VLDB2020Tokyo

Building High Throughput Permissioned Blockchain Fabrics: Challenges and Opportunities

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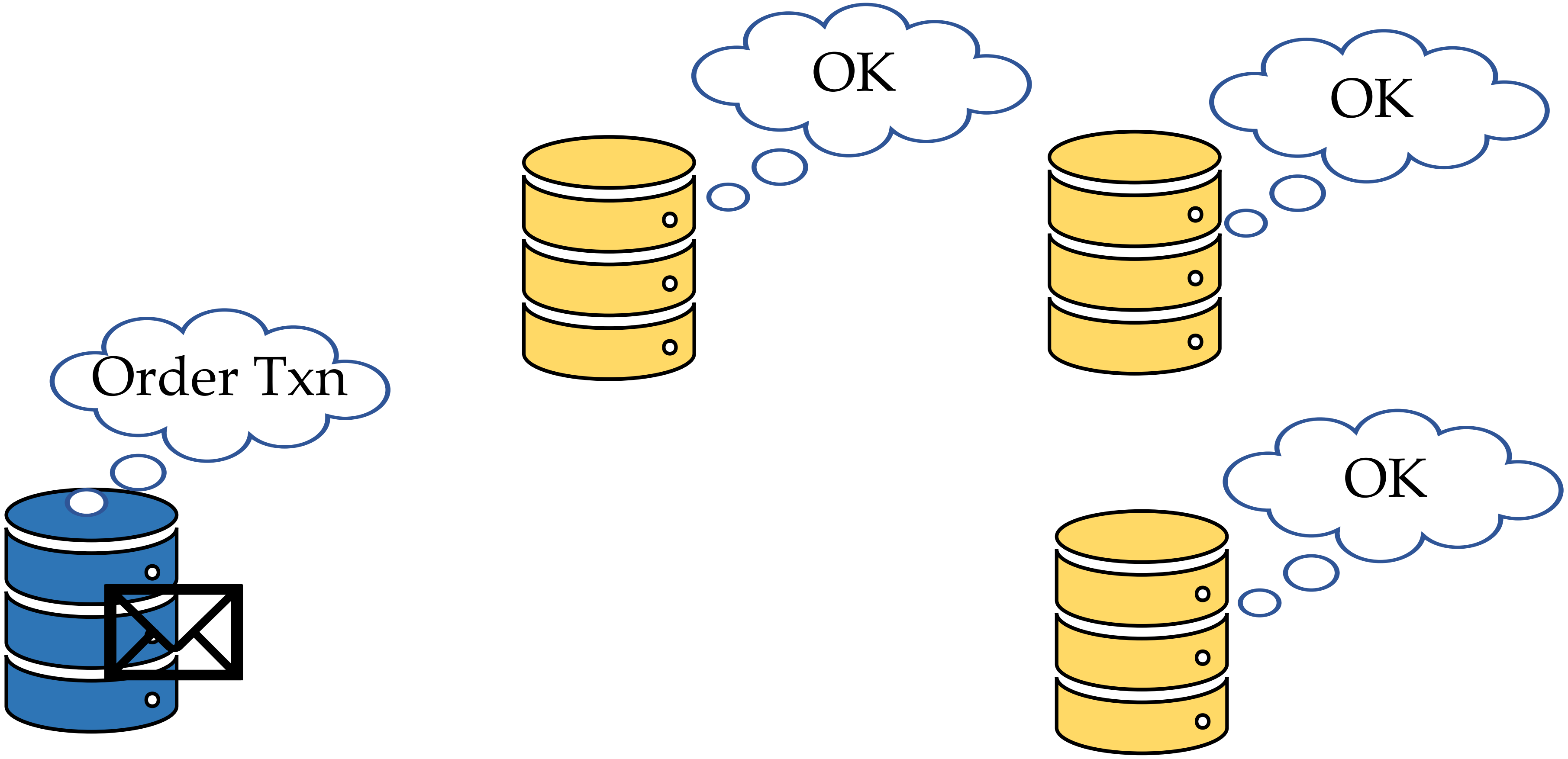
ExpoLab Creativity Unfolded

ResilientDB

At the core of *any* Blockchain application is a Byzantine Fault-Tolerant (BFT) consensus protocol.

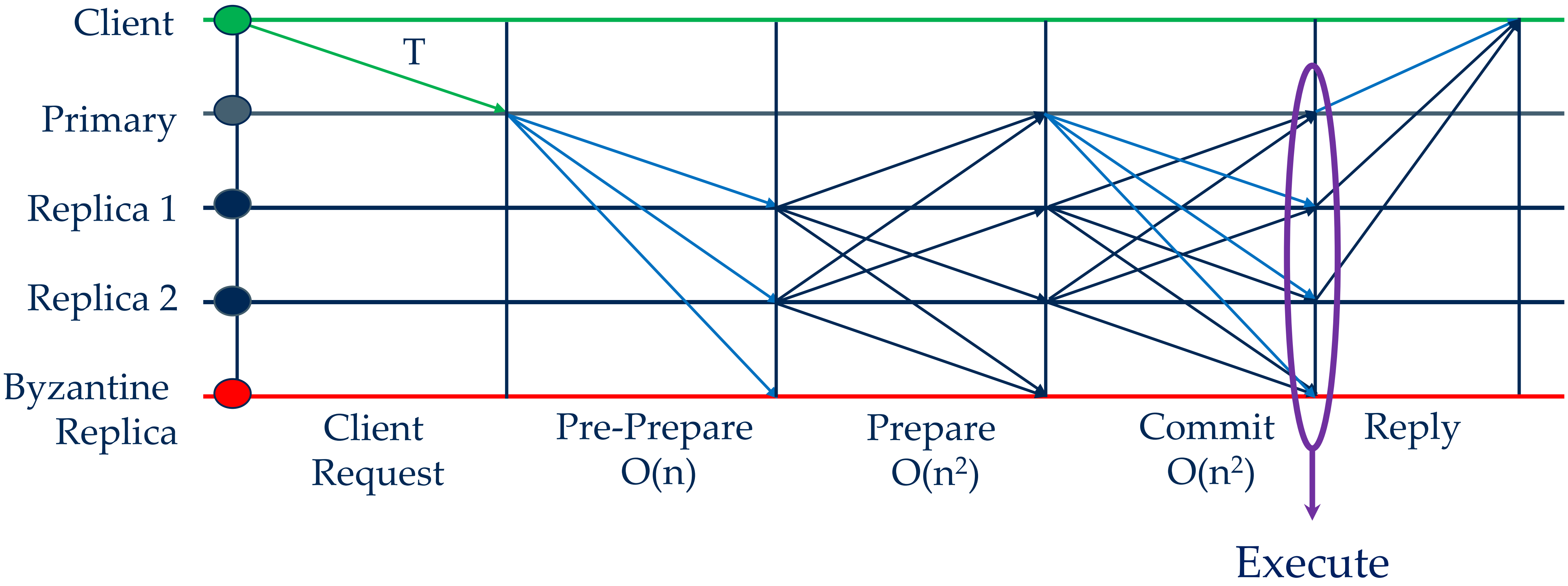


Practical Byzantine Fault-Tolerance (PBFT)

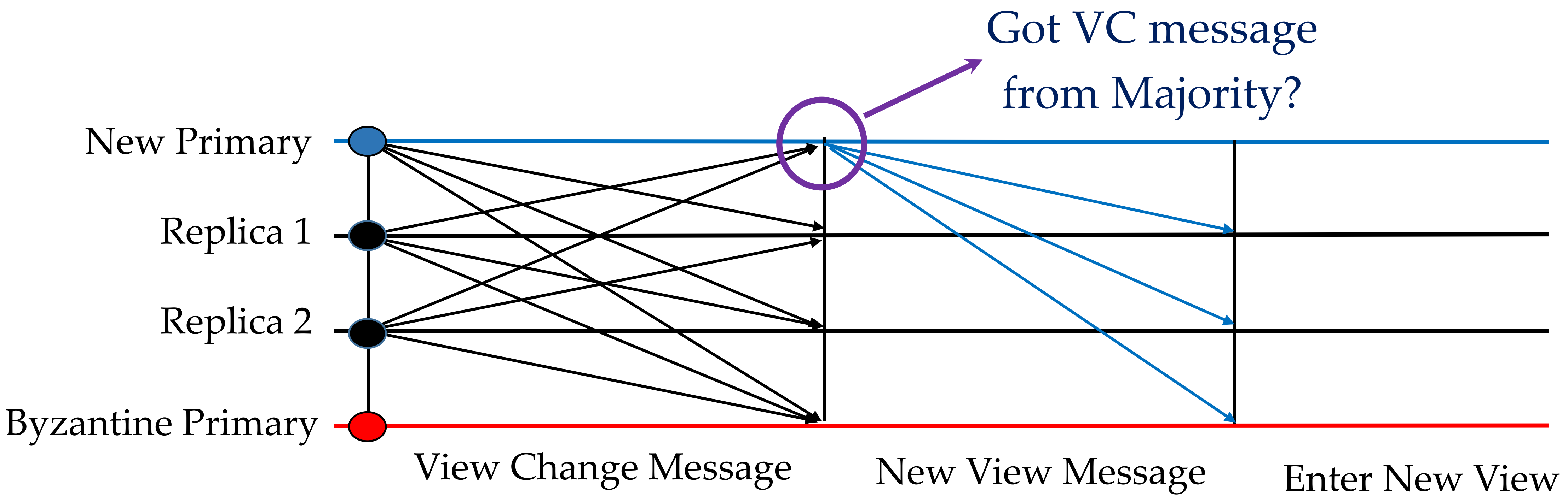
[OSDI'99]

- First *practical* Byzantine Fault-Tolerant Protocol.
- Tolerates up to **f** failures in a system of 3f+1 replicas
- Requires three phases of which two necessitate quadratic communication complexity.
- Safety is always guaranteed and Liveness is guaranteed in periods of partial synchrony.

PBFT Civil Executions



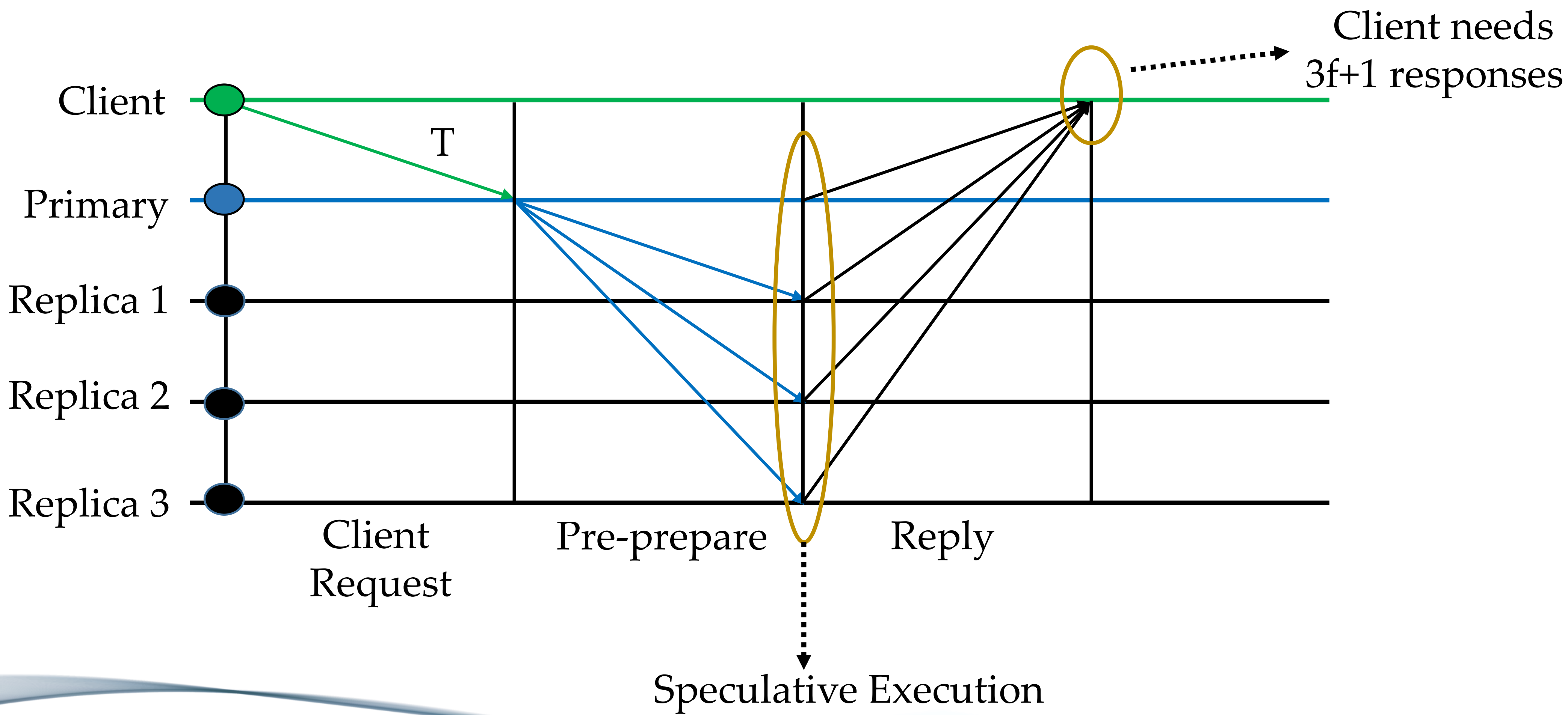
PBFT Uncivil Execution: Primary Failure
(*View Change*)



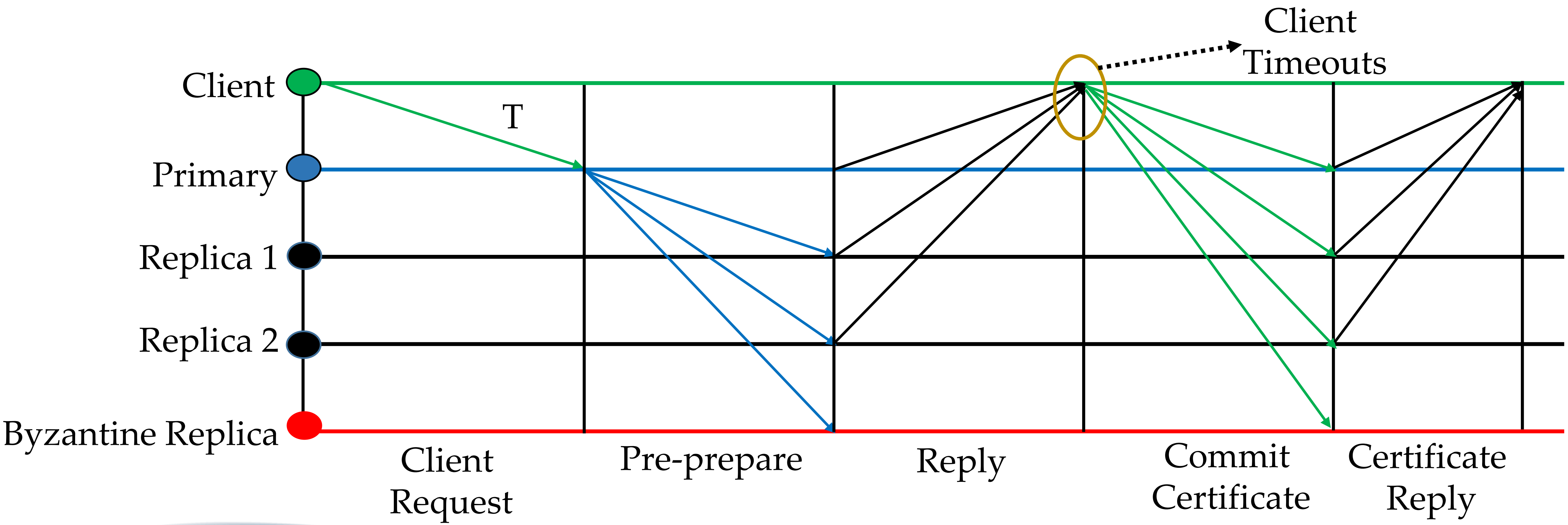
Speculative Byzantine Fault Tolerance (Zyzzyva) [SOSP'07]

- Speculation to achieve consensus in a single phase.
- Under ***no failures***, it only requires linear communication complexity.
- Requires good clients, for ensuring same order across the replicas.
- Clients need matching responses from all the 3f+1 replicas.
- Just one crash failure is sufficient to severely impact throughput.
- Recently, proven unsafe!

