# Achieving Rapid Response Times in Large Online Services

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# Faster Is Better

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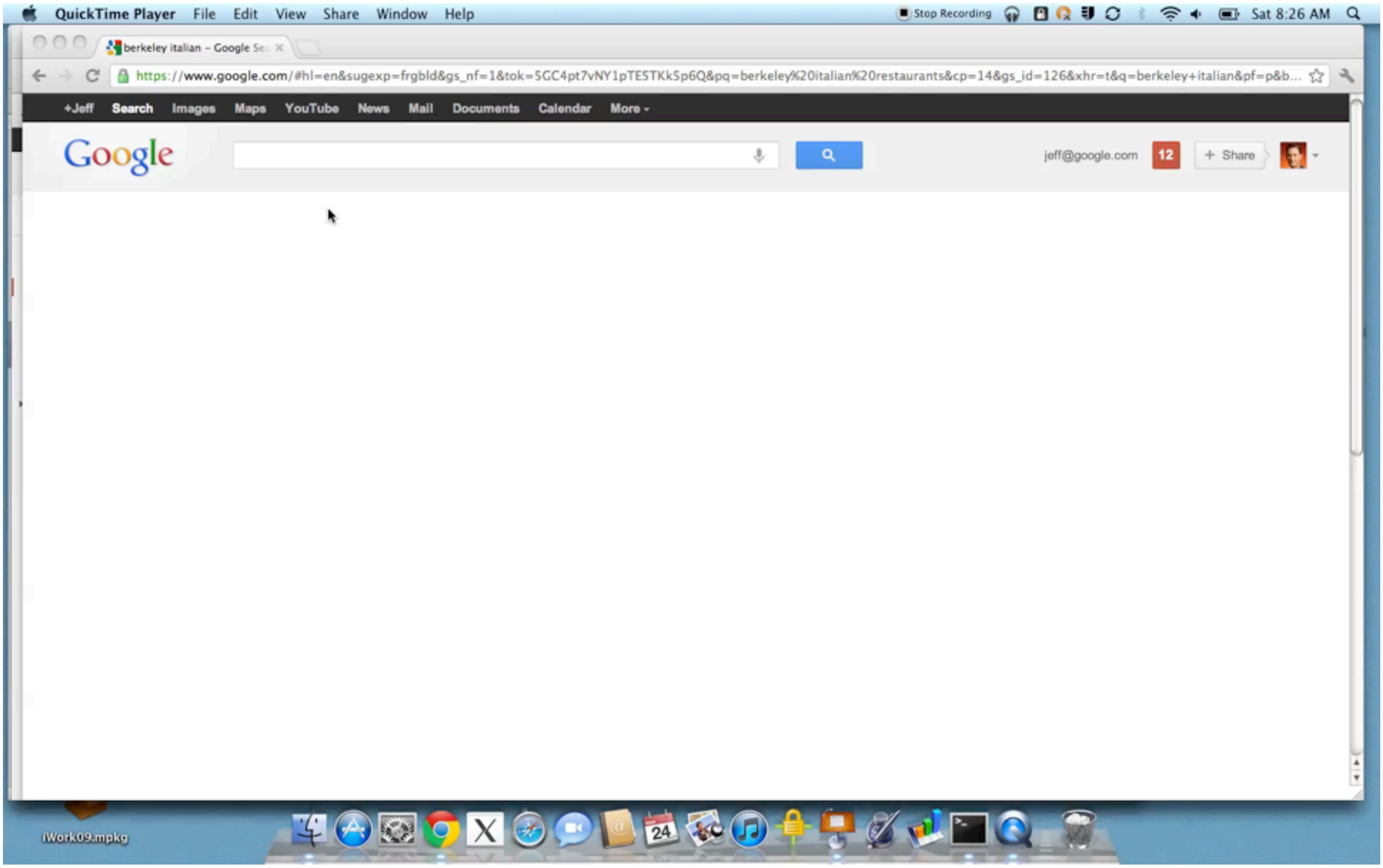
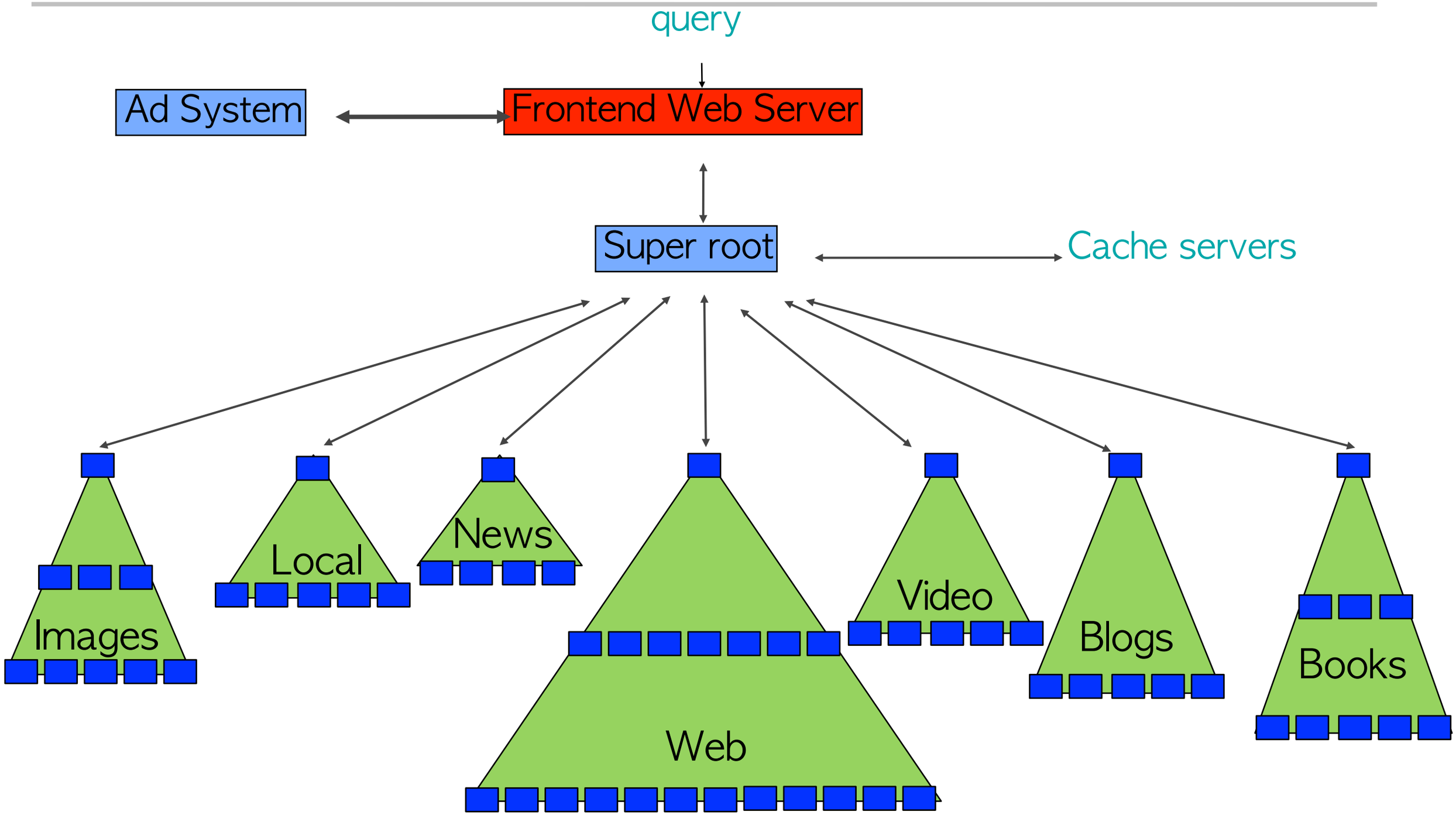


