Enlightening the I/O Path:
A Holistic Approach for Application Performance

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Apposha[1]

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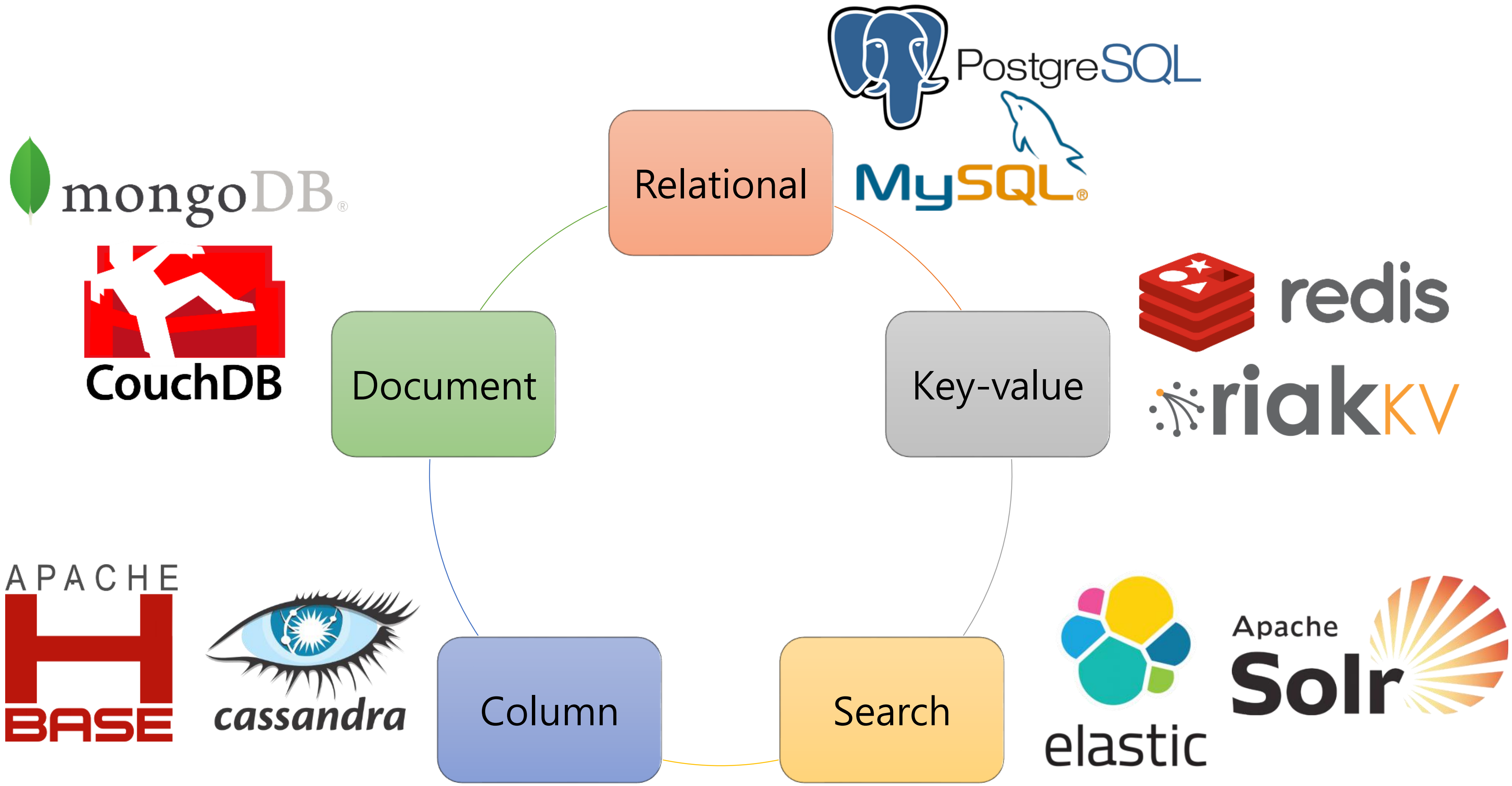
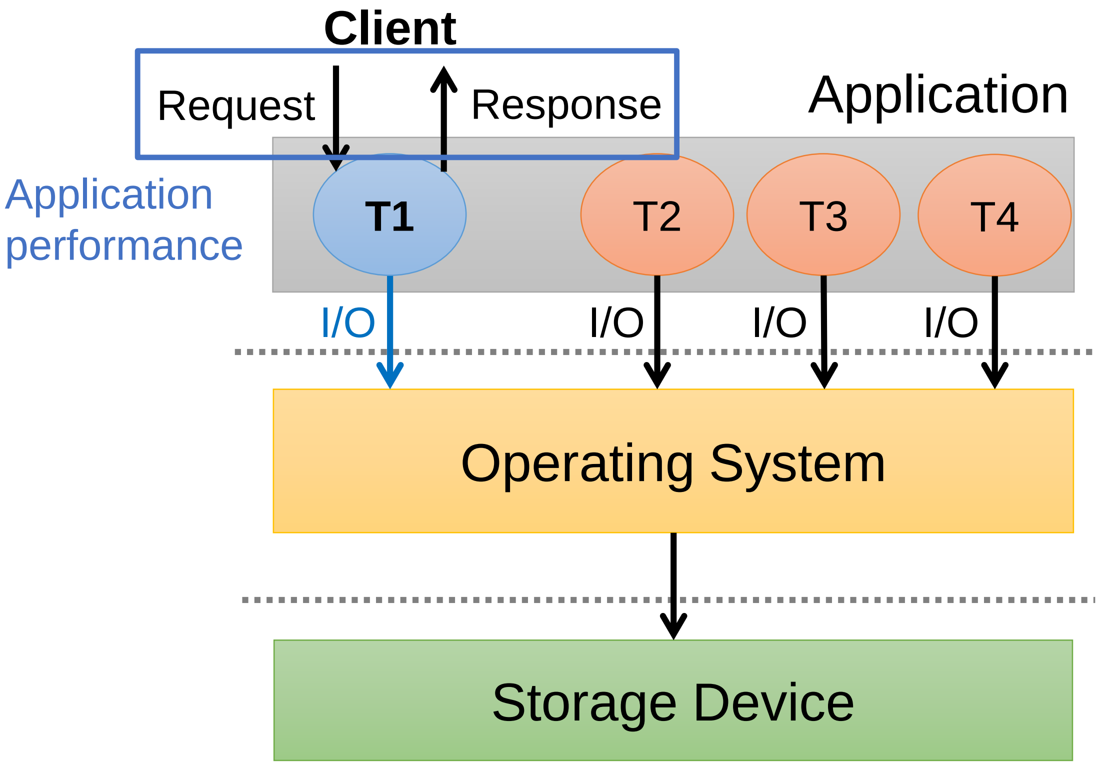
Data-Intensive Applications



Data-Intensive Applications

- Common structure



*** Example: MongoDB**

- **Client (foreground)**
- **Checkpointer**
- **Log writer**
- **Eviction worker**
- …

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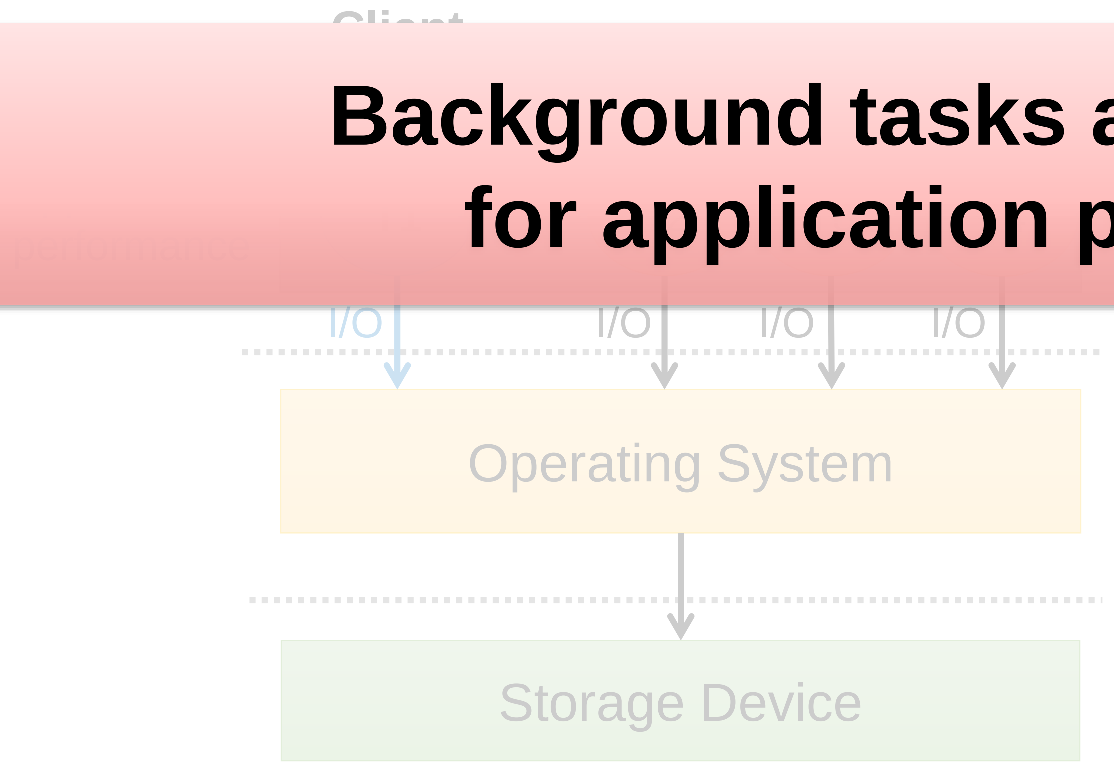

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Background tasks are problematic for application performance

Application Impact

- Illustrative experiment
  - YCSB update-heavy workload against MongoDB

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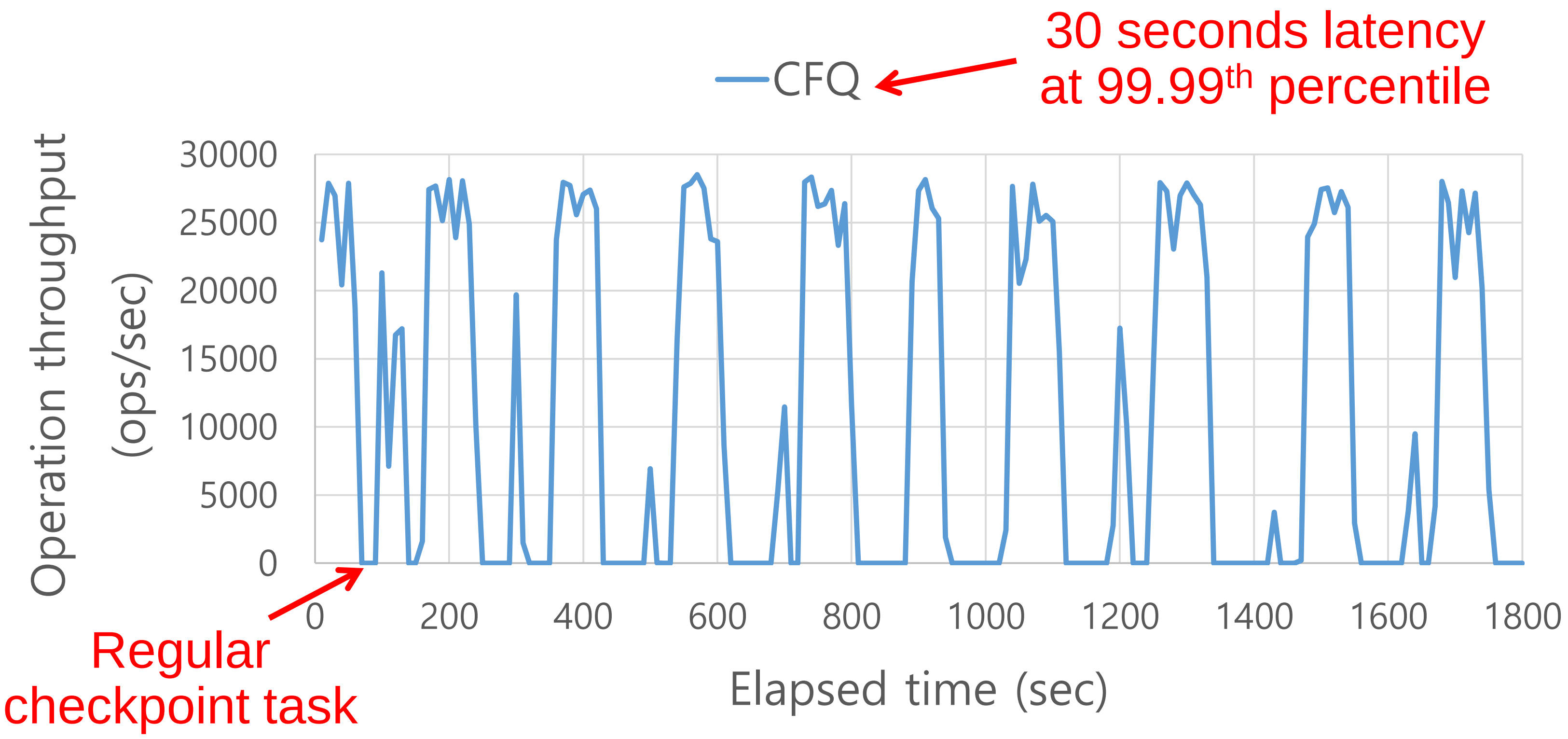

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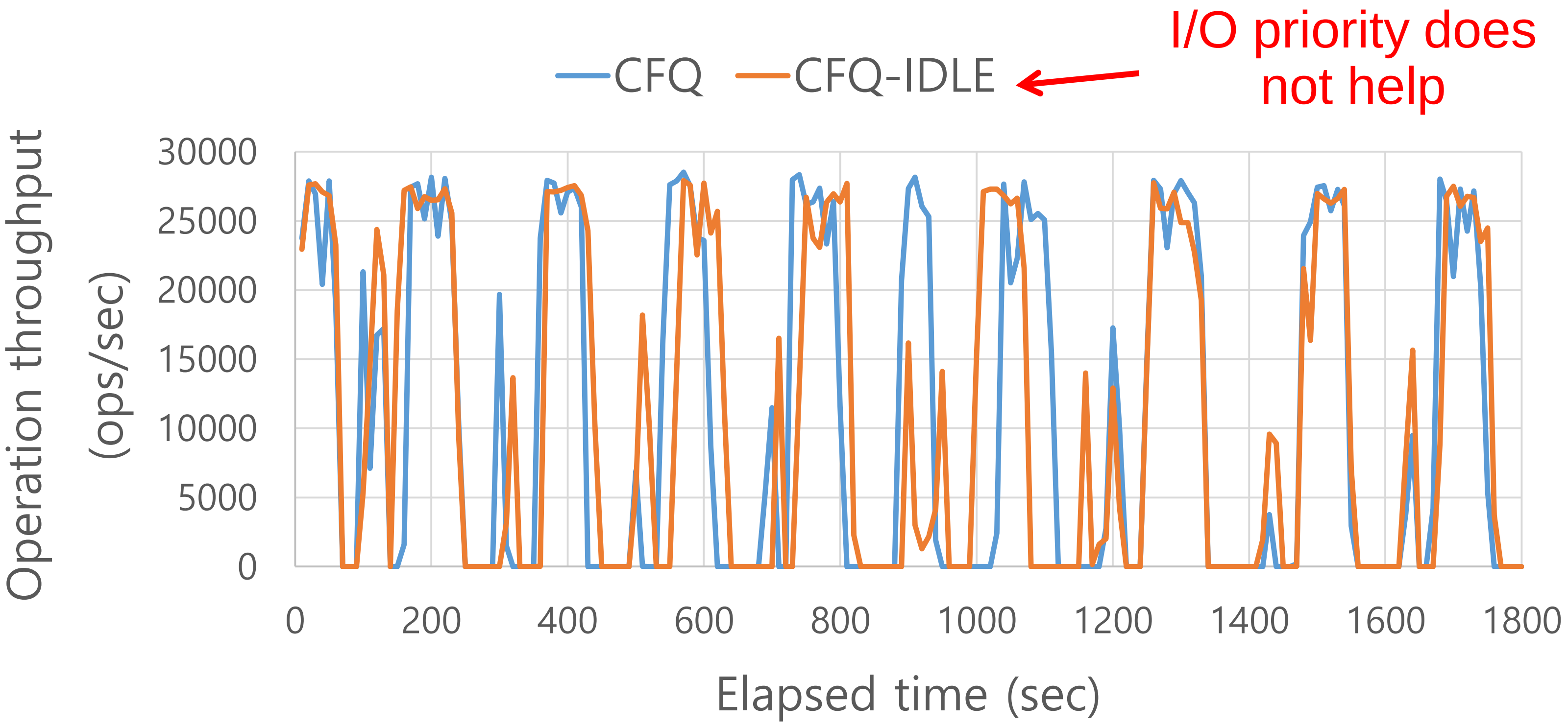

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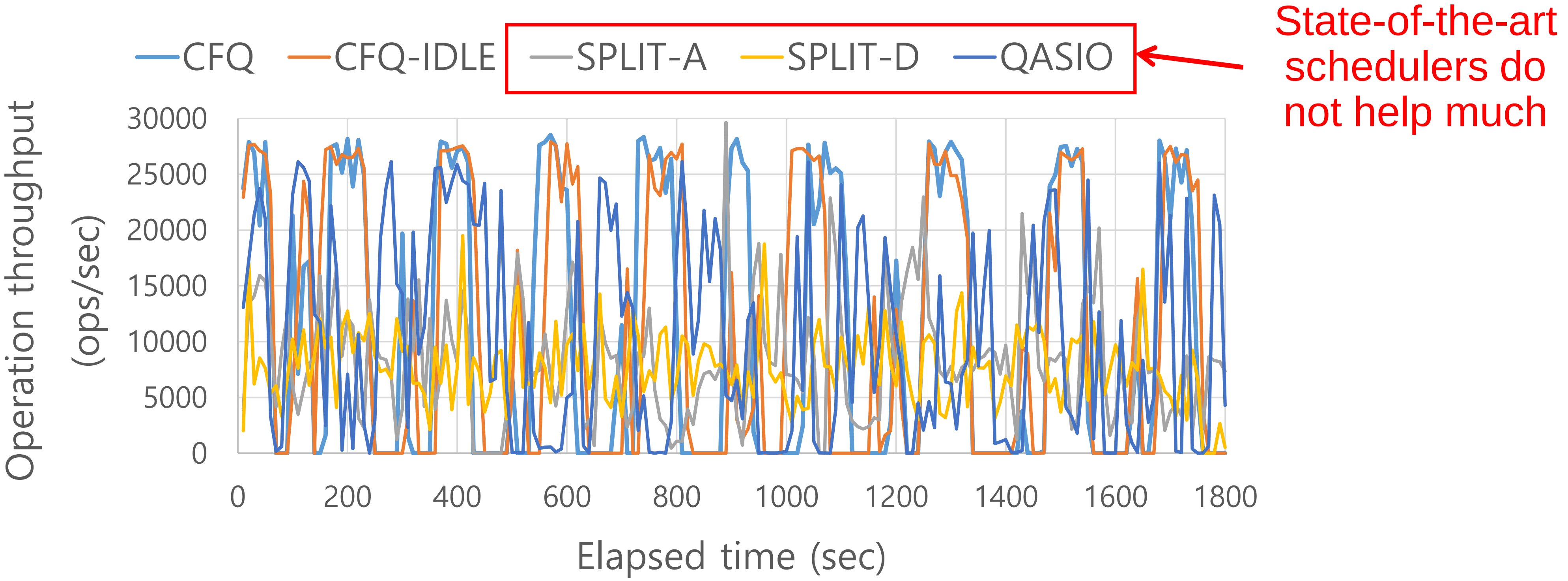

