HYDRA: Breaking the Global Ordering Barrier in Multi-BFT Consensus

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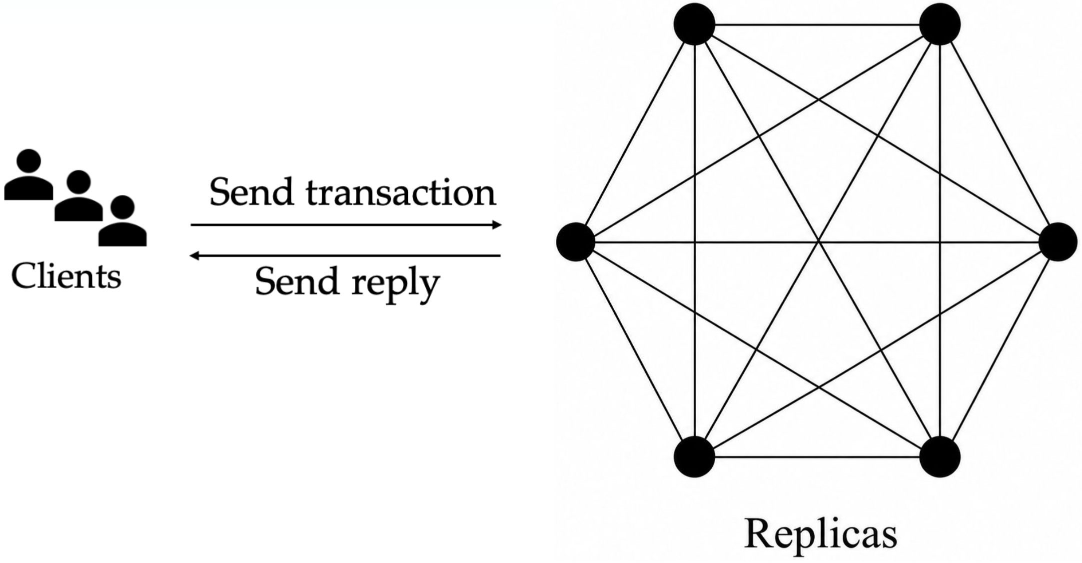
BFT Consensus

- **Byzantine Fault Tolerant (BFT) Consensus** allows a distributed system to reach agreement among replicas despite Byzantine failure (e.g., malicious attack).



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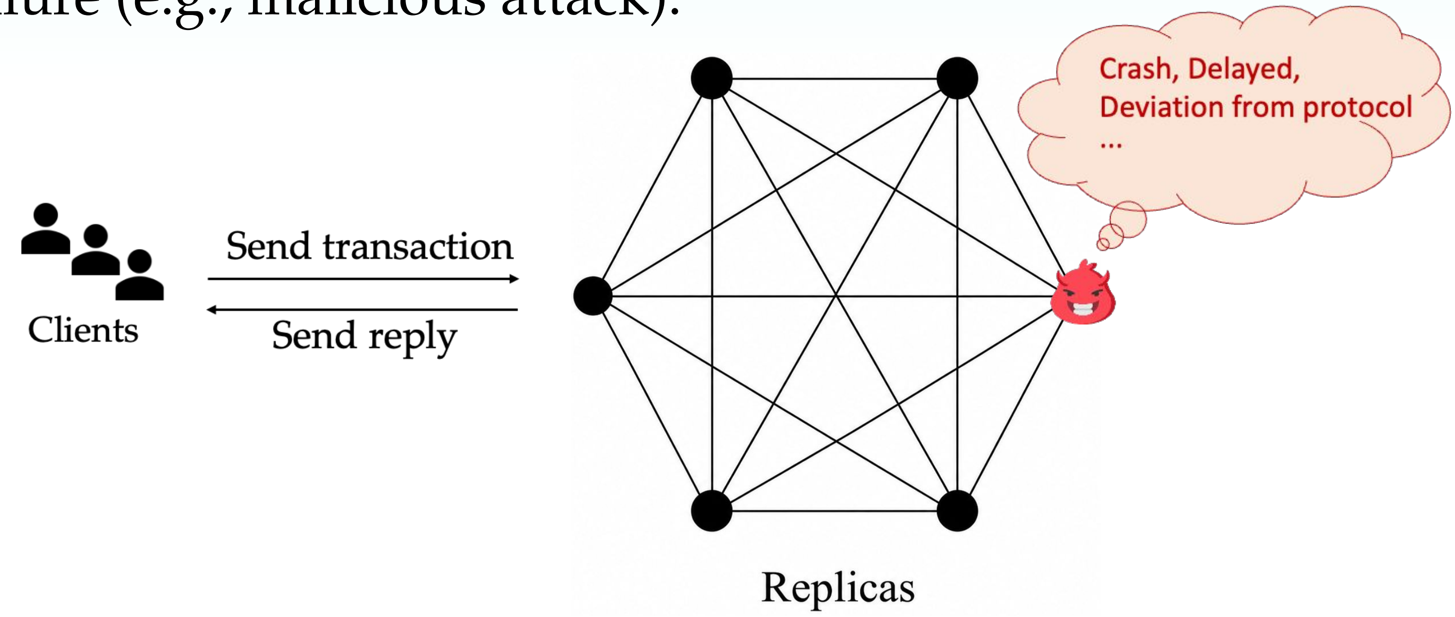
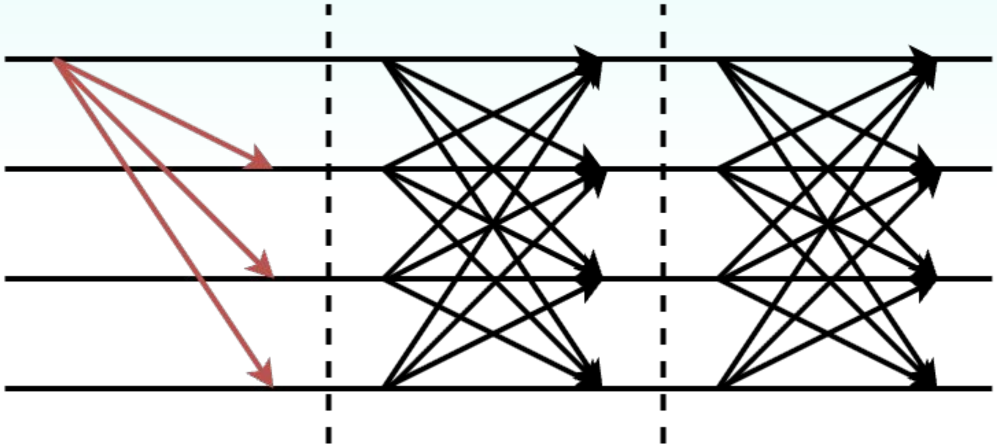