# Large Fanout Services

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# Why Does Fanout Make Things Harder?

- Overall latency ≥ latency of slowest component
  - small blips on individual machines cause delays
  - touching more machines increases likelihood of delays

- Server with 1 ms avg. but 1 sec 99%ile latency
  - touch 1 of these: 1% of requests take ≥1 sec
  - touch 100 of these: 63% of requests take ≥1 sec

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# One Approach: Squash All Variability

- Careful engineering all components of system

- Possible at small scale
  - dedicated resources
  - complete control over whole system
  - careful understanding of all background activities
  - less likely to have hardware fail in bizarre ways

- System changes are difficult
  - software or hardware changes affect delicate balance

Not tenable at large scale: need to share resources

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# Shared Environment

- Huge benefit: greatly increased utilization
- ... but hard to predict effects increase variability
  - network congestion
  - background activities
  - bursts of foreground activity
  - not just your jobs, but everyone else's jobs, too
- Exacerbated by large fanout systems

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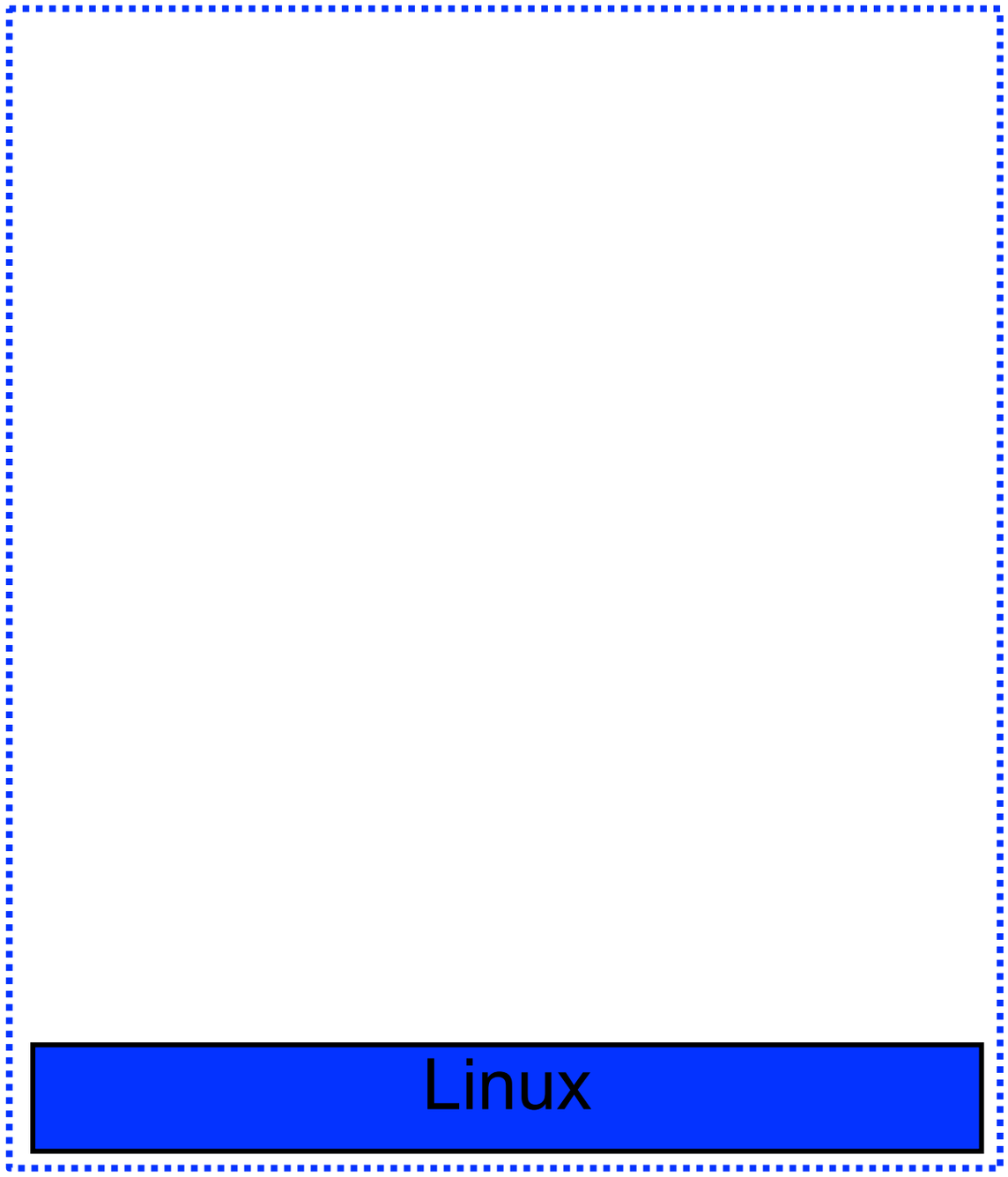