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- Independent policies in multiple layers
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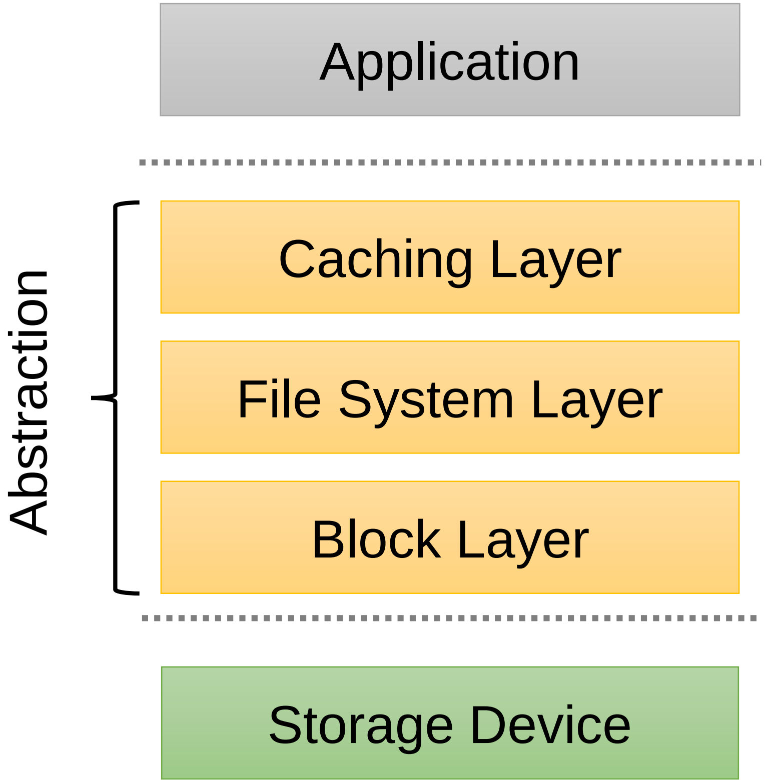

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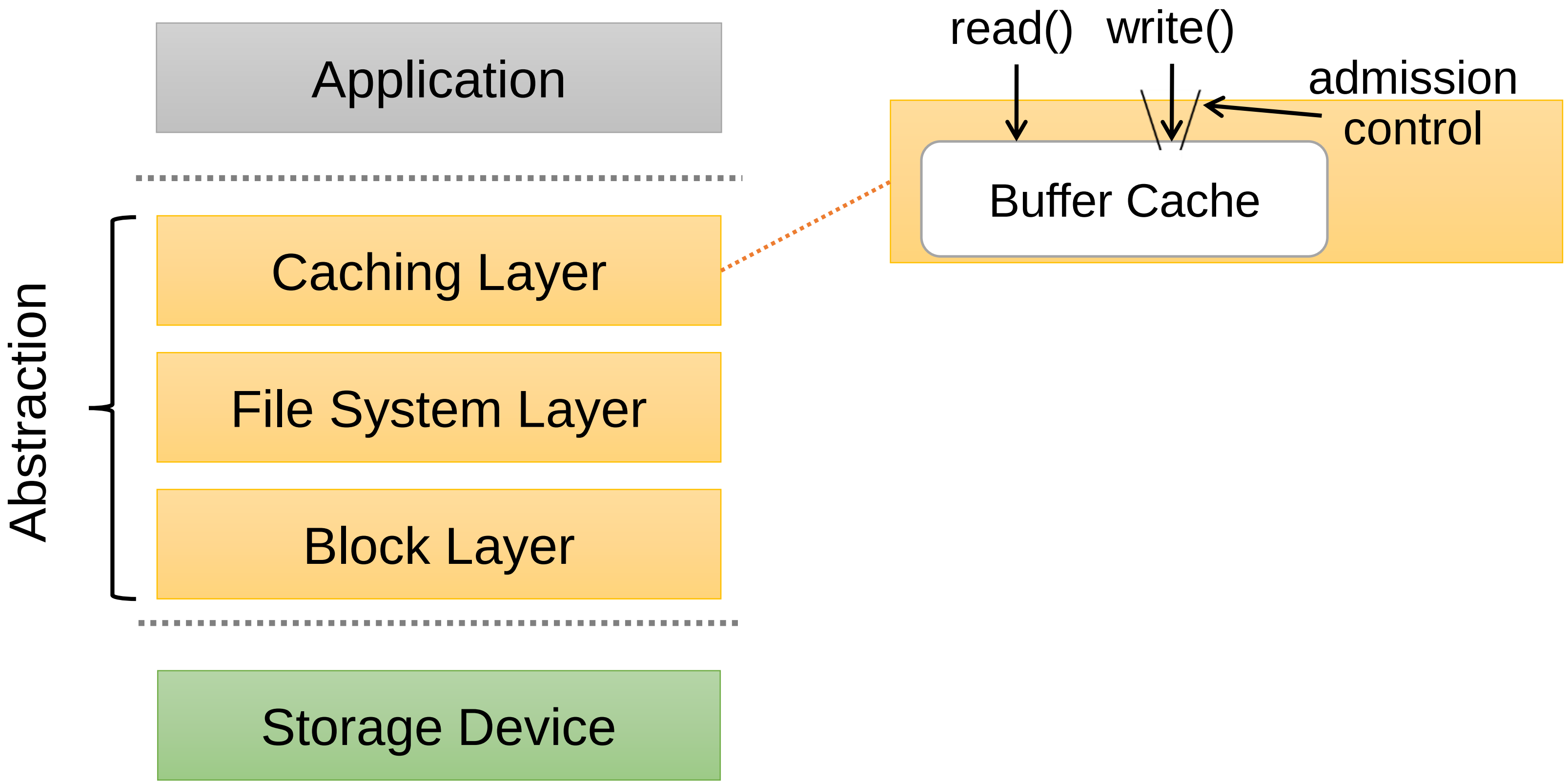

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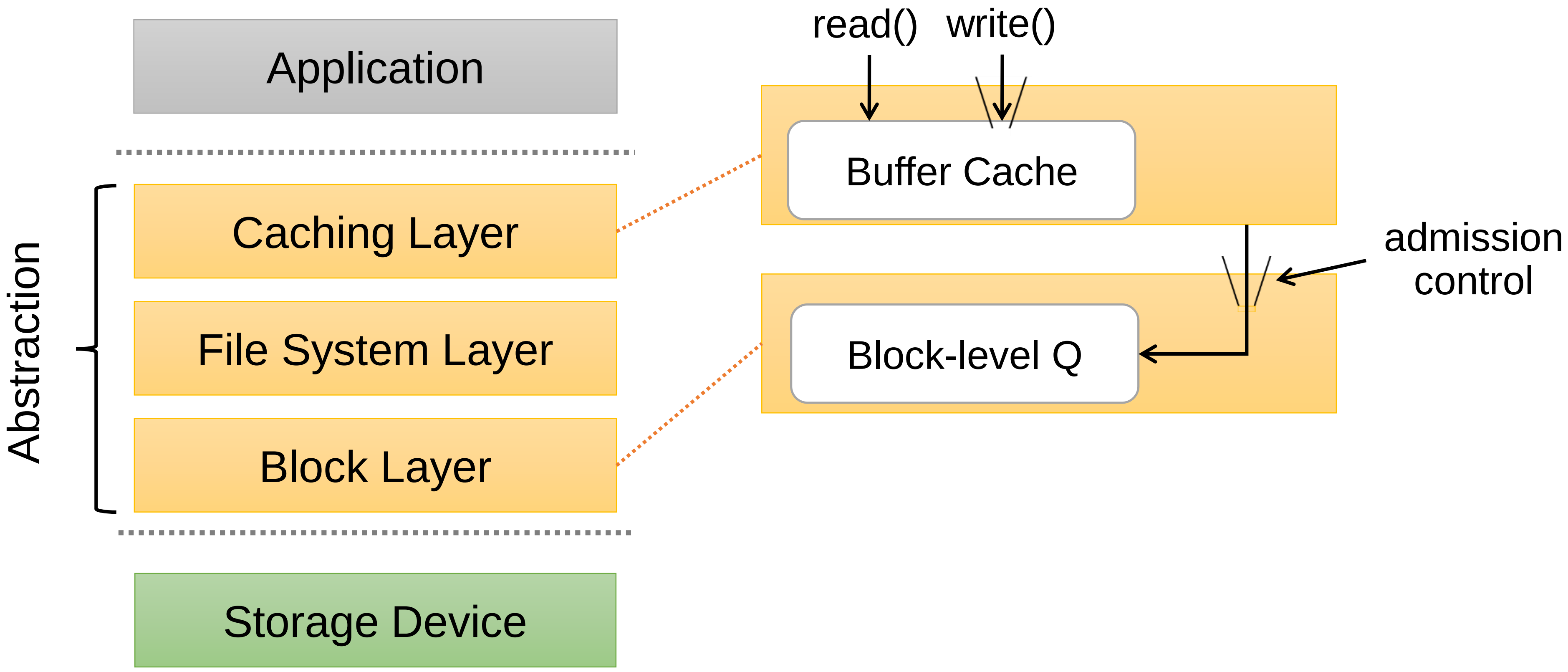

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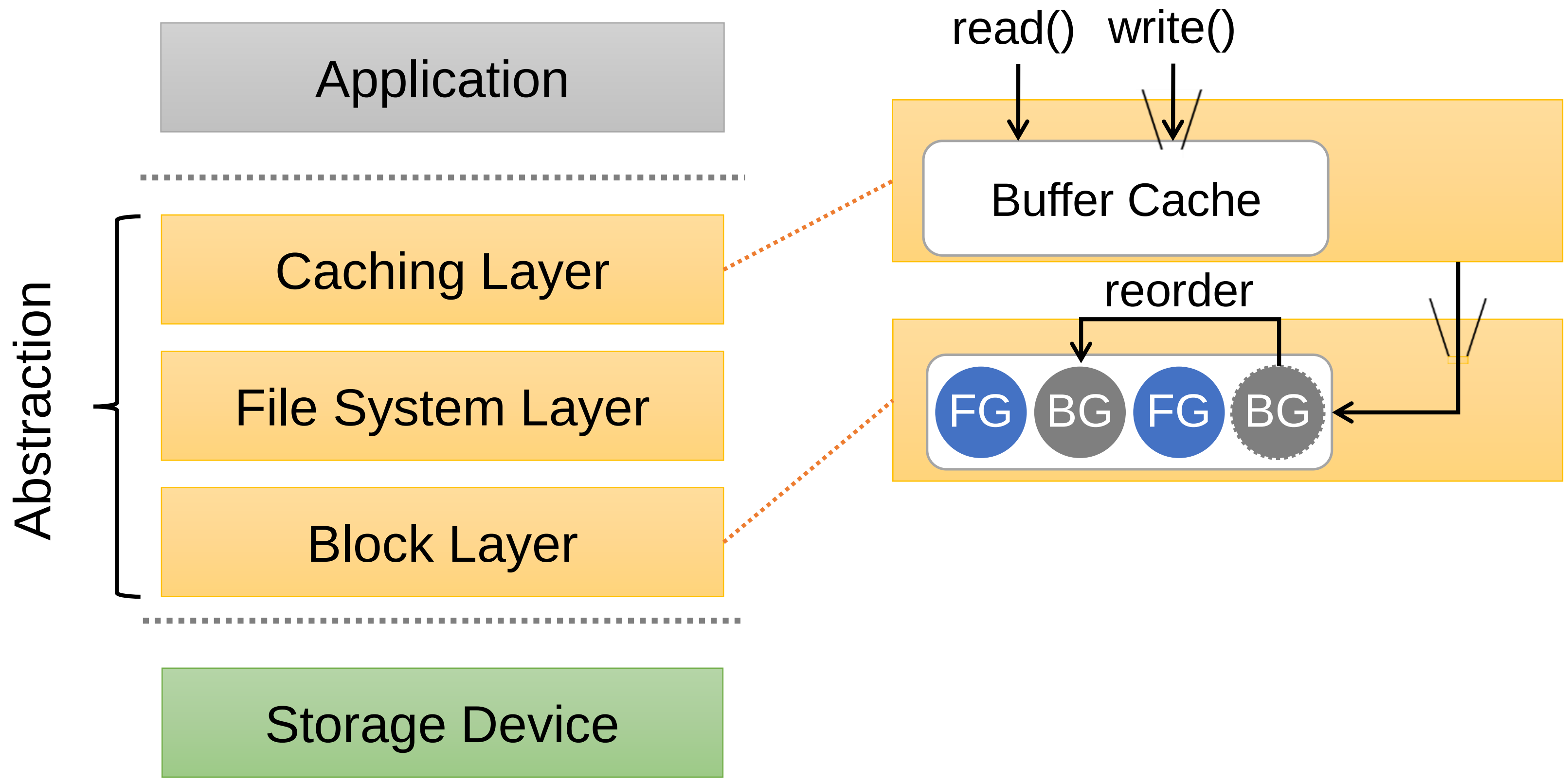

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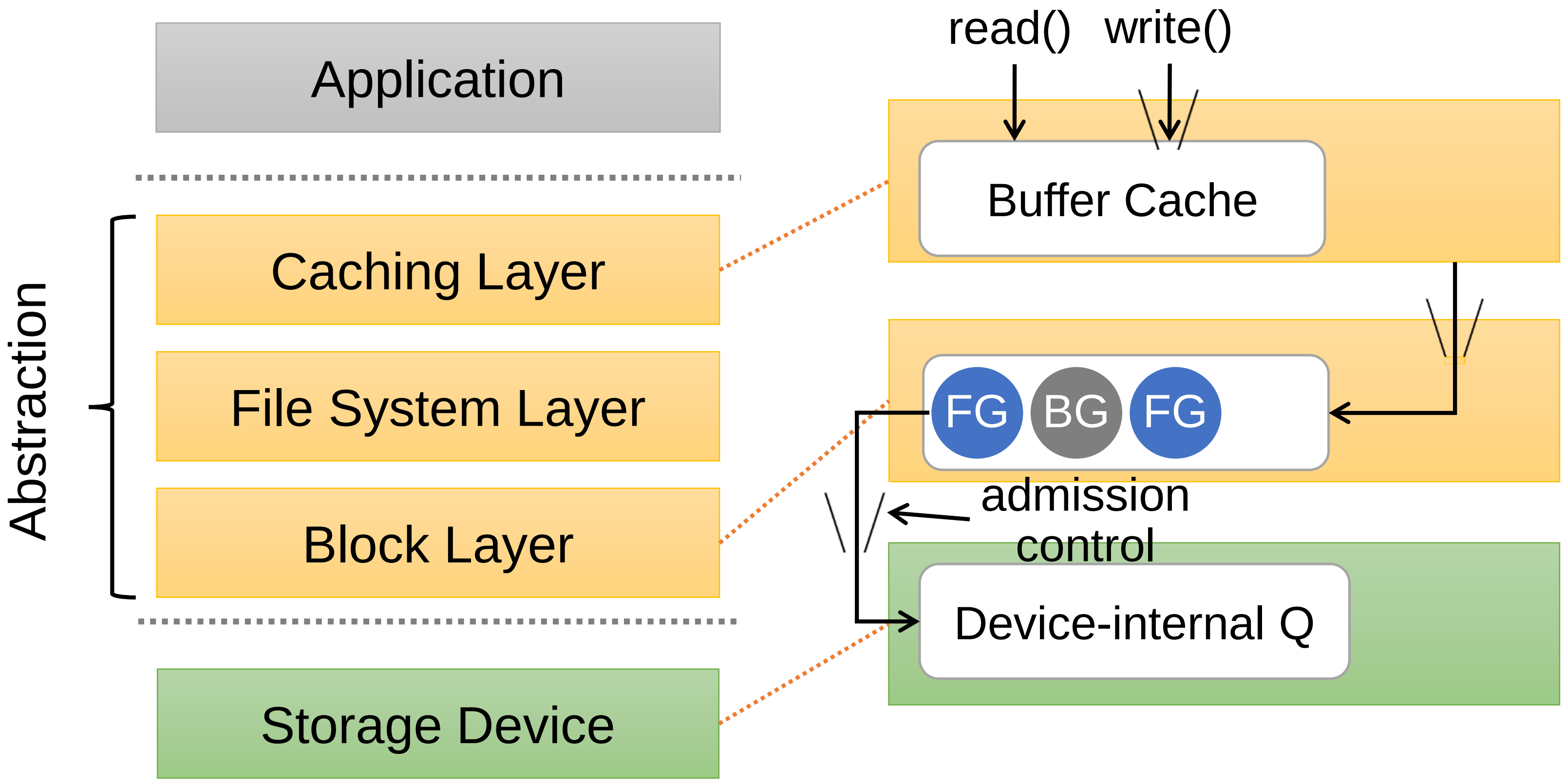

