Increasing Performance in Byzantine Fault-Tolerant Systems with On-Demand Replica Consistency

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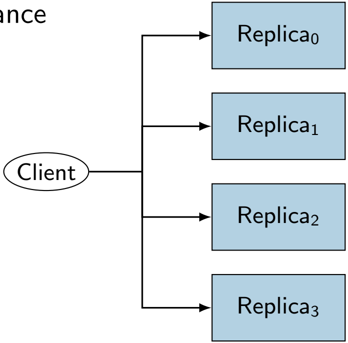
Byzantine Fault Tolerance (BFT)

- Agreement-based Byzantine fault tolerance
  - $3f + 1$ replicas to tolerate f faults
  - BFT agreement protocol
  - Client-side voting
- Drawbacks
  - **High resource usage**
  - Performance overhead for agreement



[Castro et al., Practical Byzantine fault tolerance, OSDI '99]

REFIT Project Research Goal

Resource-efficient BFT systems

Making BFT Systems More Resource-Efficient

REFIT Project Research Goal

Resource-efficient BFT systems

Optimizing **Resource Usage**

- Reduced number of replicas
- Same performance
- Recent examples
  - SPARE [Distler et al., NDSS '11]
  - ZZ [Wood et al., EuroSys '11]

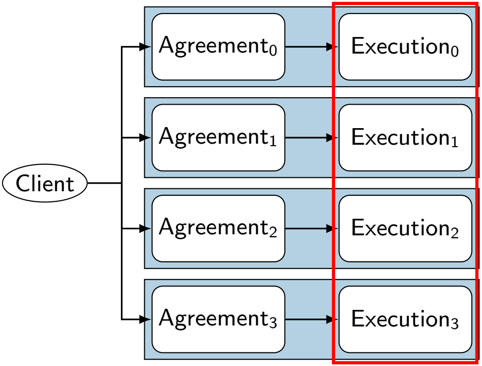
Optimizing **Performance**

- Default number of replicas
- Increased performance

$\Rightarrow$ **ODRC**

Where to Optimize?

- Agreement stage
  - BFT agreement protocol
  - Sequence of agreed requests
- Execution stage
  - Service application
  - Request processing



[Yin et al., Separating agreement from execution for Byzantine fault tolerant services, SOSP '03]

- Observations
  - Past optimizations have **significantly reduced agreement overhead**
  - Non-trivial services: **response times are dominated by execution stage**

ODRC Approach

Reducing the load on the execution stage

Basic Approach

- Traditional BFT systems
  - All $3f + 1$ replicas process all requests
  - Client waits for $f + 1$ identical replies

> **Insight**
>
> In the **absence of faults**, a client only needs $f + 1$ replies to make progress

- ODRC
  - Each request is processed by only $f + 1$ replicas
  - Load distribution across replicas
  - Additional replicas process the request in case of faults

Talk Outline

ODRC

- Selective Request Execution
- **O**n-**D**emand **R**eplica **C**onsistency
- Evaluation
- Conclusion

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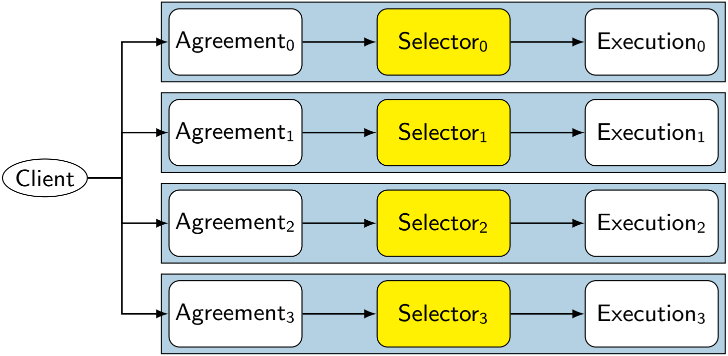
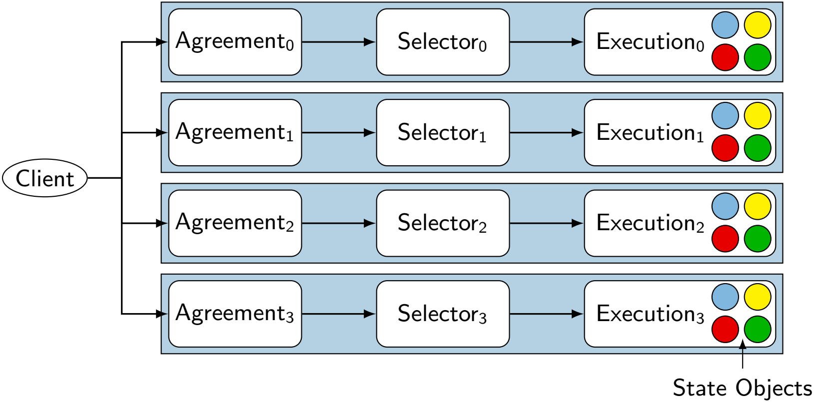
Architecture

