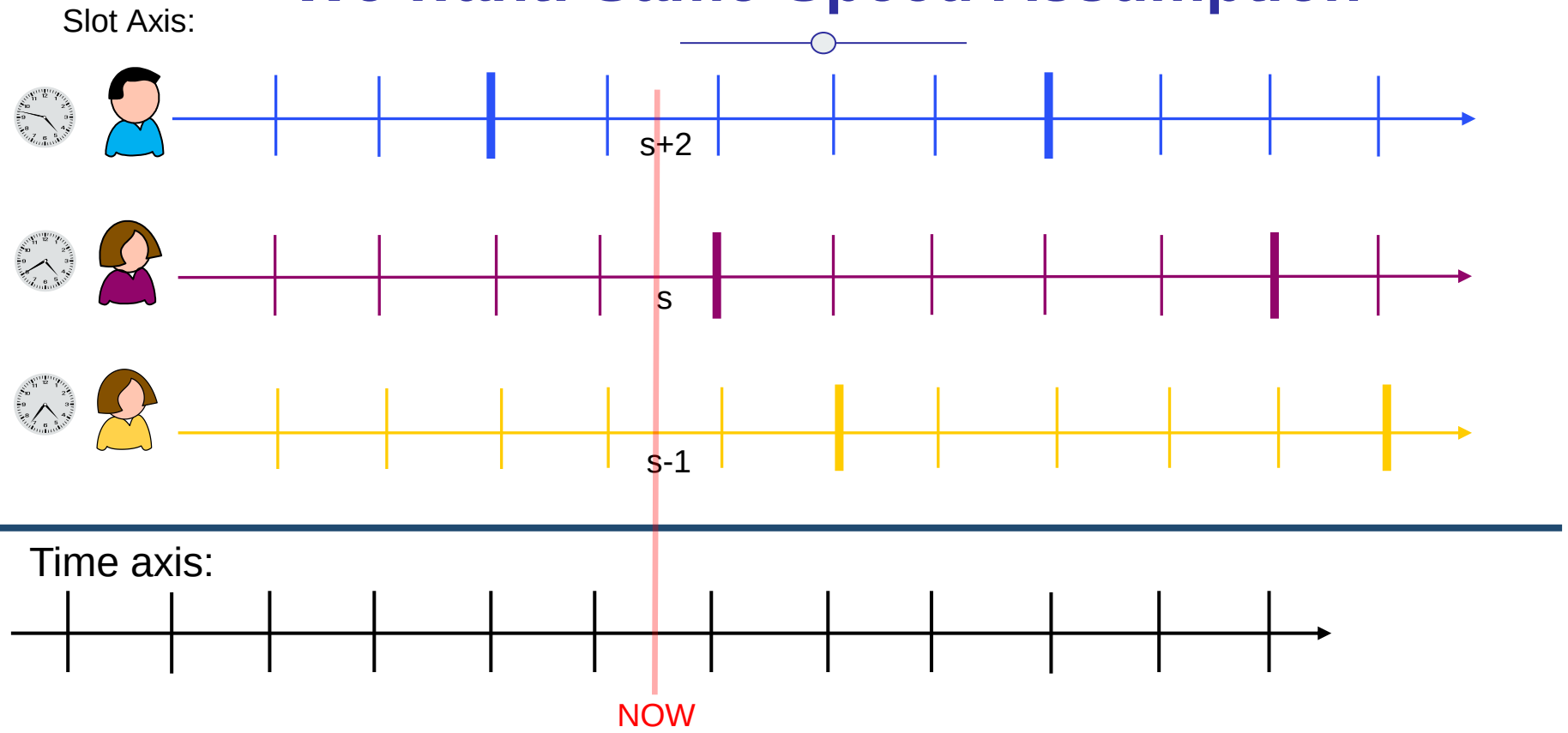

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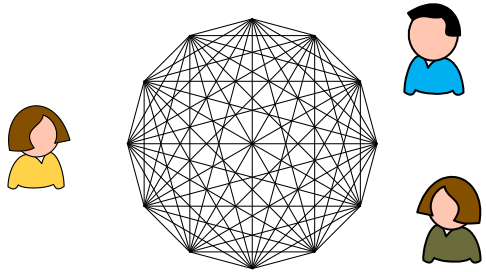
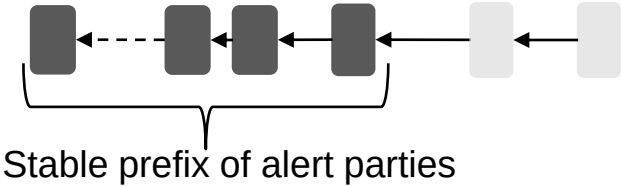
→ (Approx.) Same-speed: Initial parties do stay close enough.
→ **Joining parties** have a harder life…

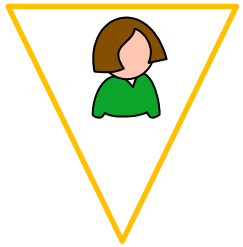
Genesis: Situation not that bad…

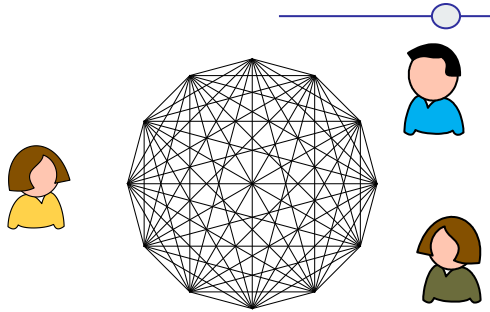


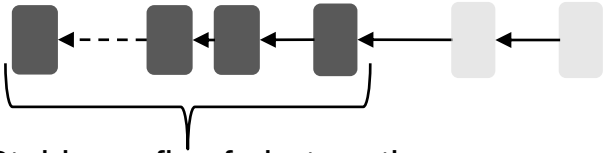


Genesis: Situation not that bad…

Joining party:







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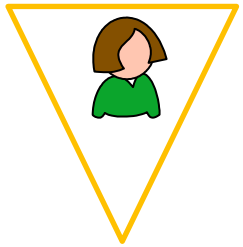
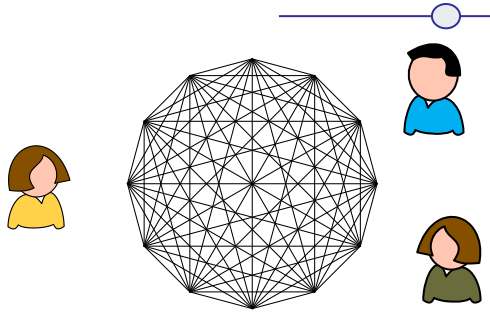
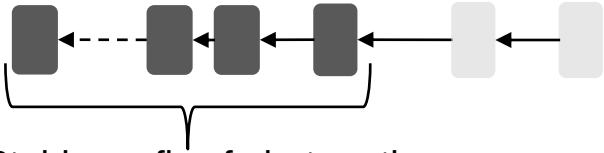
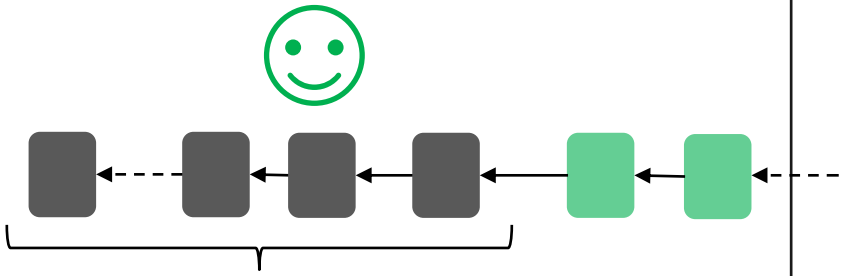