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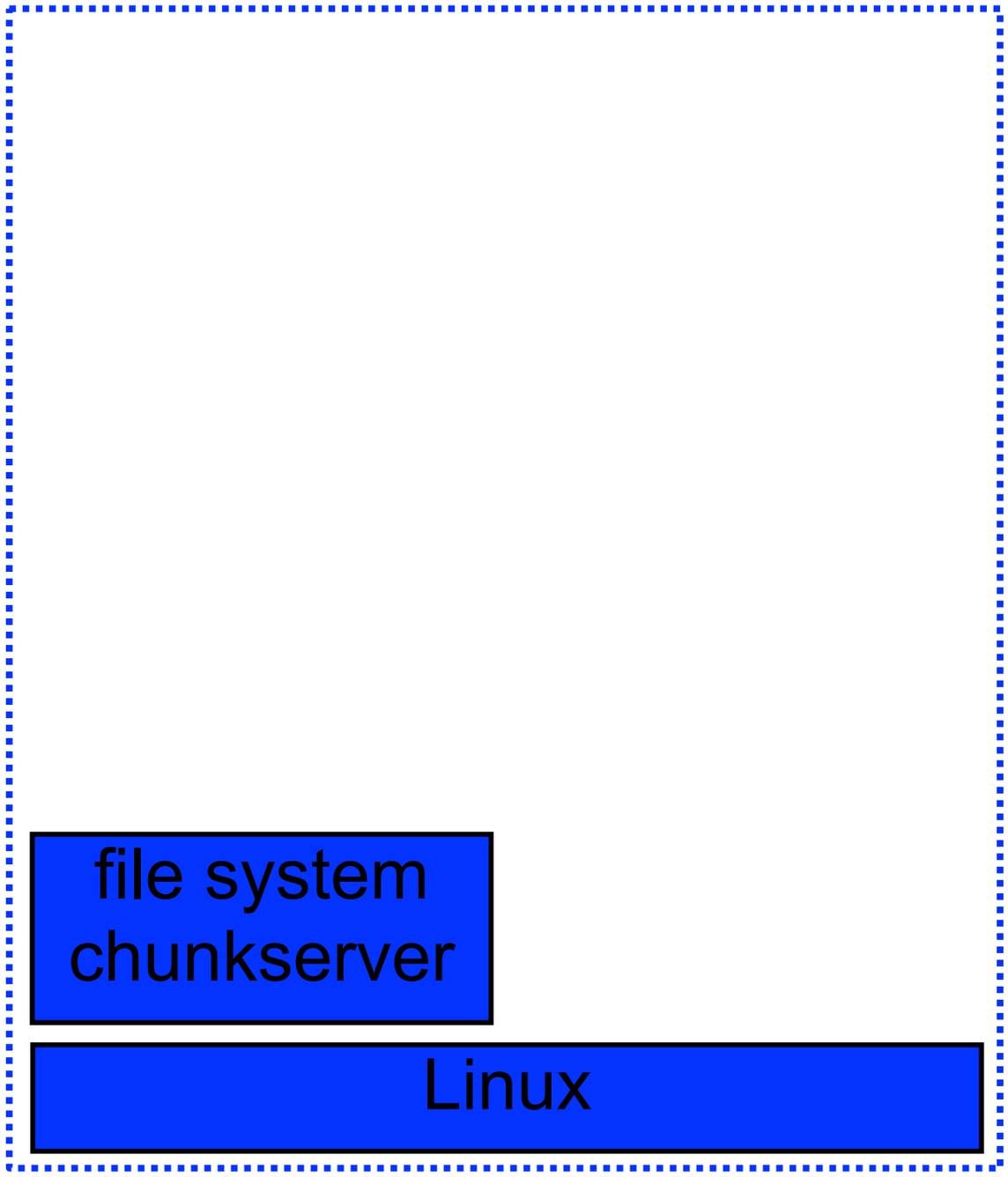


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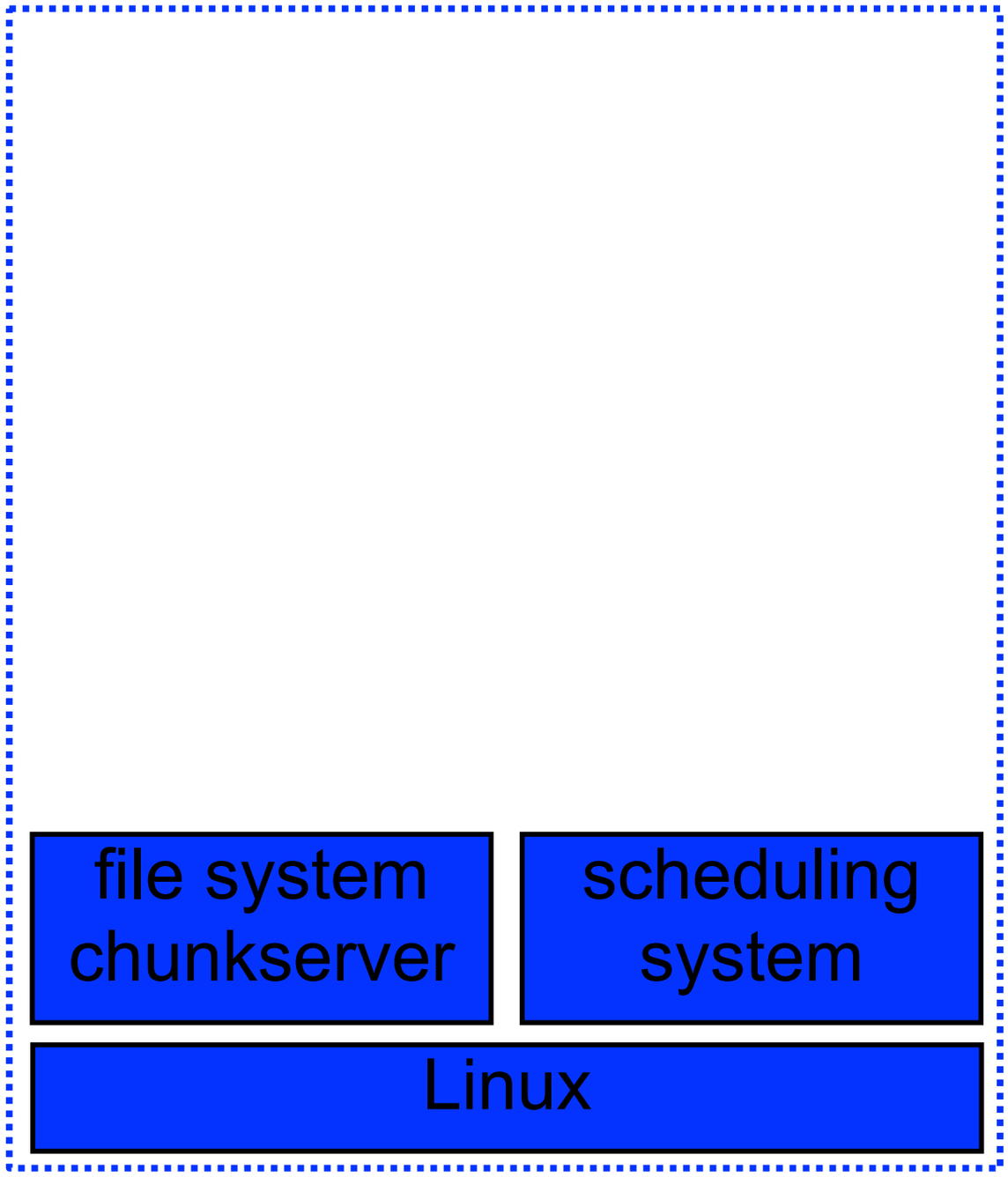