- Selector
  - Selects requests for execution
  - Stores requests that have not been selected



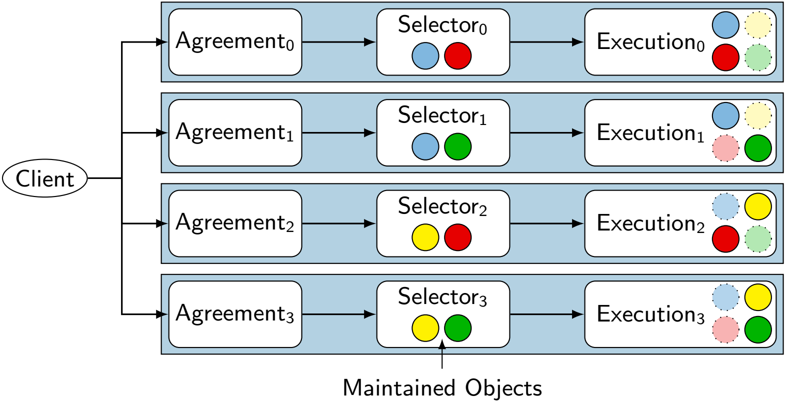
Application State

- Set of objects
  - Examples: files, directories, ...
  - Assumption: requests carry information about object access



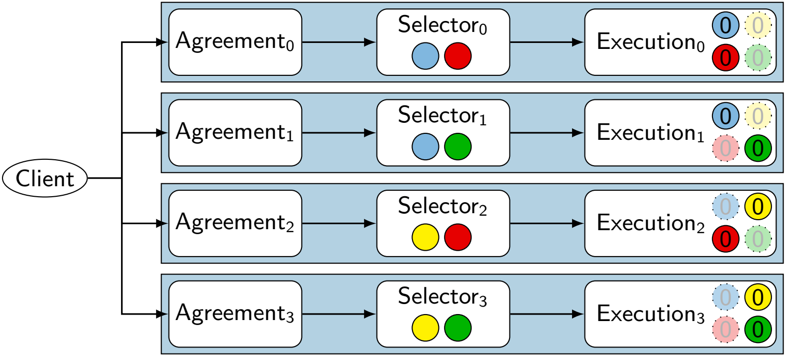
Application State Distribution

- Object distribution scheme
  - Each object is **maintained** on $f + 1$ replicas, **unmaintained** on others
  - State of unmaintained objects may be outdated



Selective Request Execution in Action

- Normal-case operation



- Garbage collection of stored requests
  - Periodic **object checkpoints** of maintained objects
  - Stable checkpoint: $f + 1$ identical checkpoints

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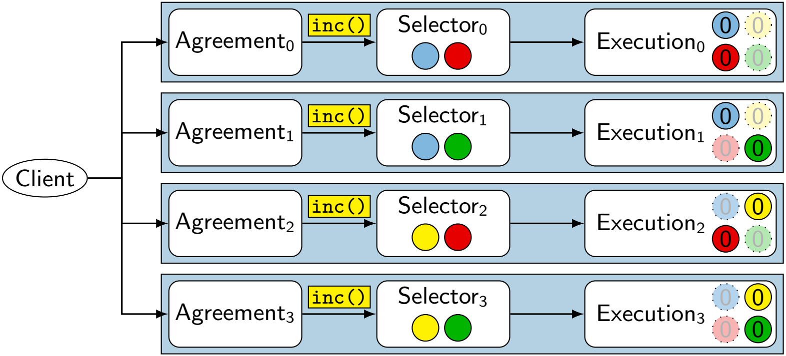

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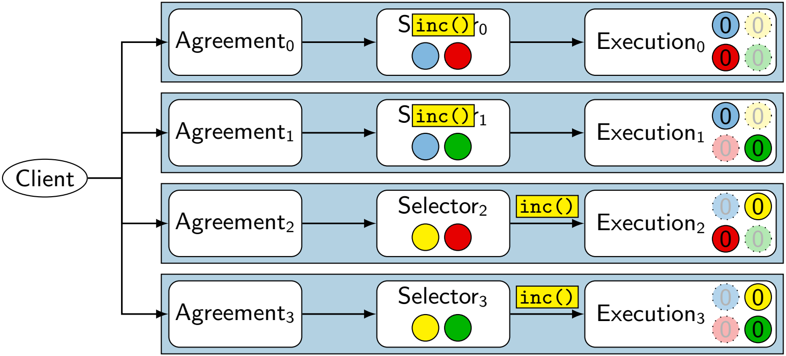