Stable prefix of alert parties



Genesis chain selection rule:

- **Good prefix** is the **densest prefix**
- **Genesis rule prefers** densest prefix

Genesis: Situation ~~not that~~ bad…

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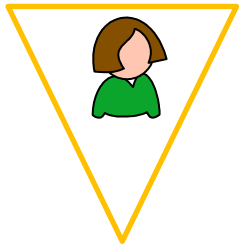

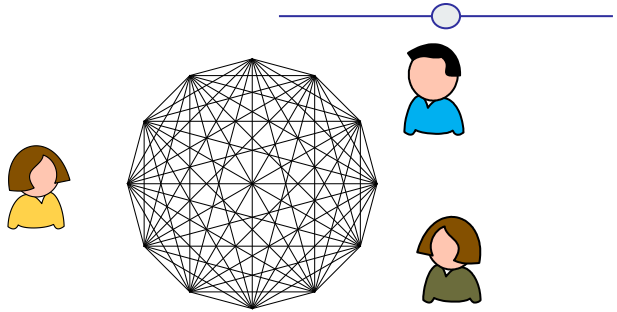

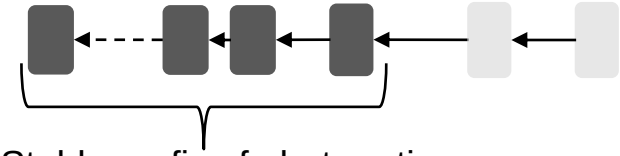

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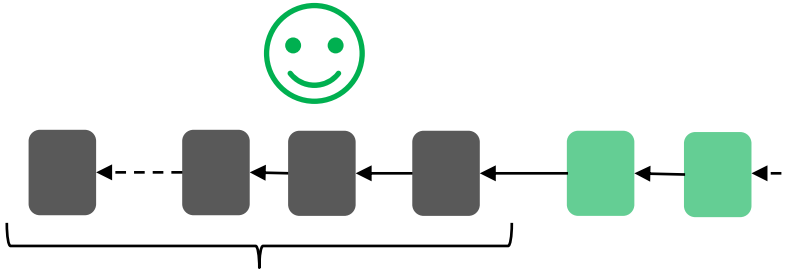

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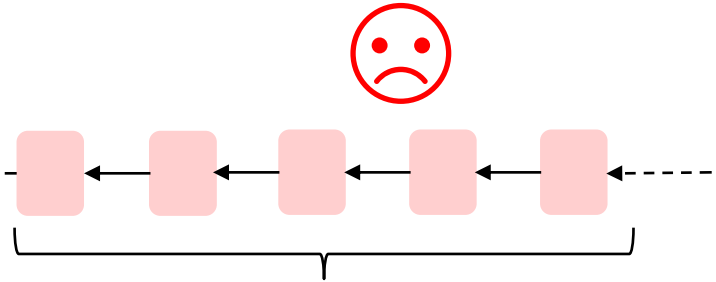

- **No cut-off** possible
- **No reliable** ledger state

…. without time-synchronization

Chronos - Overview

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- **Alert parties:** Execute Ouroboros Genesis, broadcast **sync-beacons** and **leave evidence** of beacons in the blockchain.

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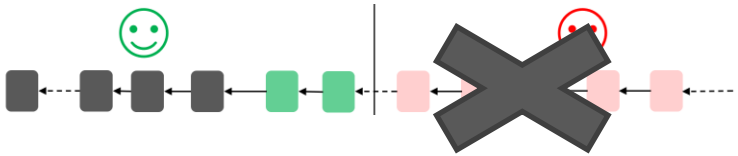
Chronos - Overview

This **not only** yields **a good time-synchronizer** but also **a good blockchain**:

→ Once the time is synchronized with alert parties, the ledger state can be computed



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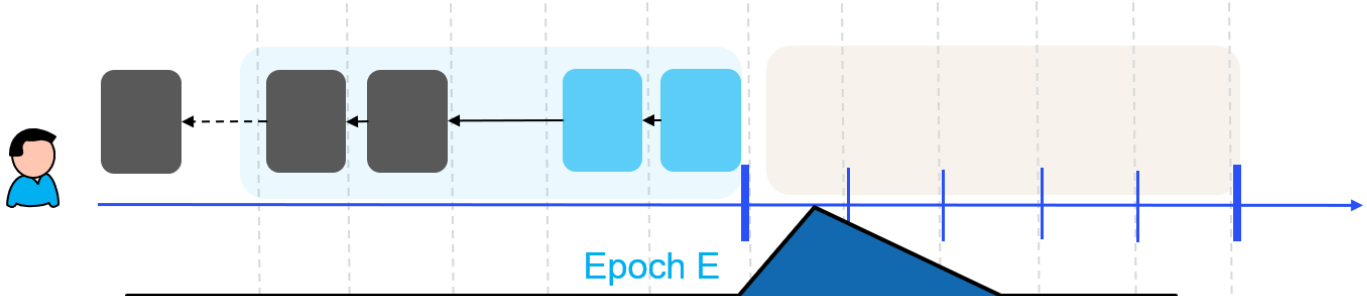
Chronos – Sync-Beacons



Additional "Timing Lottery" in the first part of the epoch:

- IF $VRF_{sk_i}(\text{"SYNC"}, seed, slot) < T(stake_i)$ THEN
  - Broadcast Sync-Beacon:

- **Normal slot leaders** pack transactions **+ beacons**.

