ResilientDB: Building Global-Scale Privacy-Preserving Blockchain Fabric

Mohammad Sadoghi

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ExpoLab
Creativity Unfolded

ExpoLab Team

Mohammad Sadoghi

(Principal Investigator)

Jelle Hellings, PostDoc

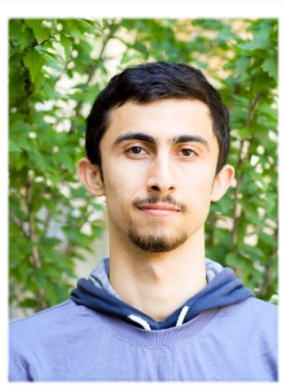
(Fault-tolerant Complexity Analysis)

Suyash Gupta, PhD

(Scalable Consensus Meta-Protocols)

Thamir Qadah, PhD

(Distributed & Coordination-free Concurrency)



Sajjad Rahnama, PhD

(Global Scale Consensus)

Dhruv Krishnan, MSc

(Scaling Fabric via Sharding)

Priya Holani, MSc

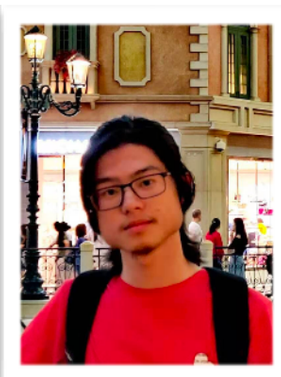
(Scaling Fabric via Sharding)

Shubham Pandey, MSc

(Scaling Fabric via RDMA)

Rohan Sogani, MSc

(Scaling Fabric via Sharding)

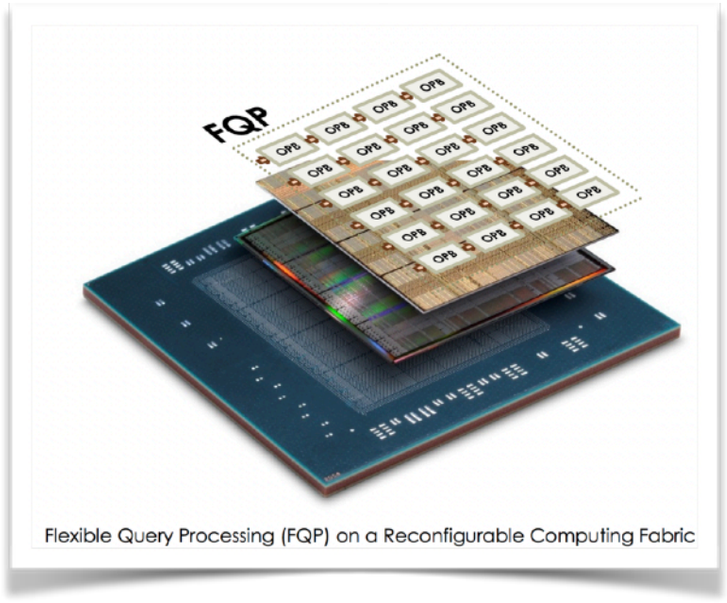


Xinyuan Sun, MSc

(Scaling Fabric via RDMA)

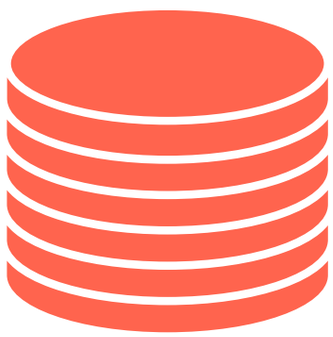
Resilient Journey…

SQL
Analytics



FPGA Acceleration: FQP (Flexible Query Processor)
[VLDB'10, ICDE'12, VLDB'13, ICDE'15, SIGMOD Record'15, ICDE'16, USENIX ATC'16, ICDCS'17, ICDE'18, TKDE'19]

Resilient Journey…

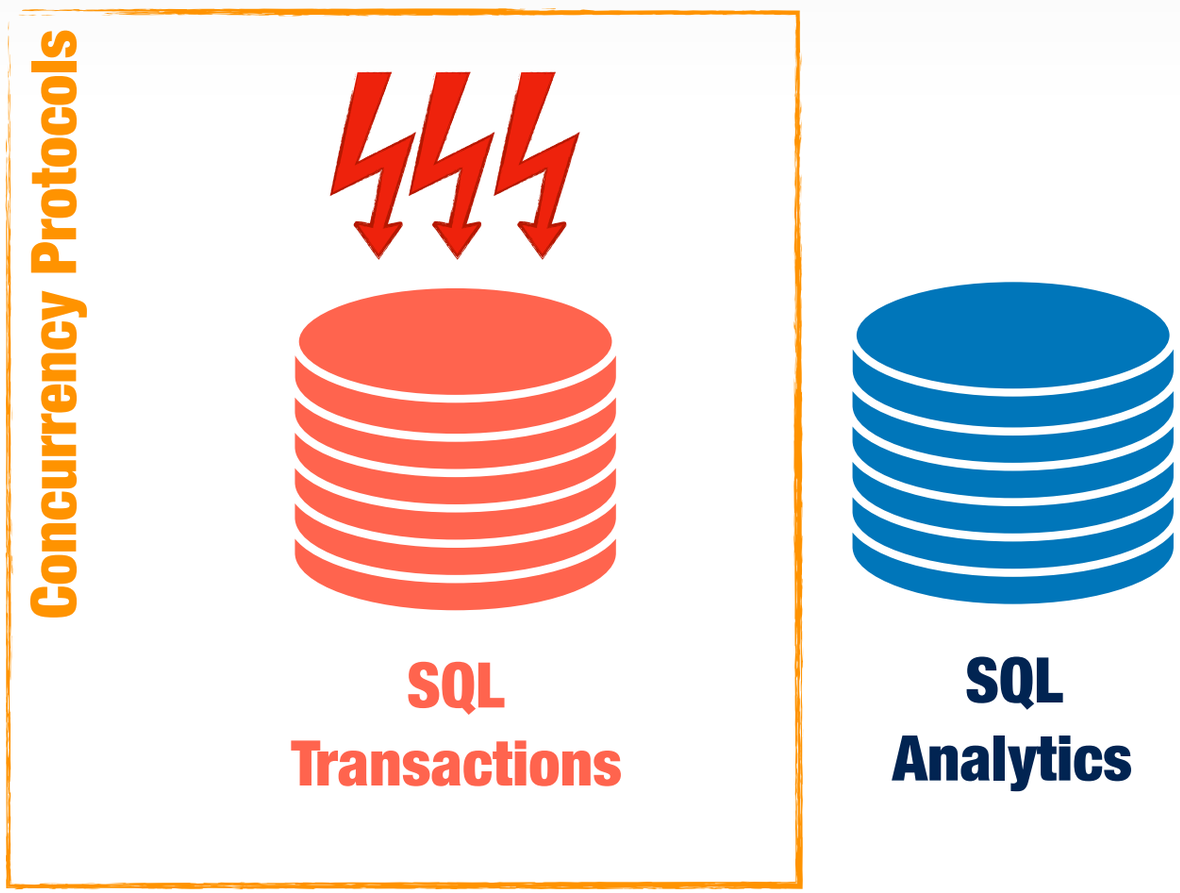


SQL
Transactions

SQL
Analytics

High-dimensional Indexing: (e.g., BE-Tree, BE-topK)
[SIGMOD'11, ICDE'12, TODS'13, ICDCS'13, ICDE'14, ICDCS'17, Middleware'17]

Resilient Journey…

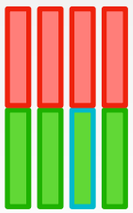


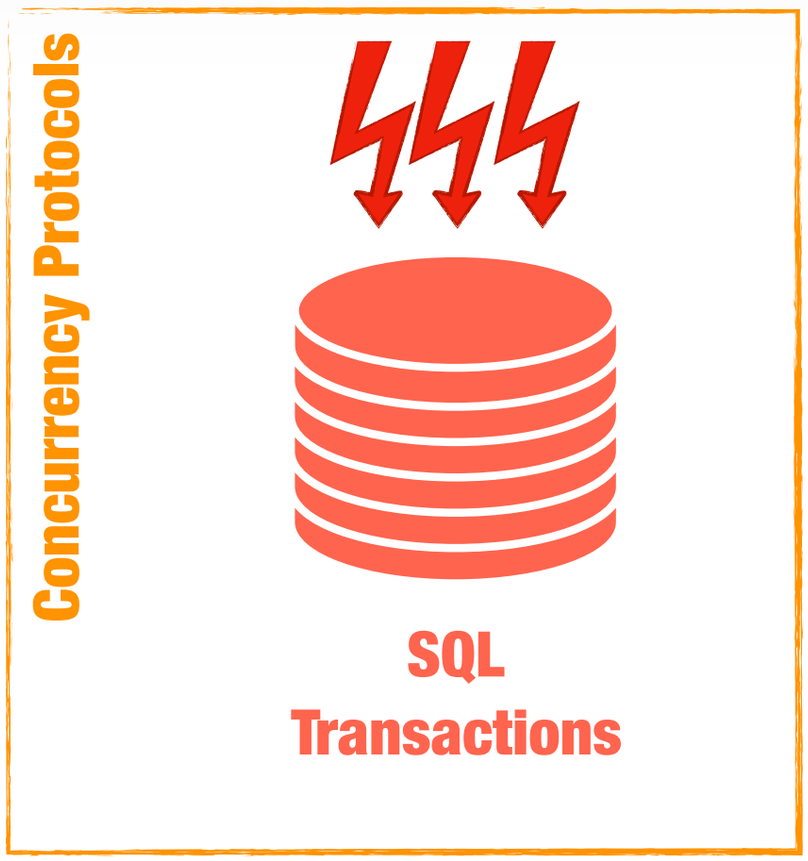
Concurrency Control Protocols: (e.g., 2VCC, QueCC - Best Paper Award)

