


Starfish:

DAG-based Consensus via Encoded Cordial Dissemination

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IOTA

Outline


Consensus problem


DAG-based consensus

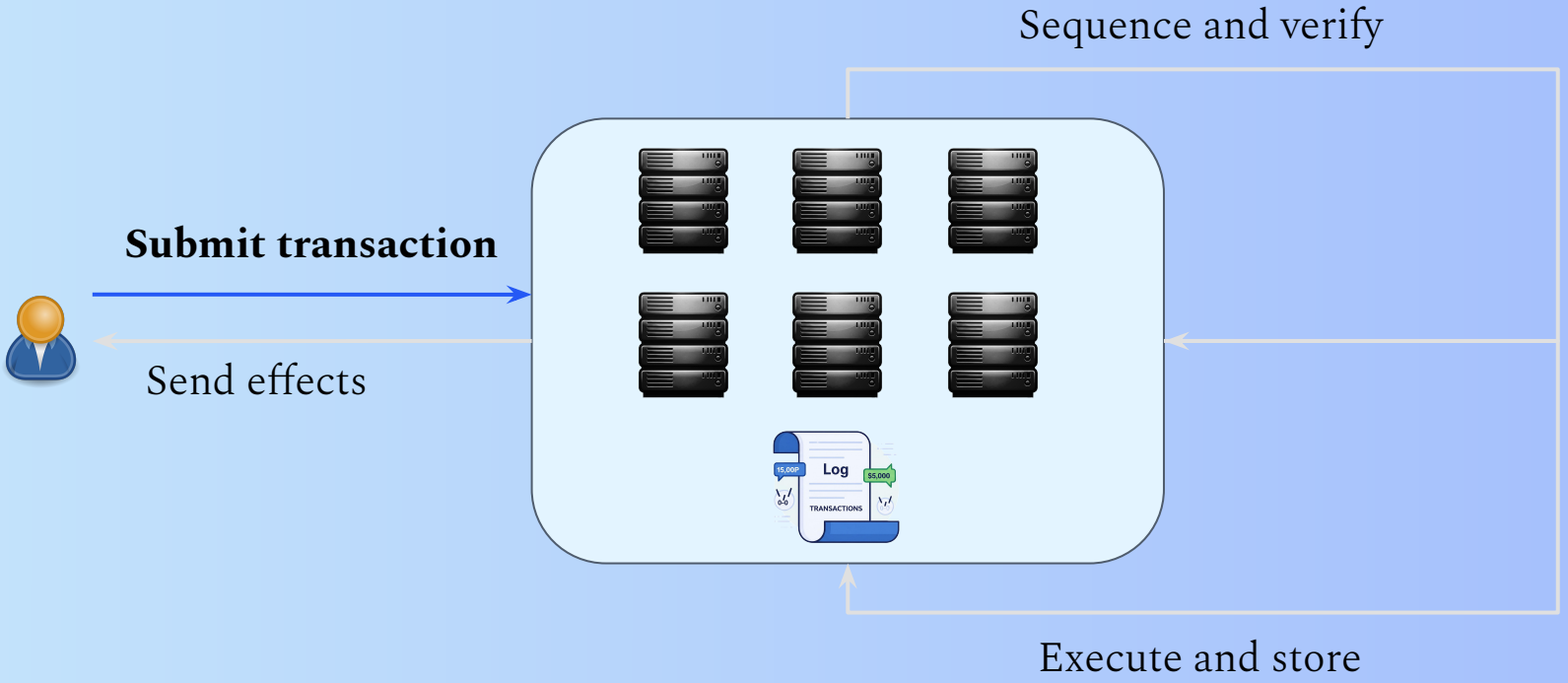

Uncertified DAG and motivation


Starfish

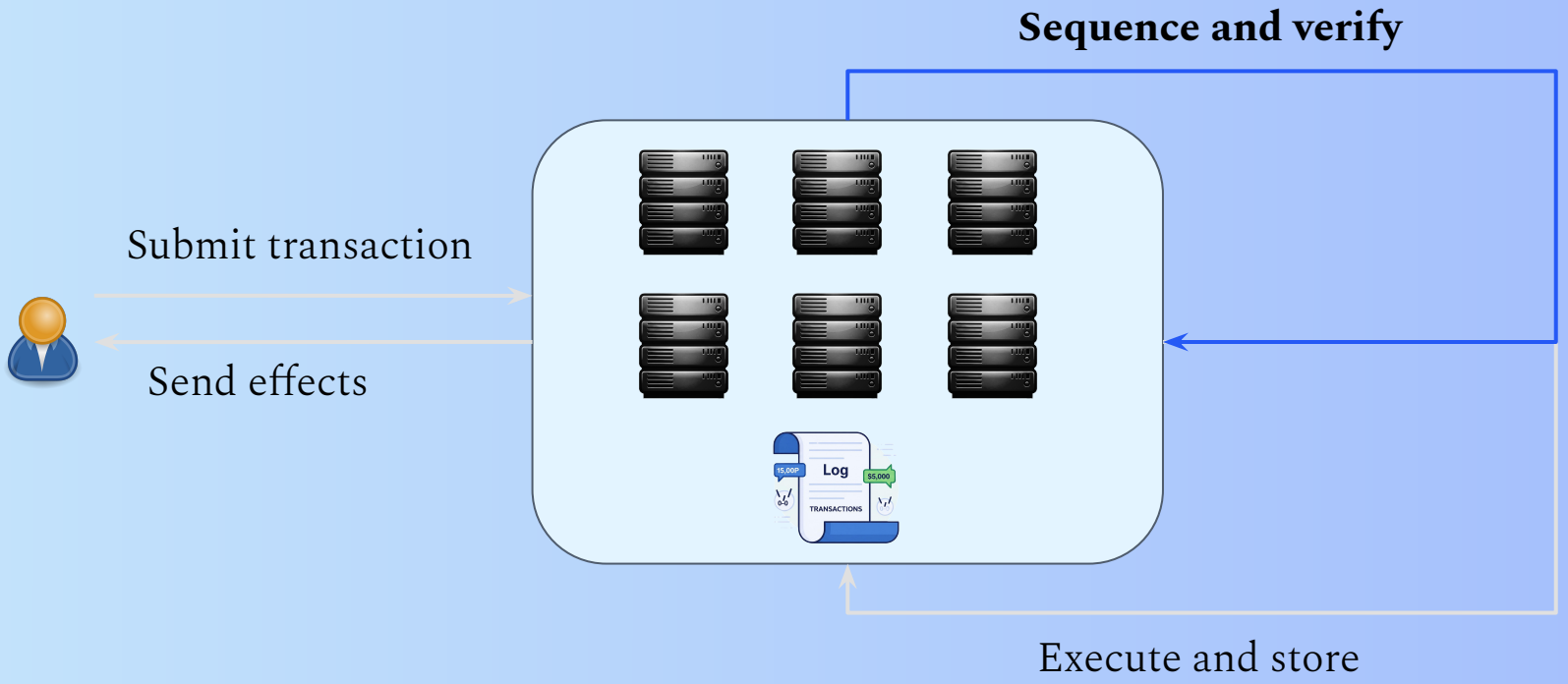

Performance and comparison

Consensus problem

Consensus


Sequence and verify
Submit transaction
Send effects
Log
TRANSACTIONS
Execute and store

Consensus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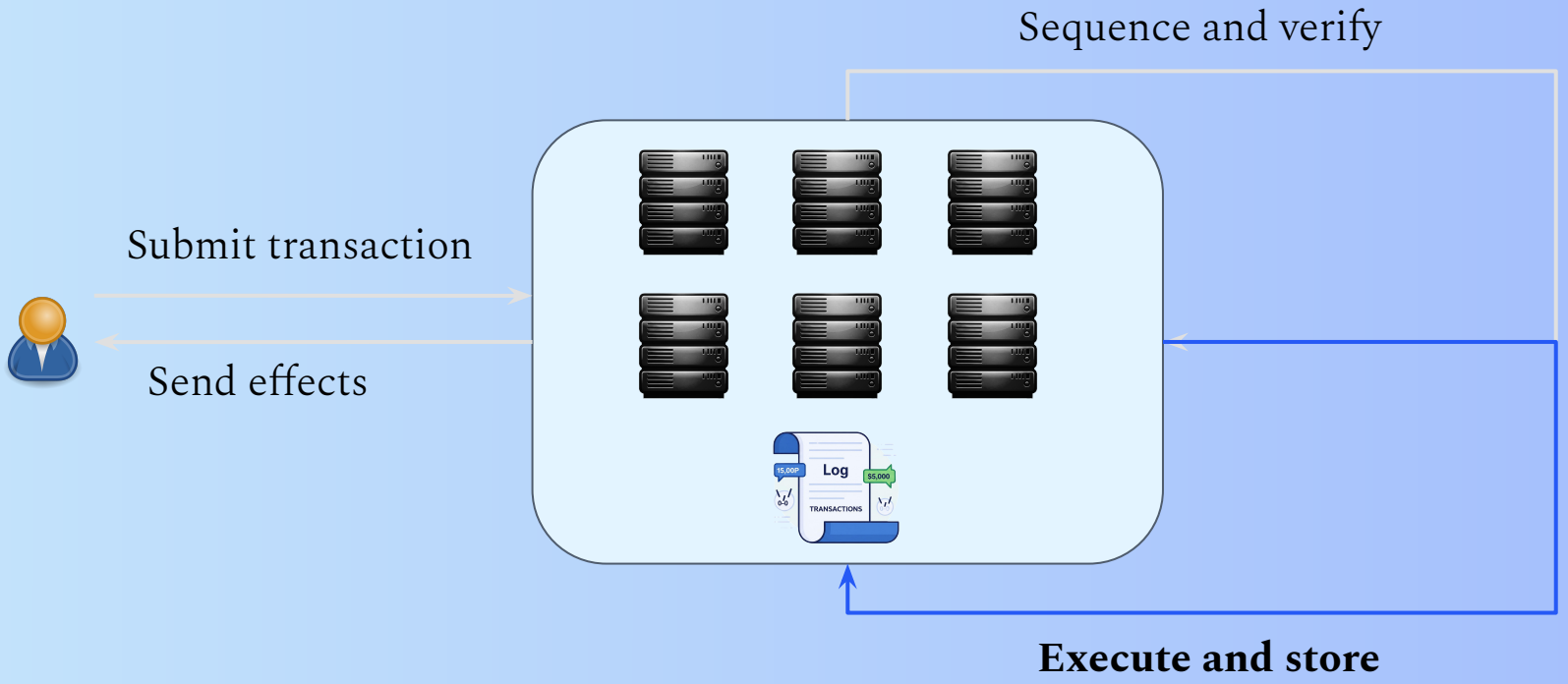
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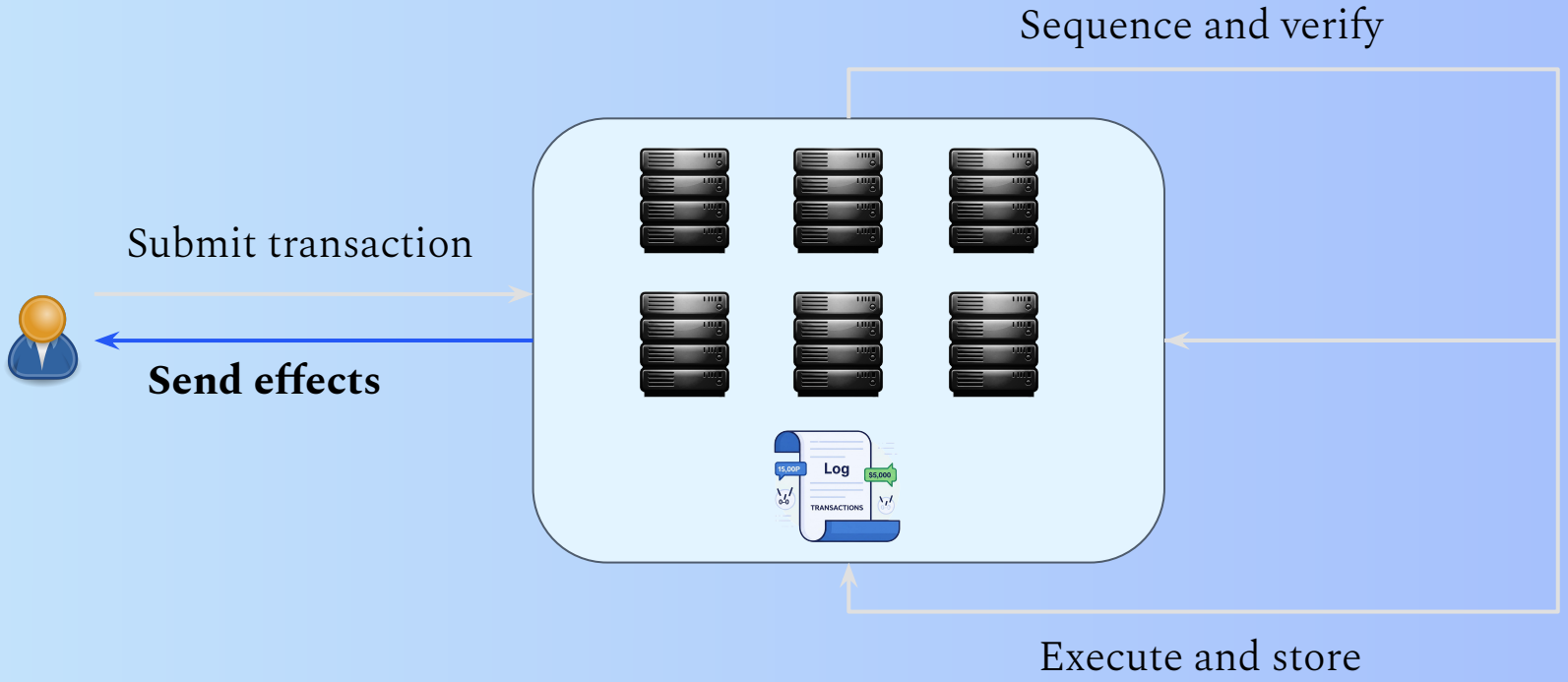
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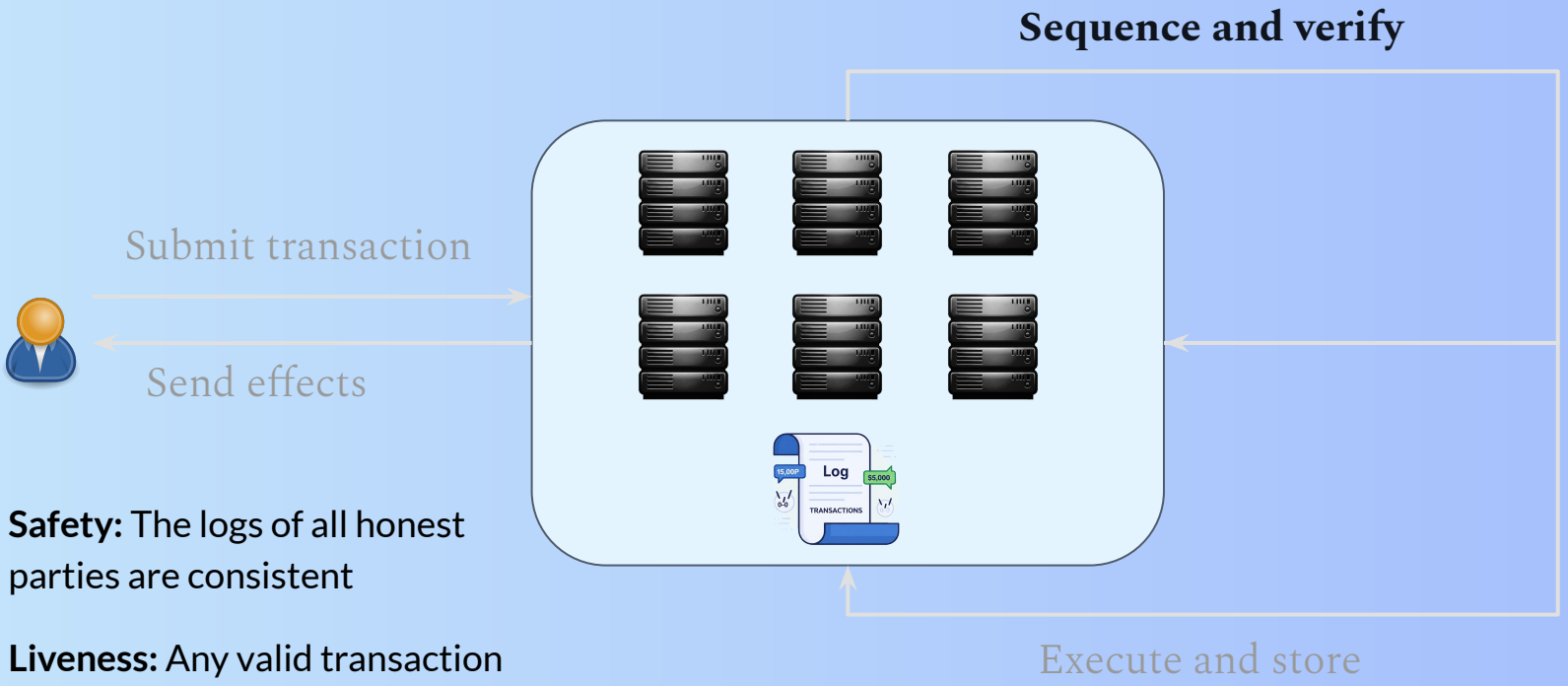
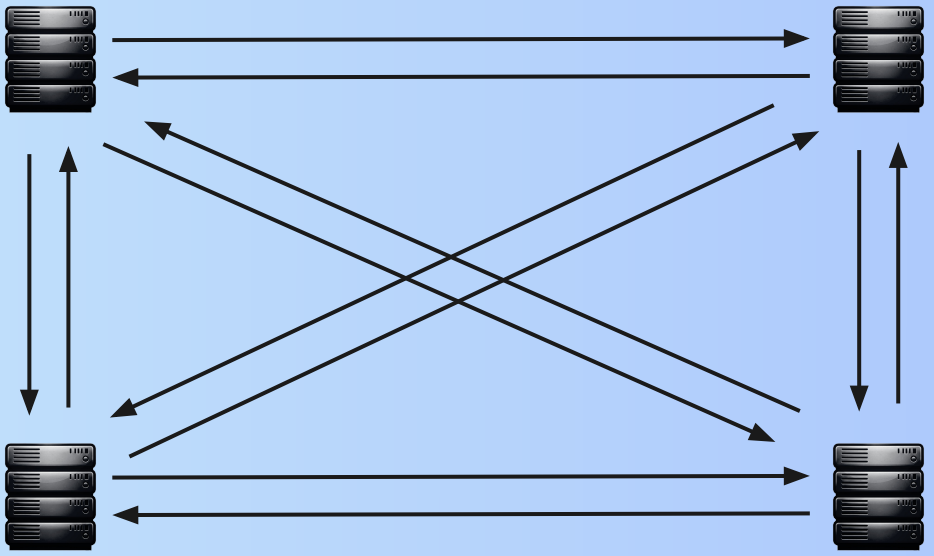


Safety: The logs of all honest parties are consistent

Liveness: Any valid transaction submitted by an honest party is eventually included in the log.