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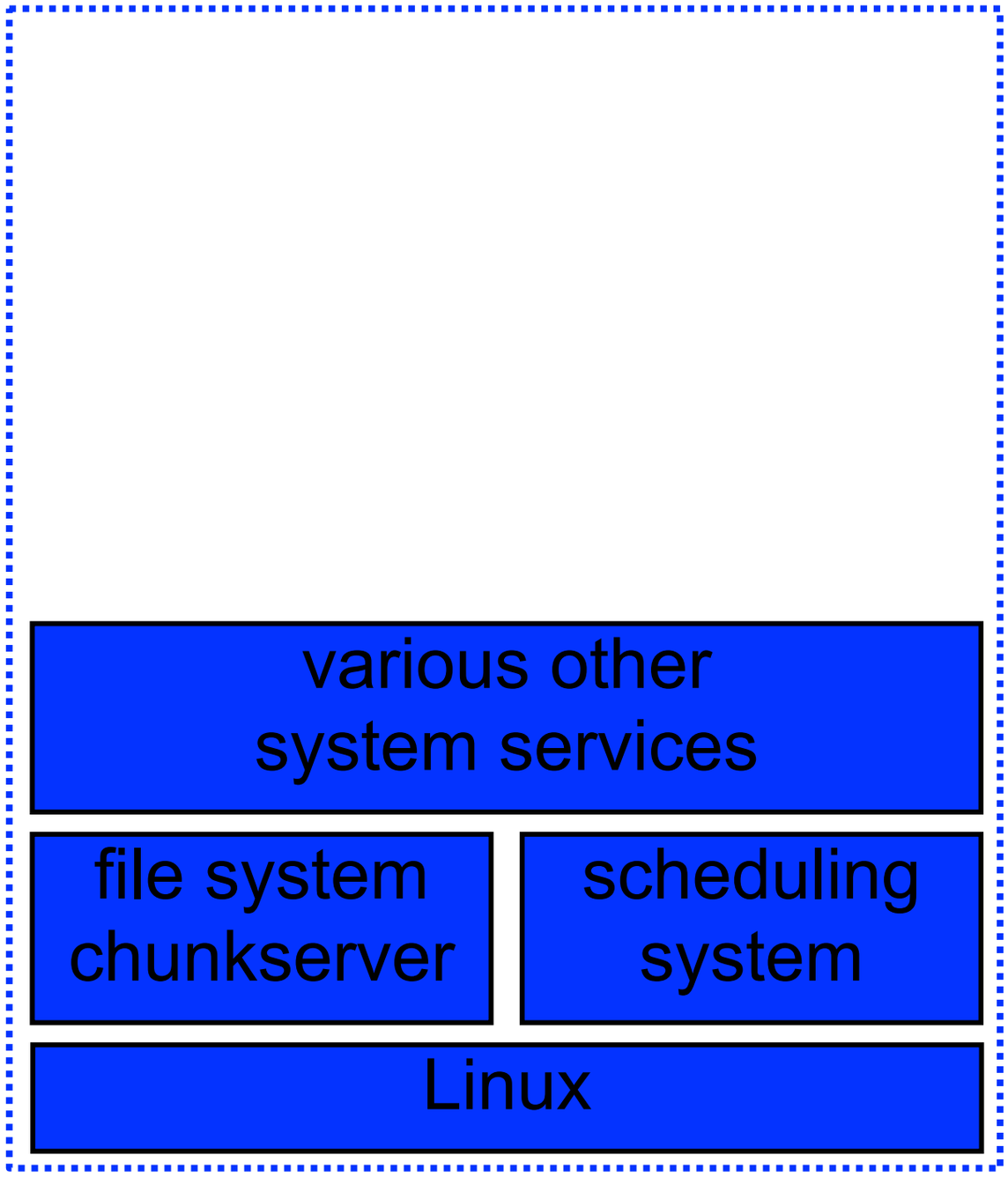


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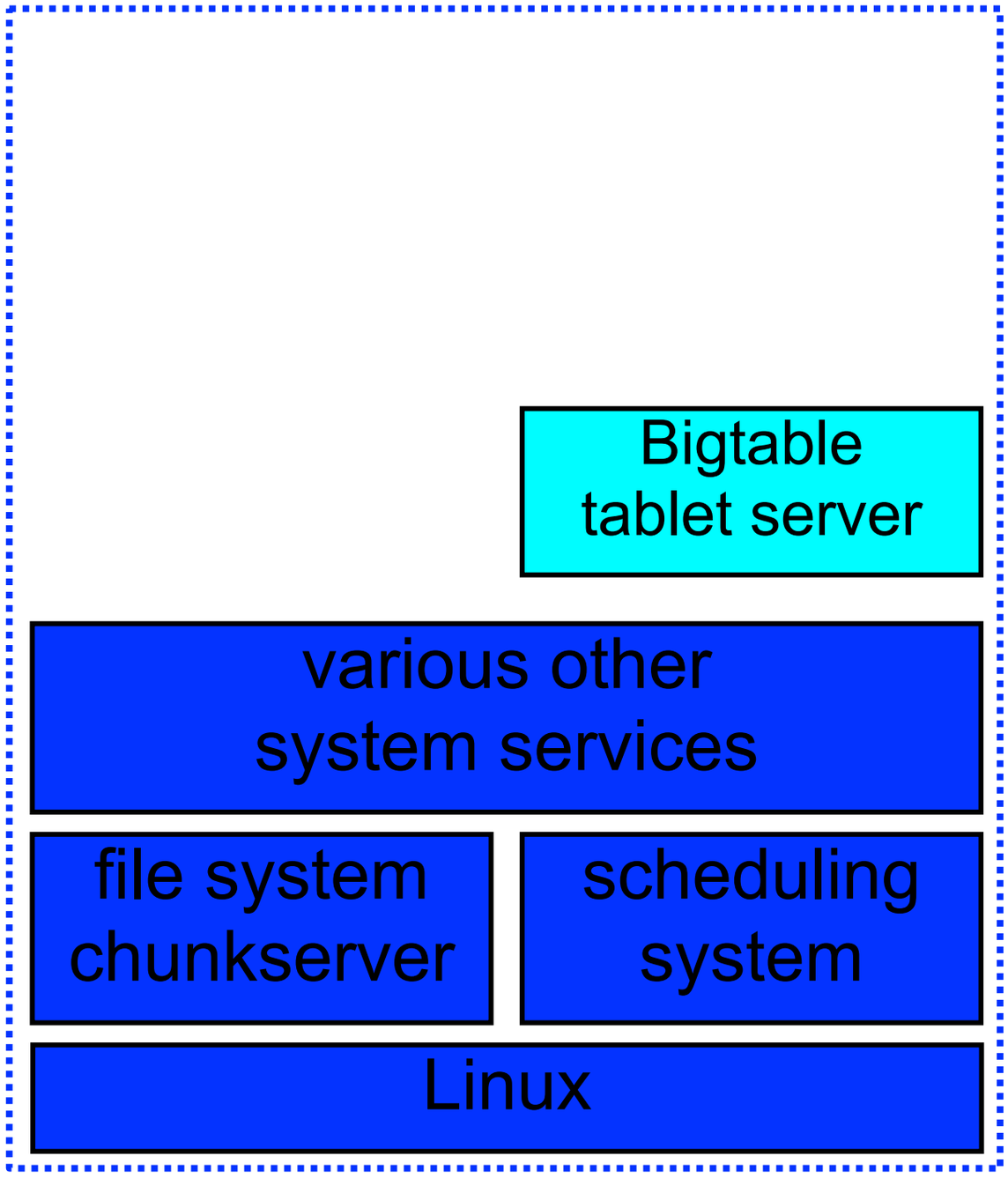