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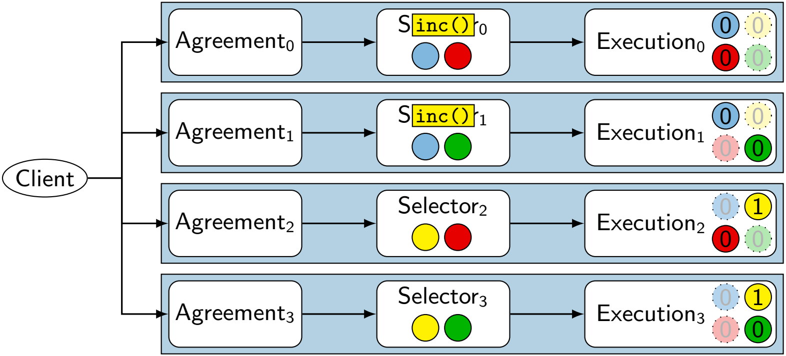

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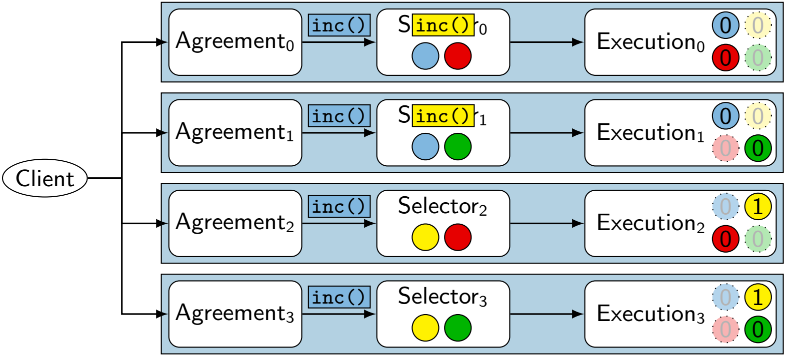

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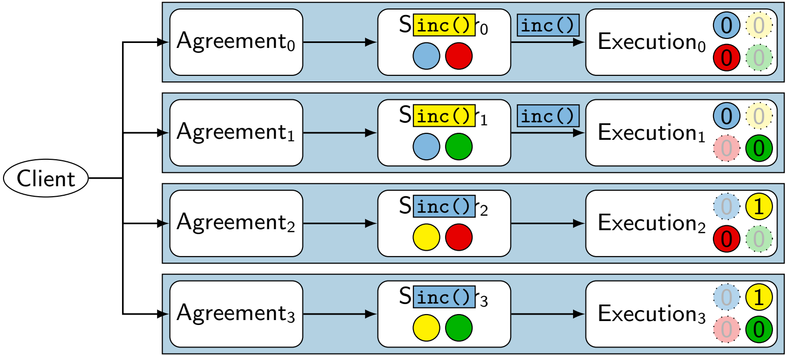

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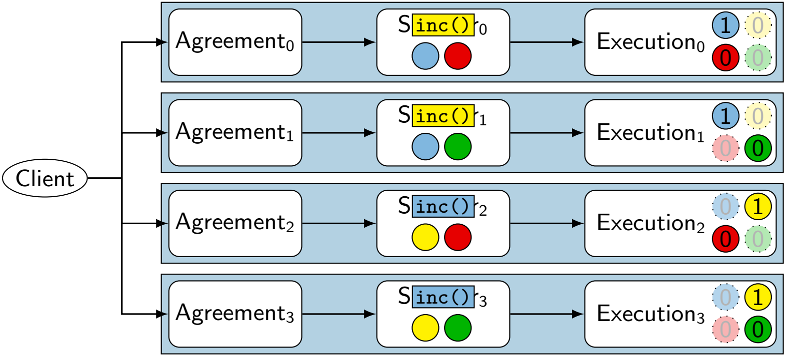