Chronos

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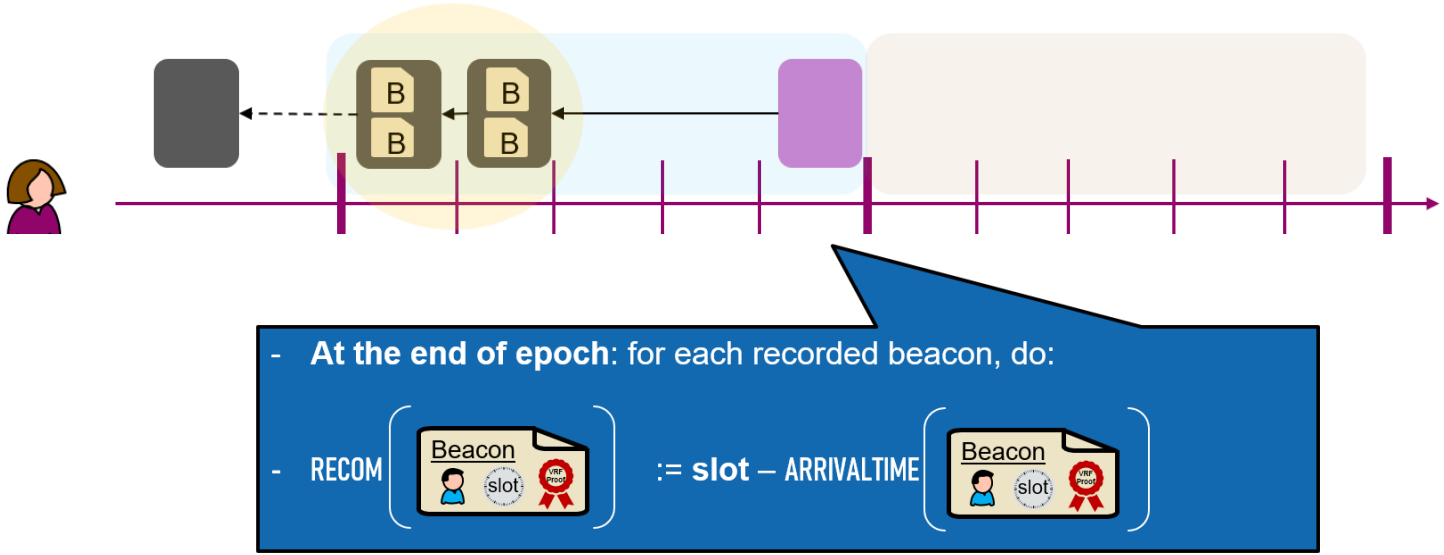
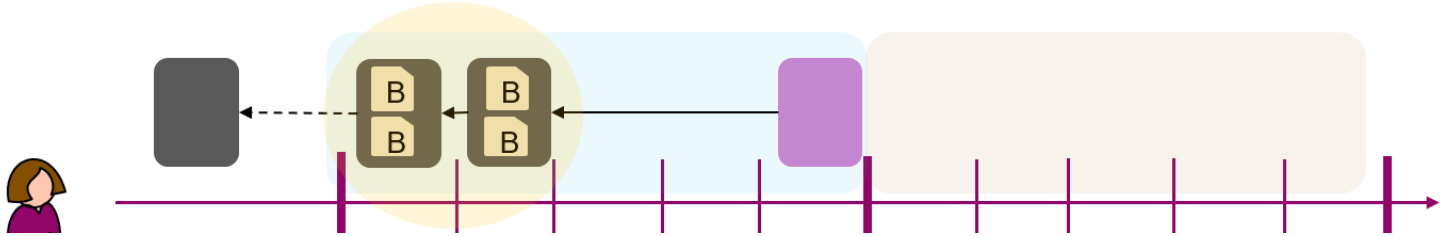
Chronos: Synchronization Procedure

- **Throughout the epochs:** Record the arrival times of valid beacons (filter out duplicates, invalid ones etc.)
- **At the end of each epoch:** Compute local clock-adjustment.



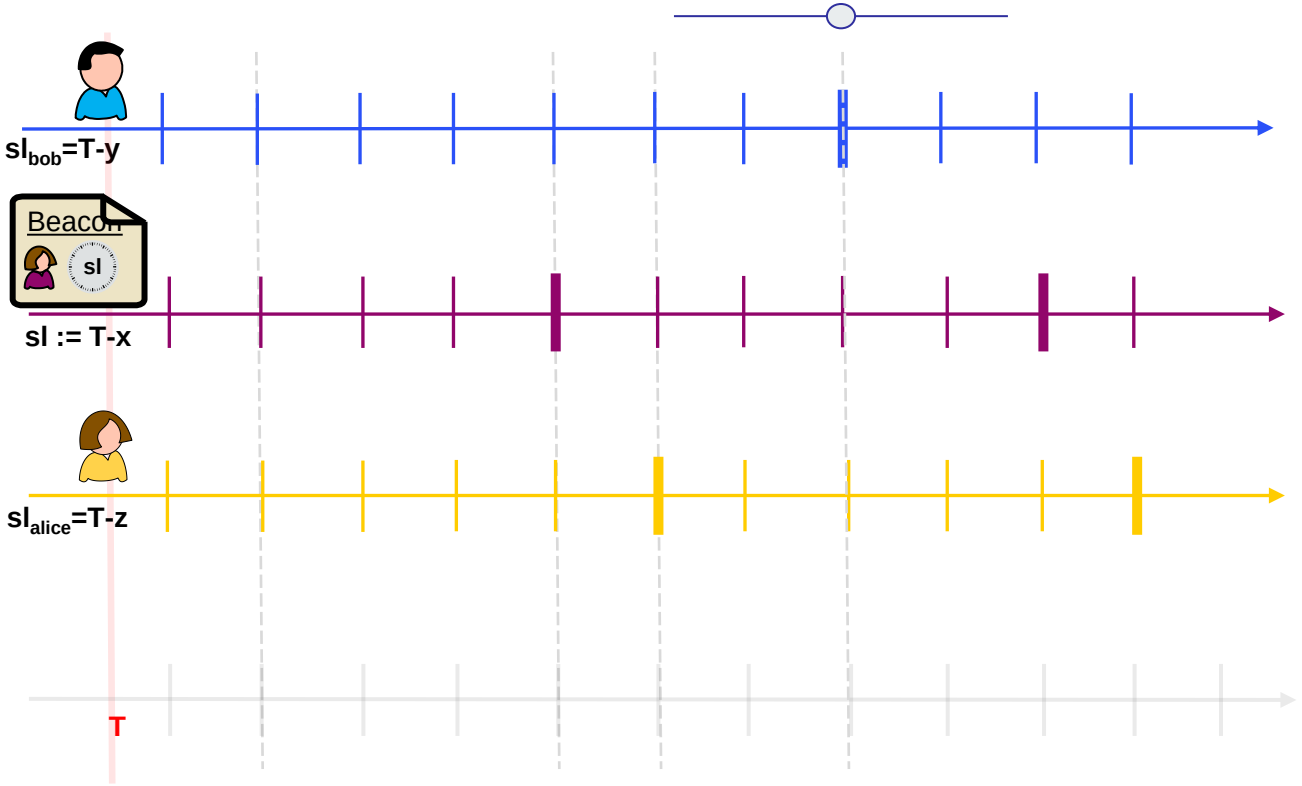
Chronos: Synchronization Procedure



Adjustment rule:

- At the end of epoch: **add** the **median of recommendations** to local time:

Synchronization Procedure - Example



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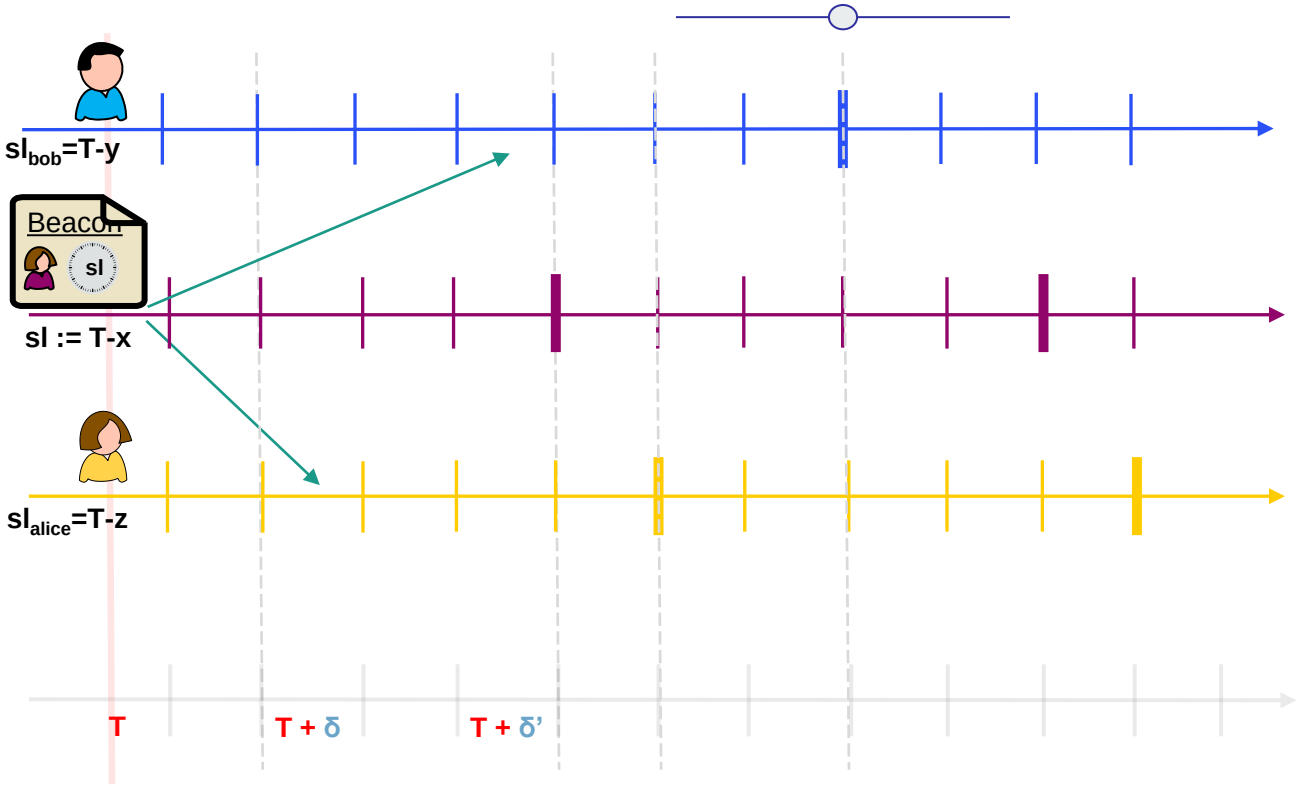

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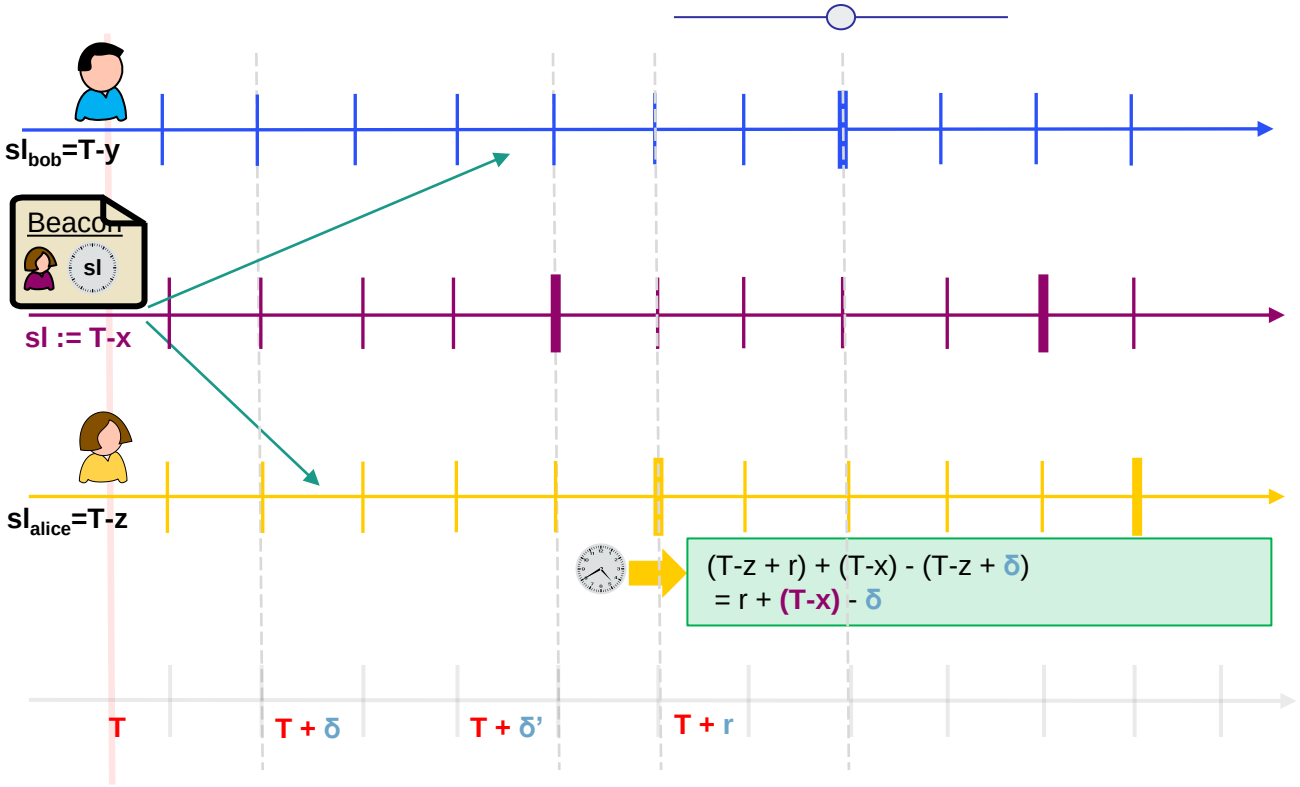

