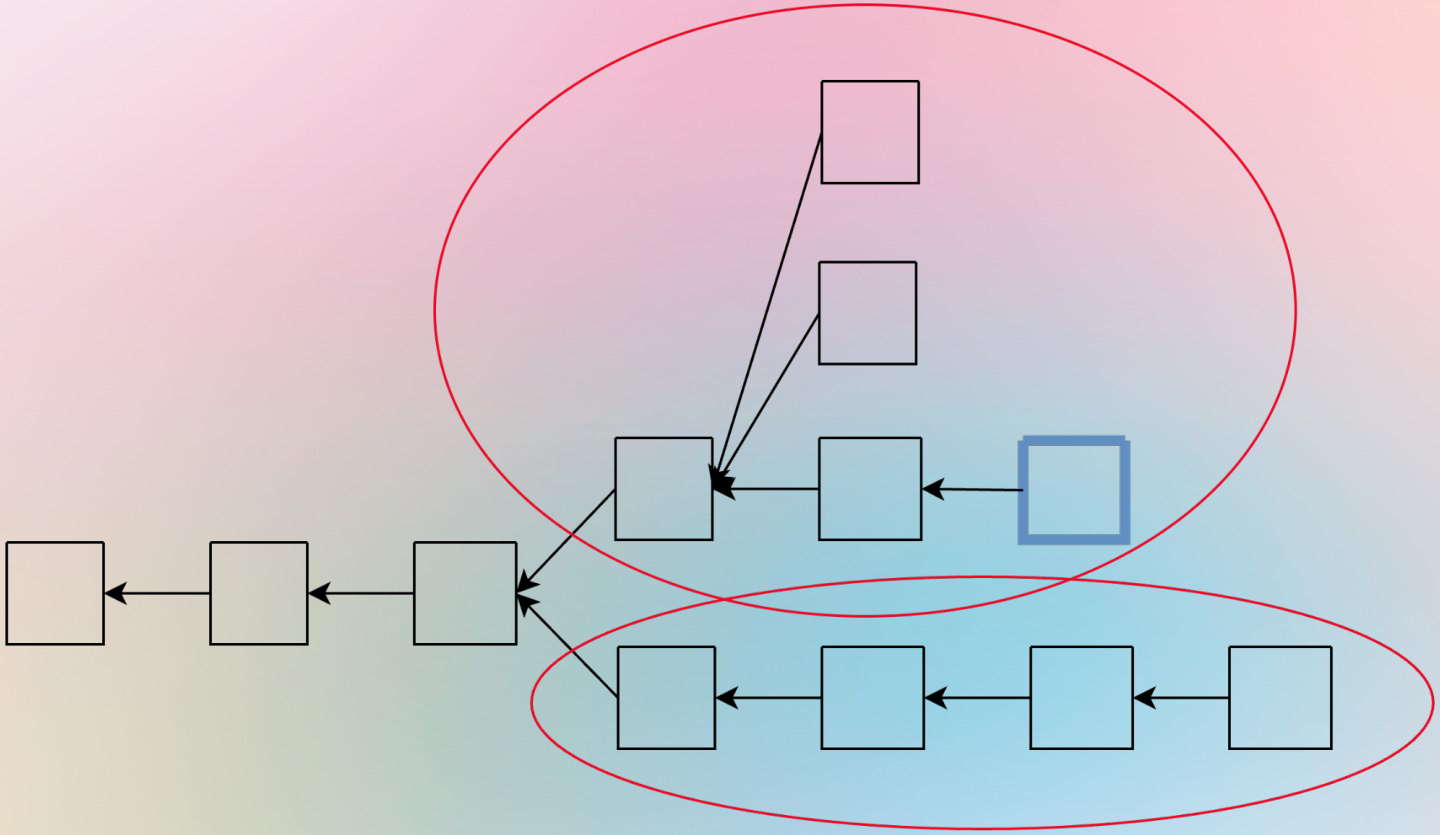
Gasper recap

Gasper = LMD-GHOST + Casper-FFG

GHOST = Greediest Heaviest Observed SubTree



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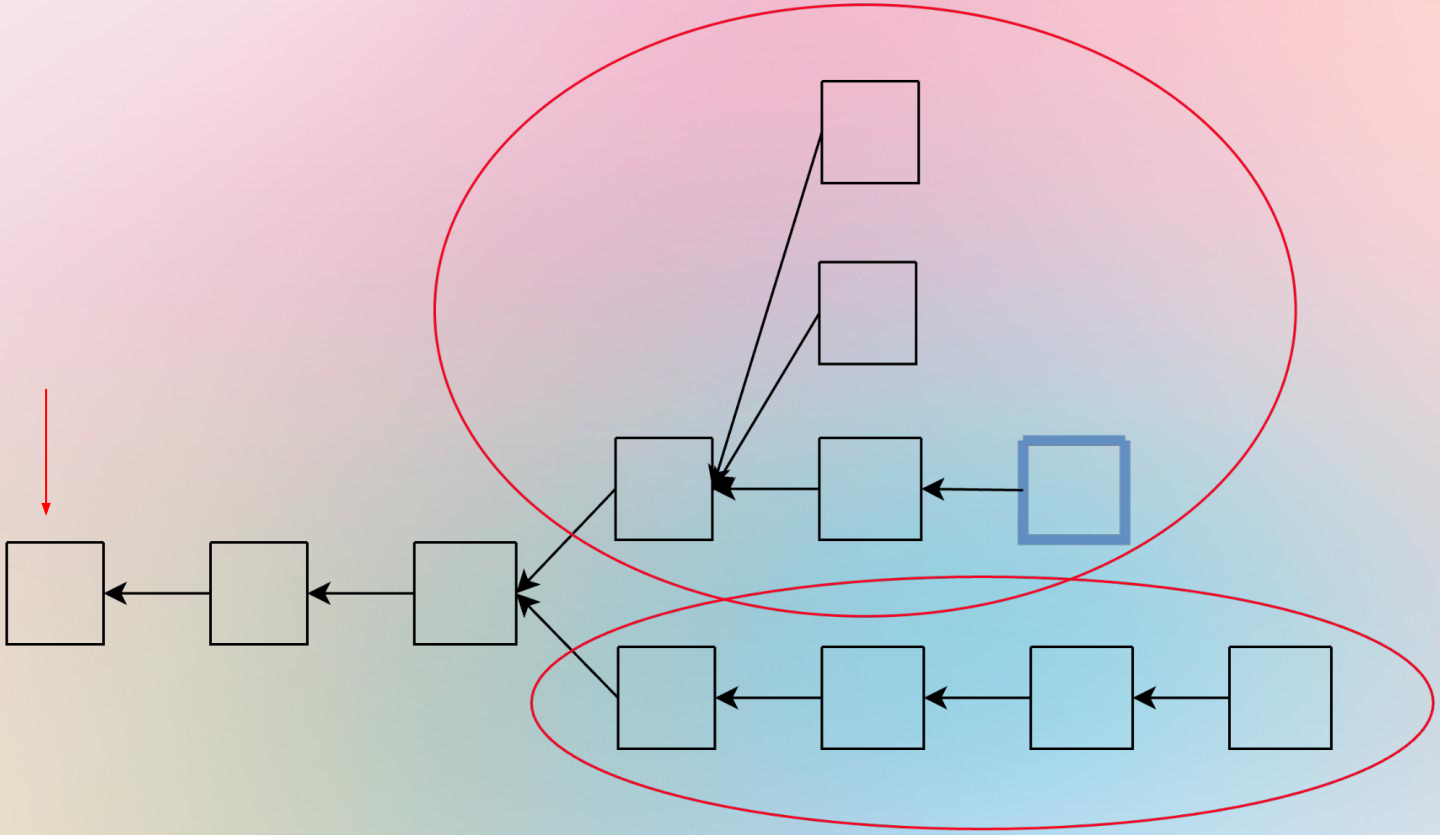

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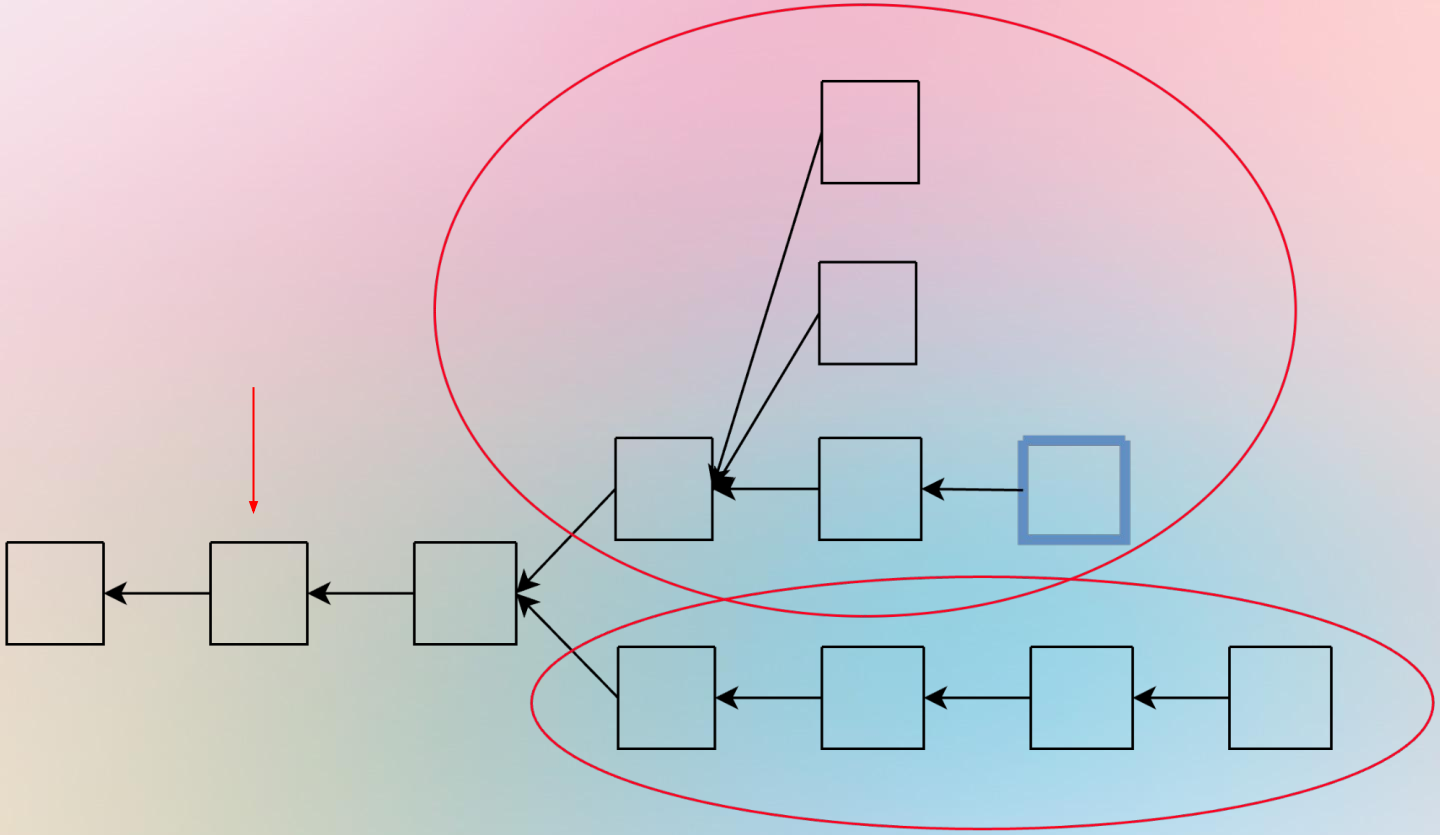

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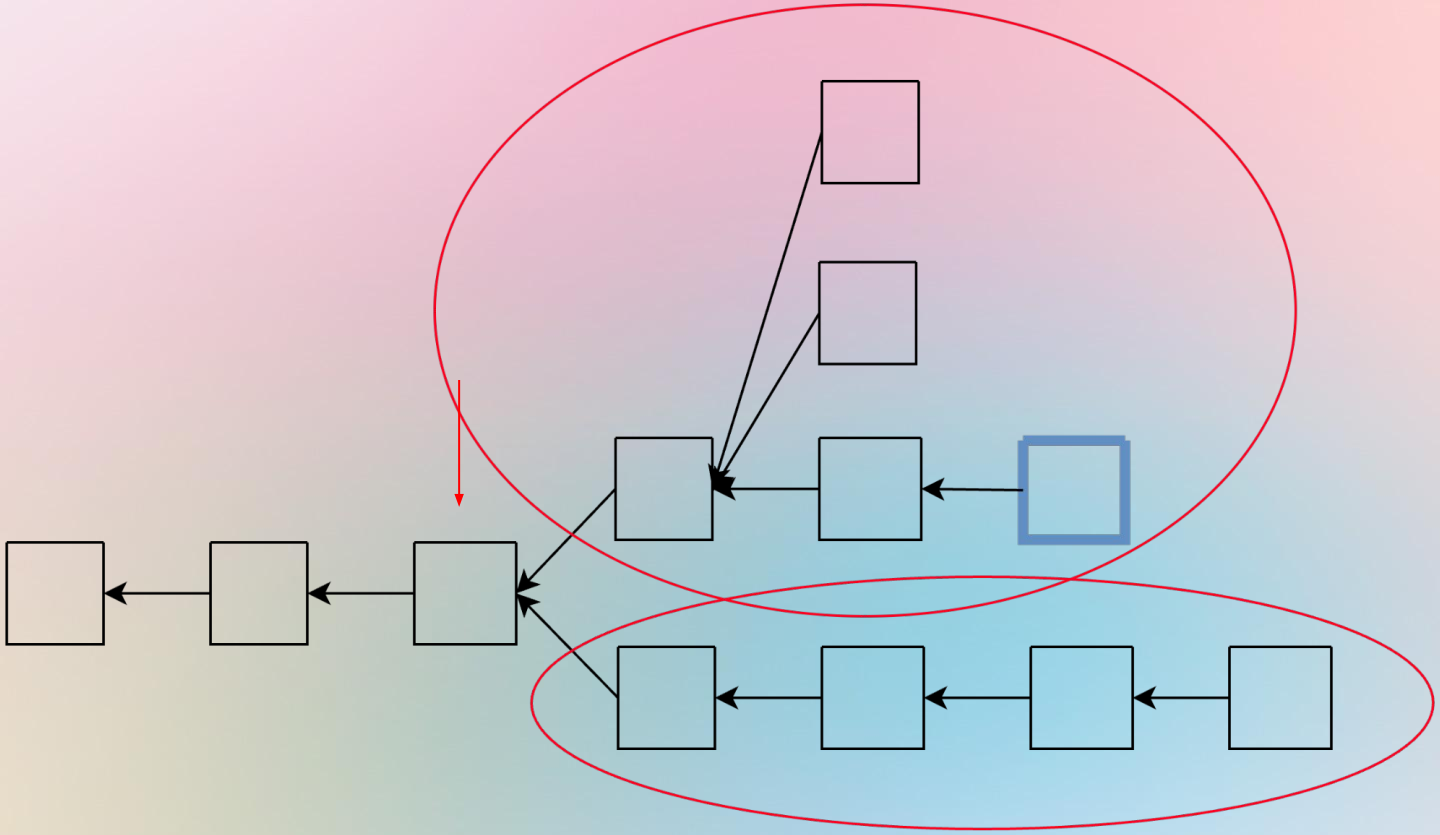

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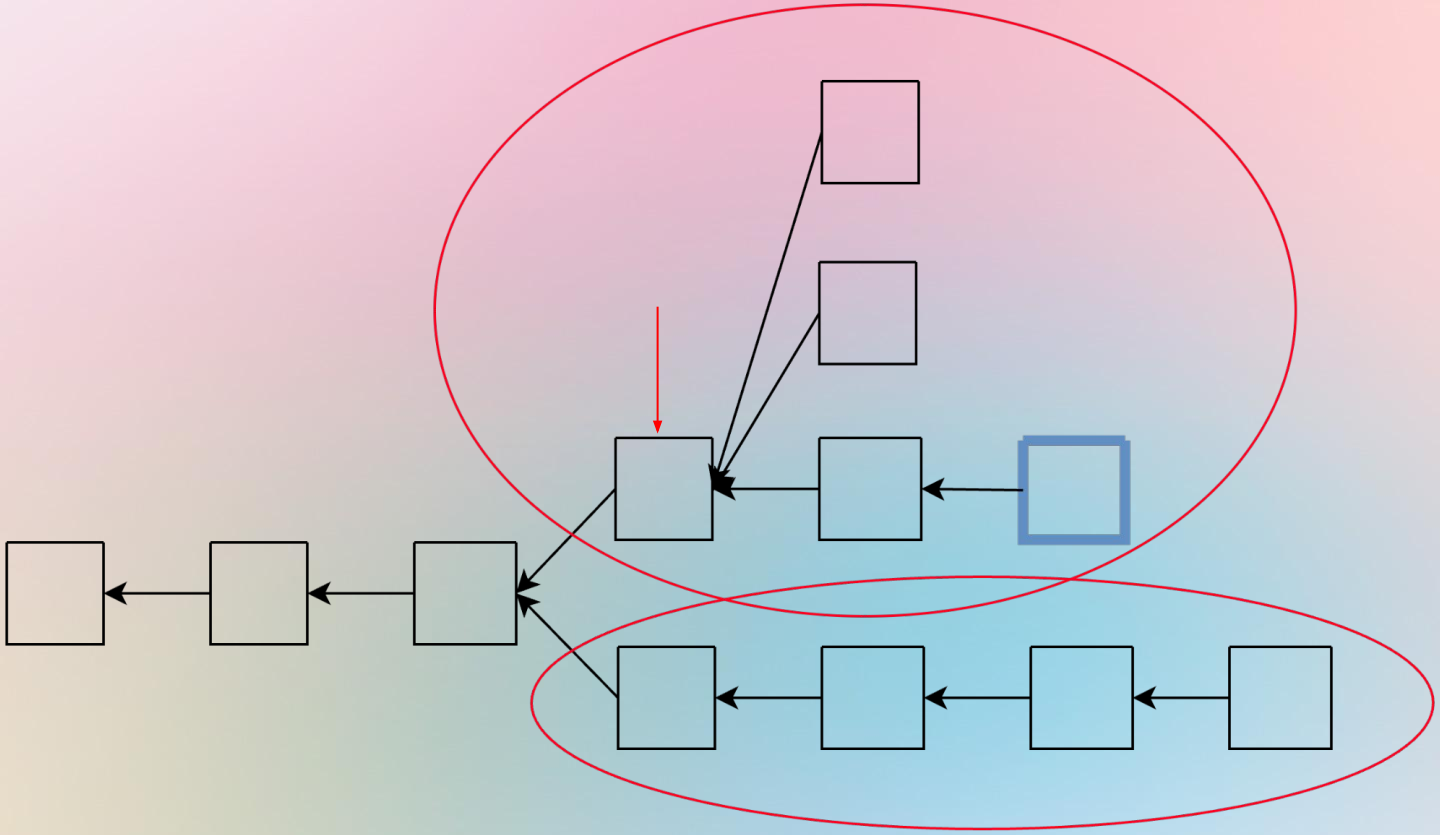

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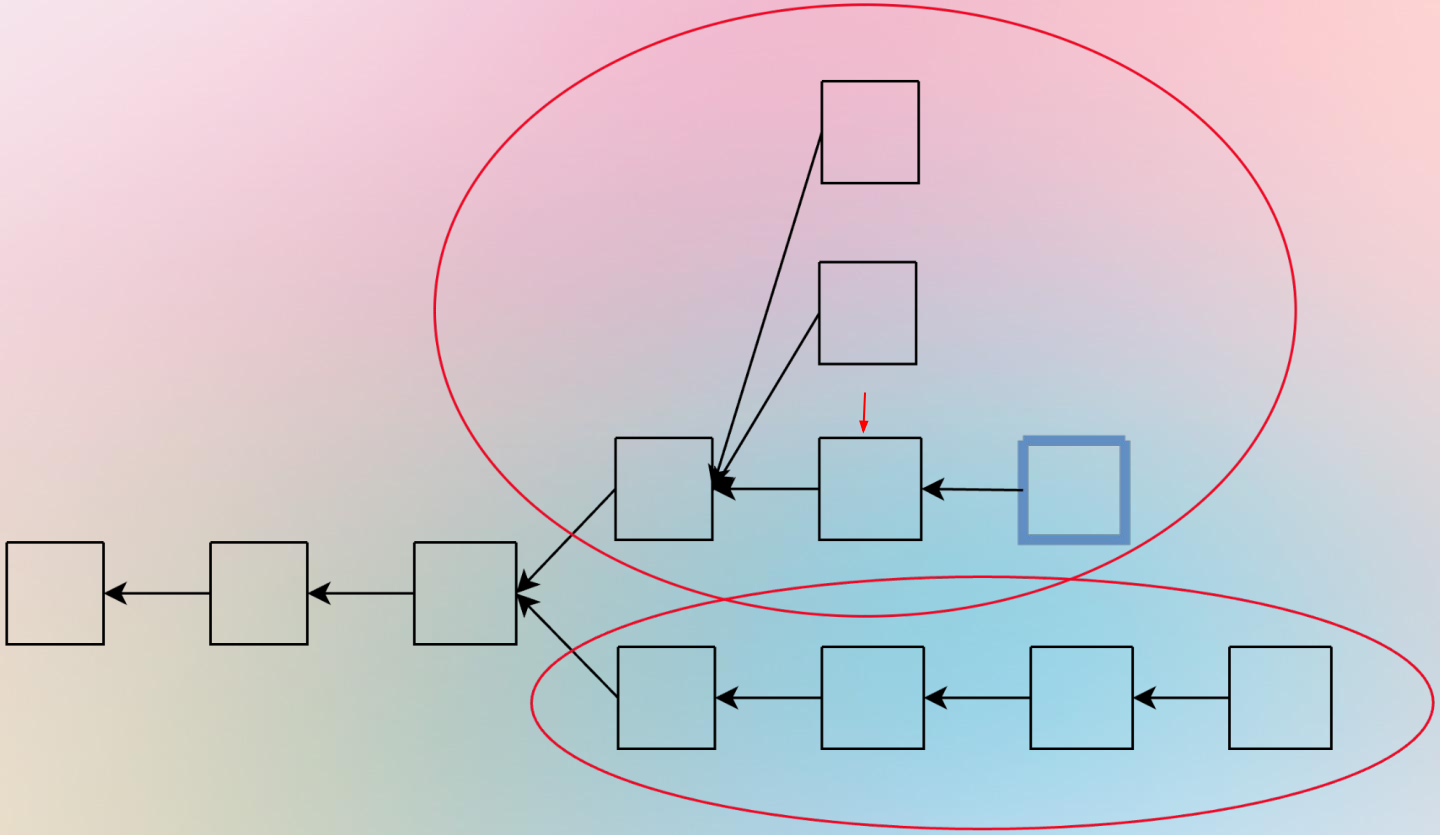

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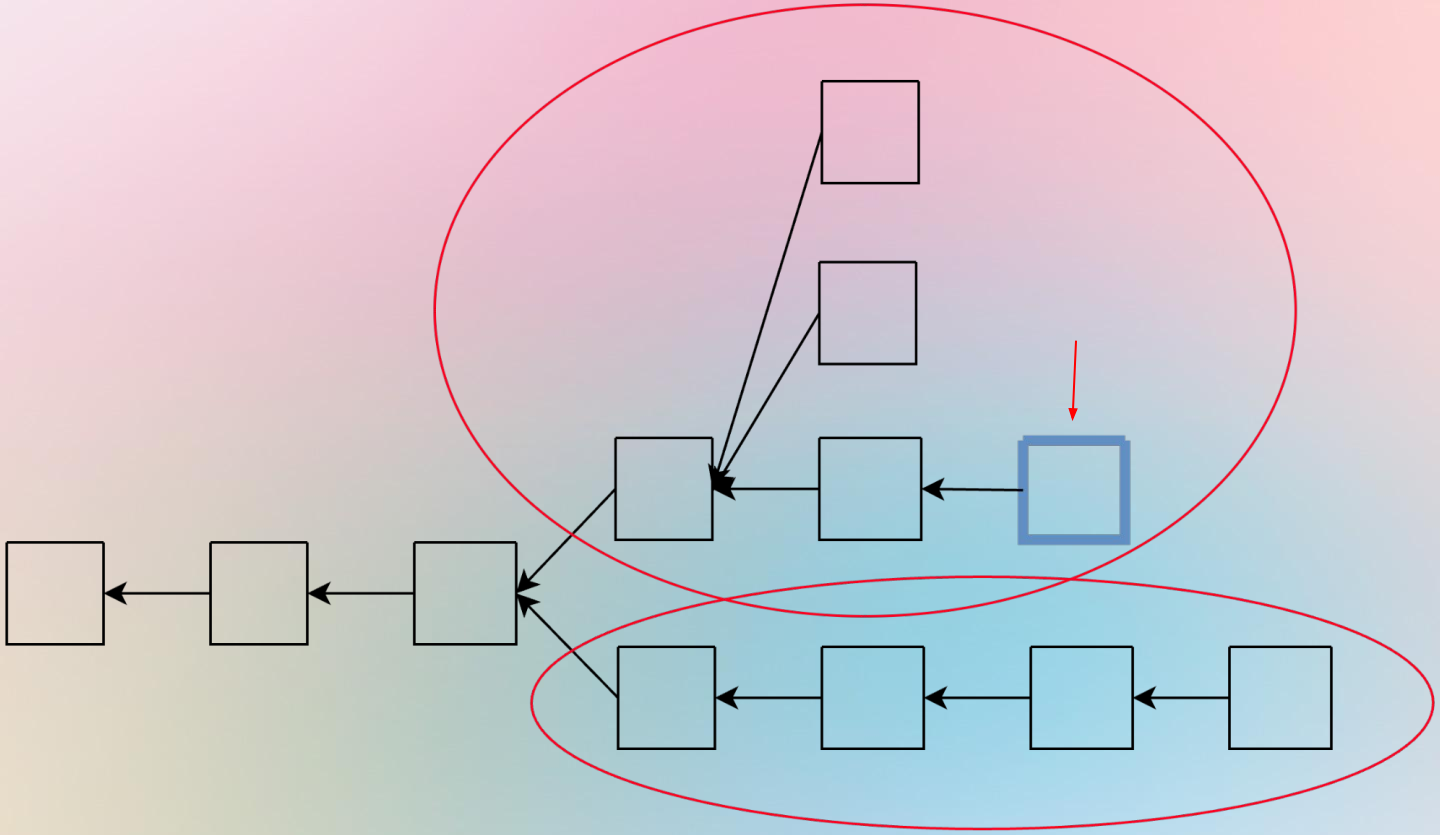