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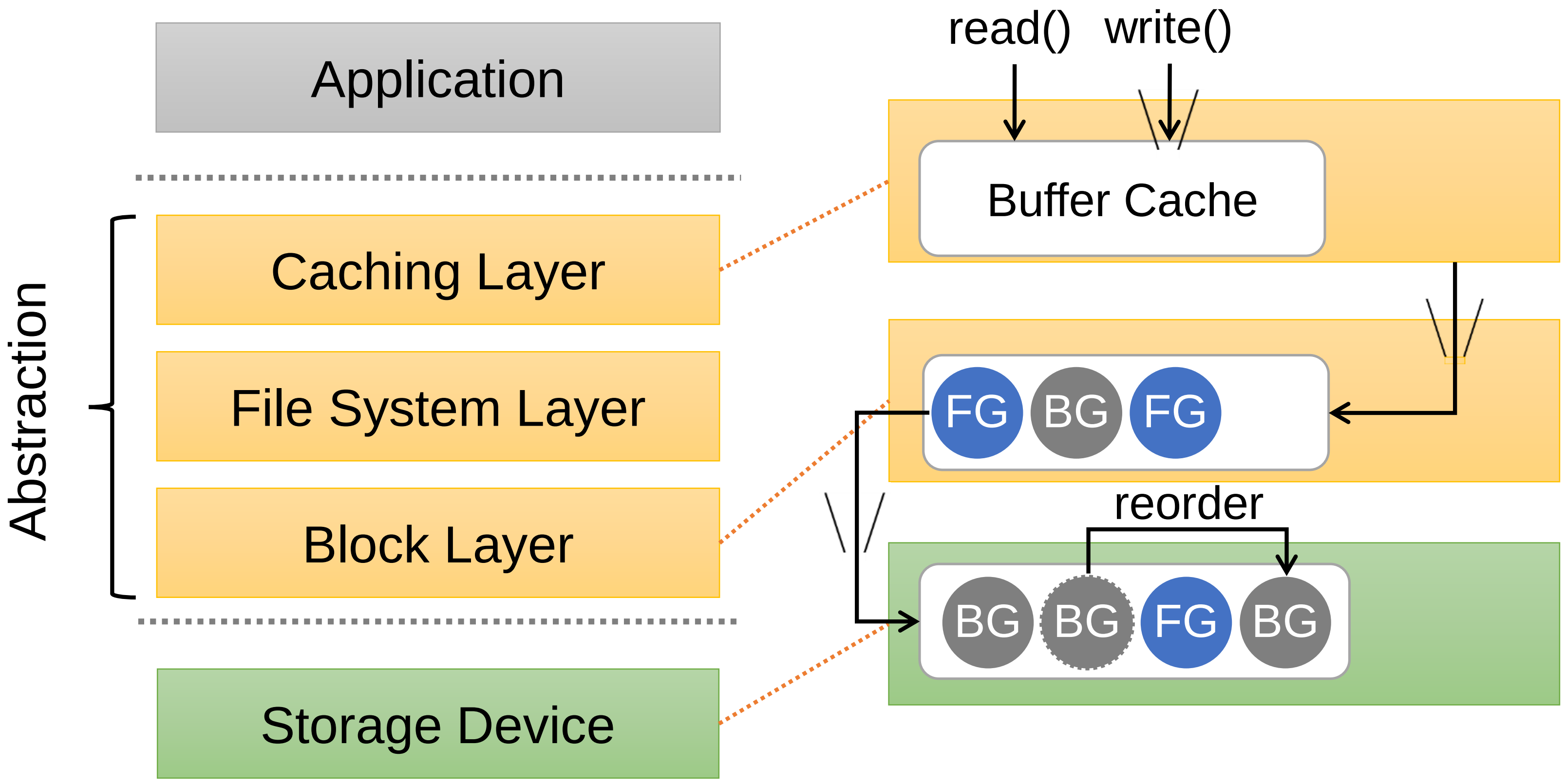

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I/O Priority Inversion

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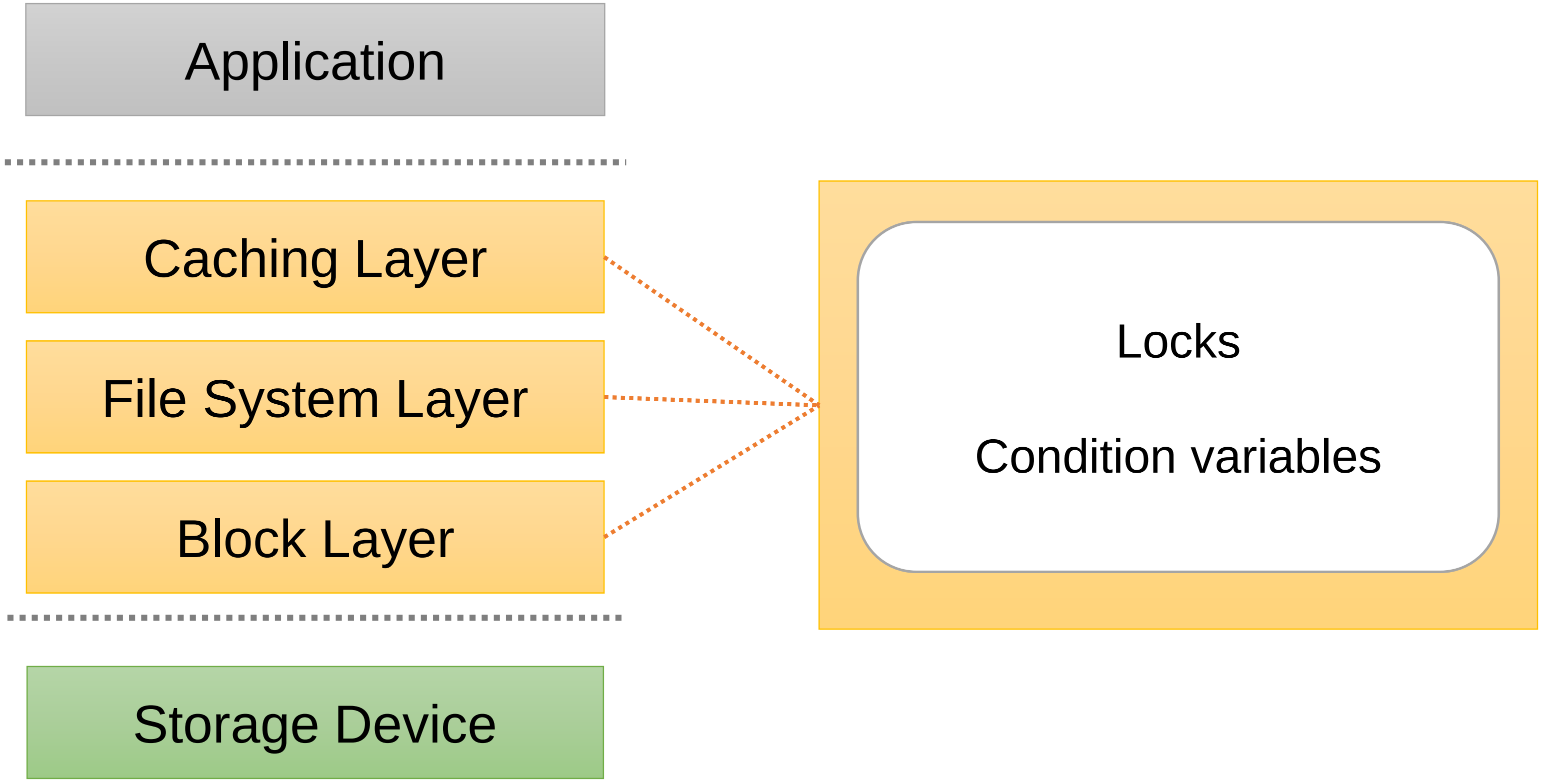

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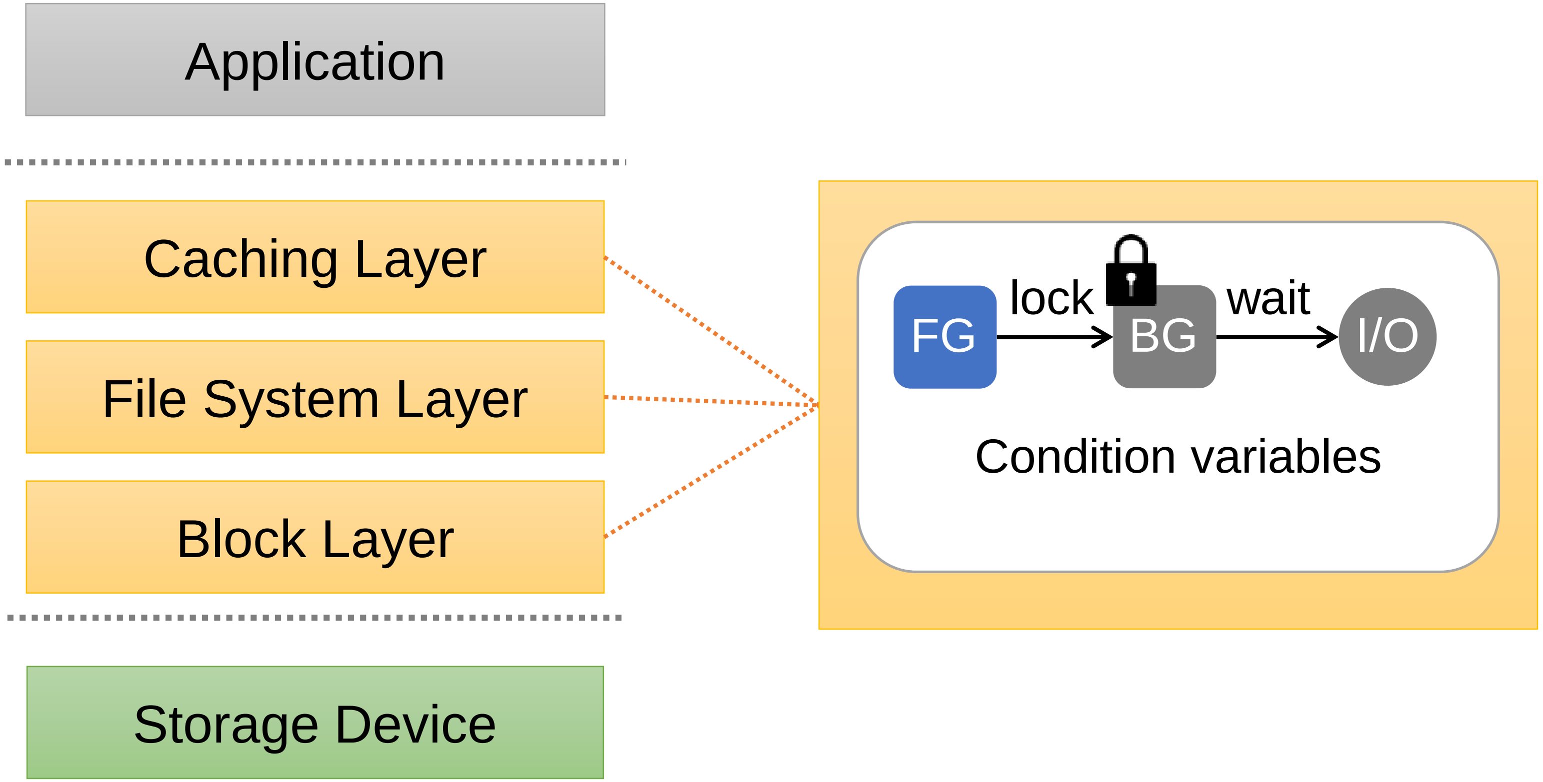

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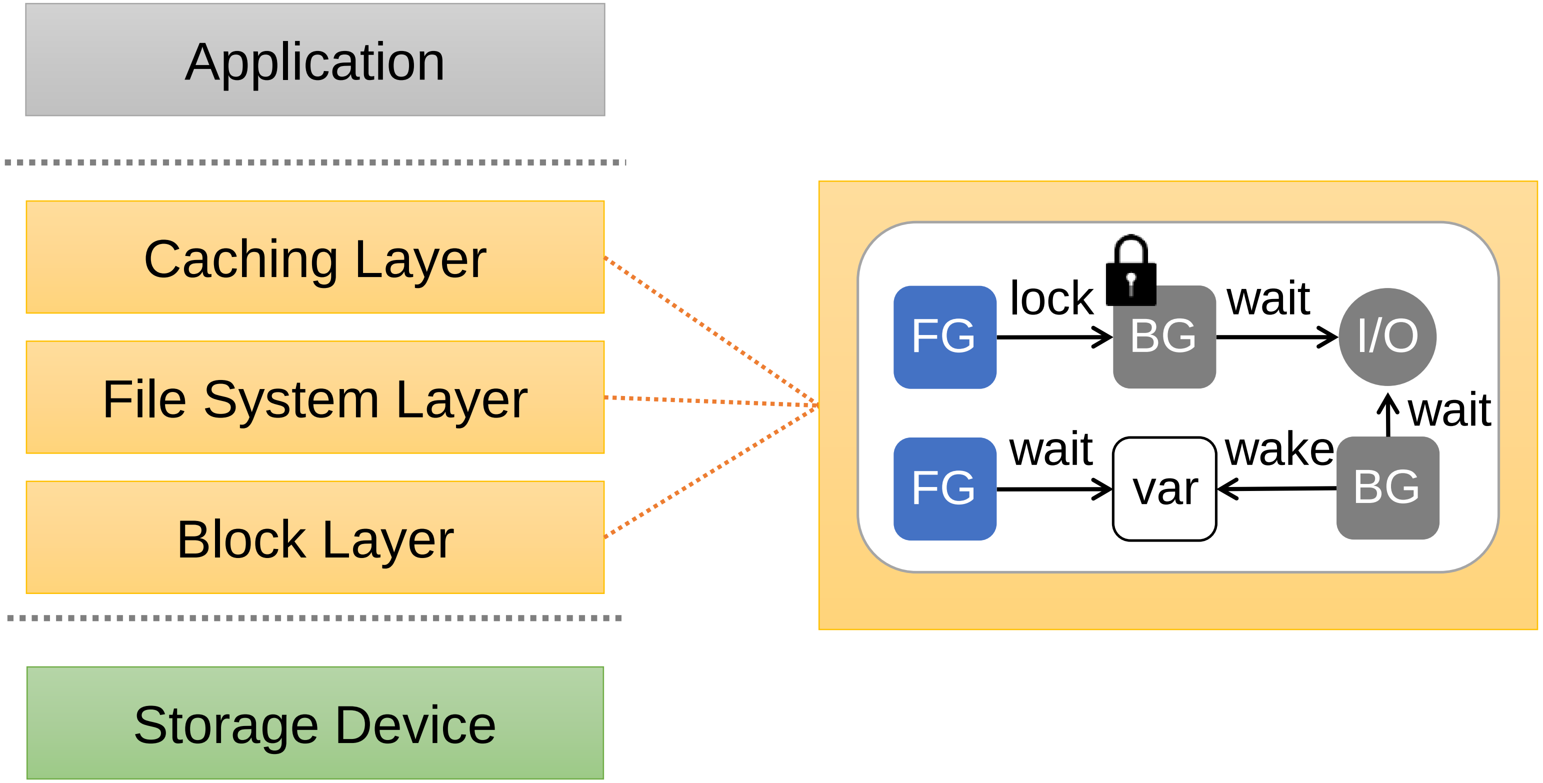

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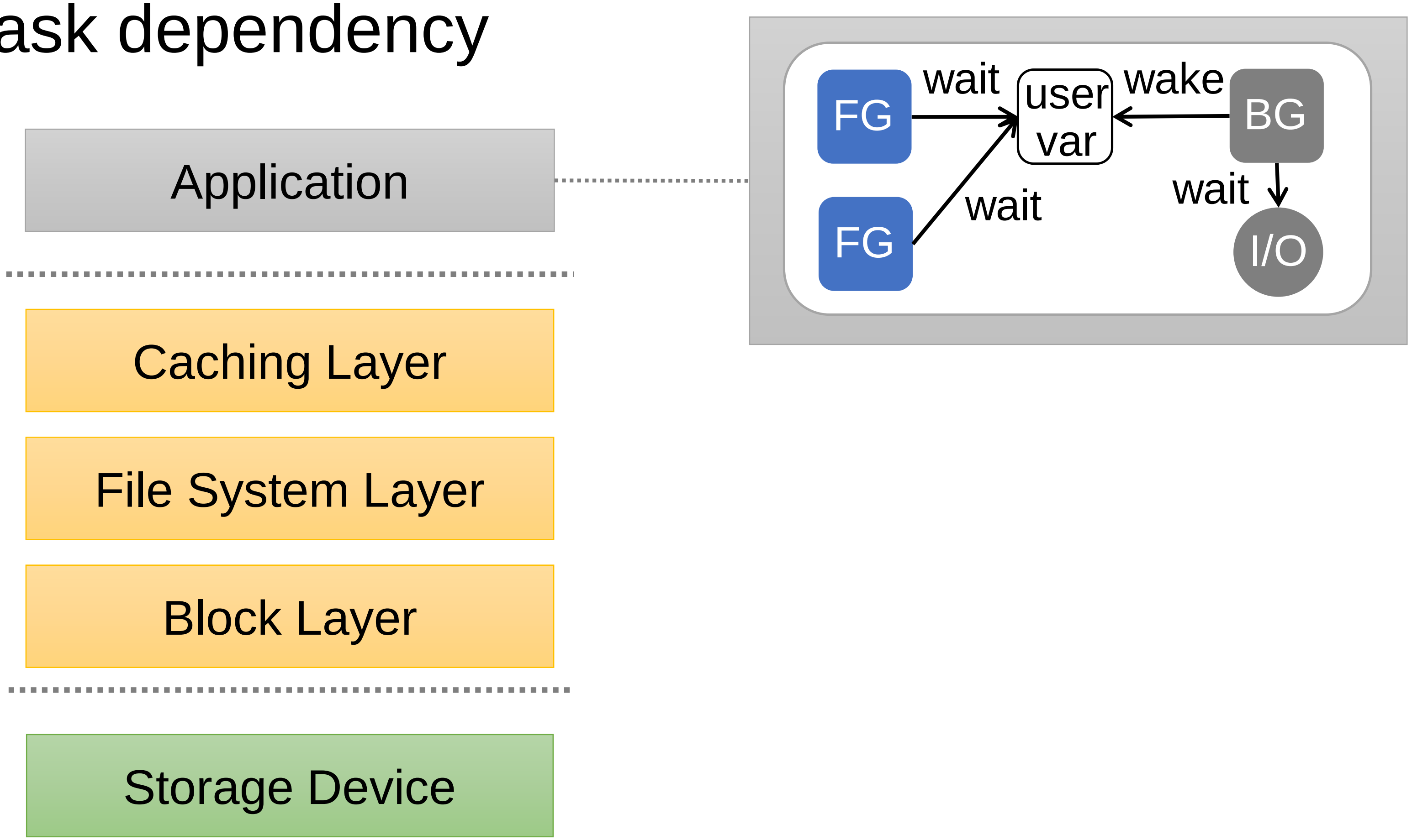