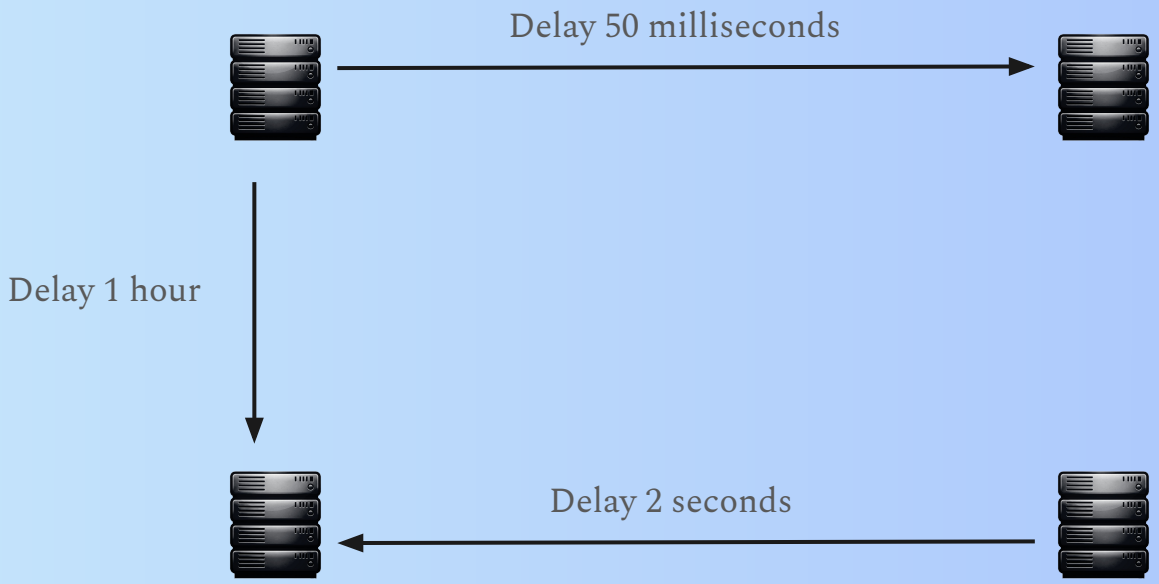
Network



Point-to-point communication

Each message is eventually delivered

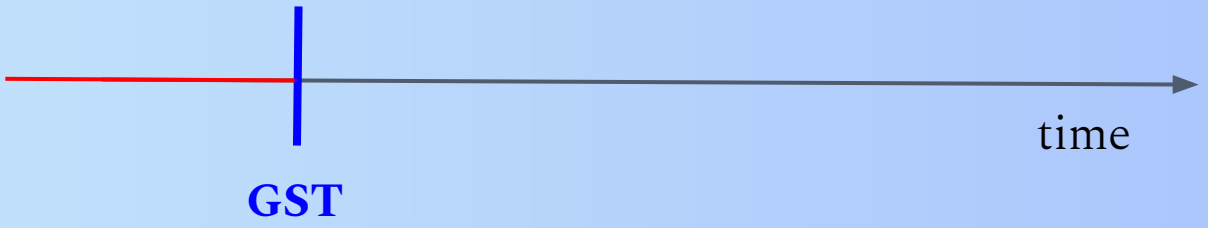
Network



Point-to-point communication

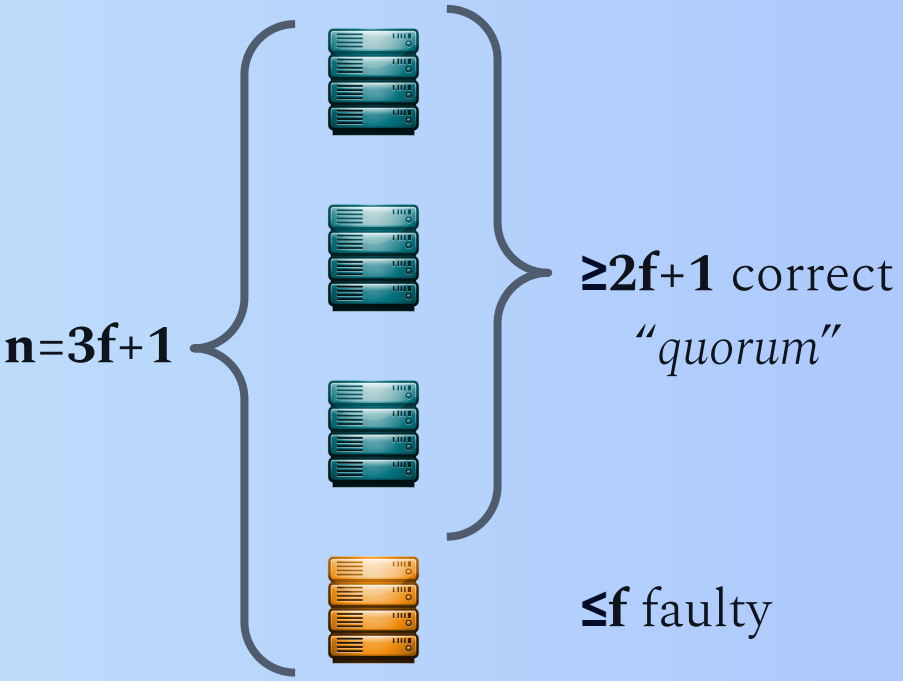
Each message is eventually delivered

Partially synchrony



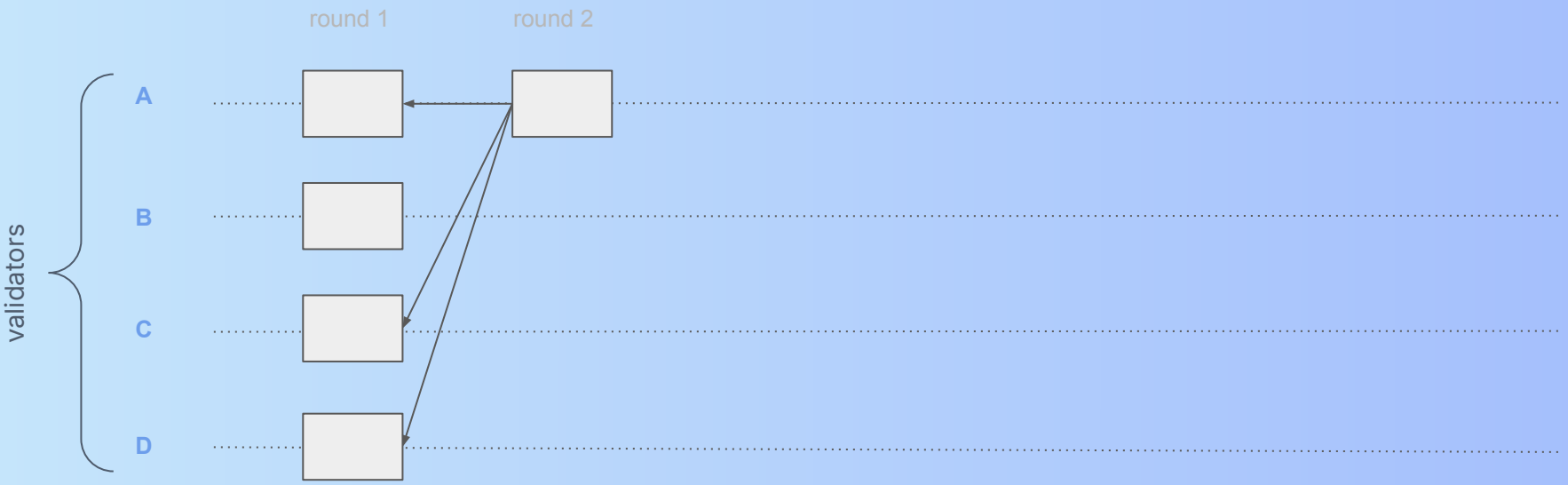
After *unknown* Global Stabilization Time (GST),
communication is synchronous with *known* delay **Δ**

Byzantine fault tolerance



DAG-based consensus

DAG as communication and logical layer



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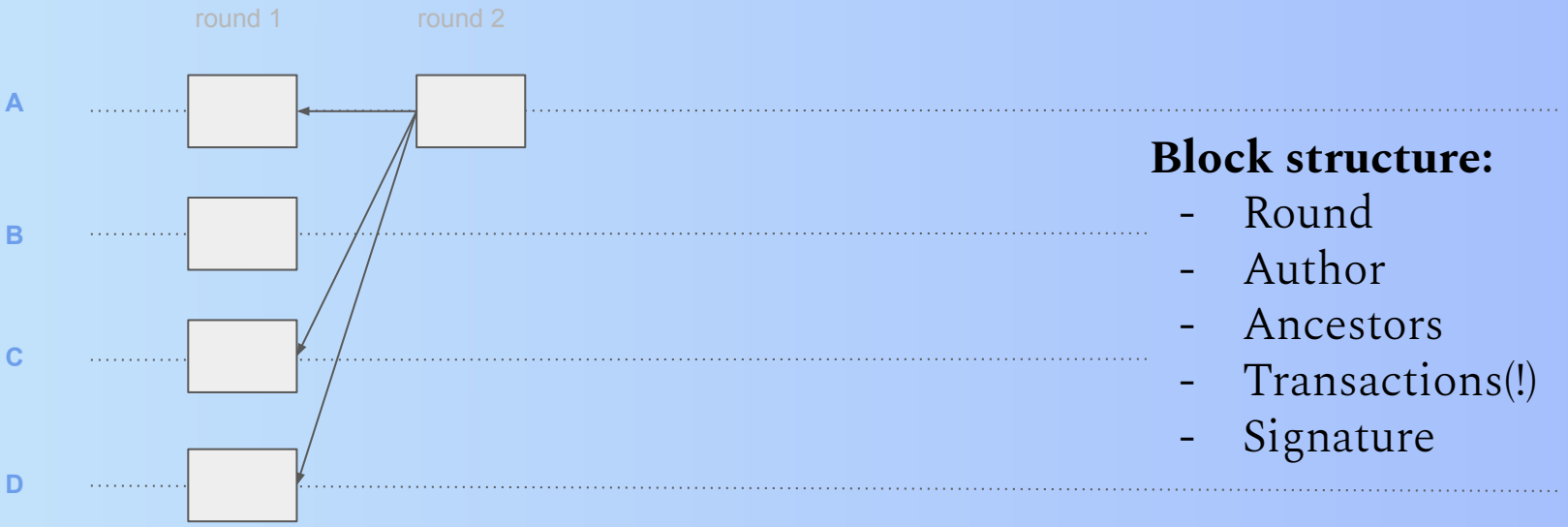
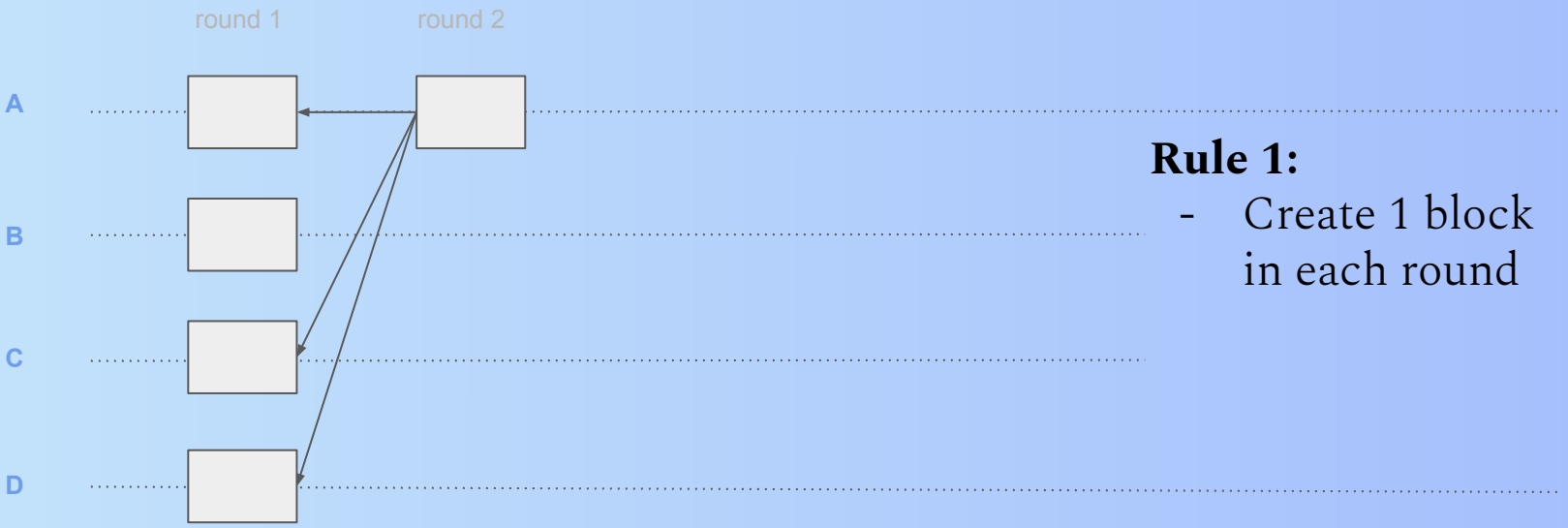


Block structure:

- Round
- Author
- Ancestors
- Transactions(!)
- Signature

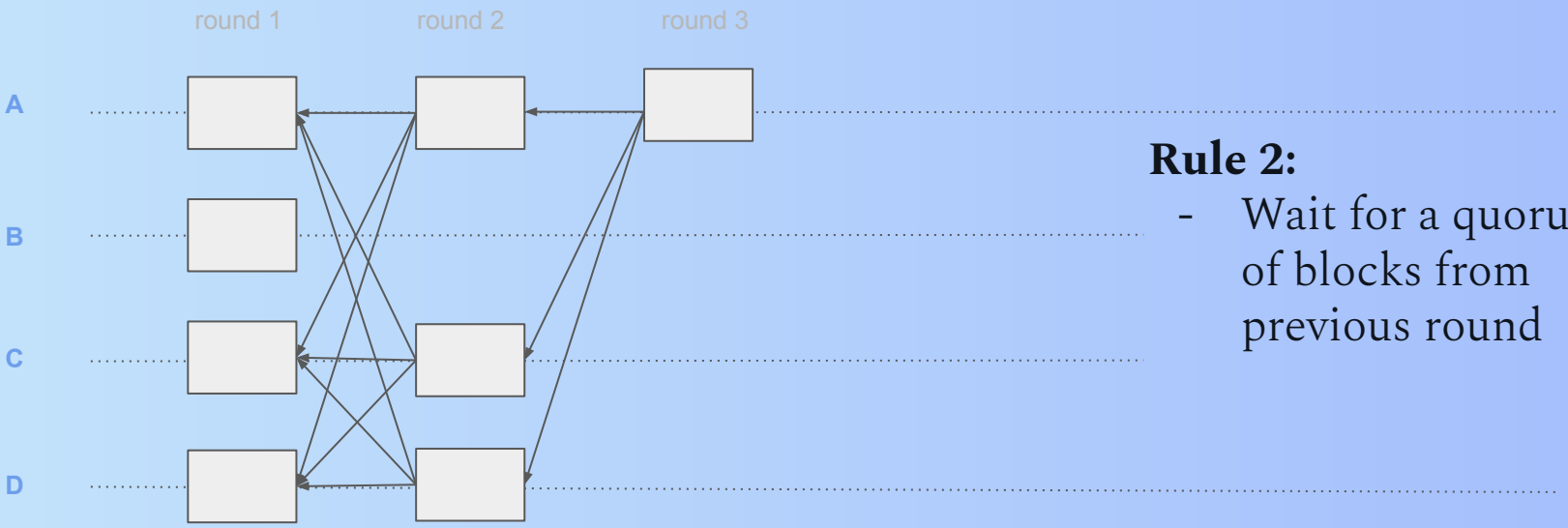
DAG as communication and logical layer



Rule 1:

- Create 1 block in each round

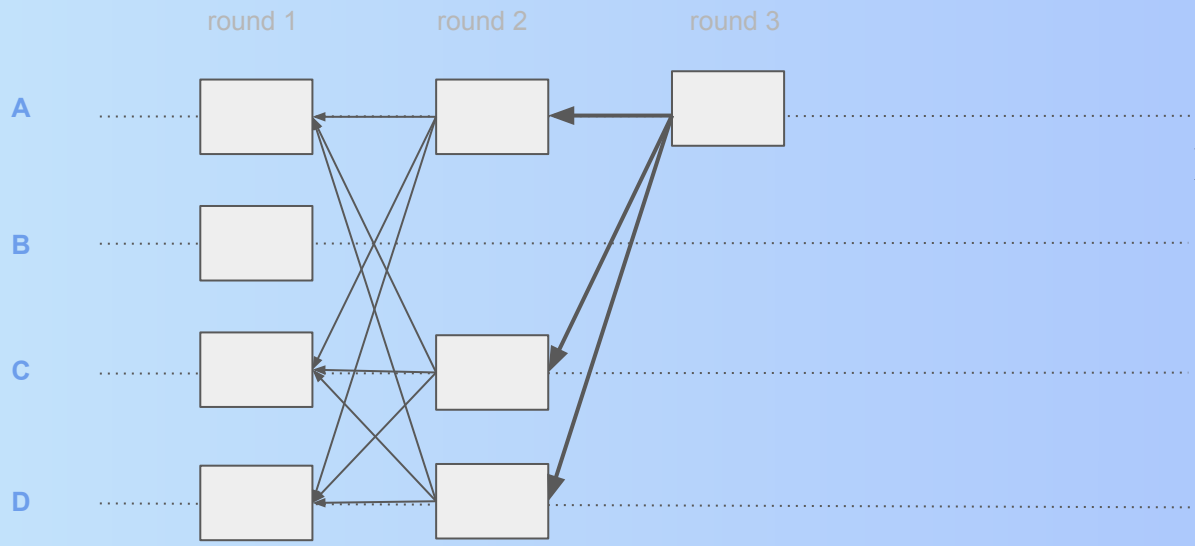
DAG as communication and logical layer



Rule 2:

- Wait for a quorum of blocks from previous round

DAG as communication and logical layer



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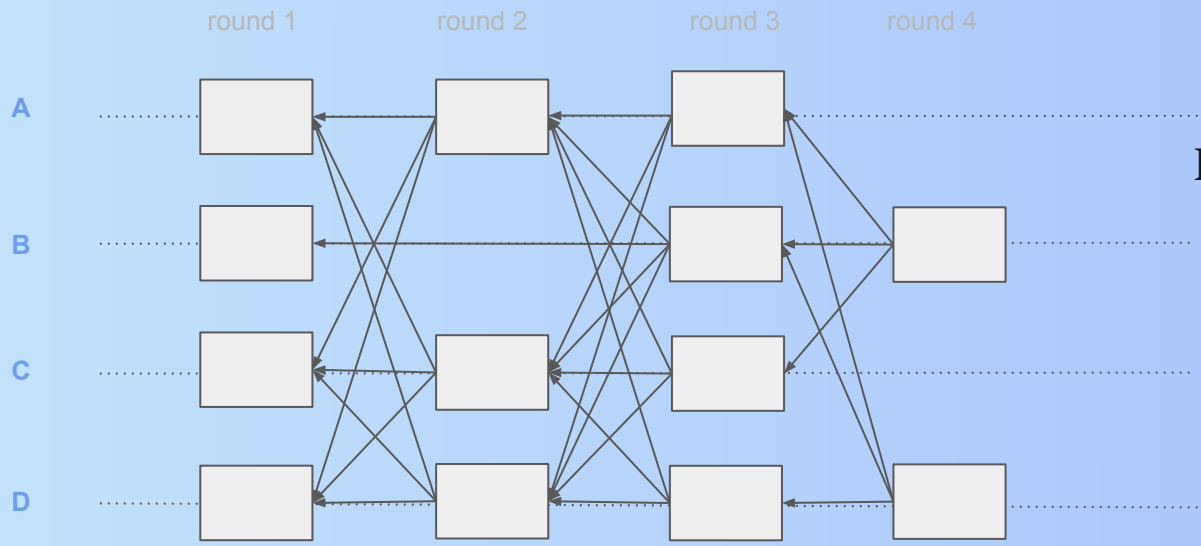
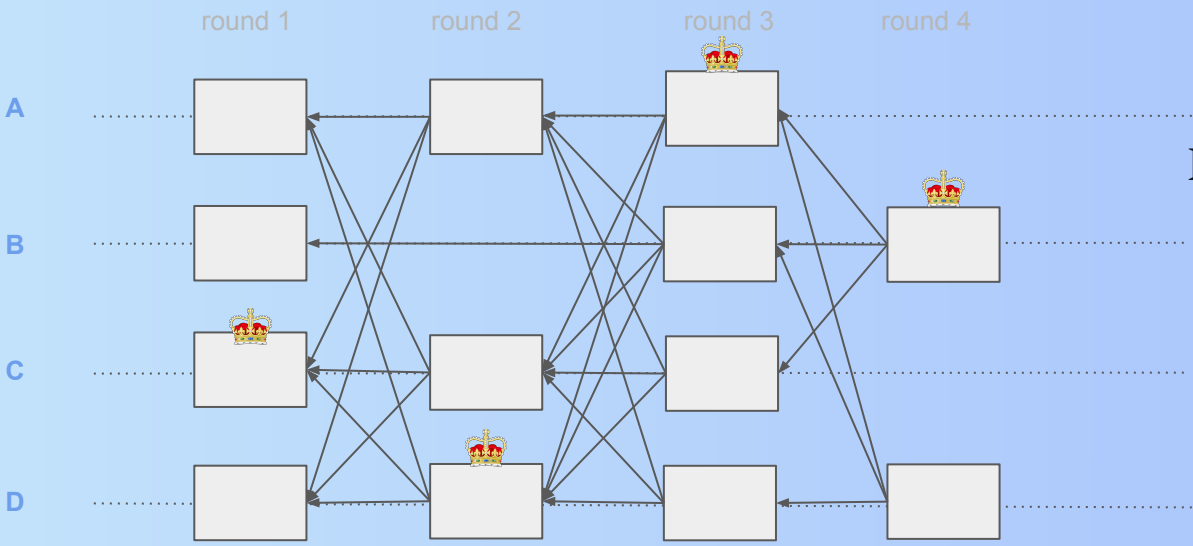


Rule 3:

- Wait for a leader in the previous round

DAG as communication and logical layer



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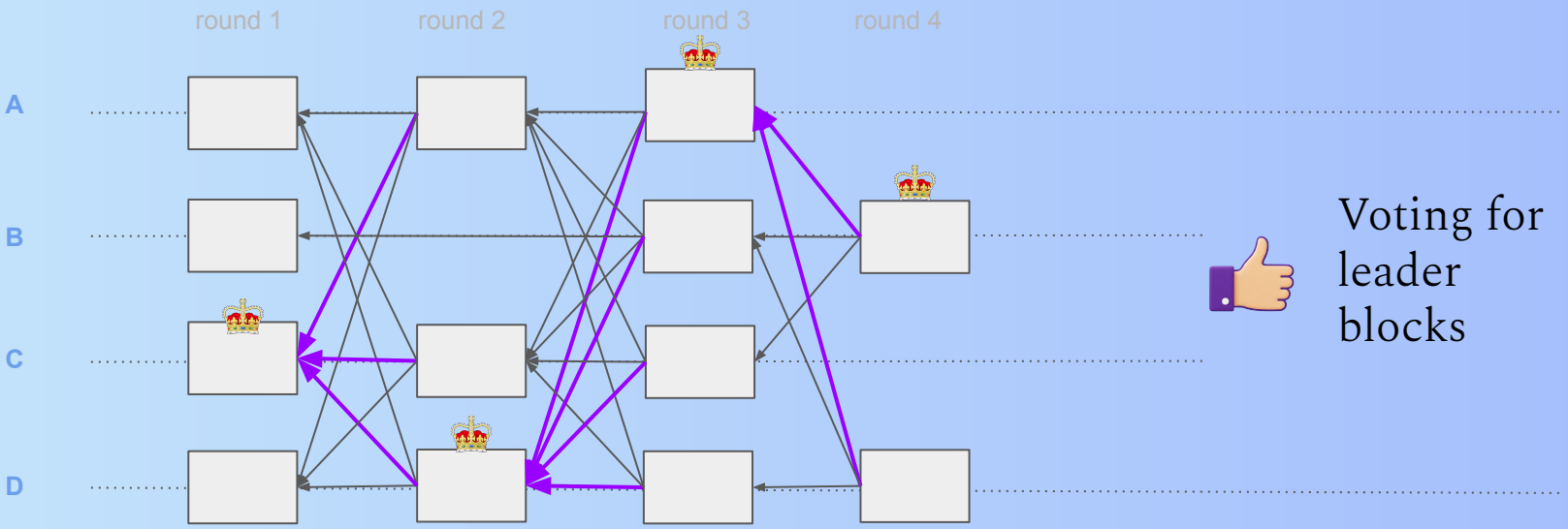
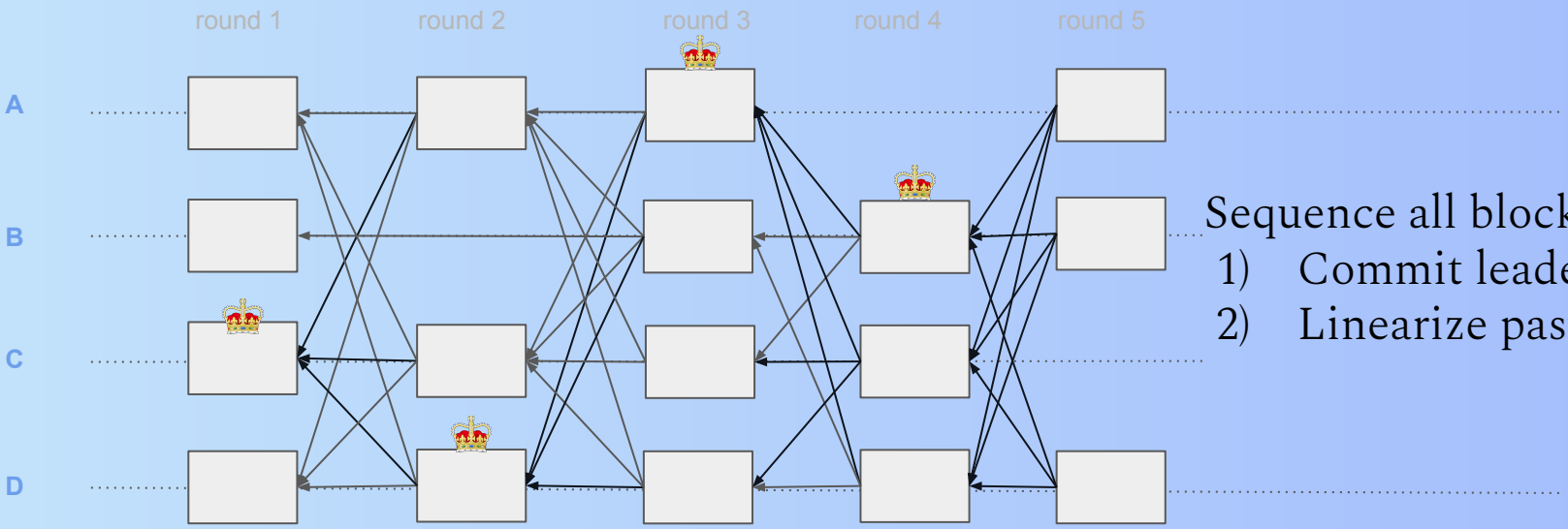


Voting for leader blocks

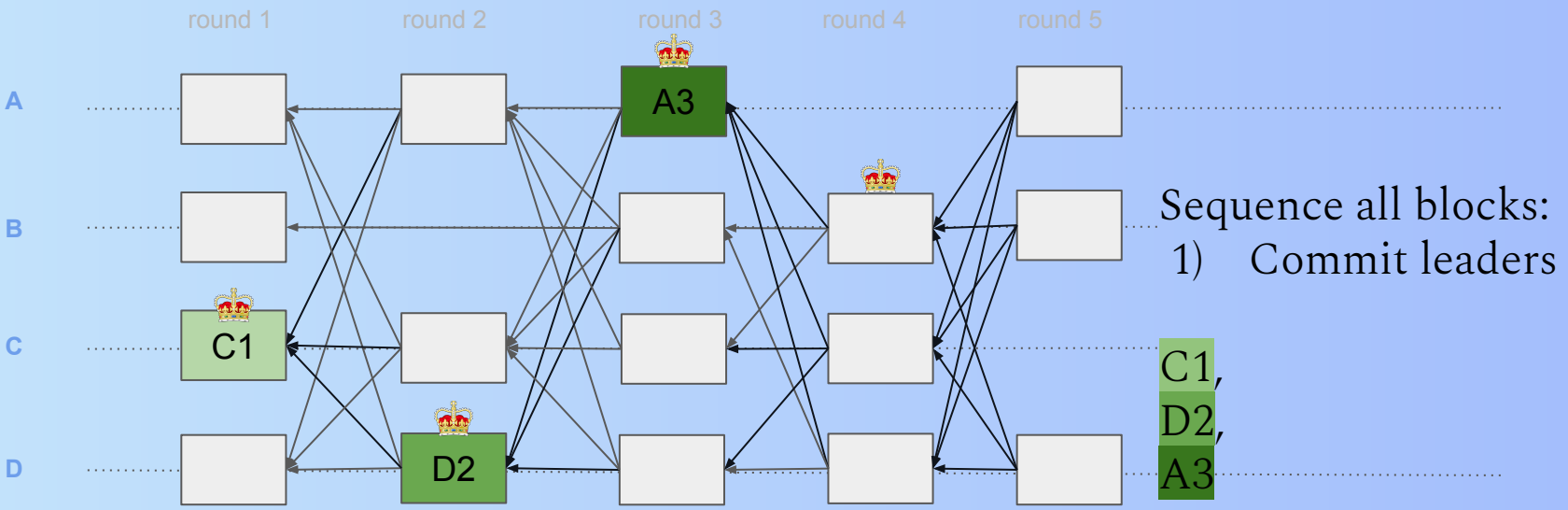
DAG as communication and logical layer



Sequence all blocks:

1) Commit leaders
2) Linearize past

DAG as communication and logical layer

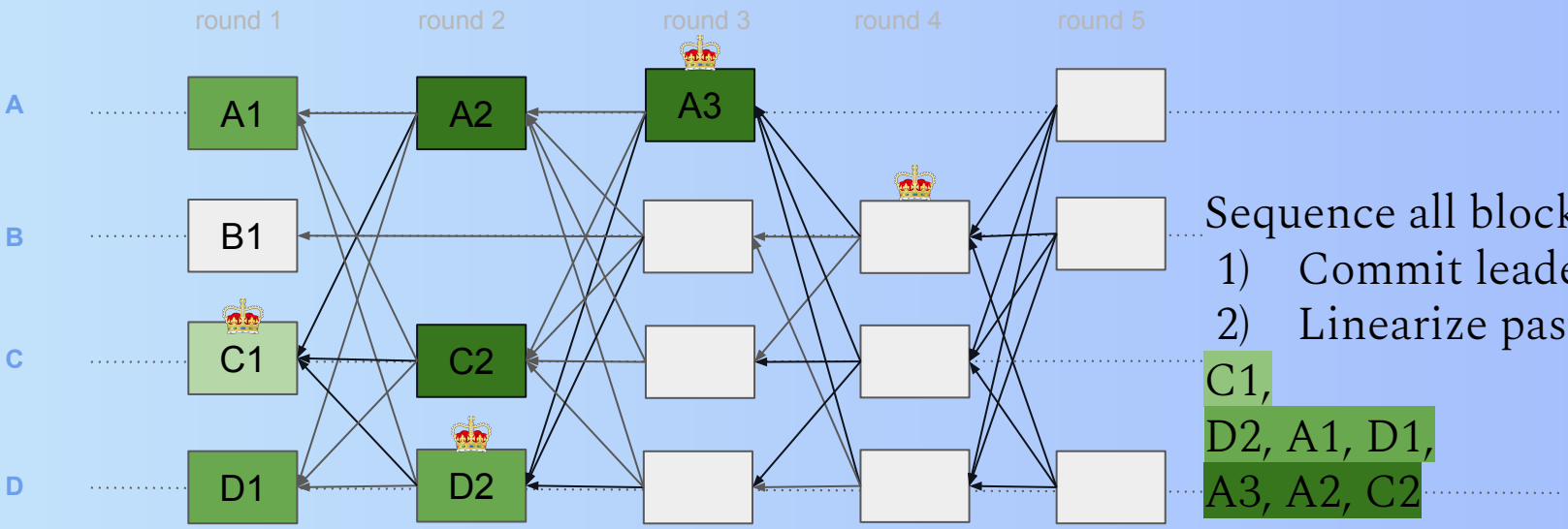


Sequence all blocks:

1) Commit leaders

C1,
D2,
A3

DAG as communication and logical layer



Sequence all blocks:

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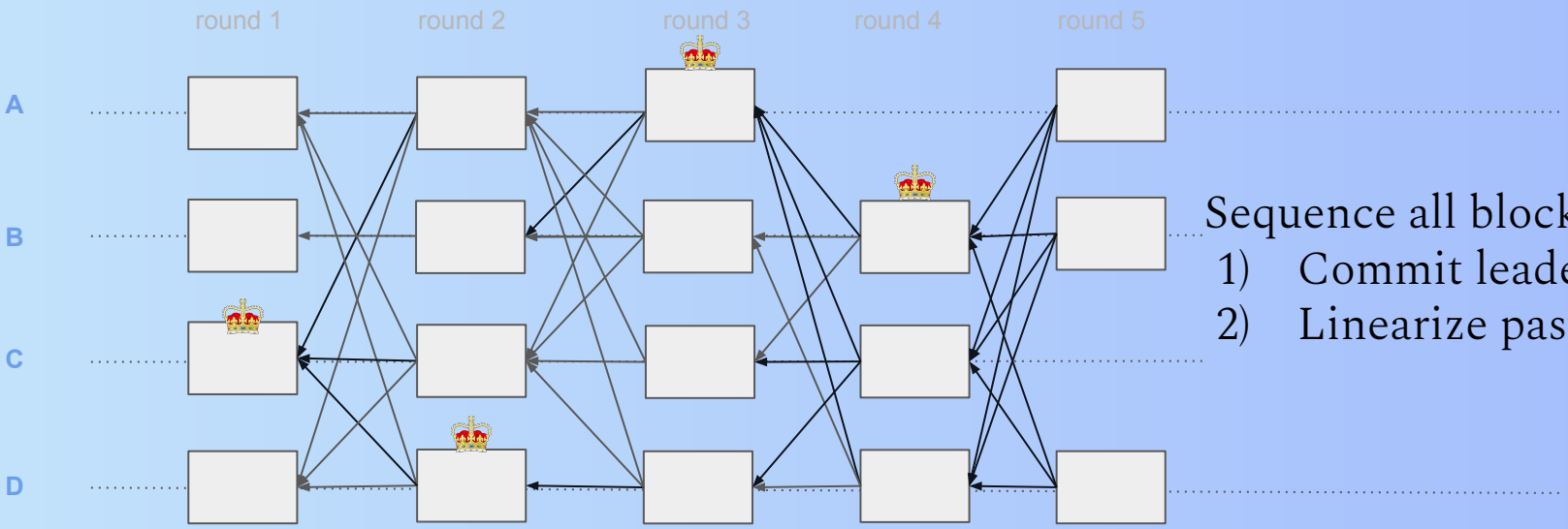
C1,
D2, A1, D1,
A3, A2, C2