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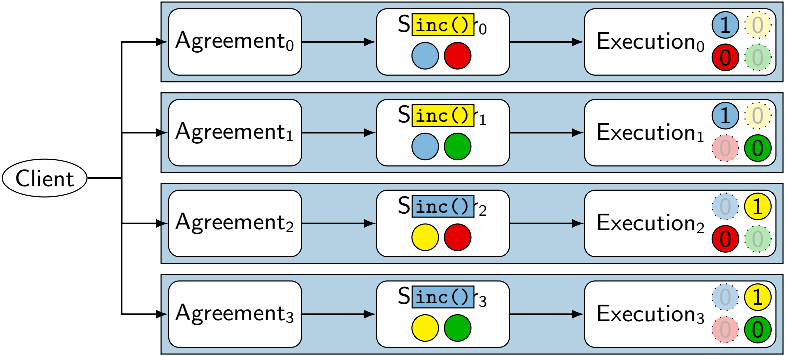
Multi-Object Operations

- Access of multiple objects
  - Only unmaintained objects ⇒ store request
  - At least one maintained object
    - Update unmaintained objects
    - Process request



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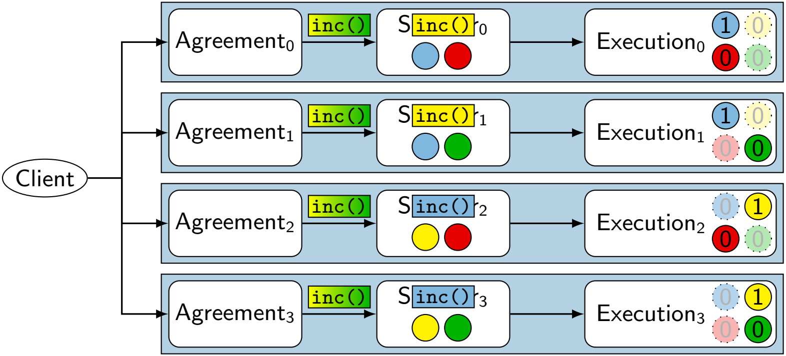

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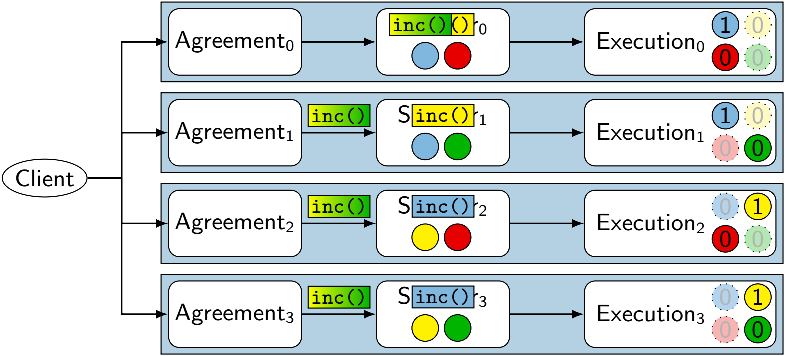

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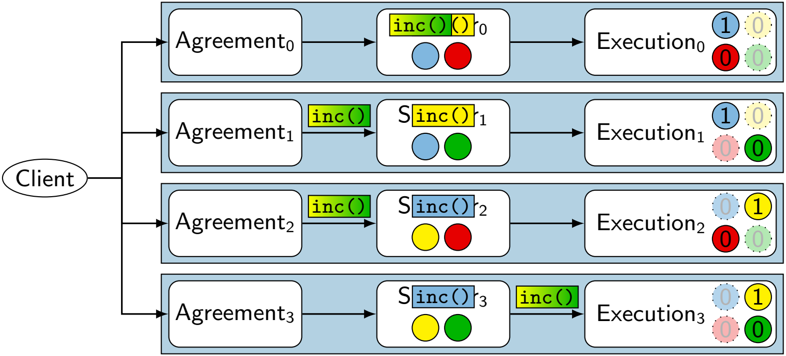

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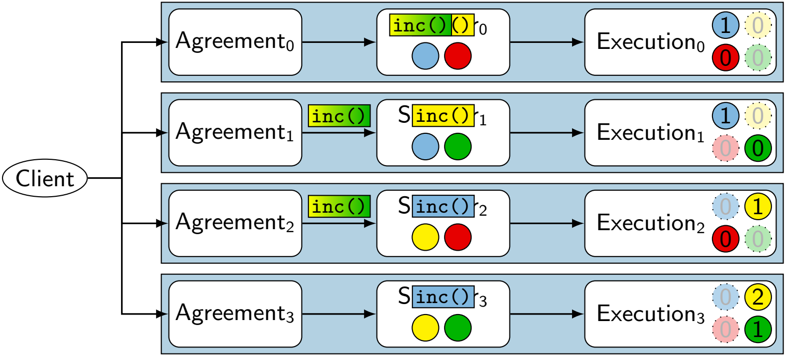