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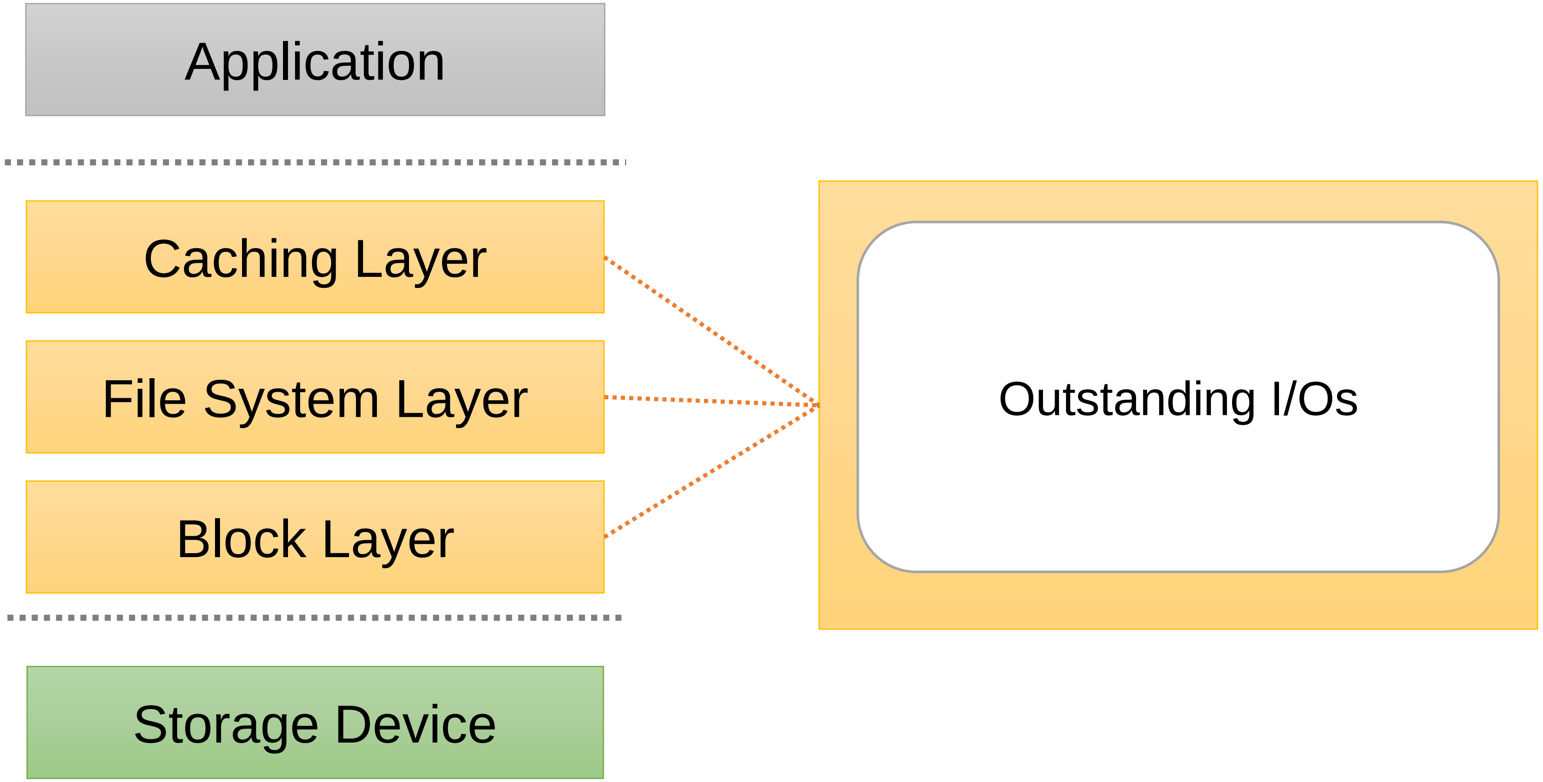

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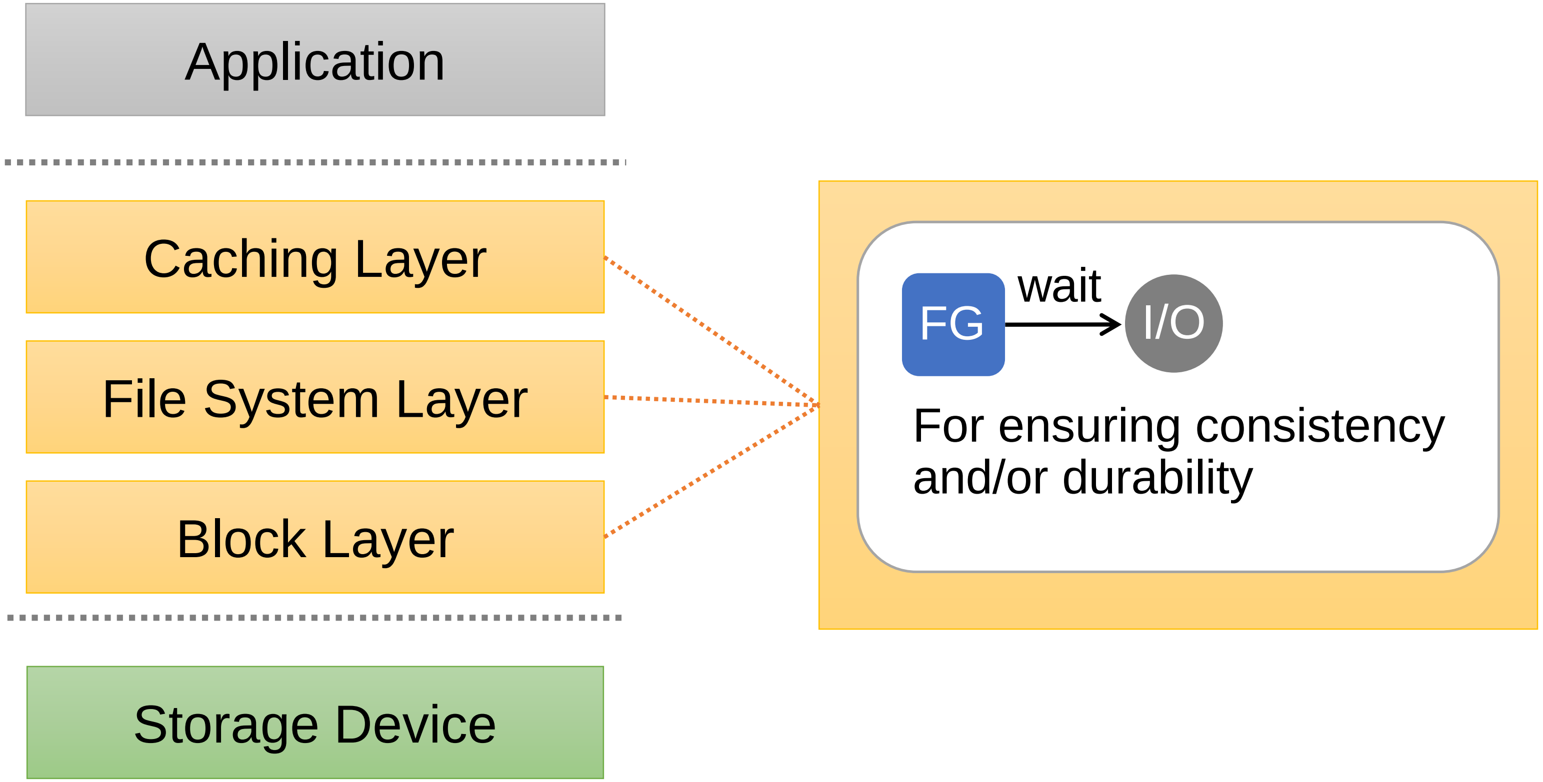
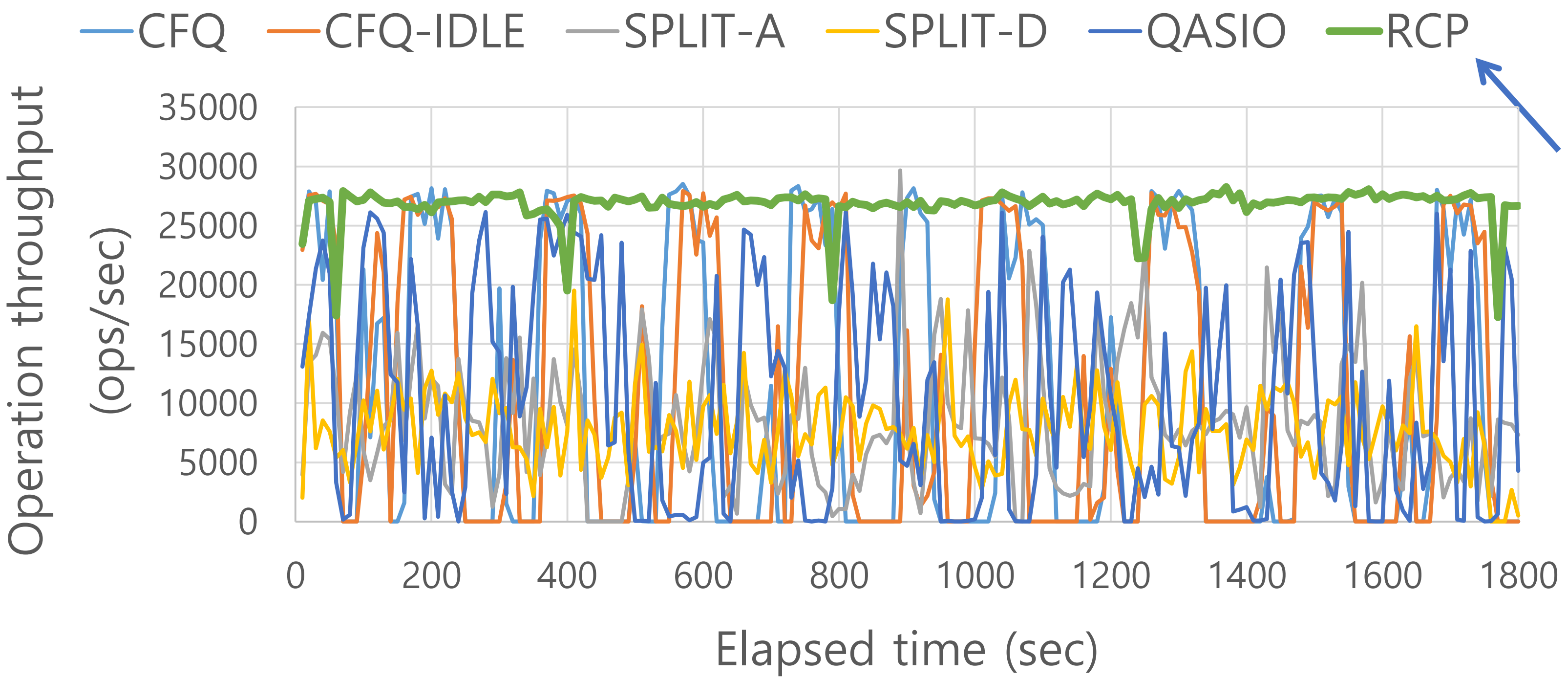


Our Approach

- Request-centric I/O prioritization (RCP)
  - Critical I/O: I/O in the critical path of request handling
  - Policy: holistically prioritizes critical I/Os along the I/O path



100 ms latency at 99.99th percentile

Challenges

- **How to accurately identify I/O criticality**

- How to effectively enforce I/O criticality

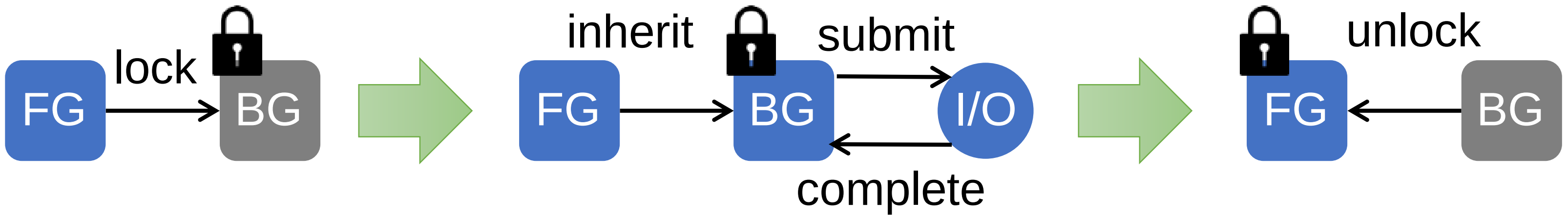
Critical I/O Detection

- Enlightenment API
  - Interface for tagging foreground tasks

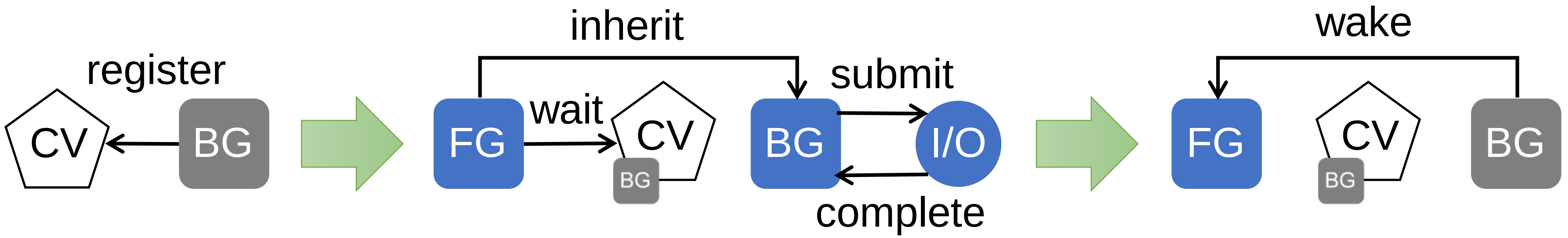
- I/O priority inheritance
  - Handling task dependency
  - Handling I/O dependency

I/O Priority Inheritance

- Handling task dependency
  - Locks



  - Condition variables



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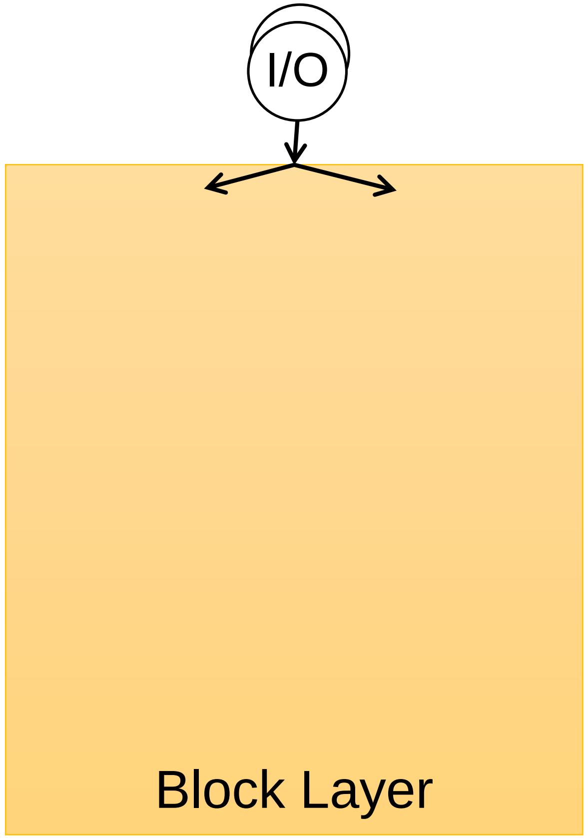

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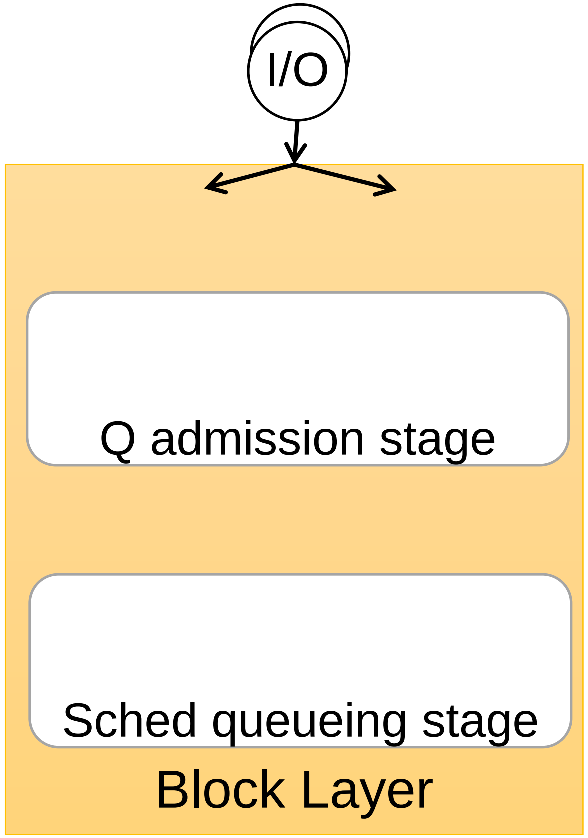

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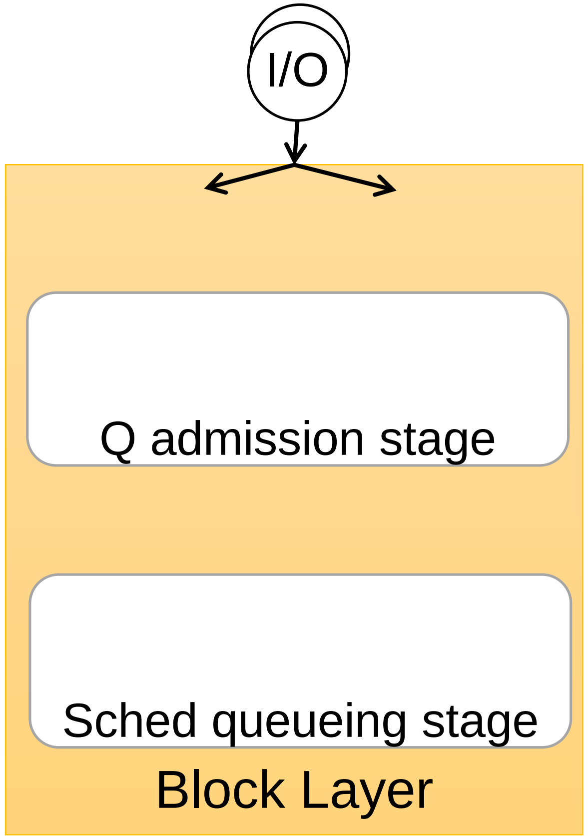
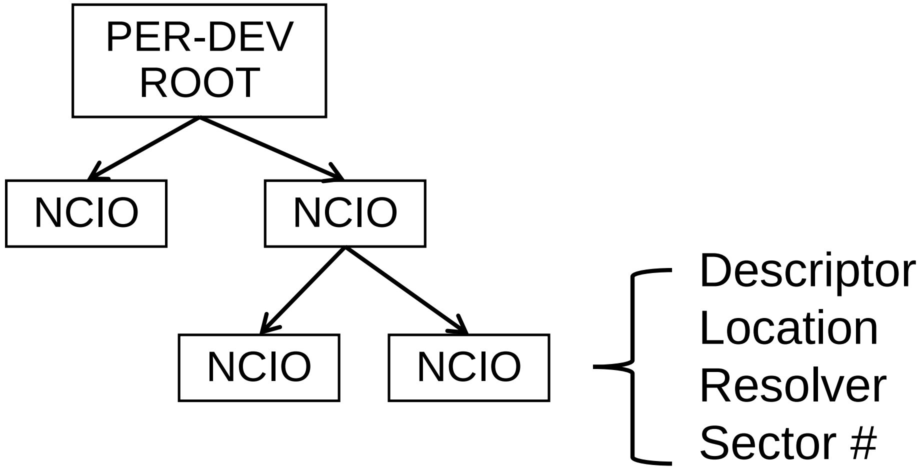