[VLDB'13, VLDB'14, VLDBJ'16, Middleware'16, TDKE'15, SIGMOD'15, ICDE'16, Middleware'18]

Resilient Journey…

QueCC: Queue-Oriented Planning and Execution Architecture





SQL Analytics

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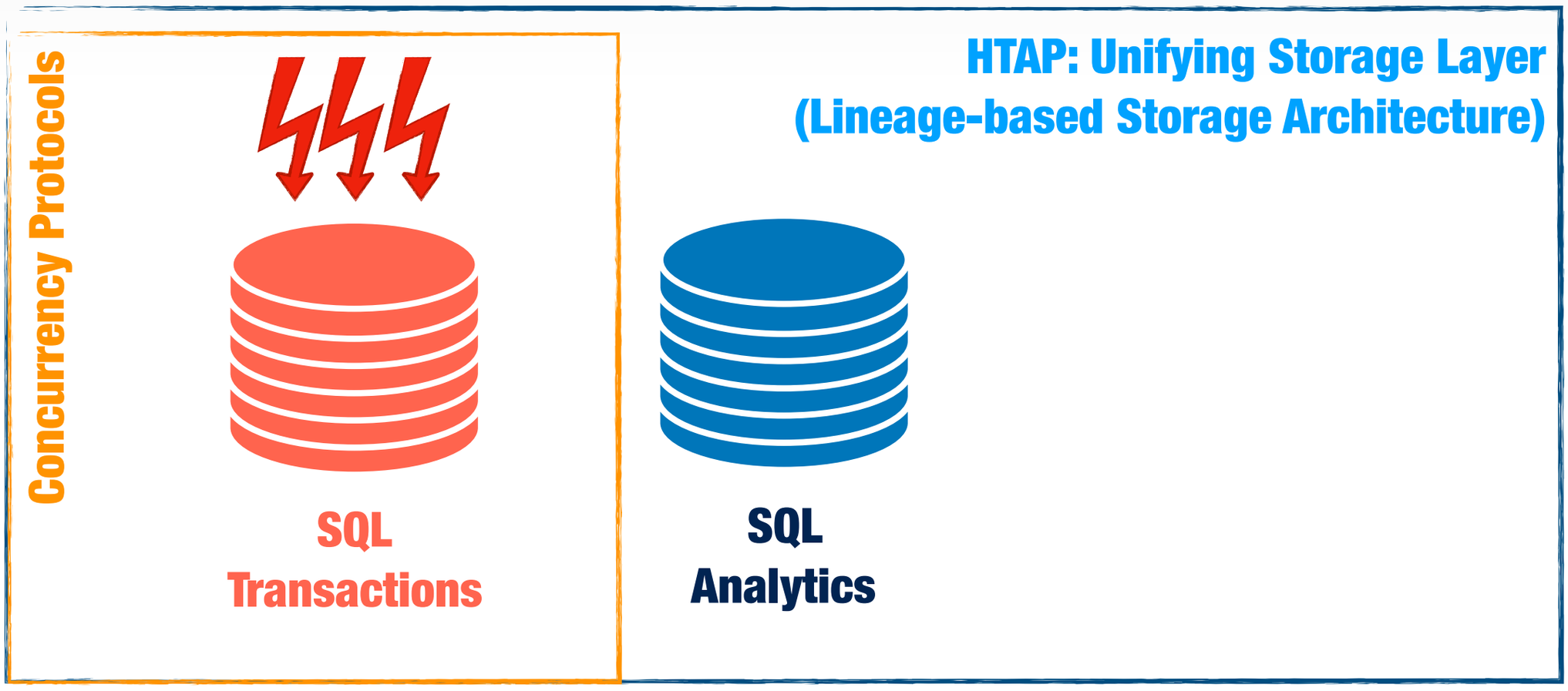
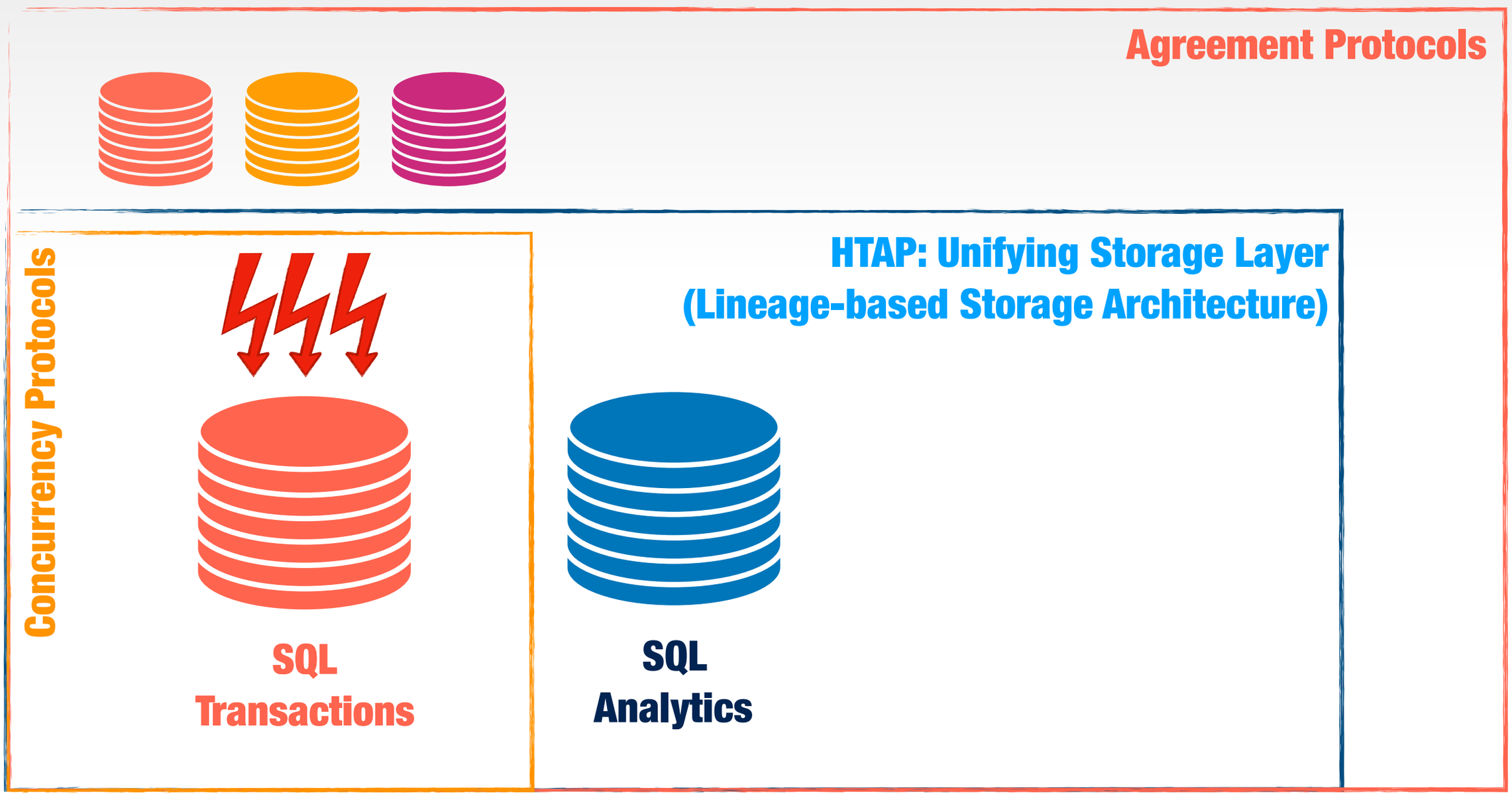


HTAP Column-store: L-Store (Lineage-based Data Store)

[VLDB'12, ICDE'14, ICDCS'16, EDBT'18, 34 filed US patents]

Graphs on SQL: (e.g., GRFusion) [SIGMOD'18, EDBT'18]

Resilient Journey…



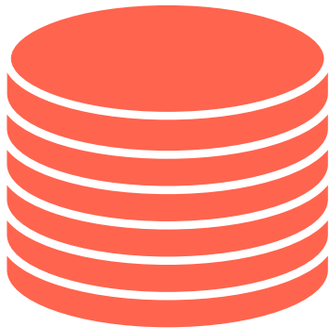
Agreement Protocols: (e.g., EasyCommit, Q-Store)
[EDBT'20, EDBT'18, DAPD'19]