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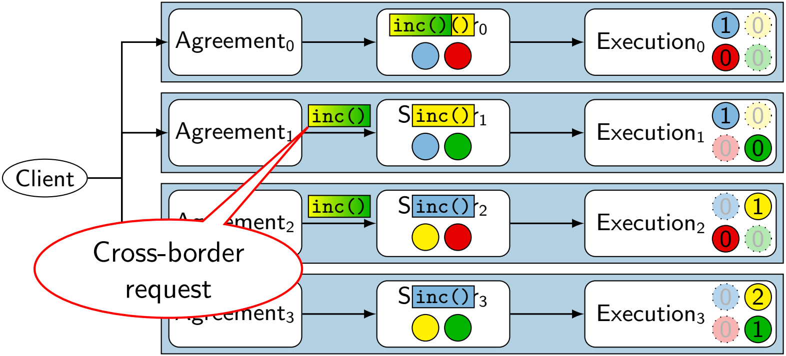

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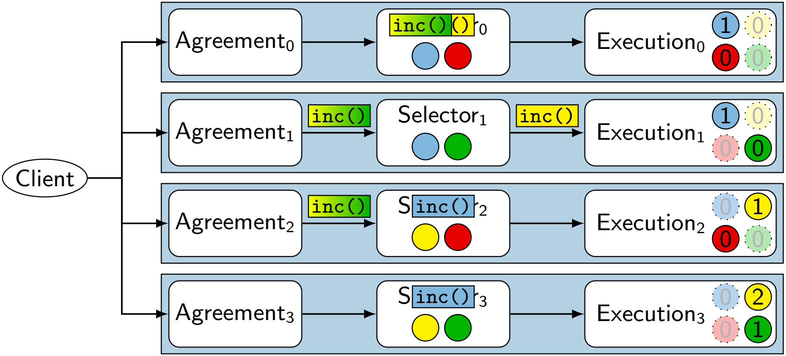

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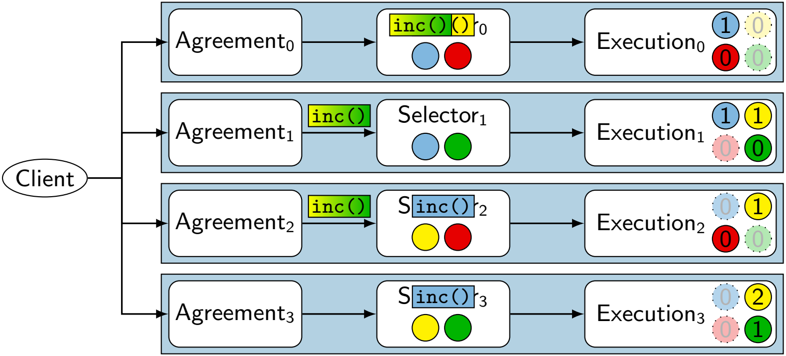

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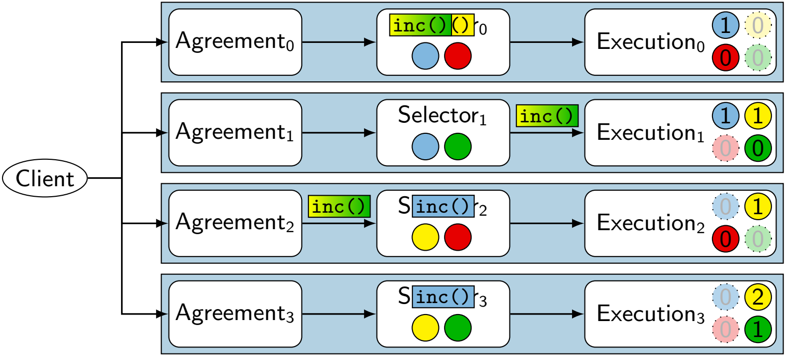

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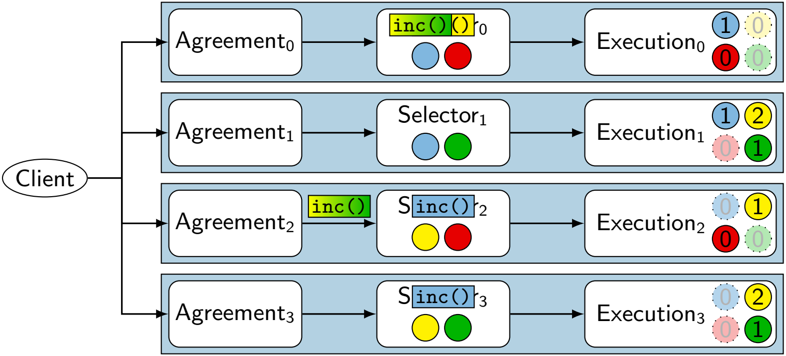