Non-critical I/O tracking



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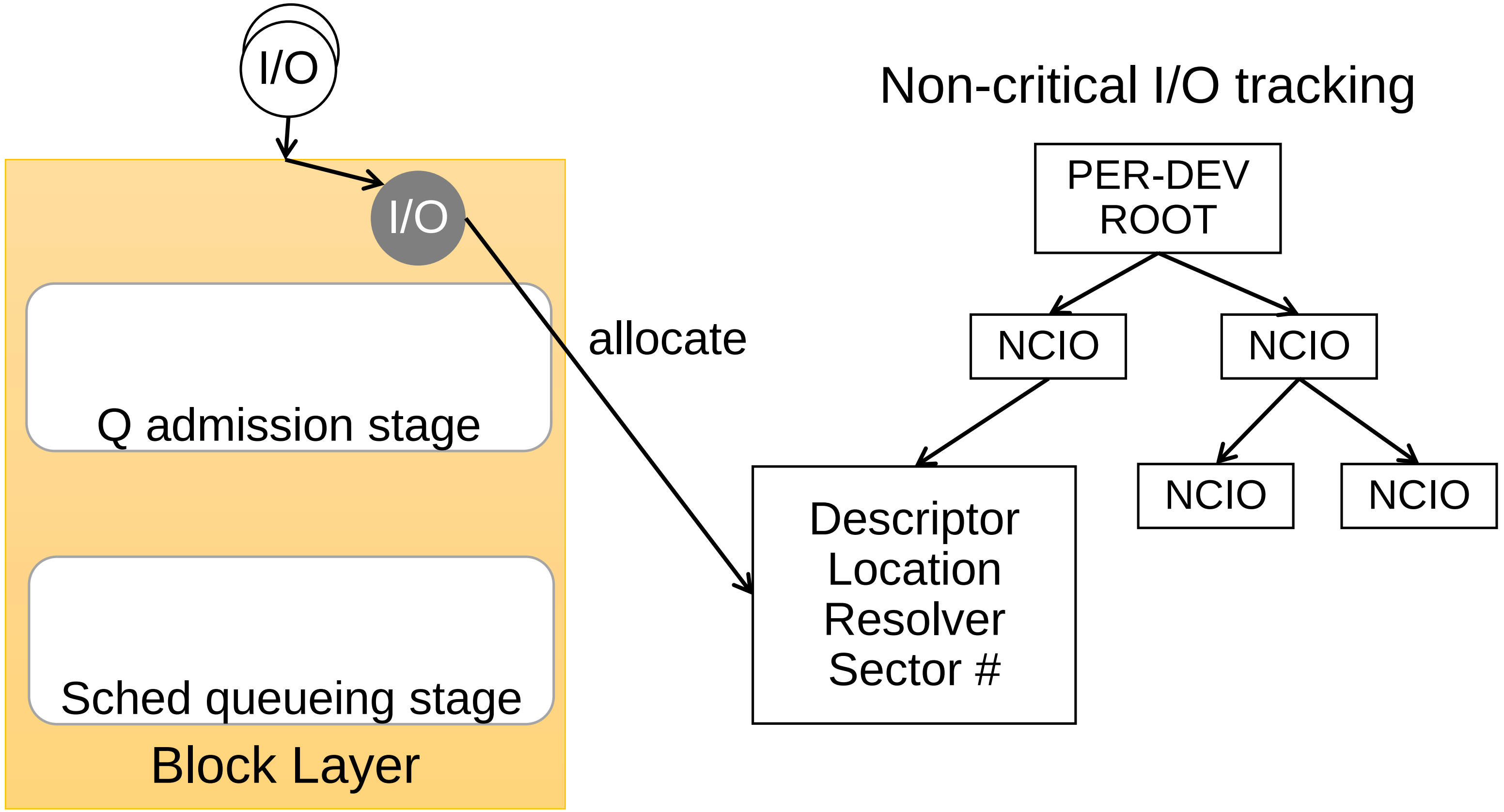

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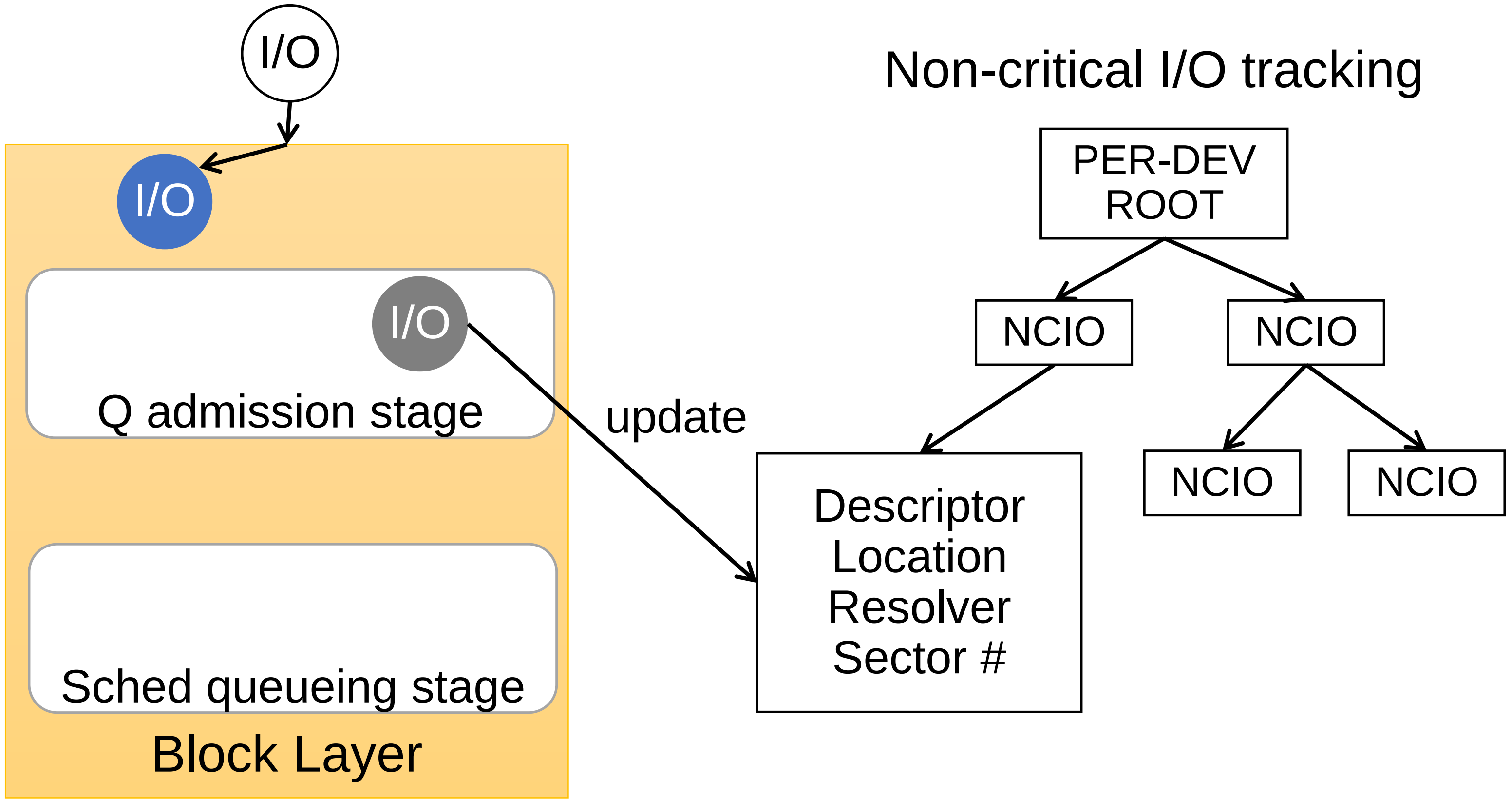

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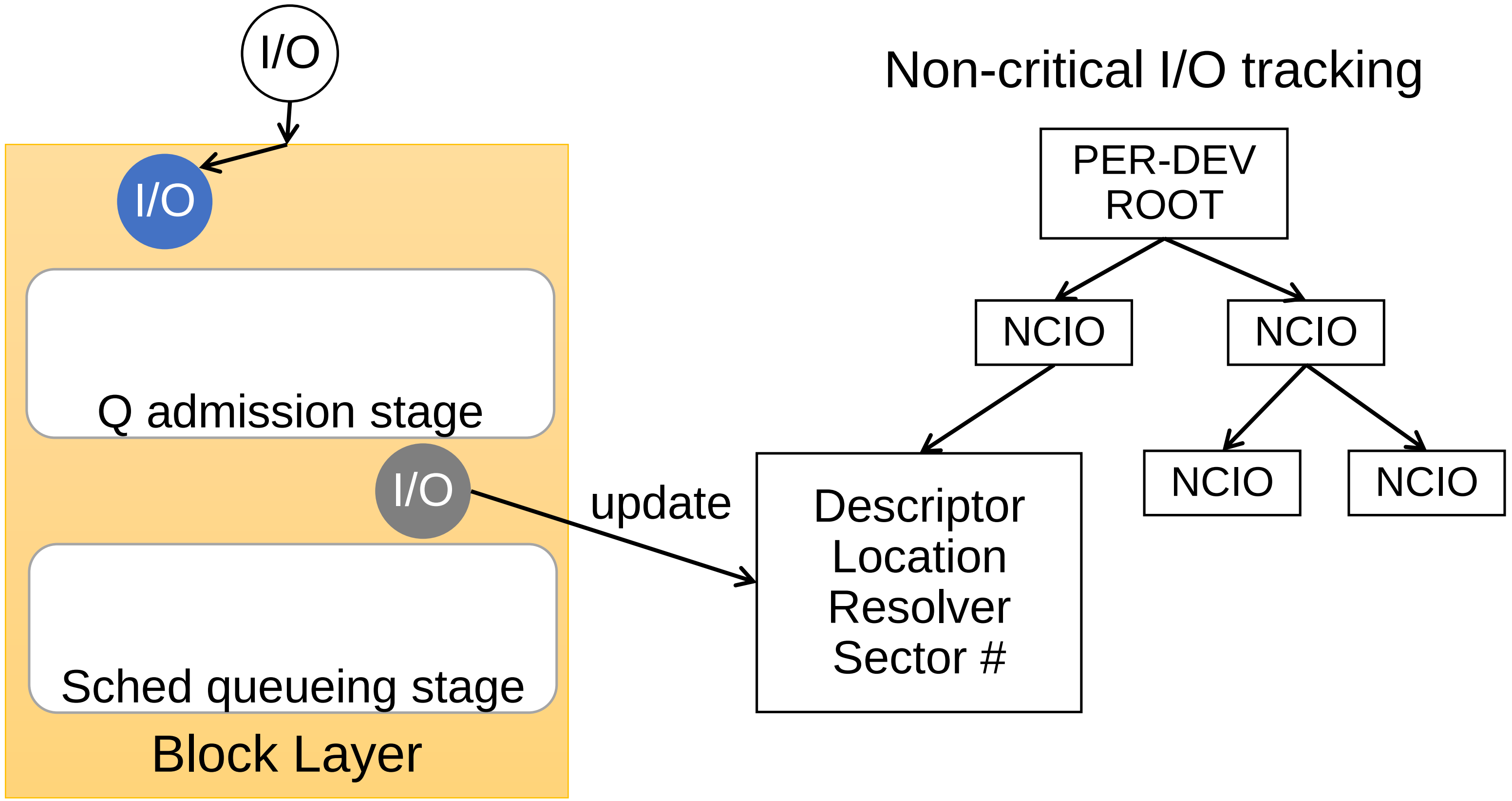

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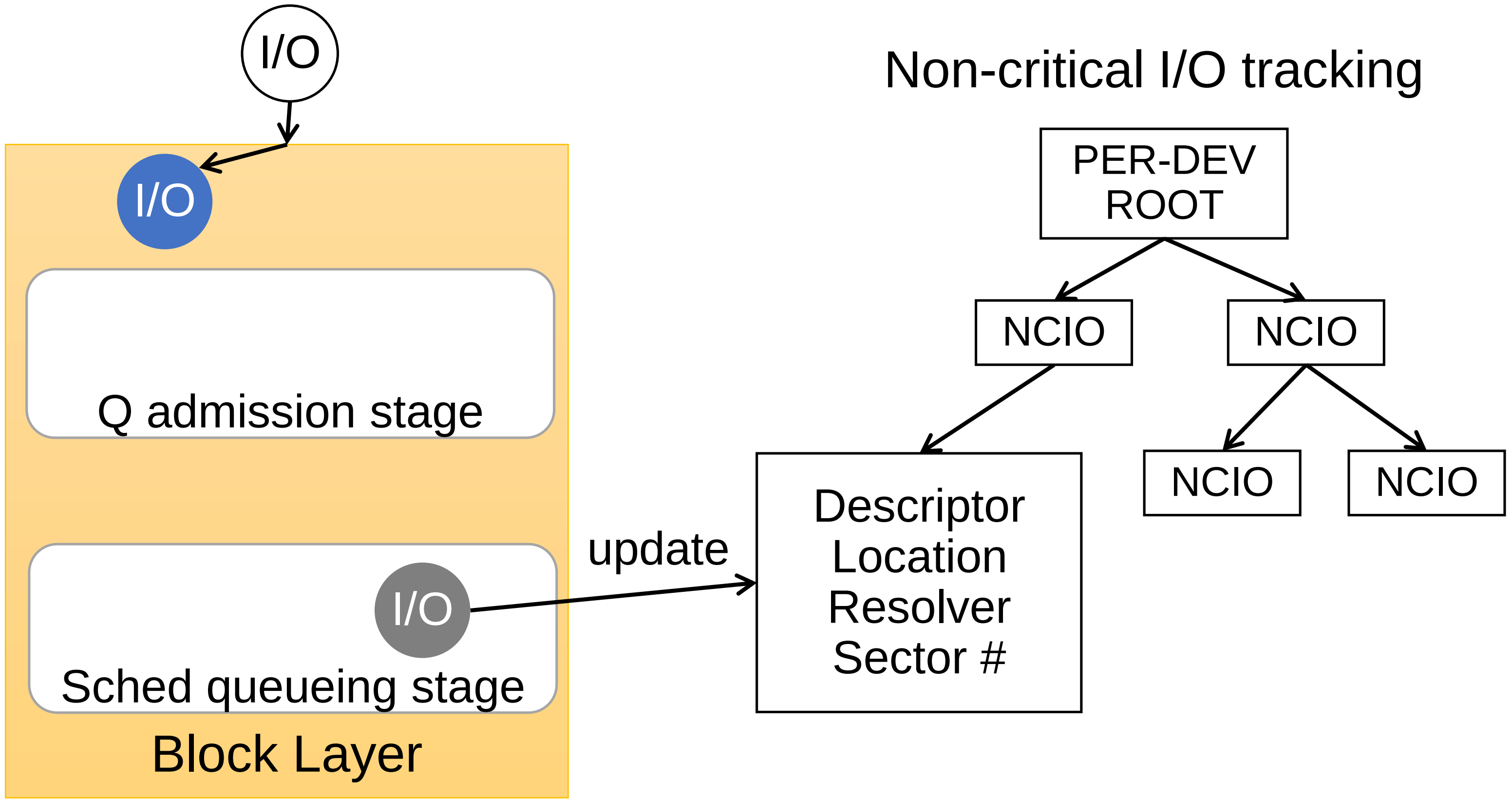

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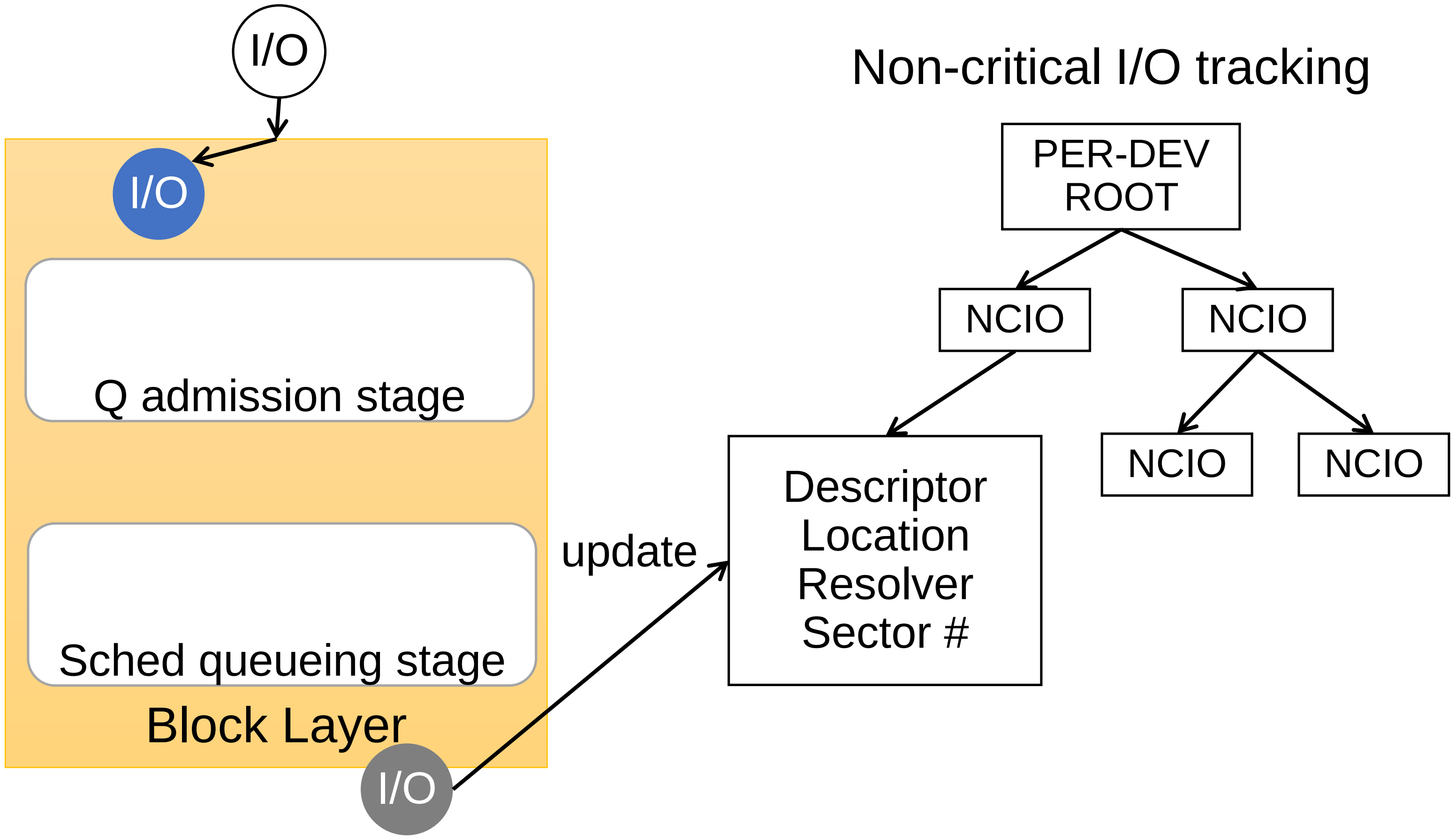