DAG as communication and logical layer



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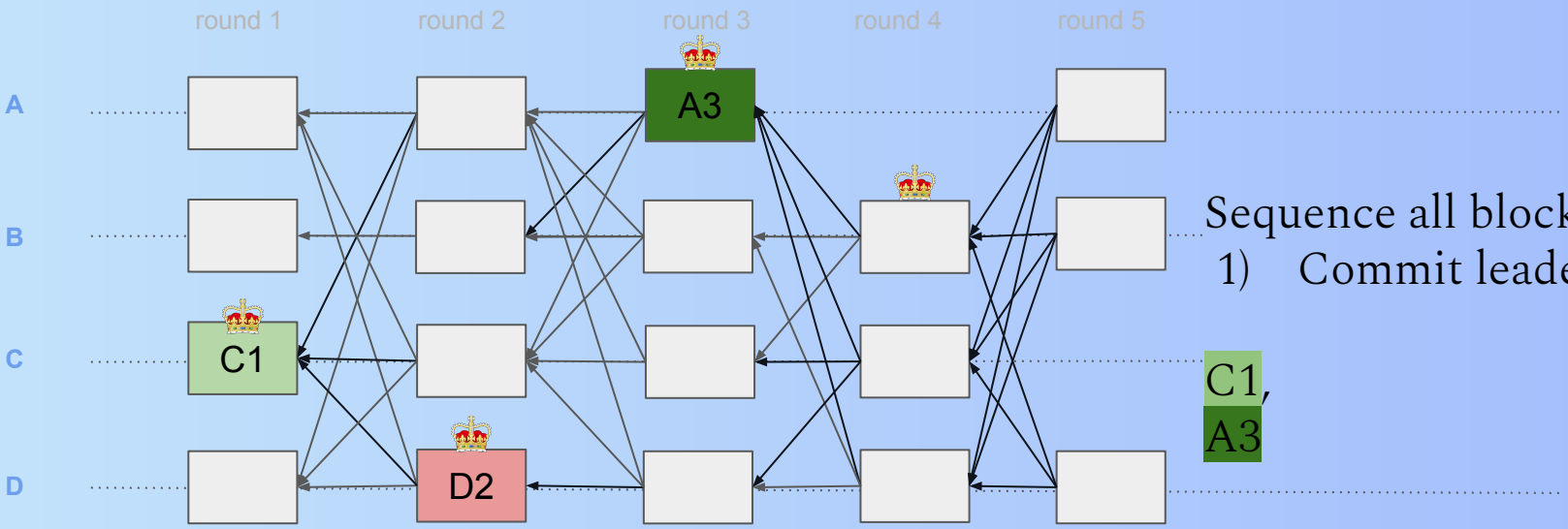

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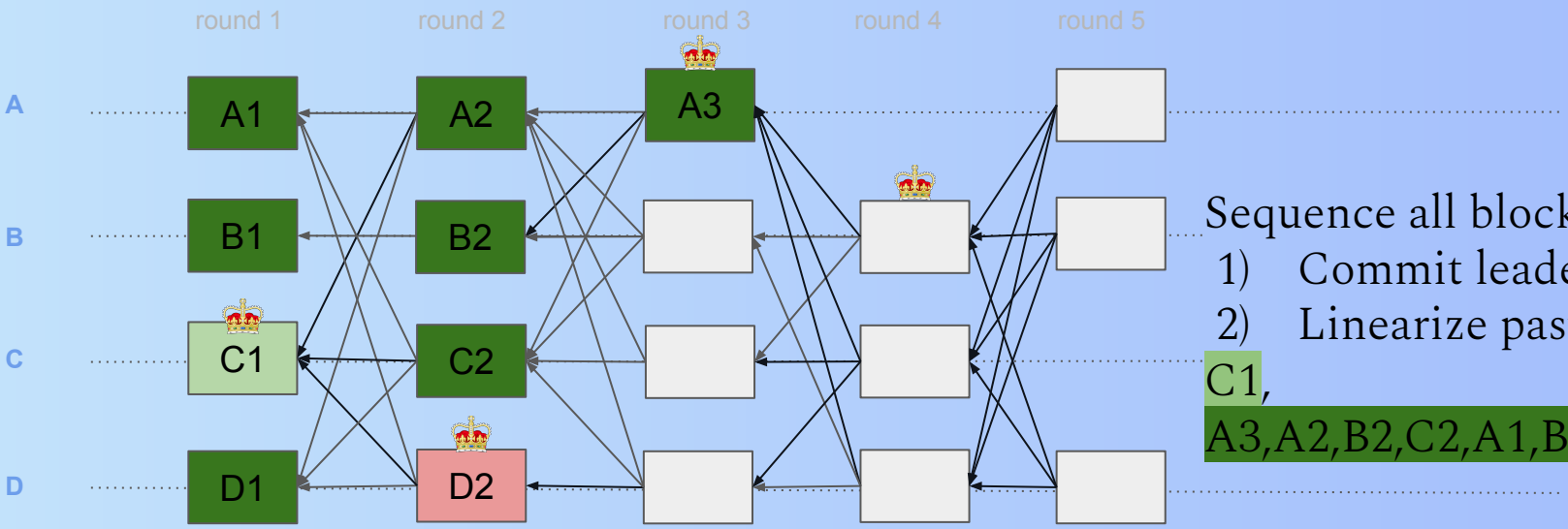


Sequence all blocks:

1) Commit leaders
2) Linearize past

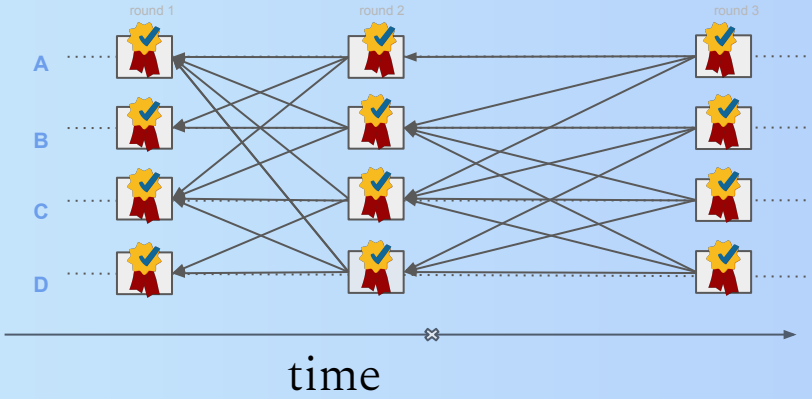
C1,

A3,A2,B2,C2,A1,B1,A1

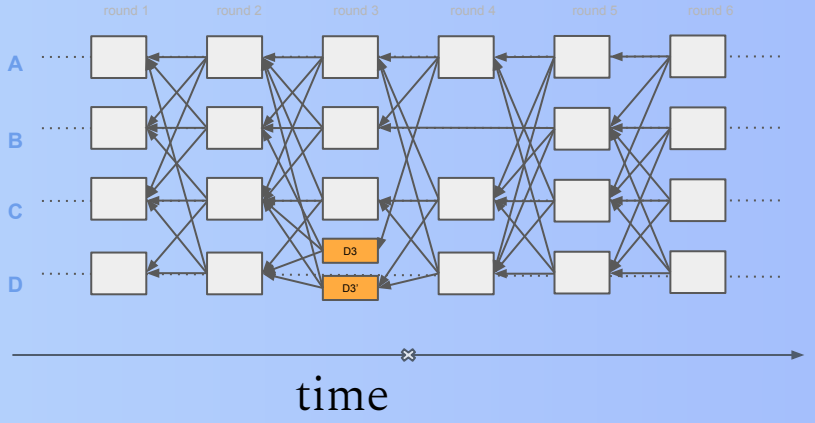
Uncertified DAG and motivation

Certified DAG vs Uncertified DAG

Each block includes a **certificate** — a quorum of 2f+1 signatures confirming its availability and uniqueness.



Each block is added **optimistically** after verifying the correctness of its causal past.



IOTA

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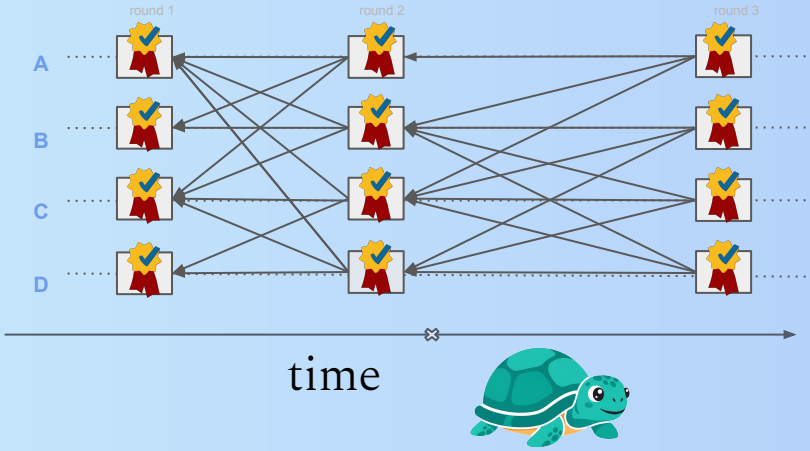

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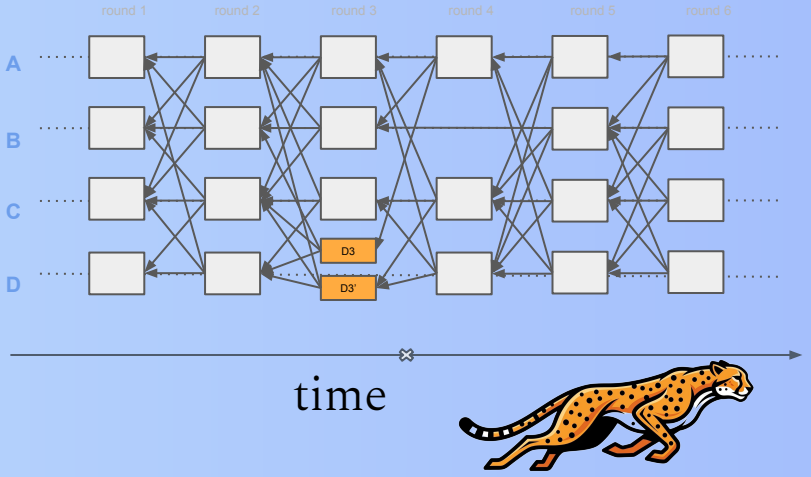

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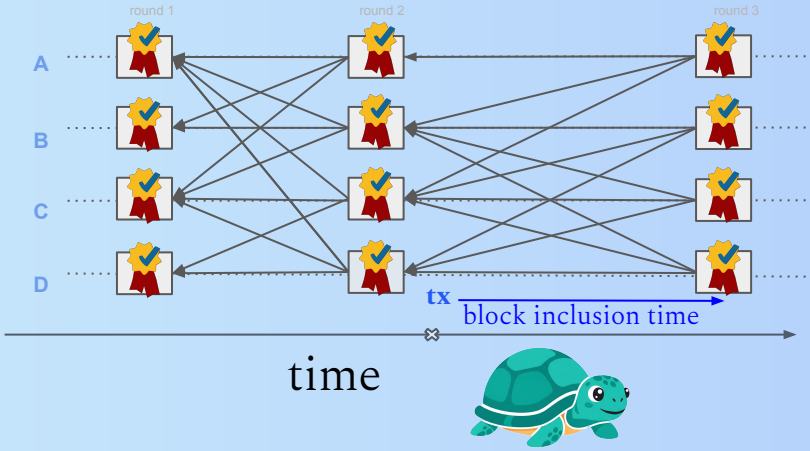

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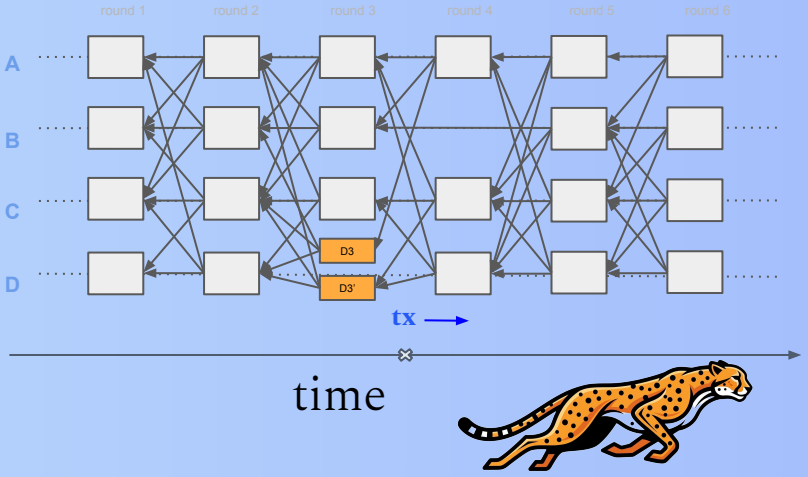
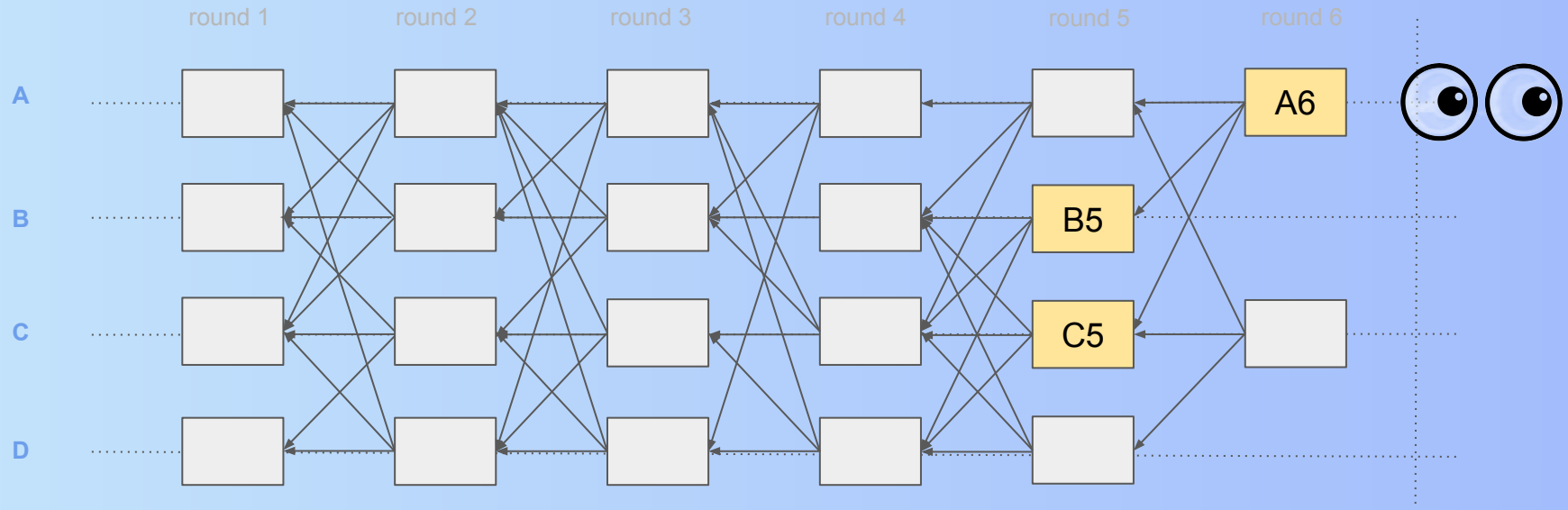


Broadcasting blocks (theory)



``**Push** to others blocks you know and think they need..." [†]
(example: A will send yellow blocks to D)

[†] *Cordial Miners*. DISC 2023

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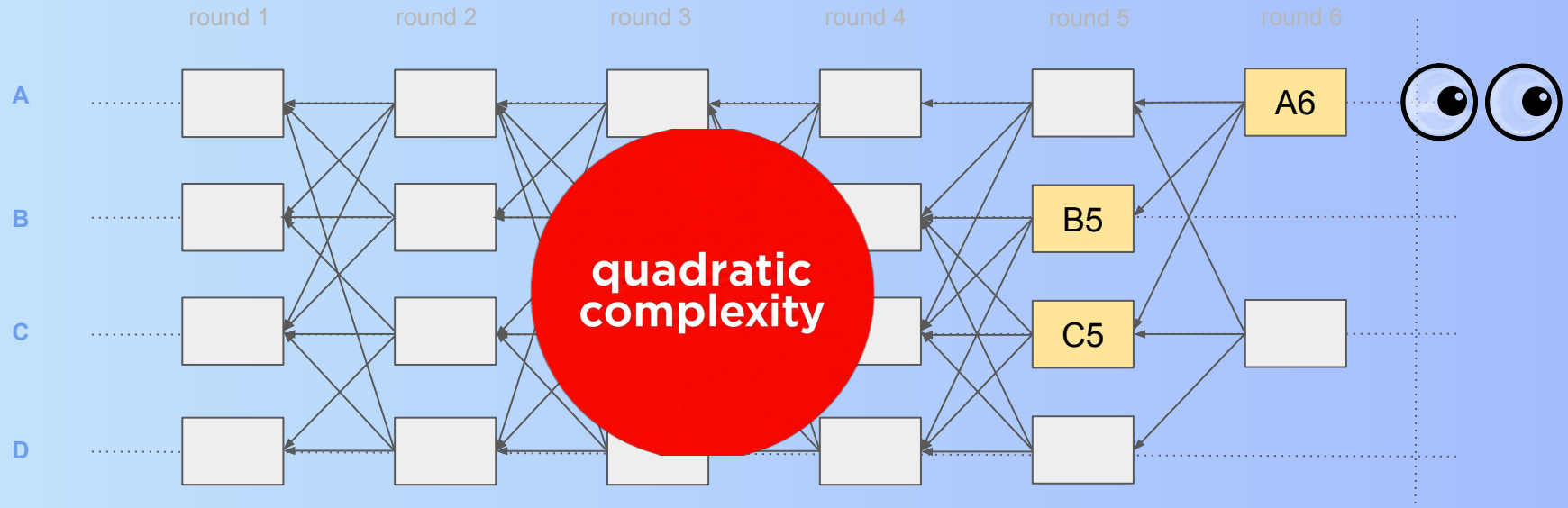