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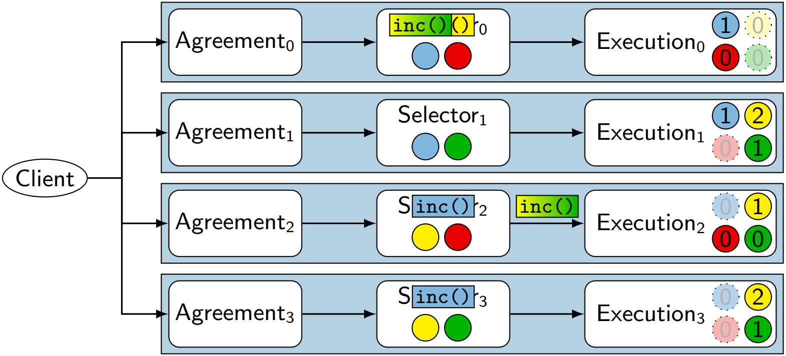

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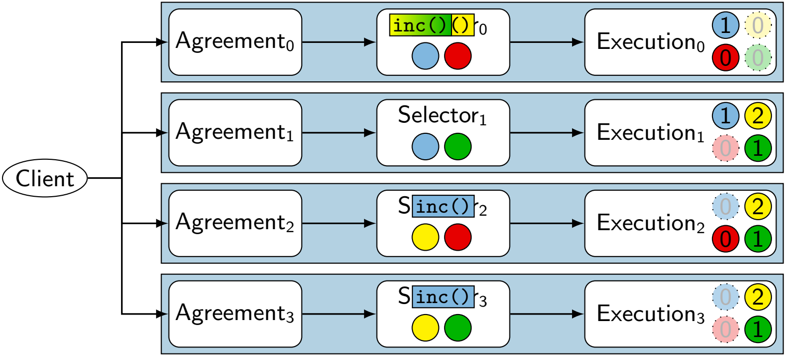

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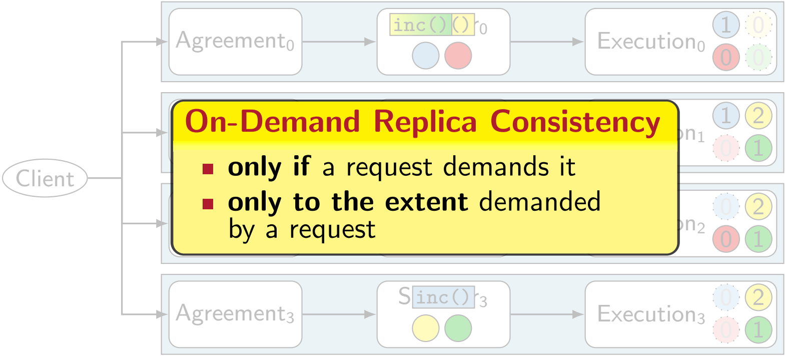
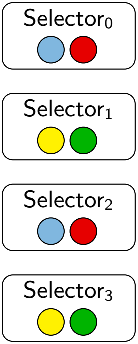


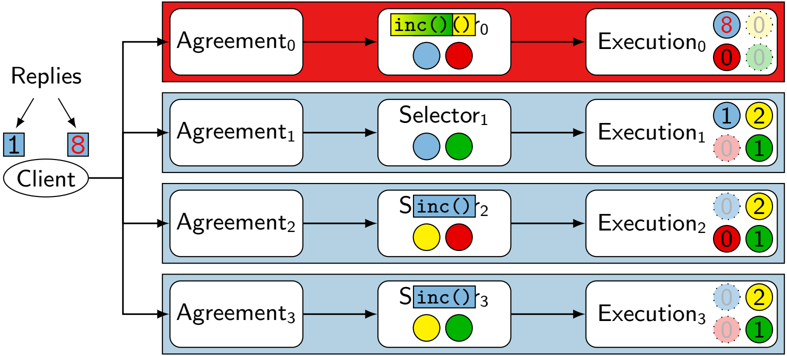
Cross-Border Requests



- Additional consistency overhead
  - Processed by more than f+1 replicas
  - Goal: minimize number of cross-border requests
- Optimized object distribution
  - Application-centric strategies
  - Consider object dependencies
- Example: Network File System (NFS)
  - Assign files and their parent directories to the same replicas
  - Subdirectories may be assigned to different replicas