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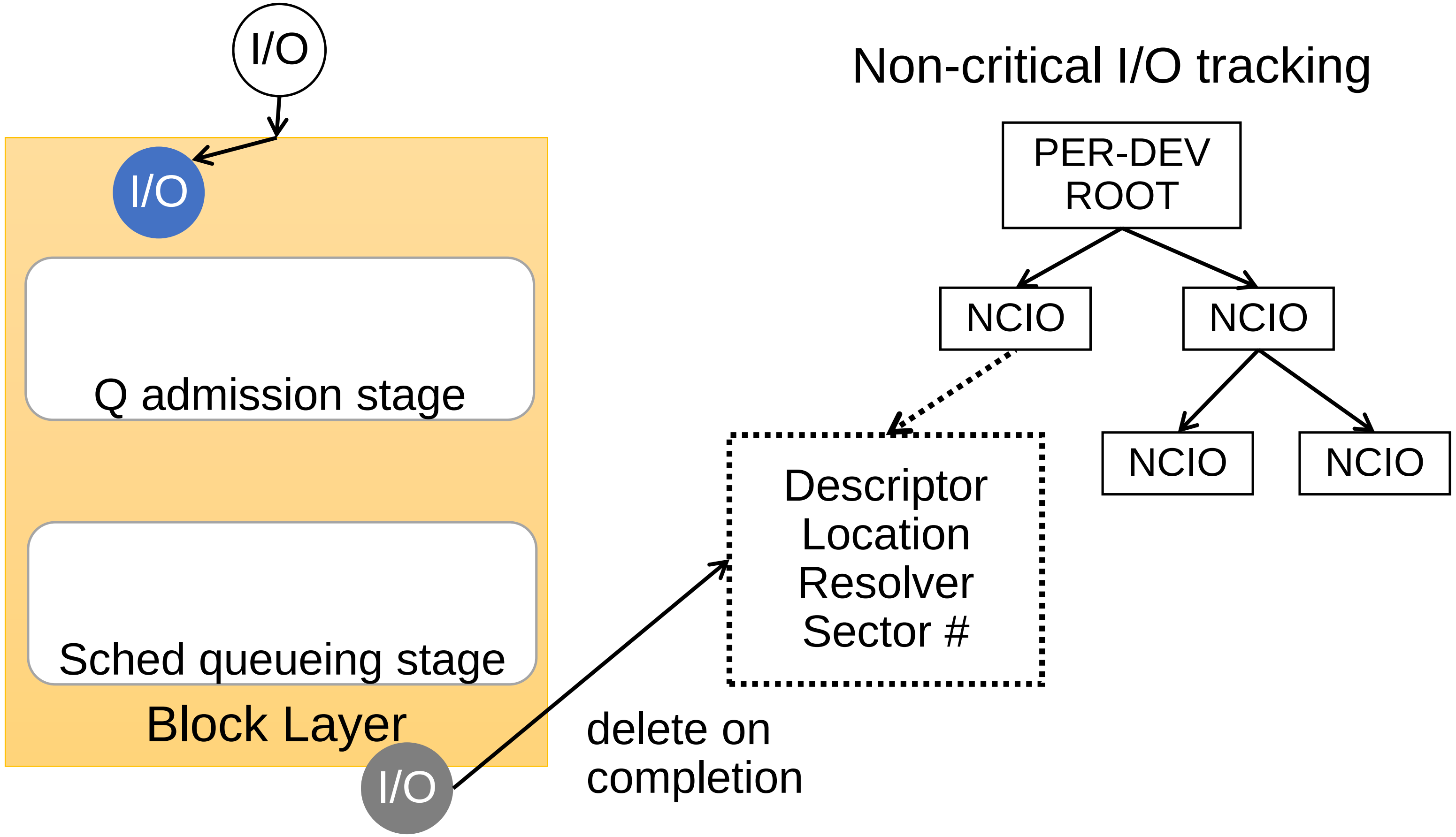
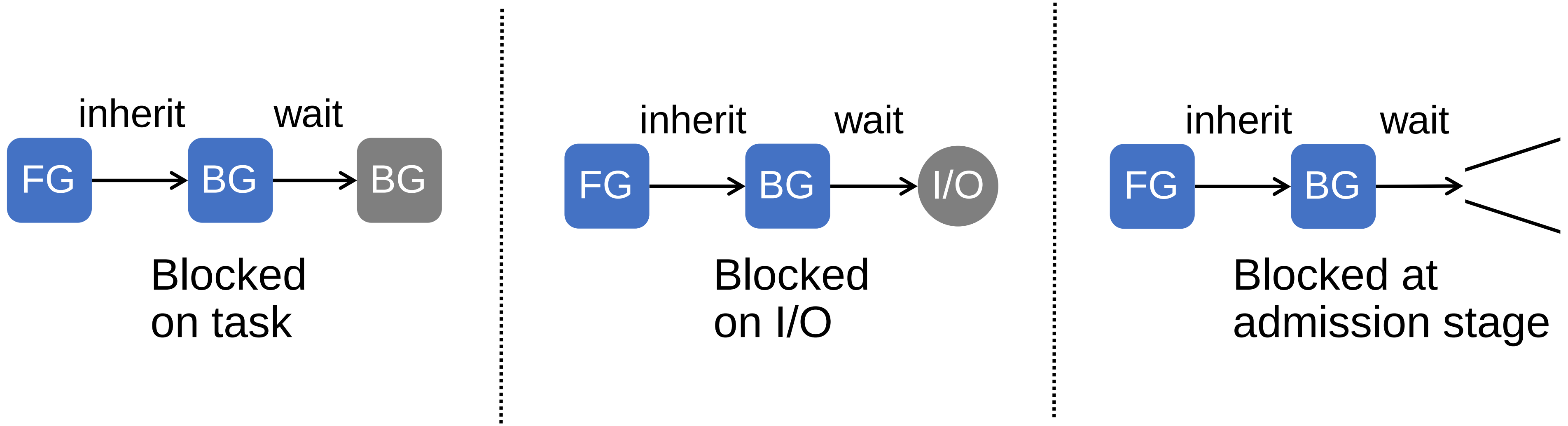


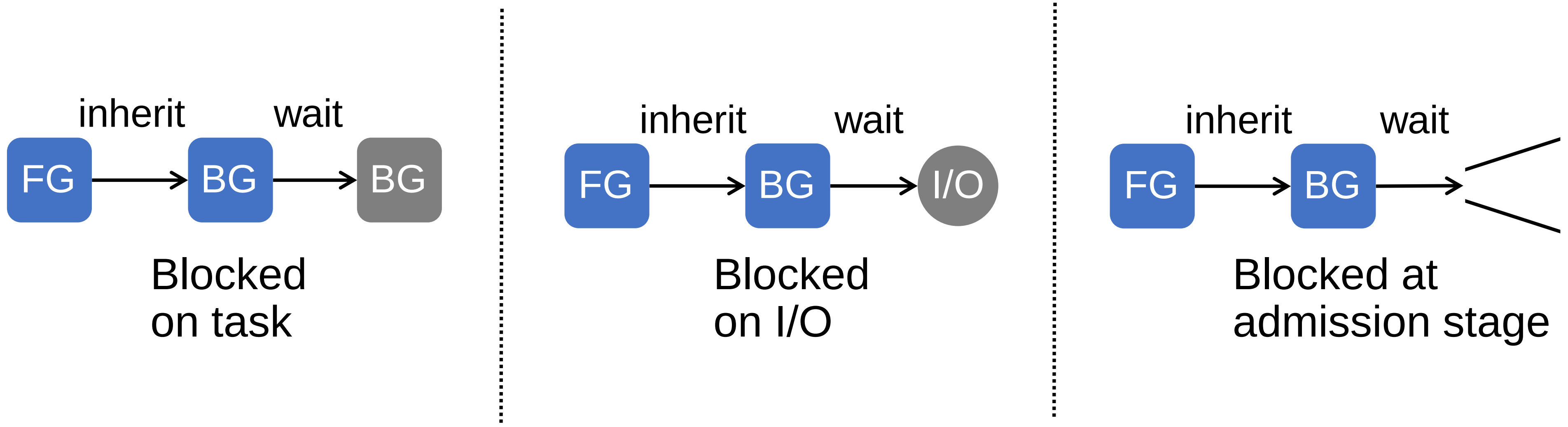
Handling Transitive Dependency

- Possible states of dependent task



Handling Transitive Dependency

- Recording blocking status



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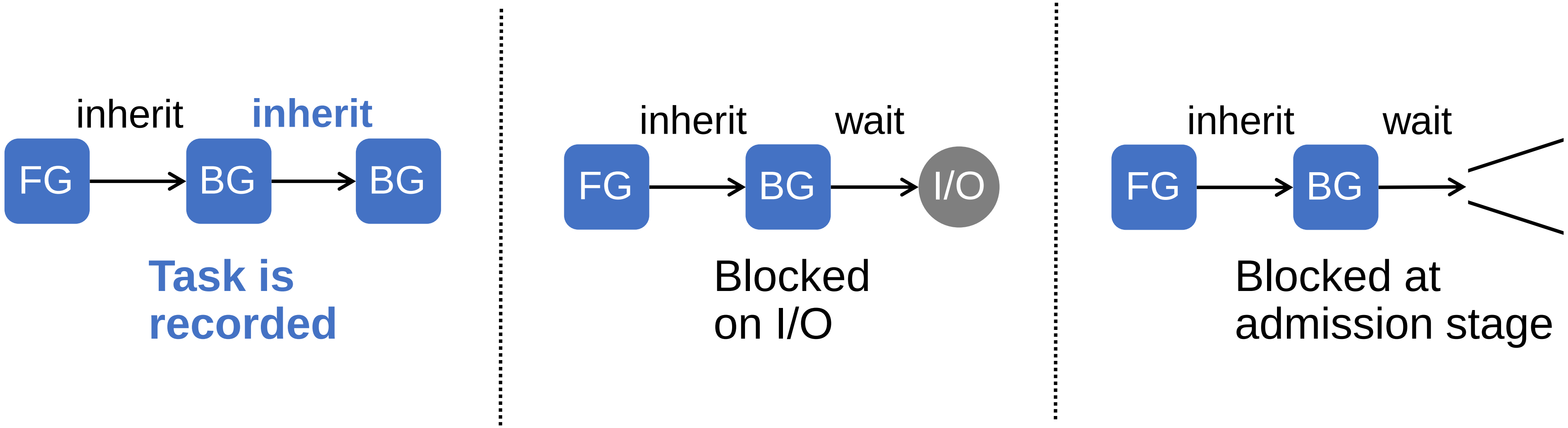

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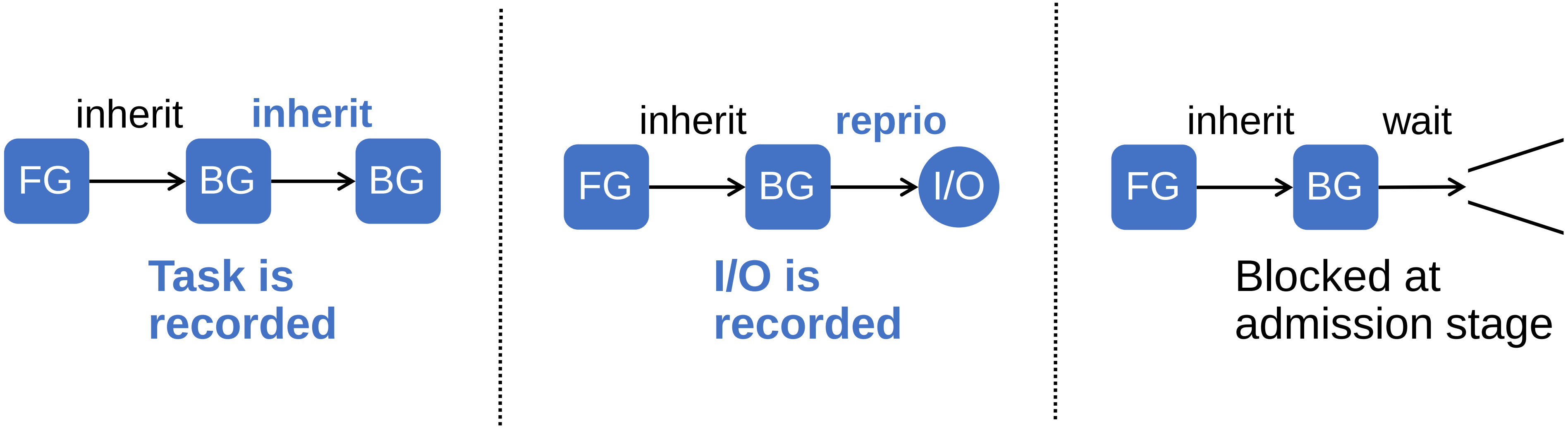

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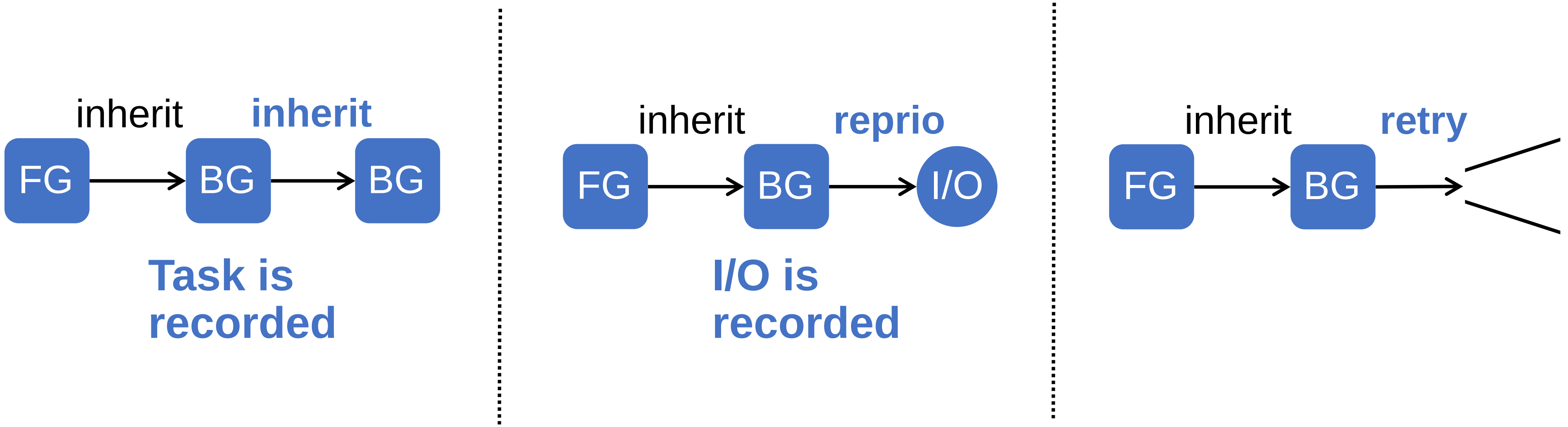

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- How to accurately identify I/O criticality
  - Enlightenment API
  - I/O priority inheritance
  - Recording blocking status

- **How to effectively enforce I/O criticality**

Criticality-Aware I/O Prioritization

- Caching layer
  - Apply low dirty ratio for non-critical writes (1% by default)

- Block layer
  - Isolate allocation of block queue slots
  - Maintain 2 FIFO queues
  - Schedule critical I/O first
  - Limit # of outstanding non-critical I/Os (1 by default)
  - Support queue promotion to resolve I/O dependency

Evaluation

- Implementation on Linux 3.13 w/ ext4
- Application studies
  - PostgreSQL relational database
    - Backend processes as foreground tasks
    - I/O priority inheritance on LWLocks (semop)
  - MongoDB document store
    - Client threads as foreground tasks
    - I/O priority inheritance on Pthread mutex and condition vars (futex)
  - Redis key-value store
    - Master process as foreground task