Leader-based BFT[1]

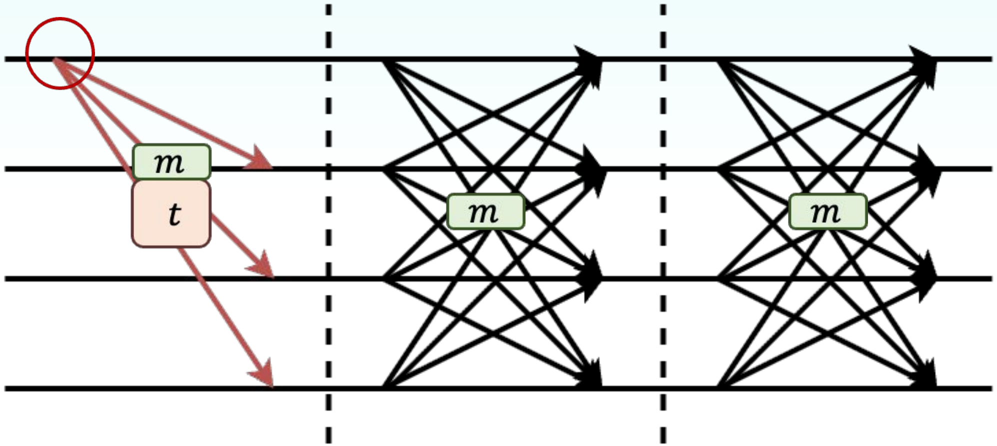


Practical Byzantine Fault Tolerance (PBFT) protocol

[1] Miguel Castro and Barbara Liskov. Practical Byzantine Fault Tolerance. In OSDI, 1999.

Leader-based BFT[1]

m: protocols's message (~100B)
t: the client's payload (~500KB)



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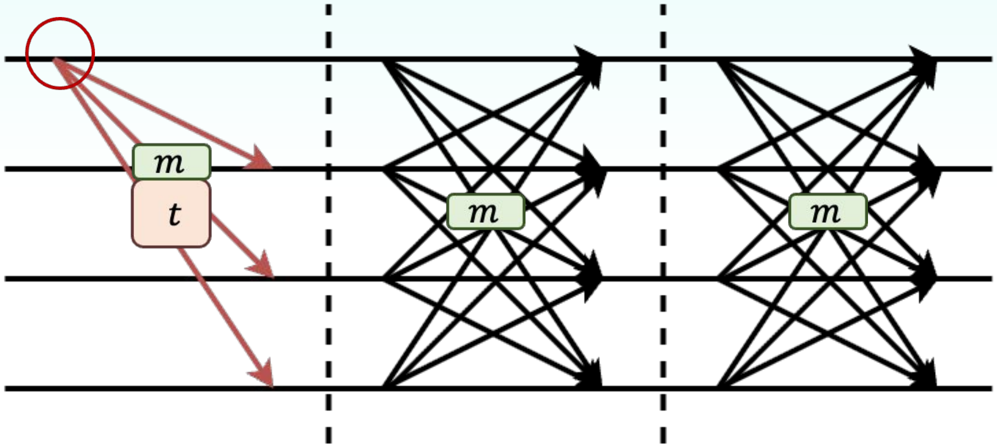


Practical Byzantine Fault Tolerance (PBFT) protocol

size(t) >> size(m)

Load Unbalanced!

$$T_{max} \approx \frac{B}{(n-1)size(t)}$$

Maximum throughput

Leader's bandwidth

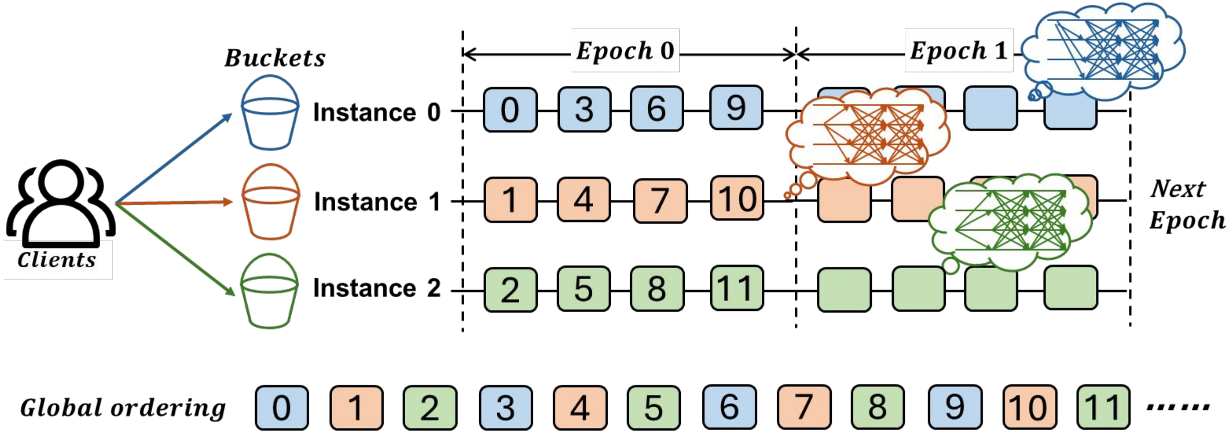
number of replicas

This cause the **Leader Bottleneck**: leader is too busy while others are idling.

[1] Miguel Castro and Barbara Liskov. Practical Byzantine Fault Tolerance. In OSDI, 1999.

Multi-BFT Consensus[1-3]

1. Client's transactions are split into distinct **Buckets**.



[1] Stathakopoulou et. al. State Machine Replication Scalability Made Simple, in ACM EuroSys'22.
[2] Stathakopoulou et. al. Mir BFT: Scalable and Robust BFT for Decentralized Networks, in Jsys'22.
[3] Gupta et. al. RCC: Resilient Concurrent Consensus for High-Throughput Secure Transaction Processing, in IEEE ICDE'21.