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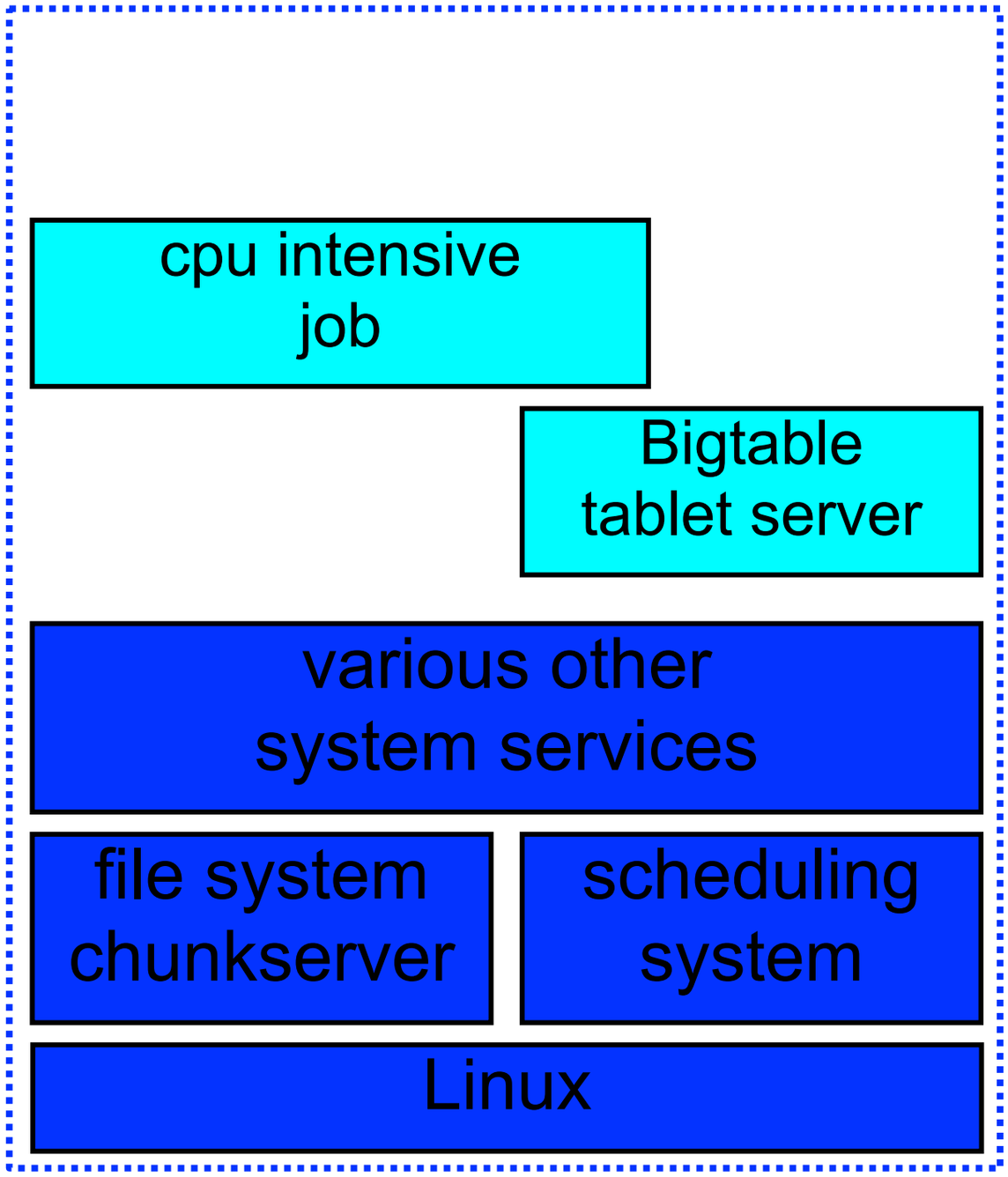