Resilient Journey…

Resilient Consensus Protocols

Agreement Protocols

Concurrency Protocols

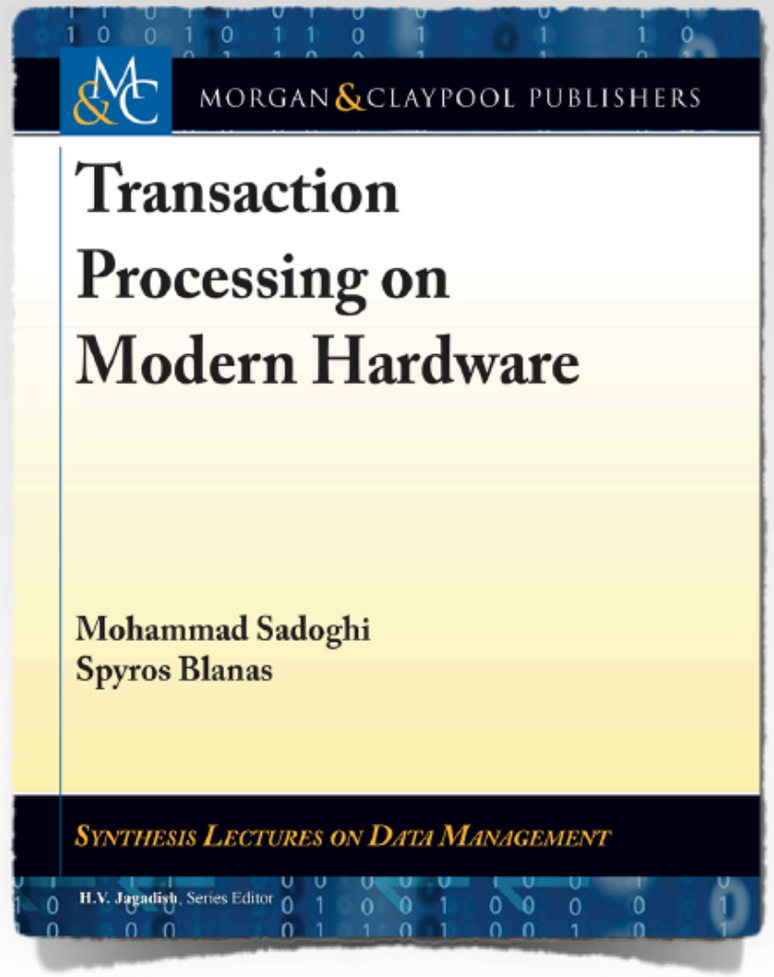


SQL Transactions

HTAP: Unifying Storage Layer (Lineage-based Storage Architecture)

SQL Analytics

Consensus Protocols: (e.g., ResilientDB, GeoBFT, PoE, MBFT, Delayed Replication, CSP, Blockplane) [VLDB'20, ICDCS'20, ICDT'20, DISC'19 (2x), SC'19, ICDE'19, arXiv'19 (6x)]



Books

Transaction Processing on Modern Hardware.

Synthesis Lectures on Data Management, Morgan & Claypool Publishers 2019

Fault-Tolerant Distributed Transactions on Blockchain.

Synthesis Lectures on Data Management, Morgan & Claypool Publishers, *to appear 2020*

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UCDAVIS

Press

Advancements TV With Ted Danson - CNBC, CityAM, Medium, Yahoo! Finance, Market Insider, CoinDesk, Crypto Media, Davis Enterprise, Times Union, WBOC TV/Radio

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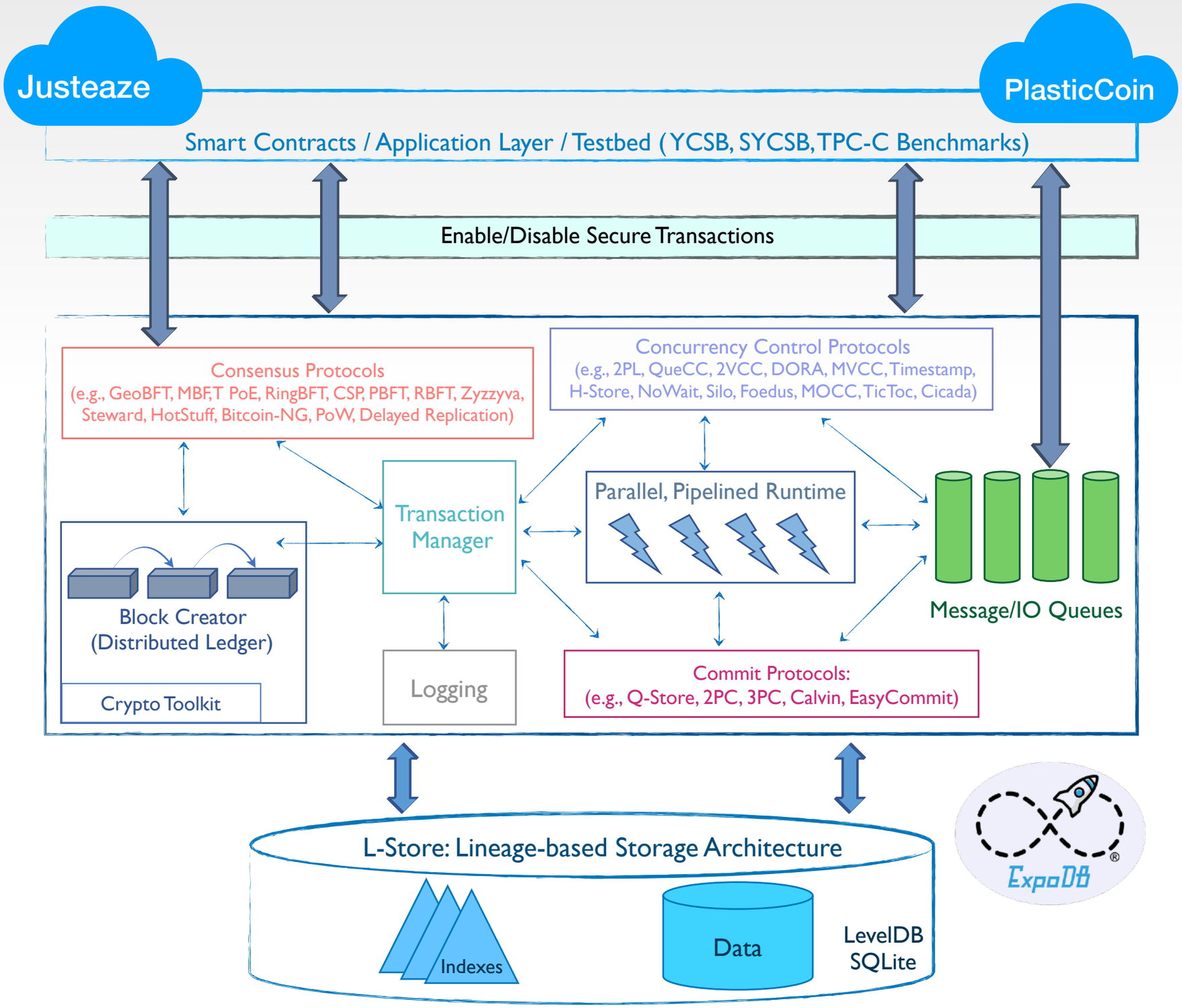
ExpoDB Architecture




ResilientDB
Security, Privacy Reloaded

Quantifiable Resiliency (Graduate Student Experiments)

Aloha Lake, Desolation Wilderness

15 Miles Long

2,500 Feet Elevation Gain

(8,700 Feet at Summit)

Tomales Point Trail, Point Reyes National Seashore

9.4 Miles Long

1,579 Feet Elevation Gain

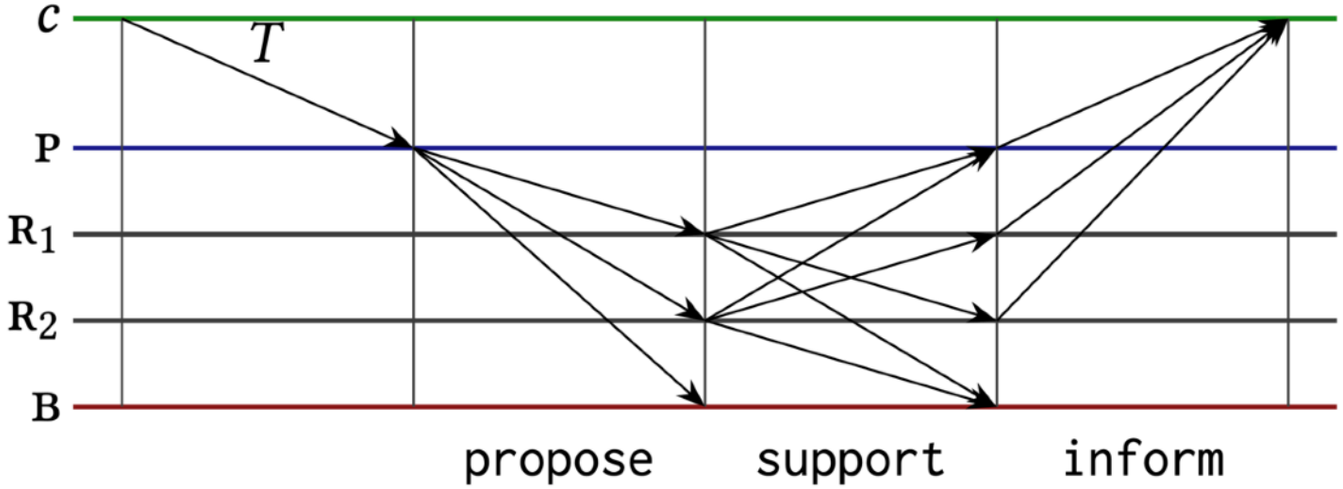
Non-Quantifiable Resiliency

Proof-of-Execution: Reaching Consensus Through Fault-Tolerant Speculation [arXiv'19]