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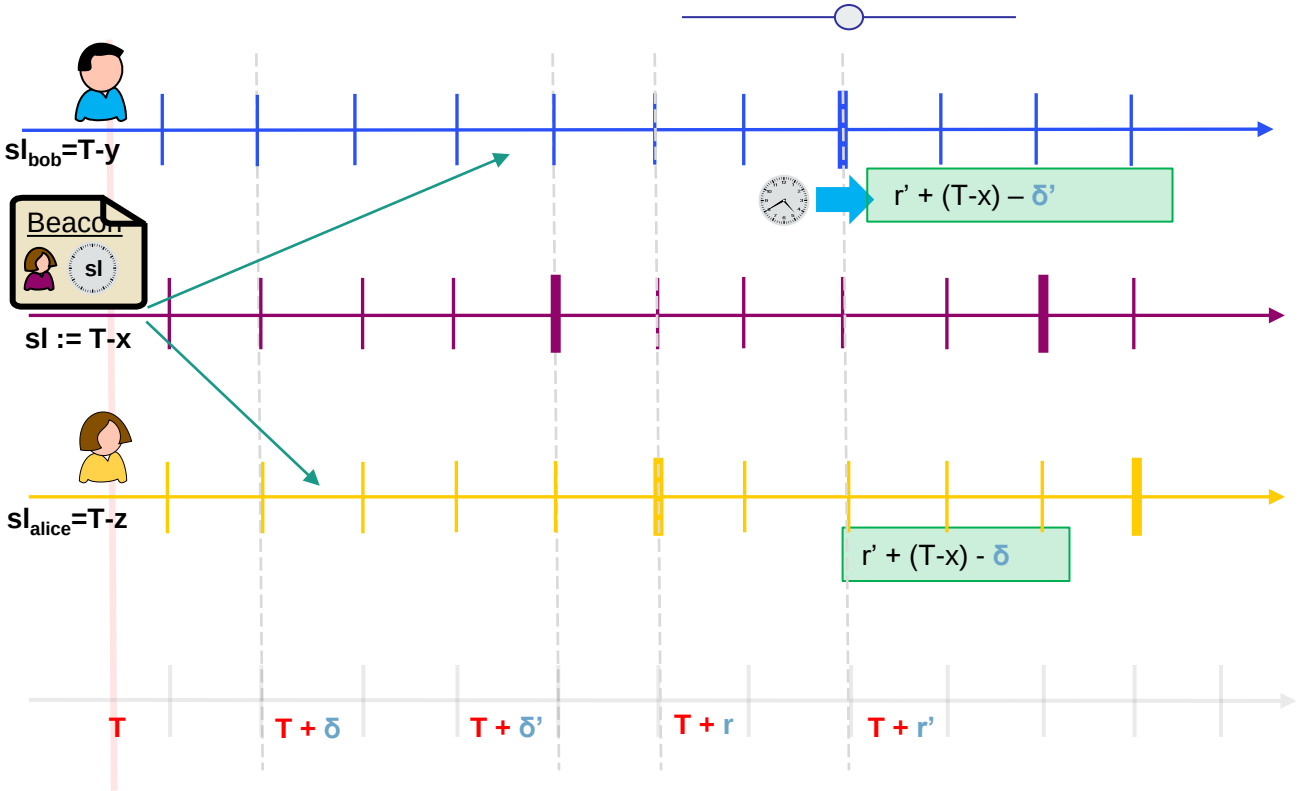
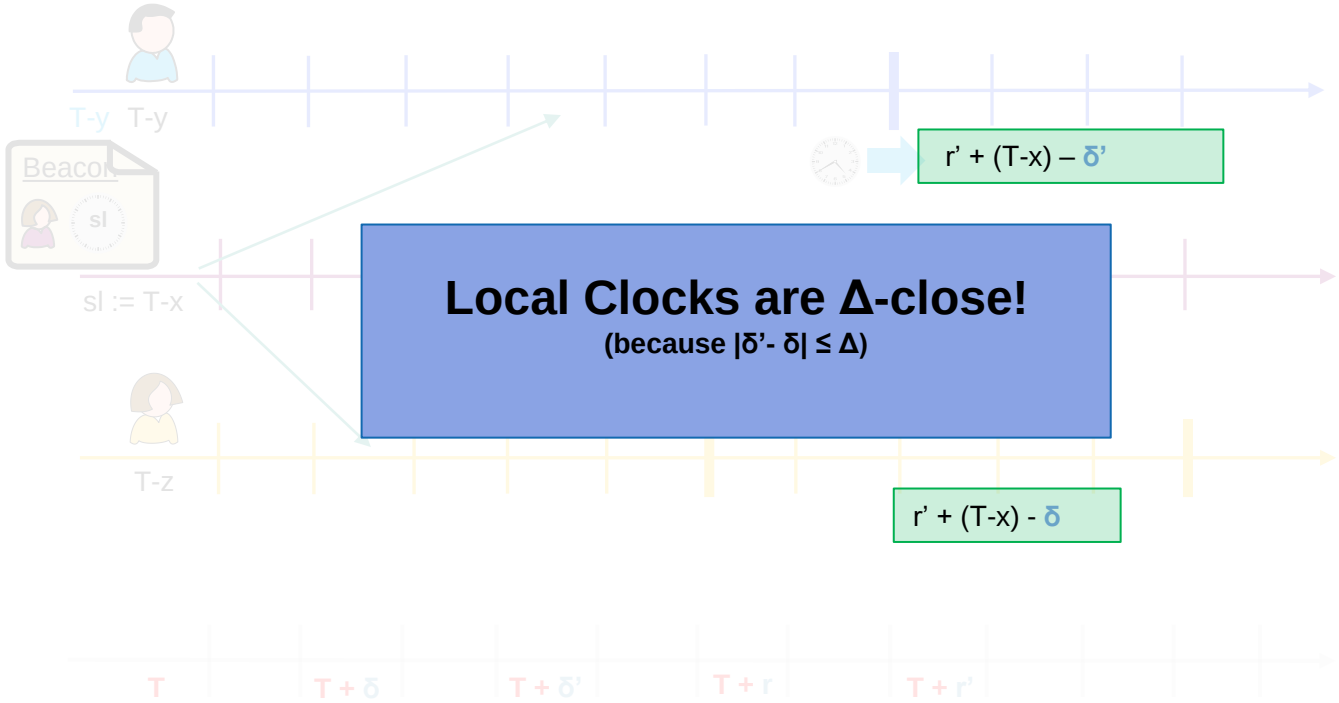
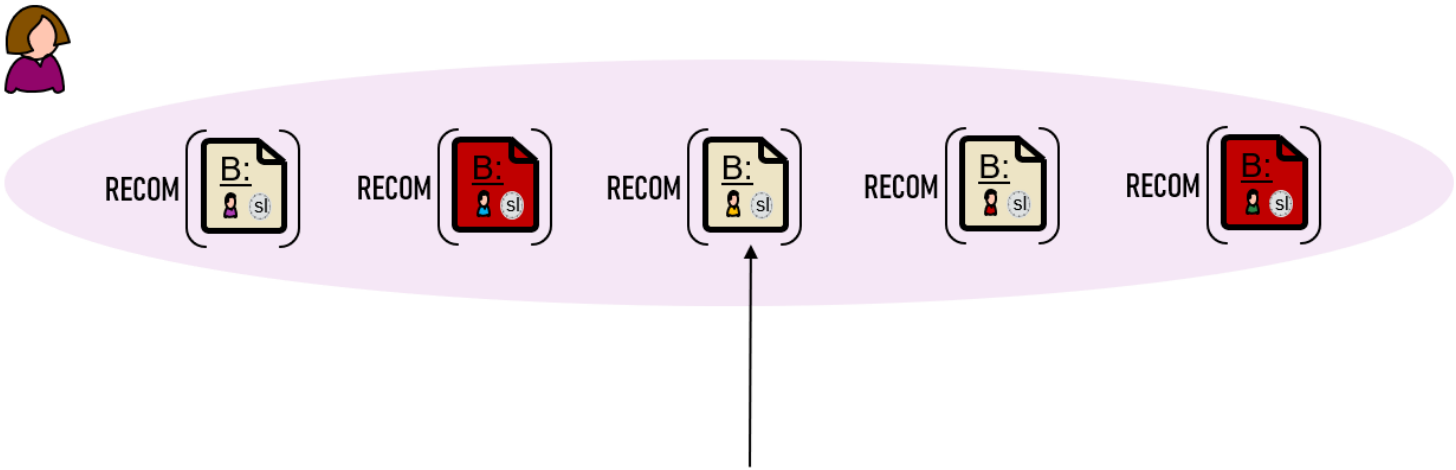


Synchronization Procedure – Property 1



Synchronization Procedure – Property 2



Furthermore, by honest-majority assumption:
→ Median, i.e., **adjustment is bounded**.