Zyzzyva Civil Executions



Zyzzyva under Failure of *one* Non-Primary Replica



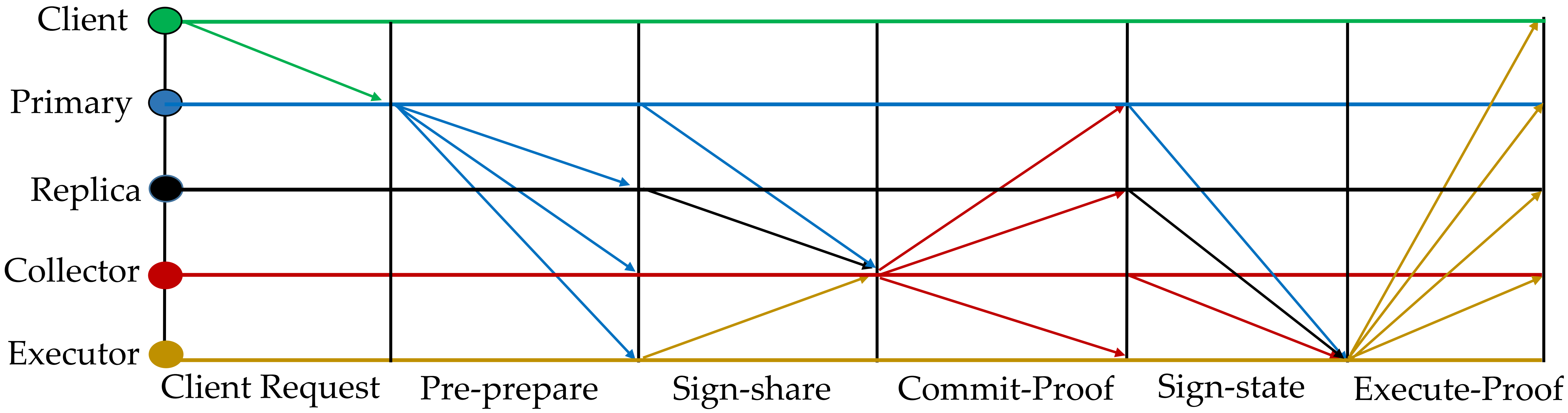
On client timeout → switches to *slow-path*.

SBFT: A Scalable and Decentralized Trust Infrastructure

[DSN’19]

- A safe alternate to Zyzzyva.
- Employs threshold signatures to linearize consensus → Splits each $O(n^2)$ phase of PBFT into two linear phases.
- Requires *twin-paths* → fast-path and slow-path.
- Introduces notion of collectors and executors.

SBFT Civil Execution



Either no failures or c+1 crash failures for c > 0 collectors if n = 3f+2c+1

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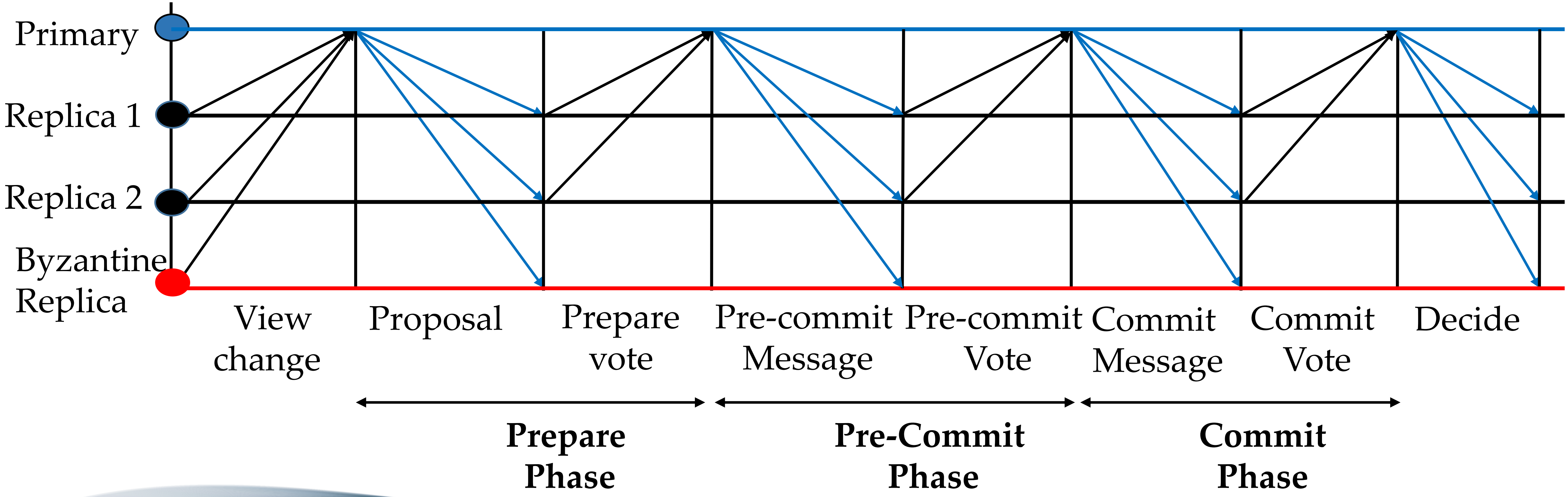
Hotstuff: BFT Consensus in the Lens of Blockchain [PODC'19]

- Splits each $O(n^2)$ phase of PBFT into two linear phases.
- Advocates leaderless consensus → Frequent primary replacement.
- Employs threshold signatures to linearize consensus → enforces sequential processing.
- **Two versions:**
  - **Basic Hotstuff:** Primary switched at the end of each consensus.
  - **Chained Hotstuff:** Employs pipelining to ensure each phase run by a distinct primary.

Hotstuff Protocol



Other Proposed Byzantine-Fault Tolerant Designs

1) System consisting of n >> 3f+1.

   ➢ Q/U [SOSP'05] expects 5f+1 replicas.

2) Use of trusted components to prevent primary equivocation.

   ➢ AHL [SIGMOD'19]

Novel Byzantine Fault-Tolerant Protocols

Proof-of-Execution (PoE)

Three-phase Linear protocol

Speculative Execution

Out-of-Order Message Processing

No dependence on clients or trusted component.

No reliance on a twin-path design.

PoE vs Other Protocols

Protocol	Phases	Messages	Resilience	Requirements
Zyzzyva	1	$\mathcal{O}(\mathbf{n})$	0	reliable clients and unsafe
PoE (our paper)	3	$\mathcal{O}(3\mathbf{n})$	$\mathbf{f}$	sign. agnostic
PBFT	3	$\mathcal{O}(\mathbf{n} + 2\mathbf{n}^2)$	$\mathbf{f}$	
HotStuff	4	$\mathcal{O}(\mathbf{n} + 3\mathbf{n}^2)$	$\mathbf{f}$	
HotStuff-TS	8	$\mathcal{O}(8\mathbf{n})$	$\mathbf{f}$	threshold sign.
SBFT	5	$\mathcal{O}(5\mathbf{n})$	0	threshold sign. and twin path

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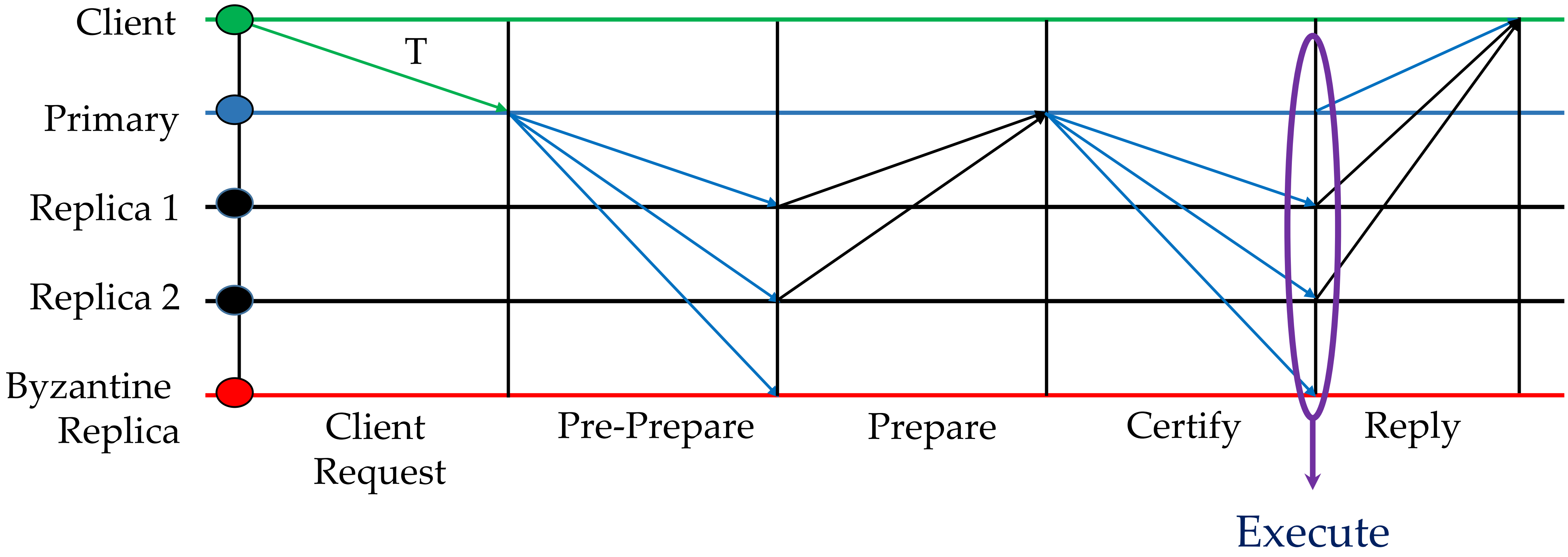
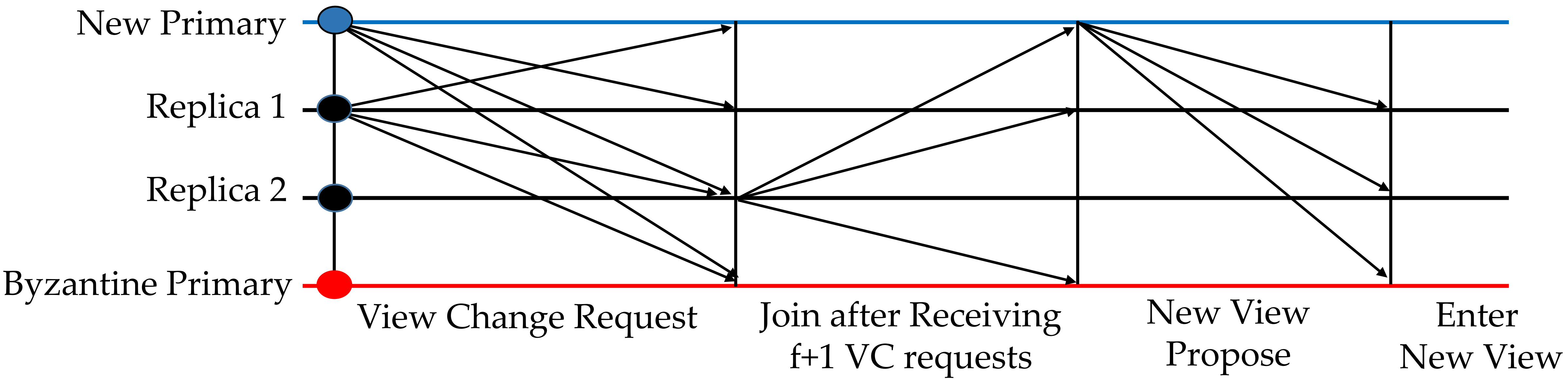
Proof-of-Execution (PoE)

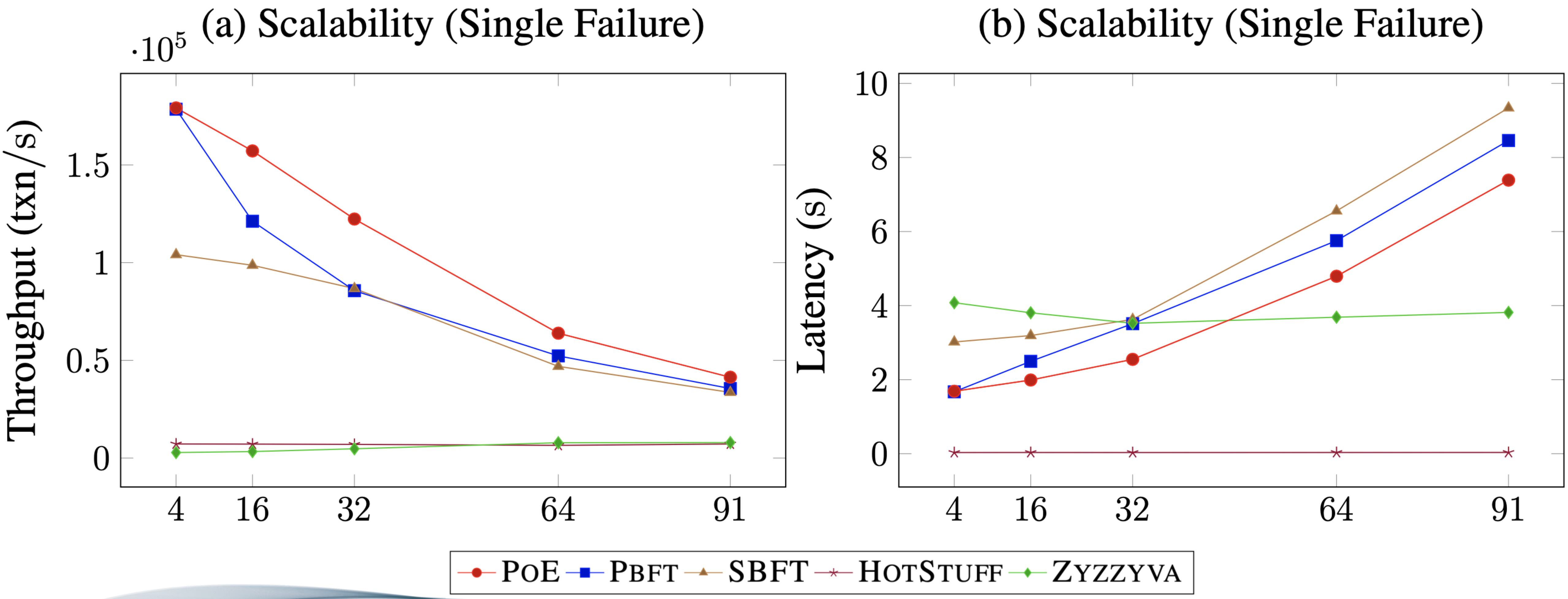


n = 4 replicas and f <= 1

PoE View Change Protocol



PoE Scalability under Single Failure



Resilient Concurrency Control (RCC) Paradigm

Democracy → Give all the replicas the power to be the primary.

Parallelism → Run multiple parallel instances of a BFT protocol.

Decentralization → Always there will be a set of ordered client requests.

RCC Defense

Why should BFT protocols rely on just ***one*** primary replica?

Malicious primary can ***throttle*** the system throughput.

Malicious primary requires ***replacemenat*** → fall in throughput.