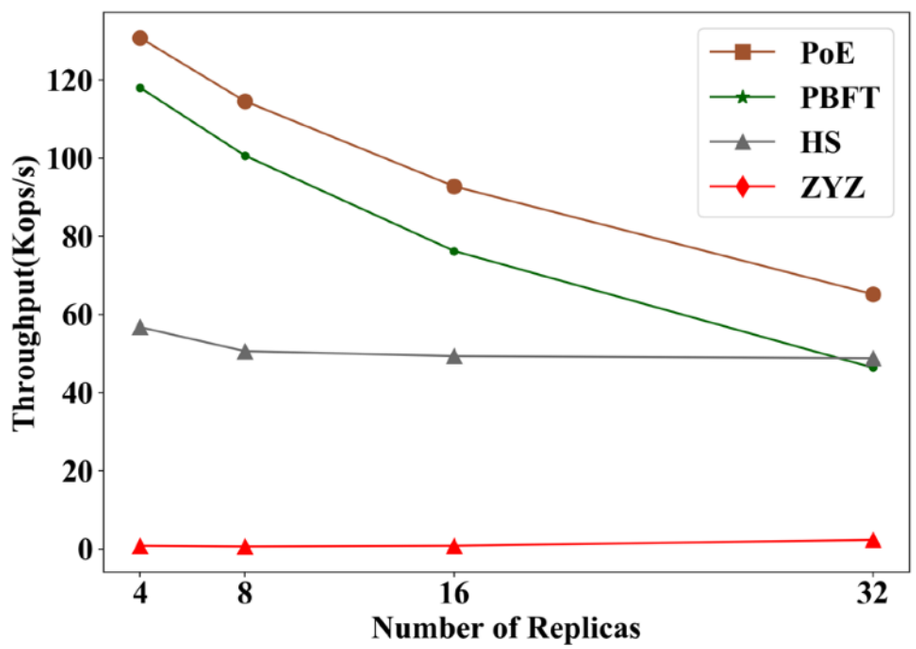
Out-of-Order message processing to reduce replica idleness

Speculative Execution with revertible/divergent replicas &

eager/irrevertible client commit



Fault-tolerant Proof-of-Execution Protocol



PoE scales beyond 32 replicas, in presence of failures, outperforms PBFT up to 40%

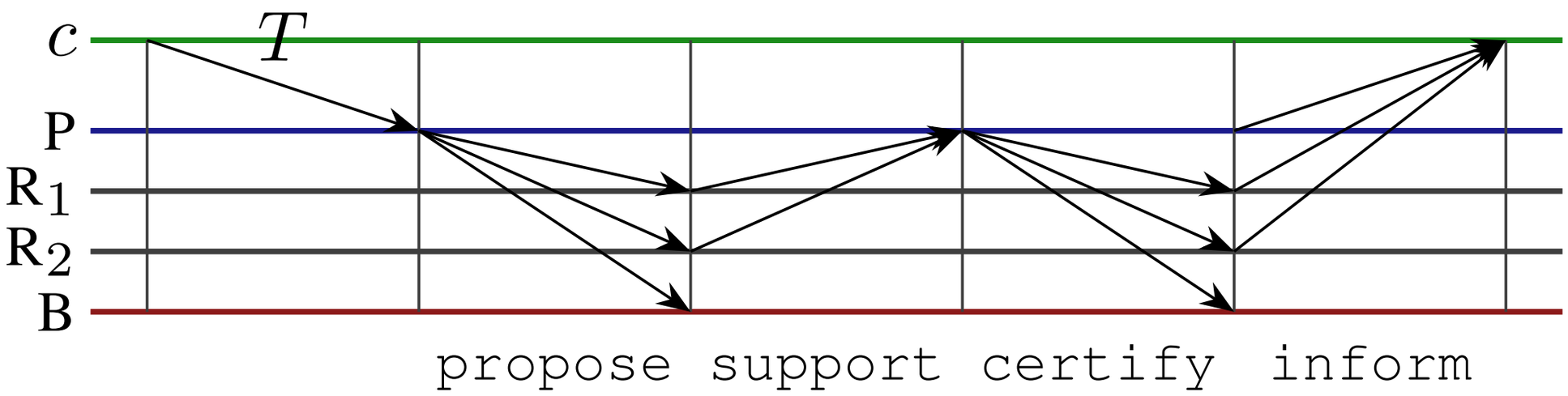
Proof-of-Execution: Reaching Consensus Through Fault-Tolerant Speculation [arXiv'19]

Out-of-Order message processing to reduce replica idleness

Speculative Execution with revertible/divergent replicas &

eager/irrevertible client commit

introducing linear message complexity



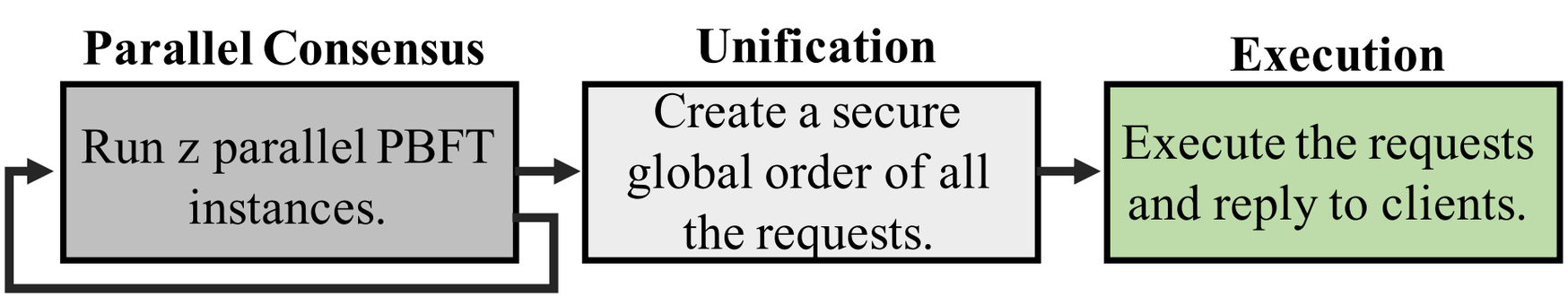
Linearized Proof-of-Execution Protocol

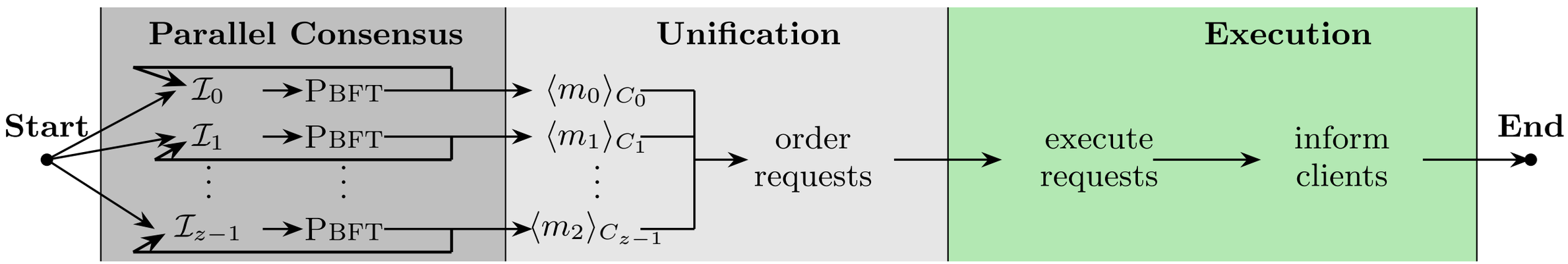
MultiBFT: Scaling Blockchain Databases Through Parallel Resilient Consensus Paradigm [arXiv'19]

A wait-free meta-protocol…

Designate multiple replicas as Primaries!

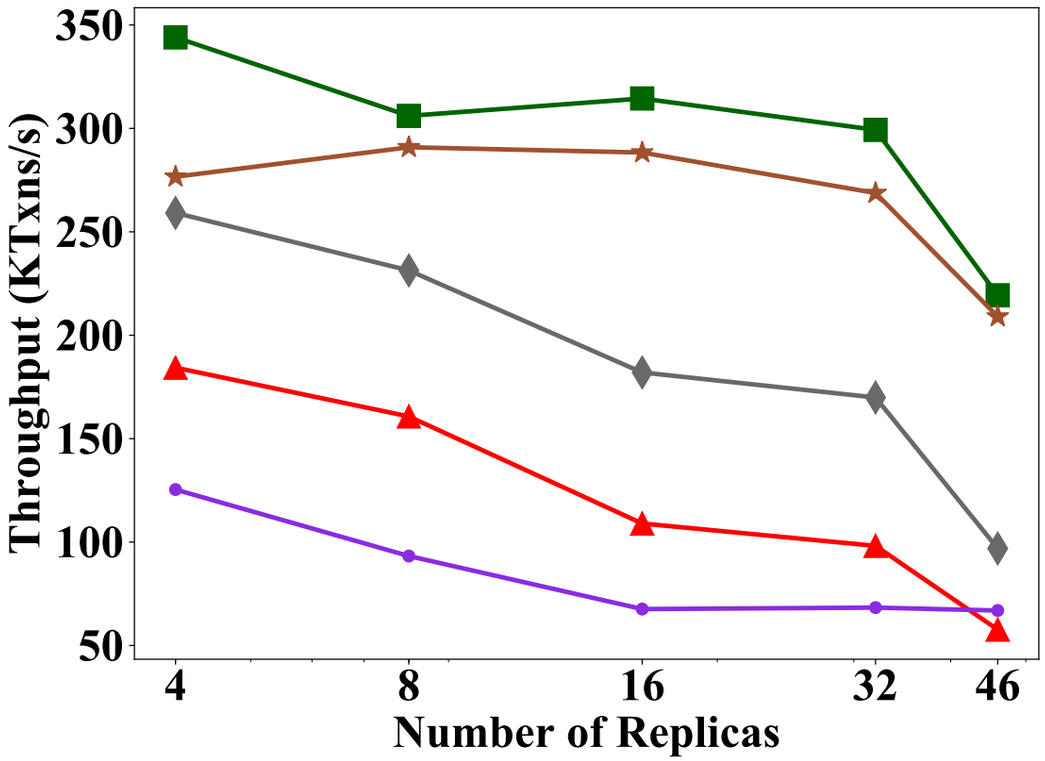
Run multiple parallel consensuses on each replica independently