Chronos

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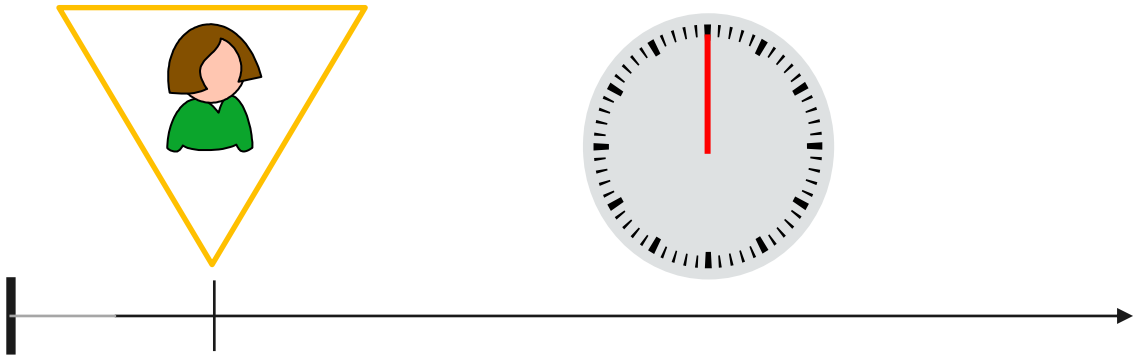
Chronos: Joining Procedure



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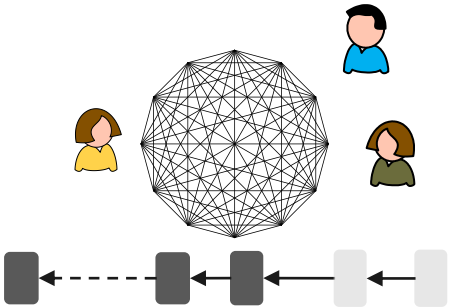

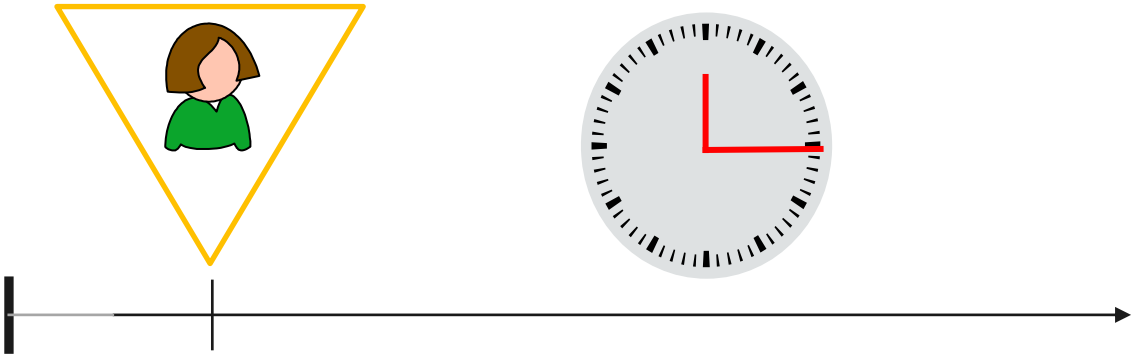

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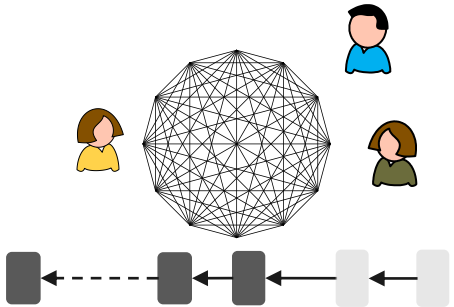

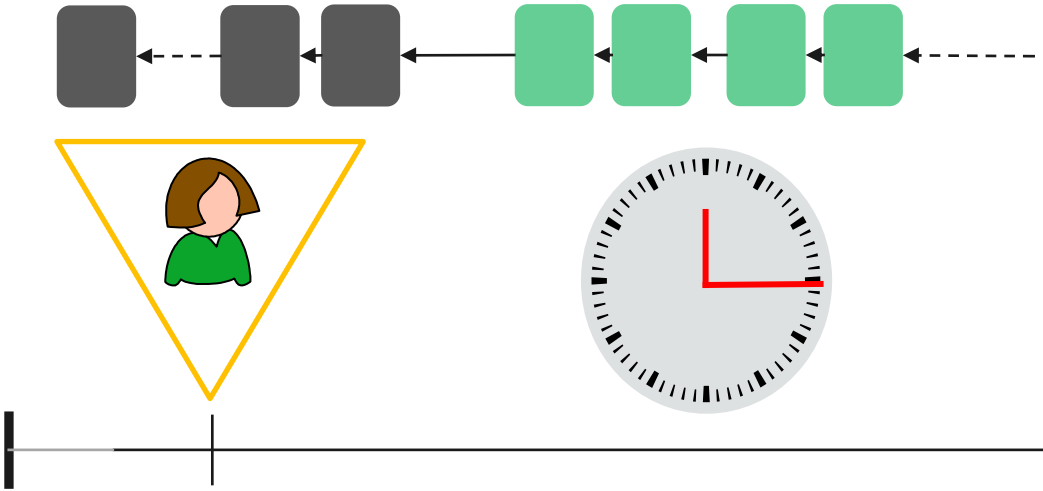

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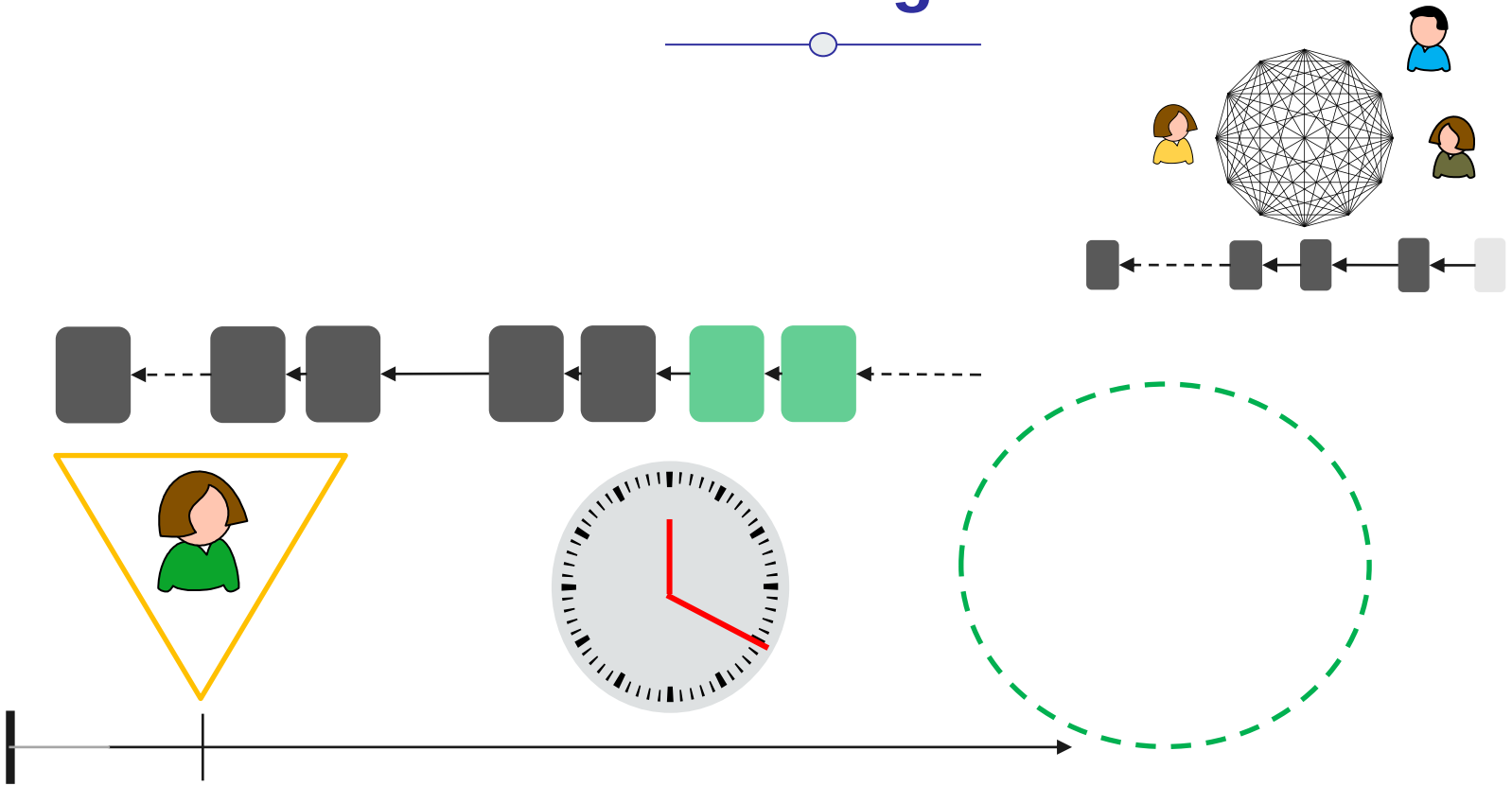