Multi-BFT Consensus[1-3]

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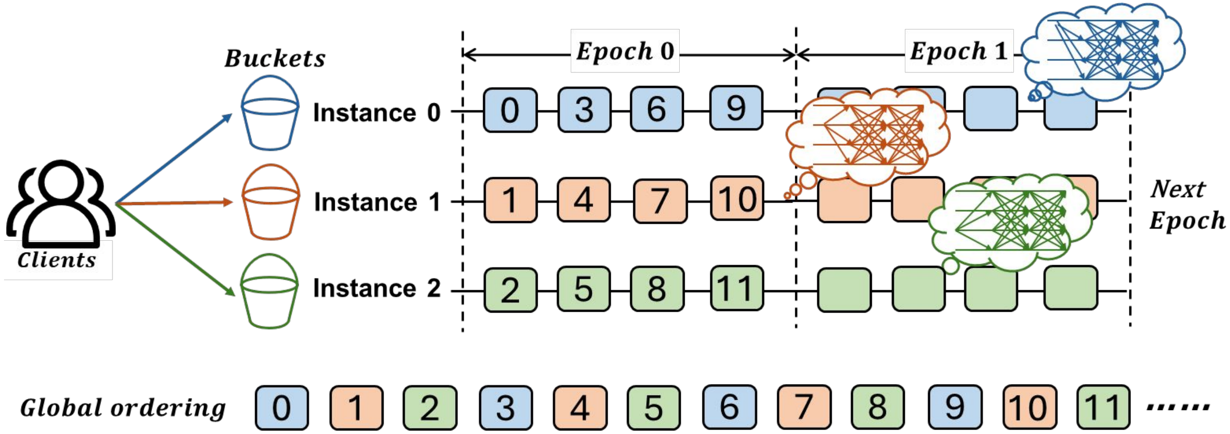

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Multi-BFT Consensus[1-3]

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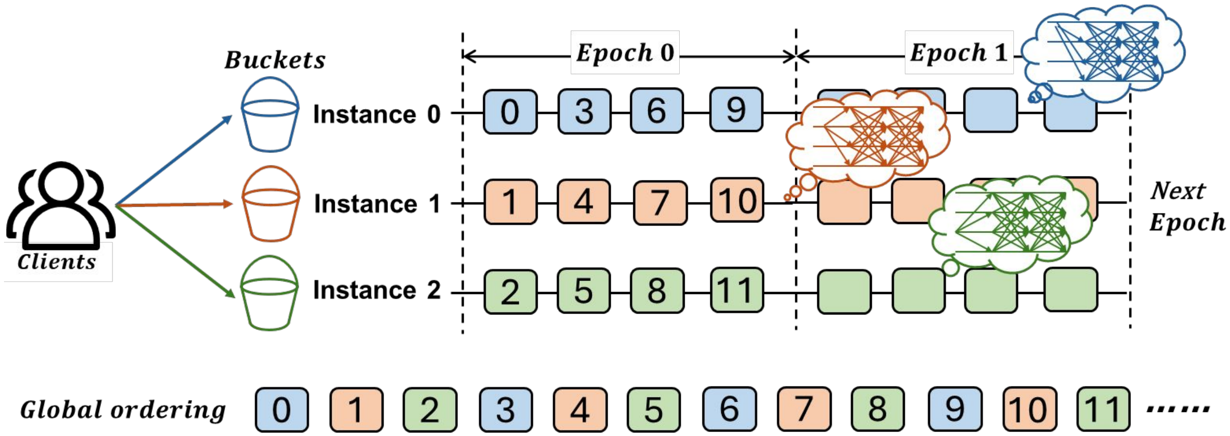
3. Each instance independently outputs a sequence of **partially committed blocks**.



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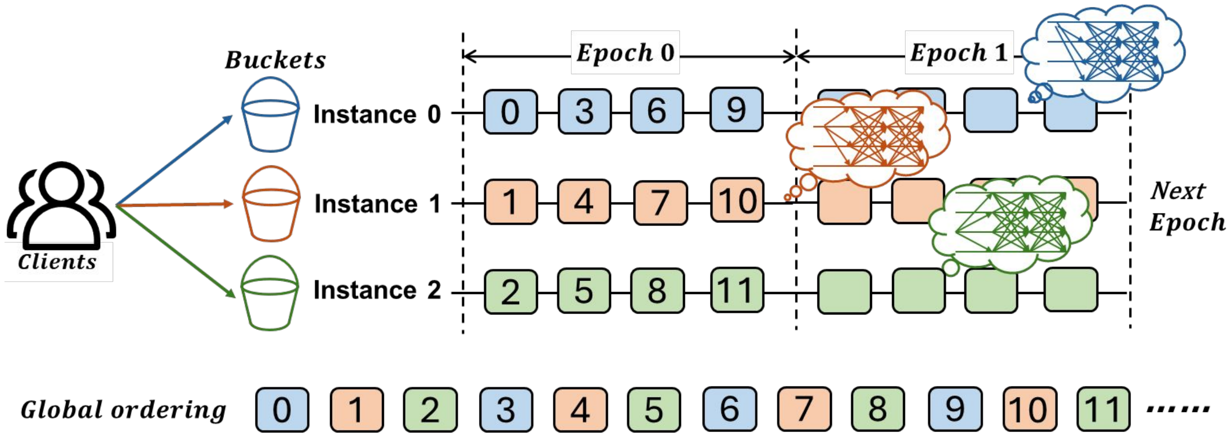
Multi-BFT Consensus[1-3]

1. Client's transactions are split into distinct **Buckets**.
2. Each replica acts as the **leader of one instance** and backups of others.
3. Each instance independently outputs a sequence of **partially committed blocks**.
4. All replicas need **Coordination** to globally order all blocks.
   - **A slow instance will easily stall the progress.**



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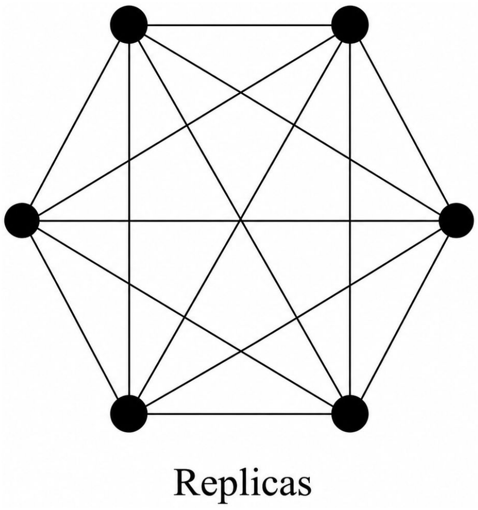
Straggler in the Network

Stragglers are slow replicas which may be significantly slower than others.