Handling Faults

- Providing additional replies on demand
  - Standard BFT clients
  - Request retransmission after timeout
  - Additional replicas process the request



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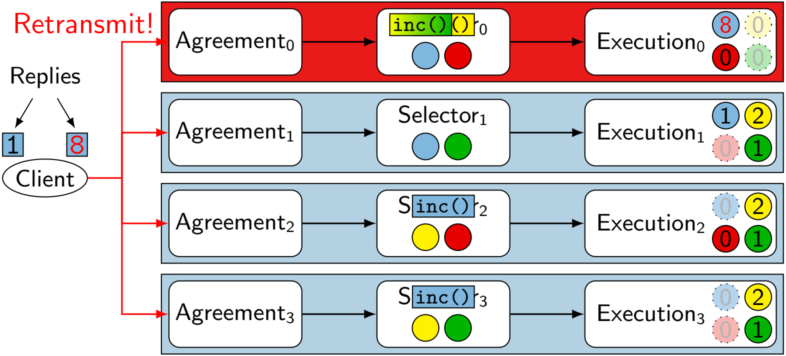

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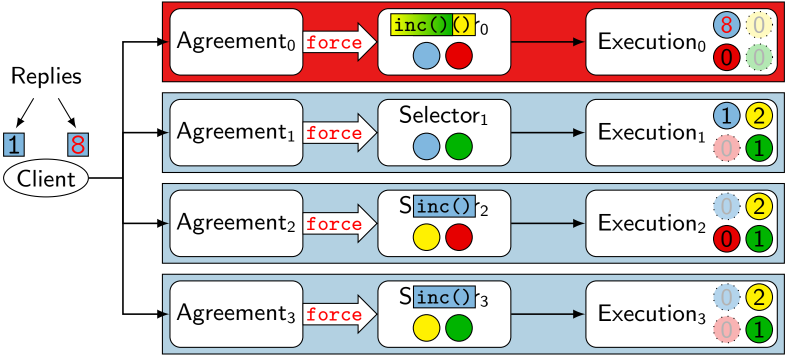

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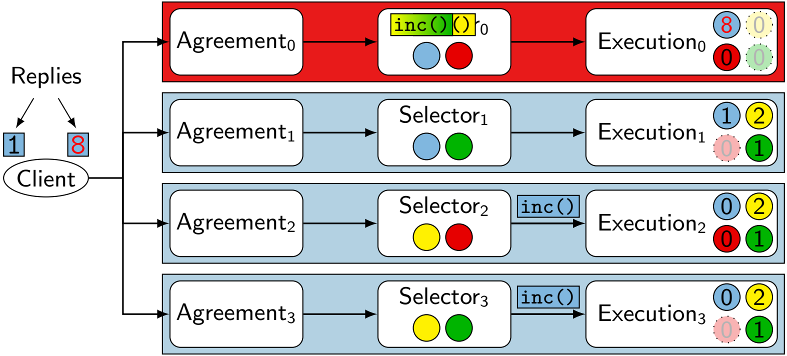

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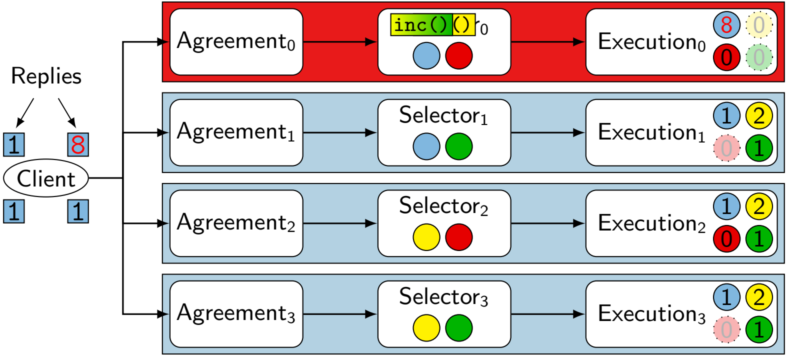