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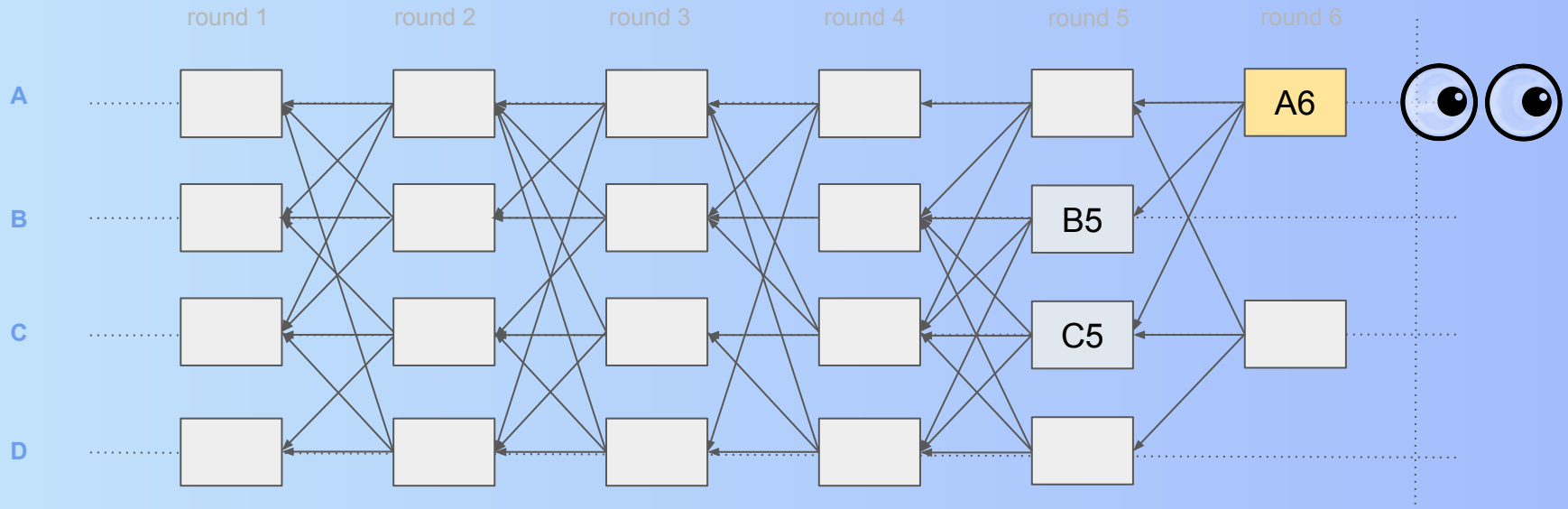
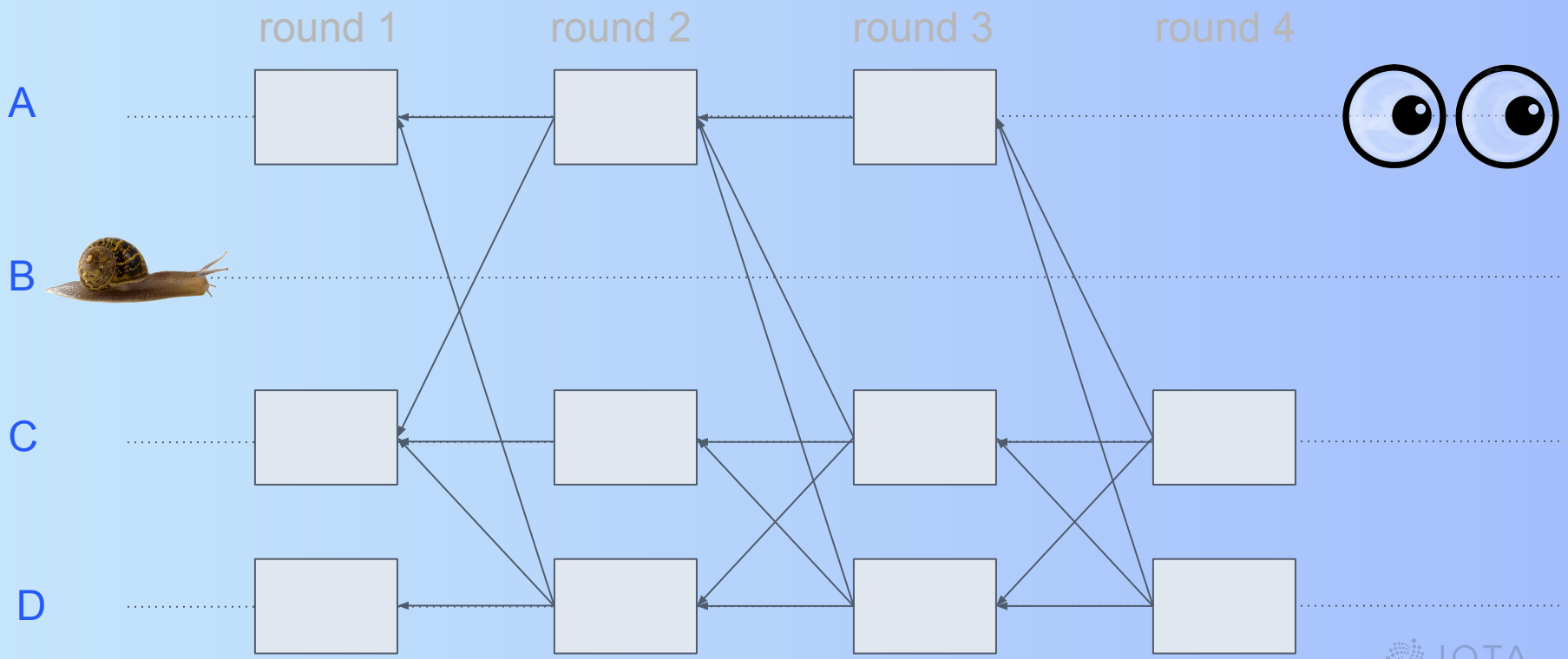
Broadcasting blocks (implementation)



``Send to others only your own blocks and **pull** the unknown ancestors..."

Mysticeti. NDSS 2025

Pull-based dissemination issue



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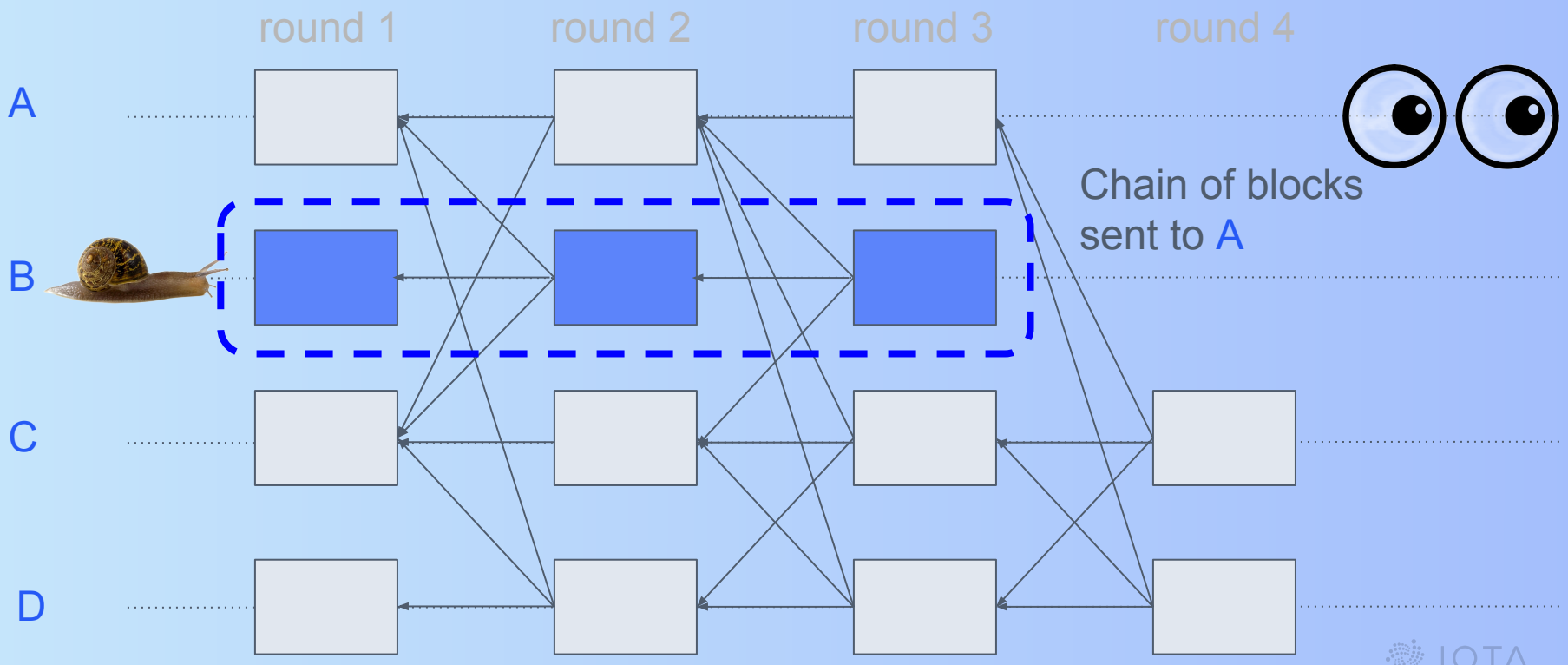

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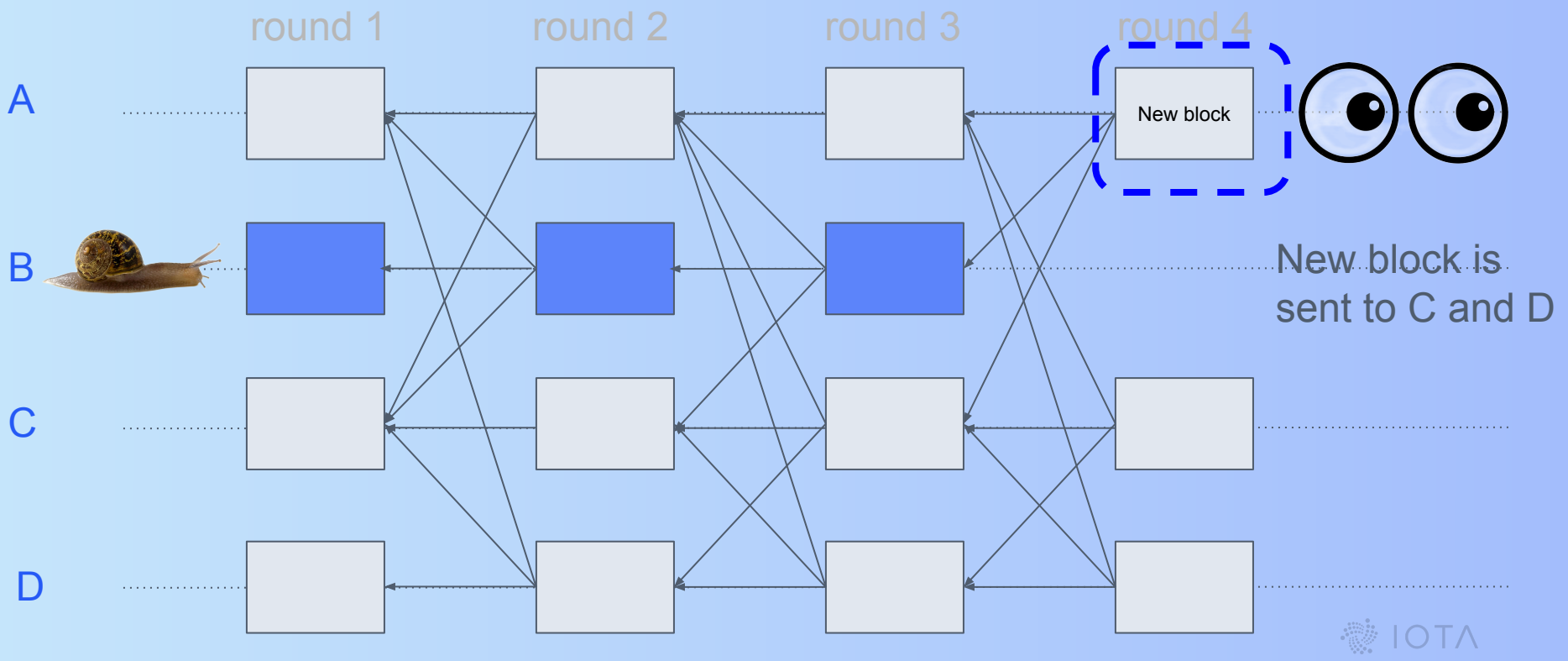

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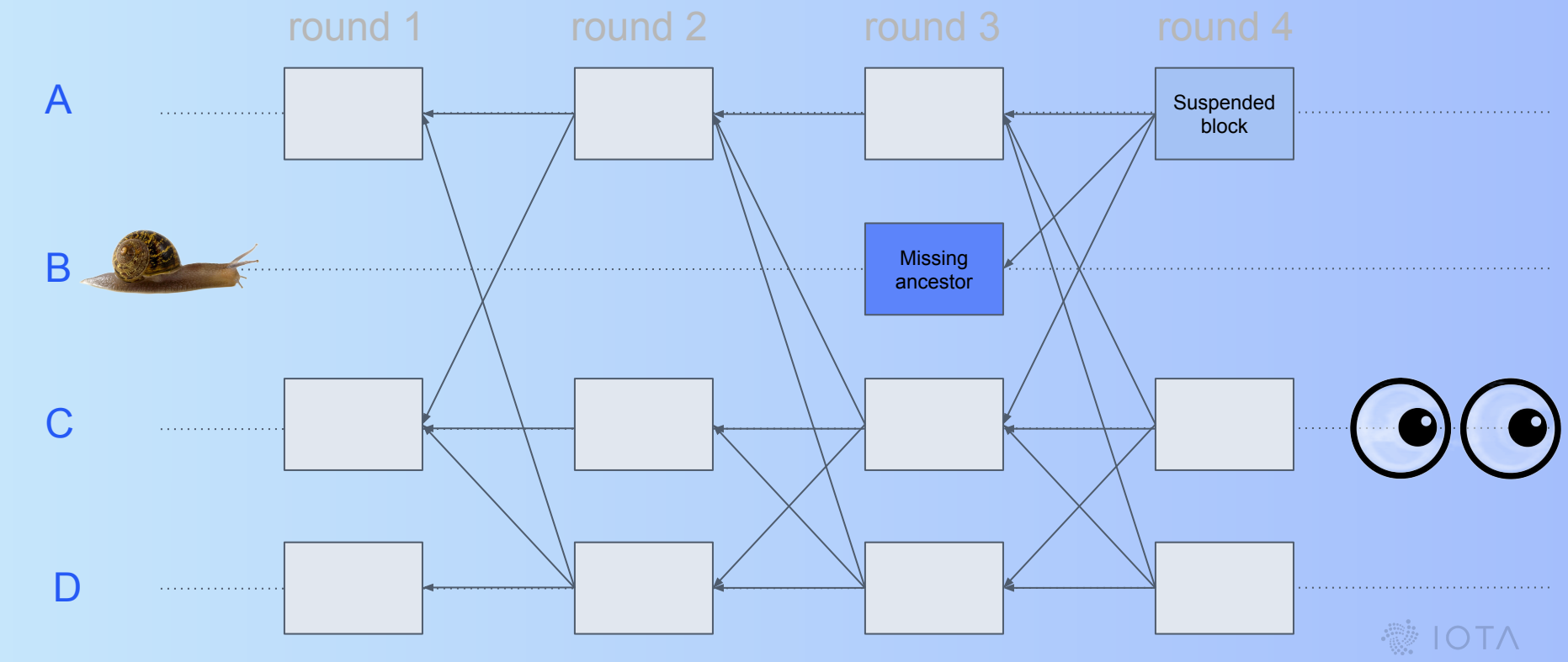

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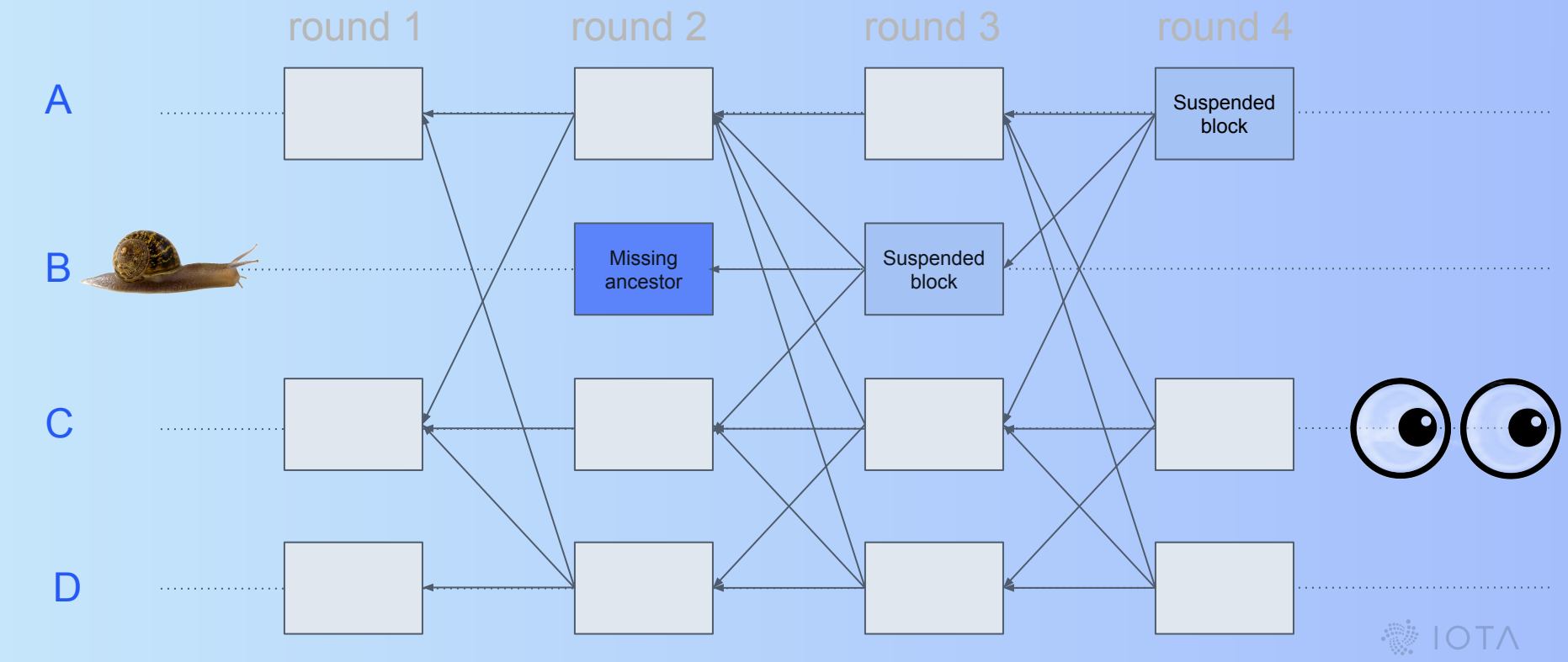