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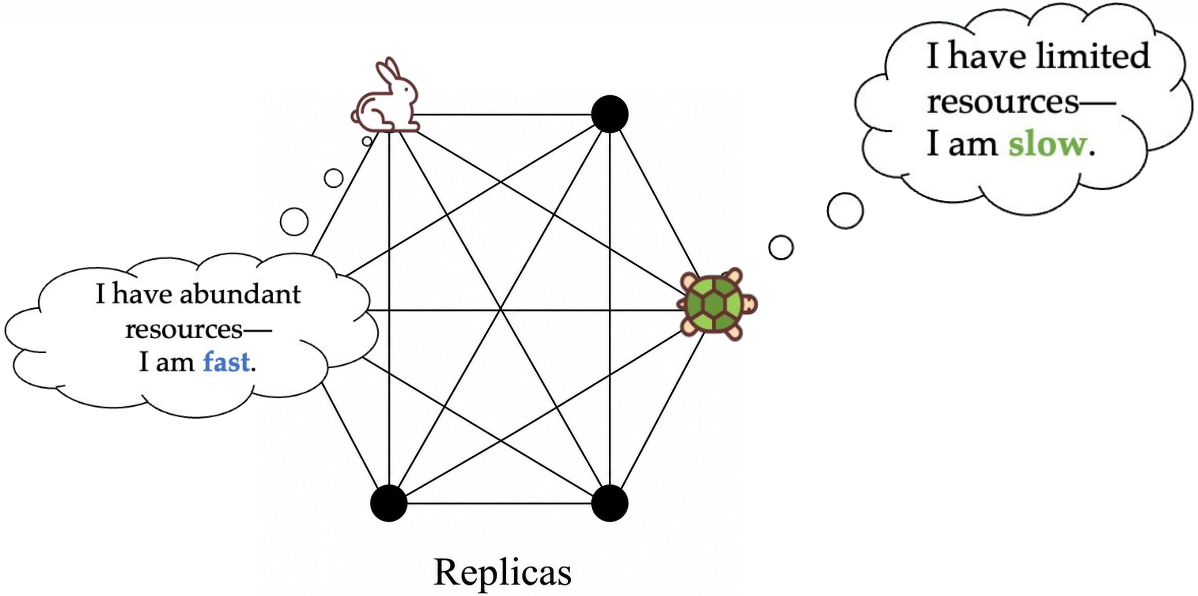

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Straggler in the Network

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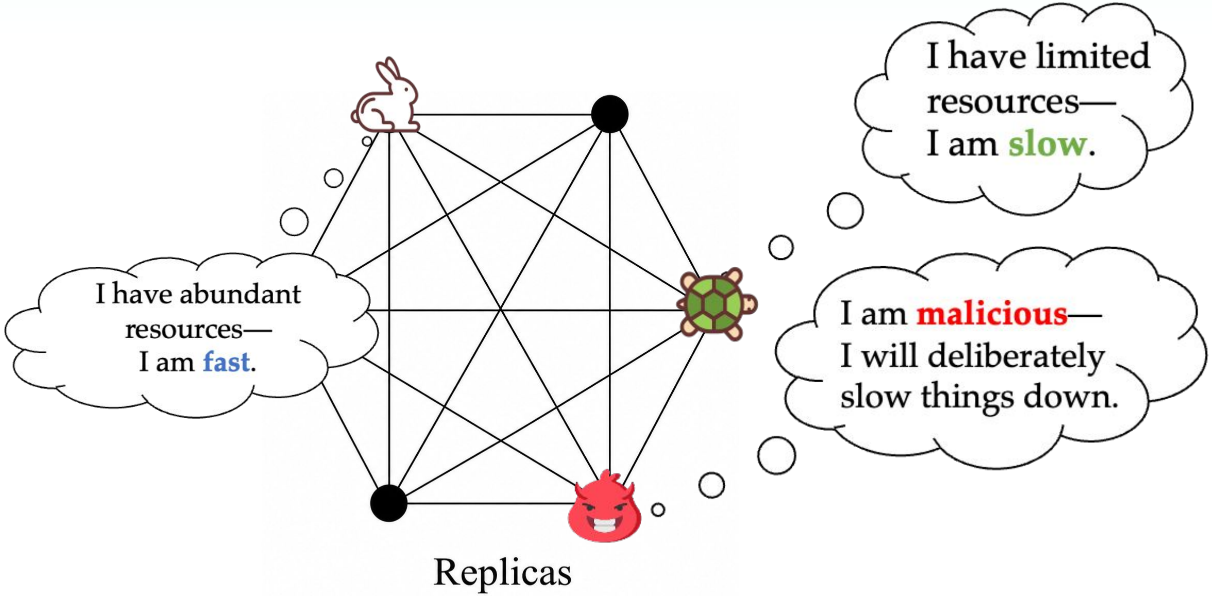
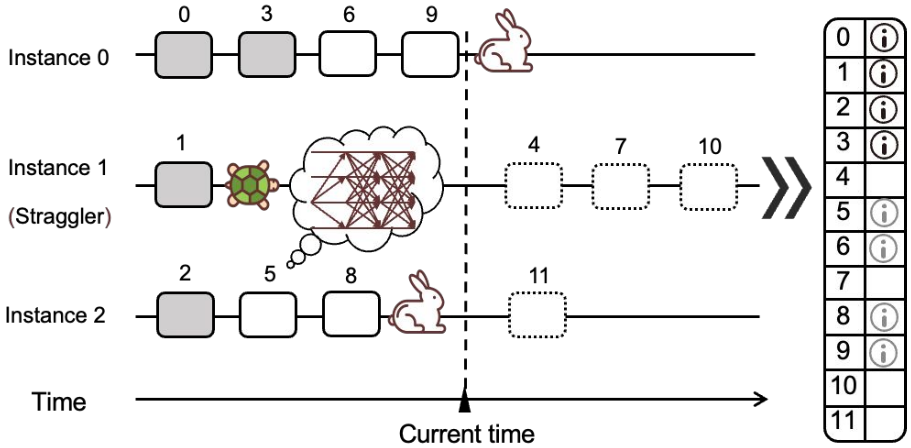
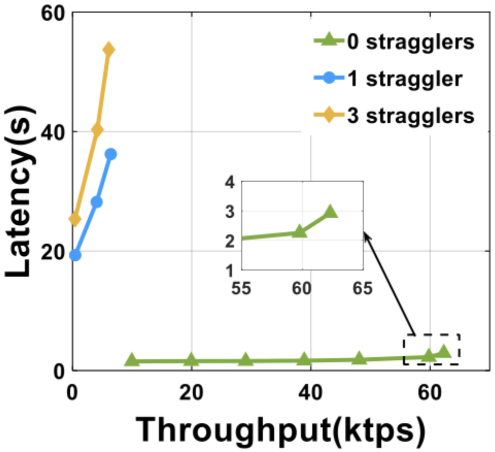
- Limited computational resources and network bandwidth
- Malicious behavior, where Byzantine replicas intentionally delay their behaviors



The impact of Stragglers

- Instance 1 is led by a **straggler replica**.
- Global Ordering needs **coordination**.
- **Performance degradation** from **waiting** for the straggler Instance 1.