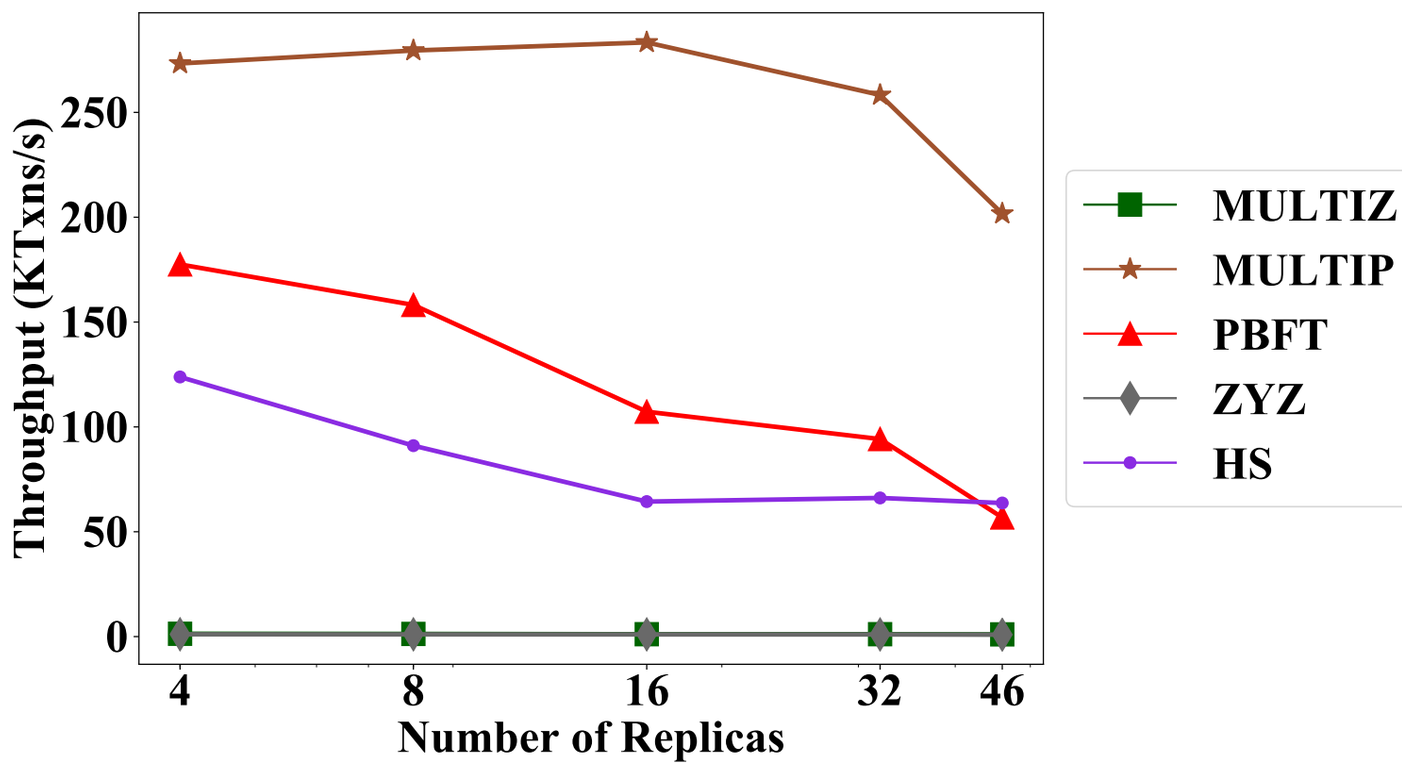


Fault-tolerant MultiBFT Protocol

MultiBFT: Scaling Blockchain Databases Through Parallel Resilient Consensus Paradigm



Throughput up to 350,000 txns/s (without failures)



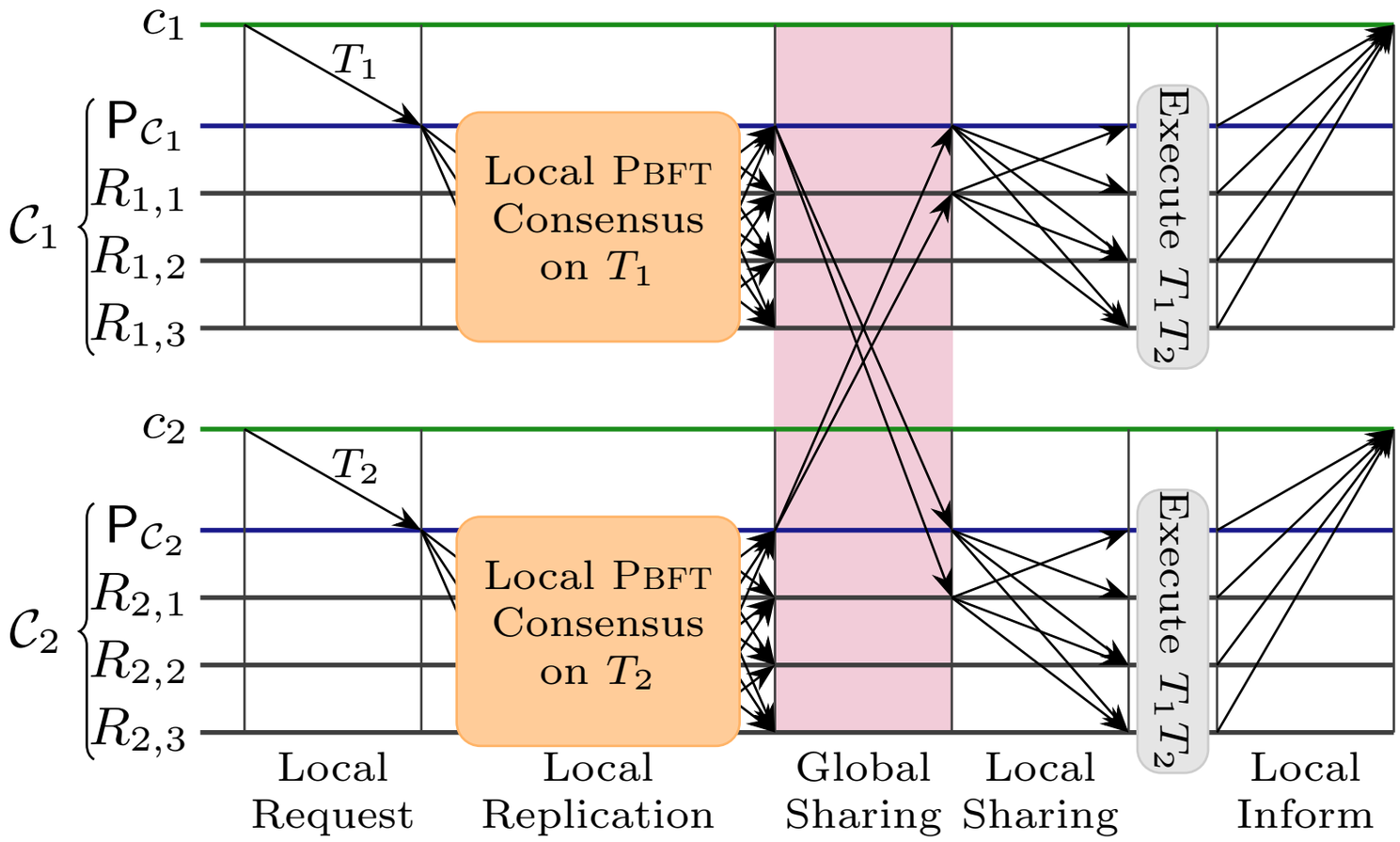
Throughput up to 300,000 txns/s (with failures)

GeoBFT: Global Scale Resilient Blockchain Fabric [VLDB'20]

A meta-protocol, locally running any BFT in parallel and independently

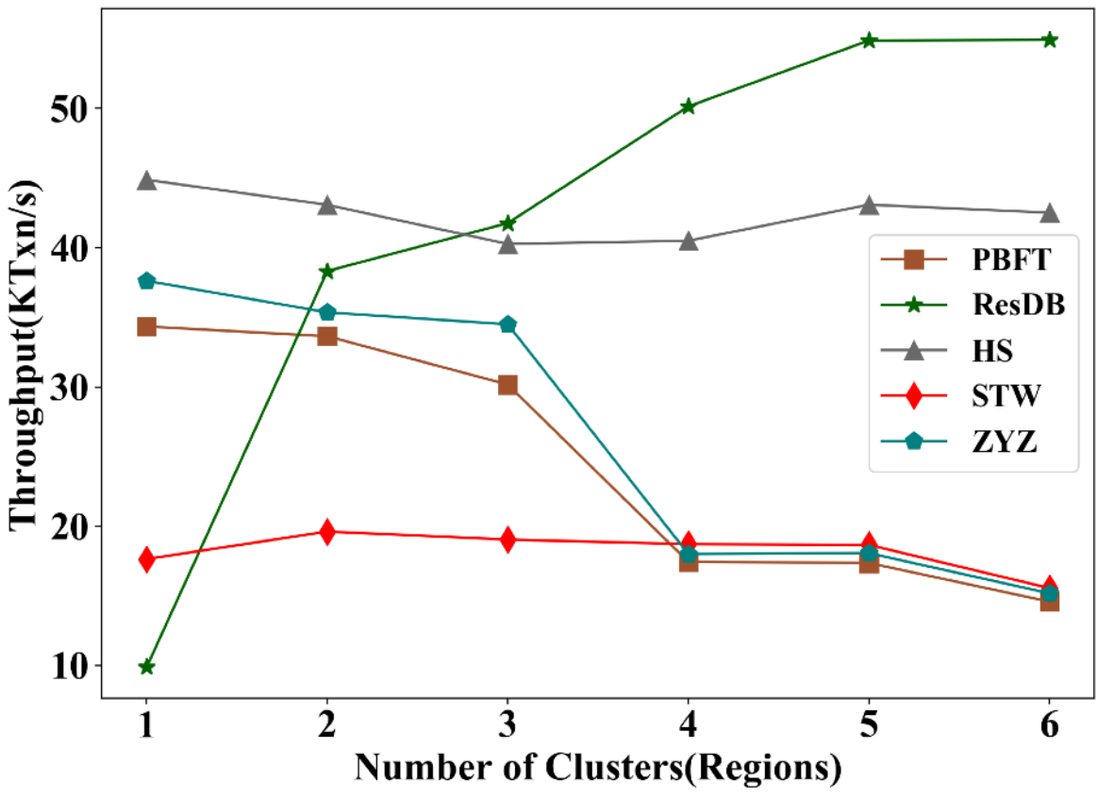
Global ordering provably requires only linear communication