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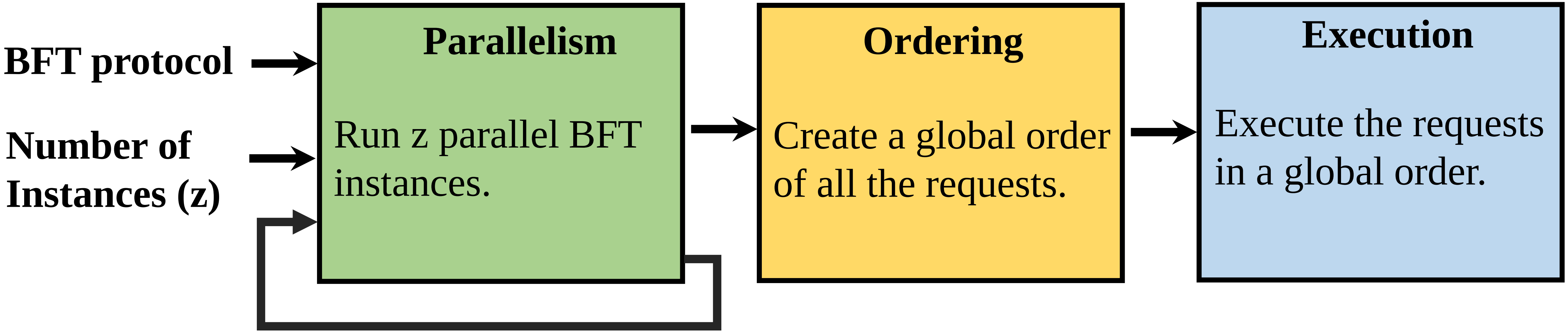
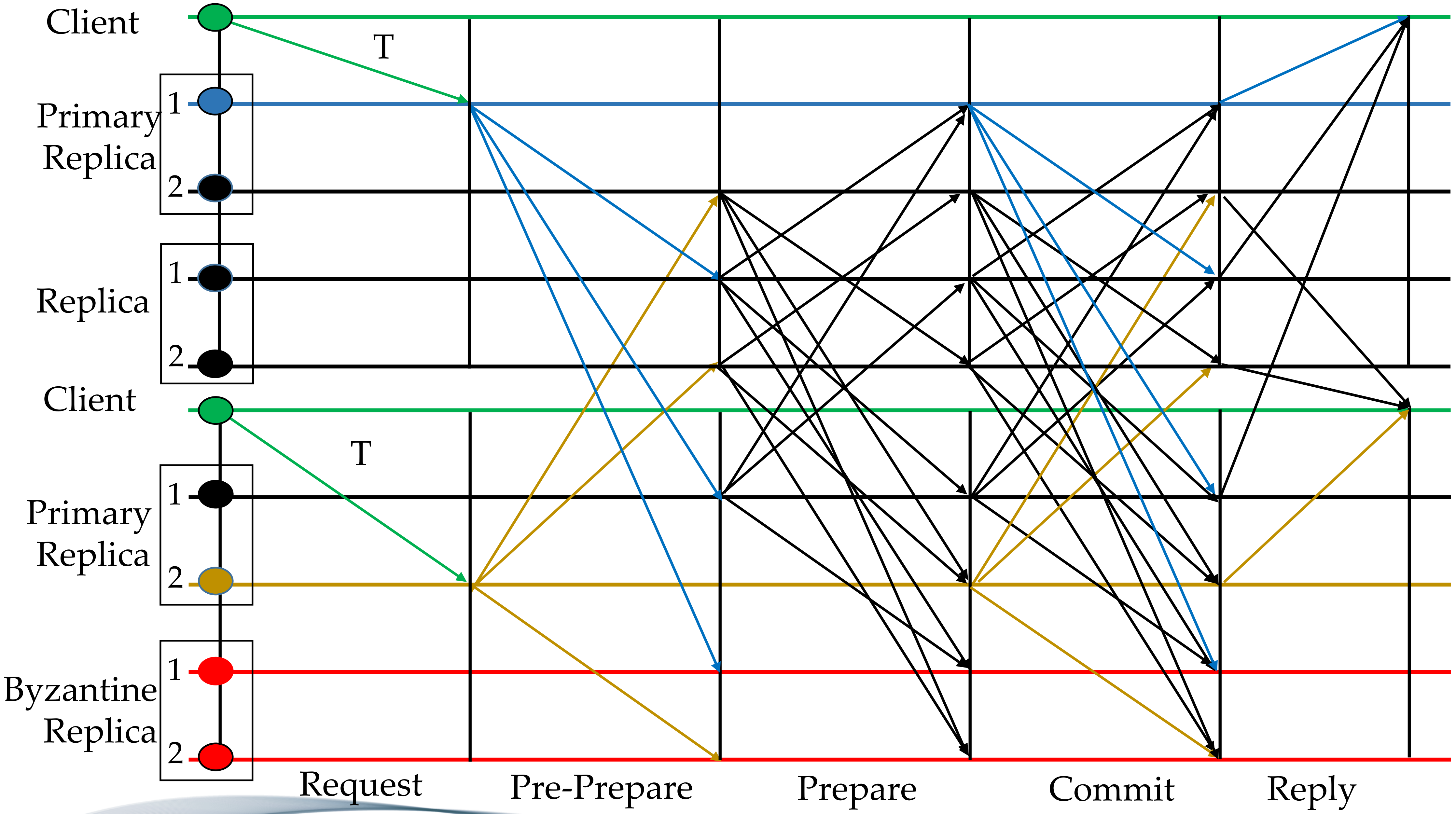
Resilient Concurrency Control Paradigm



RCC can employ several BFT protocols: PBFT, Zyzzyva, SBFT and PoE.



RCC using PBFT with 2 parallel instances on each replica

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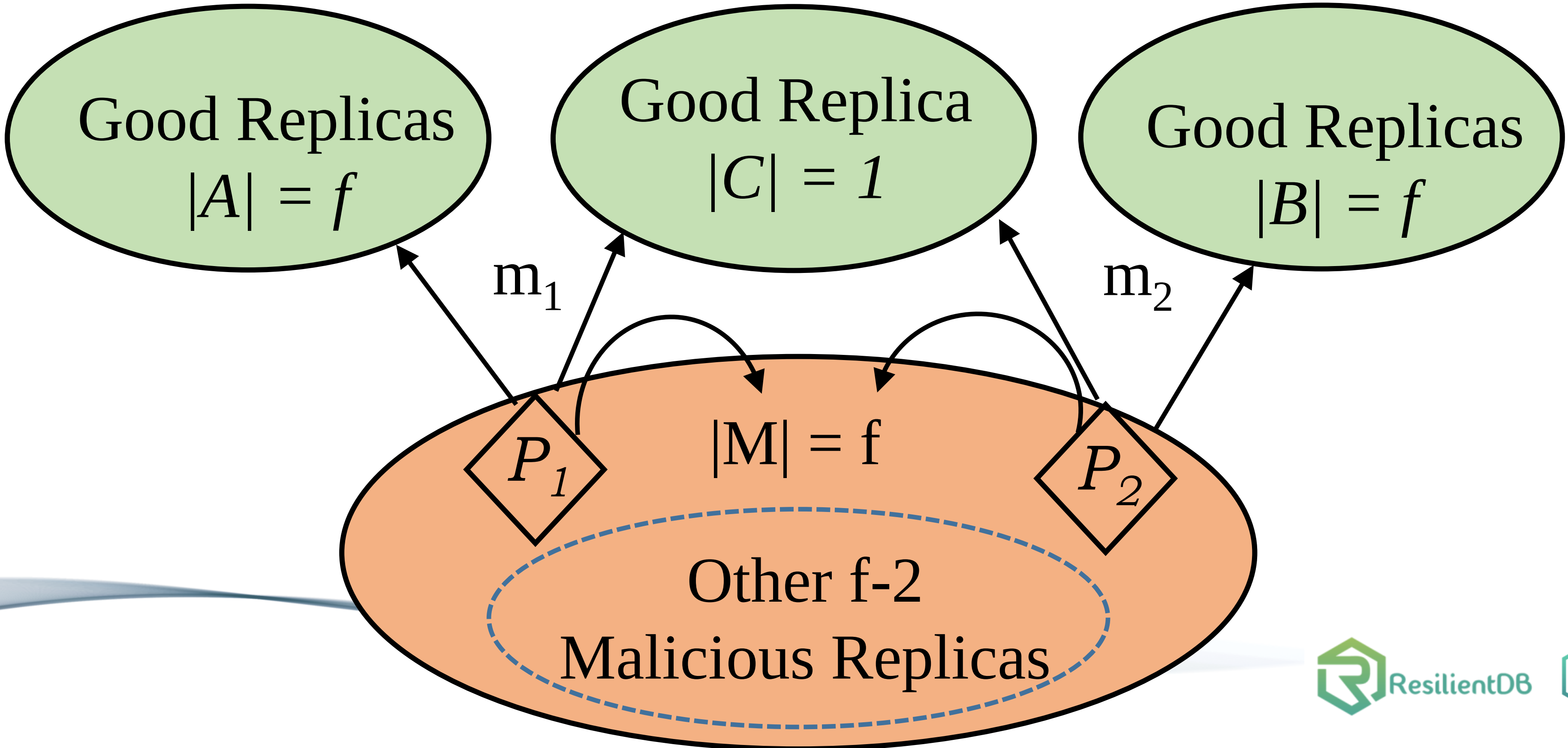
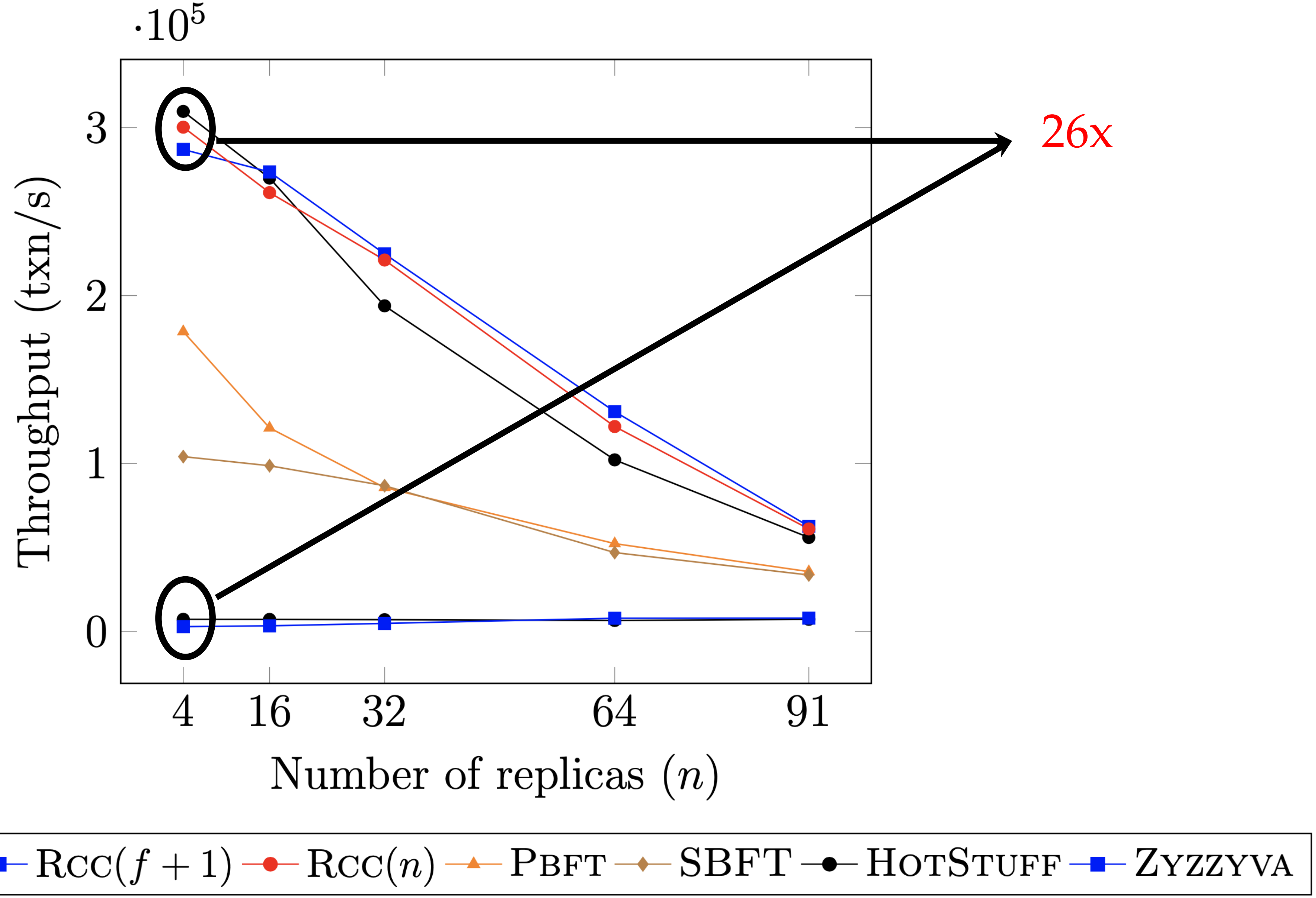
Colluding Primaries

Multiple malicious primaries can prevent liveness!

Solution → Optimistic Recovery through State Exchange.



Scalability



Single Failure Experiments

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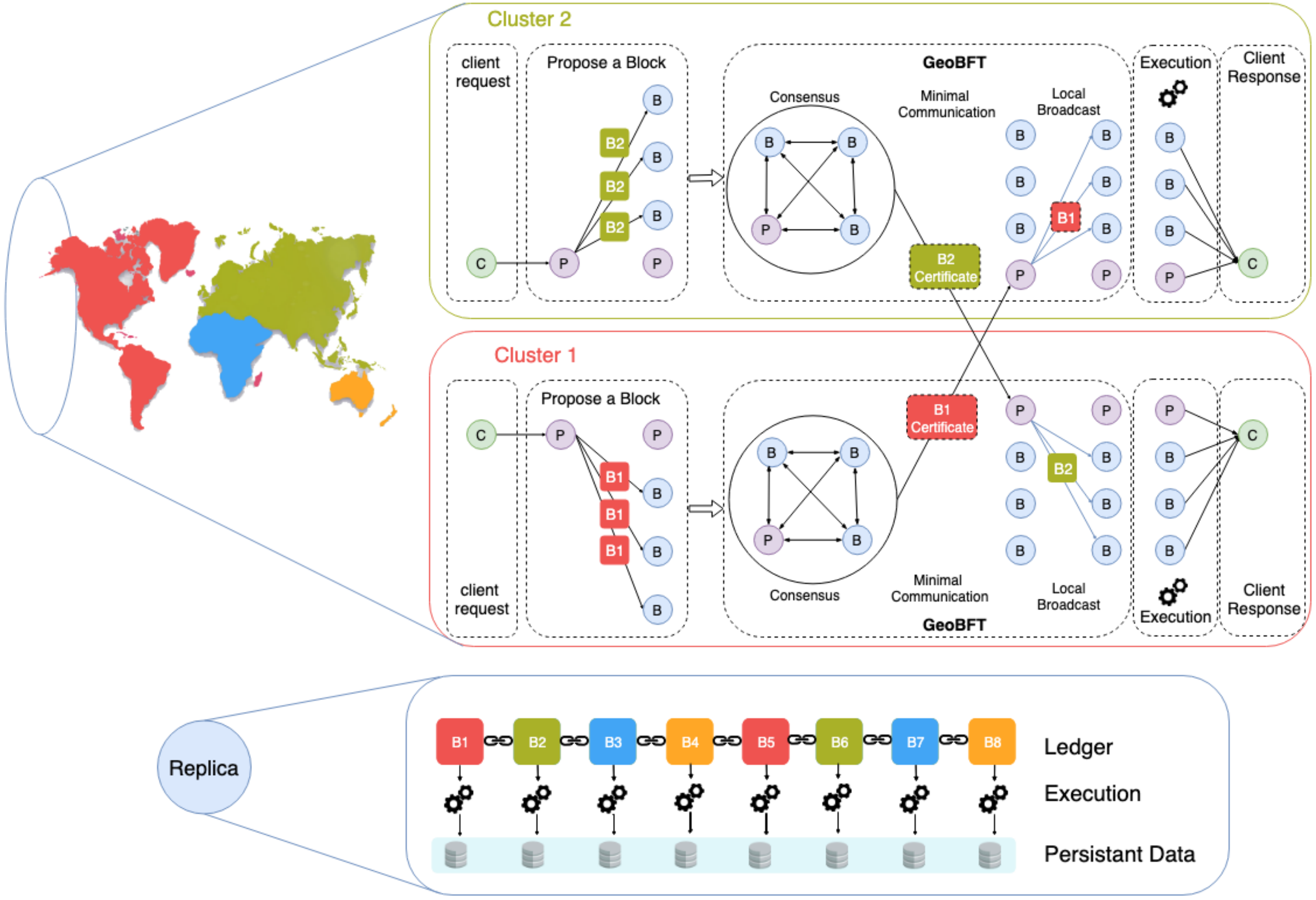
Global Scale Resilient Blockchain Fabric

- Traditional BFT protocols do not scale to geographically large distances.
- Blockchain requires decentralization → replicas can be far apart → expensive communication!
- The underlying BFT consensus protocol should be topology-aware.