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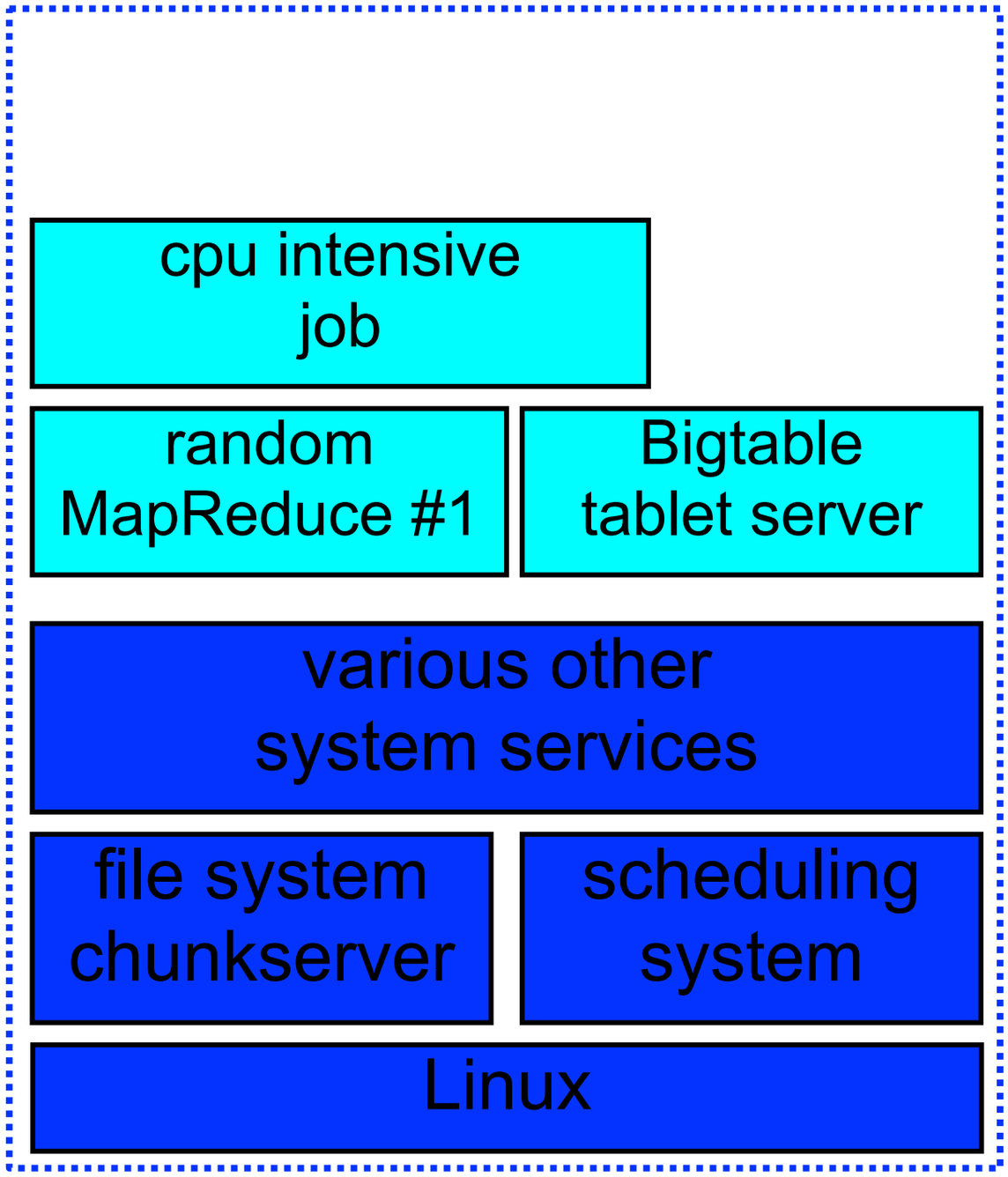


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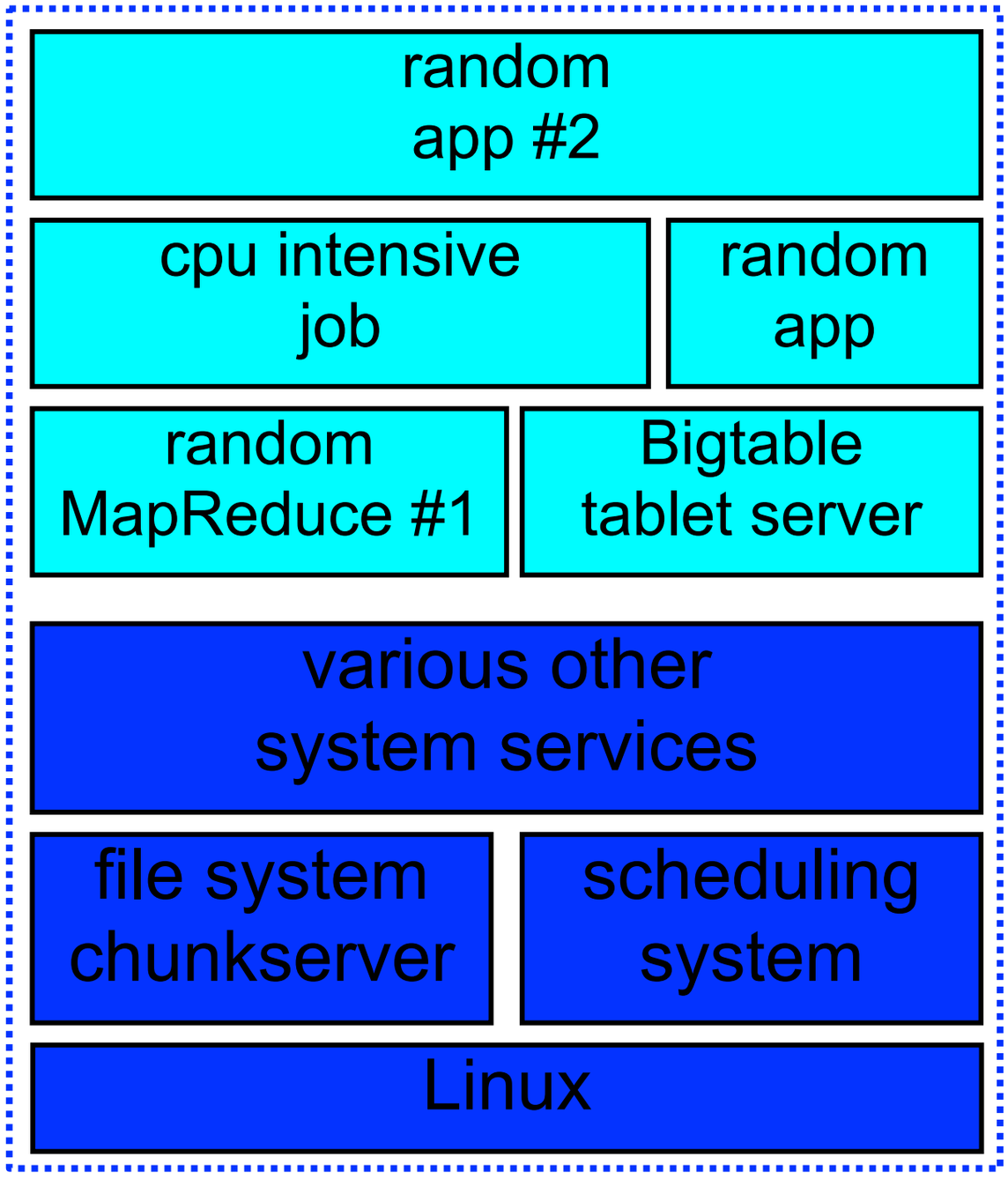

# Basic Latency Reduction Techniques

- Differentiated service classes
  - prioritized request queues in servers
  - prioritized network traffic