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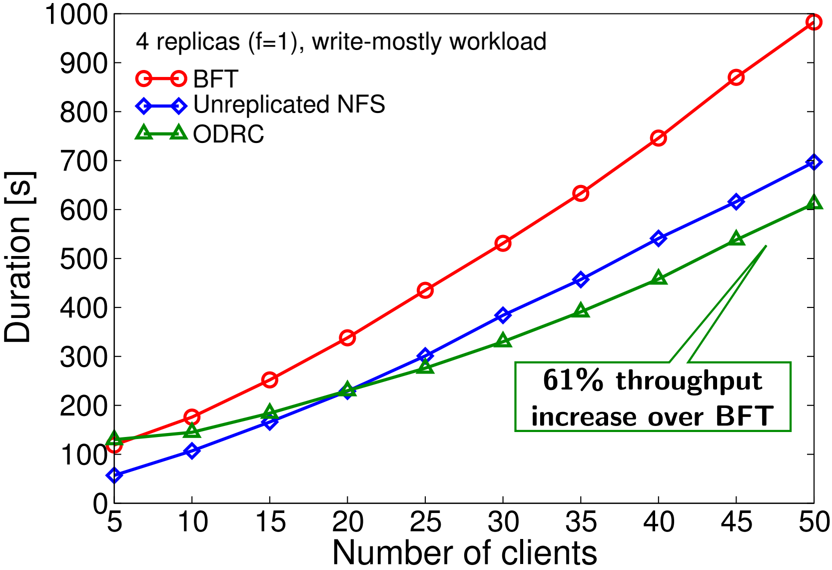
NFS Evaluation: Postmark Benchmark



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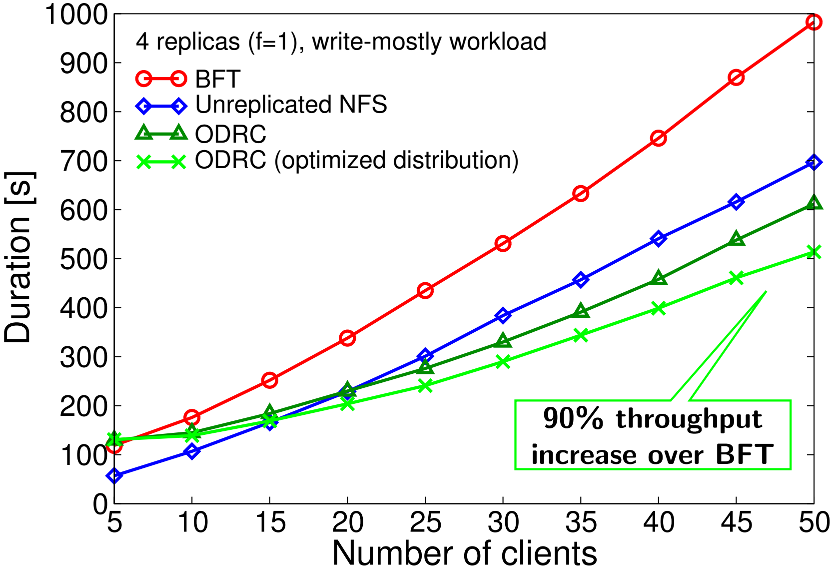
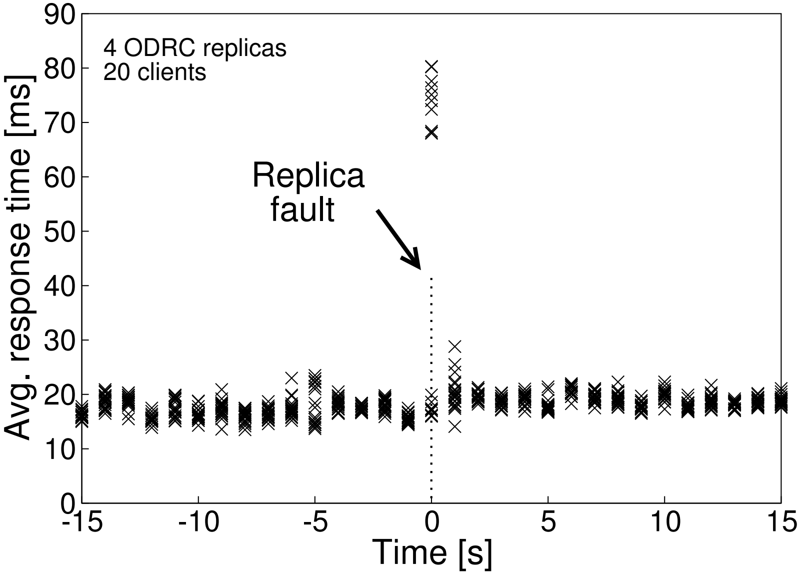


NFS Evaluation: Append-Only Micro-Benchmark



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Conclusion

- Execution matters!
- Traditional BFT systems
  - All replicas process all requests
  - Consistency overhead
- ODRC
  - Selective request execution based on object access
  - On-demand replica consistency
  - Additional replies in case of faults

Thank you very much.

Questions?