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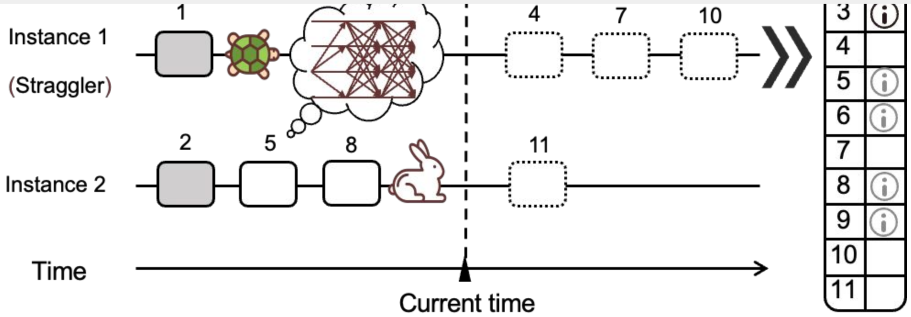
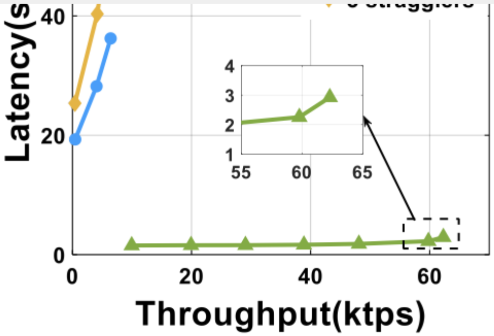
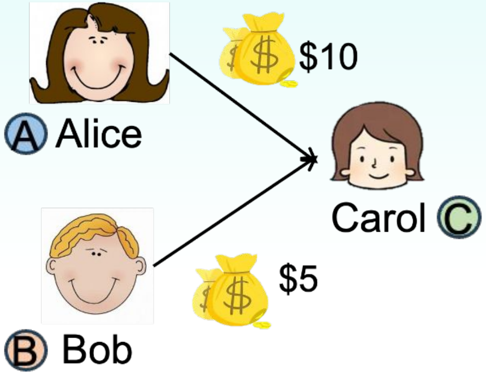
Can we eliminate the Global Ordering?





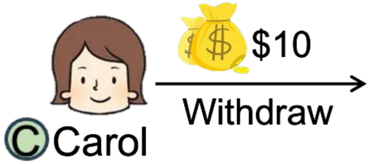
Key Observation

tx_0:



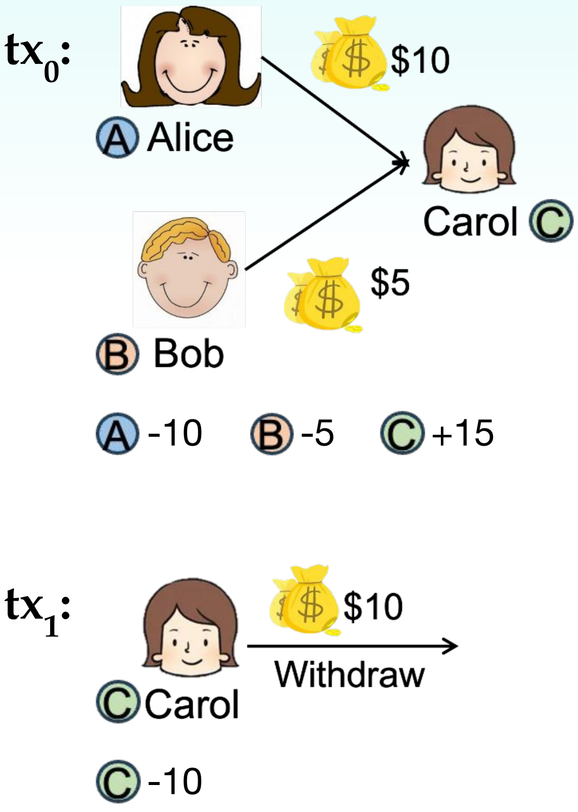
A -10 B -5 C +15

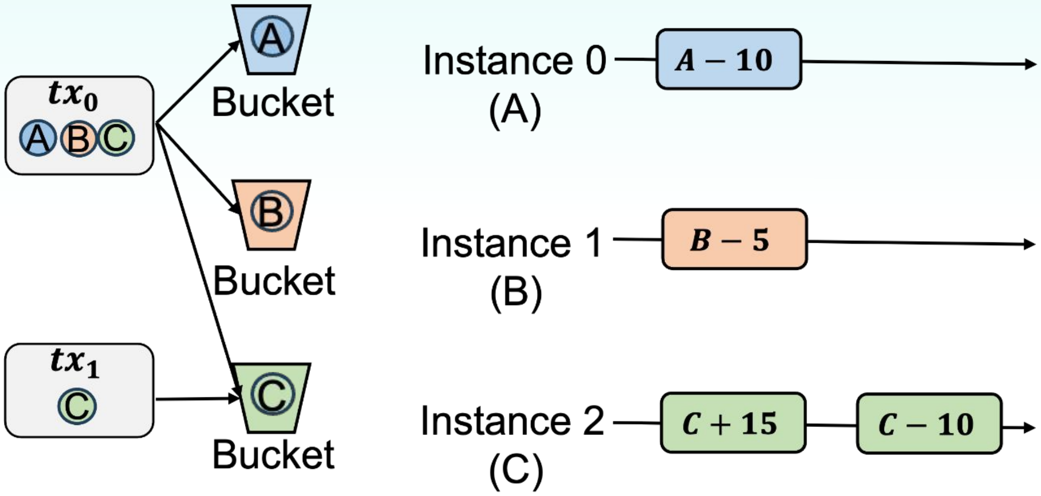
tx_1:



C -10

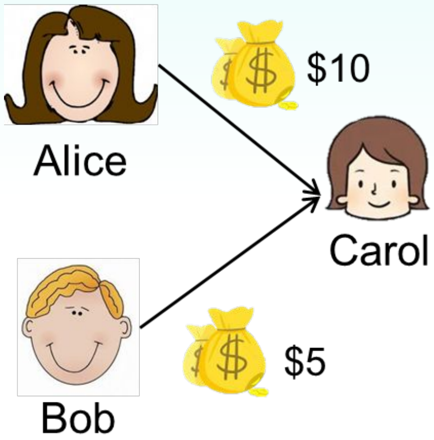
Key Observation

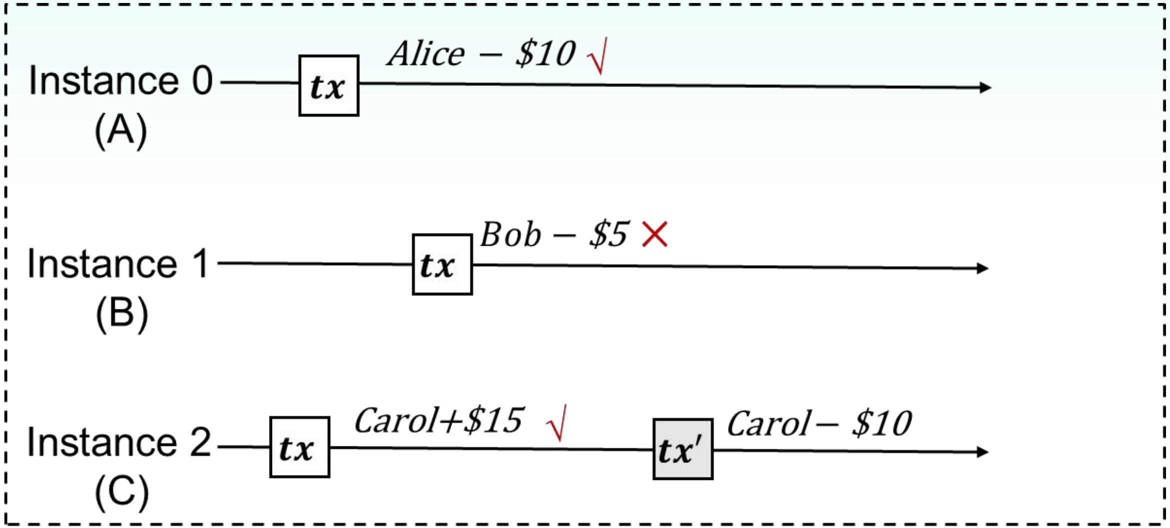




We can shard transactions at the object level, let each instance agree independently.

Challenge 1: Ensuring **atomicity** of transactions across instances.

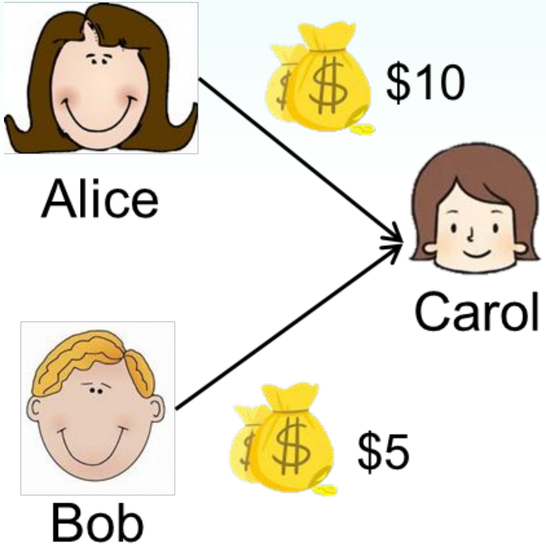


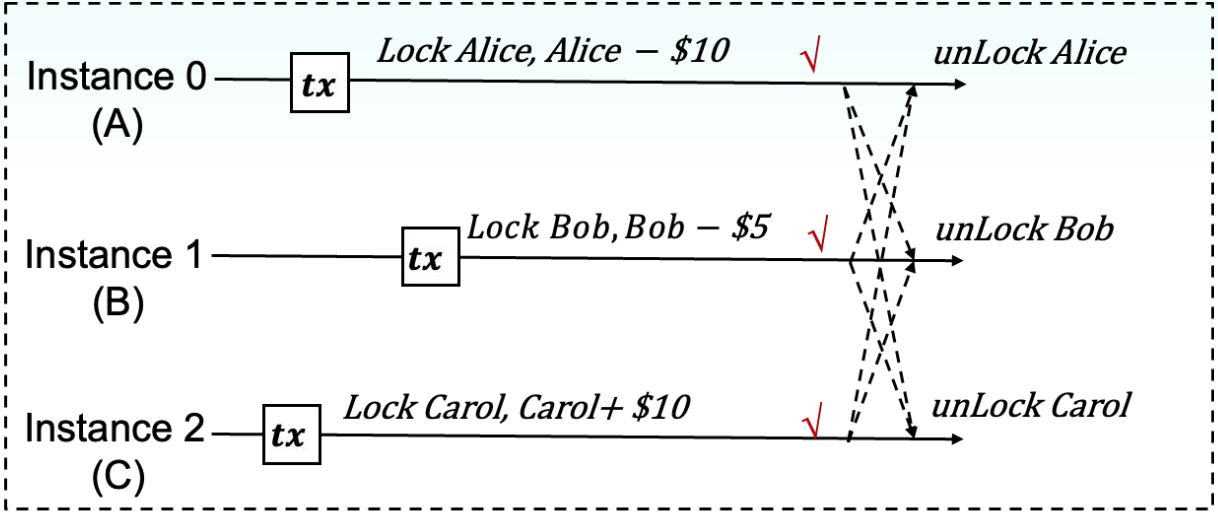


tx:

Alice − $10
Bob − $5
Carol + $15

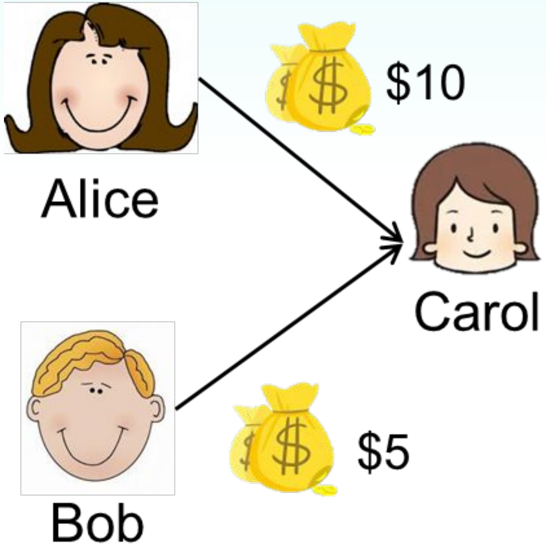
Solution: Before executing a transaction, **lock** all involved objects.