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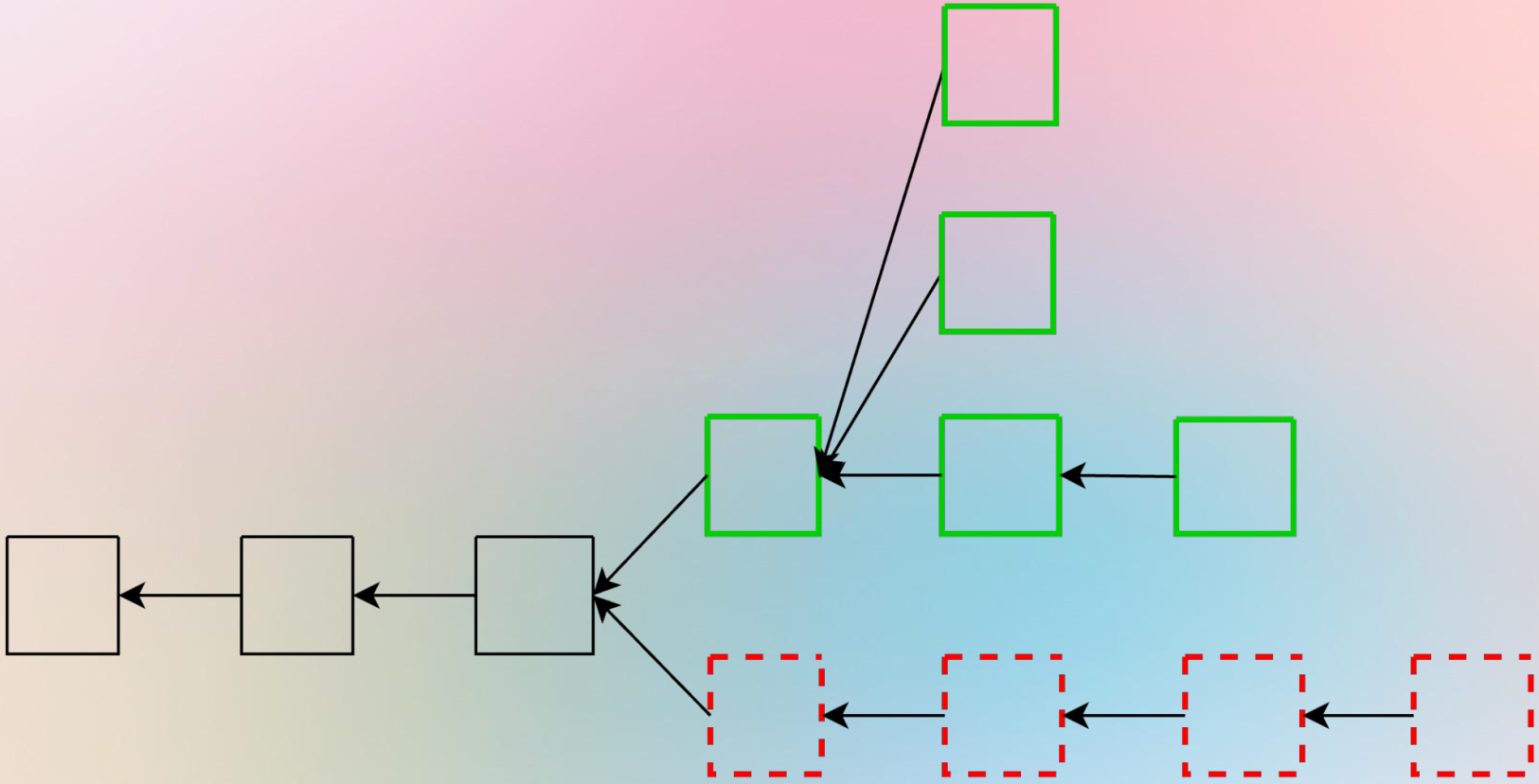
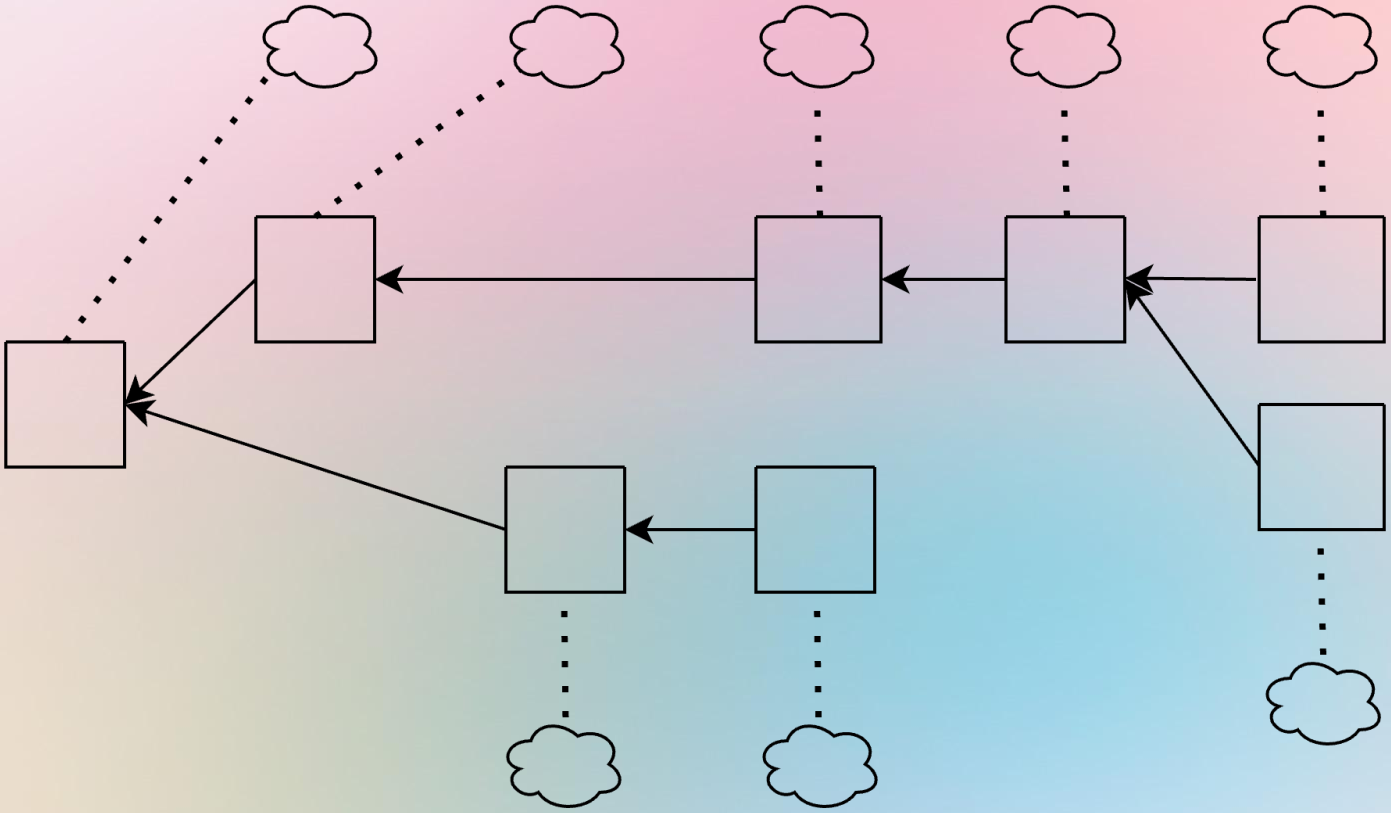
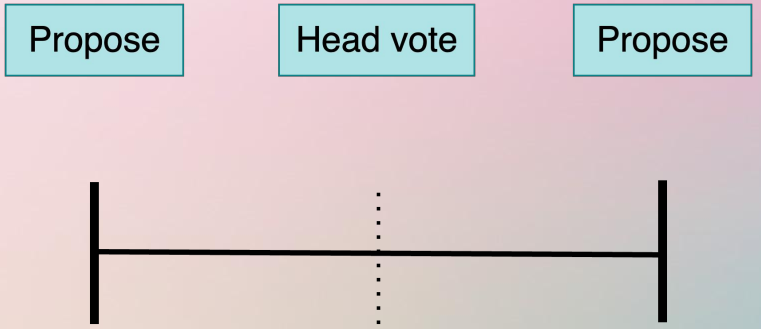


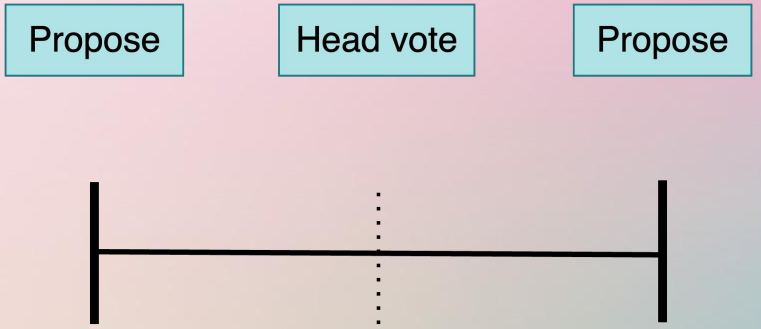
LMD-GHOST = Latest Message Driven GHOST

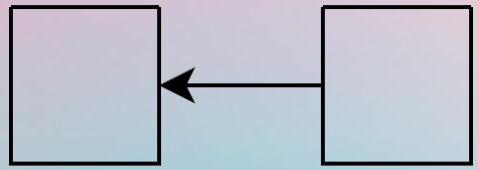


LMD-GHOST as a protocol

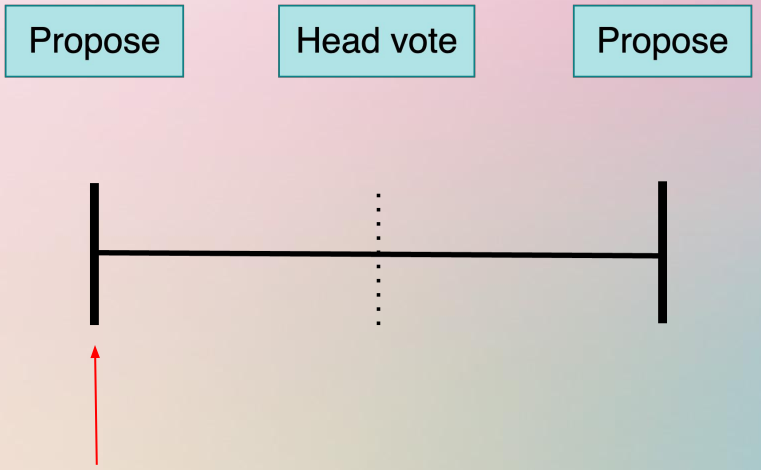


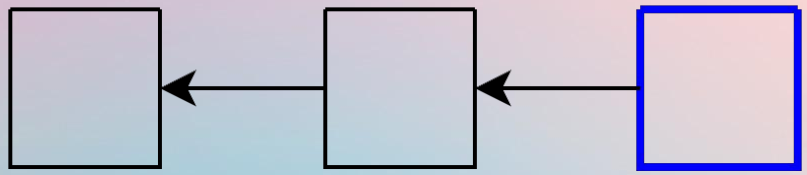
LMD-GHOST as a protocol



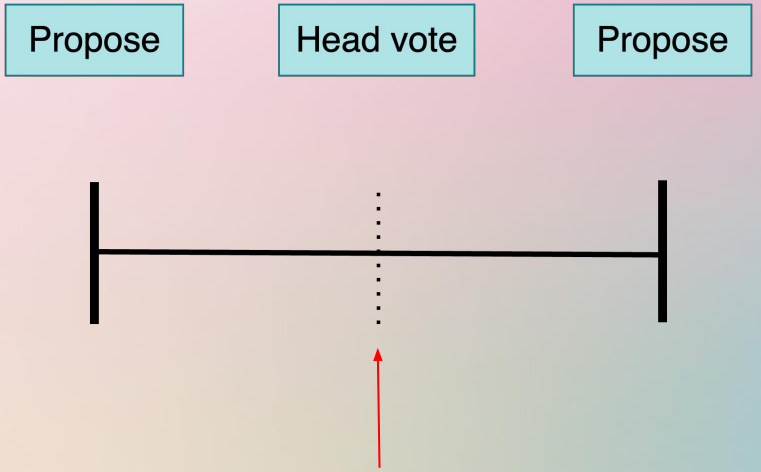


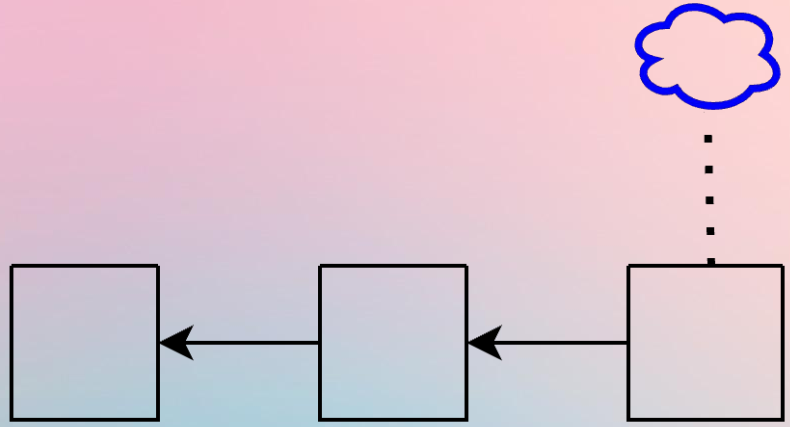
LMD-GHOST as a protocol



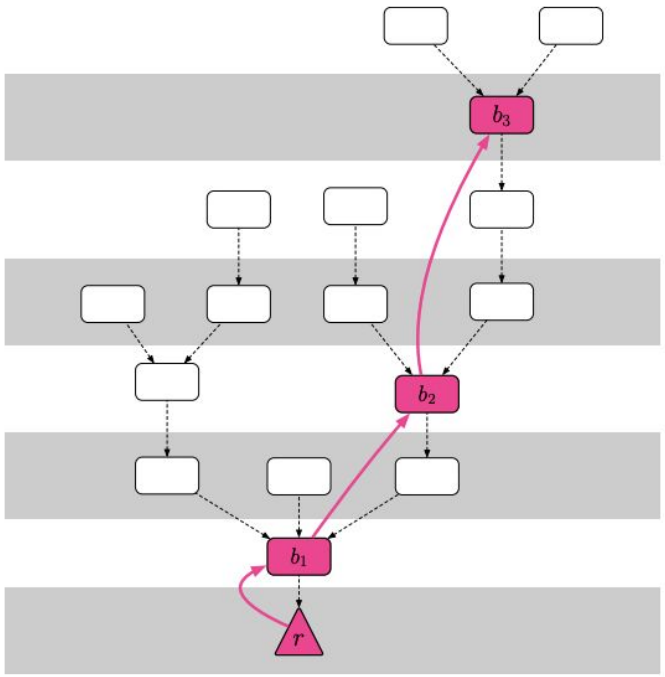


LMD-GHOST as a protocol





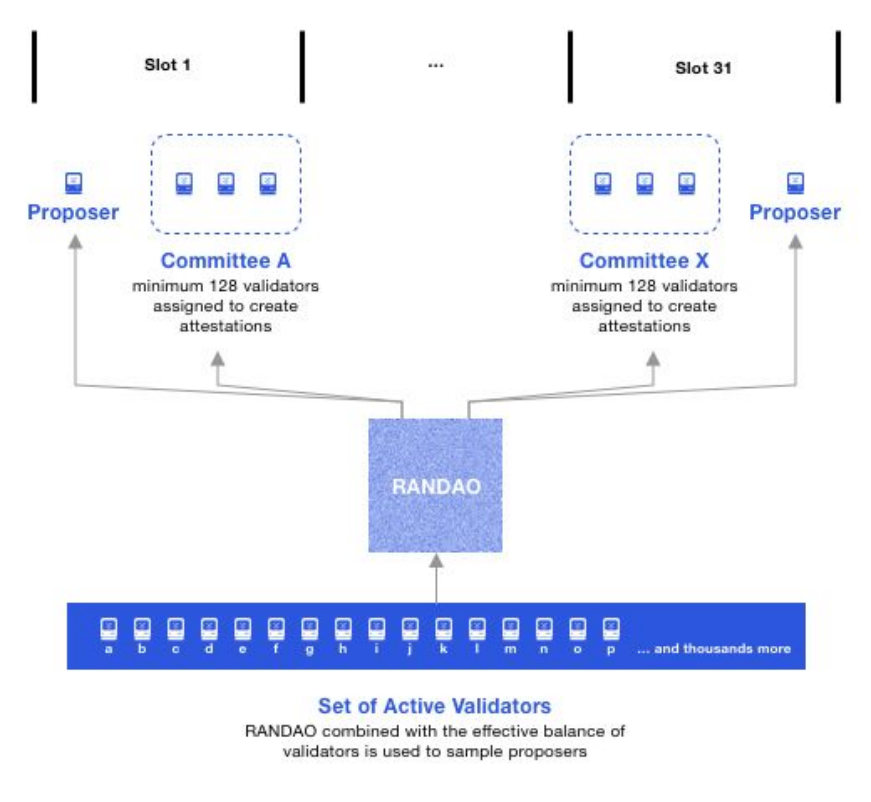
Casper FFG (Friendly Finality Gadget)



(c) The justified chain $r \rightarrow b_1 \rightarrow b_2 \rightarrow b_3$

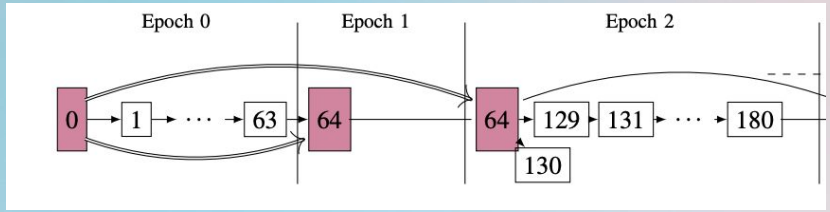
Casper the Friendly Finality Gadget
https://arxiv.org/pdf/1710.09437.pdf

Ethereum today



In each slot, a pseudorandomly elected committee votes for LMD-GHOST and for CASPER-FFG

Over 32 slots (an epoch) all validators have voted, concluding one round of voting of CASPER-FFG



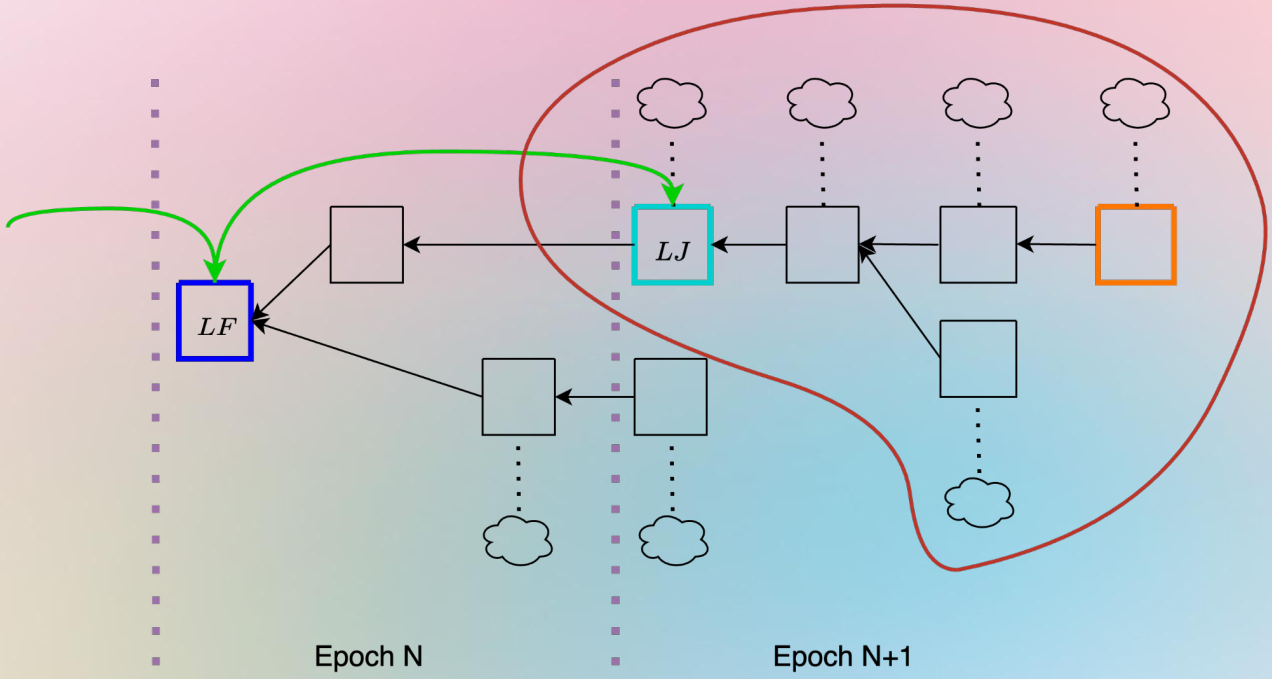
[The Beacon Chain explainer you need to read first, https://ethos.dev/beacon-chain]

[Combining GHOST and Casper, https://arxiv.org/pdf/2003.03052.pdf]

Modelled as an Ebb-and-flow protocol

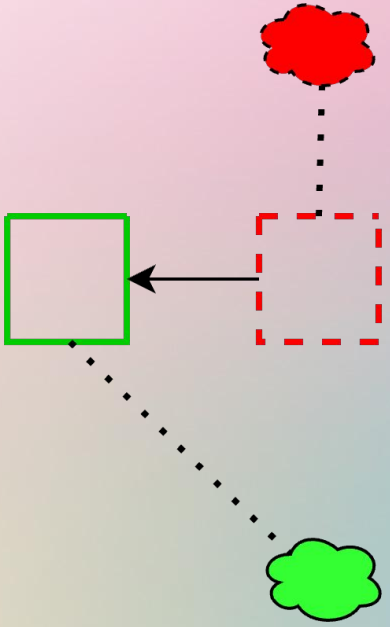
- Network model: partially synchronous network with GST, time where synchrony begins
- Participation model: dynamic until a time GAT, where it stabilizes
- Want:
  - **Dynamic availability**: available chain to be safe and live under network synchrony and dynamic participation (GST = 0, GAT = ∞)
  - **Finality**: Finalized chain to be always safe and live after max(GST, GAT)
  - **Prefix**: finalized chain is a prefix of the available chain

Hybrid fork-choice:
Start from the latest justified checkpoint, then run LMD-GHOST
=> Prefix



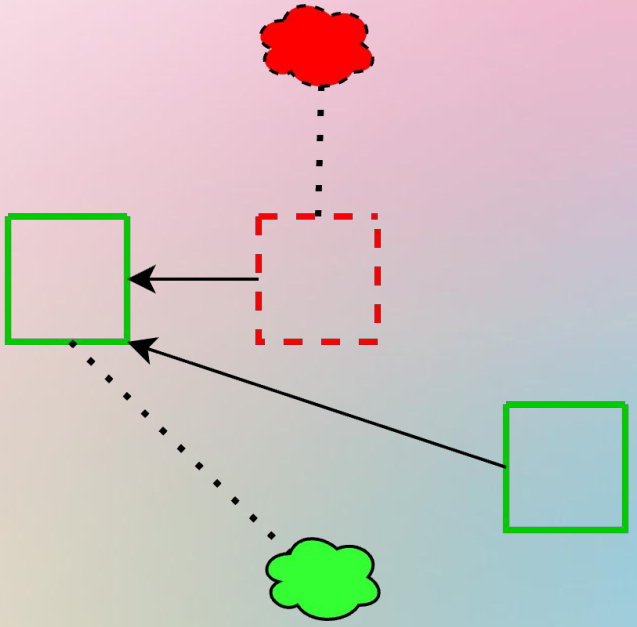
Problems of LMD-GHOST

Simple ex-ante reorg



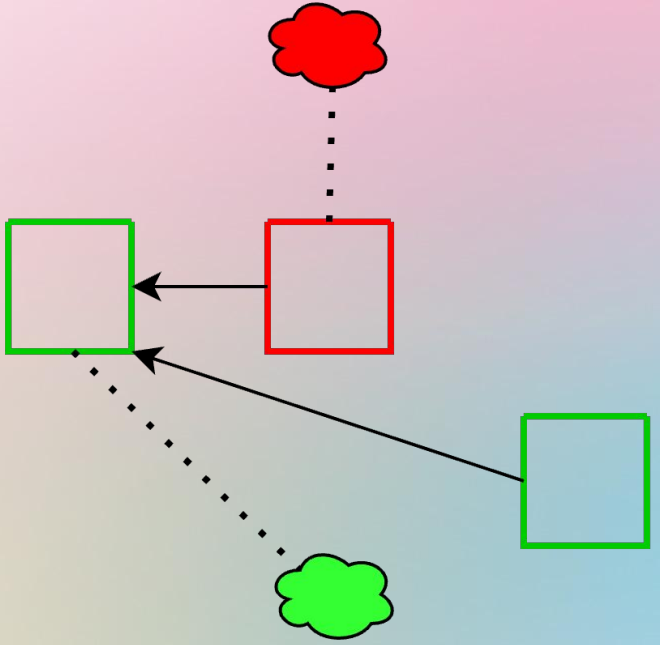
Adversary withholds a block and even just a single attestation to it

Simple ex-ante reorg



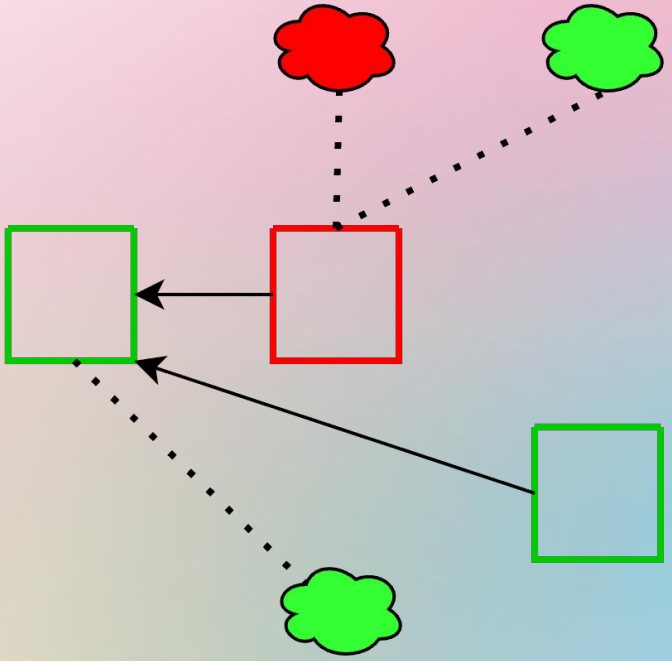
An honest proposer builds a block while unaware of the withheld one