Provably sufficient for primary to send a certificate to at most f+1 replicas, malicious primary is detectable and replaceable

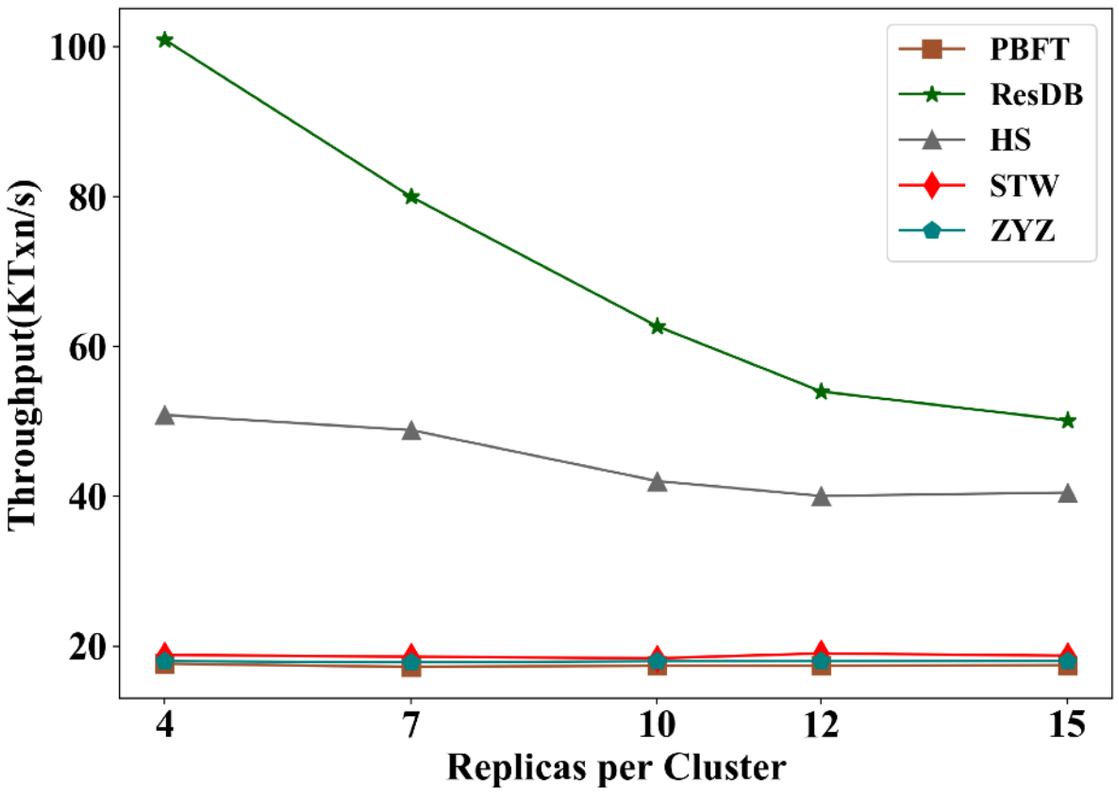


Fault-tolerant GeoBFT Protocol

GeoBFT: Global Scale Resilient Blockchain Fabric [VLDB'20]



ResilientDB easily scales across 6 countries in 4 continents due to GeoBFT protocol.



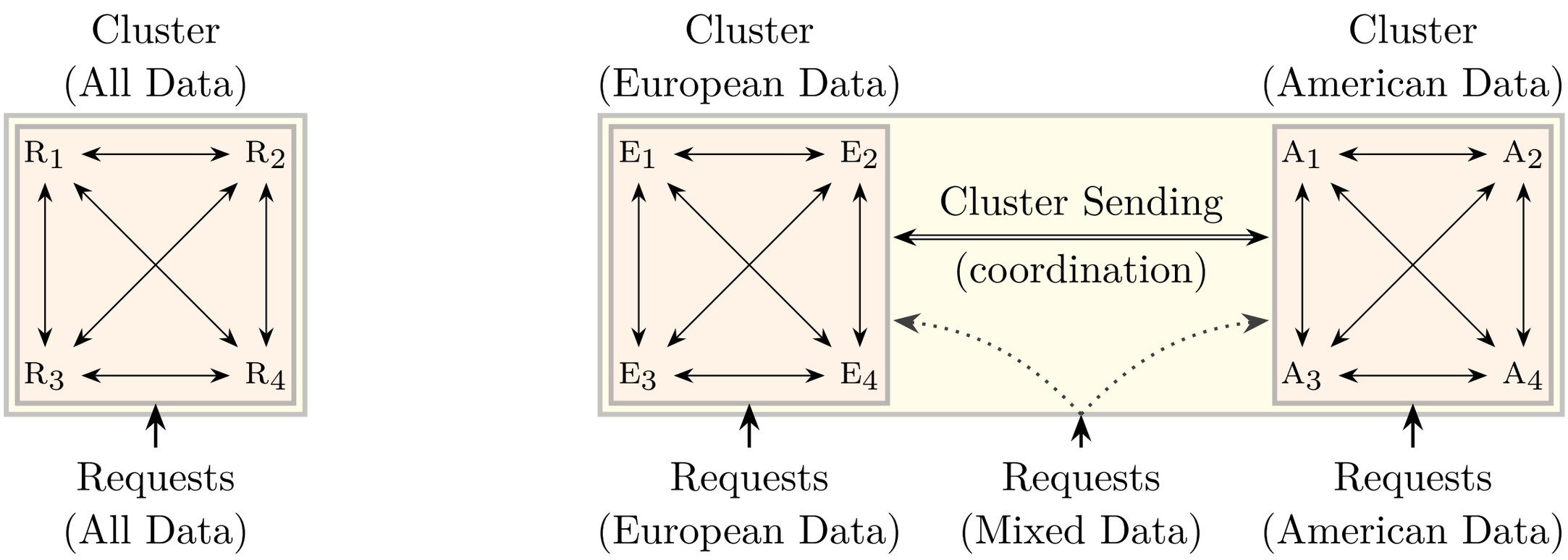
GeoBFT scales a permissioned blockchain up to 60 replicas globally.

The Fault-Tolerant Cluster-Sending Problem [DISC'19]

formalizing the problem of sending a message from one Byzantine cluster to another Byzantine cluster in a reliable manner,

establishing lower bounds on the complexity of this problem under crash failures and Byzantine failures

(linear in the size of clusters)



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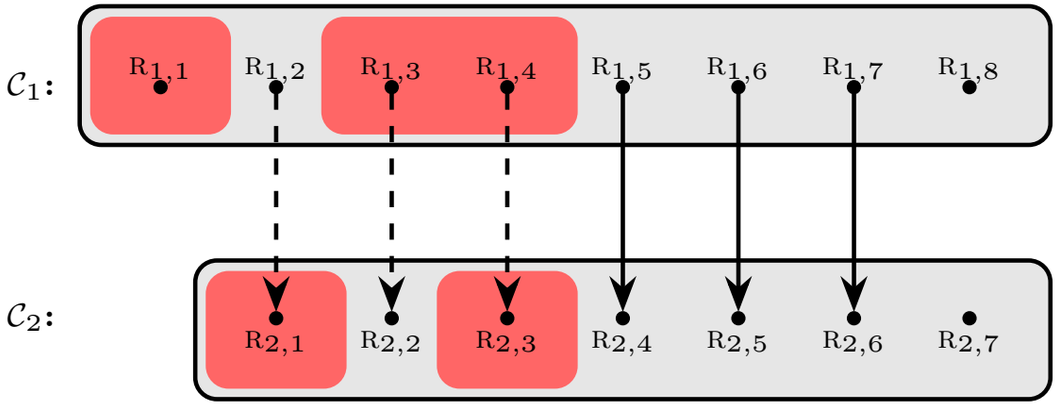