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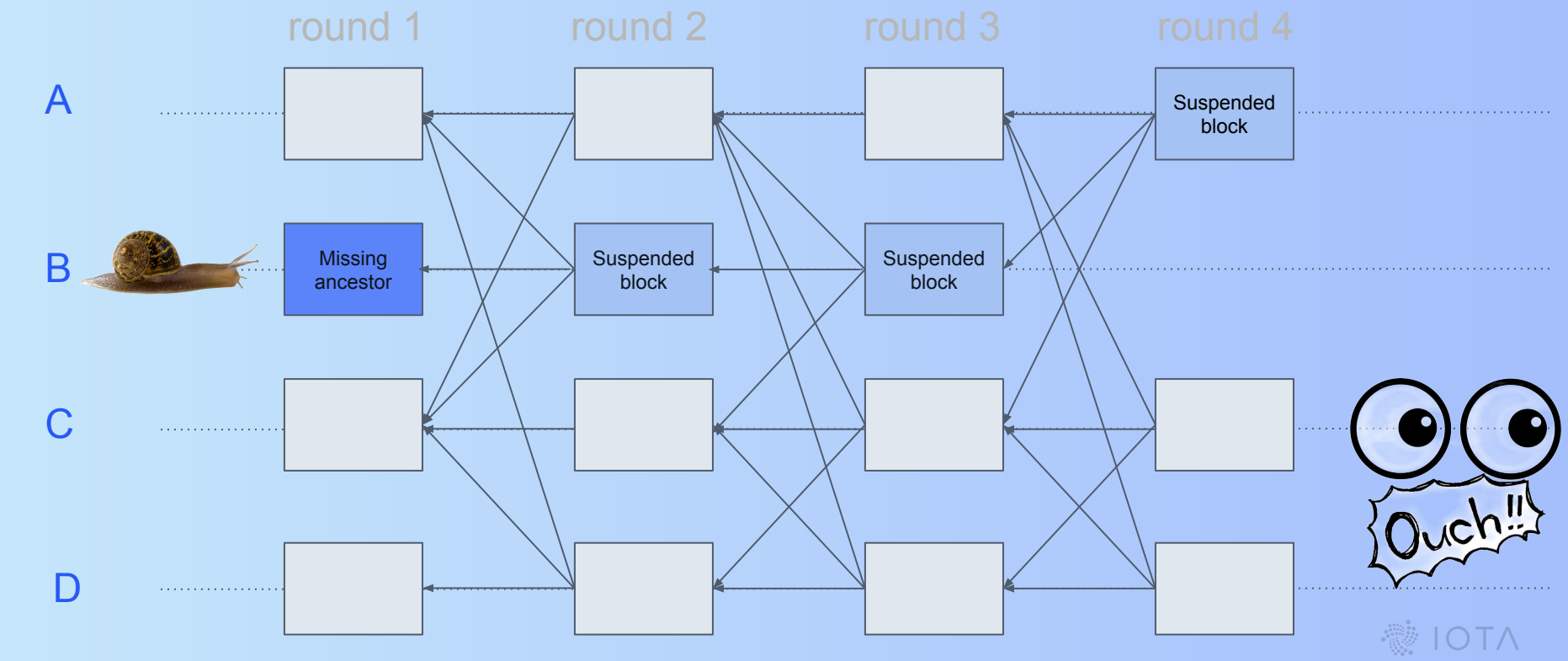

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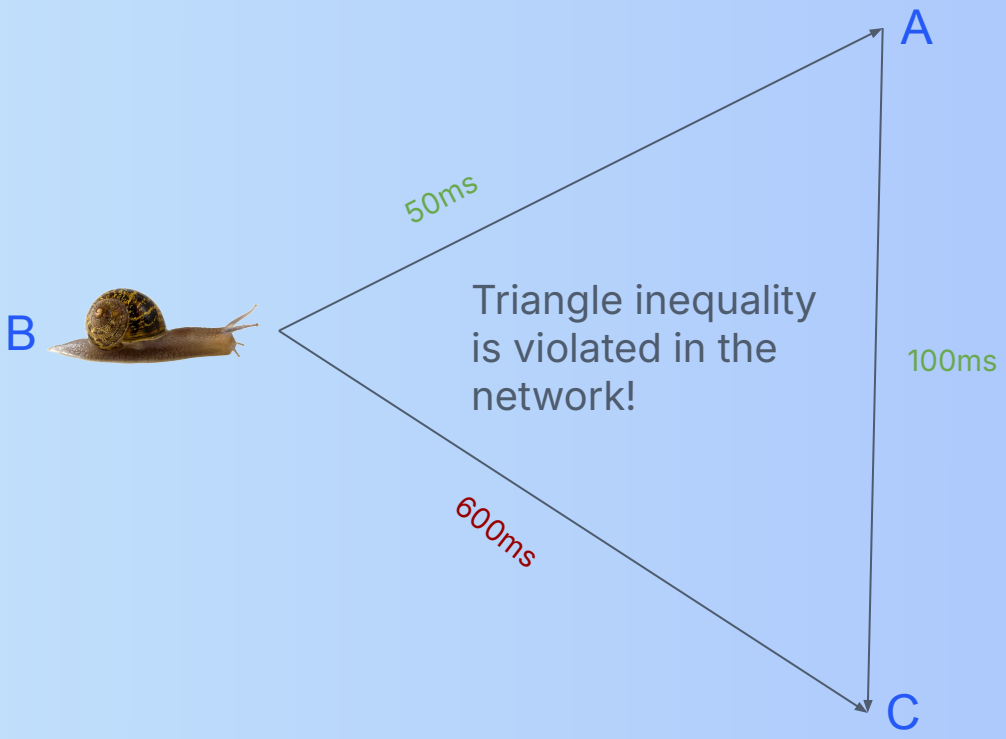


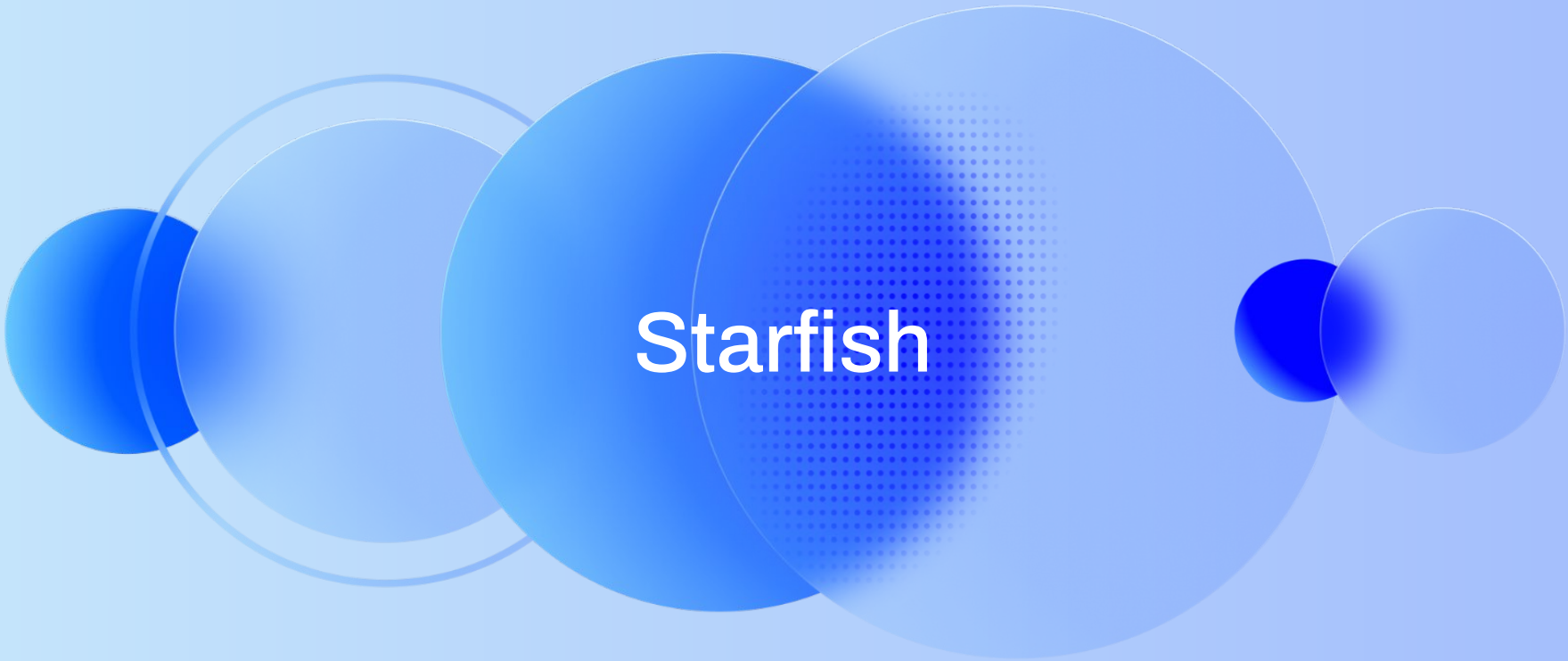
Motivation of Starfish

1. **Mitigate triangle inequality issue in network**

   Ensure that your blocks can be accepted in the local DAG of a peer upon their reception

2. **Keep bandwidth usage linear with tx data**

   Achieve linear communication complexity for transaction data even in Byzantine network


Starfish

Two ideas of Starfish

1. Decouple transaction data from block header metadata
    a. **Why:** pushing block headers is feasible because of the size
    b. **Purpose of headers:** driving DAG construction and consensus commits
    c. **When to sequence tx data:** at least 2f+1 nodes *acknowledged* that data is available

Block header:
- Round
- Author
- Ancestors
- Acknowledgements
- Tx data commitment
- Signature

Block:
- Block header
- Tx data

Two ideas of Starfish

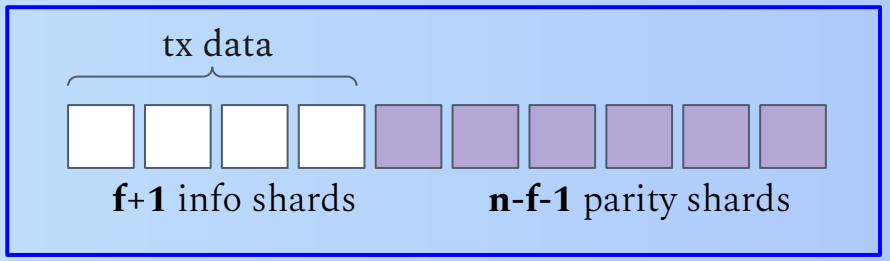
2. Encode transaction data with Reed-Solomon erasure codes

   a. **How to encode:** divide tx data into f+1 shards and encode with [n,f+1] RS codes

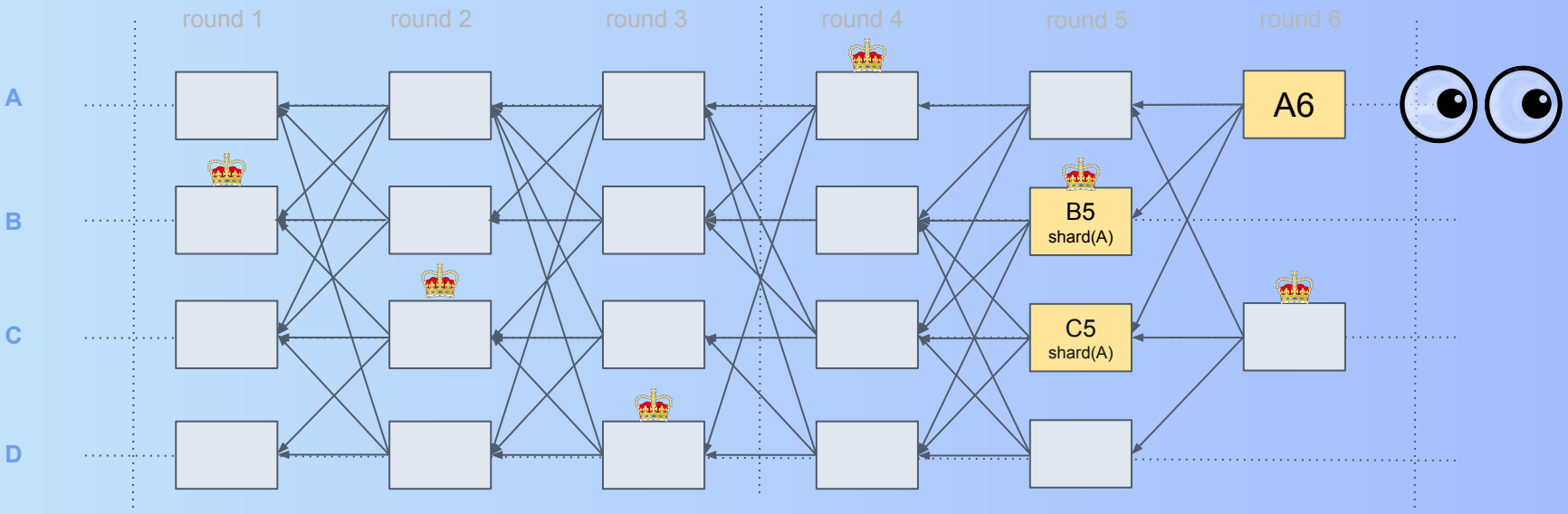
   b. **What to send (your data):** tx data + encoded tx commitment

   c. **What to send (data of other nodes):** one shard + shard proof

   d. **How to decode:** either received full data, or decode any f+1 shards



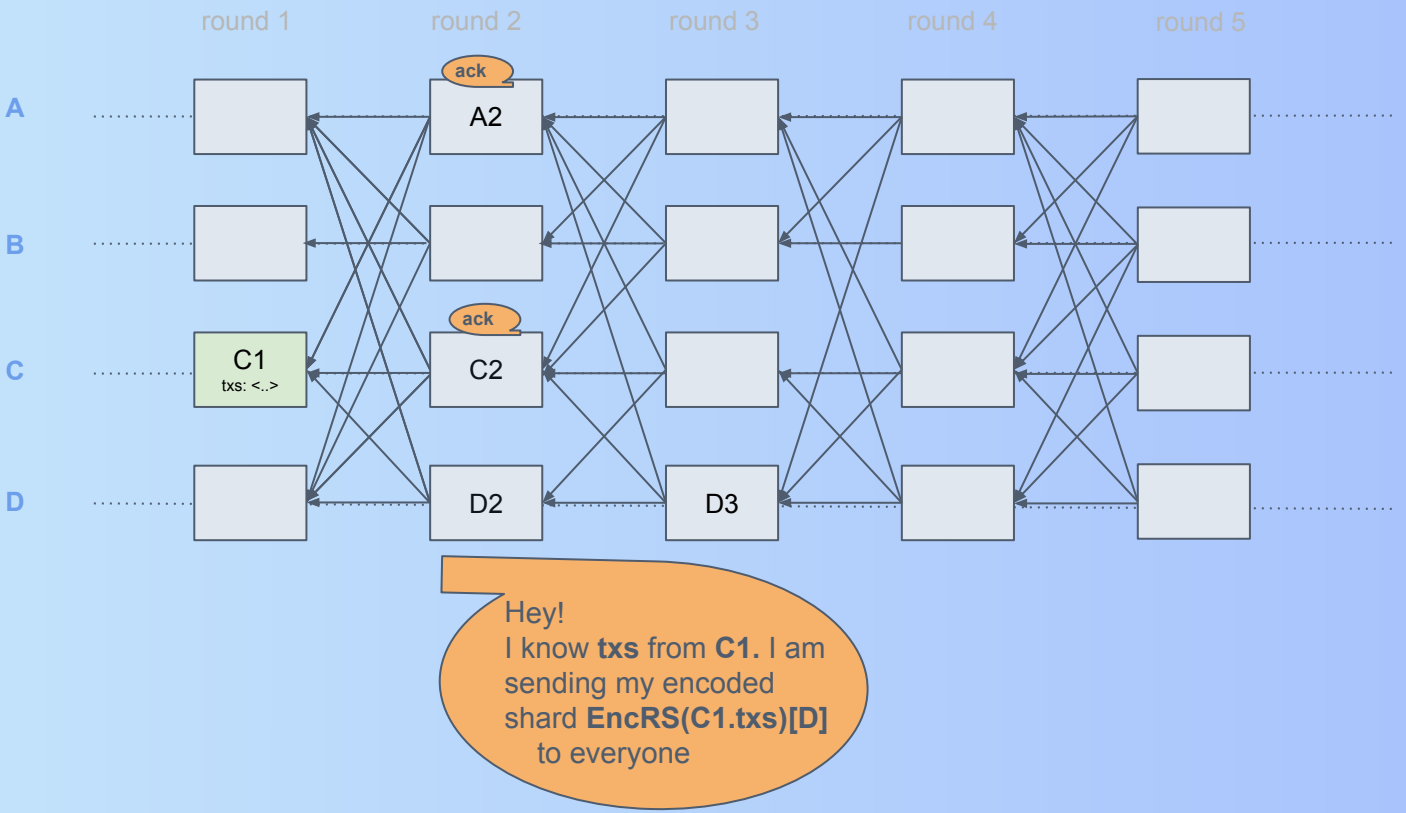
Broadcast rule in Starfish



``Send to others **block headers** (!) you know and think they need...