Vision Geo-Scale Byzantine Fault-Tolerance



GeoBFT Protocol

GeoBFT is a topology-aware protocol, which groups replicas into clusters. Each cluster runs the PBFT consensus protocol, in parallel and independently.

Local Replication

Each cluster runs PBFT to select, locally replicate, and certify a client request.

→

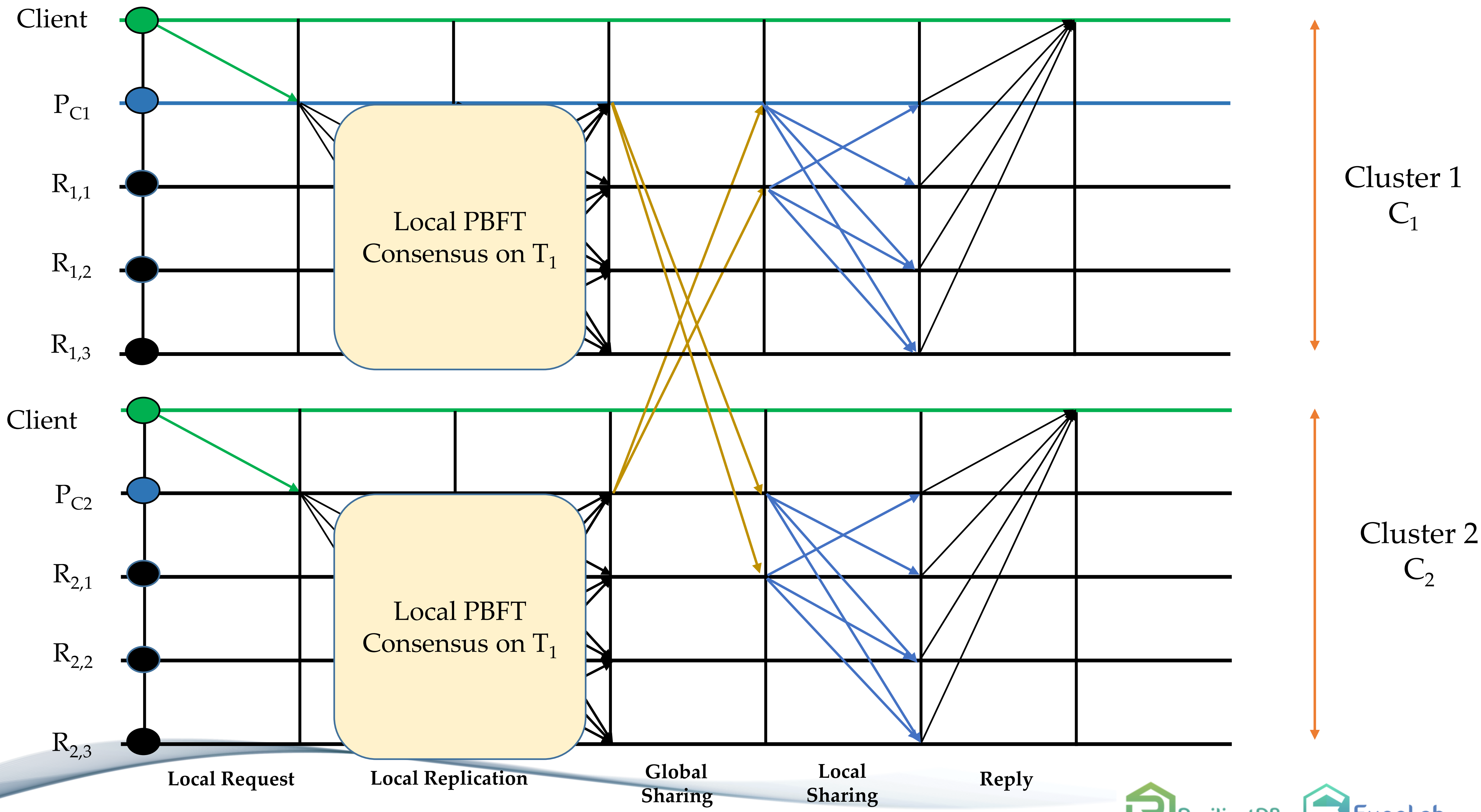
Inter-cluster Sharing

Primary at each cluster shares the certified client request with other clusters.

→

Ordering and Execution

Order the certified requests, execute them, and inform local clients.

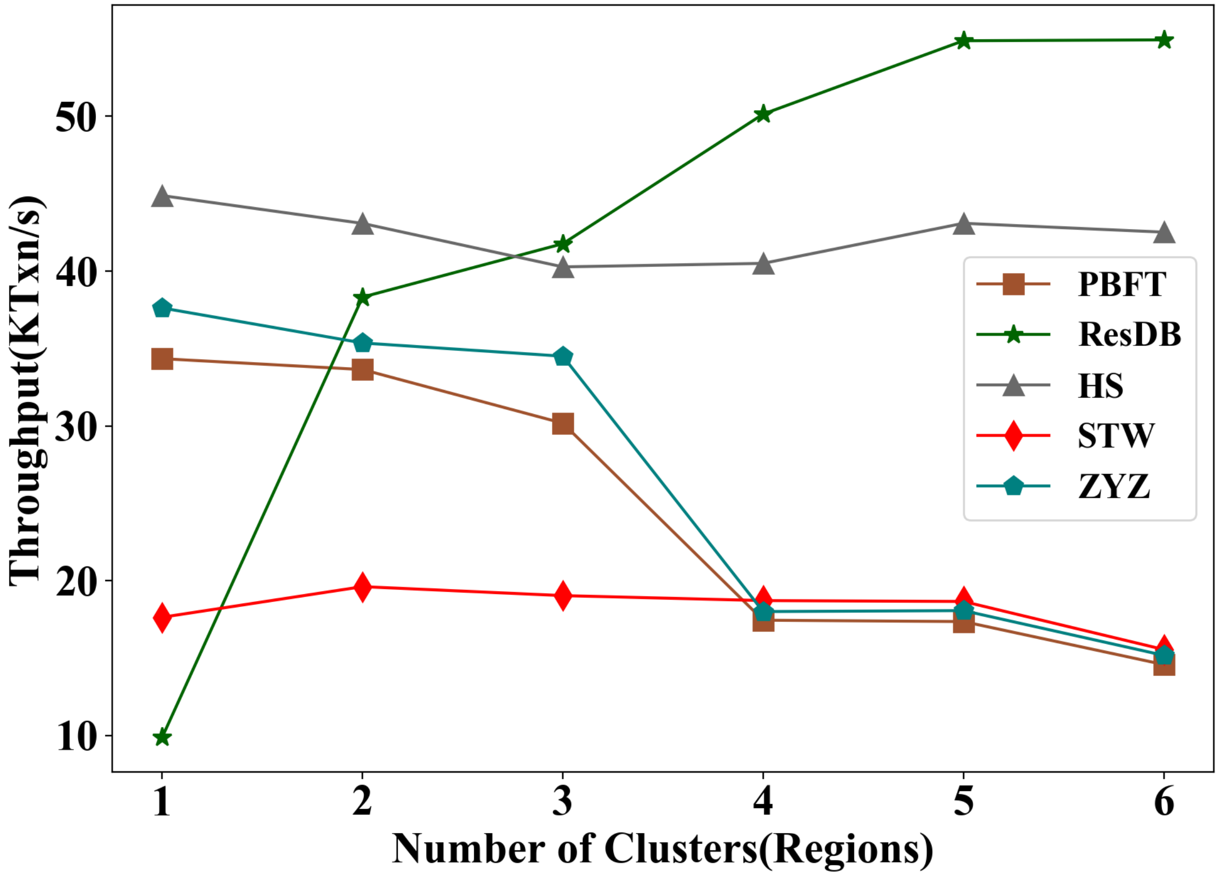


Client
P C1
R 1,1
R 1,2
R 1,3
Local PBFT
Consensus on T1
Cluster 1
C1
Client
P C2
R 2,1
R 2,2
R 2,3
Local PBFT
Consensus on T1
Cluster 2
C2
Local Request
Local Replication
Global Sharing
Local Sharing
Reply

GeoBFT Takeaways

- To ensure common ordering → linear communication among the clusters is required.
- Primary replica at each cluster sends a secure certificate to f+1 replicas of every other cluster.
- Certificates guarantee common order for execution.
- If primary sends invalid certificates → will be detected as malicious.

GeoBFT Scalability



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Permissioned Blockchain Through the Looking Glass: Architectural and Implementation Lessons Learned

Visit at: https://resilientdb.com/

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*Proceedings of the 40th IEEE ICDCS 2020.

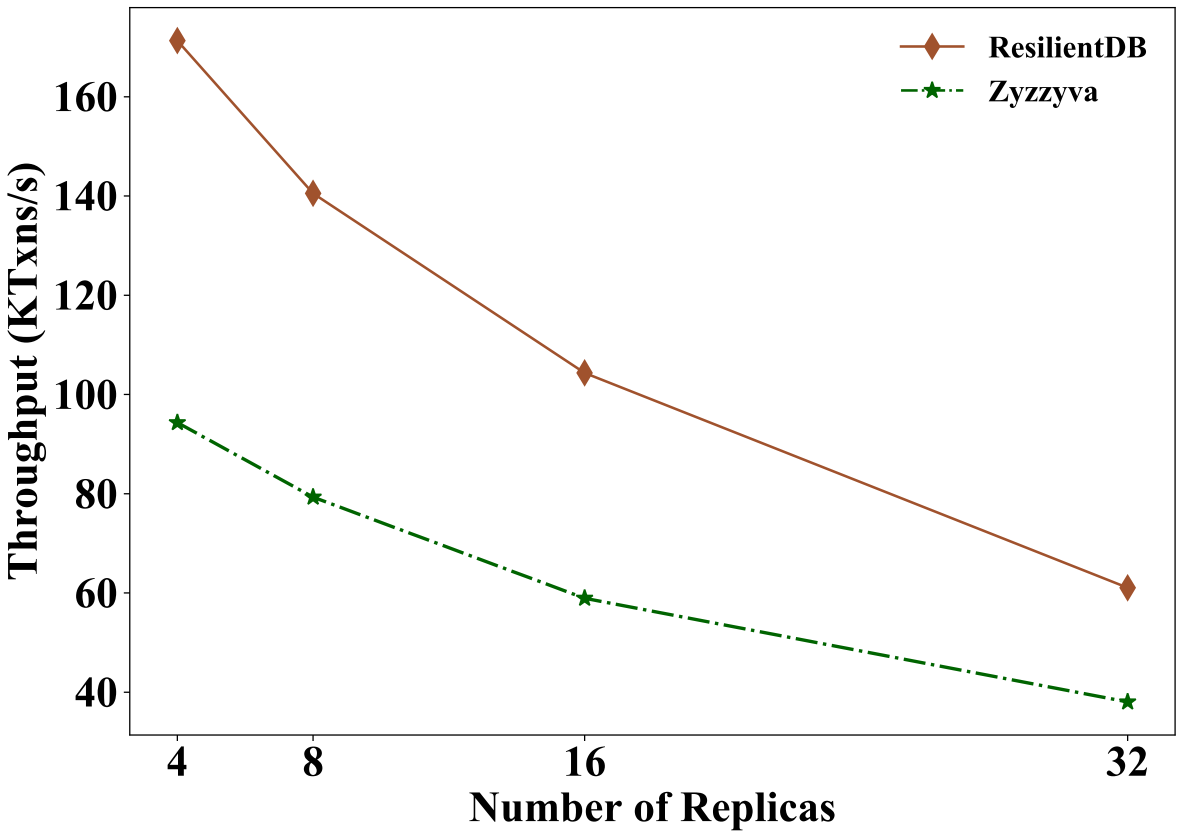
Why Should You Chose ResilientDB?

1) Bitcoin and Ethereum offer low throughputs of *10 txns/s*.
2) Existing Permissioned Blockchain Databases still have low throughputs (*20K txns/s*).
3) Prior works blame BFT consensus as *expensive*.
4) System Design is mostly *overlooked*.
5) ResilientDB adopts *well-researched* database and system practices.

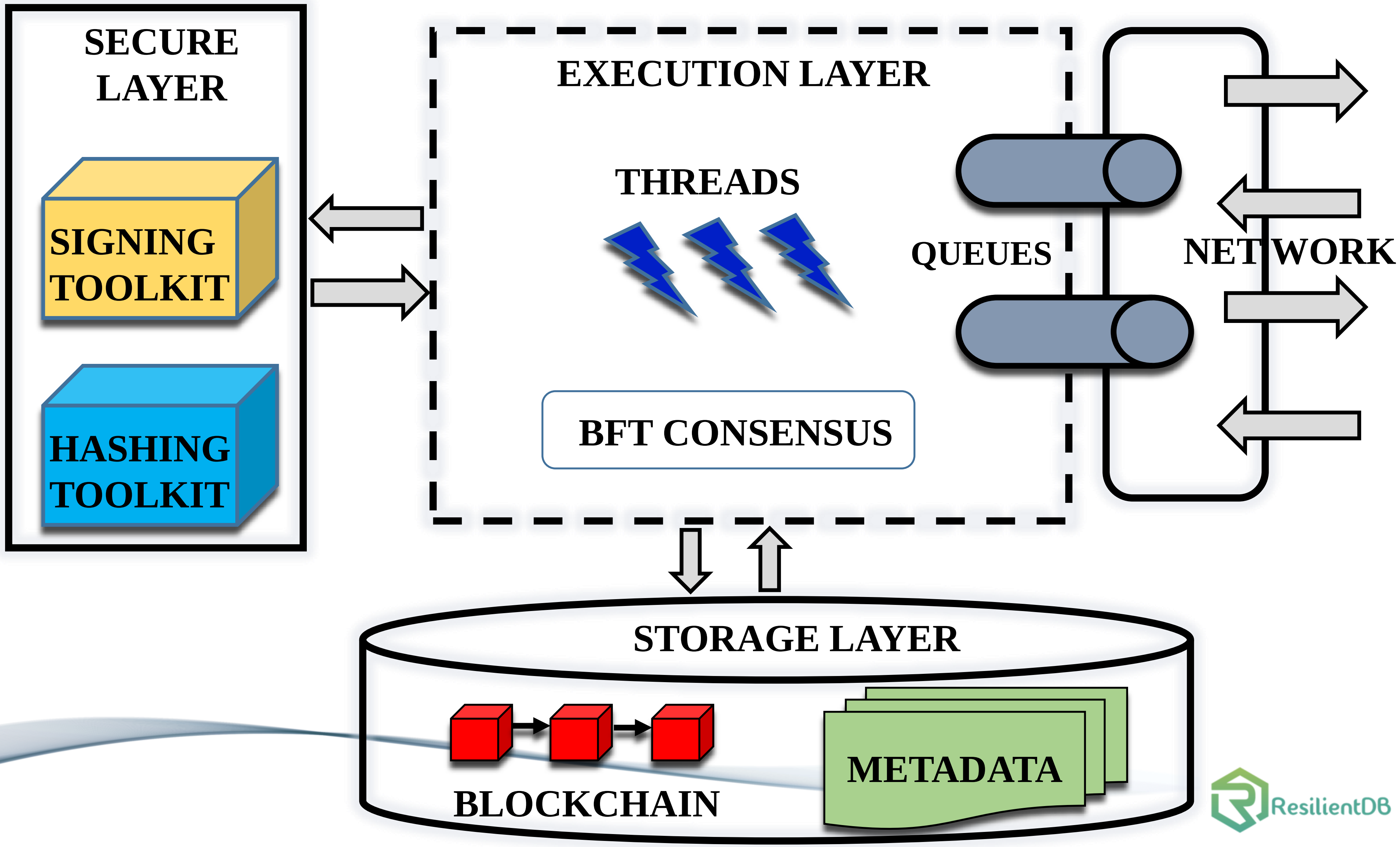
Dissecting Existing Permissioned Blockchains