	Protocol	System	Robustness	Messages	Message size
non-linear	RB-bcs	Omit	$\mathbf{n}_{\mathcal{C}_1} > 2\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > \mathbf{f}_{\mathcal{C}_2}$	$(\mathbf{f}_{\mathcal{C}_1}+1)\cdot(\mathbf{f}_{\mathcal{C}_2}+1)$	$\mathcal{O}(\|v\|)$
	RB-brs	Byzantine, RS	$\mathbf{n}_{\mathcal{C}_1} > 2\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > \mathbf{f}_{\mathcal{C}_2}$	$(2\mathbf{f}_{\mathcal{C}_1}+1)\cdot(\mathbf{f}_{\mathcal{C}_2}+1)$	$\mathcal{O}(\|v\|)$
	RB-bcs	Byzantine, RS	$\mathbf{n}_{\mathcal{C}_1} > 2\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > \mathbf{f}_{\mathcal{C}_2}$	$(\mathbf{f}_{\mathcal{C}_1}+1)\cdot(\mathbf{f}_{\mathcal{C}_2}+1)$	$\mathcal{O}(\|v\|+\mathbf{f}_{\mathcal{C}_1})$
	RB-bcs	Byzantine, CS	$\mathbf{n}_{\mathcal{C}_1} > 2\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > \mathbf{f}_{\mathcal{C}_2}$	$(\mathbf{f}_{\mathcal{C}_1}+1)\cdot(\mathbf{f}_{\mathcal{C}_2}+1)$	$\mathcal{O}(\|v\|)$
linear	PBS-bcs	Omit	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	$\mathcal{O}(\max(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}))$ (optimal)	$\mathcal{O}(\|v\|)$
	PBS-brs	Byzantine, RS	$\mathbf{n}_{\mathcal{C}_1} > 4\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 4\mathbf{f}_{\mathcal{C}_2}$	$\mathcal{O}(\max(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}))$ (optimal)	$\mathcal{O}(\|v\|)$
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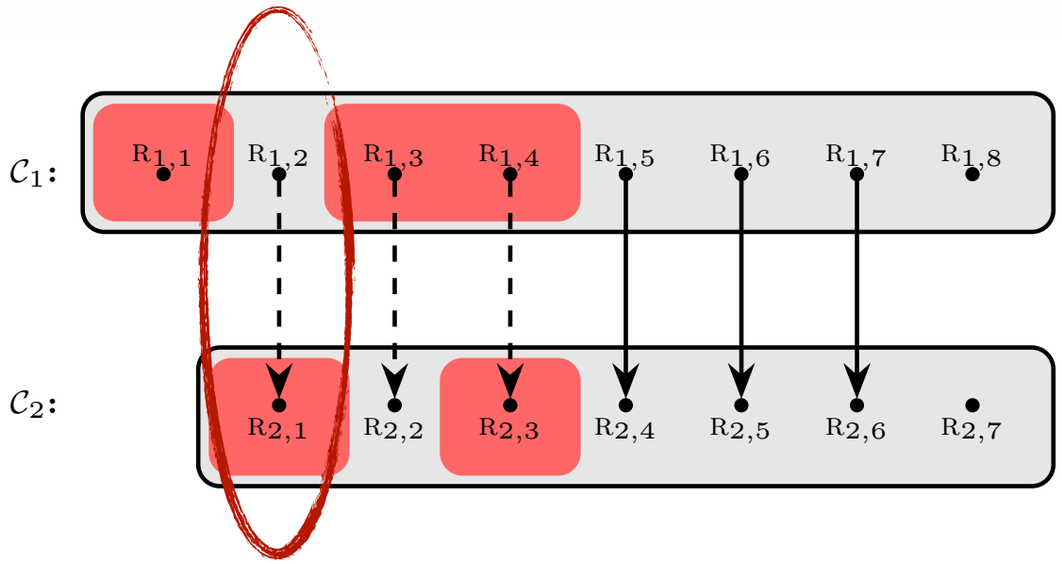
Byzantine Cluster-Sending in Expected Constant Communication [arXiv'20]

formalizing the problem of probabilistically sending a message from one Byzantine cluster to another Byzantine cluster in a reliable manner,

establishing lower bounds on the complexity of this problem under crash failures and Byzantine failures

(expected constant message complexity)



	Protocol	Robustness	Message Steps (expected)	Message Steps (worst)	O.	U.
	PBS-CS [13]	$\min(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}) > \mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2}$	$\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2} + 1$		✔	✖
	PBS-CS [13]	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	$\max(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2})$		✔	✖
	GEOBFT [12]	$\mathbf{n}_{\mathcal{C}_1} = \mathbf{n}_{\mathcal{C}_2} > 3\max(\mathbf{f}_{\mathcal{C}_1}, \mathbf{f}_{\mathcal{C}_2})$	$\mathbf{f}_{\mathcal{C}_2} + 1^{\ddagger}$	$\Omega(\mathbf{f}_{\mathcal{C}_1}\mathbf{n}_{\mathcal{C}_2})$	✖	✔
This Paper	PPCS	$\mathbf{n}_{\mathcal{C}_1} > 2\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 2\mathbf{f}_{\mathcal{C}_2}$	4	$(\mathbf{f}_{\mathcal{C}_1}+1)(\mathbf{f}_{\mathcal{C}_2}+1)$	✖	✔
This Paper	PPCS	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	$2\frac{1}{4}$	$(\mathbf{f}_{\mathcal{C}_1}+1)(\mathbf{f}_{\mathcal{C}_2}+1)$	✖	✔
This Paper	PLCS	$\min(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}) > \mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2}$	4	$\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2} + 1$	✔	✔
This Paper	PLCS	$\min(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}) > 2(\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2})$	$2\frac{1}{4}$	$\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2} + 1$	✔	✔
This Paper	PLCS	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	3	$\max(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2})$	✔	✔

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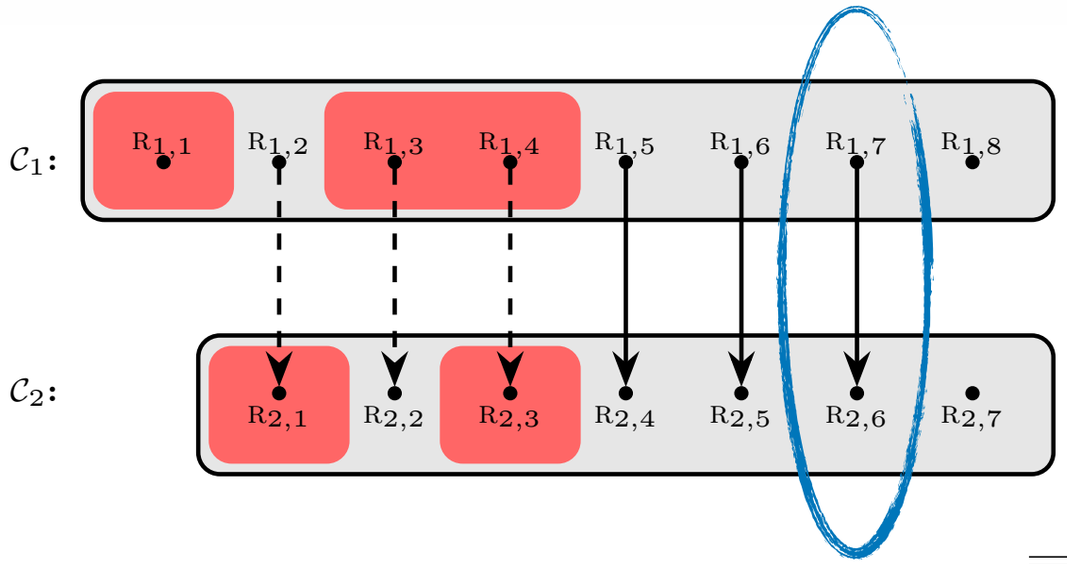

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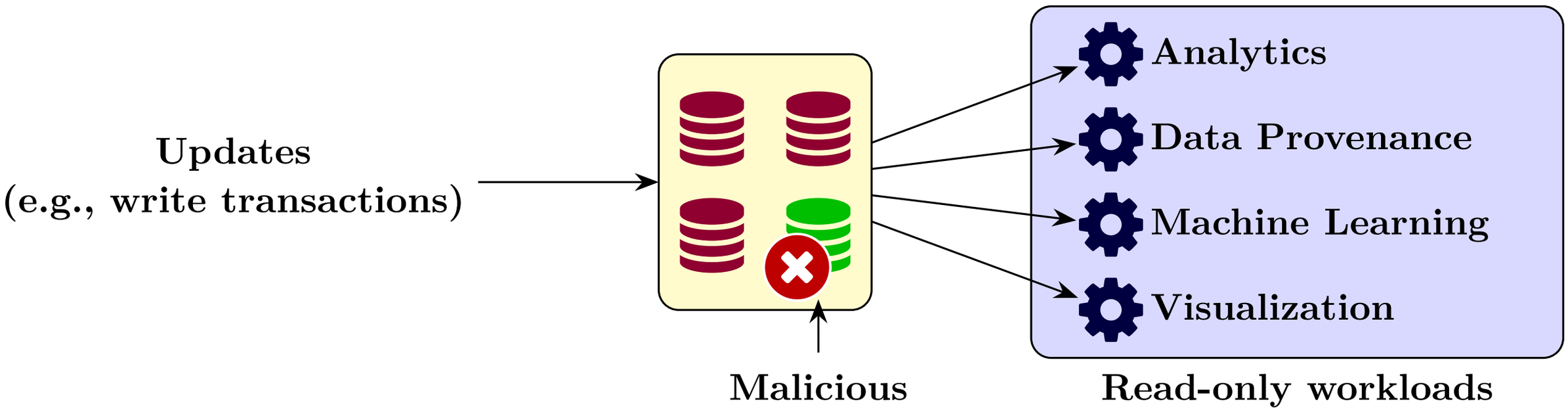
This Paper	PPCS	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	$2\frac{1}{4}$	$(\mathbf{f}_{\mathcal{C}_1}+1)(\mathbf{f}_{\mathcal{C}_2}+1)$	✖	✔
This Paper	PLCS	$\min(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}) > \mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2}$	4	$\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2} + 1$	✔	✔
This Paper	PLCS	$\min(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2}) > 2(\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2})$	$2\frac{1}{4}$	$\mathbf{f}_{\mathcal{C}_1} + \mathbf{f}_{\mathcal{C}_2} + 1$	✔	✔
This Paper	PLCS	$\mathbf{n}_{\mathcal{C}_1} > 3\mathbf{f}_{\mathcal{C}_1}$, $\mathbf{n}_{\mathcal{C}_2} > 3\mathbf{f}_{\mathcal{C}_2}$	3	$\max(\mathbf{n}_{\mathcal{C}_1}, \mathbf{n}_{\mathcal{C}_2})$	✔	✔