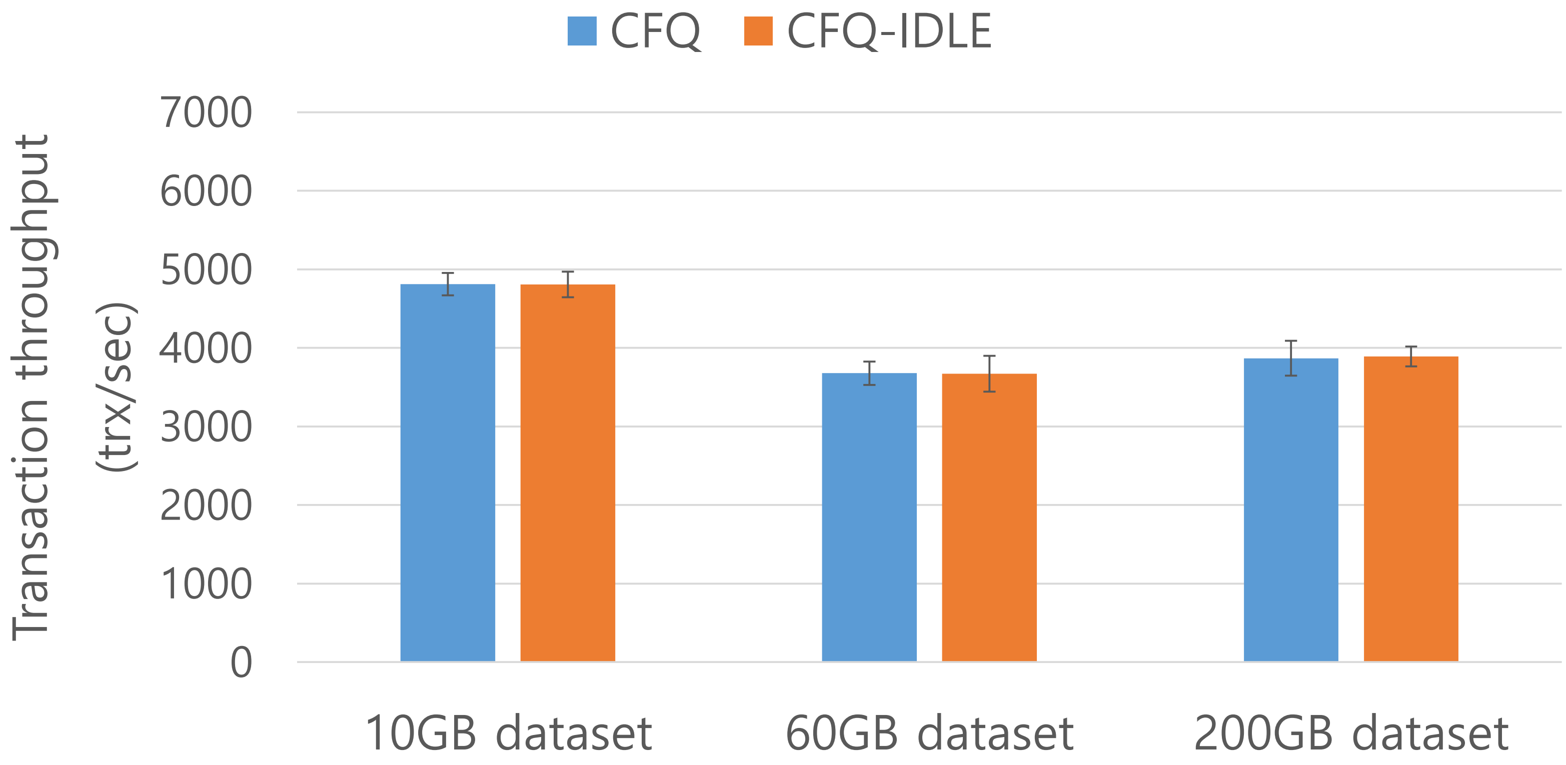
Evaluation

- Experimental setup
  - 2 Dell PowerEdge R530 (server & client)
  - 1TB Micron MX200 SSD

- I/O prioritization schemes
  - CFQ (default), CFQ-IDLE
  - SPLIT-A (priority), SPLIT-D (deadline) [SOSP'15]
  - QASIO [FAST'15]
  - **RCP**

Application Throughput

- PostgreSQL w/ TPC-C workload



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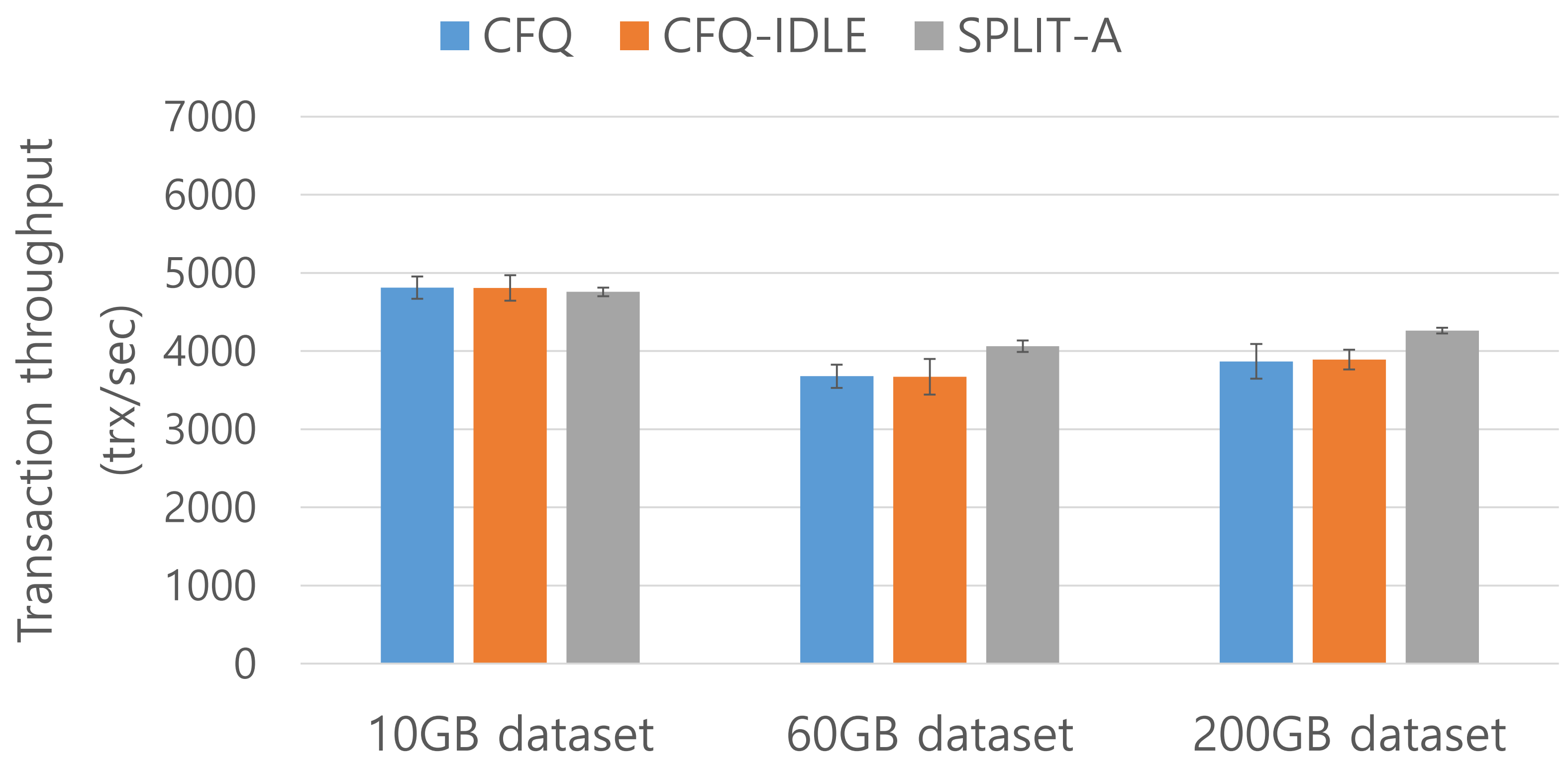

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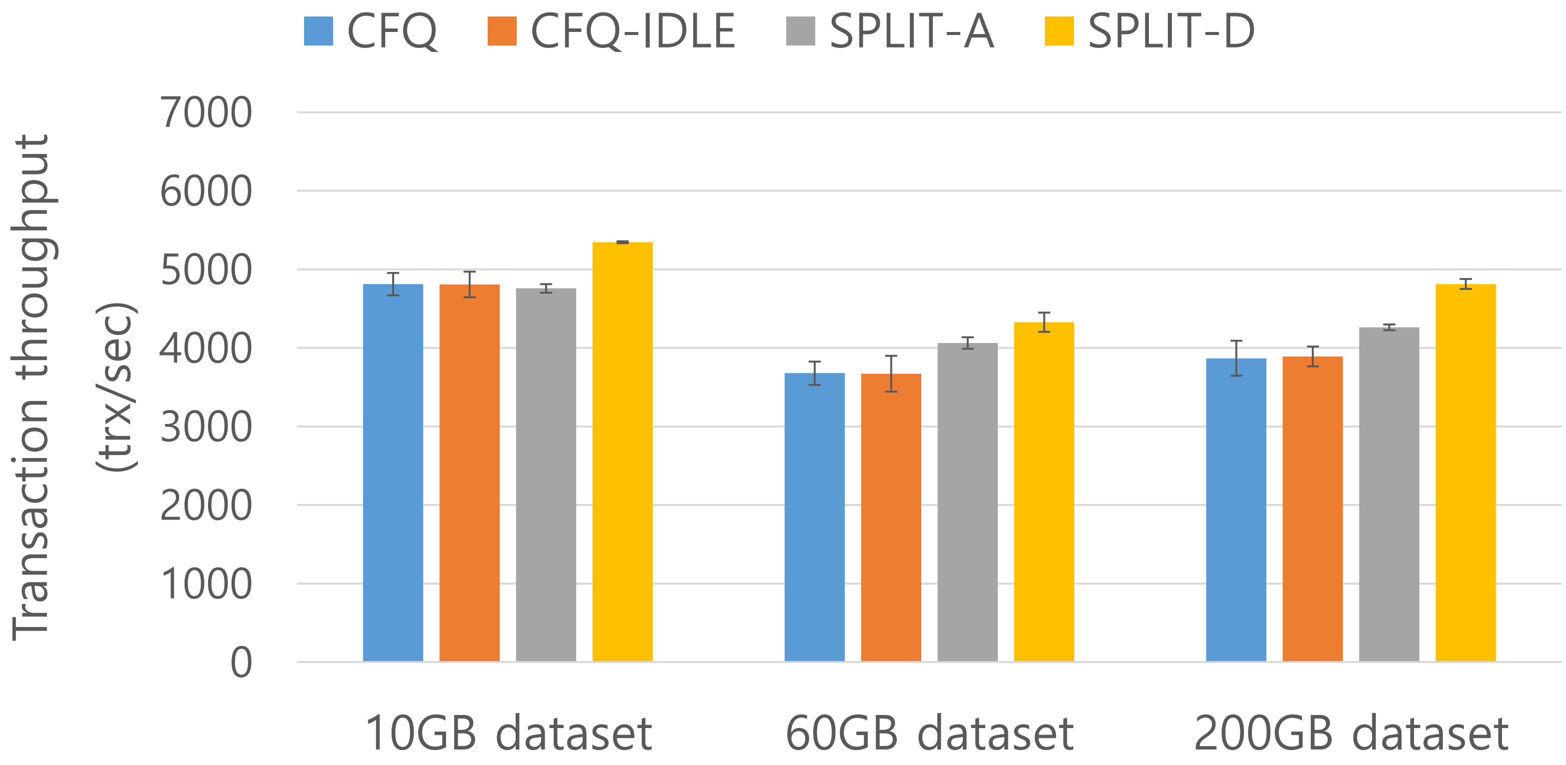

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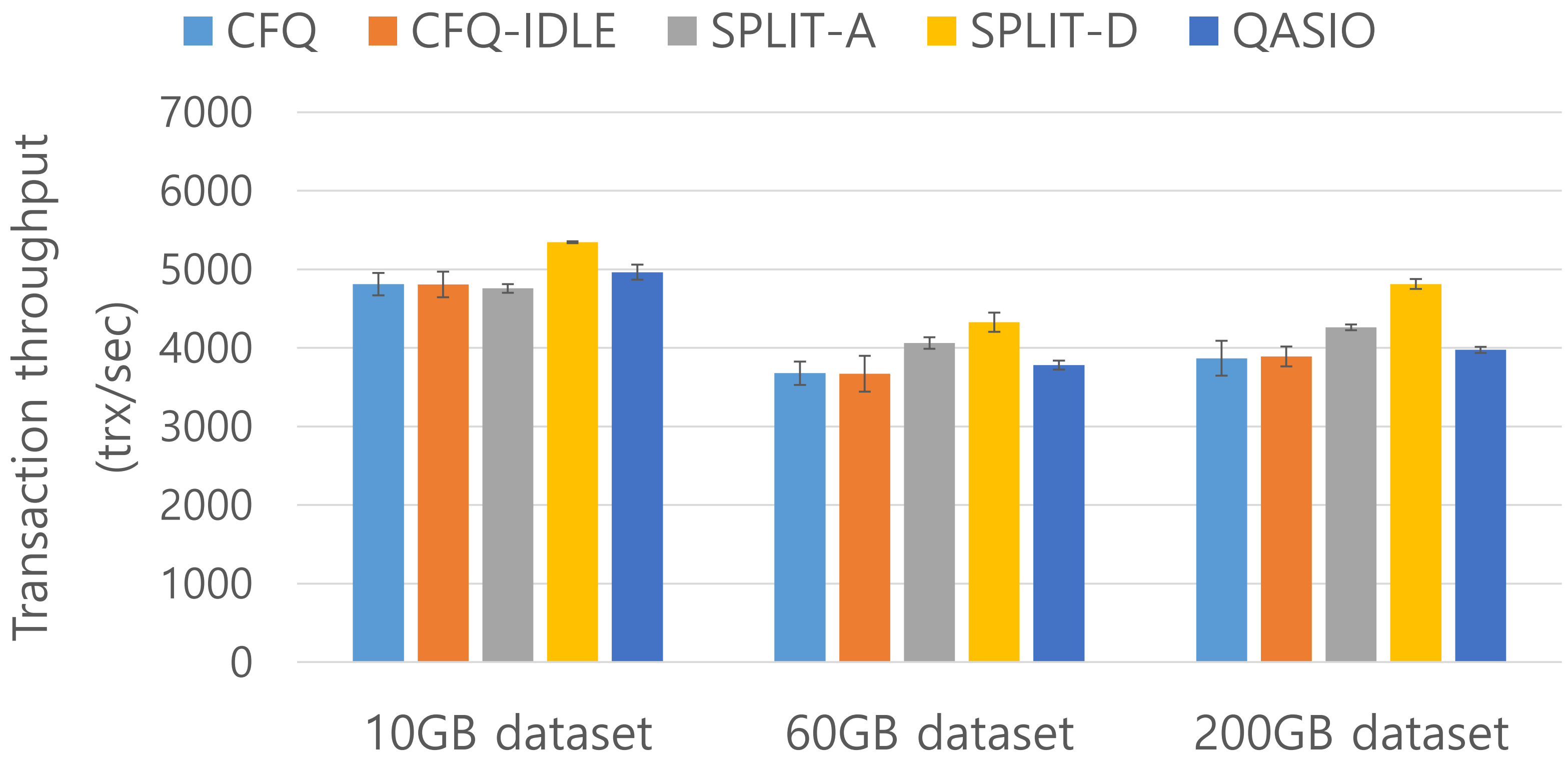

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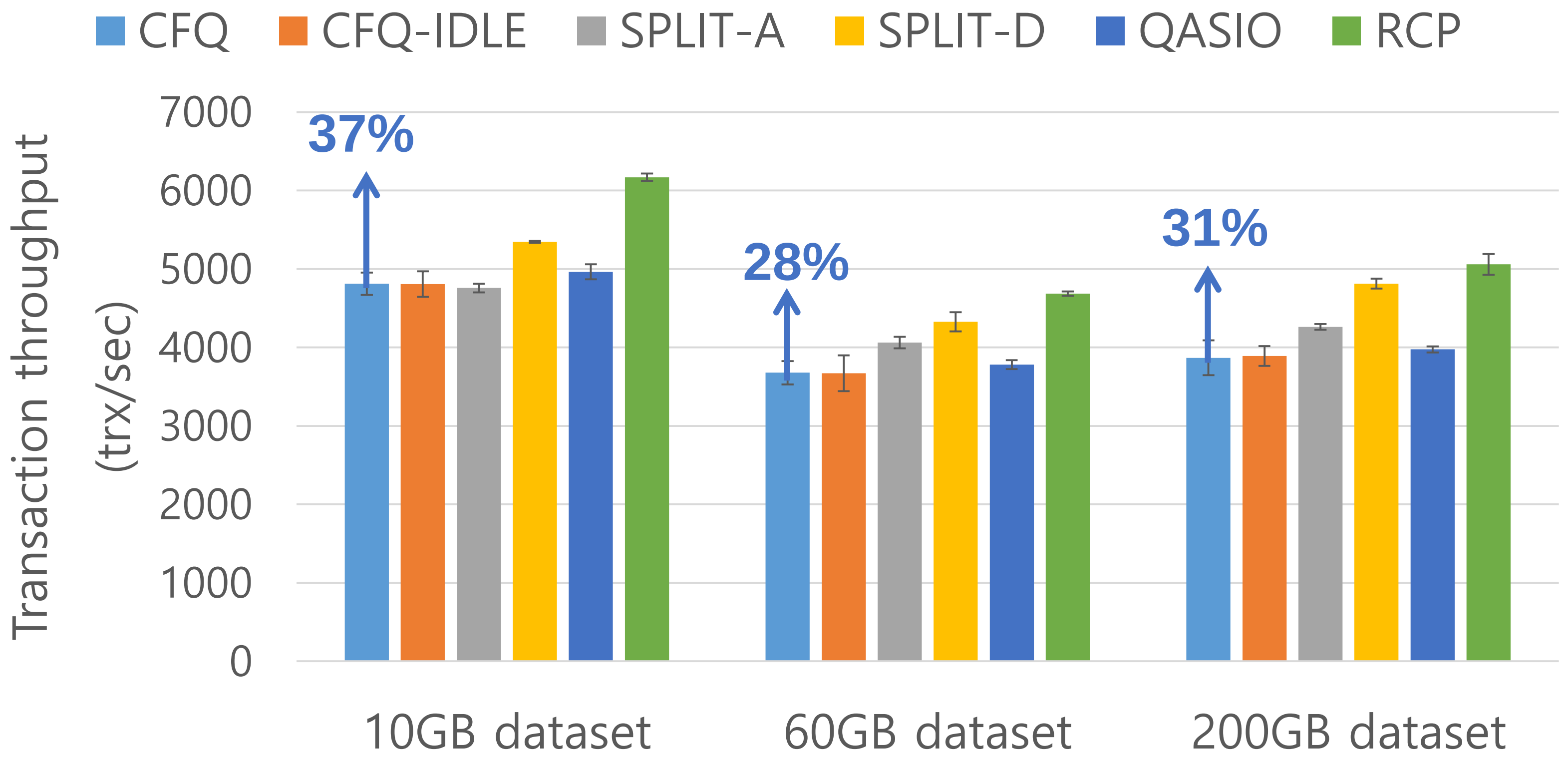