Simple ex-ante reorg



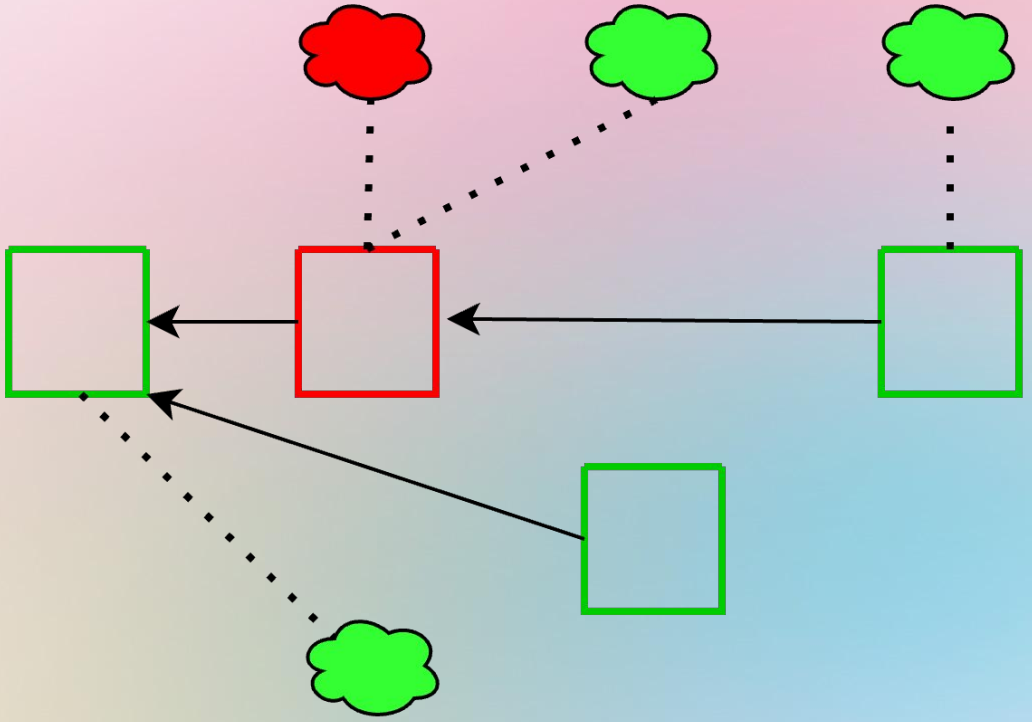
Adversary reveals its block and attestation

Simple ex-ante reorg



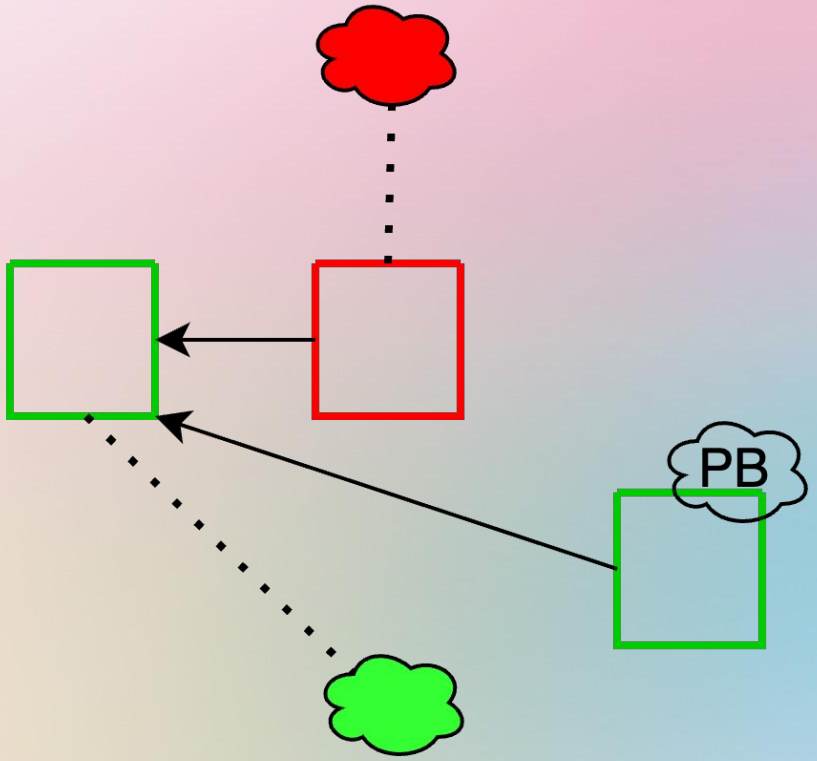
Attesters see the red block and attestation and attest to it

Simple ex-ante reorg



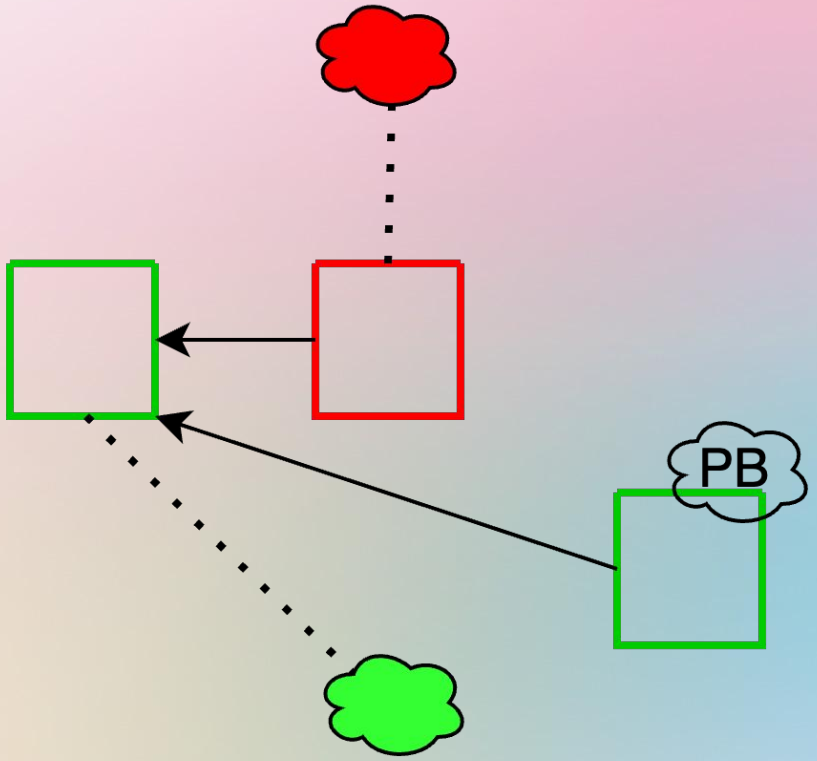
The honest proposal is forked out

Proposer boost



New block proposals have a temporary “weight boost” *during their slot.* In practice, set to 40%

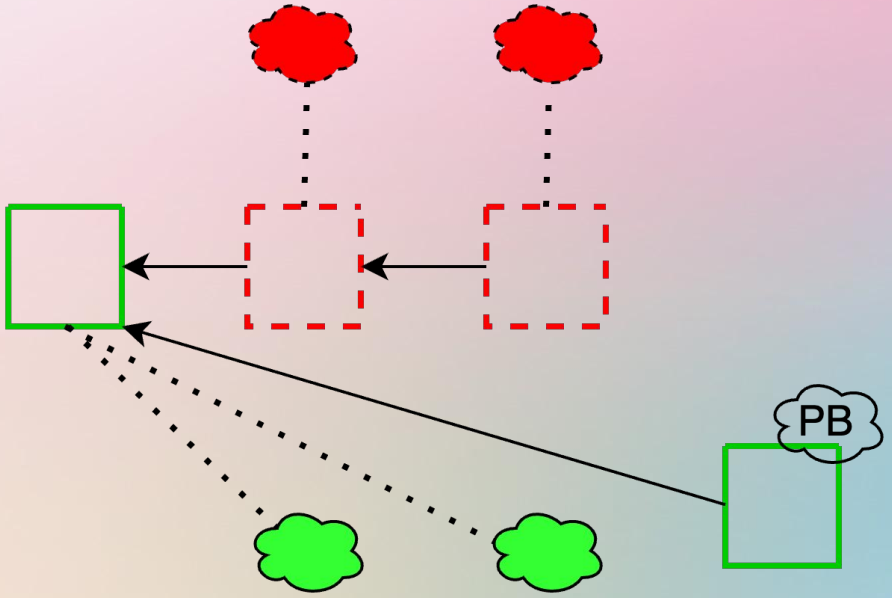
Proposer boost



New block proposals have a temporary “weight boost” *during their slot.* In practice, set to 40%

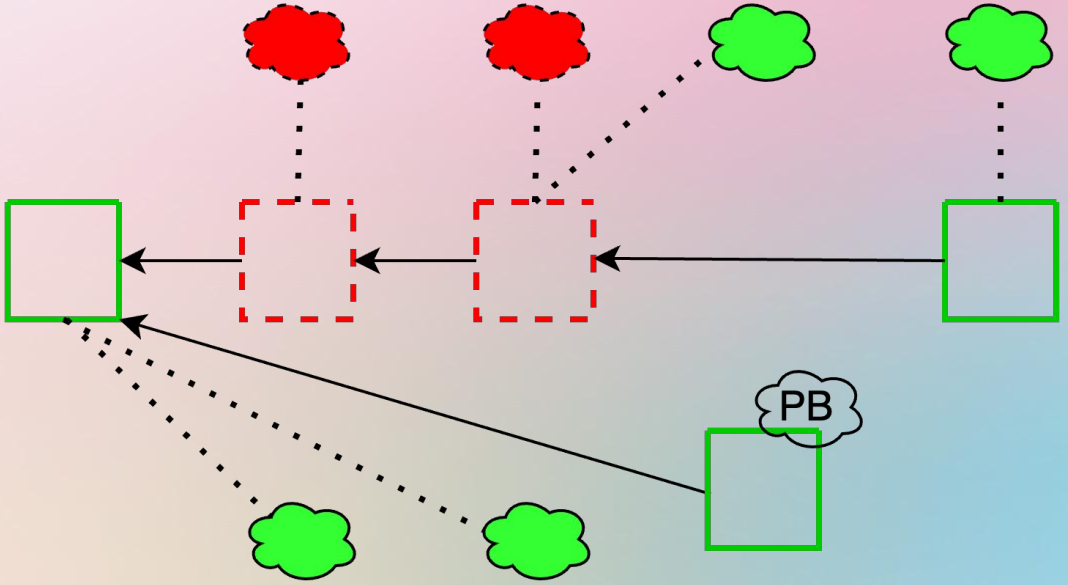
Can think of it as an hybrid of GHOST (weight = blocks) and LMD-GHOST (weight = attestations)

Ex-ante reorgs are still possible if controlling enough validators



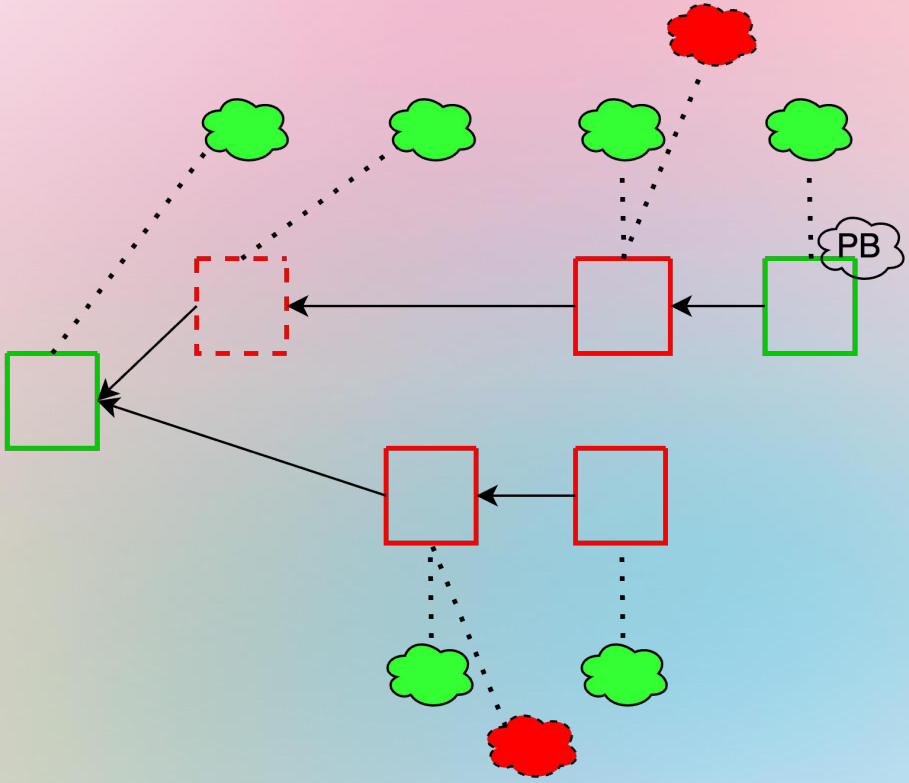
Adversary controls a few proposers in a row, withholds the block proposals and votes and reveals them to overcome the proposer boost.

Ex-ante reorgs are still possible if controlling enough validators



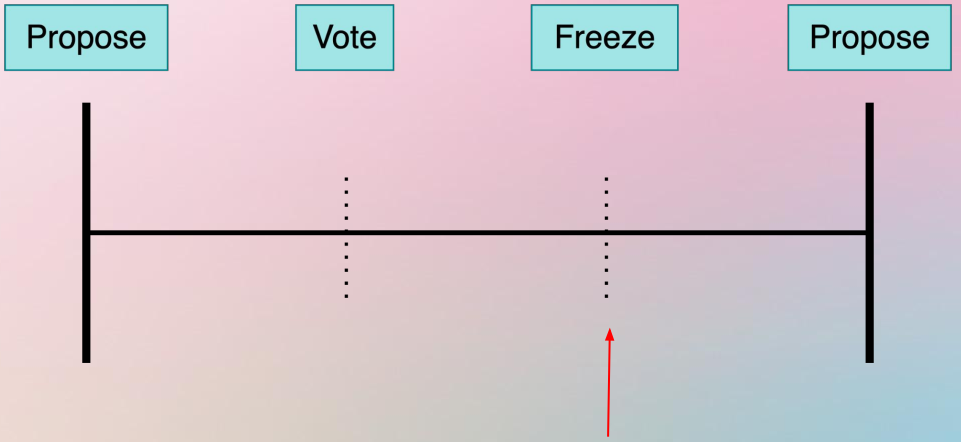
Adversary controls a few proposers in a row, withholds the block proposals and votes and reveals them to overcome the proposer boost. Honest attesters move to the adversarial branch.

Balancing attacks



Designing a theoretically secure available chain

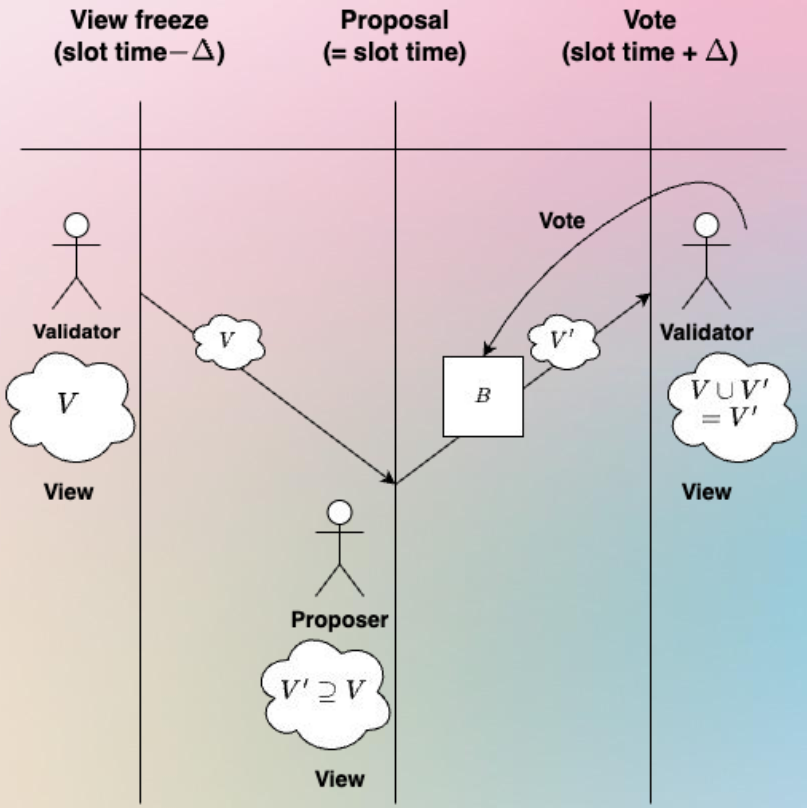
Improving on proposer boost: view-merge



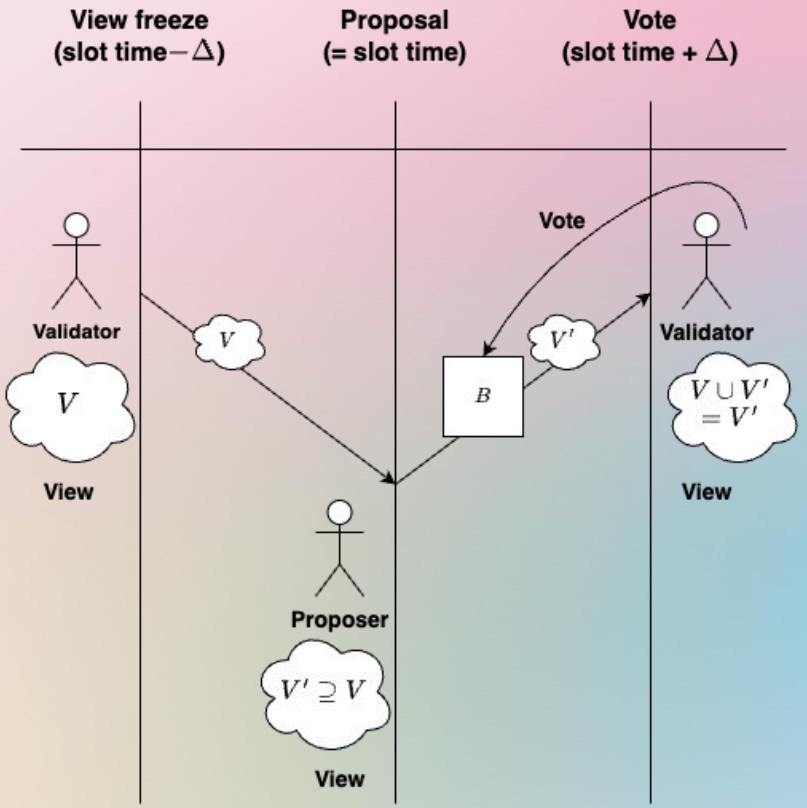
Goal: whenever an honest proposer shows up, their proposal is voted by all honest attesters

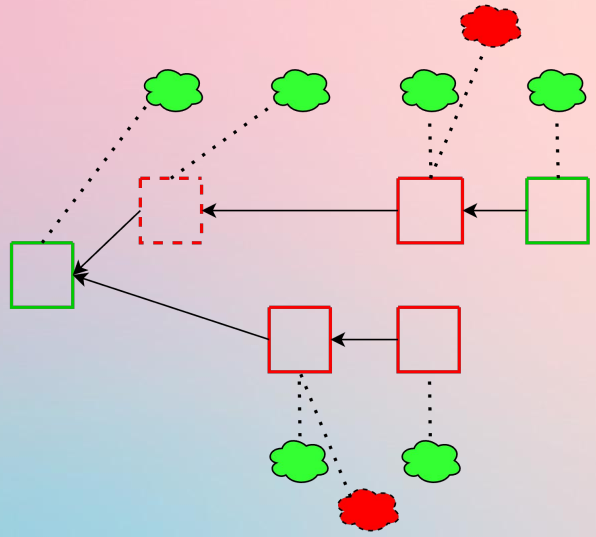
Introduce a new phase, where validators “freeze their view”: they buffer new attestations until after the next round of voting *unless the proposer says otherwise*

View-merge synchronization mechanism

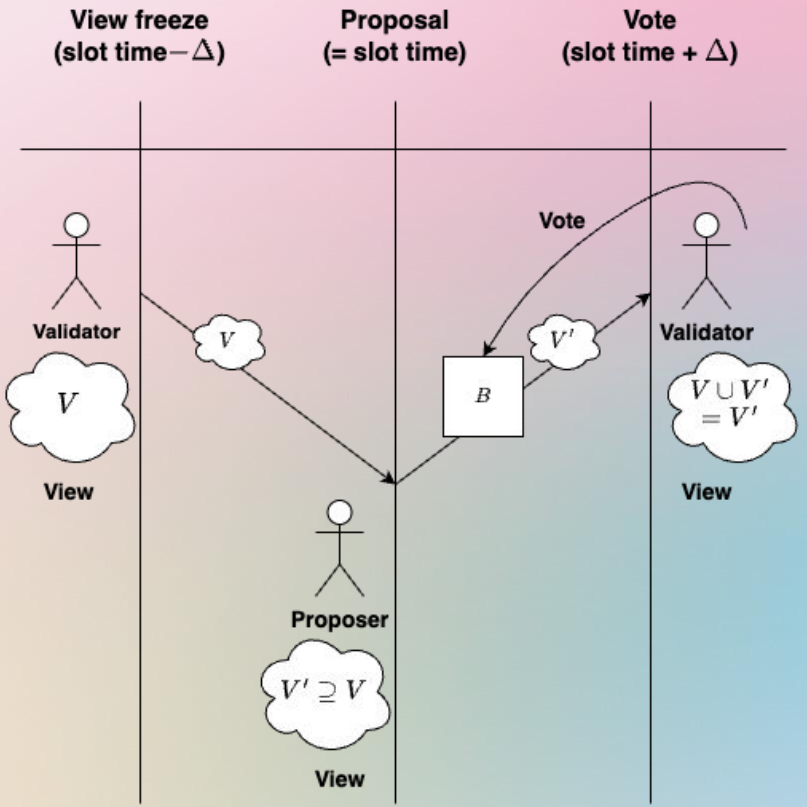


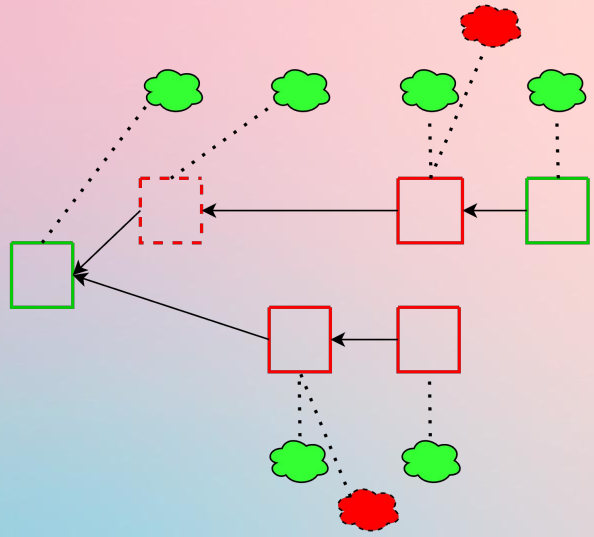
View-merge synchronization mechanism





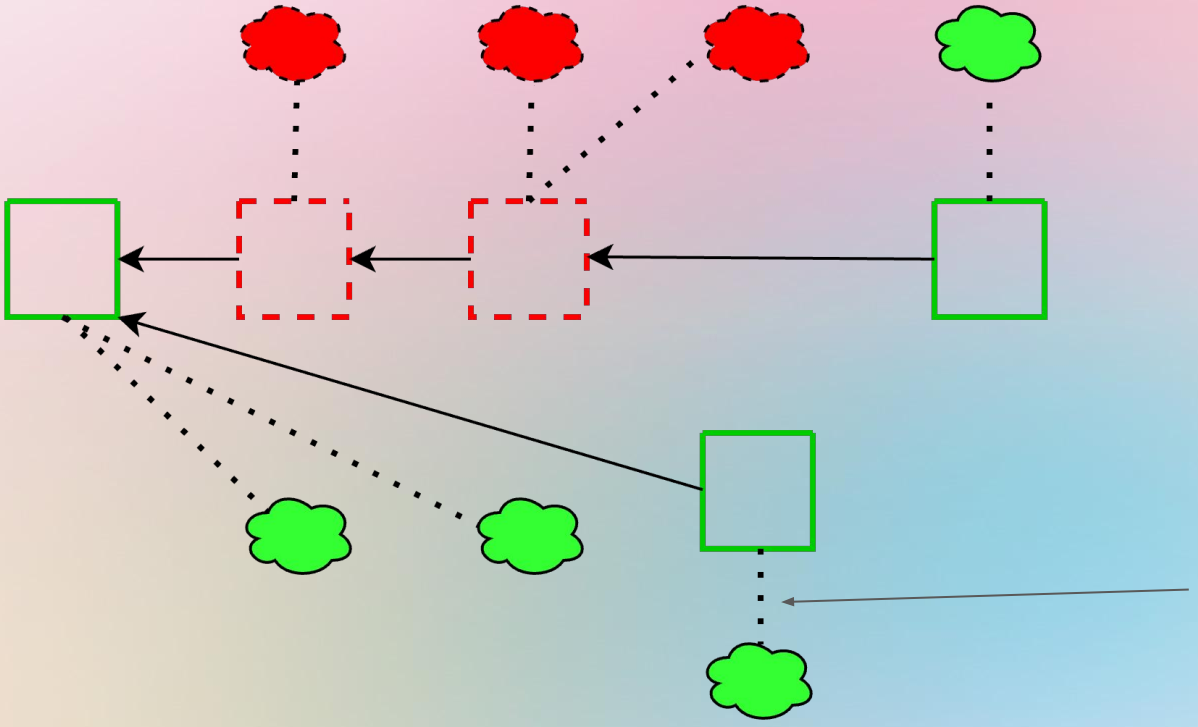
View-merge synchronization mechanism





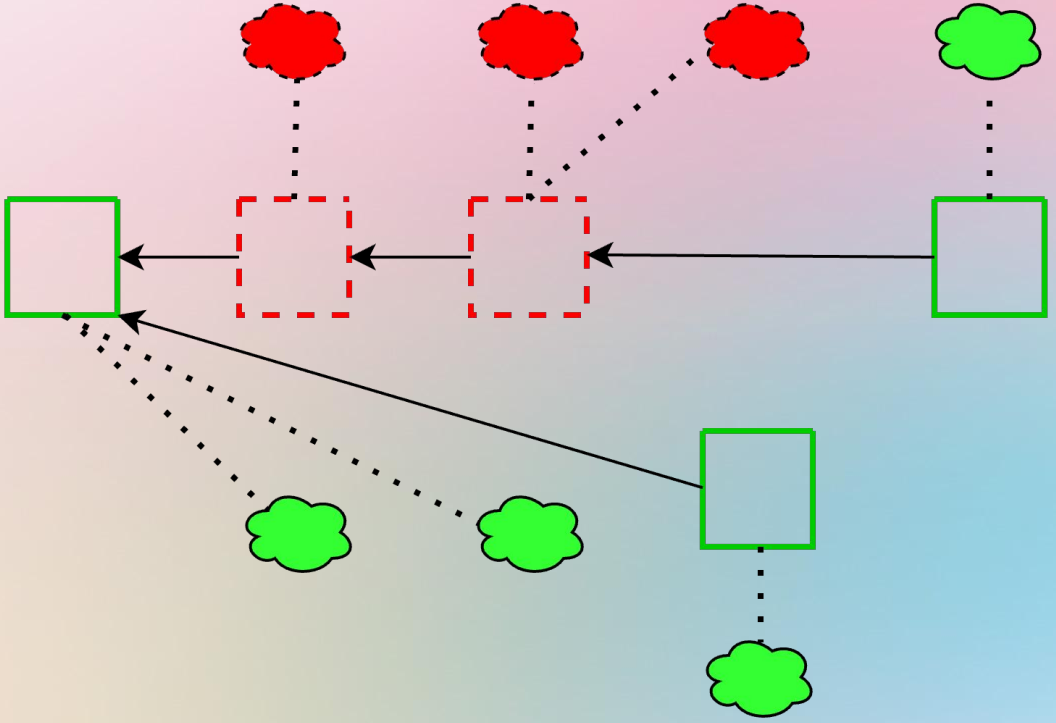
Regardless of how powerful the adversary is, honest attesters vote for honest proposals