- Reduce head-of-line blocking
  - break large requests into sequence of small requests

- Manage expensive background activities
  - e.g. log compaction in distributed storage systems
  - rate limit activity
  - defer expensive activity until load is lower

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# Synchronized Disruption

- Large systems often have background daemons
  - various monitoring and system maintenance tasks
- Initial intuition: randomize when each machine performs these tasks
  - actually a very bad idea for high fanout services
    - at any given moment, at least one or a few machines are slow
- Better to actually synchronize the disruptions
  - run every five minutes “on the dot”
  - one synchronized blip better than unsynchronized

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# Tolerating Faults vs. Tolerating Variability

- Tolerating faults:
  - rely on extra resources
    - RAIDed disks, ECC memory, dist. system components, etc.
  - ***make a reliable whole out of unreliable parts***

- Tolerating variability:
  - use these same extra resources
  - ***make a predictable whole out of unpredictable parts***

- Times scales are very different:
  - variability: 1000s of disruptions/sec, scale of **milliseconds**
  - faults: 10s of failures per day, scale of **tens of seconds**

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# Latency Tolerating Techniques

- Cross request adaptation
  - examine recent behavior
  - take action to improve latency of future requests
  - typically relate to balancing load across set of servers
  - time scale: 10s of seconds to minutes

- Within request adaptation
  - cope with slow subsystems in context of higher level request
  - time scale: right now, while user is waiting

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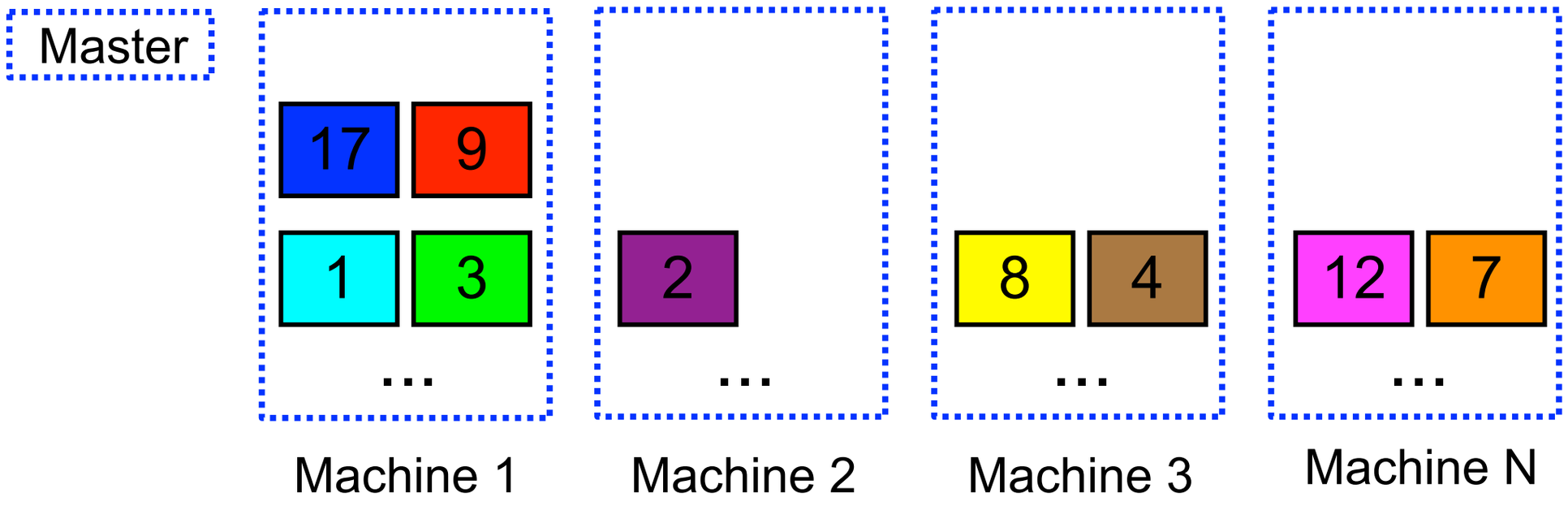
# Fine-Grained Dynamic Partitioning

- Partition large datasets/computations
  - more than 1 partition per machine (often 10-100/machine)
  - e.g. BigTable, query serving systems, GFS, ...

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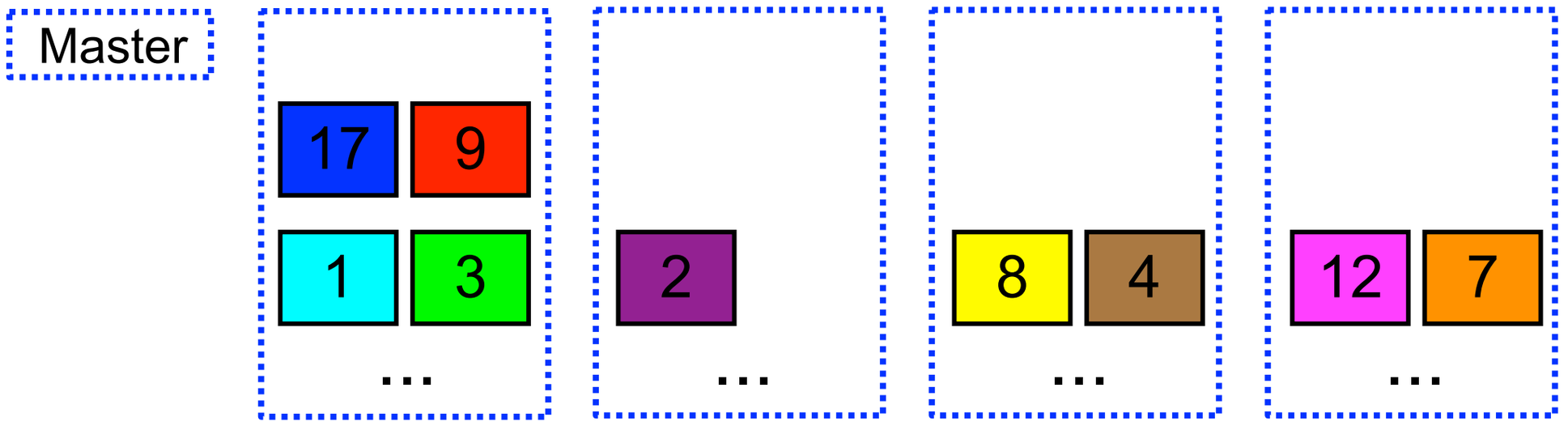
# Load Balancing

- Can shed load in few percent increments
  - prioritize shifting load when imbalance is more severe