1) Single-threaded Monolithic Design
2) Successive Phases of Consensus
3) Integrated Ordering and Execution
4) Strict Ordering
5) Off-Chain Memory Management
6) Expensive Cryptographic Practices

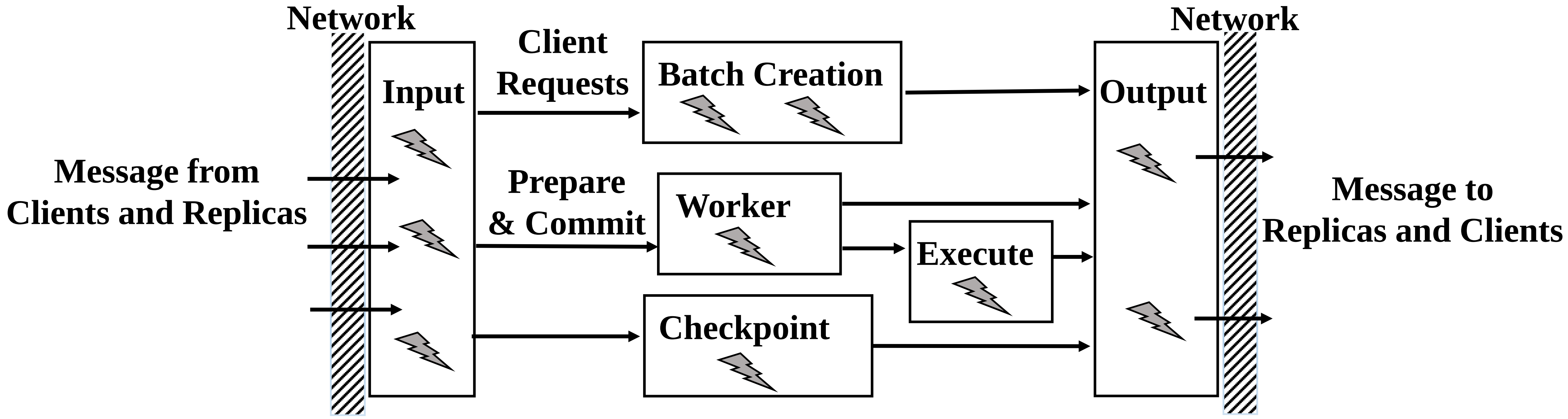
Can a well-crafted system based on a classical BFT protocol outperform a modern protocol?



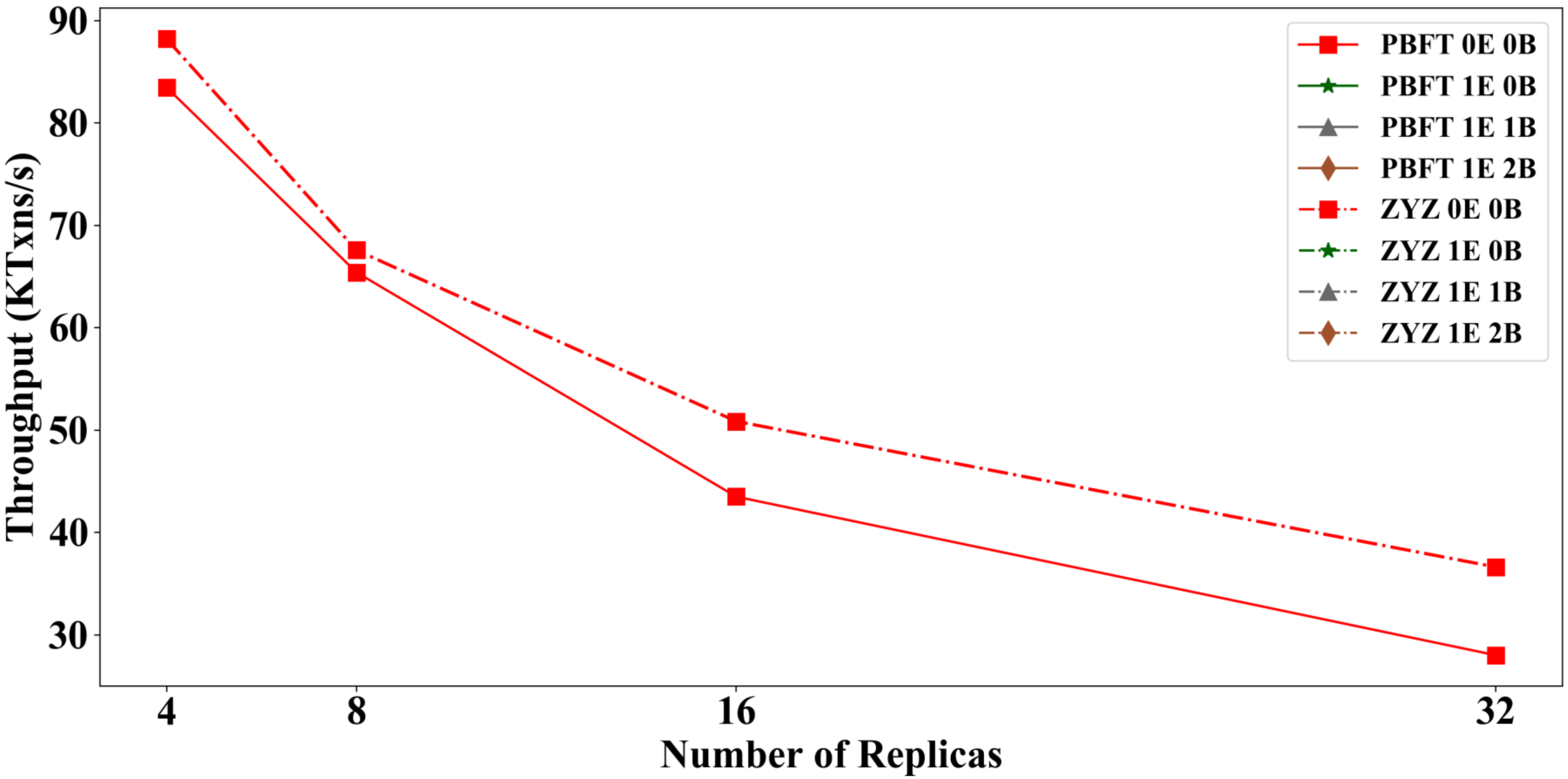
ResilientDB Architecture



ResilientDB Multi-Threaded Deep Pipeline

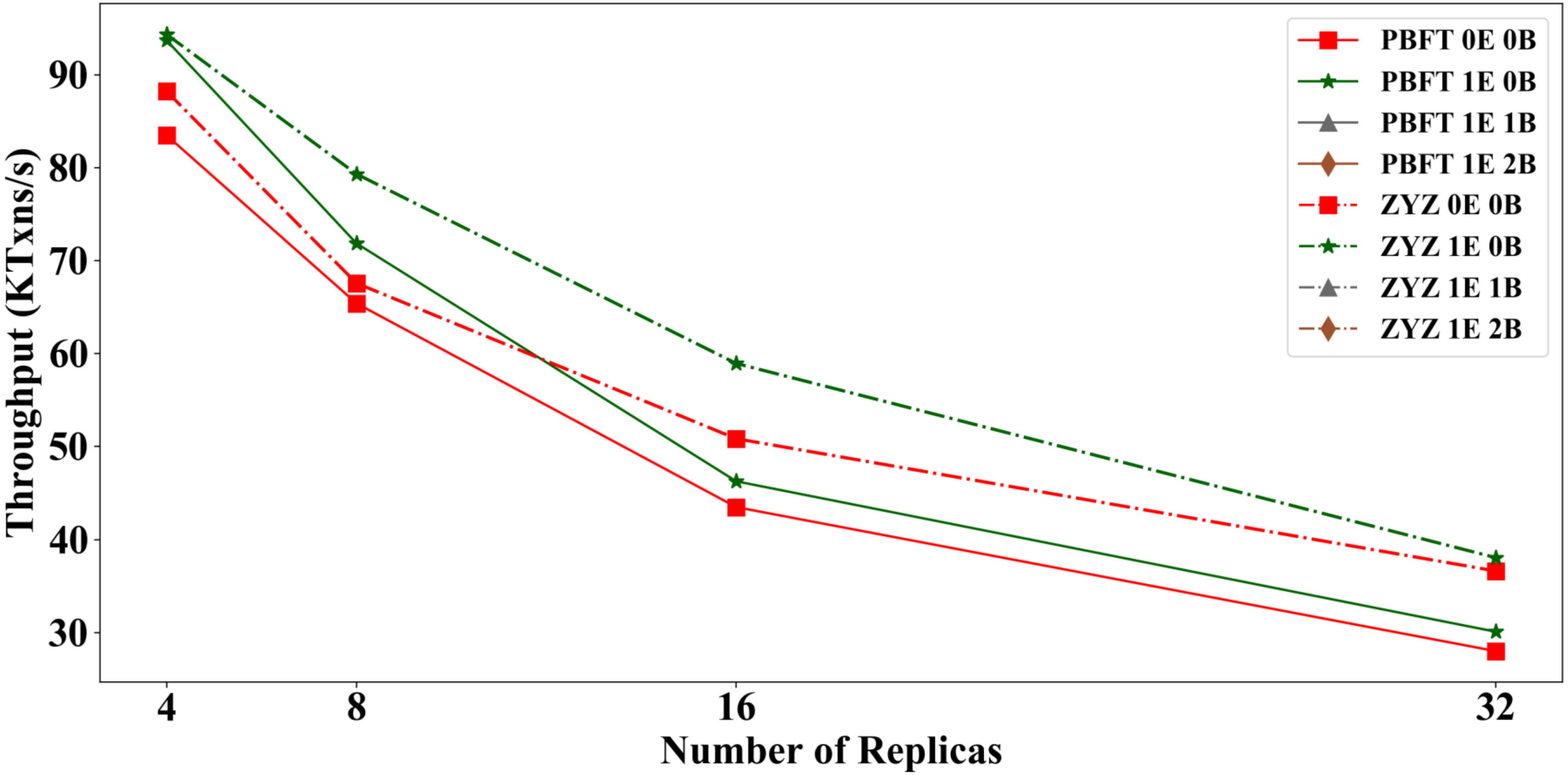


Insight 1: Multi-Threaded pipeline Gains



Parallelizing and Pipelining tasks across worker, execution (E) and batch-threads (B).

Insight 1: Multi-Threaded pipeline Gains



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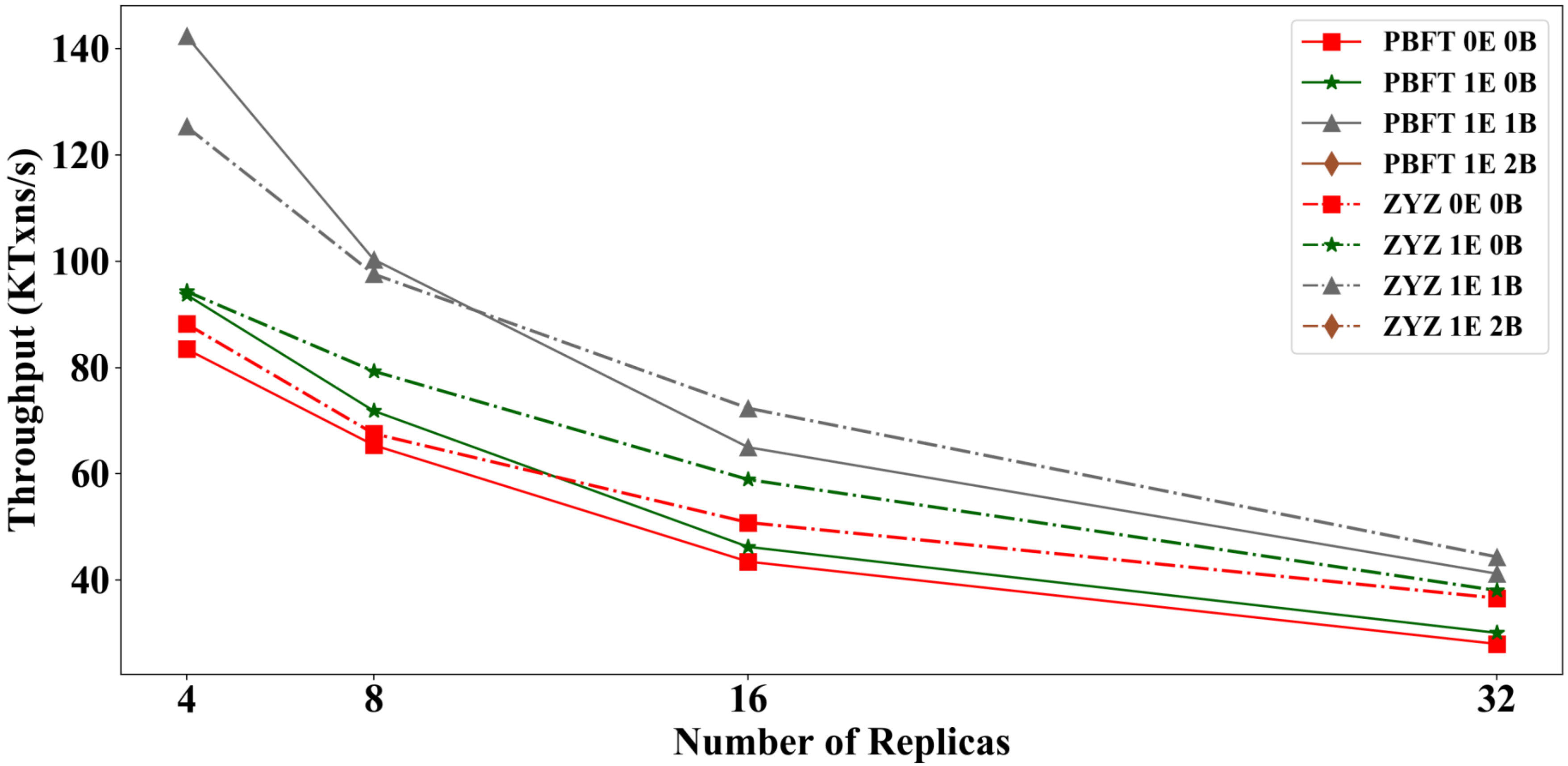