… but ex-ante reorgs are still possible



Honest attesters vote for the honest proposal, but it's not enough to overcome the adversarial votes

… but ex-ante reorgs are still possible



The root cause is that *committees* allow for weight accumulation over multiple slots, even if LMD counts only one vote per validator

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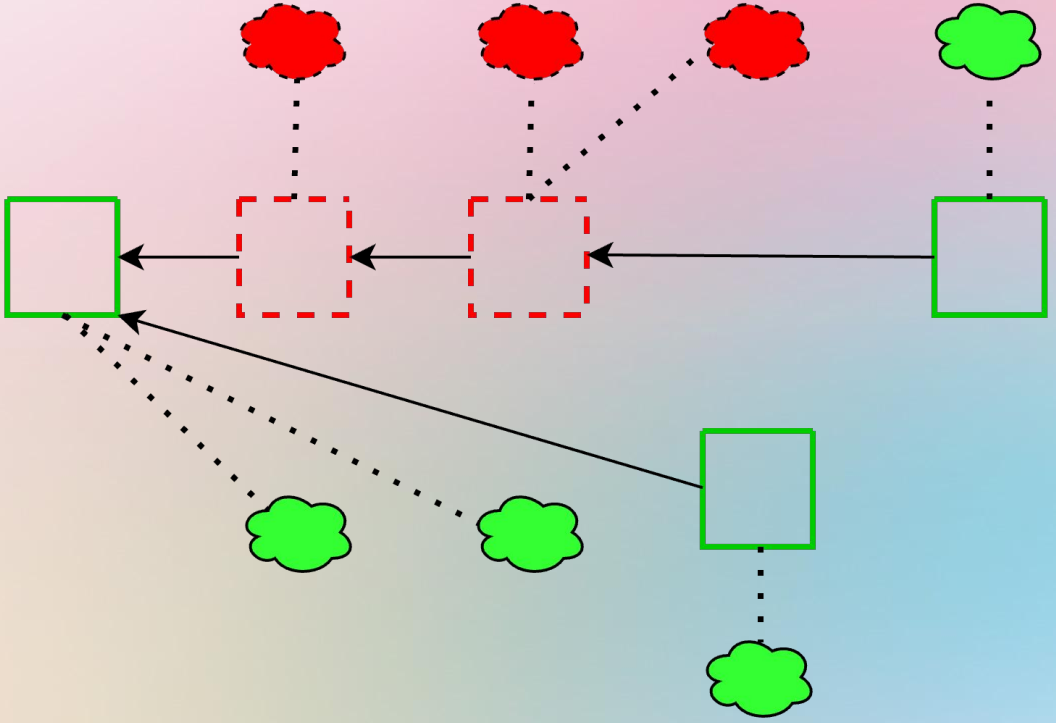
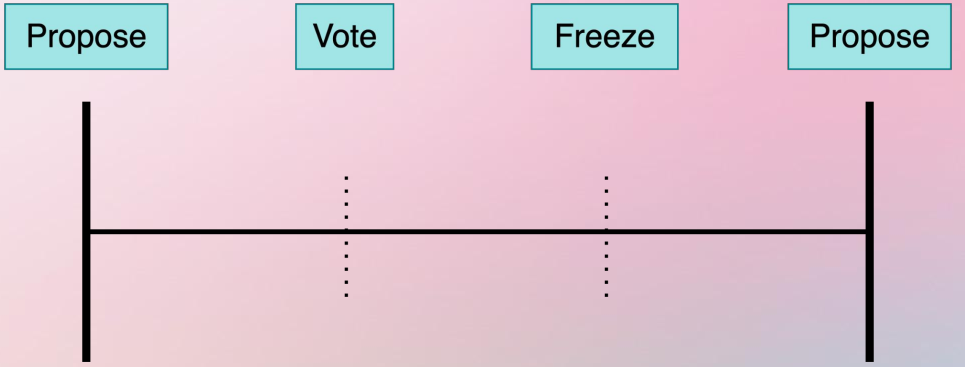


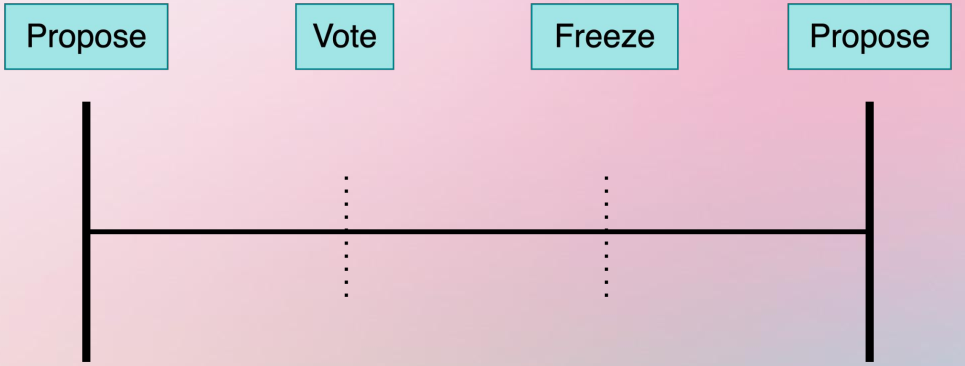
The root cause is that *committees* allow for weight accumulation over multiple slots, even if LMD counts only one vote per validator

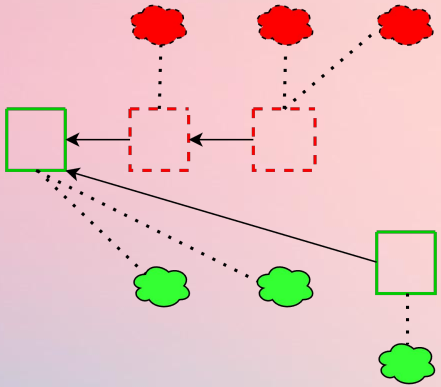
"Simple" solution: do away with committees. Everyone votes every slot

RLMD-GHOST



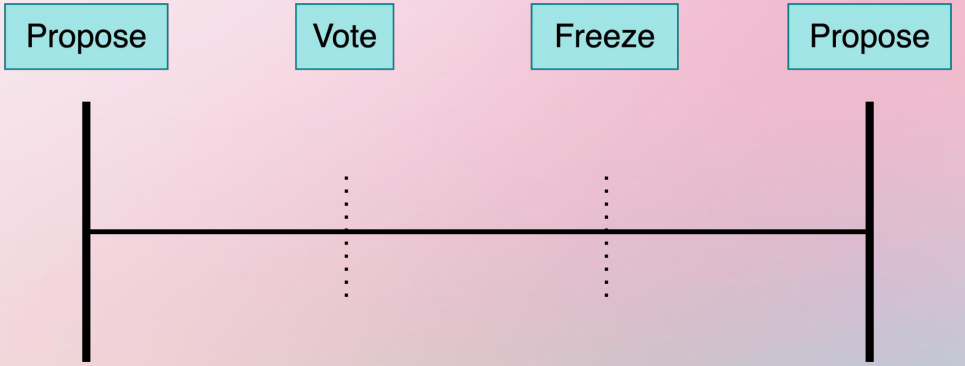
RLMD-GHOST

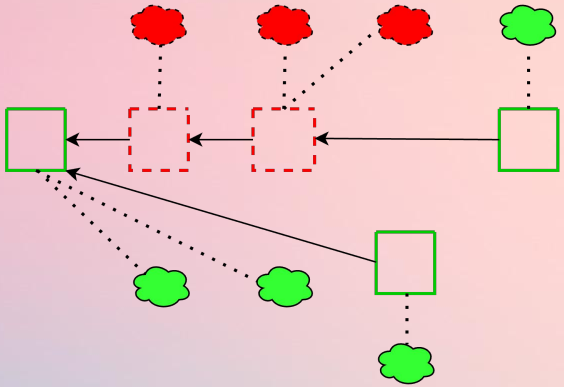




- View-merge => honest proposals are voted by all honest validators

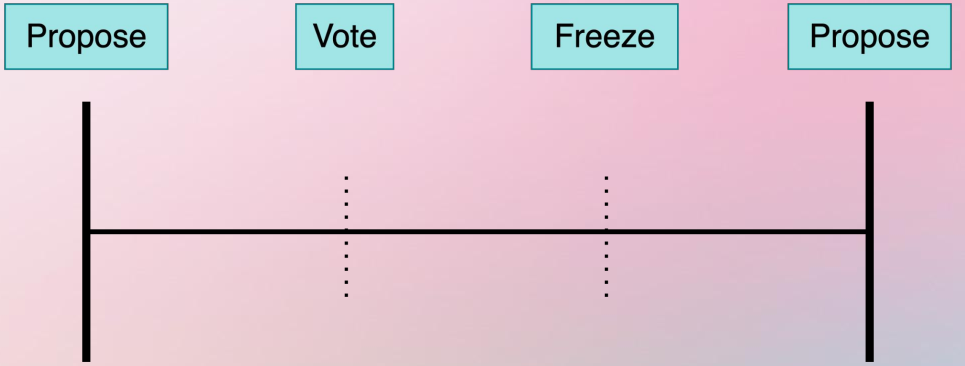
RLMD-GHOST

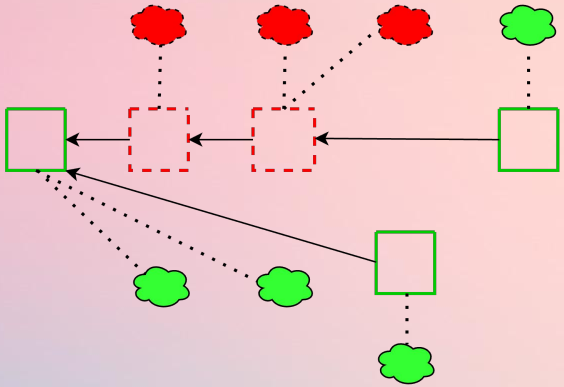




- View-merge => honest proposals are voted by all honest validators
- No committees => if all honest validators vote for something, it stays in the canonical chain forever

RLMD-GHOST

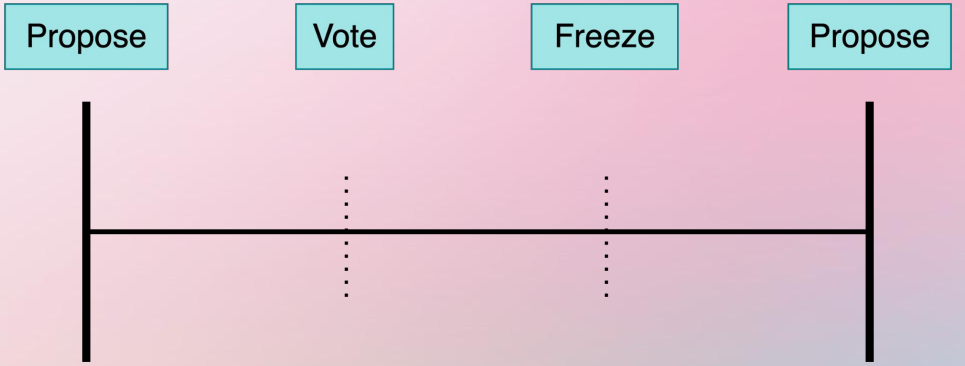


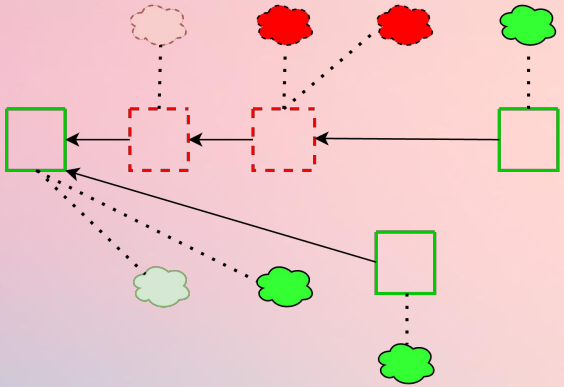


- View-merge => honest proposals are voted by all honest validators
- No committees => if all honest validators vote for something, it stays in the canonical chain forever

Together =>
Reorg resilience: honest proposals are never reorged

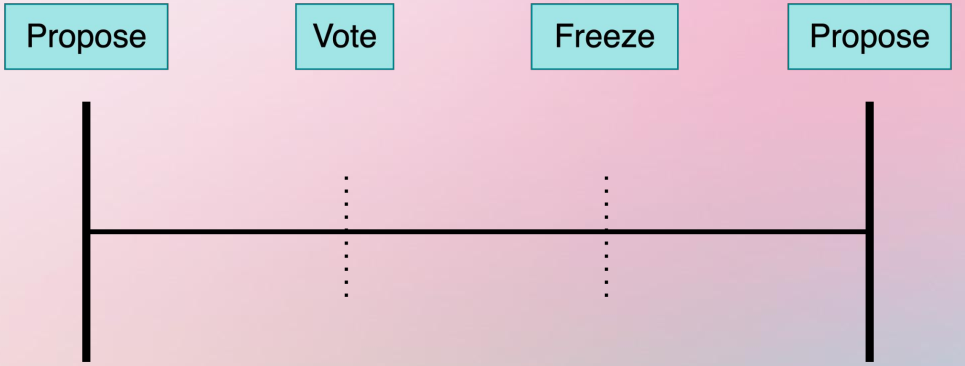
RLMD-GHOST

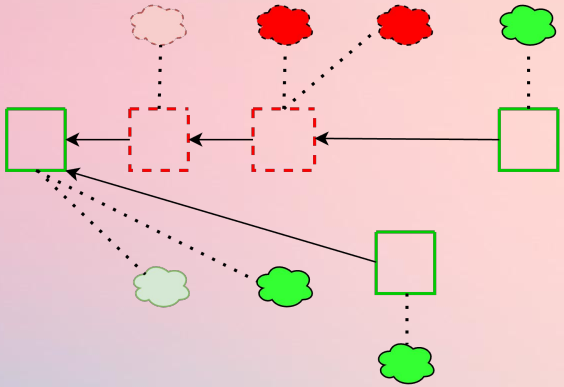




Vote expiry (**R** = recent): attestations don't contribute fork-choice weight after some number of slots

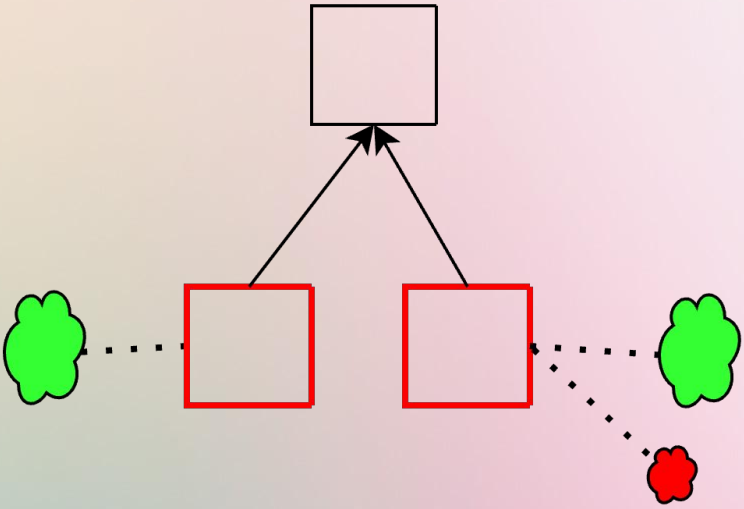
RLMD-GHOST

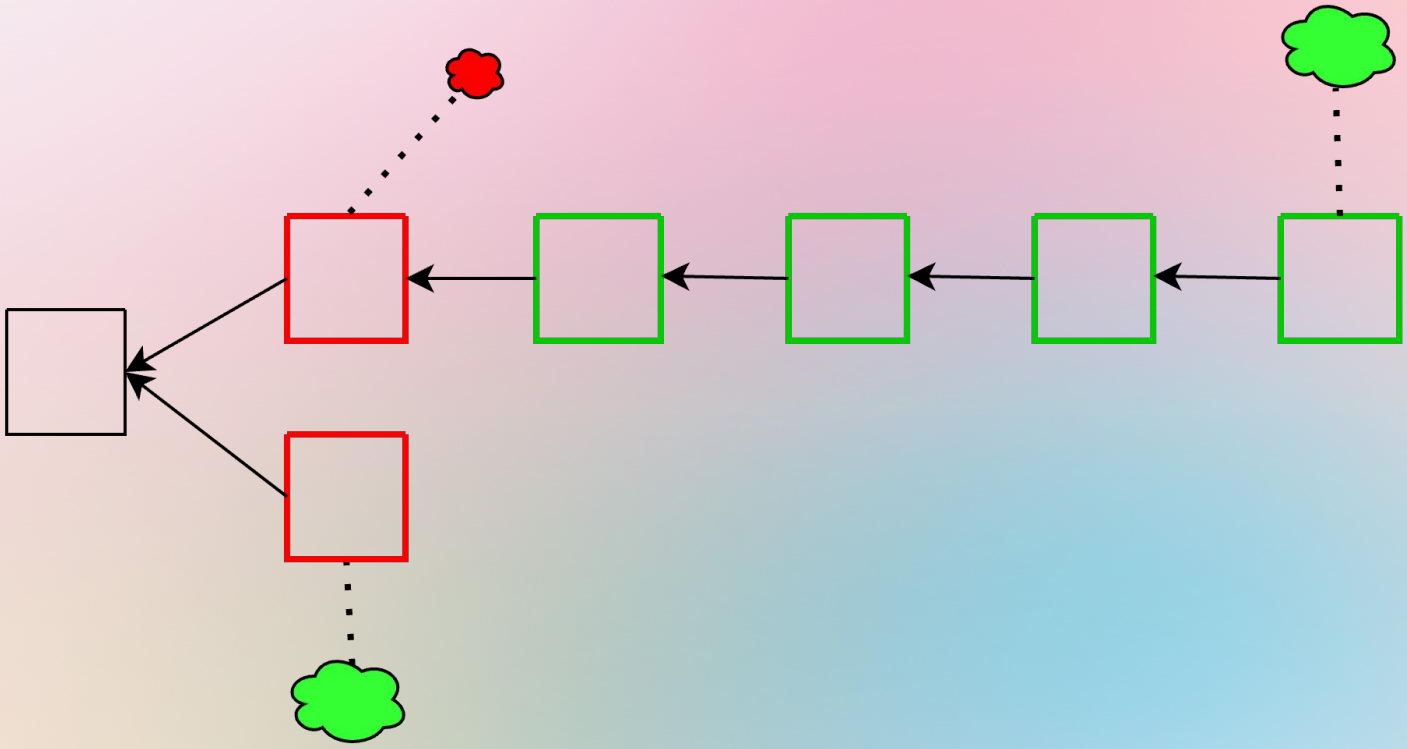


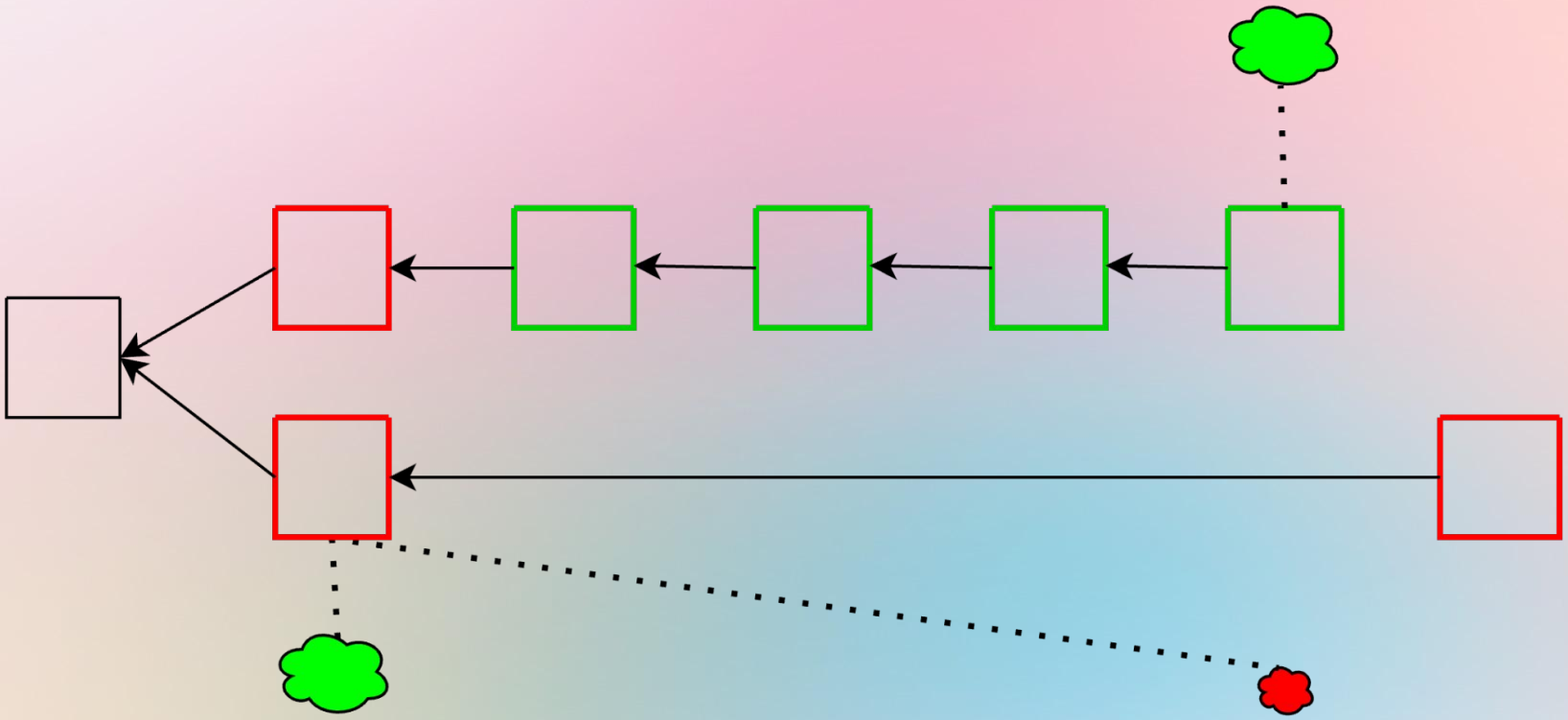


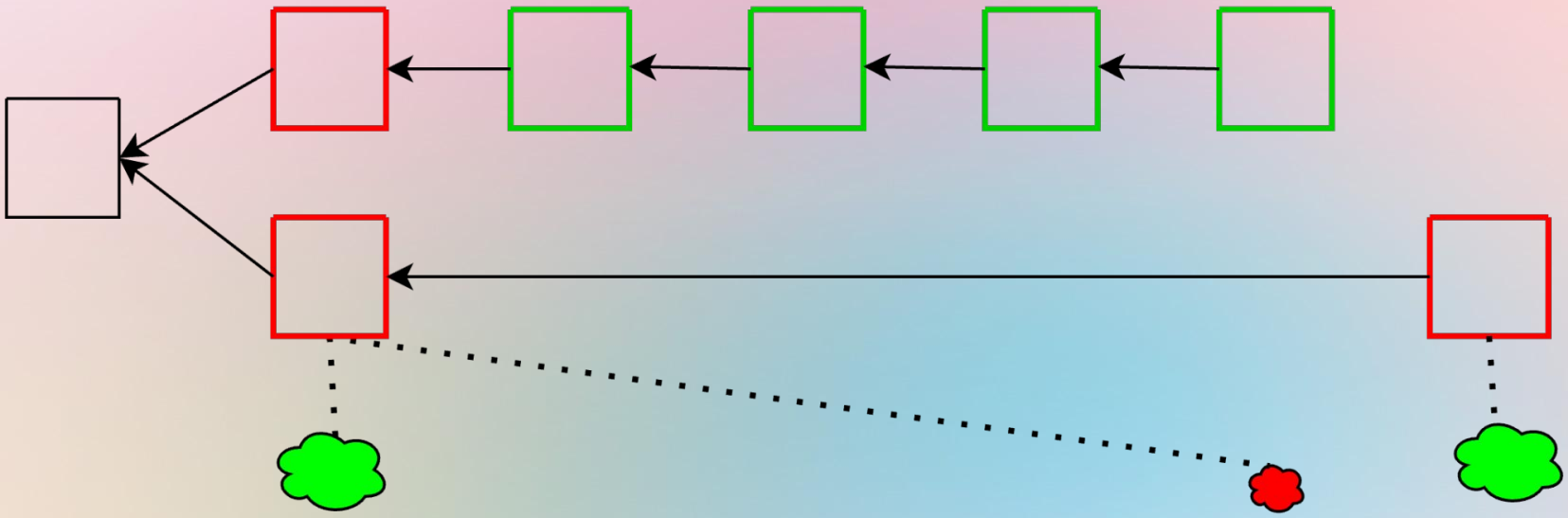
Vote expiry (**R** = recent): attestations don't contribute fork-choice weight after some number of slots