In addition, send your **encoded shard** when the transaction data is available"

Sequencing tx data in Starfish



IOTA

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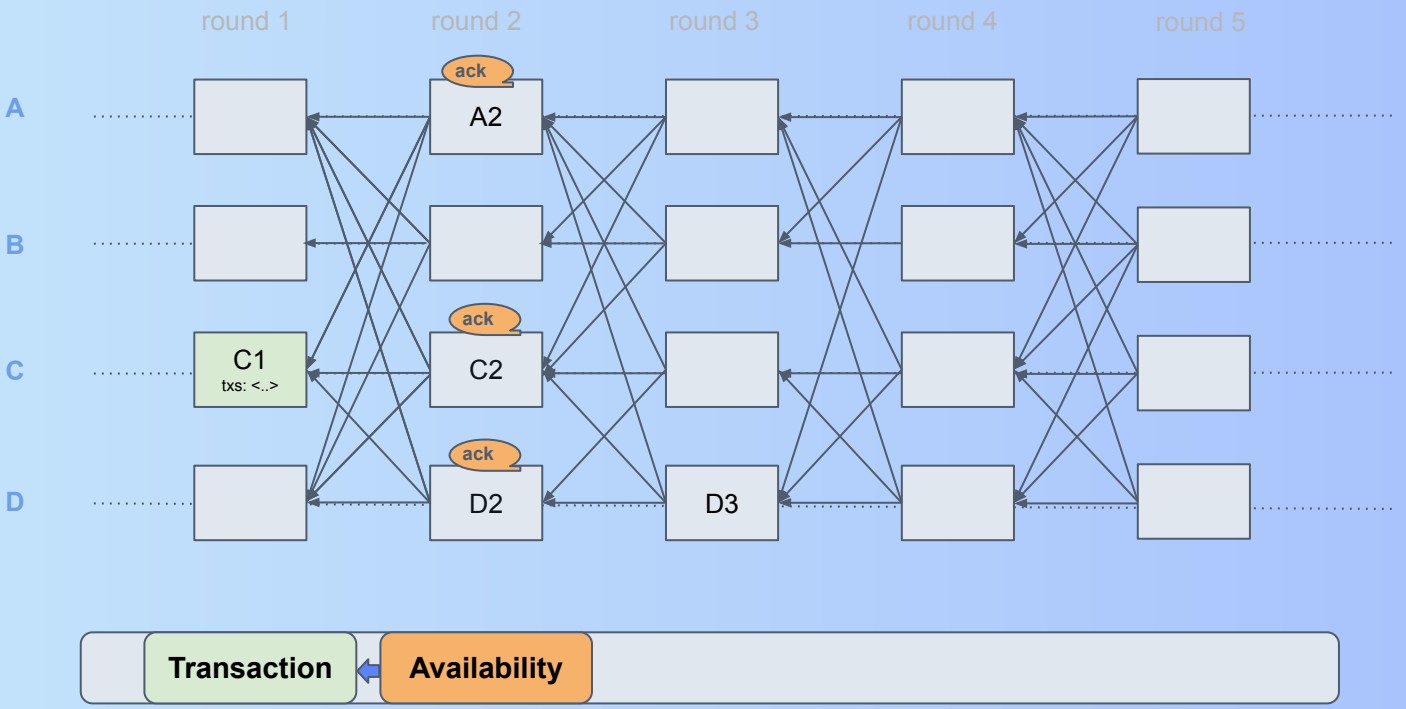
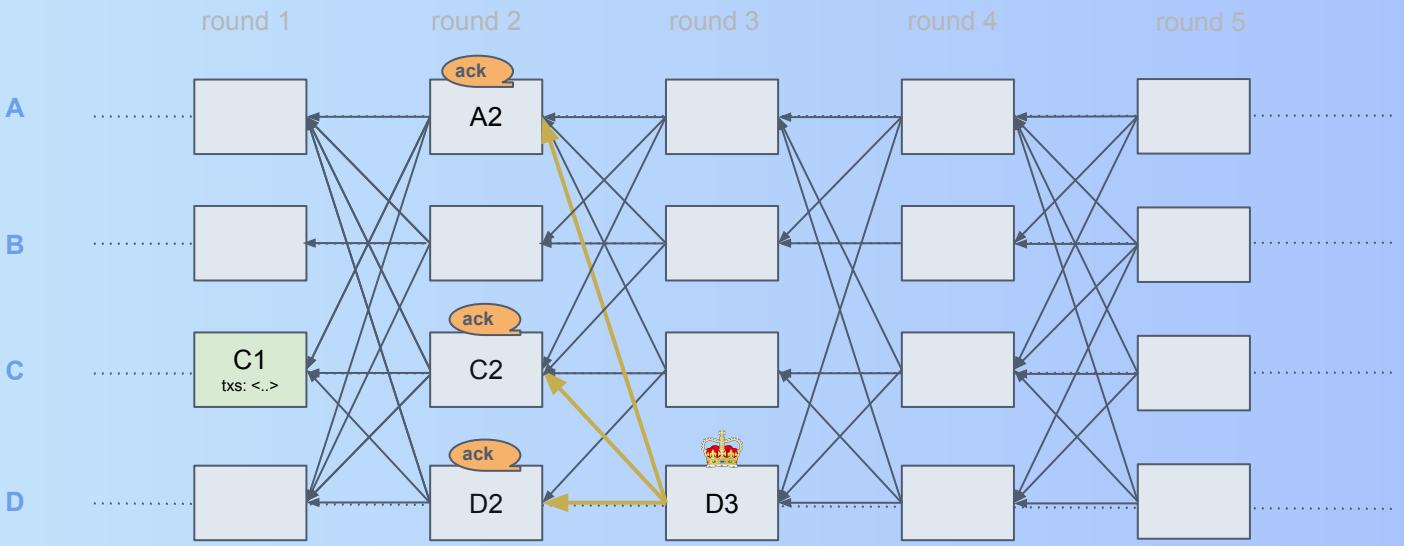
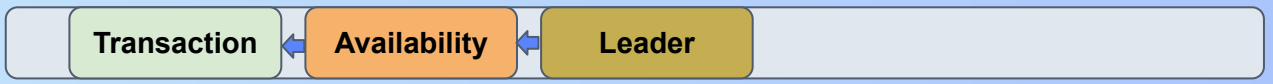


Sequencing tx data in Starfish



2f+1 acks are visible from the leader



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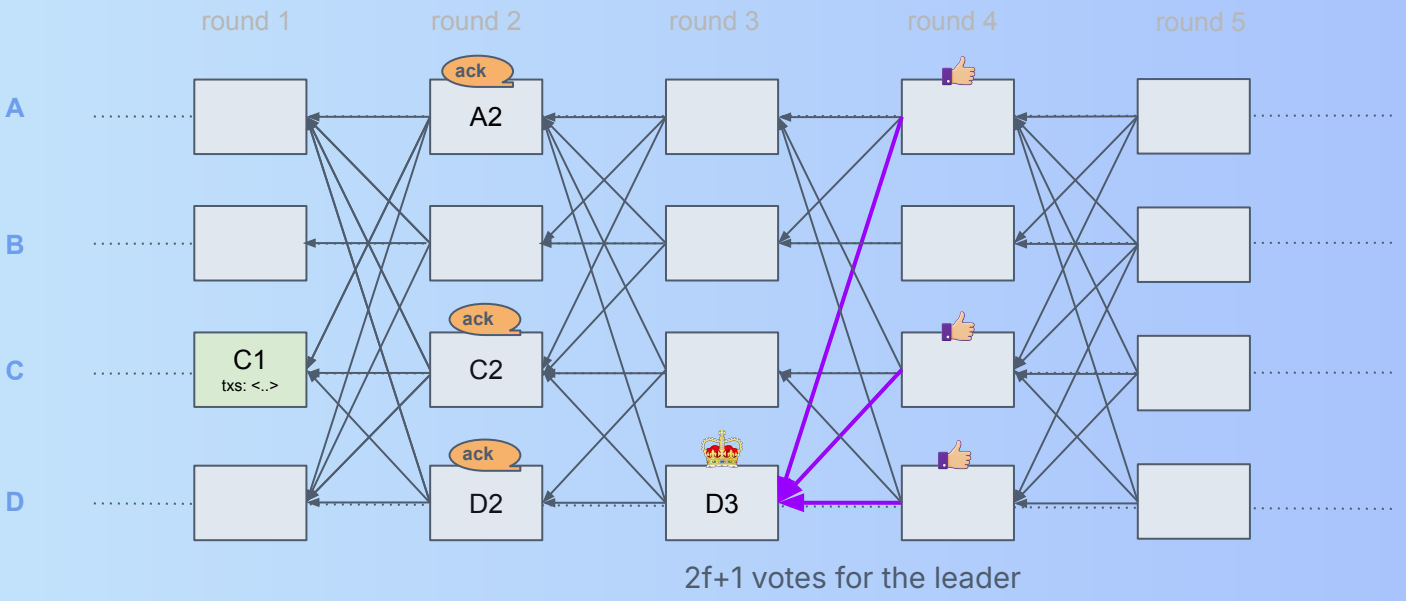
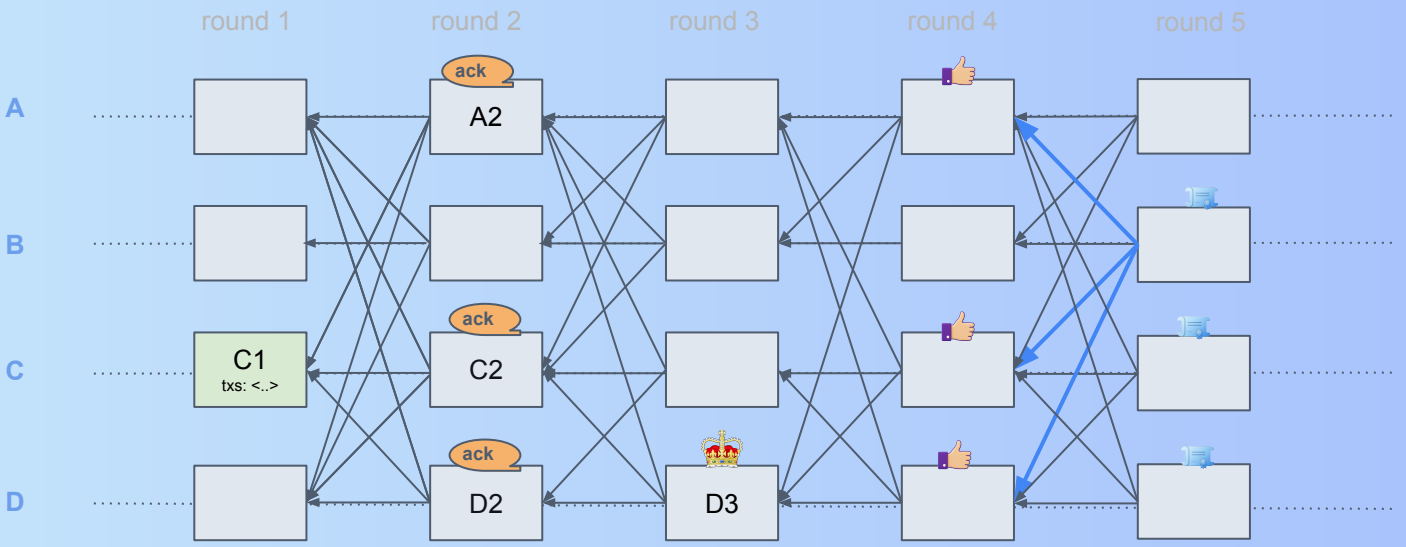
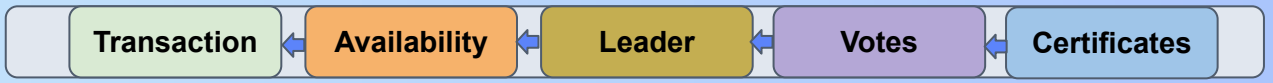


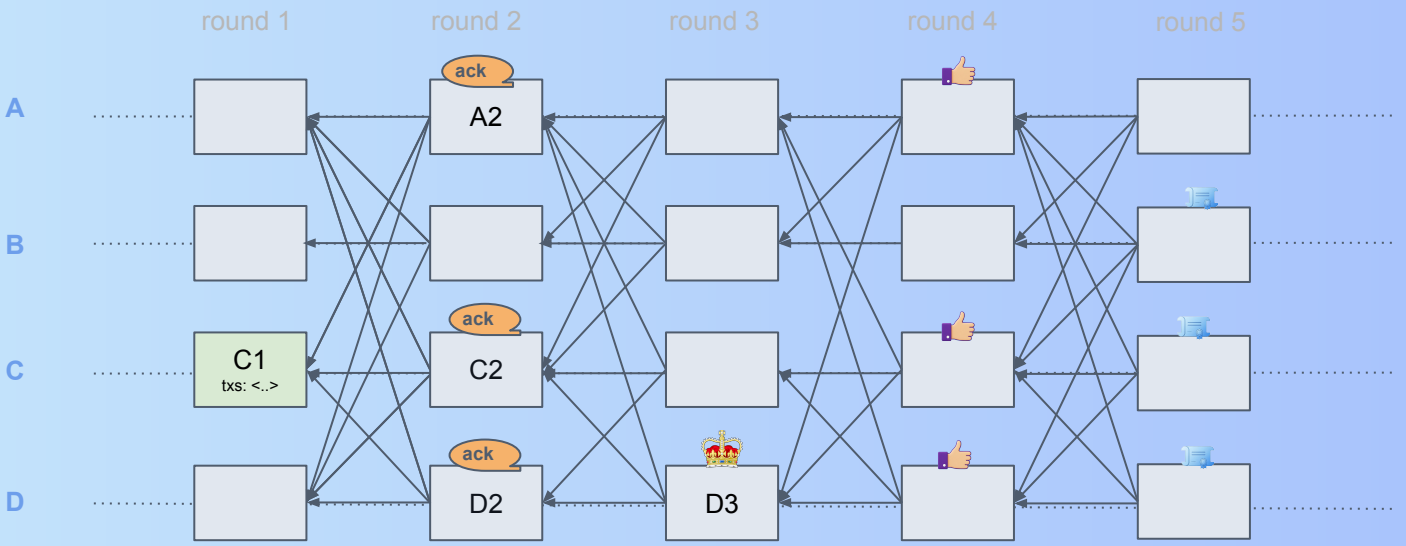
Sequencing tx data in Starfish

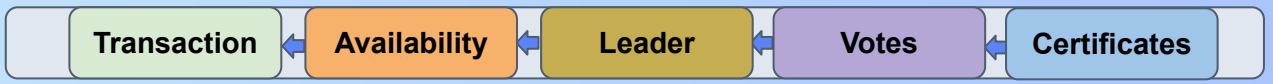




IOTA

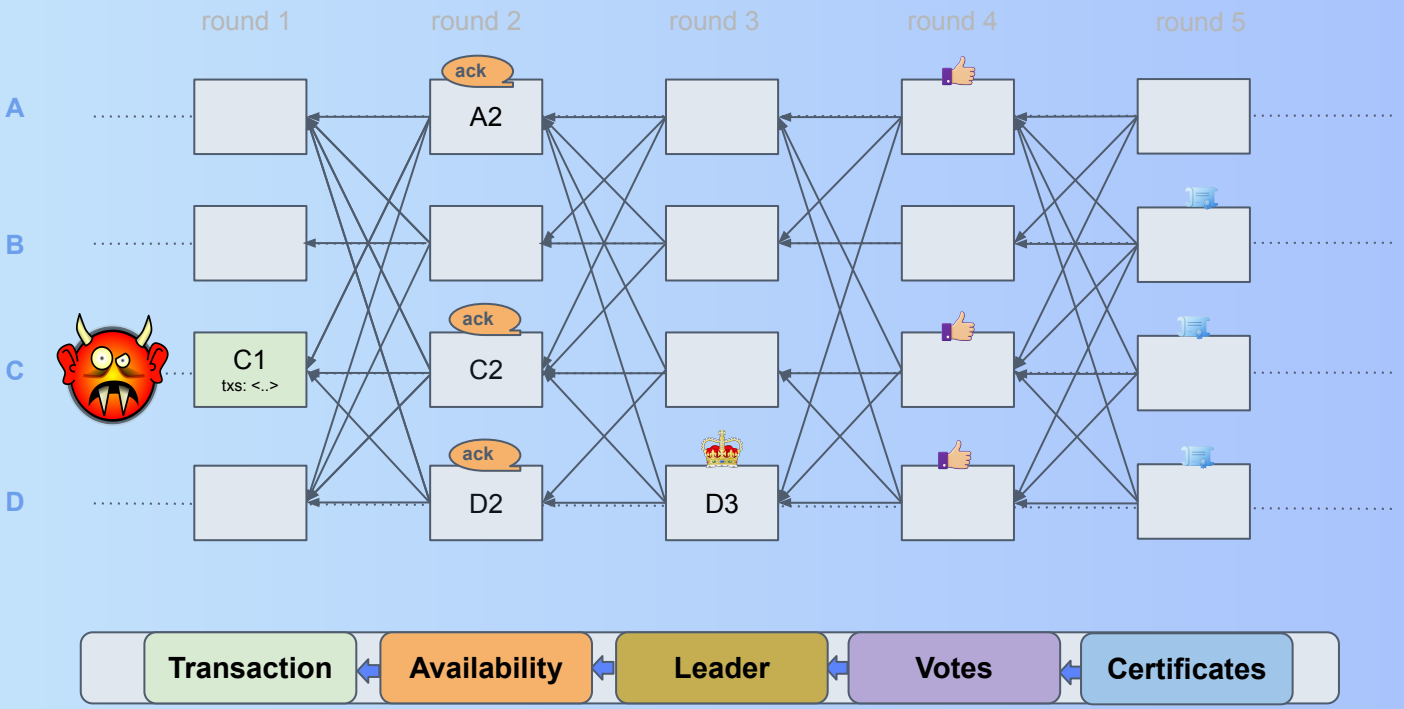
Sequencing tx data in Starfish





IOTA

Recoverability of committed transaction data



B didn't get from C transactions in **C1**...