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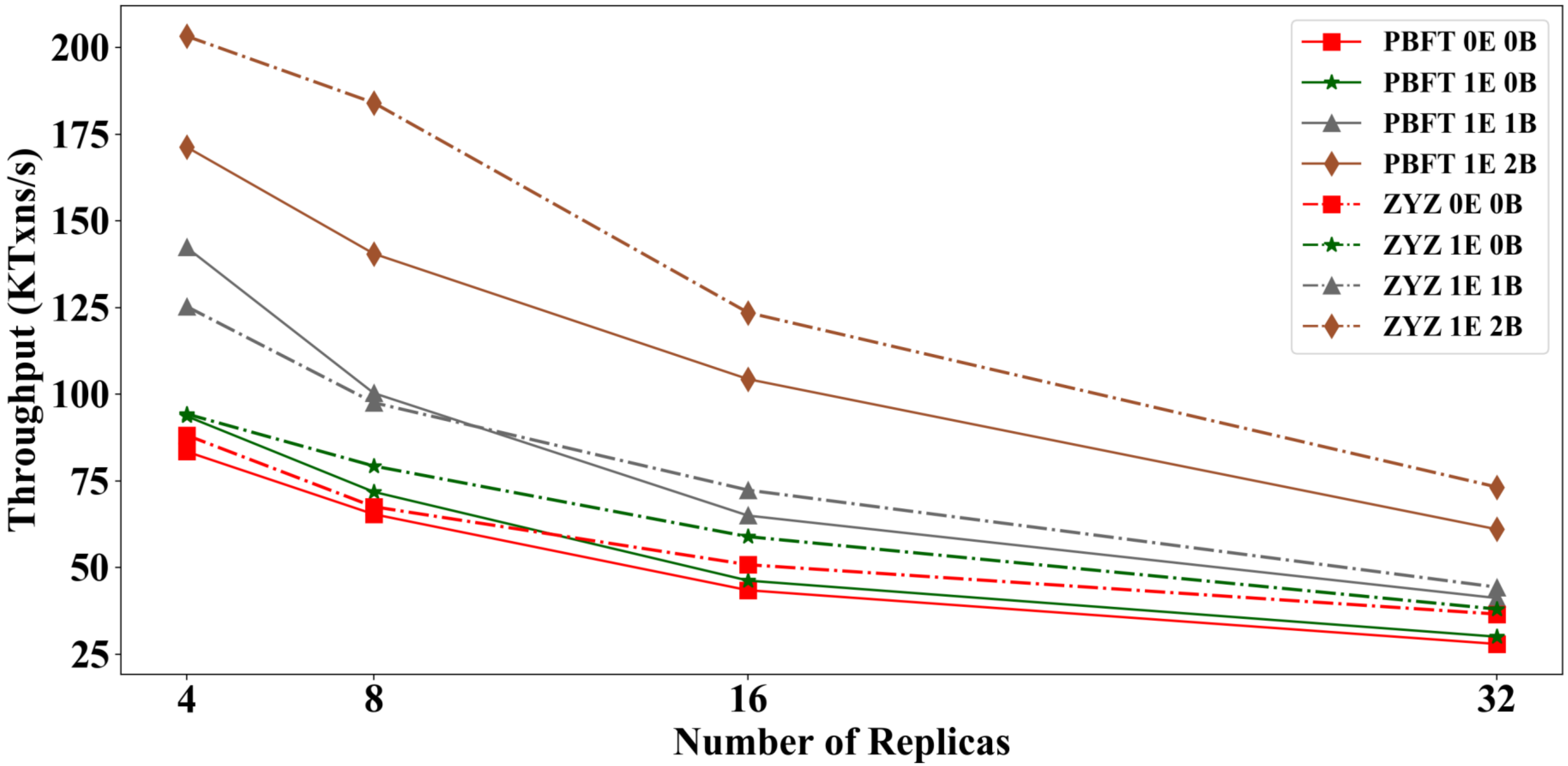
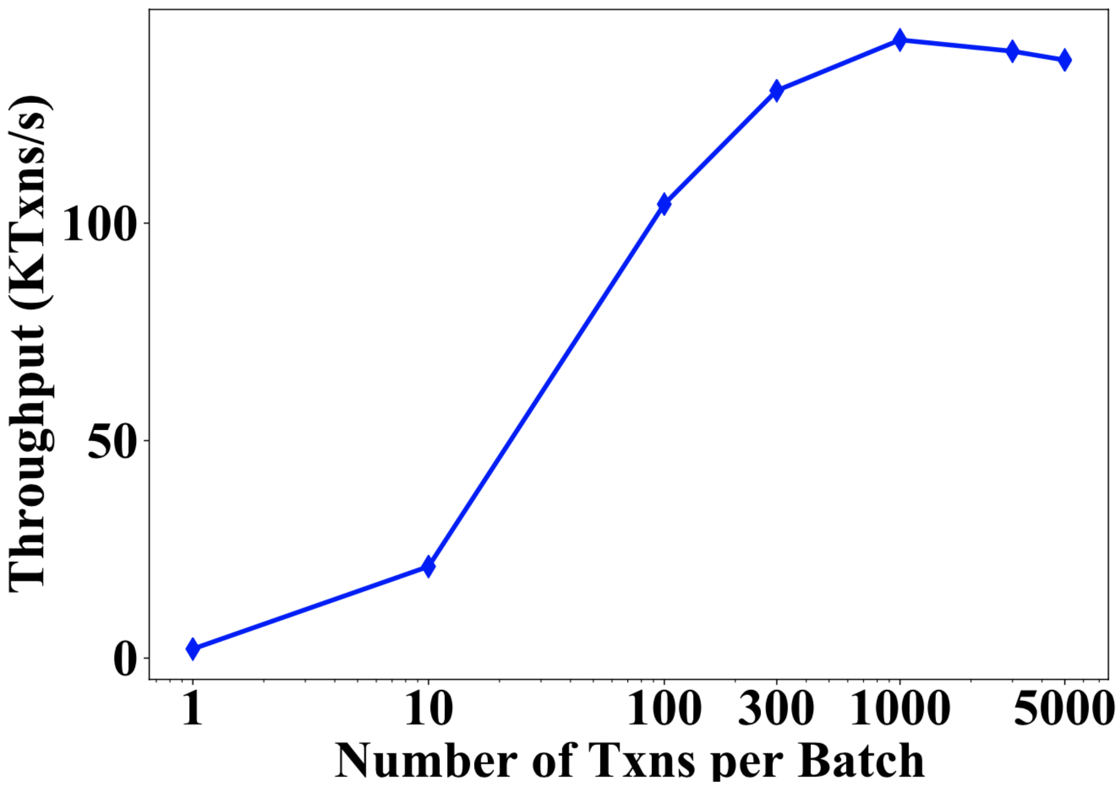
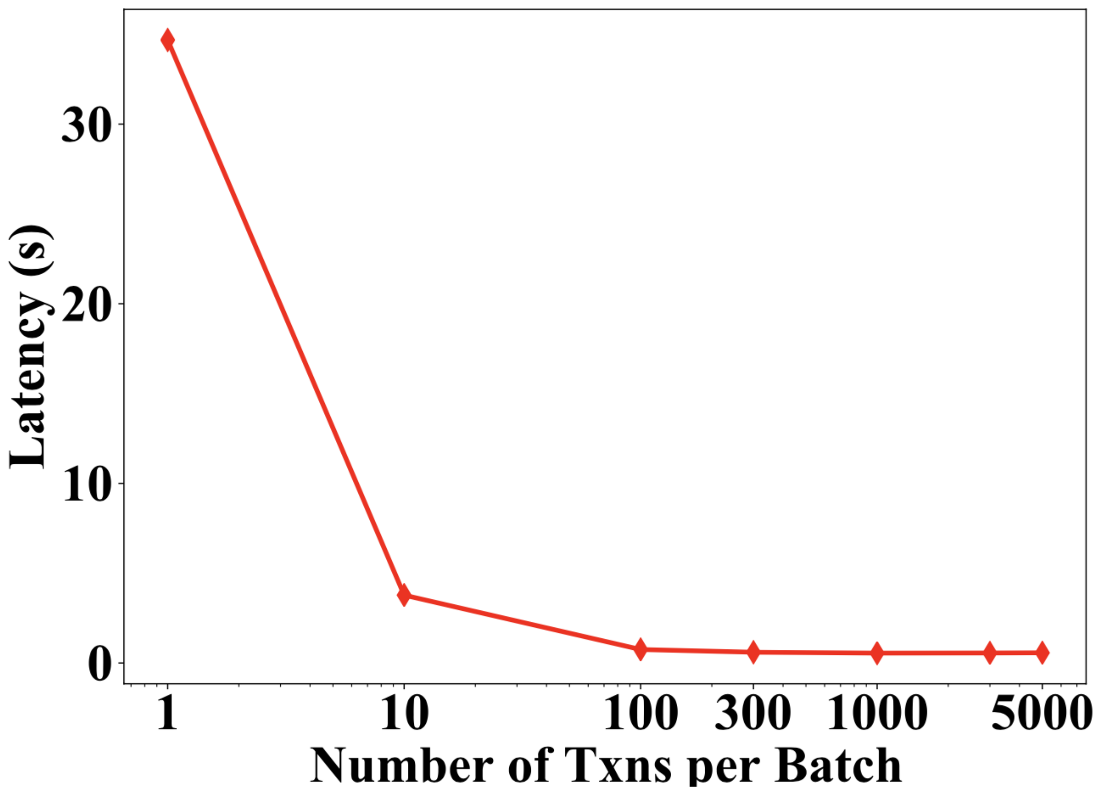


Parallelizing and Pipelining tasks across worker, execution (E) and batch-threads (B).

Insight 2: Optimal Batching Gains





More transactions batched together → increase in throughput
→reduced phases of consensus.

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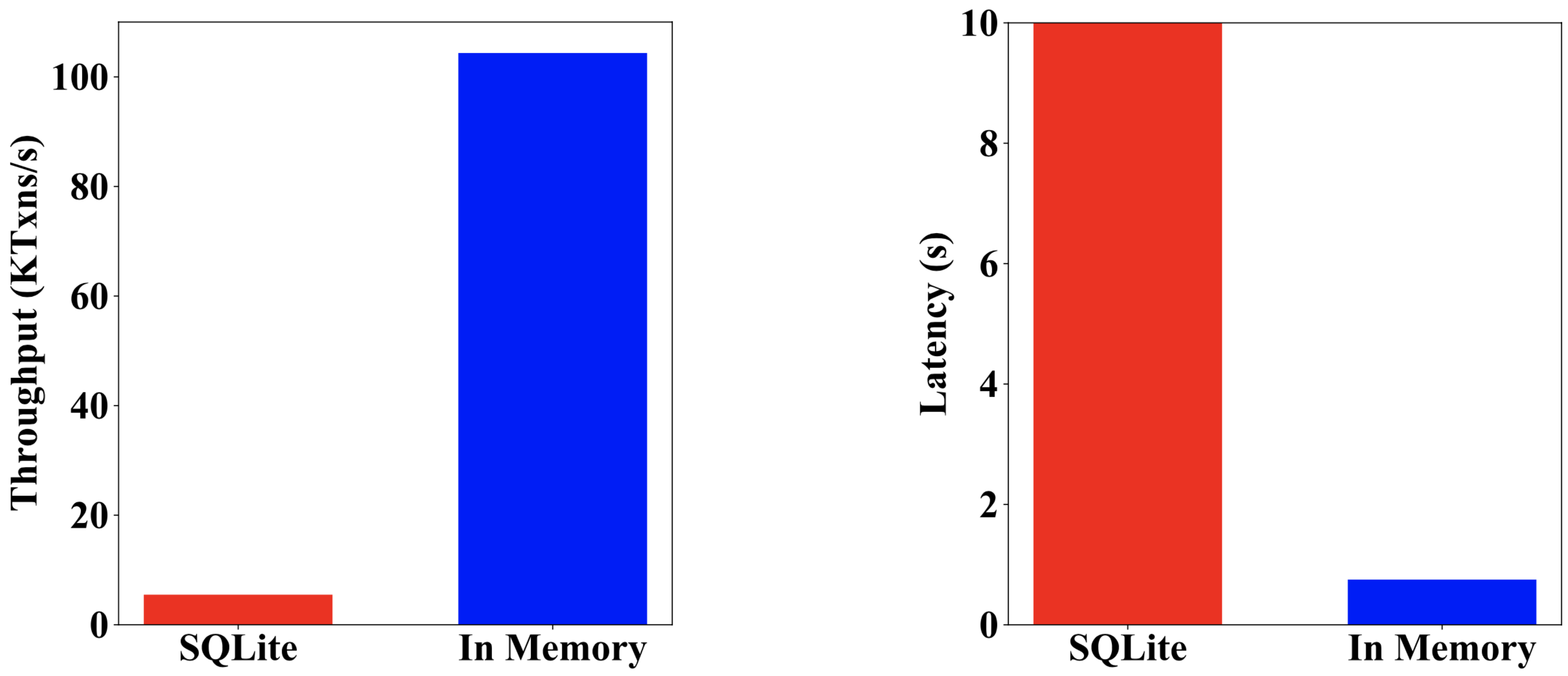
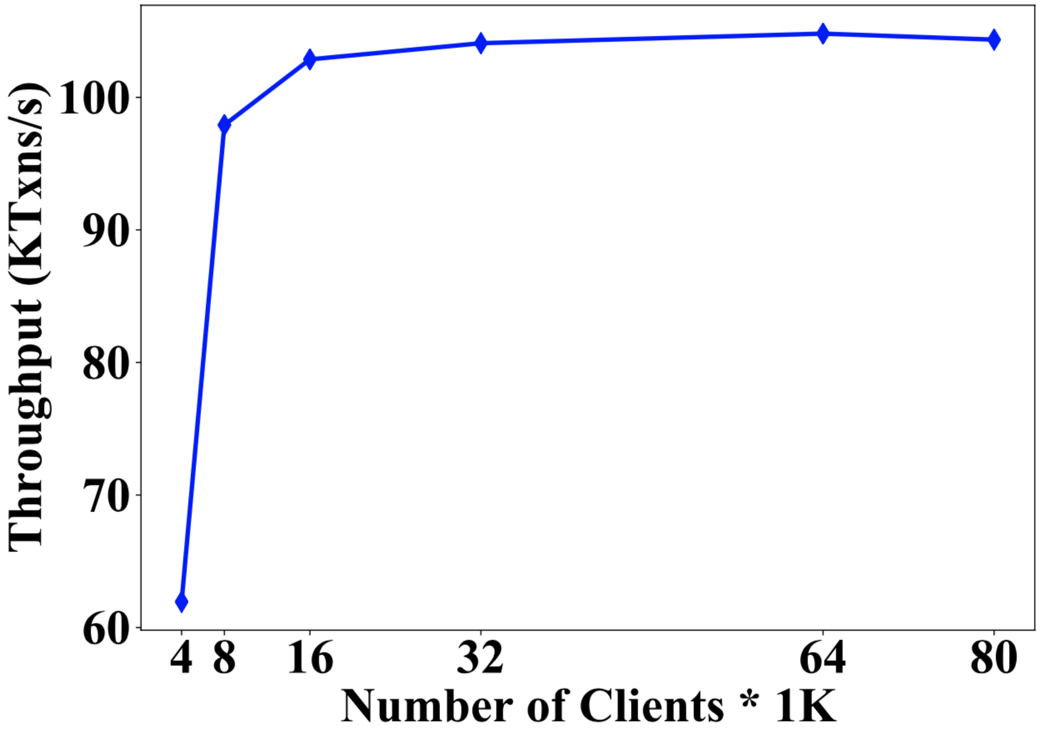
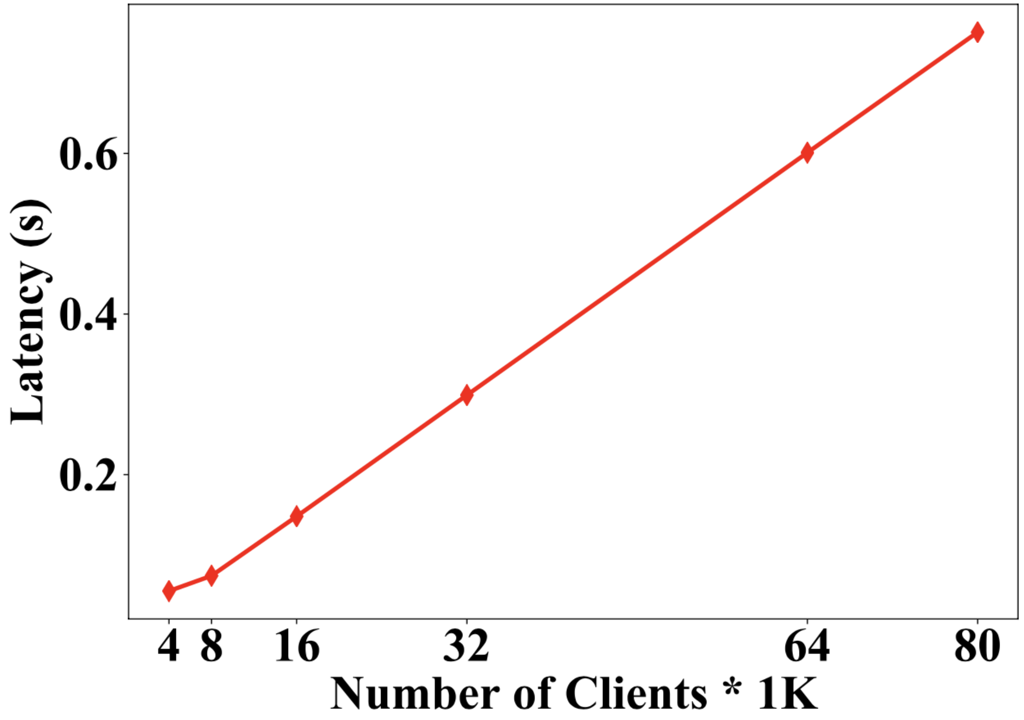
Insight 3: Memory Storage Gains



In-memory blockchain storage → reduces access cost.