=> can always recover from a large portion of the validator set going offline

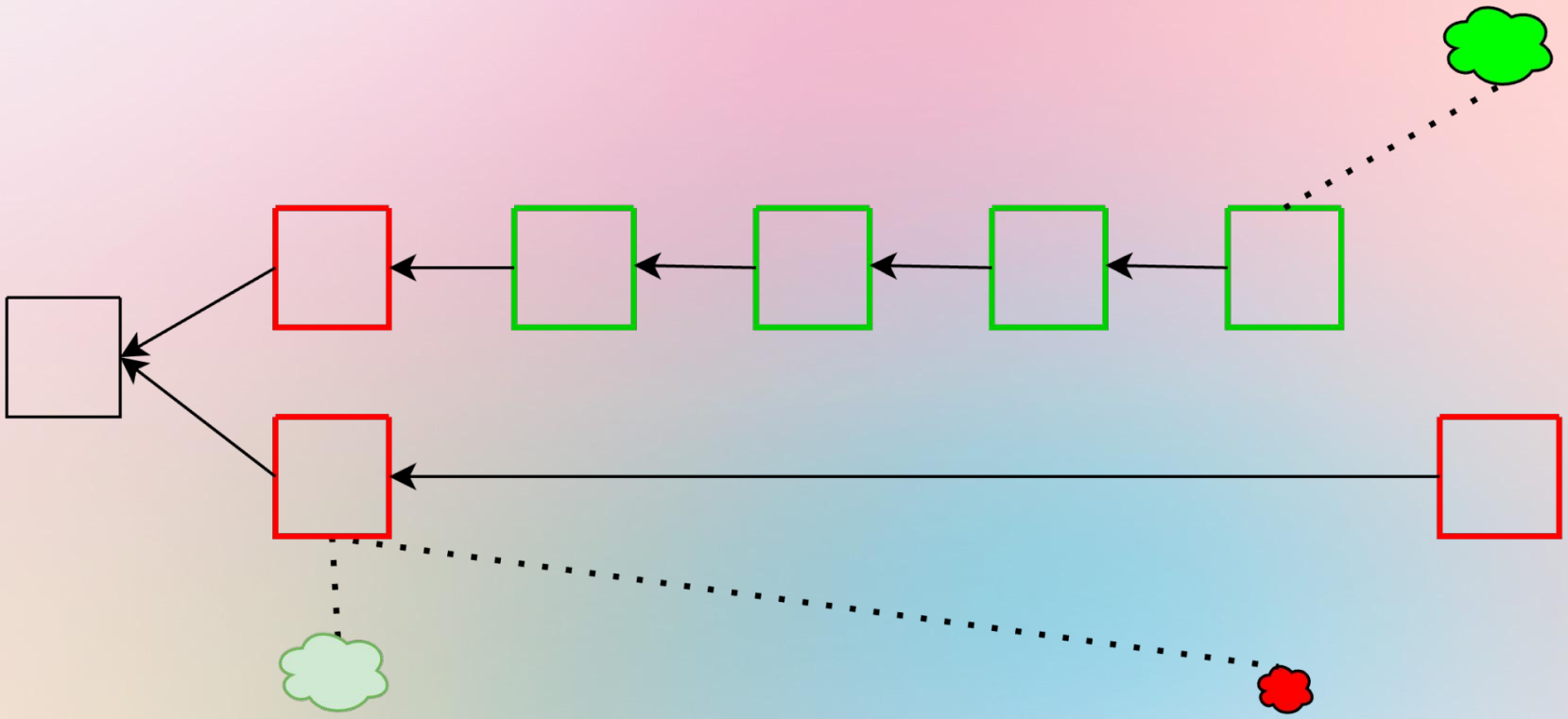




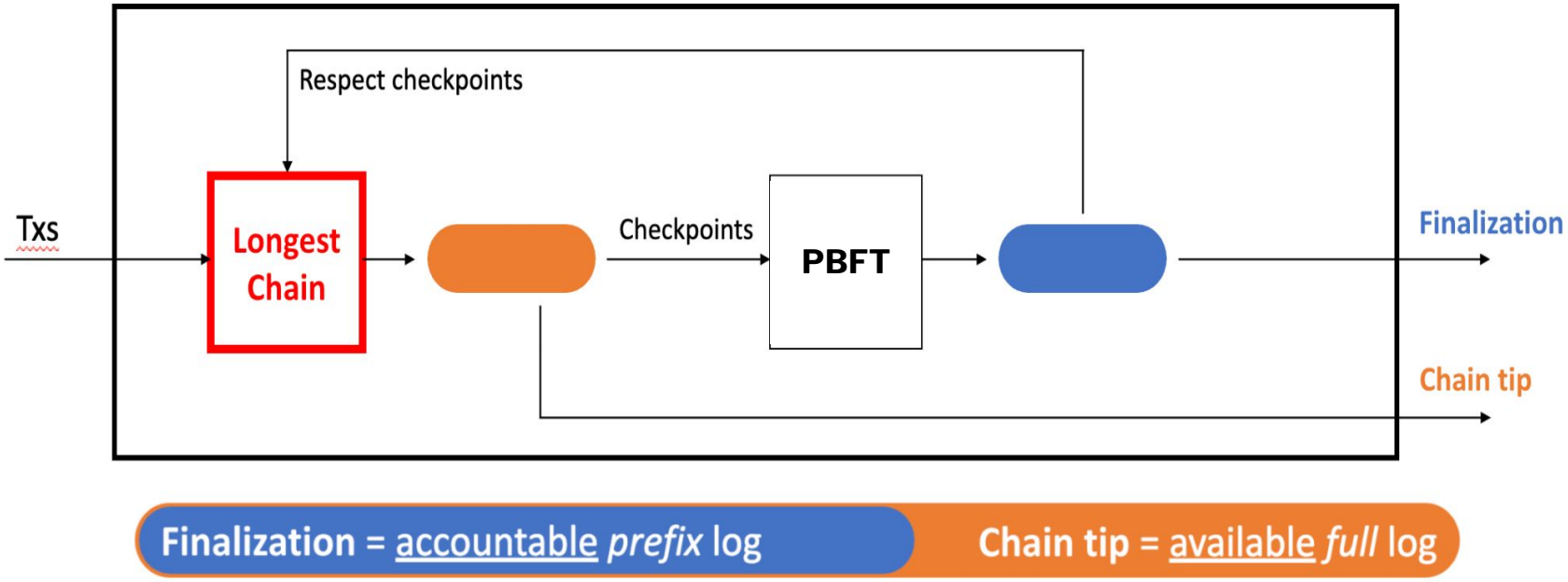


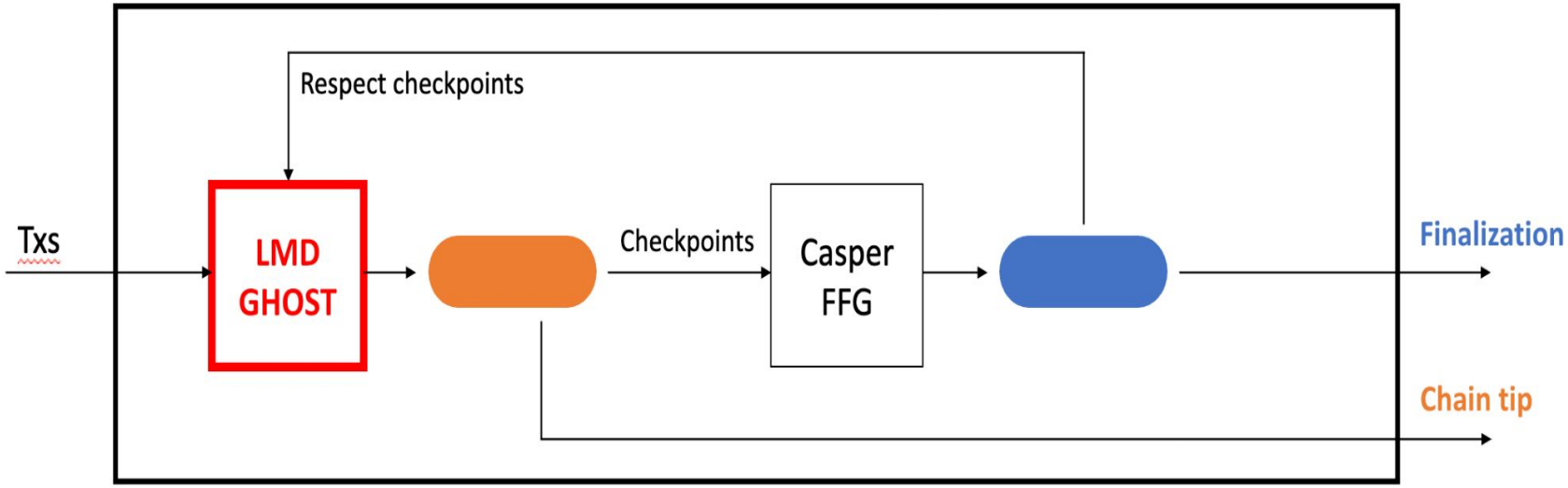


... while with expiry



SSF protocol


Respect checkpoints
Txs
Longest Chain
Checkpoints
PBFT
Finalization
Chain tip
Finalization = accountable prefix log
Chain tip = available full log



Finalization = accountable *prefix* log

Chain tip = available *full* log

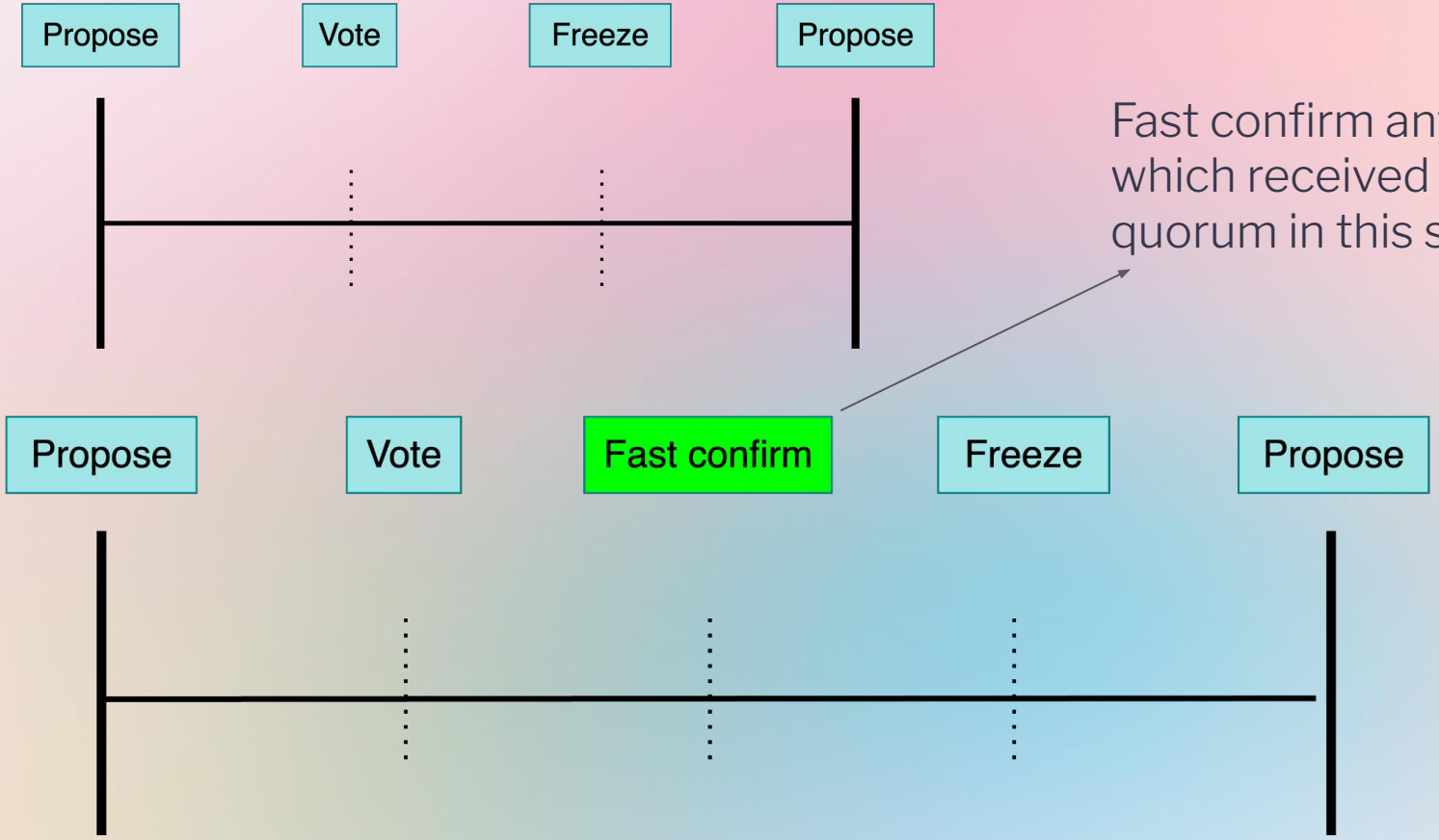
A key idea

Only attempt to finalize blocks which are **already confirmed by the underlying available protocol** (LMD-GHOST for us)

=> Finality gadget does not interfere with available protocol under *permanent* network synchrony

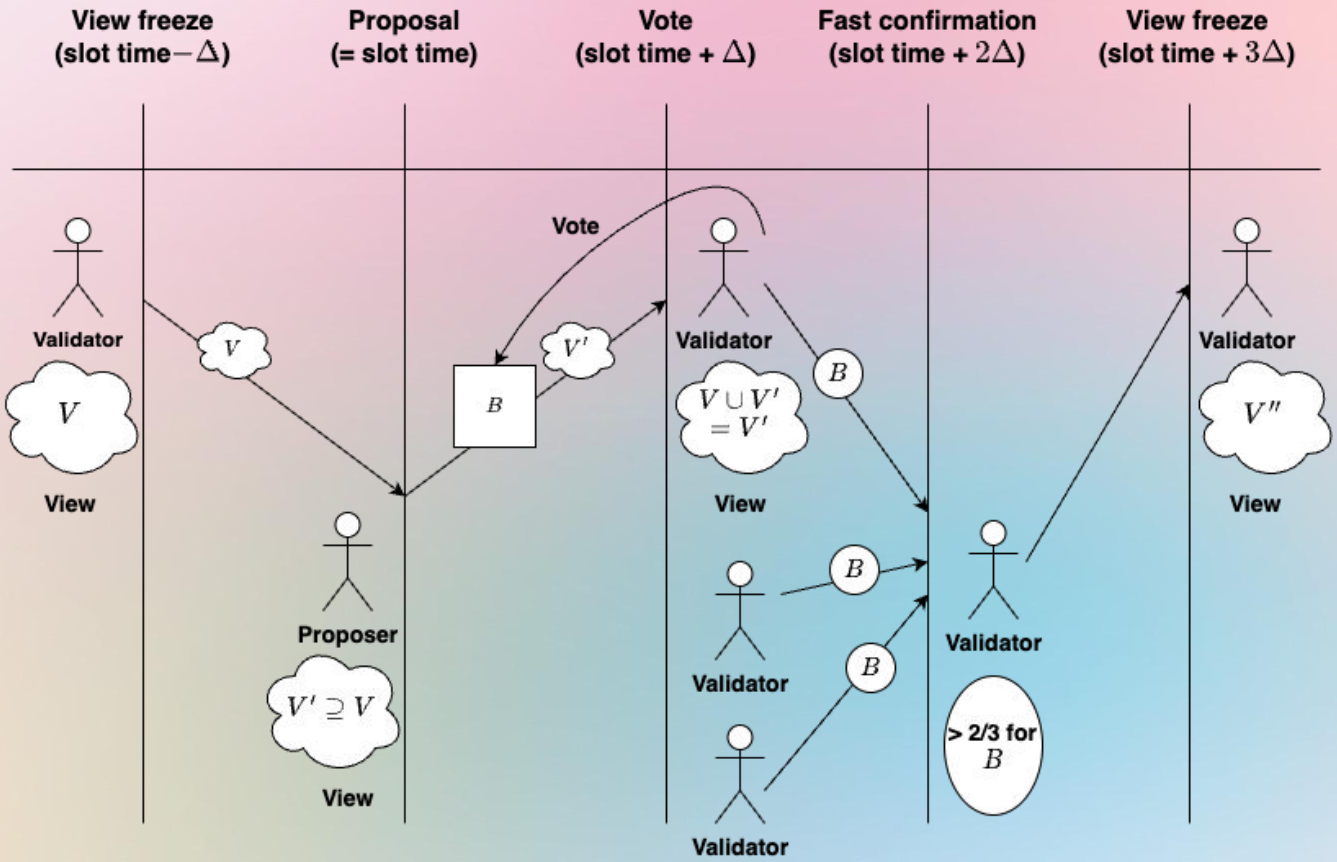
=> “all” we have to worry about is behavior when *recovering from periods of asynchrony*, when the gadget might interfere (tricky)

Add fast confirmation to RLMD-GHOST



Fast confirm any block which received a ⅔ quorum in this slot

Add fast confirmation to RLMD-GHOST



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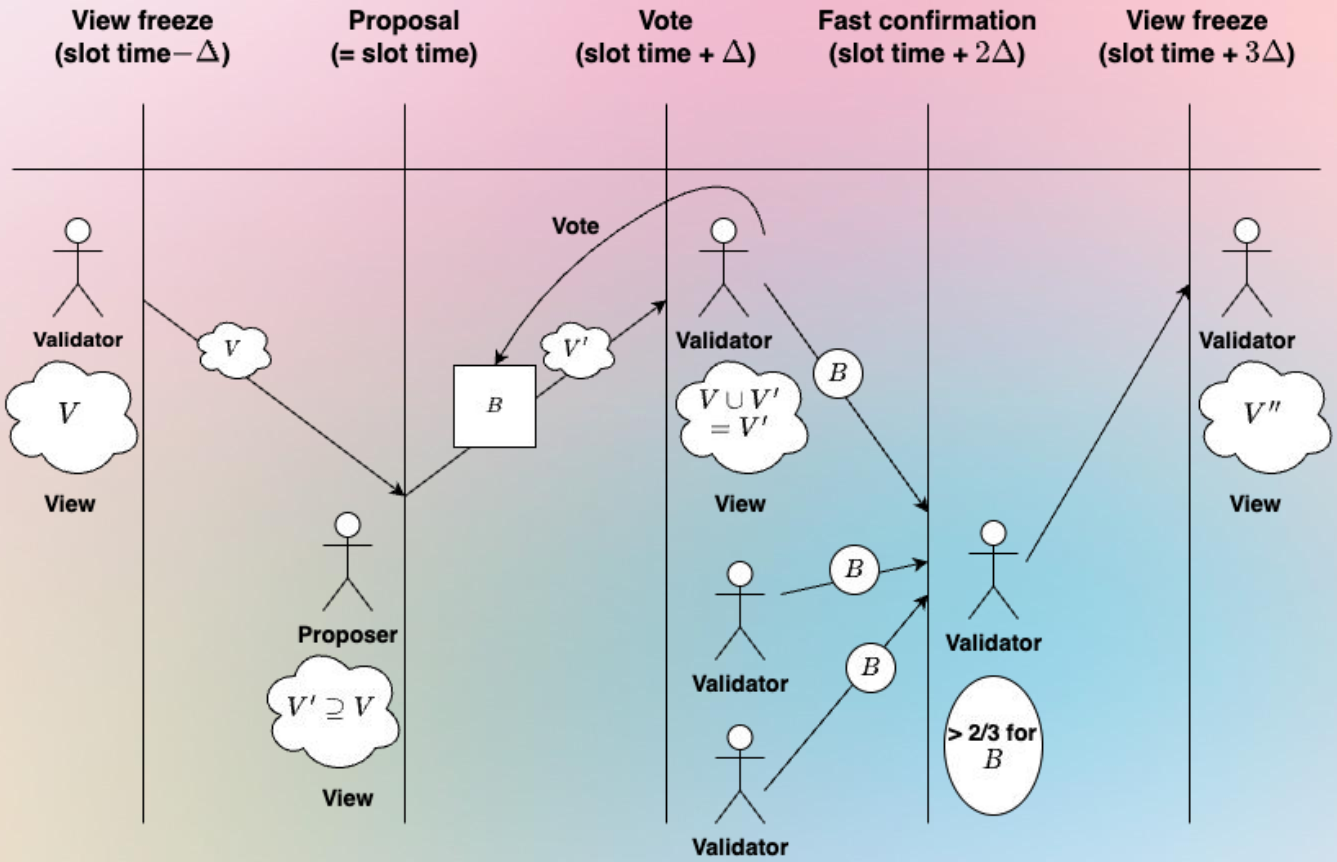
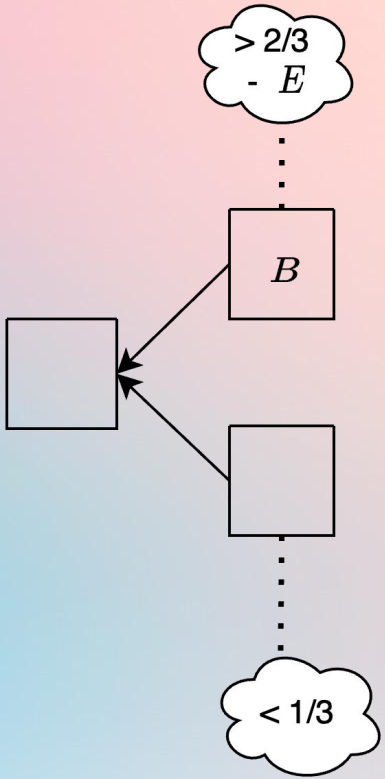


Security guarantees under synchrony and honest majority

If an honest validator fast confirms B, then every honest validator sees the ⅔ quorum for B before freezing its view.

=> *Unless there are at least ⅓ equivocations (E),* every honest validator sees B as canonical in the next slot and votes for it



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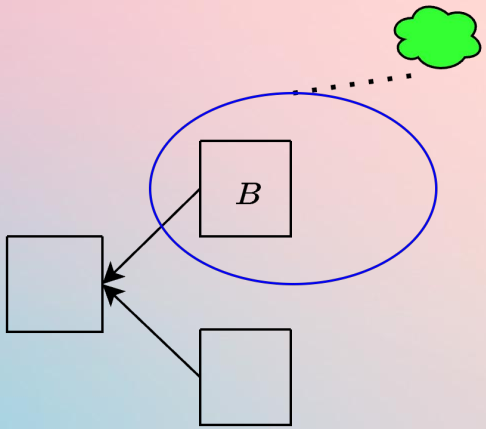
=> *Unless there are at least ⅓ equivocations (E),* every honest validator sees B as canonical in the next slot and votes for it

=> Every honest validator votes on the subtree of B in the next slot. B remains in the canonical chain forever *if there is an honest majority*



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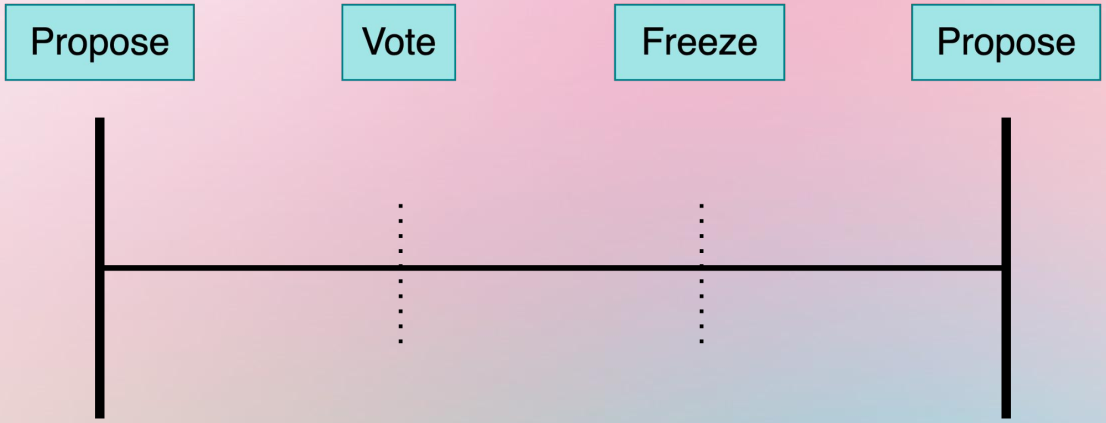

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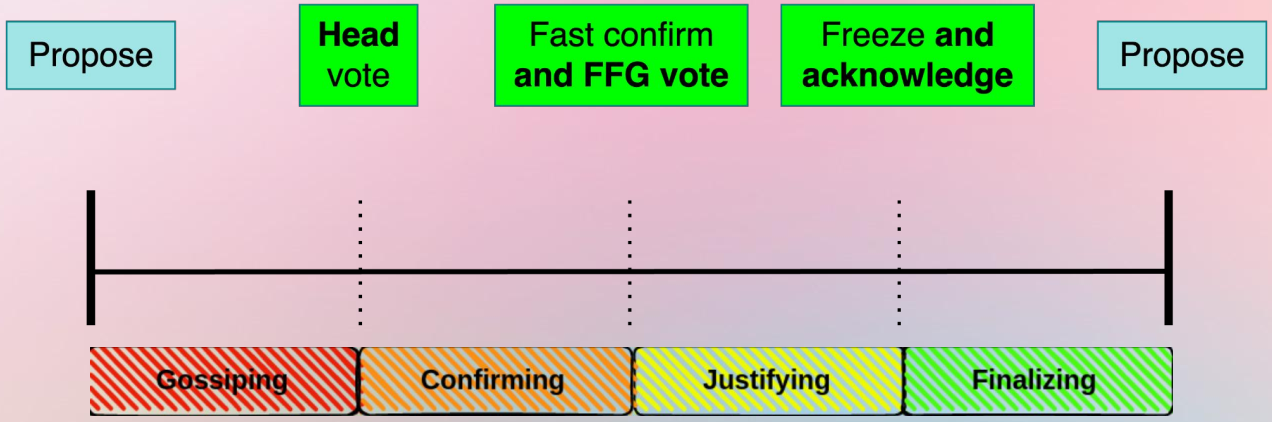

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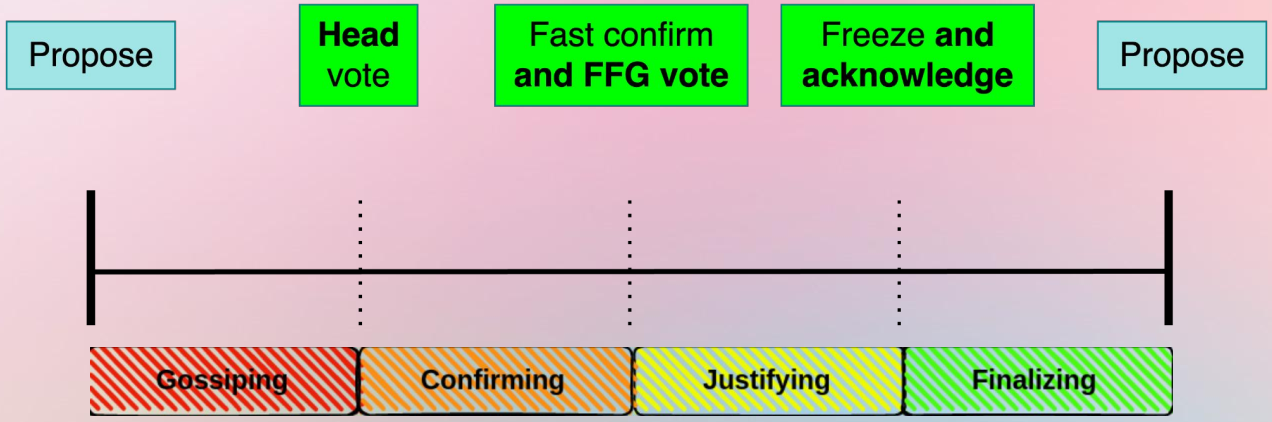
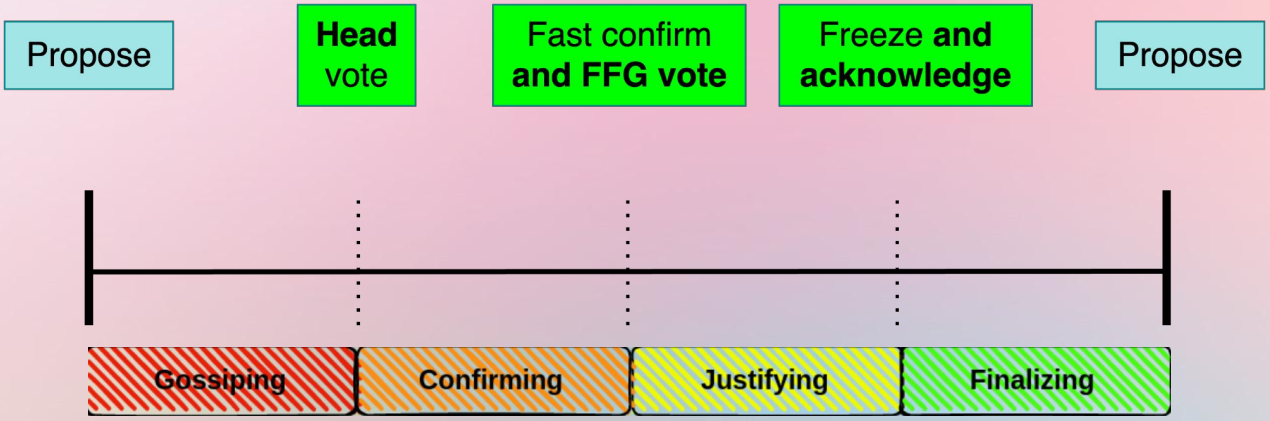


Fork-choice: start from latest justified, run RLMD-GHOST.