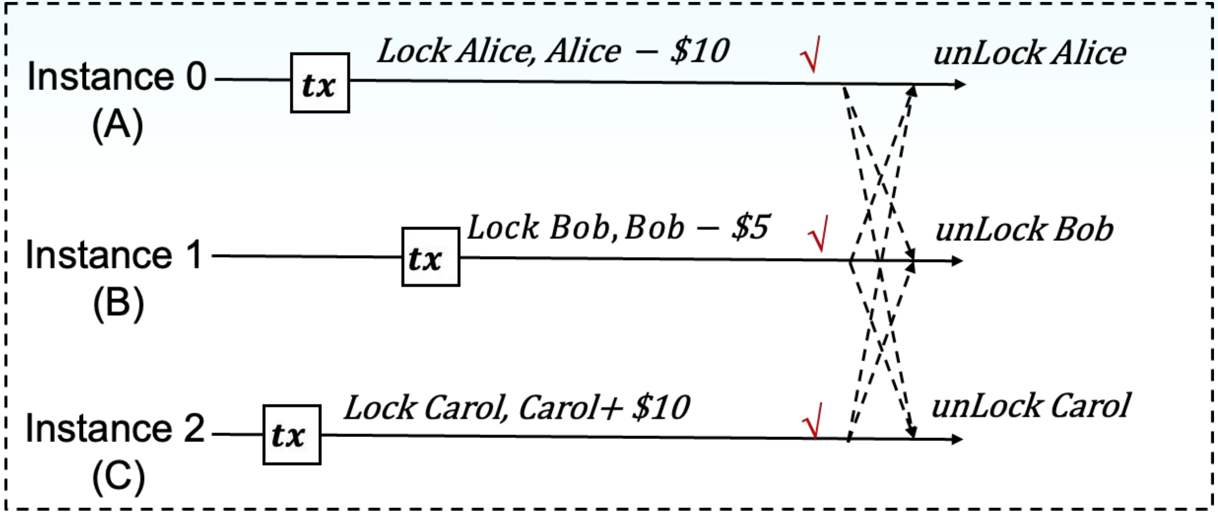




If execution on all objects succeeds, unlock them.

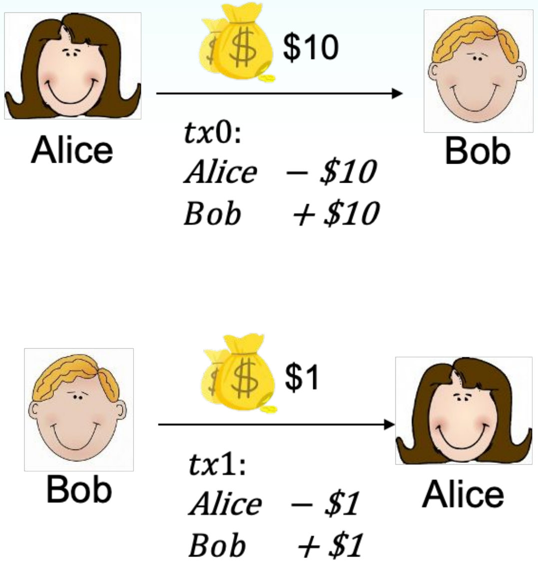
Solution: Before executing a transaction, **lock** all involved objects.

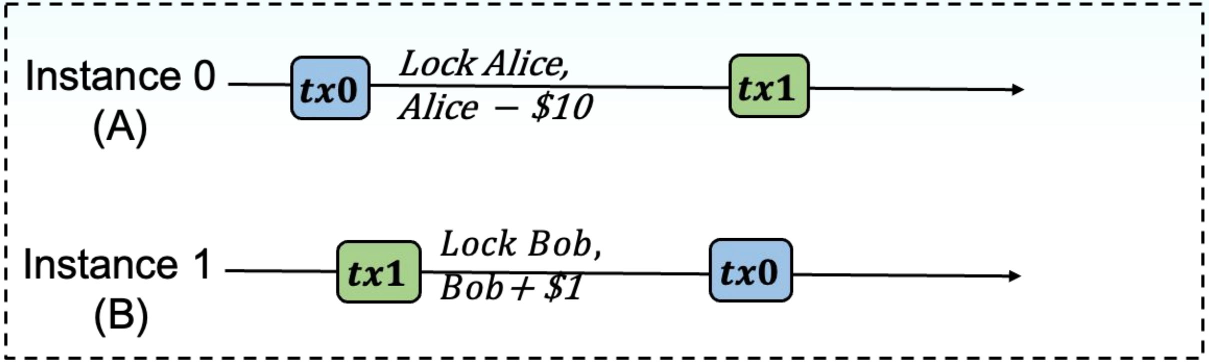




If execution on any object fails, roll back the successful ones and then unlock all objects.

Challenge 2: Locking may lead to deadlock.