Insight 4: Number of Clients





Too many clients → increases average latency.

ResilientDB: Hands On

Visit at: https://github.com/resilientdb/resilientdb

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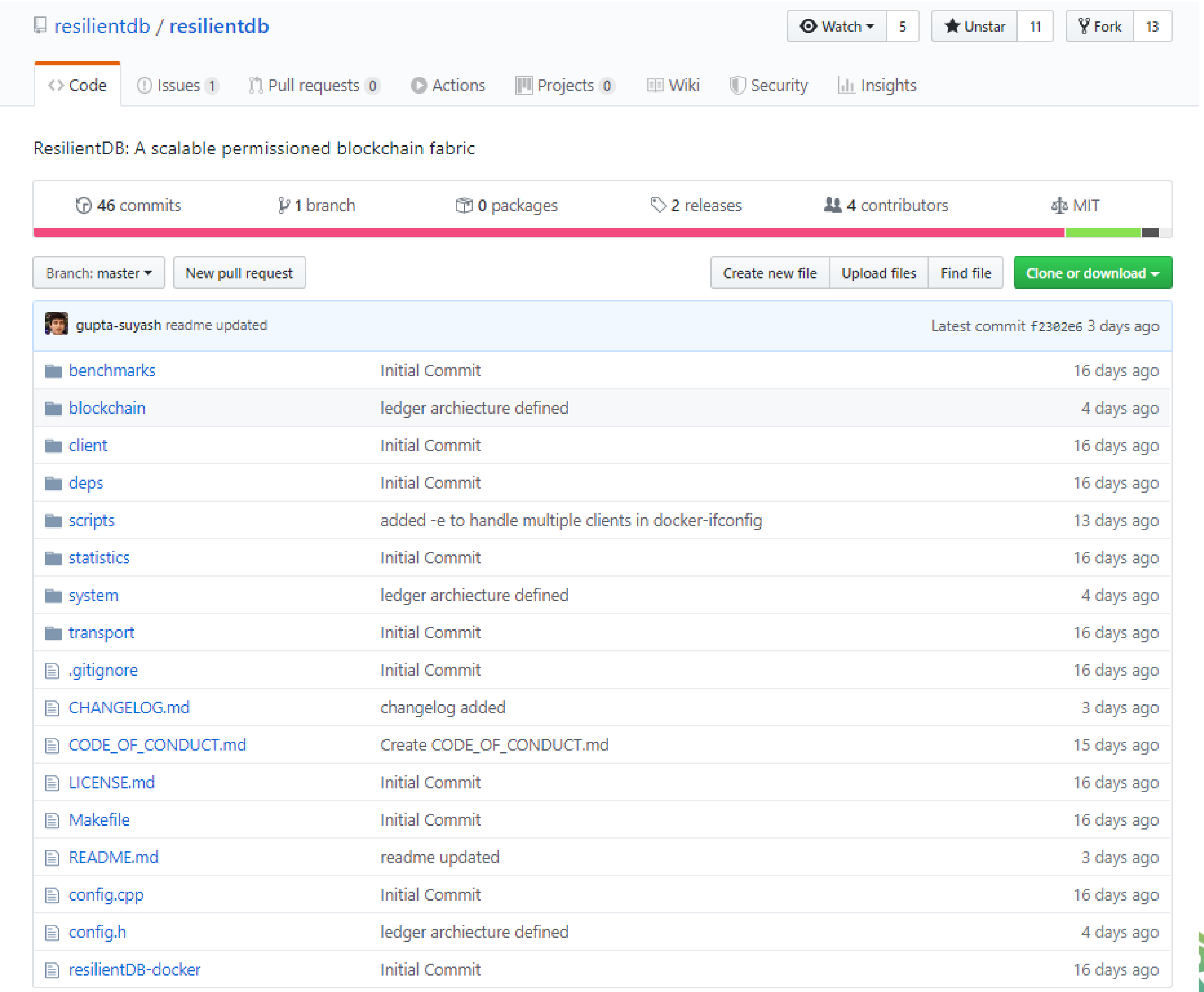
How to Run ResilientDB?



ResilientDB

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How to Run ResilientDB?

- Go to https://github.com/resilientdb/resilientdb and Fork it!
- Install Docker-CE and Docker-Compose (Links on git)
- Use the Script *"resilientDB-docker"* as following:

  ./resilientDB-docker --clients=1 --replicas=4

  ./resilientDB-docker -d [default 4 replicas and 1 client]

- Result will be printed on STDOUT and stored in *res.out* file.

Docker CE

What is Docker?

> *an open-source project that automates the deployment of software applications inside **containers** by providing an additional layer of abstraction and automation of **OS-level virtualization** on Linux.*

- Run a distributed program on one machine
- Simulate with lightweight virtual machines

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ResilientDB ExpoLab Creativity Unfolded

Resilient DB

./resilientDB-docker -d

- Remove old Containers
- Create new Containers
- Create IP address settings
- Install dependencies
- Compile Code
- Run binary files
- Gather the results

```
sajjad@sajjad-xps:~/WS/expo/resilientdb|master⚡
>  ./resilientDB-docker -d
Number of Replicas:     4
Number of Clients:      1
Stopping previous containers...
Stopping s3 ... done
Stopping s1 ... done
Stopping s4 ... done
Stopping c1 ... done
Stopping s2 ... done
Removing s3 ... done
Removing s1 ... done
Removing s4 ... done
Removing c1 ... done
Removing s2 ... done
Removing network resilientdb_default
Successfully stopped
Creating docker compose file ...
Docker compose file created --> docker-compose.yml
Starting the containers...
Creating network "resilientdb_default" with the default driver
Creating s4 ... done
Creating c1 ... done
Creating s1 ... done
Creating s2 ... done
Creating s3 ... done
ifconfig file exists... Deleting File
Deleted
Server sequence --> IP
c1 --> 172.21.0.3
s1 --> 172.21.0.4
s2 --> 172.21.0.6
s3 --> 172.21.0.2
s4 --> 172.21.0.5
Put Client IP at the bottom
ifconfig.txt Created!

Checking Dependencies...
Installing dependencies..
/home/sajjad/WS/expo/resilientdb
Dependencies has been installed
```

Resilient DB

- Throughput
  - Transaction per second
- Average Latency
  - The from client request to client reply
- Working Thread idleness
  - The time that thread is waiting
- WT0: Consensus Messages
- WT1 and WT2: Batch Threads
- WT3: checkpointing Thread
- WT4: Execute Theread

```
Throughputs:
0: 38525
1: 38530
2: 38558
3: 38551
4: 38564
Latencies:
latency 4: 0.505870

idle times:
Idleness of node: 0
Worker THD 0: 116.227
Worker THD 1: 62.0772
Worker THD 2: 62.2130
Worker THD 3: 105.098
Worker THD 4: 74.9193
Idleness of node: 1
Worker THD 0: 39.3157
Worker THD 1: 0.00000
Worker THD 2: 0.00000
Worker THD 3: 104.700
Worker THD 4: 74.8603
Idleness of node: 2
Worker THD 0: 35.0847
Worker THD 1: 0.00000
Worker THD 2: 0.00000
Worker THD 3: 102.415
Worker THD 4: 78.1078
Idleness of node: 3
Worker THD 0: 38.4452
Worker THD 1: 0.00000
Worker THD 2: 0.00000
Worker THD 3: 107.512
Worker THD 4: 77.6965
Memory:
0: 172 MB
1: 156 MB
2: 155 MB
3: 156 MB
4: 812 MB

avg thp: 4: 38541
avg lt : 1: .505
Code Ran successfully ---> res.out
```

Configuration Parameters to Play

• NODE_CNT	Total number of replicas, minimum 4, that is, f=1.
• THREAD_CNT	Total number of threads at primary (at least 5)
• CLIENT_NODE_CNT	Total number of clients (at least 1).
• MAX_TXN_IN_FLIGHT	Multiple of Batch Size
• DONE_TIMER	Amount of time to run the system.
• BATCH_THREADS	Number of threads at primary to batch client transactions.
• BATCH_SIZE	Number of transactions in a batch (at least 10)
• TXN_PER_CHKPT	Frequency at which garbage collection is done.
• USE_CRYPTO	To switch on and off cryptographic signing of messages.
• CRYPTO_METHOD_ED25519	To use ED25519 based digital signatures.
• CRYPTO_METHOD_CMAC_AES	To use CMAC + AES combination for authentication

PBFT: Practical Byzantine Fault Tolerance

Main Functions

- Client/client_main.cpp
- System/client_thread.cpp
- System/main.cpp

client_main.cpp ×

client > client_main.cpp > ...

```cpp
int main(int argc, char *argv[])
{
    printf("Running client...\n\n");
    // 0. initialize global data structure
    parser(argc, argv);
    assert(g_node_id >= g_node_cnt);
    uint64_t seed = get_sys_clock();
    srand(seed);
    printf("Random seed: %ld\n", seed);

    int64_t starttime;
    int64_t endtime;
    starttime = get_server_clock();
    // per-partition malloc
    printf("Initializing stats... ");
    fflush(stdout);
    stats.init(g_total_client_thread_cnt);
    printf("Done\n");
    printf("Initializing transport manager... ");
    fflush(stdout);
    tport_man.init();
    printf("Done\n");
    printf("Initializing client manager... ");
    Workload *m_wl = new YCSBWorkload;
    m_wl->Workload::init();
```

client_thread.cpp ×

system > client_thread.cpp > ...

```cpp

RC ClientThread::run()
{

    tsetup();
    printf("Running ClientThread %ld\n", _thd_id);

    while (true)
    {
        keyMTX.lock();
        if (keyAvail)
        {
            keyMTX.unlock();
            break;
        }
        keyMTX.unlock();
    }

    BaseQuery *m_query;
    uint64_t iters = 0;
    uint32_t num_txns_sent = 0;
    int txns_sent[g_node_cnt];
    for (uint32_t i = 0; i < g_node_cnt; ++i)
        txns_sent[i] = 0;

    run_starttime = get_sys_clock();
```

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PBFT: Practical Byzantine Fault Tolerance

Process Messages

- Transport/message.cpp
- System/worker_thread.cpp
- System/worker_thread_pbft.cpp
- Worker Thread: Run function
- Worker Thread: Process function

worker_thread.cpp ×

system > worker_thread.cpp > WorkerThread::run()

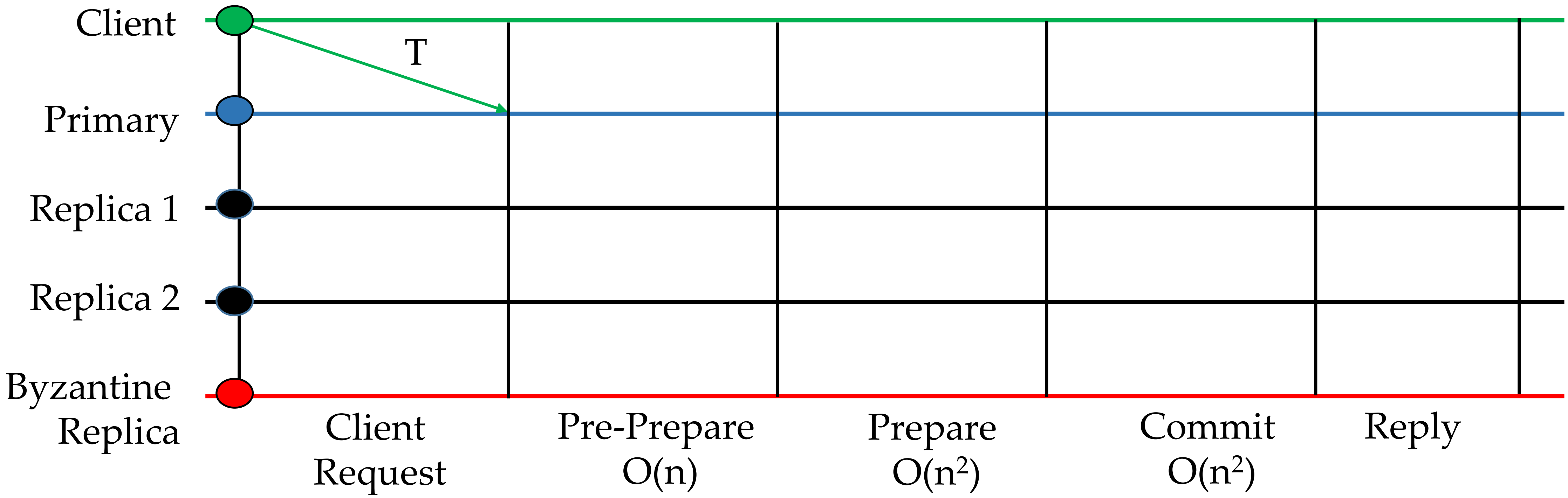
```
/**
 * Starting point for each worker thread.
 *
 * Each worker-thread created in the main() starts here. Each worker-thread is alive
 * till the time simulation is not done, and continuousy perform a set of tasks.
 * Thess tasks involve, dequeuing a message from its queue and then processing it
 * through call to the relevant function.
 */
RC WorkerThread::run()
{
    tsetup();
    printf("Running WorkerThread %ld\n", _thd_id);

    uint64_t agCount = 0, ready_starttime, idle_starttime = 0;

    // Setting batch (only relevant for batching threads).
    next_set = 0;

    while (!simulation->is_done())
    {
        txn_man = NULL;
        heartbeat();
        progress_stats();

#if VIEW_CHANGES
        // Thread 0 continously monitors the timer for each batch.
        if (get_thd_id() == 0)
        {
            check_for_timeout();
        }

        if (g_node_id != get_current_view(get_thd_id()))
        {
            check_switch_view();
        }
#endif

        // Dequeue a message from its work_queue.
        Message *msg = work_queue.dequeue(get_thd_id());
```

worker_thread.cpp ×

system > worker_thread.cpp > WorkerThread::process(Message *)

```
void WorkerThread::process(Message *msg)
{
    RC rc __attribute__((unused));

    switch (msg->get_rtype())
    {
    case KEYEX:
        rc = process_key_exchange(msg);
        break;
    case CL_BATCH:
        rc = process_client_batch(msg);
        break;
    case BATCH_REQ:
        rc = process_batch(msg);
        break;
    case PBFT_CHKPT_MSG:
        rc = process_pbft_chkpt_msg(msg);
        break;
    case EXECUTE_MSG:
        rc = process_execute_msg(msg);
        break;
#if VIEW_CHANGES
    case VIEW_CHANGE:
        rc = process_view_change_msg(msg);
        break;
    case NEW_VIEW:
        rc = process_new_view_msg(msg);
        break;
#endif
    case PBFT_PREP_MSG:
        rc = process_pbft_prep_msg(msg);
        break;
    case PBFT_COMMIT_MSG:
        rc = process_pbft_commit_msg(msg);
        break;
    default:
        printf("Msg: %d\n", msg->get_rtype());
        fflush(stdout);
        assert(false);
        break;
    }
}
```

PBFT Failure-Free Flow



PBFT: Practical Byzantine Fault Tolerance

Process Client Message

- System/worker_thread_pbft.cpp
- process_client_batch Function
- Create and Send Batch Request
  - create_and_send_batchreq Function
  - Create Transactions
  - Create Digest
- BatchRequest Class
  - Pre-Prepare Message

worker_thread_pbft.cpp

system > worker_thread_pbft.cpp > ...

```cpp
/**
 * Processes an incoming client batch and sends a Pre-prepare message to al rep
 *
 * This function assumes that a client sends a batch of transactions and
 * for each transaction in the batch, a separate transaction manager is created
 * Next, this batch is forwarded to all the replicas as a BatchRequests Message
 * which corresponds to the Pre-Prepare stage in the PBFT protocol.
 *
 * @param msg Batch of Transactions of type CientQueryBatch from the client.
 * @return RC
 */
RC WorkerThread::process_client_batch(Message *msg)
{
    //printf("ClientQueryBatch: %ld, THD: %ld :: CL: %ld :: RQ: %ld\n",msg->txn
    //fflush(stdout);

    ClientQueryBatch *clbtch = (ClientQueryBatch *)msg;

    // Authenticate the client signature.
    validate_msg(clbtch);

#if VIEW_CHANGES
    // If message forwarded to the non-primary.
    if (g_node_id != get_current_view(get_thd_id()))
    {
        client_query_check(clbtch);
        return RCOK;
    }

    // Partial failure of Primary 0.
    fail_primary(msg, 9);
#endif

    // Initialize all transaction mangers and  uint64_t Message::txn_id  e.
    create_and_send_batchreq(clbtch, clbtch->txn_id);

    return RCOK;
}
```