FFG votes: source = latest justified, target block = highest confirmed block descending from justified (justified is always confirmed)

Acknowledgment: if there is a new justified checkpoint, acknowledge it, committing to start your fork-choice from it. A quorum of acks = finality

Progression of honest slot t



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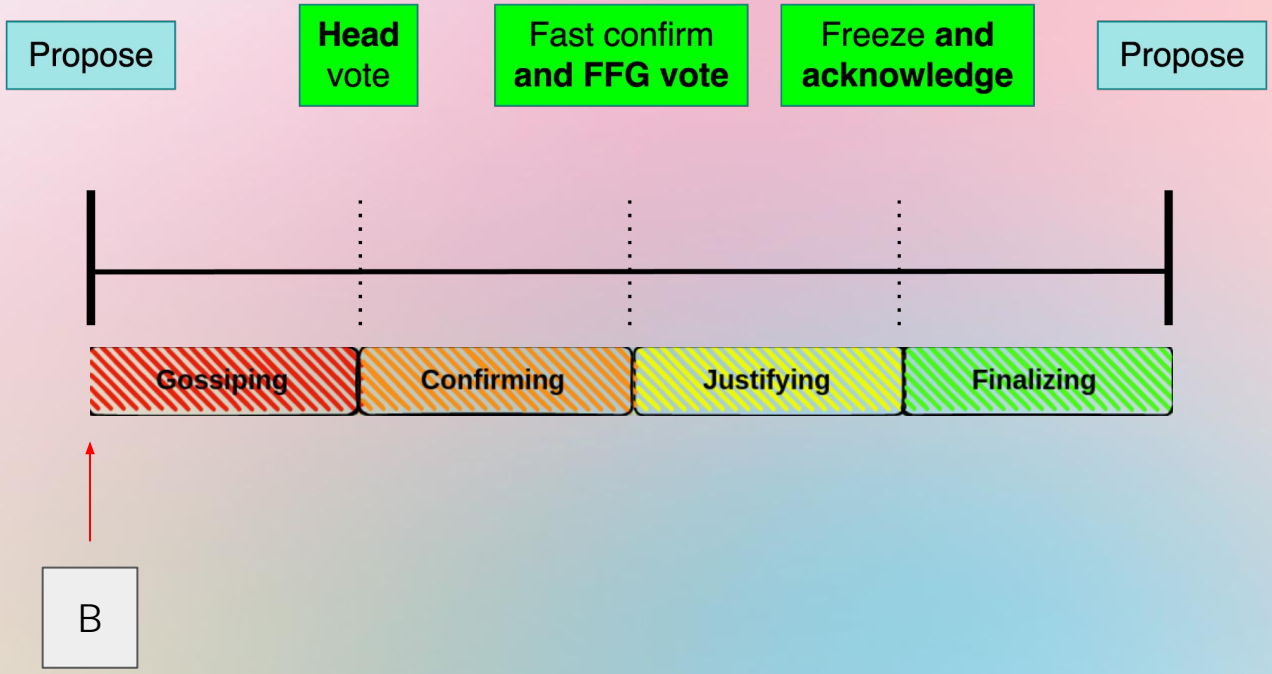
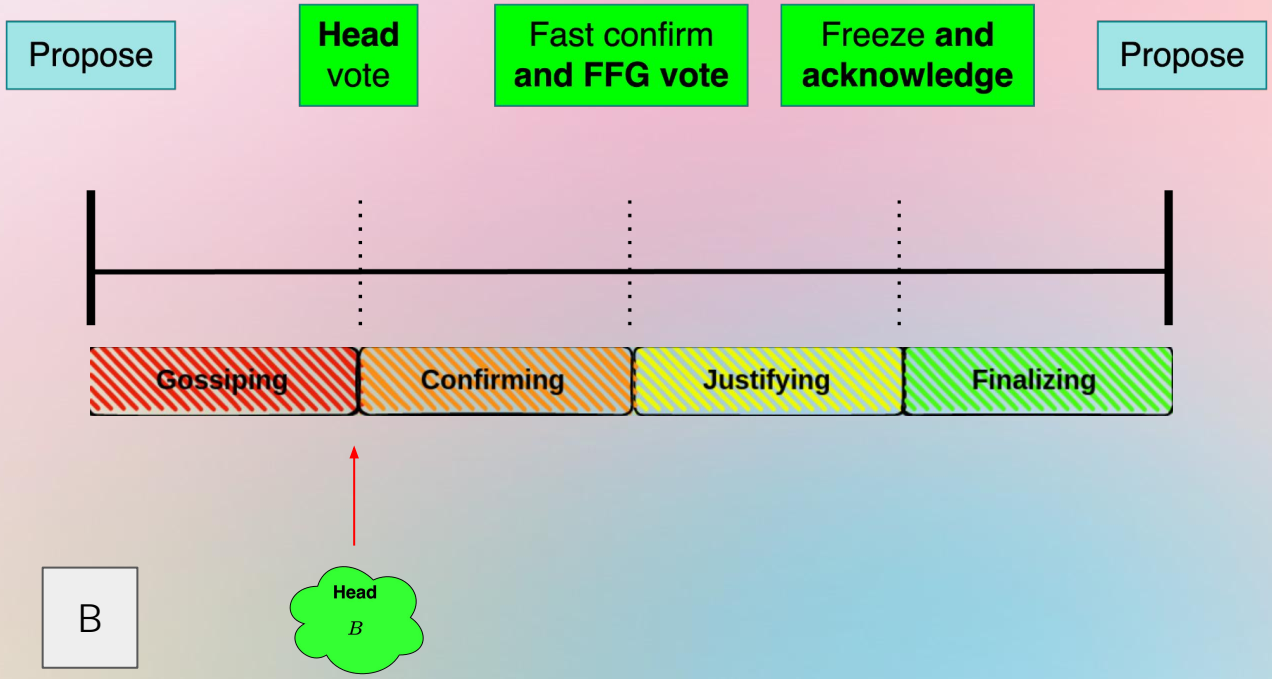


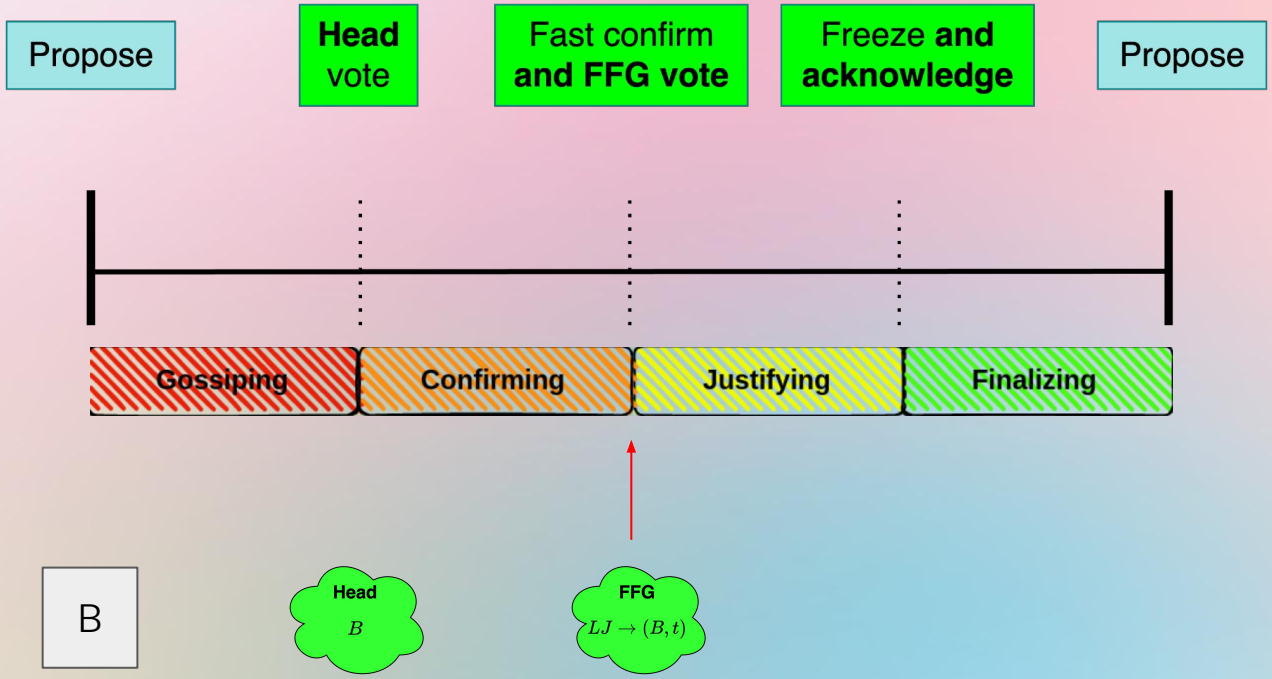
Honest block proposal B is made timely

Progression of honest slot t



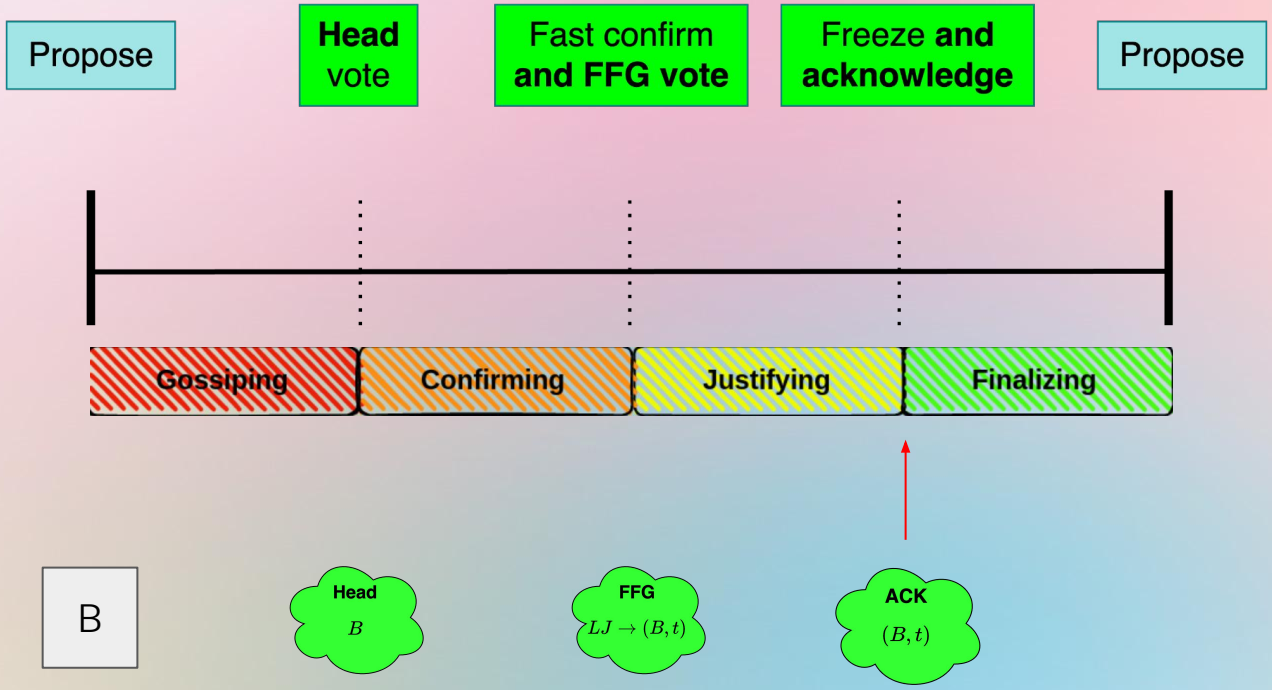
All honest validators vote for B (*view-merge*), forming a ⅔ quorum of head votes for it

Progression of honest slot t



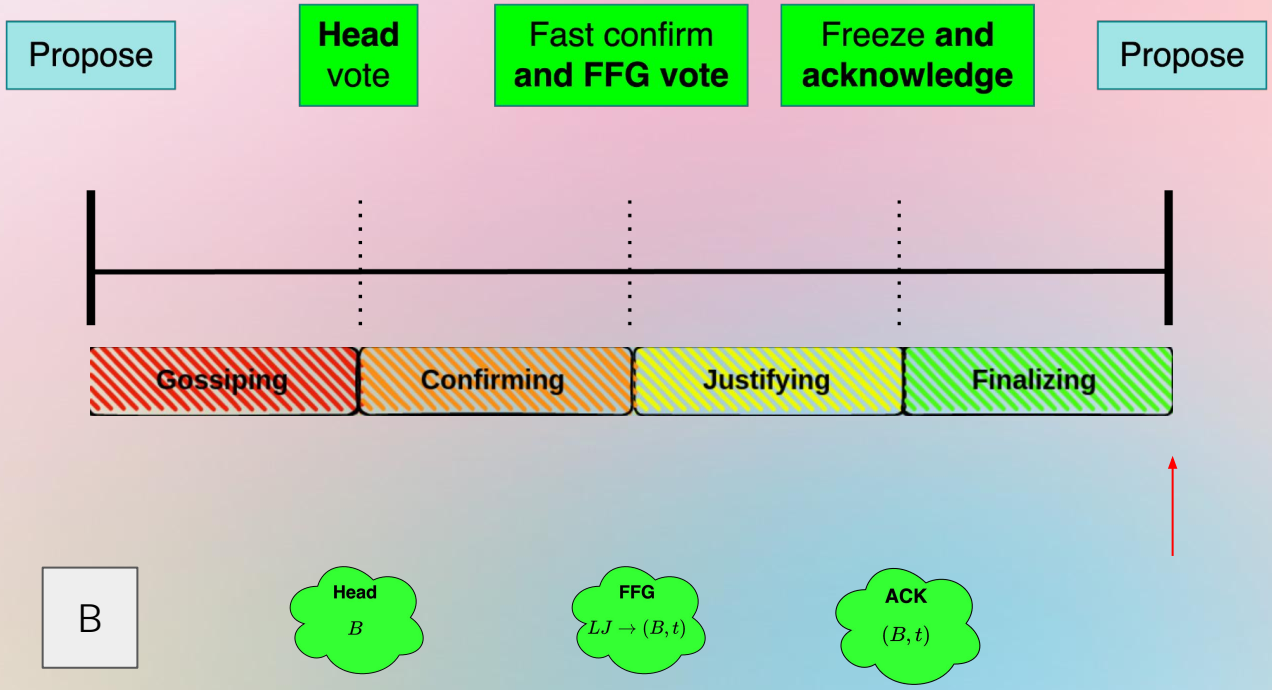
All honest validators get the quorum for B, fast confirm B and use it as their FFG target.
A supermajority link LJ -> (B,t) forms

Progression of honest slot t



All honest validators justify (B,t) *before freezing their view.* Their fork-choice starts from B. They acknowledge (B,t), and a supermajority acknowledgment of (B,t) forms.

Progression of honest slot t



Everyone sees B as finalized.

- Acknowledgments do not affect the fork-choice:

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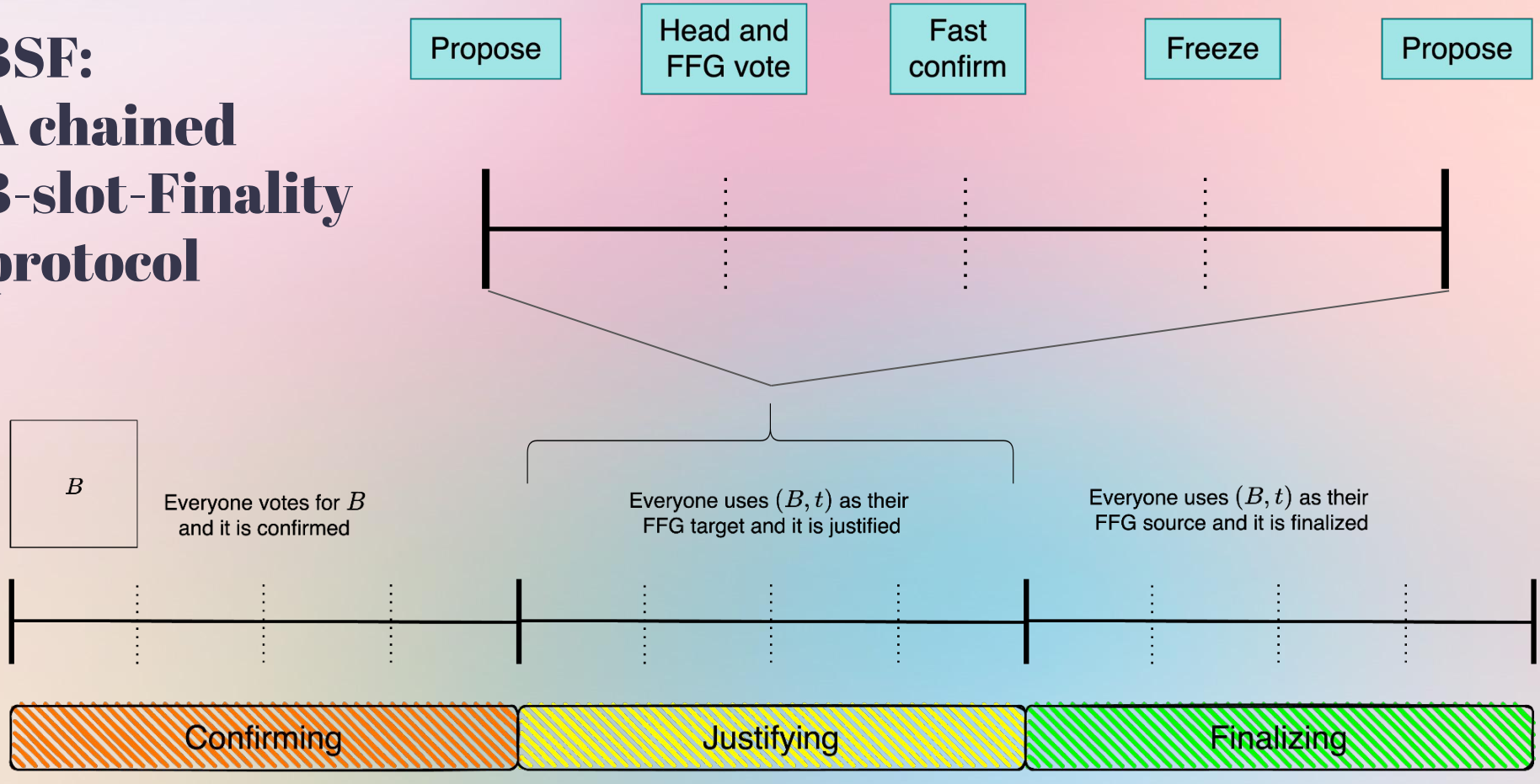
- We need at least the latest *off-chain* justification to be taken into account by the fork-choice

Removing filtering

- A justification is processed against *the state of the target* (not source, so inactivity leak works automatically). In particular we care about:
  - Effective balances
  - Active and slashed status
- For on-chain processing over a short period of time (e.g. target at slot 100, justification processed at slot 110), we can keep small diffs in the state.
- Exceptionally, any chain containing a justified checkpoint can process its justification by being provided the relevant attestations + a witness encoding the necessary state.
- This kind of “chain agnostic” justification certificate is also used for off-chain justification

3SF: A chained 3-slot-Finality protocol

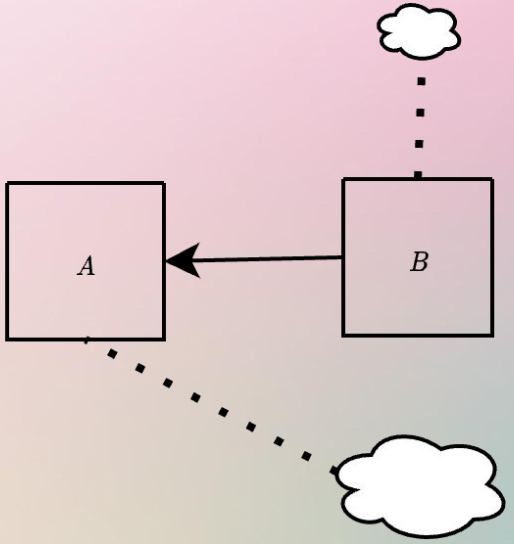


Fork-choice in the Ethereum Roadmap

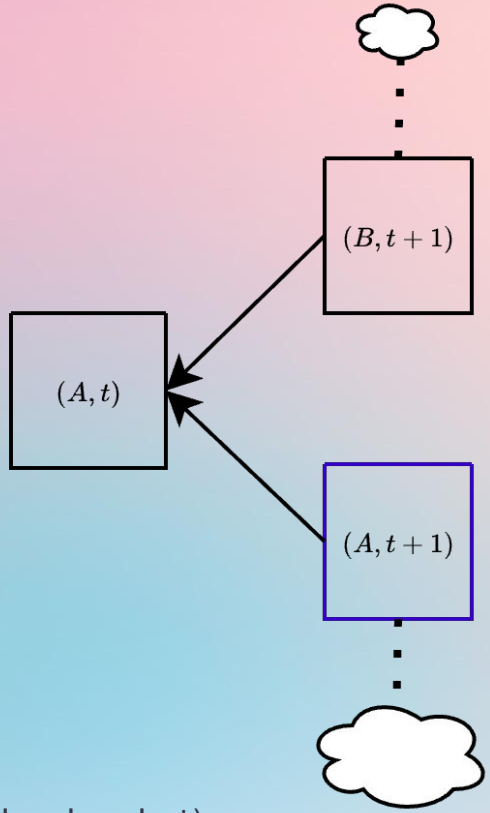
Fork-choice in the Ethereum Roadmap

- SSF (or fast finality):
  - Optimally secure consensus protocol
  - Fast confirmation of high value transactions, e.g. fast deposits on exchanges
  - Faster bridging
  - Better L2 interoperability
- ePBS
- DAS

(Block, slot) fork-choice: enshrining empty slots

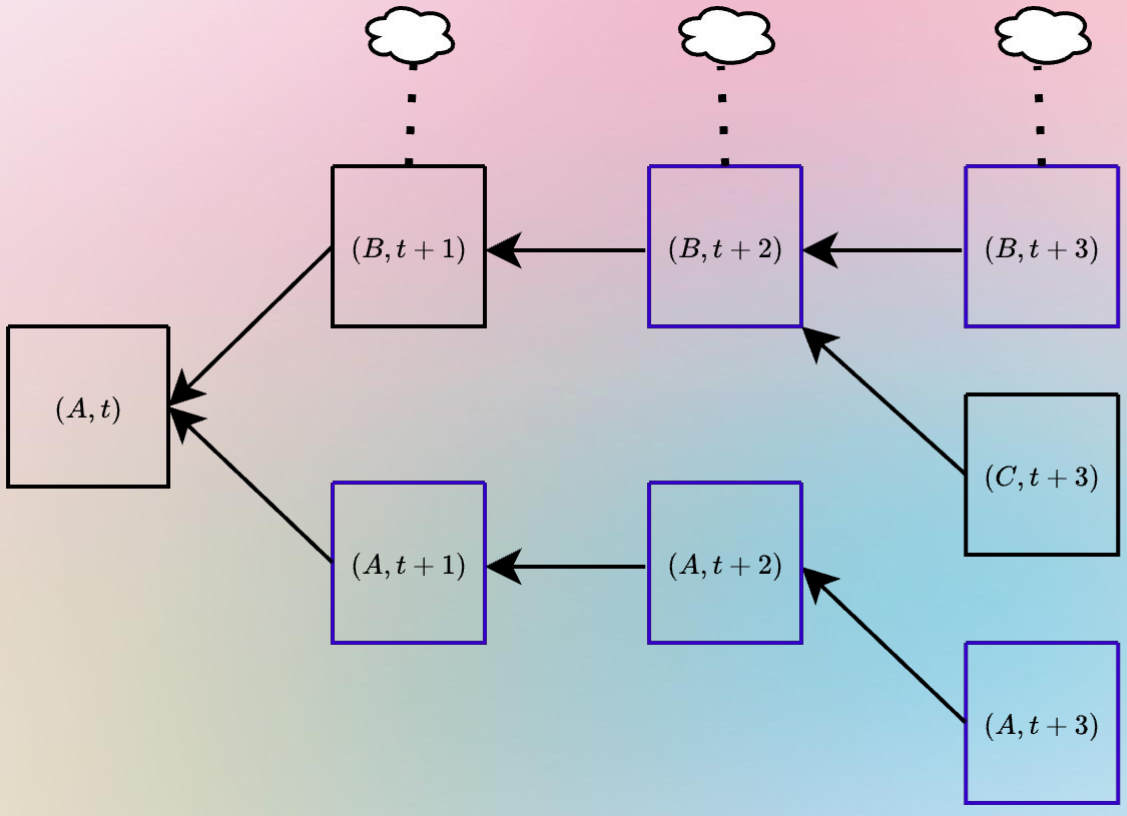


Status quo

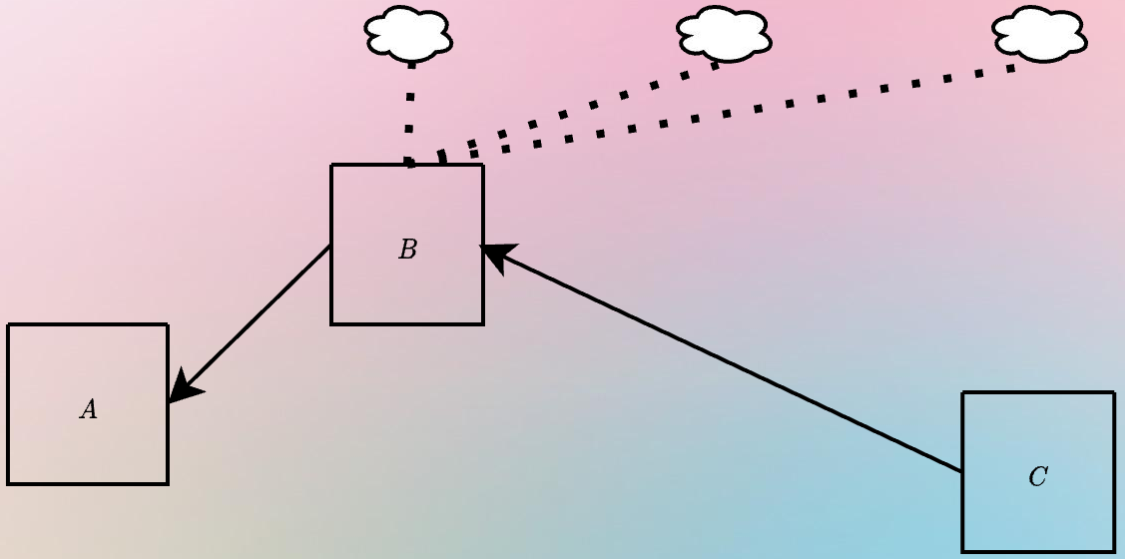


(Block, slot)