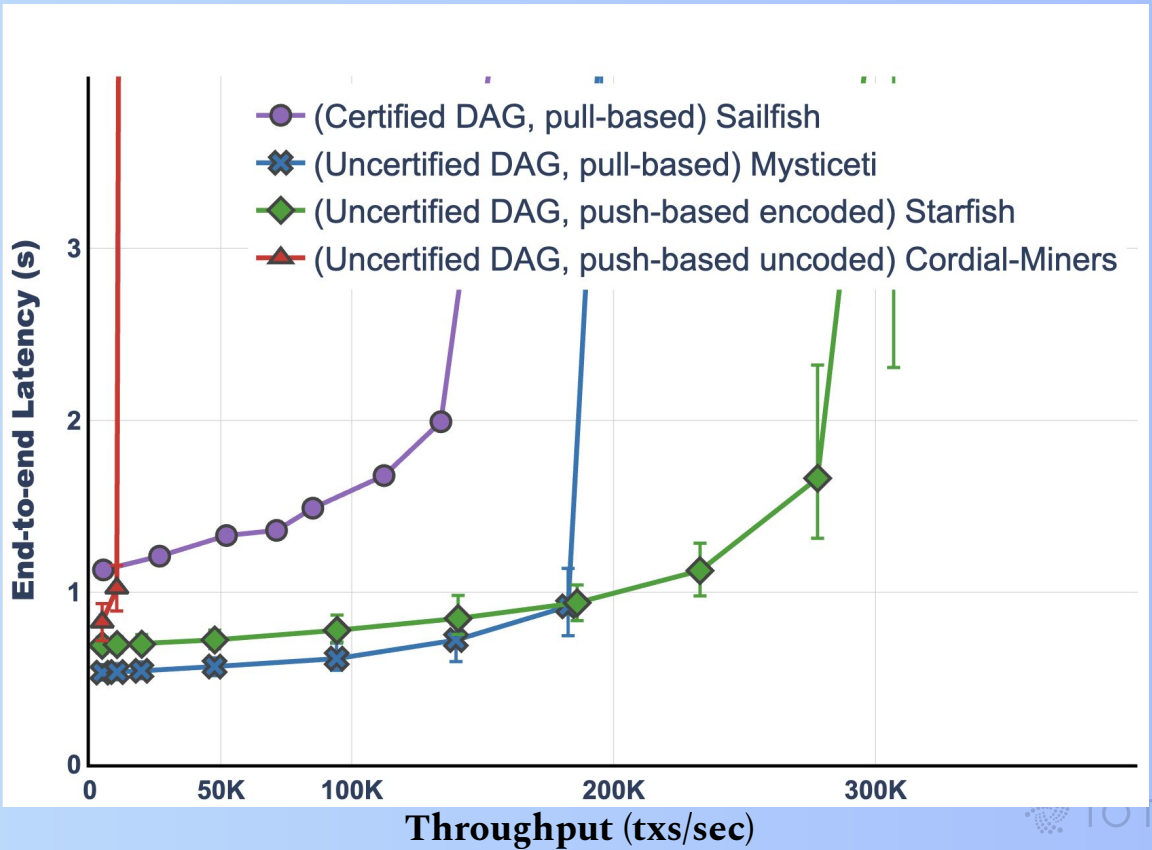
But recover from shards sent by A and D

IOTA

Performance and comparison

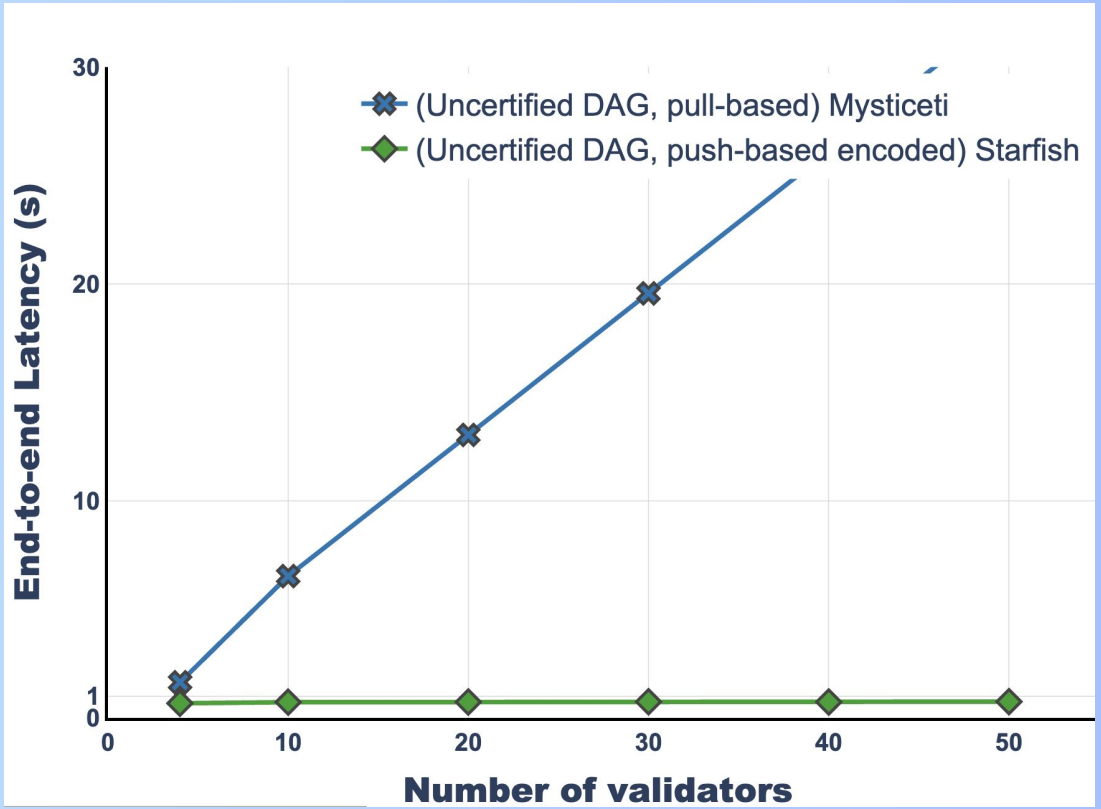
Baseline (no Byzantine validators)

- 100 validators
- geo-distributed network over 10 regions
- 512B-sized transactions
- Amazon EC2 m5d.4xlarge machines

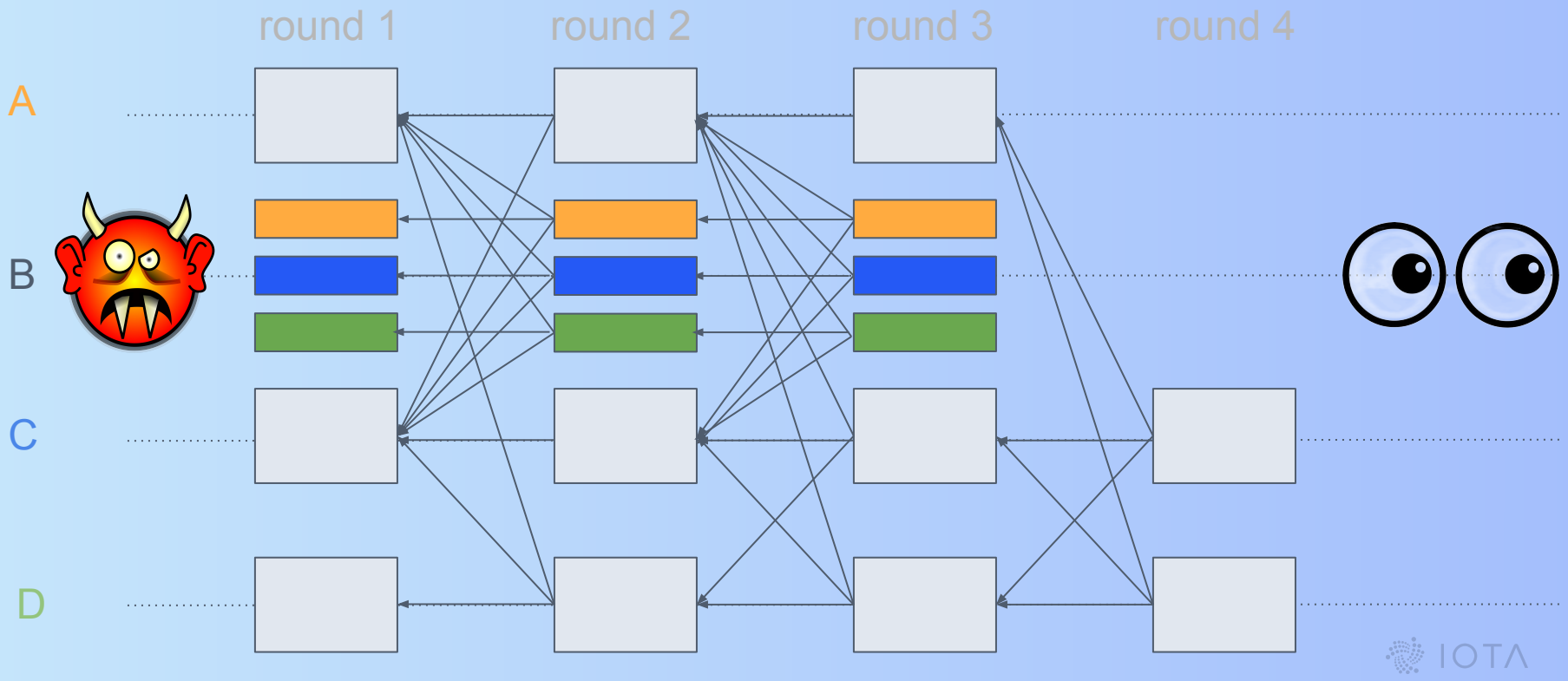


Equivocating chains bomb (only 1 Byzantine validator)

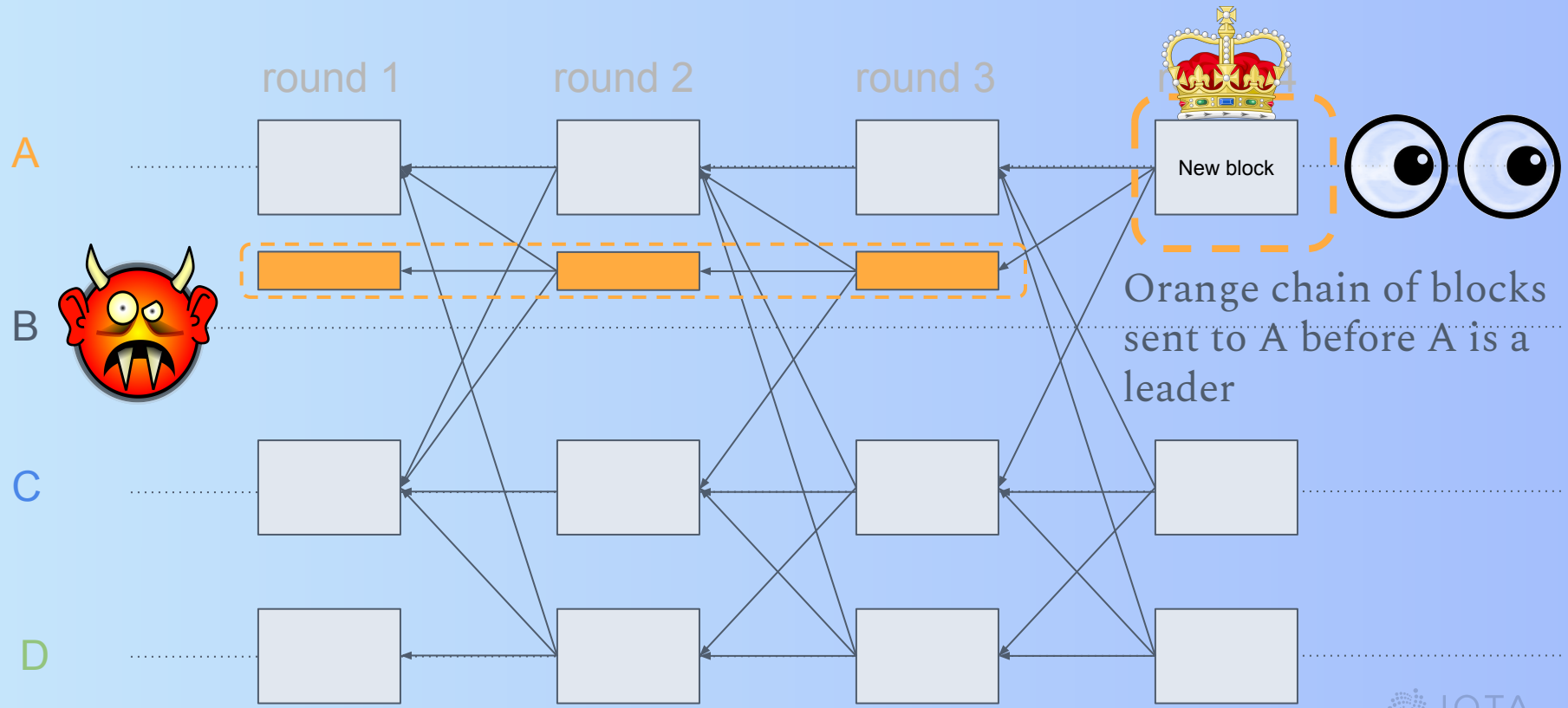
- 10-50 validators
- geo-distributed network over 10 regions
- 512B-sized transactions
- Target load 10,000 txs / sec
- Amazon EC2 m5d.4xlarge machines



Equivocating chains bomb attack



Equivocating chains bomb attack



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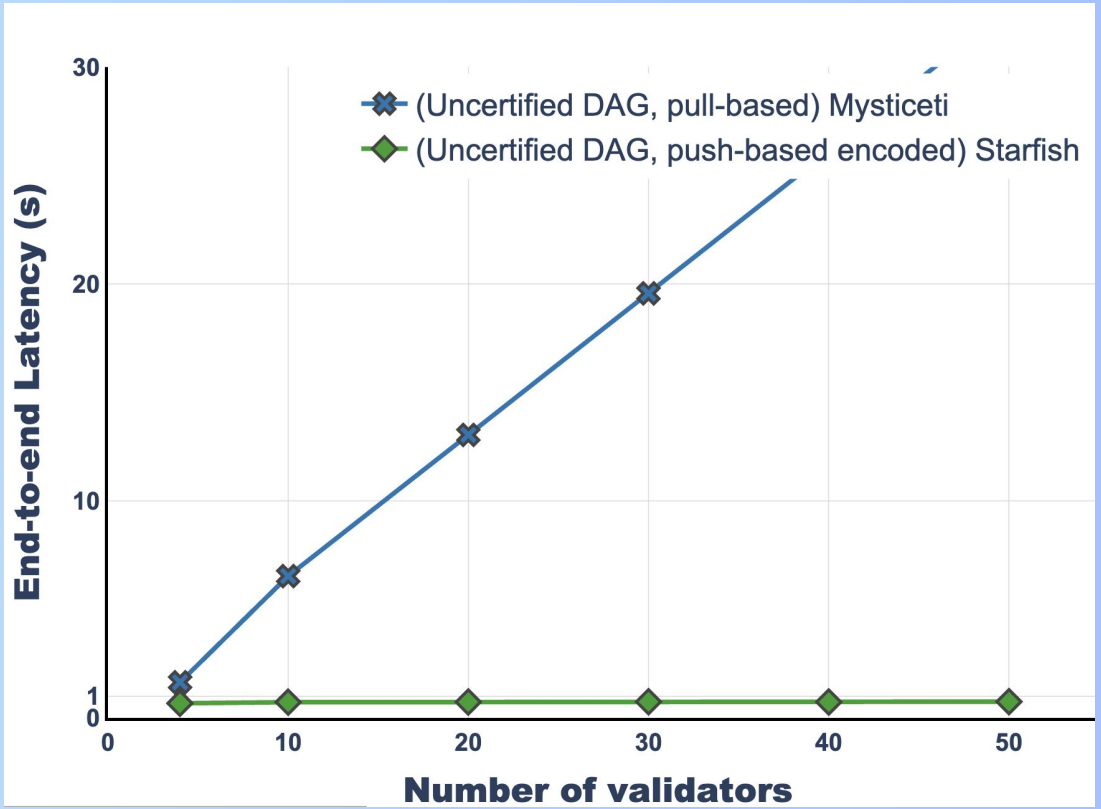

Comparison

	Byzantine broadcast primitive	Avg. block latency	Avg. e2e latency	One failure leader	Amort. comm. complexity
Bullshark	RBC for all blocks	14δ	$+2\delta$	$+(8\Delta + 8\delta)$	$O(n)$
Shoal	RBC for all blocks	12δ	$+2\delta$	$+(8\Delta + 4\delta)$	$O(n)$
Shoal++	RBC for all blocks	5δ	$+0.5\delta$	$+(8\Delta + 4\delta)$	$O(n^2)$
Sailfish 1	RBC for all blocks	9δ	$+2\delta$	$+(8\Delta + 2\delta)$	$O(n)$
Sailfish 2	RBC for all blocks	5δ	$+\delta$	$+(4\Delta + 2\delta)$	$O(n^2)$
BBCA-chain	BBCA for leaders	4δ	$+1.5\delta$	$+4\Delta$	$O(n^2)$
Cordial Miners	None	5δ	$+0.5\delta$	$+6\Delta$	$O(n^2)$
Mysticeti	None	4δ	$+0.5\delta$	$+4\Delta$	$O(n^2)$
Starfish	**None**	5δ	$+0.5\delta$	$+2\Delta$	$O(n)$

Summary

Starfish ...

- is a **high-performance** partially synchronous BFT protocol
- is built on **uncertified DAG**
- relies on **push-based** block dissemination strategy with **encoding**
- achieves **lowest latency** in the class of DAG-based protocols with **linear amortized communication complexity**
- has significantly better **robustness** against **Byzantine attacks** than existing uncertified DAG protocols

More info:

Thank you!

Questions?