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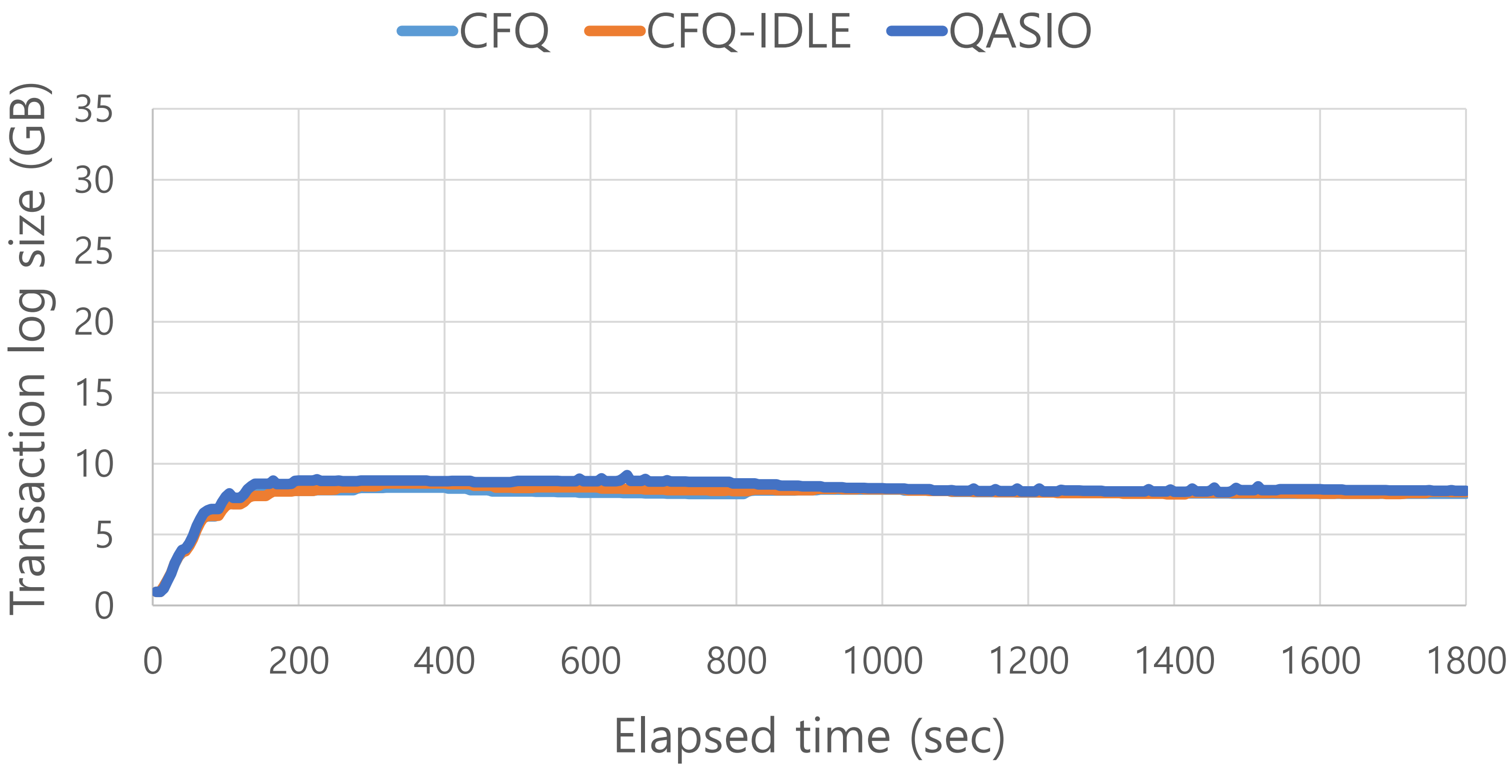
- Impact on background task



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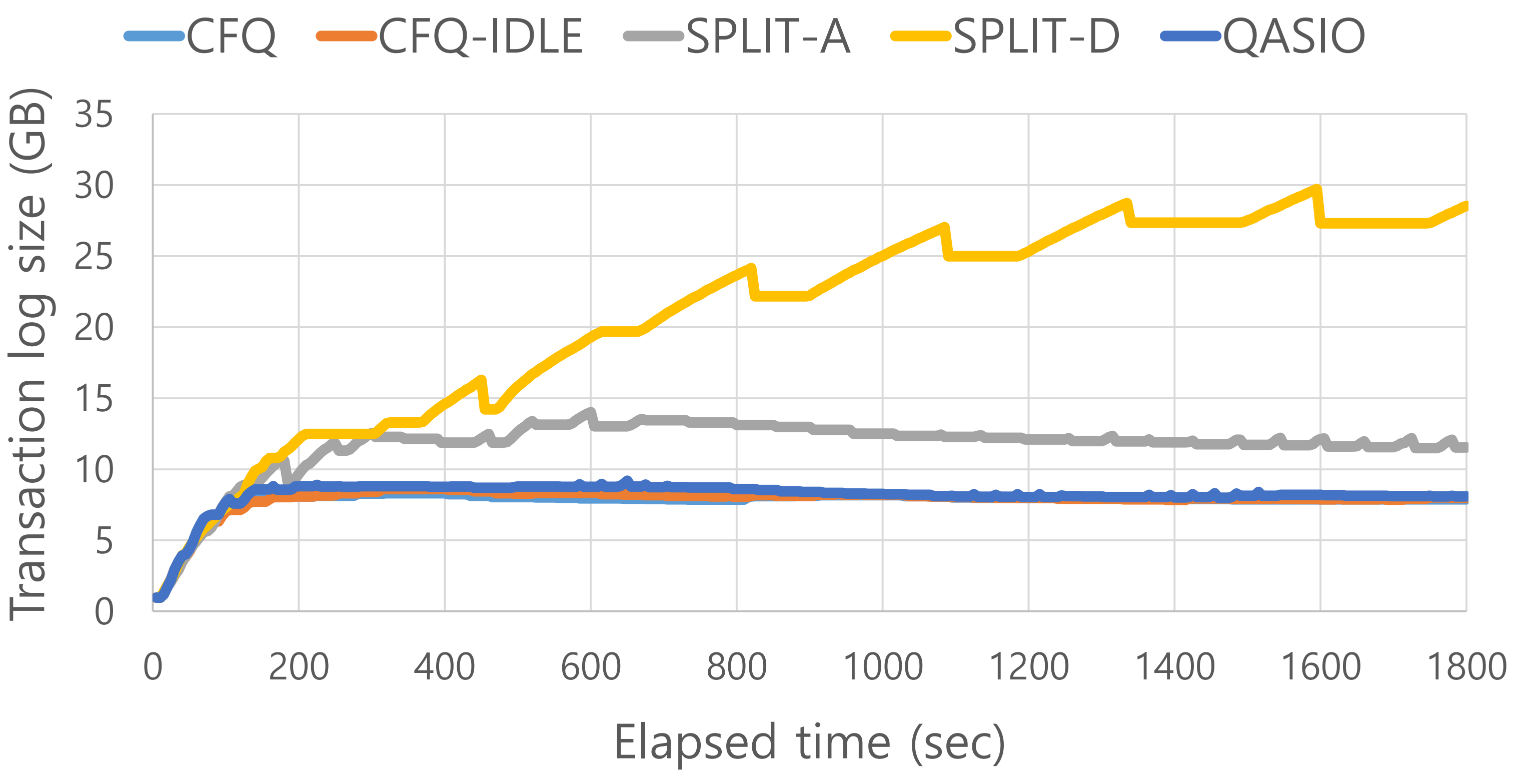

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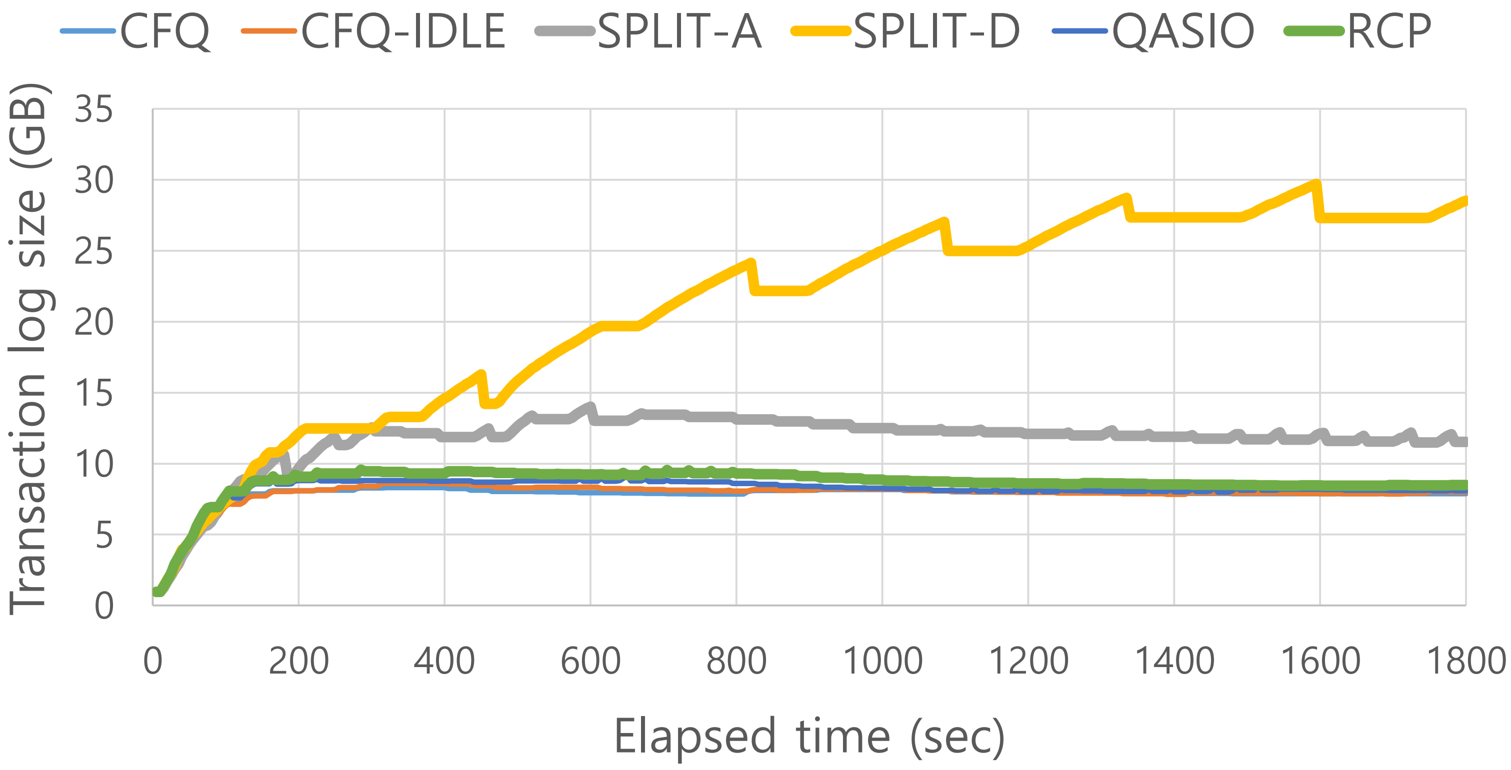
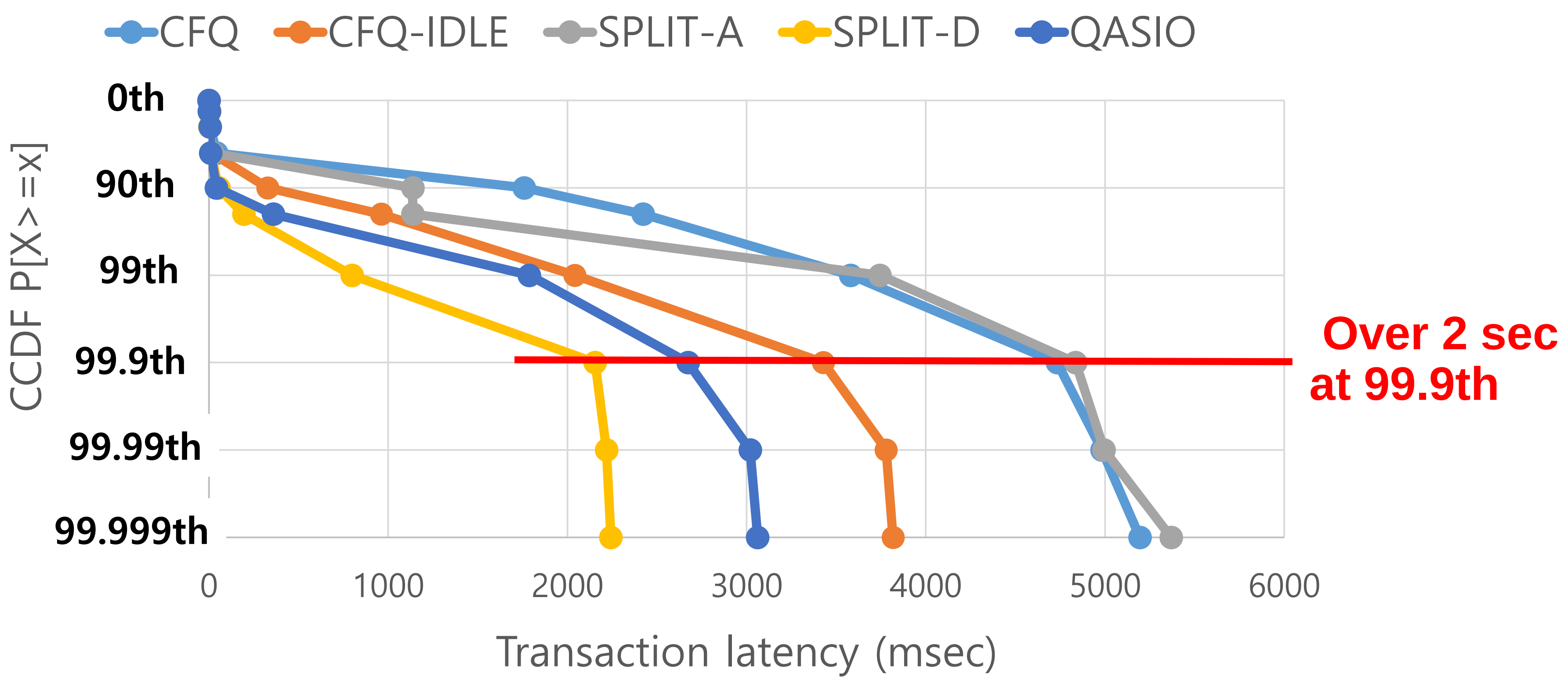


Our scheme improves application throughput w/o penalizing background tasks

Application Latency

- PostgreSQL w/ TPC-C workload



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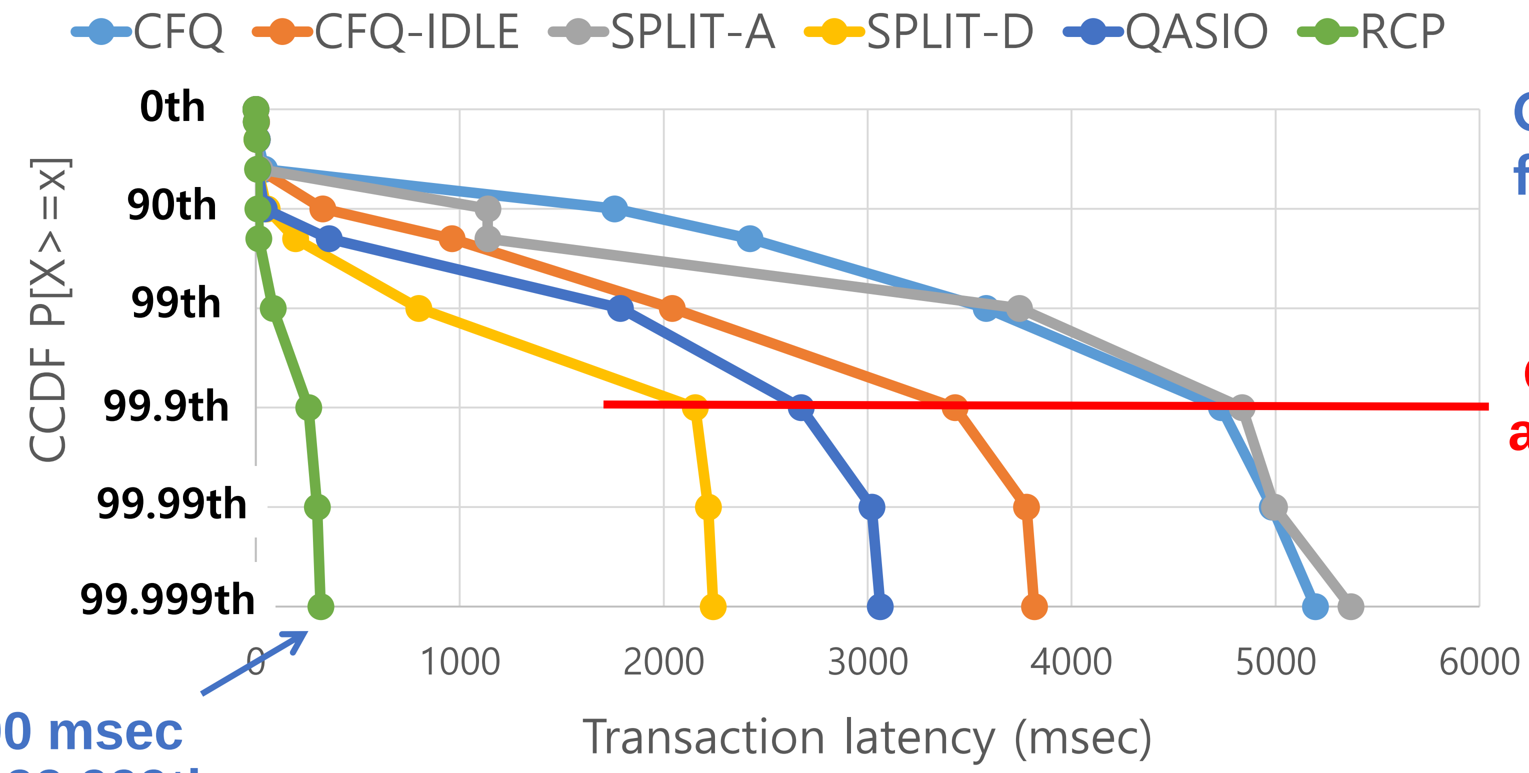

Our scheme is effective for improving tail latency

Over 2 sec at 99.9th

300 msec at 99.999th

Summary of Other Results

- Performance results
  - MongoDB: 12%-201% throughput, 5x-20x latency at 99.9^{th}
  - Redis: 7%-49% throughput, 2x-20x latency at 99.9^{th}

- Analysis results
  - System latency analysis using LatencyTOP
  - System throughput vs. Application latency
  - Need for holistic approach

Conclusions

- Key observation
  - All the layers in the I/O path should be considered as a whole with I/O priority inversion in mind for effective I/O prioritization
- Request-centric I/O prioritization
  - Enlightens the I/O path solely for application performance
  - Improves throughput and latency of real applications
- Ongoing work
  - Practicalizing implementation
  - Applying RCP to database cluster with multiple replicas

Thank You!

- Questions and comments

- Contact
  - sangwook@apposha.io