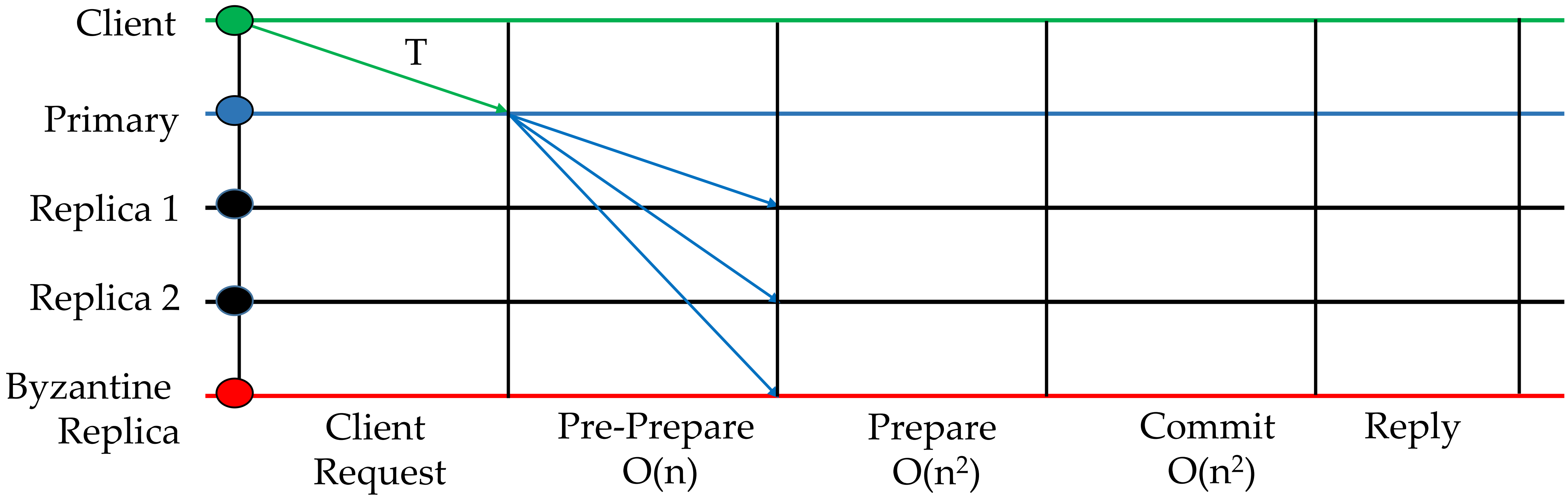
worker_thread.cpp

system > worker_thread.cpp > WorkerThread::create_and_send_batchreq(ClientQueryBatch *, uint64_t)

```cpp
 * This function is used by the primary replicas to create and set
 * transaction managers for each transaction part of the ClientQueryBatch message
 * by the client. Further, to ensure integrity a hash of the complete batch is
 * generated, which is also used in future communication.
 *
 * @param msg Batch of transactions as a ClientQueryBatch message.
 * @param tid Identifier for the first transaction of the batch.
 */
void WorkerThread::create_and_send_batchreq(ClientQueryBatch *msg, uint64_t tid)
{
    // Creating a new BatchRequests Message.
    Message *bmsg = Message::create_message(BATCH_REQ);
    BatchRequests *breq = (BatchRequests *)bmsg;
    breq->init(get_thd_id());

    // Starting index for this batch of transactions.
    next_set = tid;

    // String of transactions in a batch to generate hash.
    string batchStr;

    // Allocate transaction manager for all the requests in batch.
    for (uint64_t i = 0; i < get_batch_size(); i++)
    {
        uint64_t txn_id = get_next_txn_id() + i;

        //cout << "Txn: " << txn_id << " :: Thd: " << get_thd_id() << "\n";
        //fflush(stdout);
        txn_man = get_transaction_manager(txn_id, 0);

        // Unset this txn man so that no other thread can concurrently use.
        while (true)
        {
            bool ready = txn_man->unset_ready();
            if (!ready)
            {
                continue;
            }
            else
            {
                break;
            }
        }
```

ResilientDB ExpoLab Creativity Unfolded

PBFT Failure-Free Flow



PBFT: Practical Byzantine Fault Tolerance

Process Batch Request (Prepare)

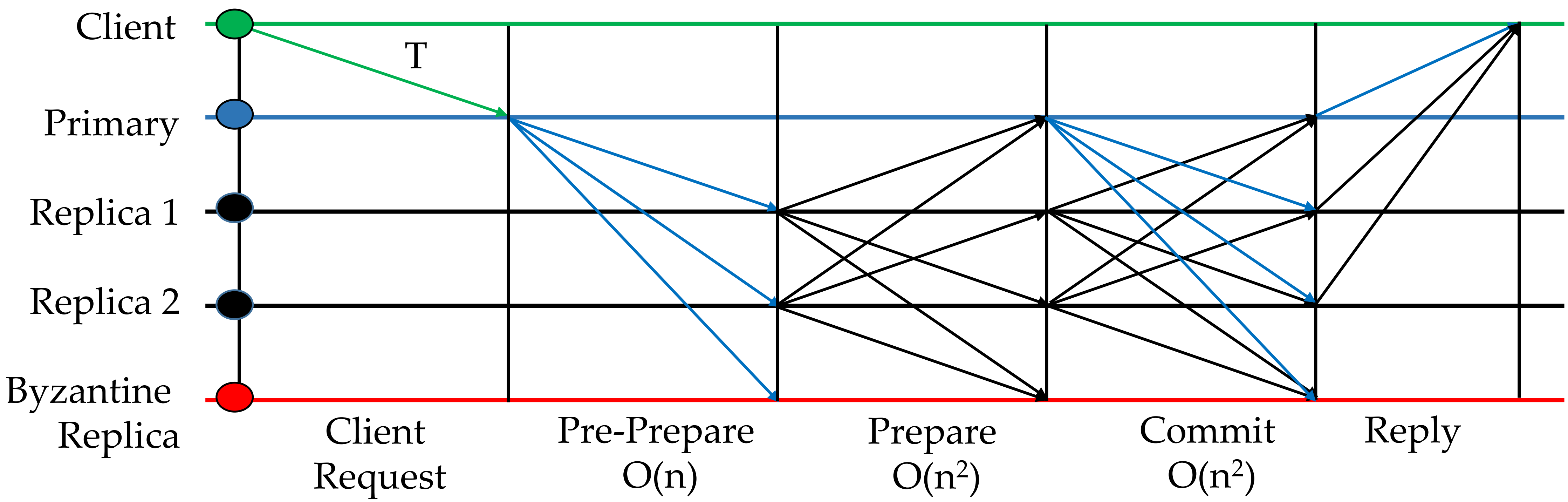
- System/worker_thread_pbft.cpp
- process_batch Function
- Create and Send Prepare Message
  - Create Transactions
  - Save Digest
- PBFTPrepare Class
  - Prepare Message

worker_thread_pbft.cpp ×

system > worker_thread_pbft.cpp > WorkerThread::process_batch(Message *)

```
/**
 * Process incoming BatchRequests message from the Primary.
 *
 * This function is used by the non-primary or backup replicas to process an incoming
 * BatchRequests message sent by the primary replica. This processing would require
 * sending messages of type PBFTPrepMessage, which correspond to the Prepare phase of
 * the PBFT protocol. Due to network delays, it is possible that a repica may have
 * received some messages of type PBFTPrepMessage and PBFTCommitMessage, prior to
 * receiving this BatchRequests message.
 *
 * @param msg Batch of Transactions of type BatchRequests from the primary.
 * @return RC
 */
RC WorkerThread::process_batch(Message *msg)
{
    uint64_t cntime = get_sys_clock();

    BatchRequests *breq = (BatchRequests *)msg;

    //printf("BatchRequests: TID:%ld : VIEW: %ld : THD: %ld\n",breq->txn_id, breq->view, get_
    //fflush(stdout);

    // Assert that only a non-primary replica has received this message.
    assert(g_node_id != get_current_view(get_thd_id()));

    // Check if the message is valid.
    validate_msg(breq);

```

PBFT Failure-Free Flow



PBFT: Practical Byzantine Fault Tolerance

Process Prepare and Commit Messages(Prepare)

- System/worker_thread_pbft.cpp
- process_pbft_prepare Function
  - Count Prepare Messages
  - Create and Send commit Message
  - PBFTCommit Message
- process_pbft_commit Function
  - Count commit messages
  - Create and Send execute Message
  - ExecuteMessage Class

worker_thread_pbft.cpp ×

system > worker_thread_pbft.cpp > ...

```
/**
 * Processes incoming Prepare message.
 *
 * This functions precessing incoming messages of type PBFTPrepMessage. If
 * received 2f identical Prepare messages from distinct replicas, then it c
 * and sends a PBFTCommitMessage to all the other replicas.
 *
 * @param msg Prepare message of type PBFTPrepMessage from a replica.
 * @return RC
 */
RC WorkerThread::process_pbft_prep_msg(Message *msg)
{
    //cout << "PBFTPrepMessage: TID: " << msg->txn_id << " FROM: " << msg->
    //fflush(stdout);

    // Start the counter for prepare phase.
    if (txn_man->prep_rsp_cnt == 2 * g_min_invalid_nodes)
    {
        txn_man->txn_stats.time_start_prepare = get_sys_clock();
    }

    // Check if the incoming message is valid.
    PBFTPrepMessage *pmsg = (PBFTPrepMessage *)msg;
    validate_msg(pmsg);

    // Check if sufficient number of Prepare messages have arrived.
    if (prepared(pmsg))
    {
        // Send Commit messages.
        txn_man->send_pbft_commit_msgs();

        // End the prepare counter.
        INC_STATS(get_thd_id(), time_prepare, get_sys_clock() - txn_man->tx
    }

    return RCOK;
}
```

worker_thread_pbft.cpp ×

system > worker_thread_pbft.cpp > WorkerThread::process_pbft_commit_msg(Message *)

```
/**
 * Processes incoming Commit message.
 *
 * This functions precessing incoming messages of type PBFTCommitMessage
 * received 2f+1 identical Commit messages from distinct replicas, then
 * execute-thread to execute all the transactions in this batch.
 *
 * @param msg Commit message of type PBFTCommitMessage from a replica.
 * @return RC
 */
RC WorkerThread::process_pbft_commit_msg(Message *msg)
{
    //cout << "PBFTCommitMessage: TID " << msg->txn_id << " FROM: " << m
    //fflush(stdout);

    if (txn_man->commit_rsp_cnt == 2 * g_min_invalid_nodes + 1)
    {
        txn_man->txn_stats.time_start_commit = get_sys_clock();
    }

    // Check if message is valid.
    PBFTCommitMessage *pcmsg = (PBFTCommitMessage *)msg;
    validate_msg(pcmsg);

    txn_man->add_commit_msg(pcmsg);

    // Check if sufficient number of Commit messages have arrived.
    if (committed_local(pcmsg))
    {
#if TIMER_ON
        // End the timer for this client batch.
        server_timer->endTimer(txn_man->hash);
#endif

        // Add this message to execute thread's queue.
        send_execute_msg();

        INC_STATS(get_thd_id(), time_commit, get_sys_clock() - txn_man->
```

PBFT: Practical Byzantine Fault Tolerance

Process Execute Message

- System/worker_thread.cpp
- Internal Message
- process_execute Function
- Execute the Transactions in batch in order
- Create and send Client Response
- ClientResponse Class

worker_thread.cpp

system > worker_thread.cpp > WorkerThread::process_execute_msg(Message *)

```cpp
/**
 * Execute transactions and send client response.
 *
 * This function is only accessed by the execute-thread, which executes the transactions
 * in a batch, in order. Note that the execute-thread has several queues, and at any
 * point of time, the execute-thread is aware of which is the next transaction to
 * execute. Hence, it only loops on one specific queue.
 *
 * @param msg Execute message that notifies execution of a batch.
 * @ret RC
 */
RC WorkerThread::process_execute_msg(Message *msg)
{
    //cout << "EXECUTE " << msg->txn_id << " :: " << get_thd_id() <<"\n";
    //fflush(stdout);

    uint64_t ctime = get_sys_clock();

    // This message uses txn man of index calling process_execute.
    Message *rsp = Message::create_message(CL_RSP);
    ClientResponseMessage *crsp = (ClientResponseMessage *)rsp;
    crsp->init();

    ExecuteMessage *emsg = (ExecuteMessage *)msg;

    // Execute transactions in a shot
    uint64_t i;
    for (i = emsg->index; i < emsg->end_index - 4; i++)
    {
        //cout << "i: " << i << " :: next index: " << g_next_index << "\n";
        //fflush(stdout);

        TxnManager *tman = get_transaction_manager(i, 0);

        inc_next_index();

        // Execute the transaction
        tman->run_txn();

        // Commit the results.
        tman->commit();

        crsp->copy_from_txn(tman);
```

PBFT: Practical Byzantine Fault Tolerance

Work Queue

- Lock Free queues
- All the messages are being stored in these queues
- System/work_queue.cpp
- Multiple queues for different Threads
- Dequeue and Enqueue Interfaces
- Enqueue in IOThread
- Dequeue in Worker Thread

work_queue.cpp

system > work_queue.cpp > ...

```
void QWorkQueue::enqueue(uint64_t thd_id, Message *msg, bool busy)
{
    uint64_t starttime = get_sys_clock();
    assert(msg);
    DEBUG_M("QWorkQueue::enqueue work_queue_entry alloc\n");
    work_queue_entry *entry = (work_queue_entry *)mem_allocator.align_alloc(sizeof(work_queue_ent
    entry->msg = msg;
    entry->rtype = msg->rtype;
    entry->txn_id = msg->txn_id;
    entry->batch_id = msg->batch_id;
    entry->starttime = get_sys_clock();
    assert(ISSERVER || ISREPLICA);
    DEBUG("Work Enqueue (%ld,%ld) %d\n", entry->txn_id, entry->batch_id, entry->rtype);

    if (msg->rtype == CL_QRY || msg->rtype == CL_BATCH)
    {
        if (g_node_id == get_current_view(thd_id))
        {
            //cout << "Placing \n";
            while (!new_txn_queue->push(entry) && !simulation->is_done())
            {
            }
        }
        else
        {
            assert(entry->rtype < 100);
            while (!work_queue[0]->push(entry) && !simulation->is_done())
            {
            }
        }
    }
```

PBFT: Practical Byzantine Fault Tolerance

IO Thread and Transport Layer

- Multiple Input Threads
- Multiple Output Threads
- System/io_thread.cpp
- Transport Layer: TCP Sockets
- Nano Message Library
- Transport/transport.cpp

io_thread.cpp ×

system > io_thread.cpp > ...

```cpp
RC InputThread::server_recv_loop()
{

    myrand rdm;
    rdm.init(get_thd_id());
    RC rc = RCOK;
    assert(rc == RCOK);
    uint64_t starttime = 0;
    uint64_t idle_starttime = 0;
    std::vector<Message *> *msgs;
    while (!simulation->is_done())
    {
        heartbeat();

#if VIEW_CHANGES
        if (g_node_id != get_current_view(get_thd_id()))
        {
            uint64_t tid = get_thd_id() - 1;
            uint32_t nchange = get_newView(tid);

            if (nchange)
            {
                set_current_view(get_thd_id(), get_current_view(get_thd_id()) + 1);
                set_newView(tid, false);
            }
        }
#endif

        msgs = tport_man.recv_msg(get_thd_id());
```

Thank You