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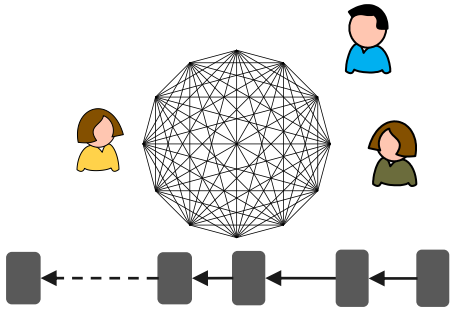

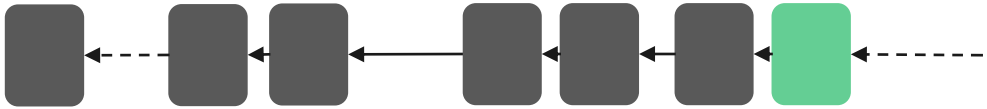

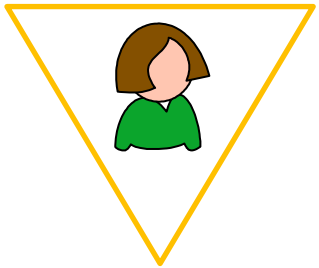

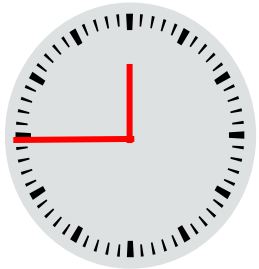

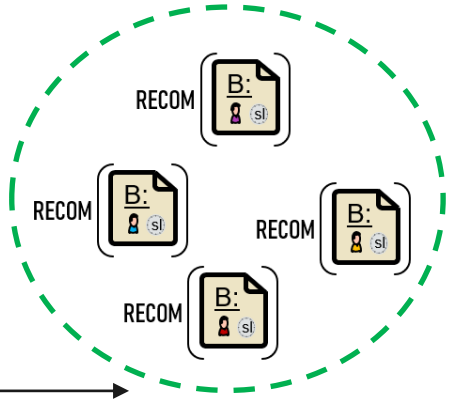

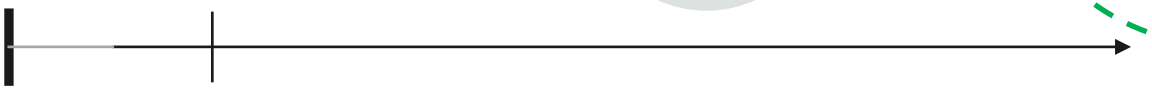

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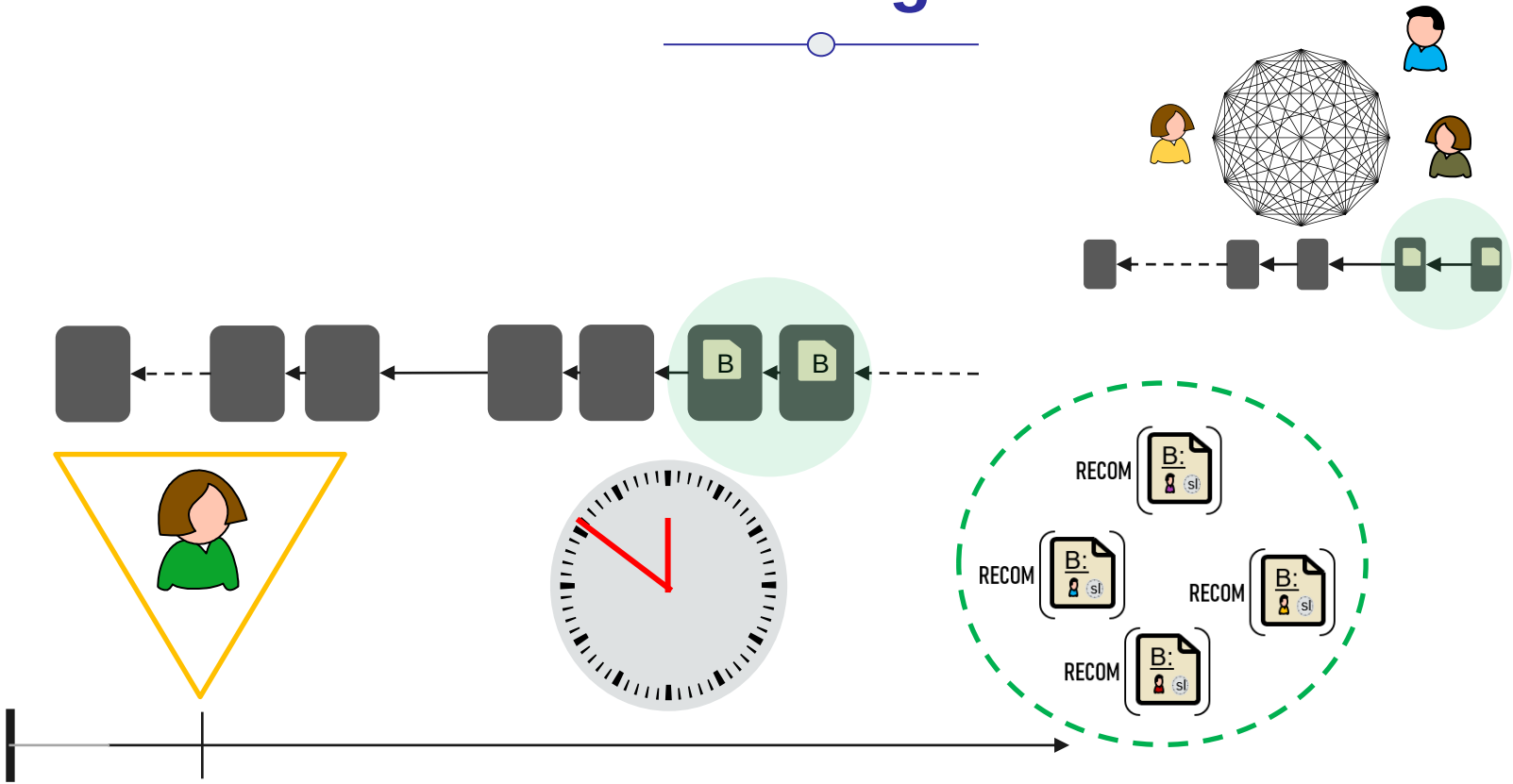