(Block, slot) fork-choice: enshrining empty slots



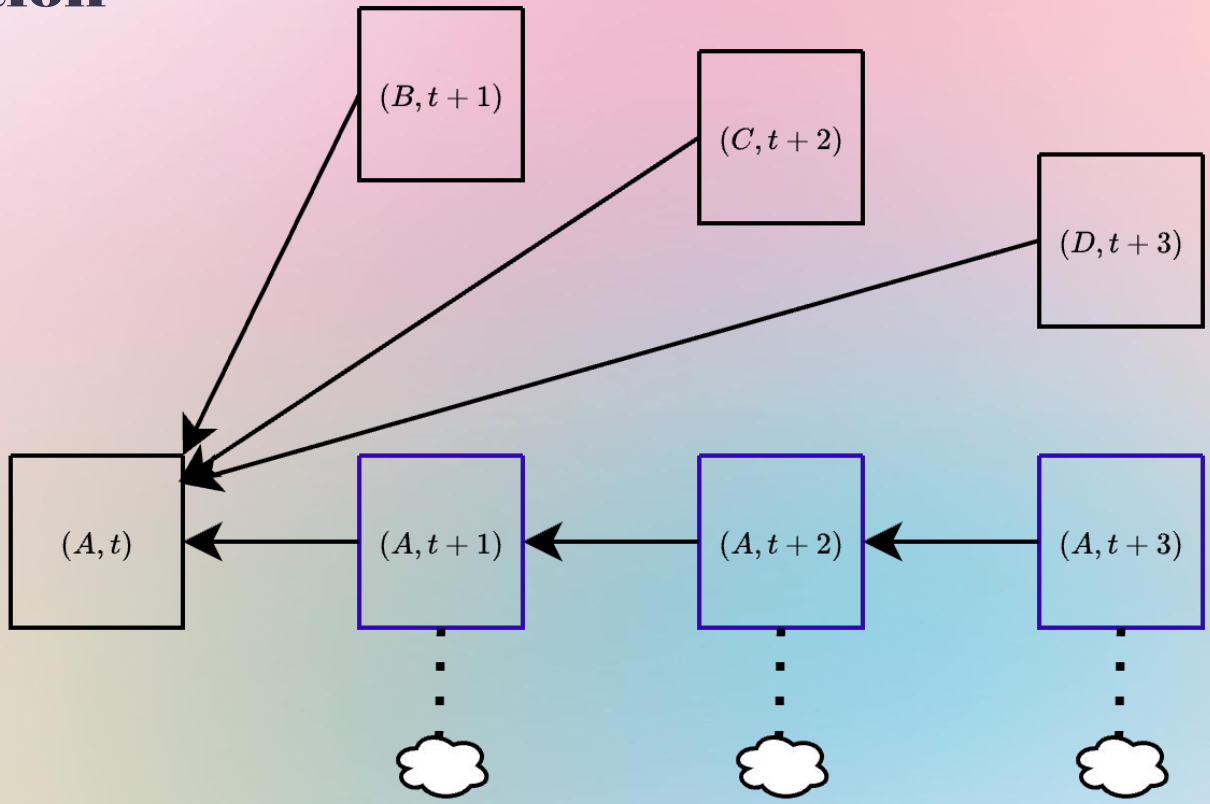
Block-slot fork-choice: enshrining empty slots



Applications

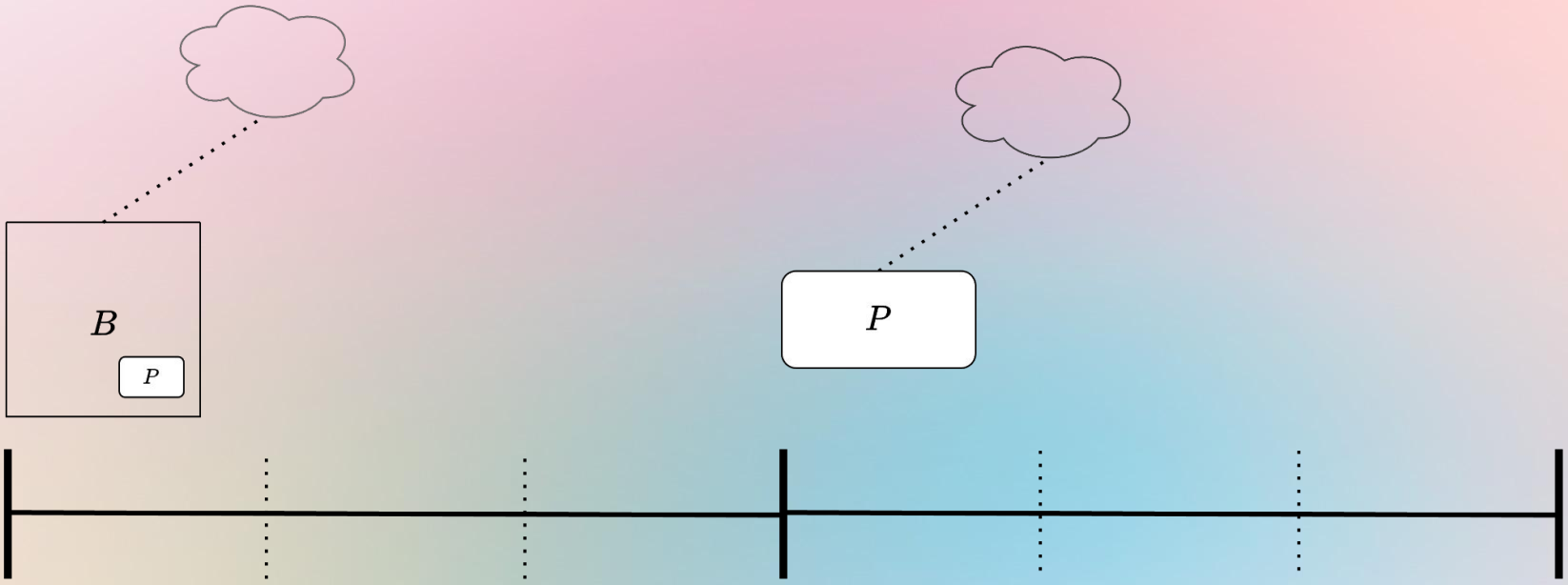
- Committee-enforceable properties: if a proposal does fulfill a certain property, the attesting committee votes “against it” (for the empty block)
  - ILs satisfaction (one possible way of doing this)
  - Bid maximization (MEV burn)
- ePBS fork-choice: proposers accept bids from builders. If they don’t publish them on time, the empty block wins and the builder is off the hook.
- DAS fork-choice: if a block is unavailable, most honest validators will not vote for it, i.e., they will vote against it, for the empty block. Thus, no unavailable block should ever “look” canonical

Challenge: higher latency halts block production

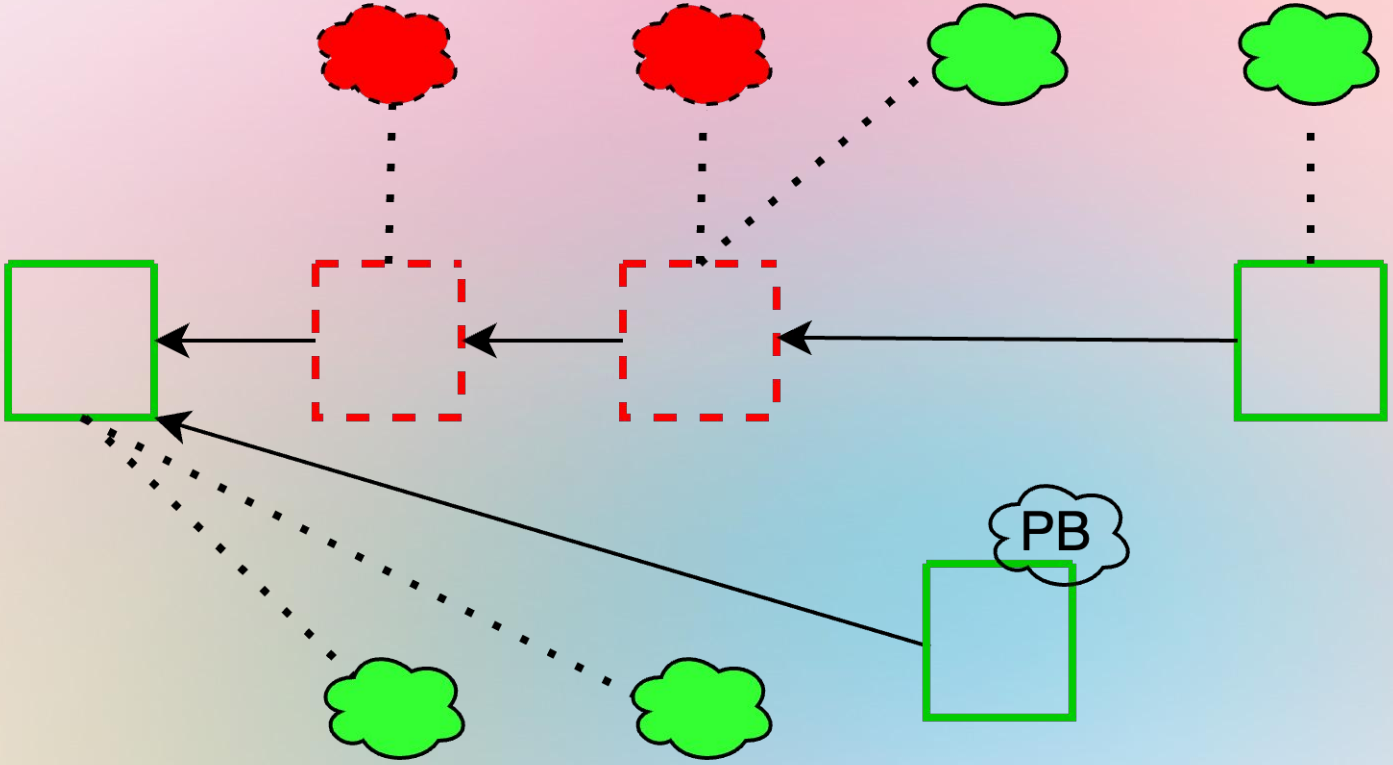


Fork-choice in the Ethereum Roadmap: ePBS

Two-slot ePBS



Ex-ante reorgs, ePBS version



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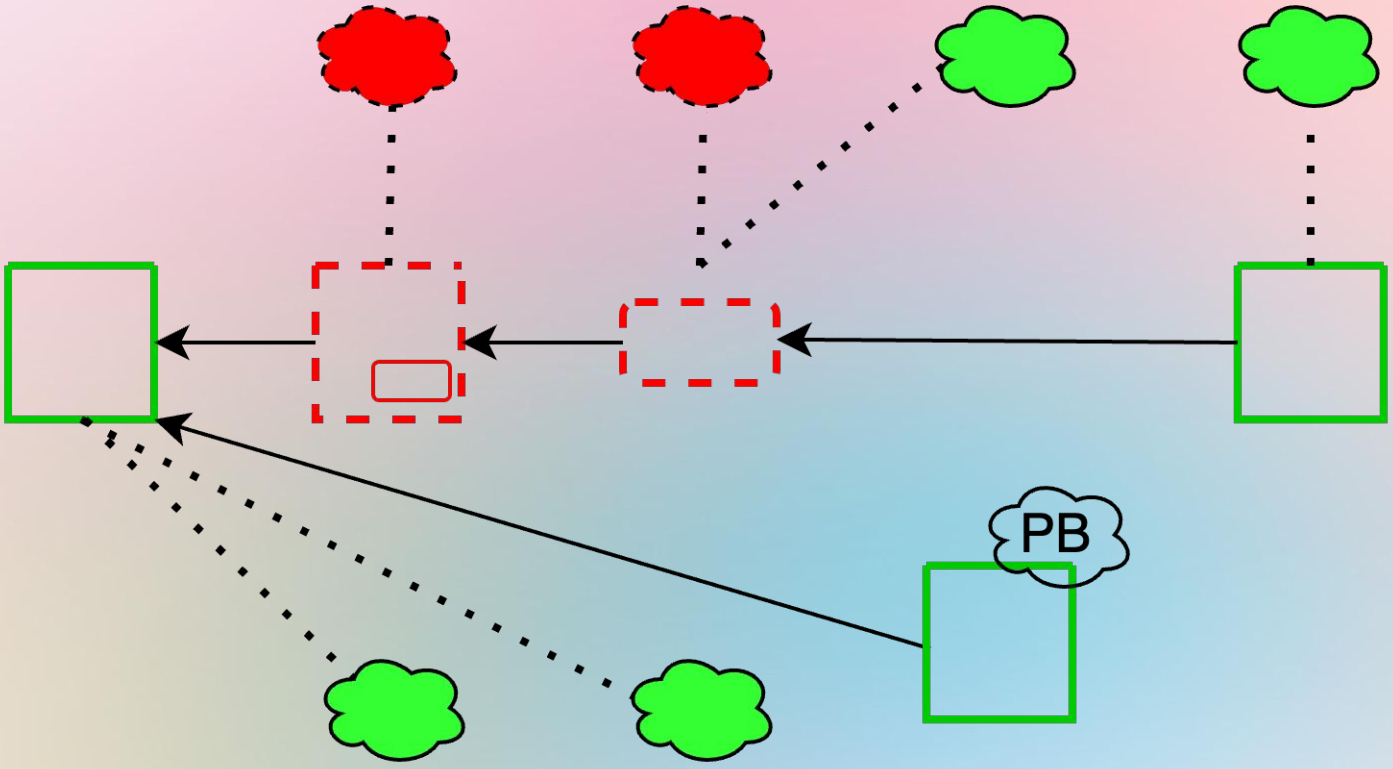

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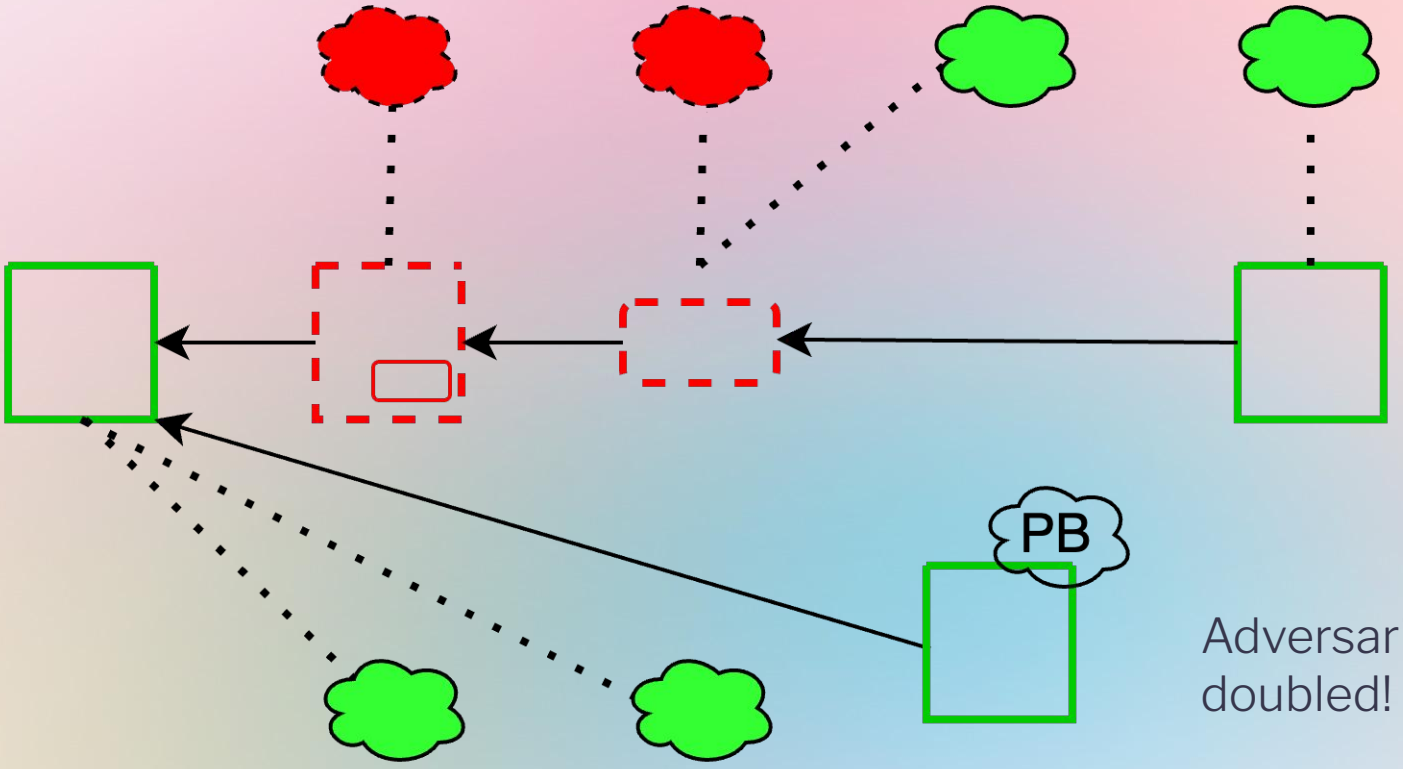
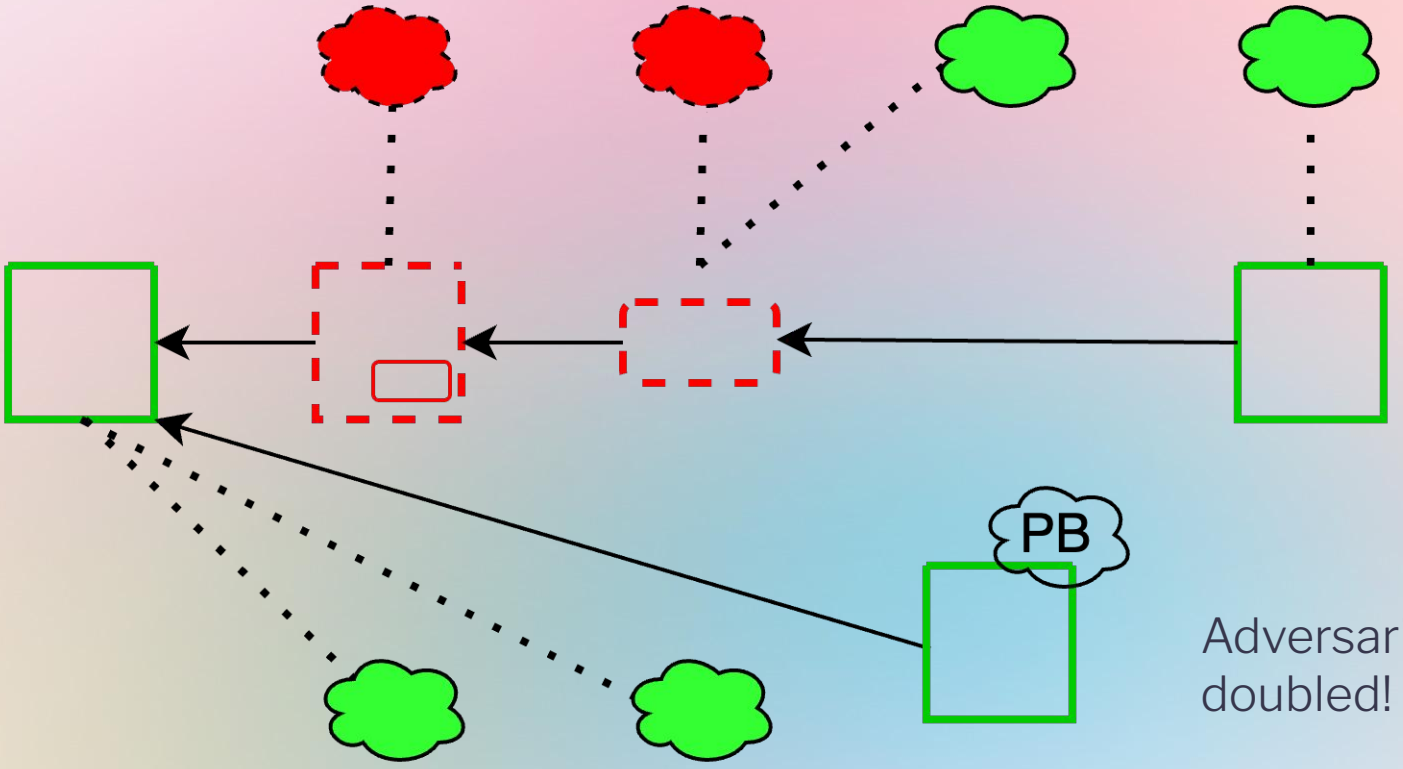


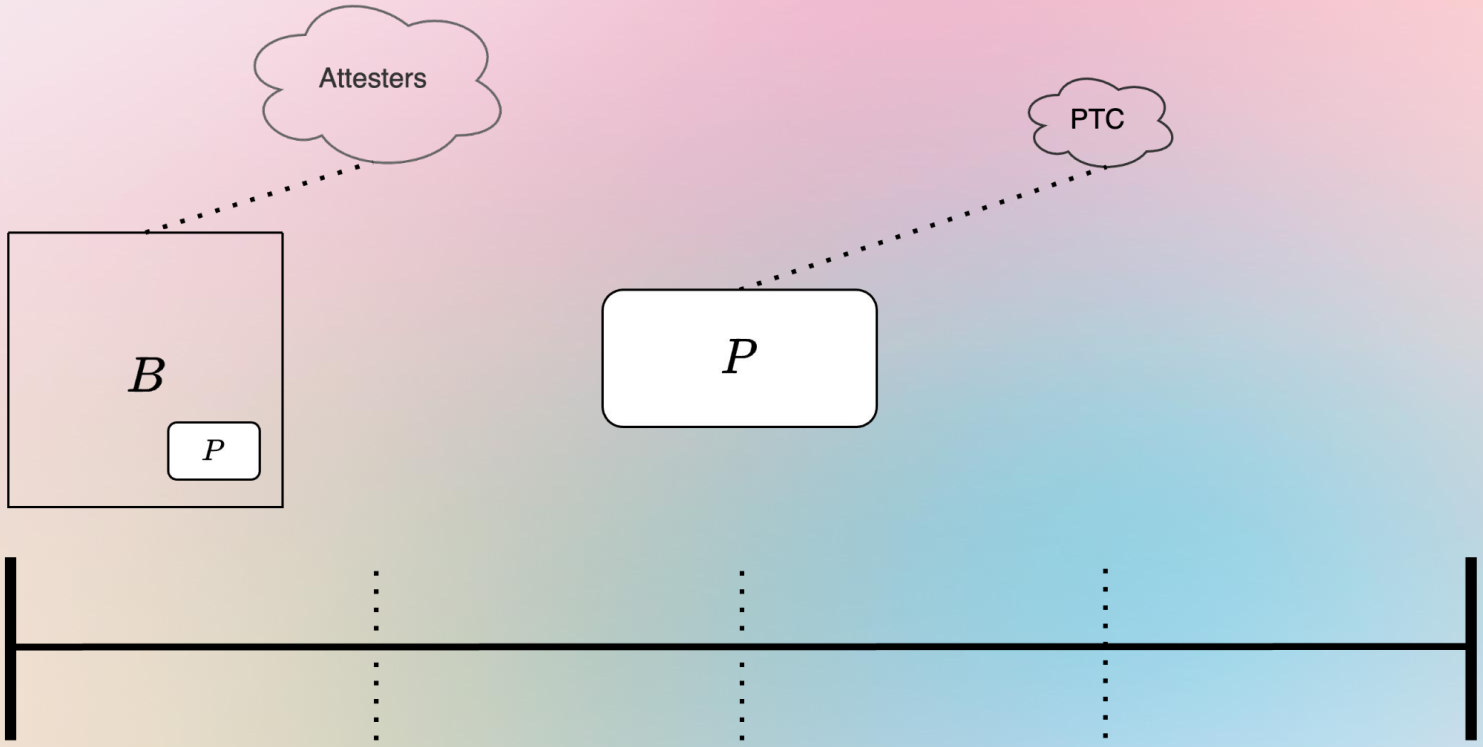
Adversarial power doubled!

Ex-ante reorgs, ePBS version

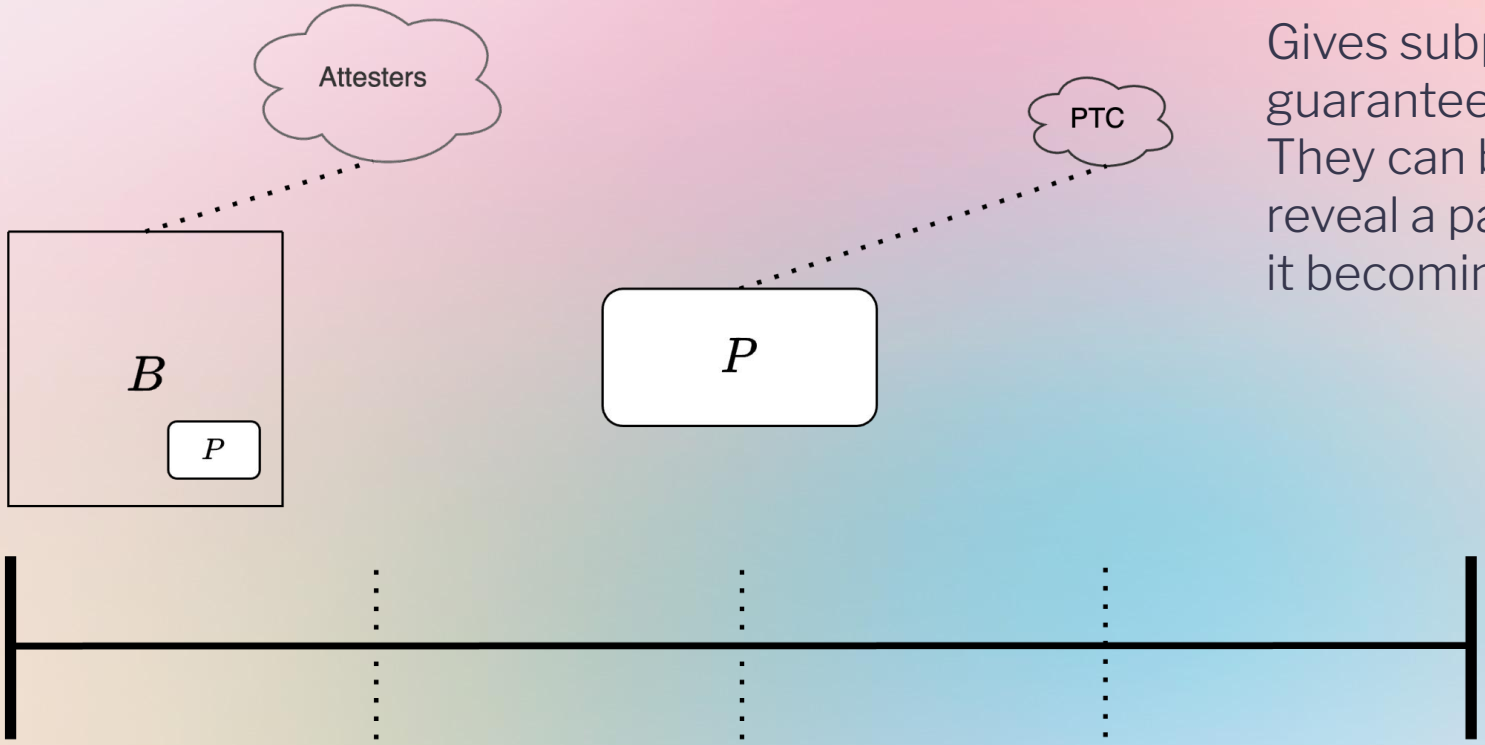


Adversarial power doubled!