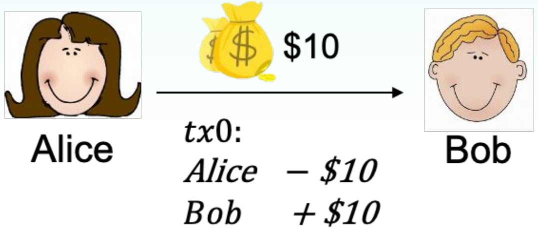


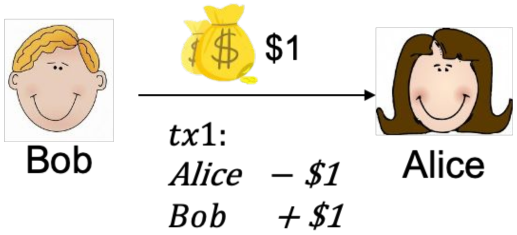


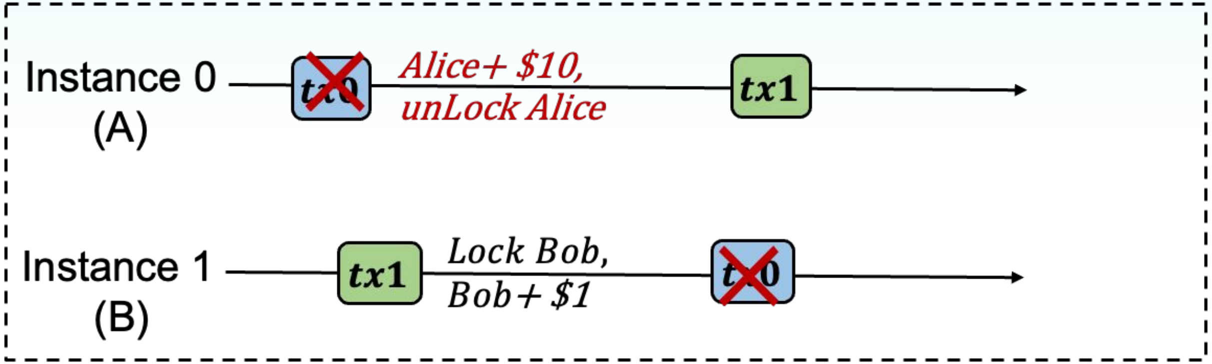
tx0: lock Alice, waiting for lock Bob

tx1: lock Bob, waiting for lock Alice

Solution: Detect **deadlock cycles** and deterministically abort transactions.







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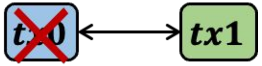


Evaluation Setting

Testbed:

- AWS EC2 c5a.2xlarge machines
- 8vCPUs and 16GB RAM Ubuntu Linux 22.04
- Deployed both in LAN and WAN

Baseline protocols:

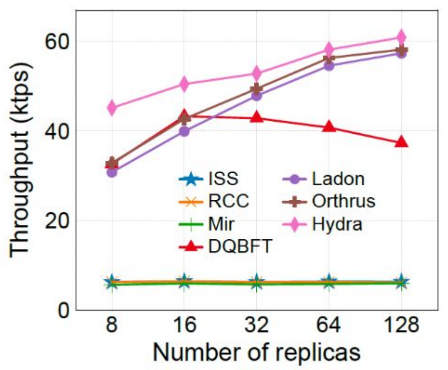
- ISS[1]
- Mir-BFT[2]
- RCC[3]
- DQBFT[4]
- Ladon[5]
- Orthrus[6]

Selected Research Questions:

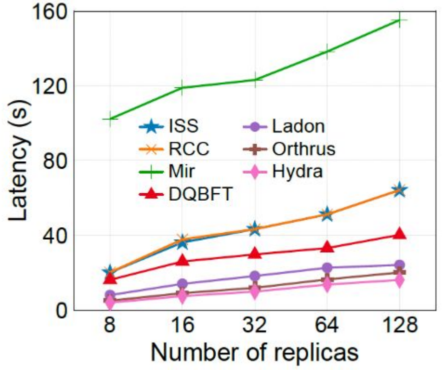
- How does Hydra perform as compared to the Baseline protocols?
- How does Hydra perform in varying proportions of cross-instance transactions?

[1] Stathakopoulou et. al. State Machine Replication Scalability Made Simple, in ACM EuroSys'22.
[2] Stathakopoulou et. al. Mir BFT: Scalable and Robust BFT for Decentralized Networks, in Jsys'22.
[3] Gupta et. al. RCC: Resilient Concurrent Consensus for High-Throughput Secure Transaction Processing, in IEEE ICDE'21.
[4] Balaji Arun and Binoy Ravindran. Scalable Byzantine Fault Tolerance via Partial Decentralization, in PVLDB'22.
[5] Lyu et. al. Ladon: High-Performance Multi-BFT Consensus via Dynamic Global Ordering, in ACM EuroSys'25.
[6] Lyu et. al. Orthrus: Accelerating Multi-BFT Consensus through Concurrent Partial Ordering of Transactions, in IEEE ICDE'25.

Scalability of Hydra and other Multi-BFT protocols



(a) #Straggler = 1, WAN



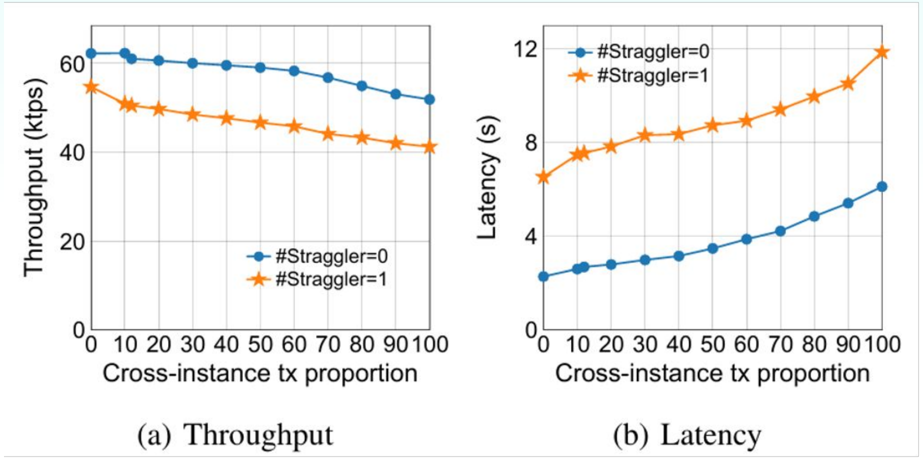
(b) #Straggler = 1, WAN

- 12%[1] cross-instance transactions
- 1 Stragglers
- WAN

- **With one straggler**
  - higher throughput **(9X)**
  - Lower latency

[1] Zhang et. al. TxAllo: Dynamic Transaction Allocation in Sharded Blockchain Systems, in IEEE ICDE'2023.

Performance of Hydra with different proportions of cross-instance transactions



- 0-100% cross-instance transactions
- 0 / 1 Stragglers
- WAN

- **With one straggler**
  - throughput decreases by 24.6%
- **Without stragglers**
  - throughput decreases by 16%

Contributions

Hydra: Concurrent Consensus Without **Global Ordering Barrier**

- Adopts an **Object-Centric** atomic execution model.
- **Eliminates the Global Ordering bottleneck** in Multi-BFT.