Coordination-Free Byzantine Replication With Minimal Communication Costs [ICDT'20]

formalizing the Byzantine learner problem to support efficient analytics for blockchain applications

introducing the delayed-replication algorithm, utilizing information dispersal techniques, giving rise to a coordination-free, push-based, minimal communication protocol



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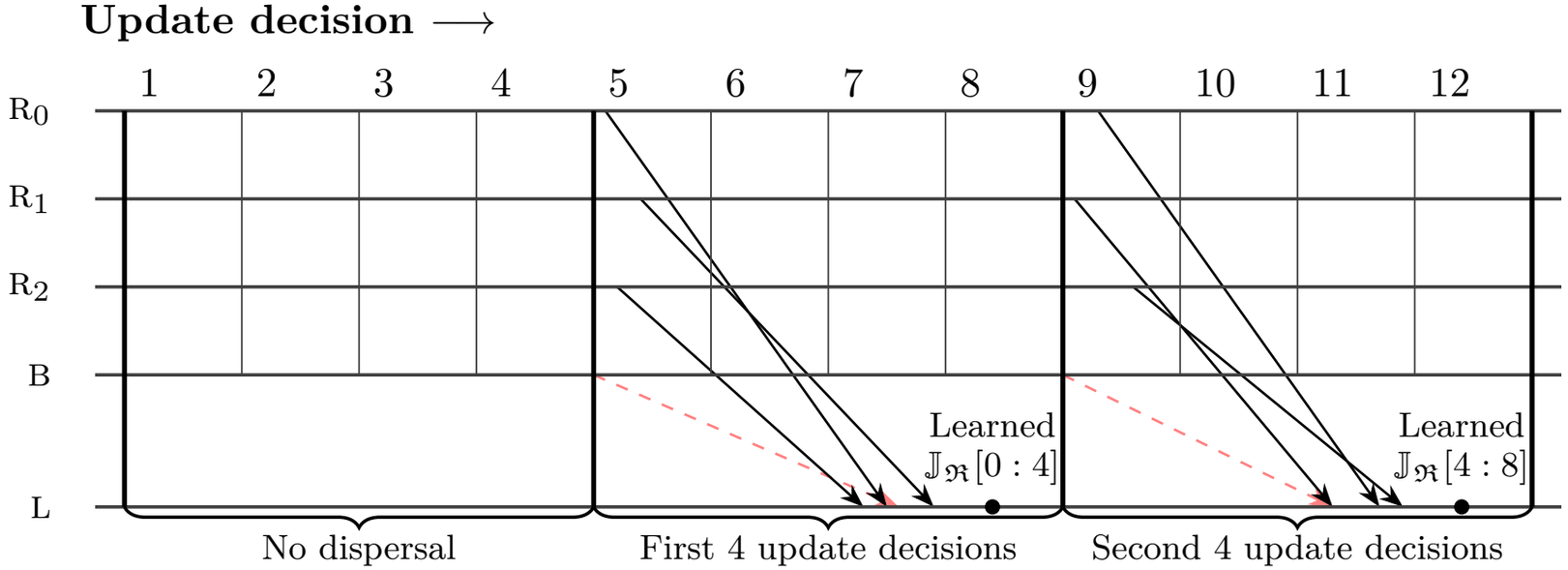


System	Checksum	Complexity for the learner		
		Data sent per replica	*Data received*	*Decode steps*
$\mathbf{b} = 0$	None	$\mathcal{O}(s/\mathbf{g})$	$\mathcal{O}(s(\mathbf{n}/\mathbf{g}))$	$u/\mathbf{n}$
$\mathbf{b} < \mathbf{g}$	Simple	$\mathcal{O}(s/\mathbf{g})$	$\mathcal{O}(s(\mathbf{n}/\mathbf{g}))$	$\binom{\mathbf{g}+\mathbf{b}}{\mathbf{g}}(u/\mathbf{n})$
$\mathbf{b} < \mathbf{g}$	Tree	$\mathcal{O}(s/\mathbf{g} + (u/\mathbf{n})\log(\mathbf{n}))$	$\mathcal{O}(s(\mathbf{n}/\mathbf{g}) + u\log(\mathbf{n}))$	$u/\mathbf{n}$

Permissioned Blockchain Through the Looking Glass: Architectural and Implementation Lessons Learned [ICDCS'20]

Single-threaded Monolithic Design

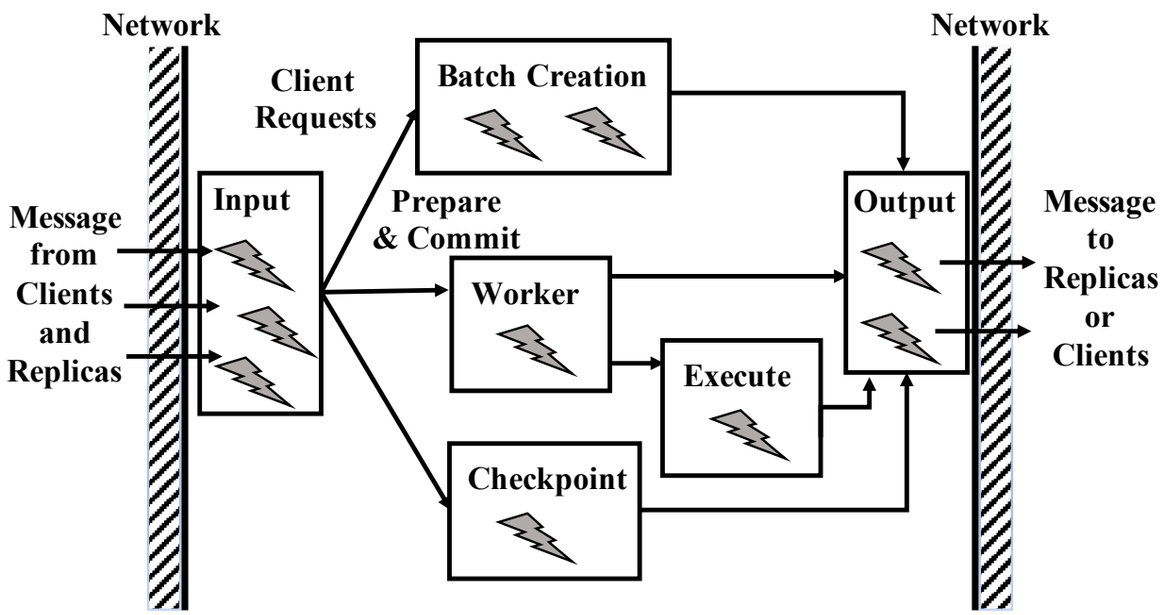
Out-of-ordering Consensus Communication

De-coupled Ordering and Execution

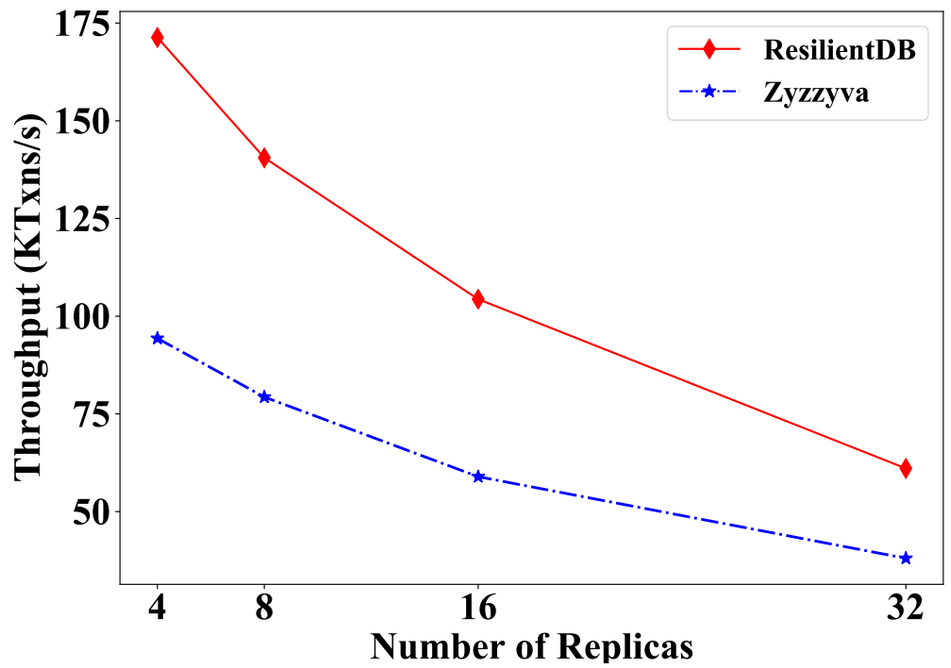
Off-Chain Memory Management

Expensive Cryptographic Practices (DS vs. MAC)

Smart Contracts Code Generation (Pre-compilation)



Multi-Threaded Deep Pipeline



Can a well-crafted system based on a classical BFT protocol outperform a modern protocol?

Revisit Resiliency

(Graduate Student Experiment Continues)

Mount Tallac, Lake Tahoe
12.1 Miles Long
3,931 Feet Elevation Gain
(9,738 Feet at Summit)

Fostering Resiliency

(Offering Stress Management and Well-Being Courses at UC Davis)

THE CALIFORNIA AGGIE

Seminar spotlight: “Becoming an Extraordinary Human”

The California Aggie, April 6, 2020

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Thank You

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