One-slot ePBS with PTC (Payload Timeliness Committee)

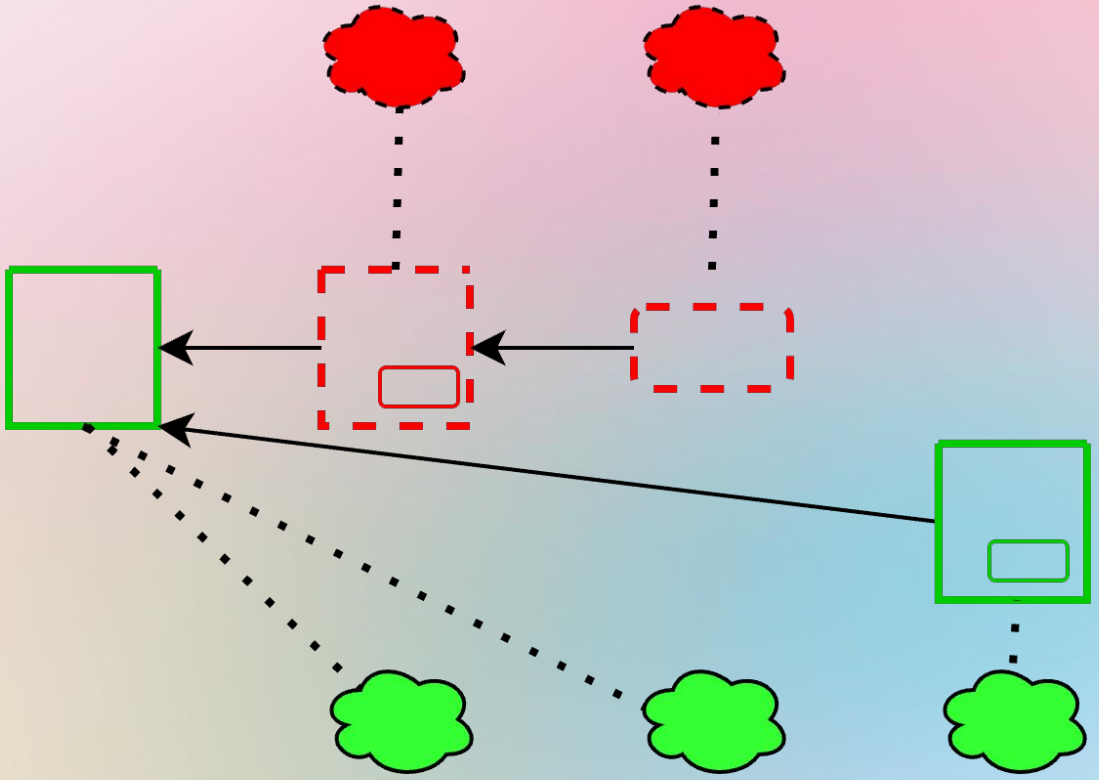


One-slot ePBS with PTC (Payload Timeliness Committee)



Gives subpar guarantees to builders… They can be forced to reveal a payload without it becoming canonical

RLMD-GHOST with ePBS



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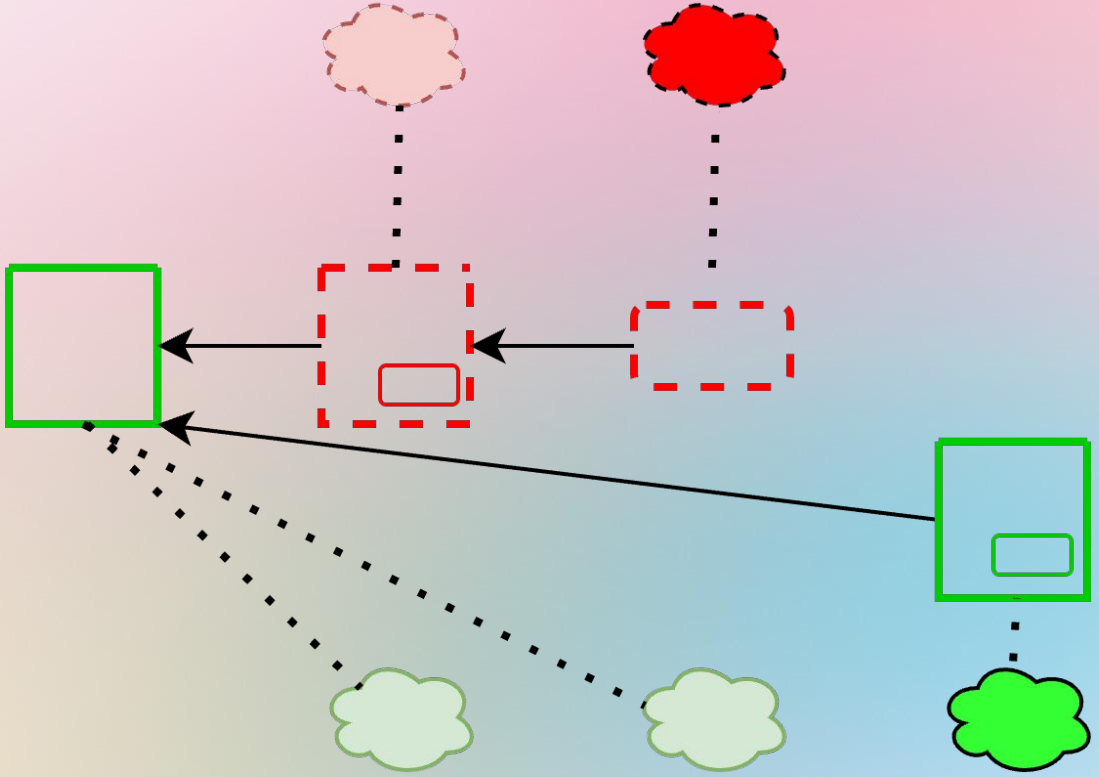

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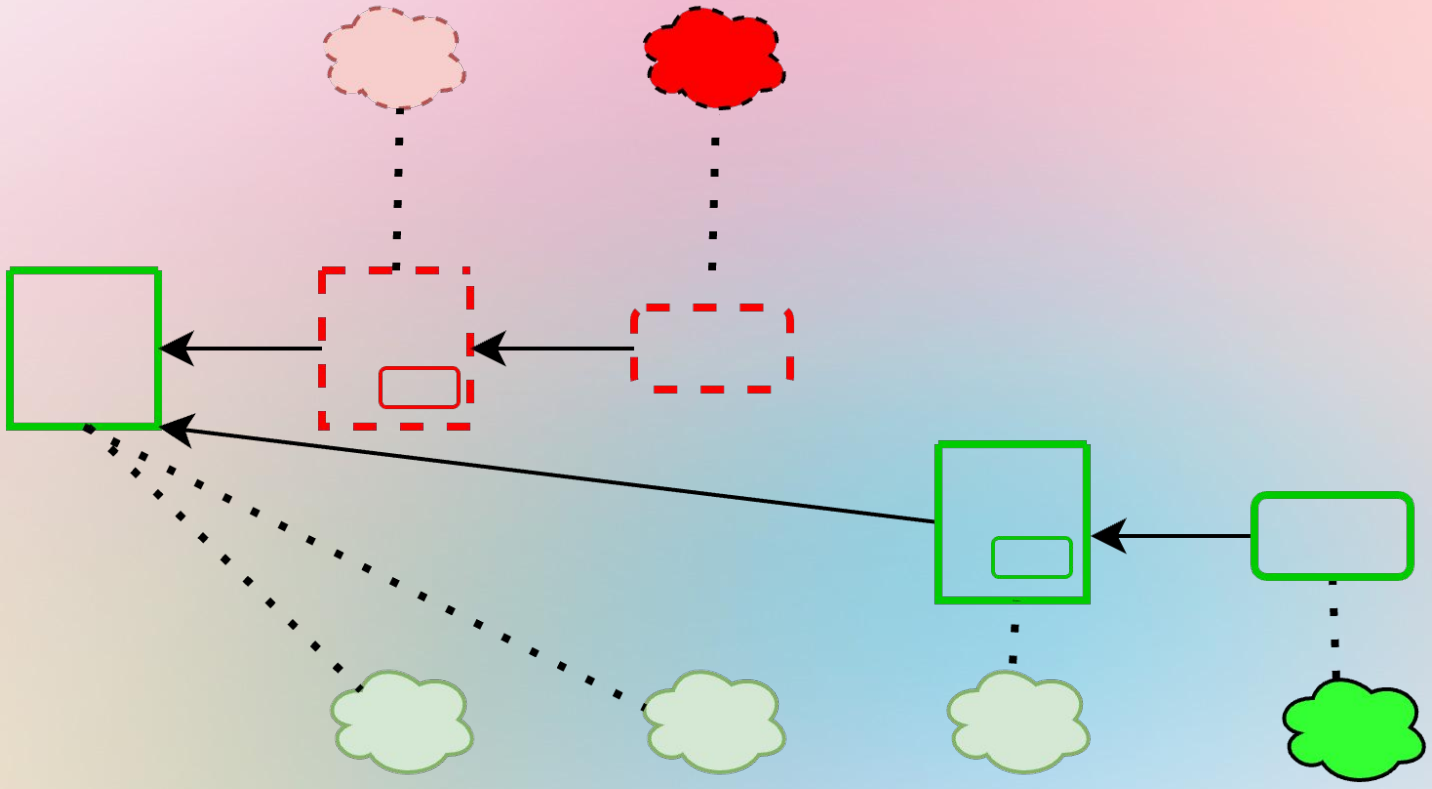
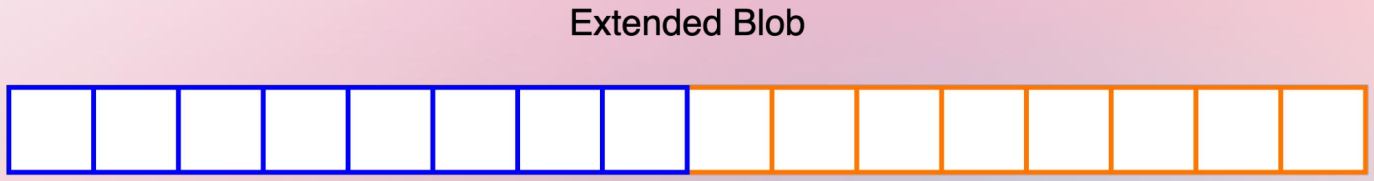


Fork-choice in the Ethereum Roadmap: PeerDAS

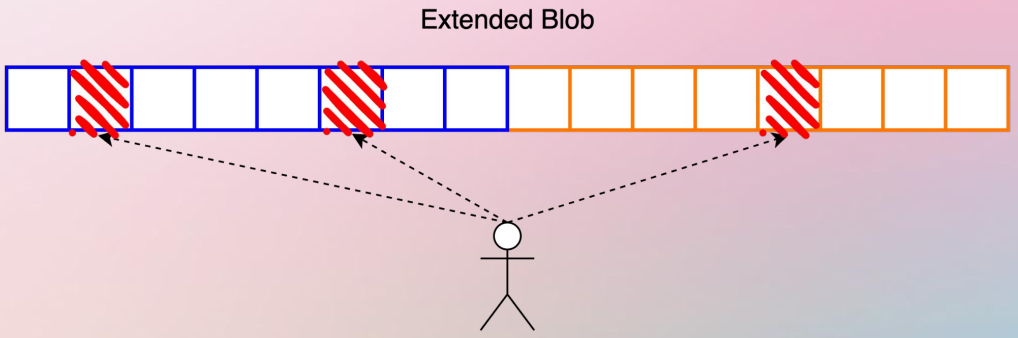
Data Availability Sampling



We *extend* blobs, introducing redundancy which allows **reconstruction** of the full data whenever having at least 50% of it

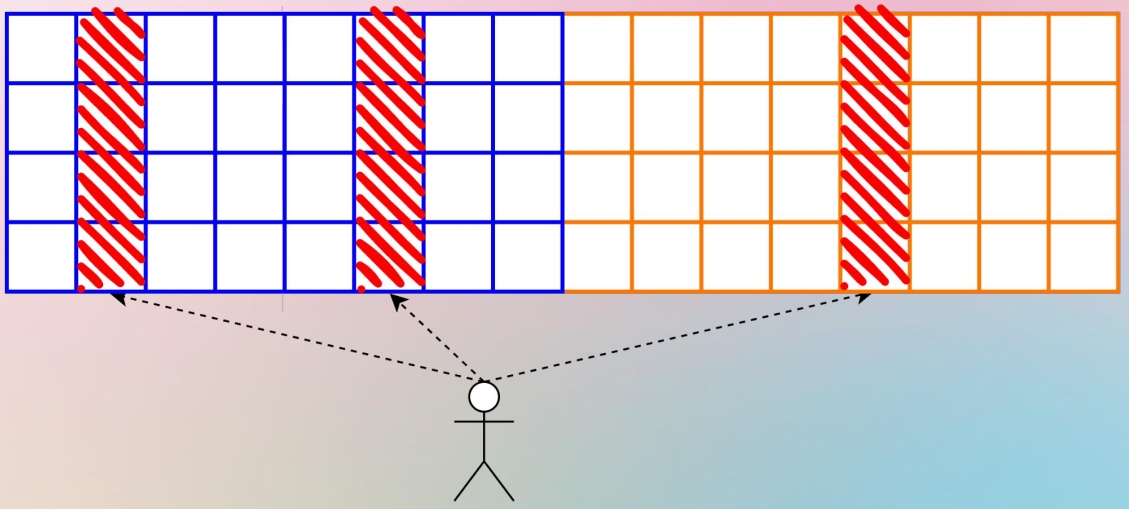
=> Checking availability of a blob only requires making sure that 50% of it is available

Data Availability Sampling



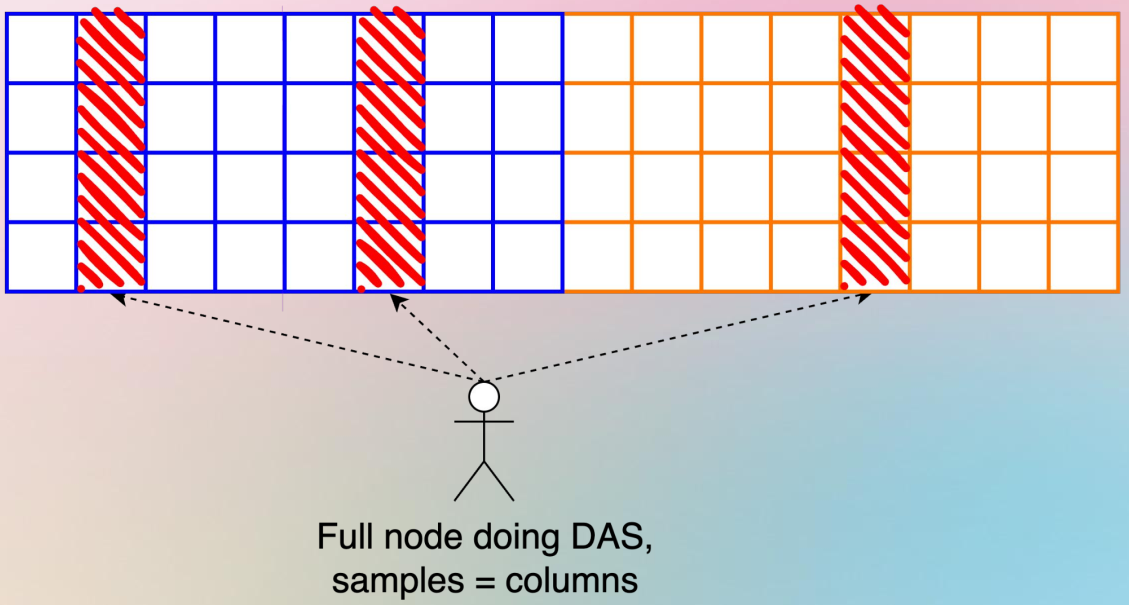
Ultimately, we want full nodes to only download a few chunks of data of their choice (**samples**) to verify that the data is available, instead of the whole data

Data Availability Sampling



Full node doing DAS,
samples = columns

Data Availability Sampling



Like sampling for each blob, but using the same choice of indices

Fork-choice implications

If we do enough sampling *before voting*, we get a great global property: Only at most a small percentage **δ** of the honest validators will see unavailable data as available

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a majority always votes *against* unavailable blocks

=> with the (block, slot) fork-choice, this means that no validator will ever see an unavailable block as canonical

The fork-choice essentially works as if we didn't have DAS at all!

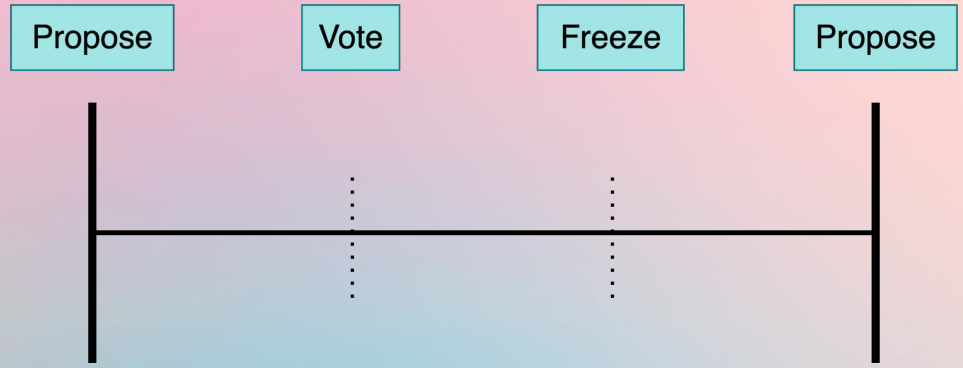
Thank you!

Alternative available chain

Merge-less available chain

Same structure as before, but:

- Fork-choice change: head is the highest block supported by a majority of the voting weight
- No view-merge message necessary.



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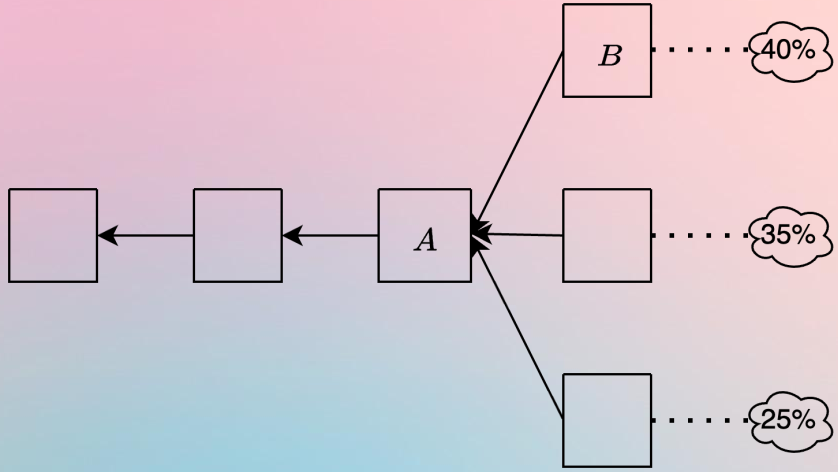
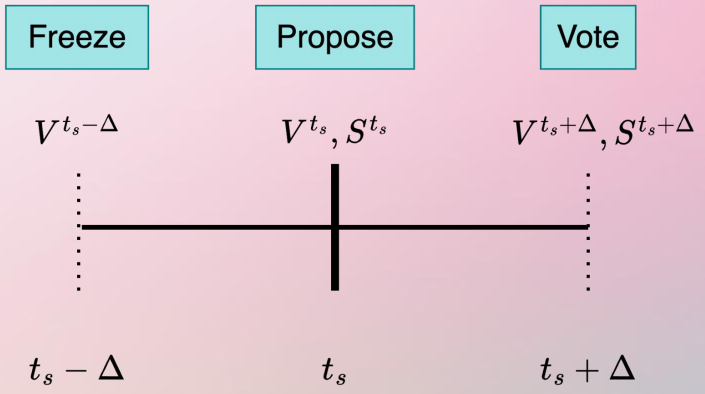


Synchronization mechanism: time-shifted quorum



V^t = latest unexpired votes from non-equivocators received by time t

S^t = voters by time t

t_s = time of slot s

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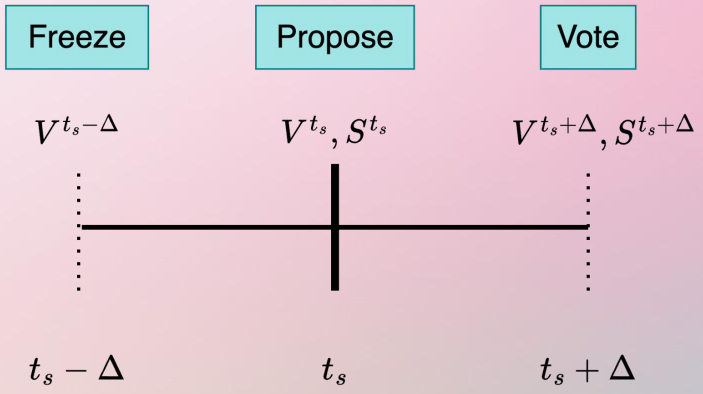

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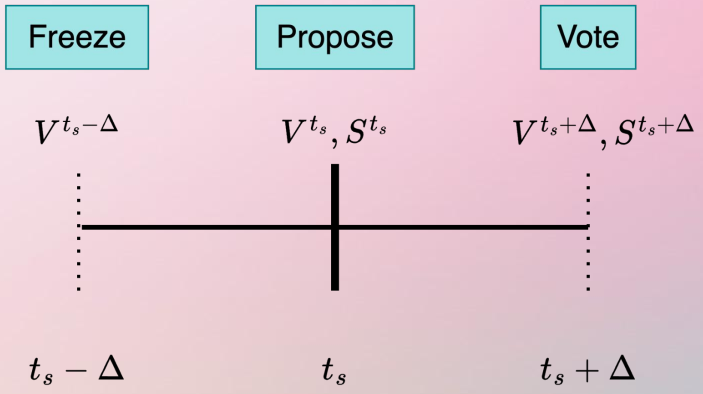
S^t = voters by time t

t_s = time of slot s

$V^{t_s-\Delta} \subseteq V^{t_s}$ and $S^{t_s} \subseteq S^{t_s+\Delta}$

Synchronization mechanism: time-shifted quorum



V^t = latest unexpired votes from non-equivocators received by time t
S^t = voters by time t
t_s = time of slot s

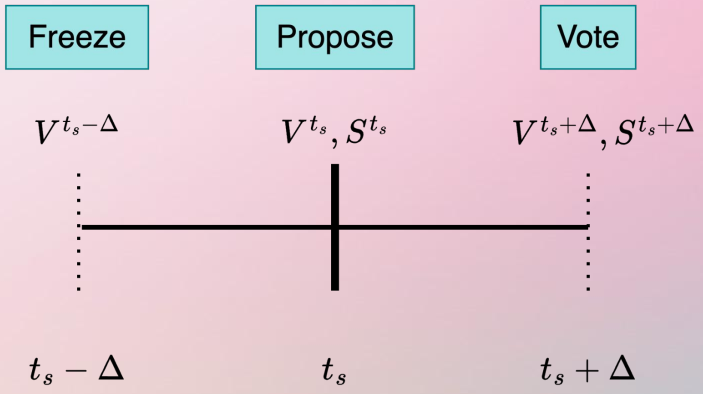
$V^{t_s-\Delta} \subseteq V^{t_s}$ and $S^{t_s} \subseteq S^{t_s+\Delta}$

B is canonical when voting at slot s if

$$|V_B^{t_s-\Delta}| > |S^{t_s+\Delta}|/2$$
$$\implies |V_B^{t_s}| \geq |V_B^{t_s-\Delta}| > |S^{t_s+\Delta}|/2 \geq |S^{t_s}|/2$$
$$\implies |V_B^{t_s}| > |S^{t_s}|/2$$

$\implies$ B is also canonical for the proposer

Synchronization mechanism: time-shifted quorum



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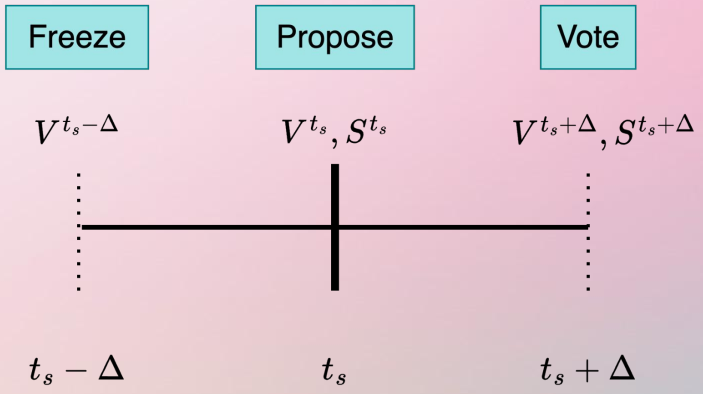
$$\implies |V_B^{t_s}| \geq |V_B^{t_s-\Delta}| > |S^{t_s+\Delta}|/2 \geq |S^{t_s}|/2$$

$$\implies |V_B^{t_s}| > |S^{t_s}|/2$$

$\implies$ B is also canonical for the proposer

Synchronization mechanism: time-shifted quorum



V^t = latest unexpired votes from non-equivocators received by time t

S^t = voters by time t

t_s = time of slot s

$V^{t_s-\Delta} \subseteq V^{t_s}$ and $S^{t_s} \subseteq S^{t_s+\Delta}$

B is canonical when voting at slot s if

$$|V_B^{t_s-\Delta} \cap V^{t_s+\Delta}| > |S^{t_s+\Delta}|/2$$

If an equivocation or a later vote is seen by the proposer, it will be seen by the voter as well, and discarded by the intersection with its current view