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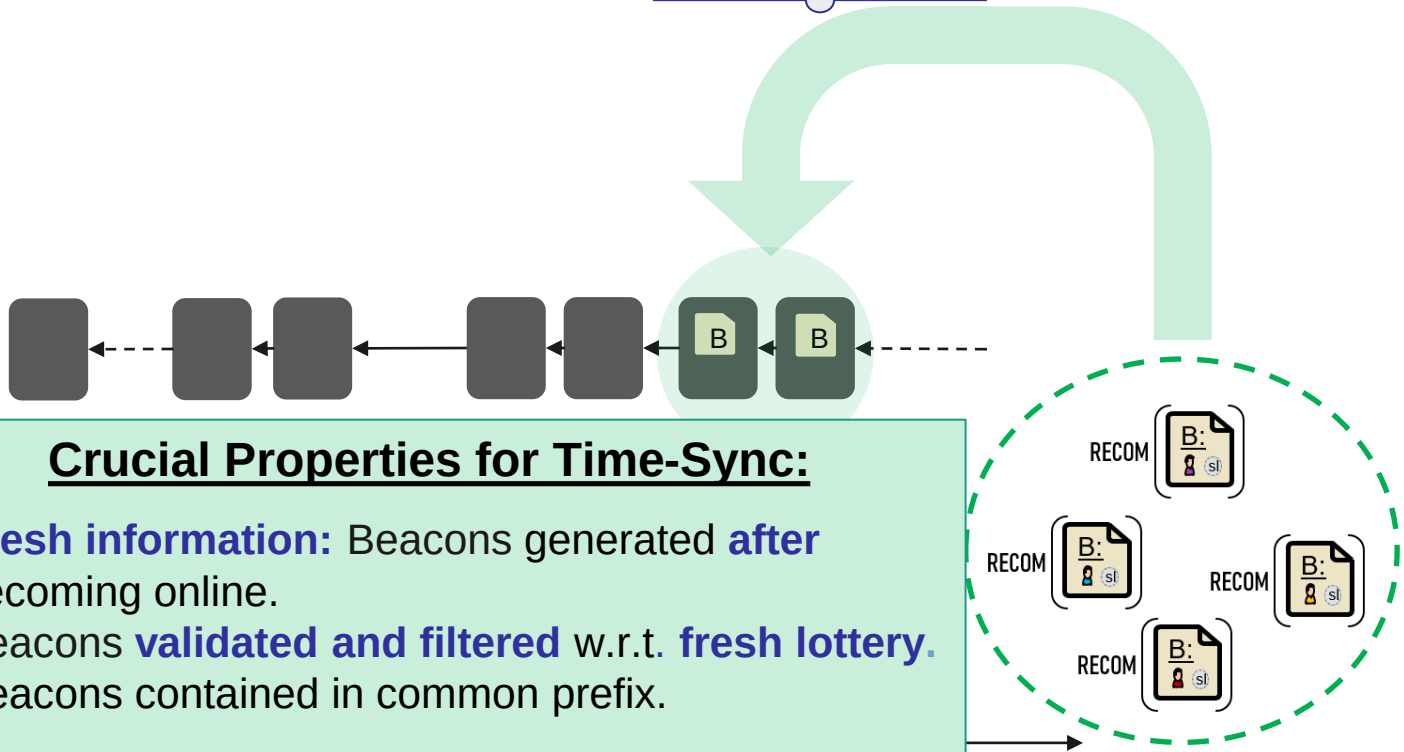
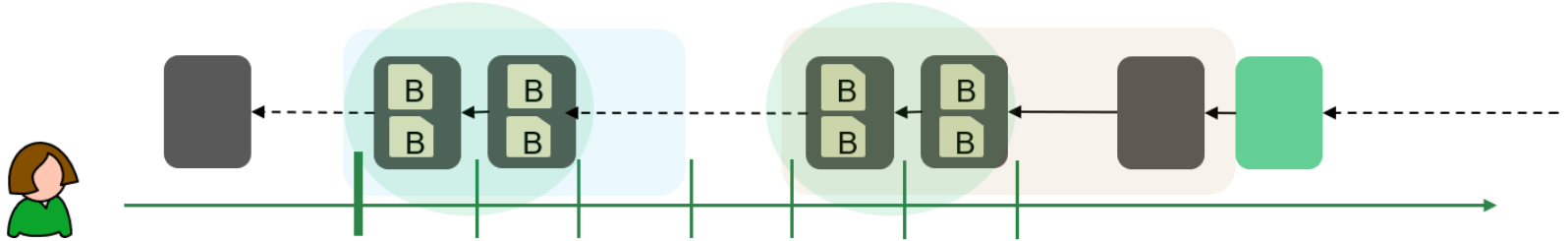


Crucial Properties for Time-Sync:

- **Fresh information:** Beacons generated **after** becoming online.
- Beacons **validated and filtered** w.r.t. **fresh lottery**.
- Beacons contained in common prefix.

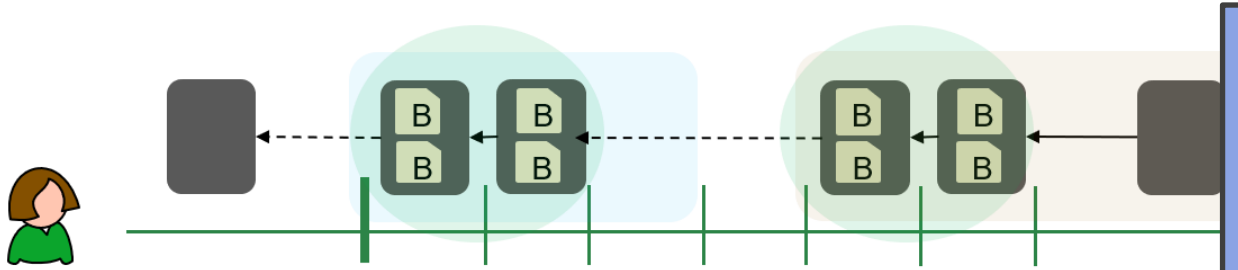
Chronos: Joining Procedure



- **Time-synchronization is possible:**
  - Agreement on evidence & freshness of beacons:
    → Reasoning like before to conclude Δ-closeness.

- **Clock adjustments of** alert parties **can be retraced** exactly!
  - Stop when computed timestamp is before the next sync-slot

Chronos: Joining Procedure



Note:

Any external observer can perform these operations.

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Summary

Ouroboros Chronos is:

- A time synchronizer for the dynamic ad-hoc setting, …

  …where parties have access to a CRS (Genesis block);

  …where parties have access to a bounded-delay diffusion network and (approx.) same-speed clocks;

  …and where the honest-majority condition holds.

Summary

Ouroboros Chronos is:

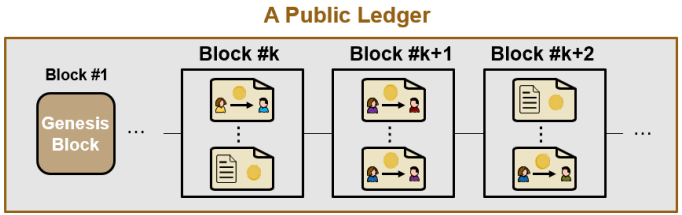
- A PoS blockchain protocol in the dynamic ad hoc setting (with a bounded-delay network), …

  … where parties can bootstrap the blockchain from the Genesis Block only.

  … where no external timing service is needed as new parties bootstrap the time (based on (approx.) same-speed local clocks).

  … whose security is based on the honest-stake majority assumption.

Ouroboros Chronos =



+

A Global Clock

Images: https://openclipart.org/, https://publicdomainvectors.org/

Thanks to Dominic Hicks for editing the video.