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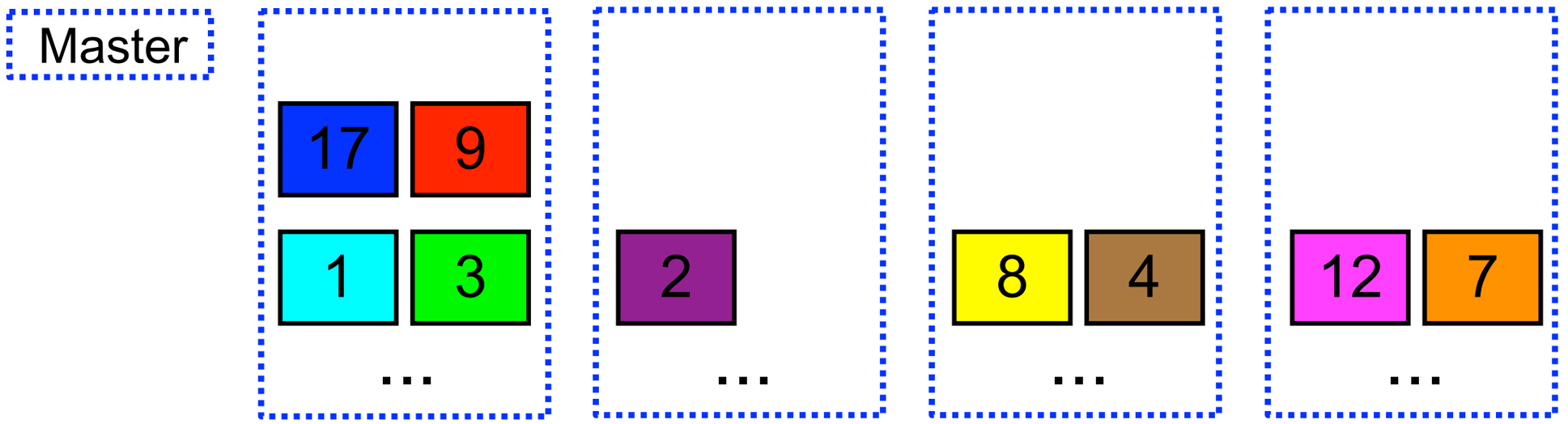


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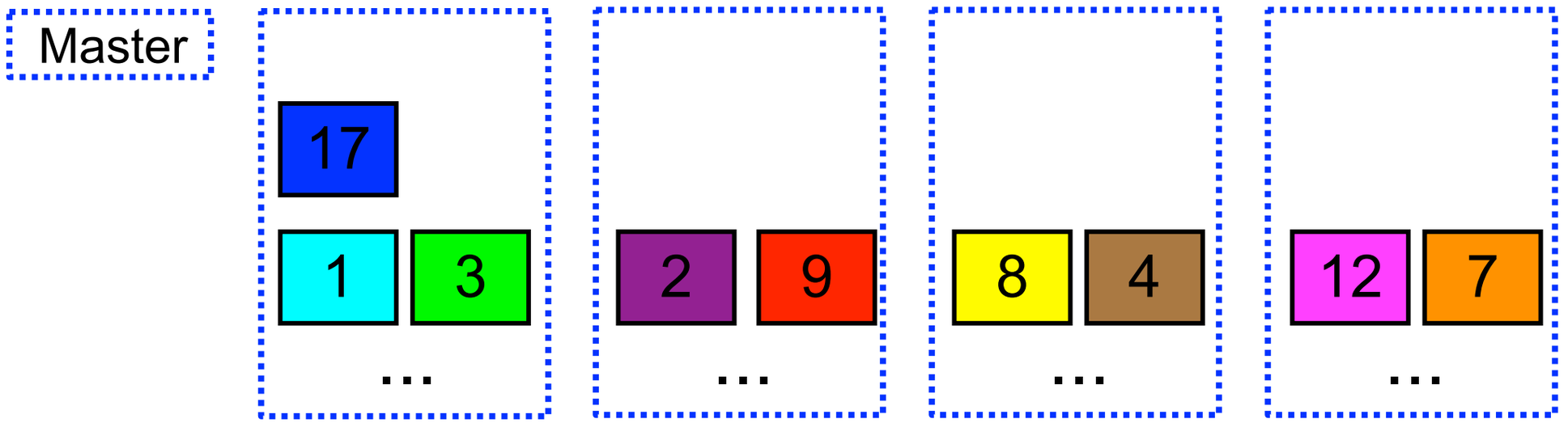


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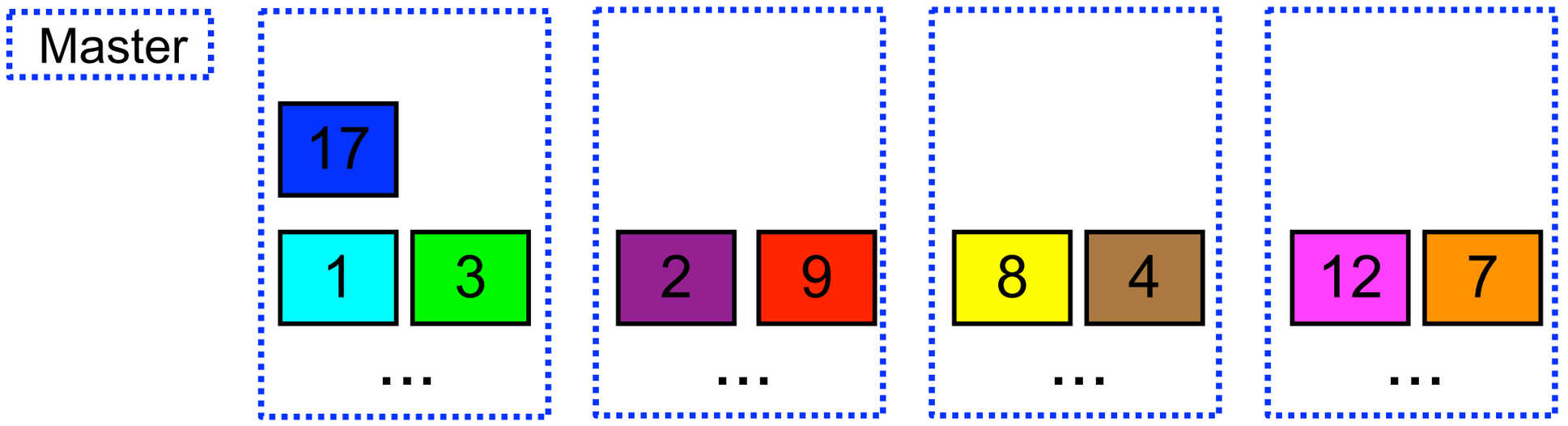


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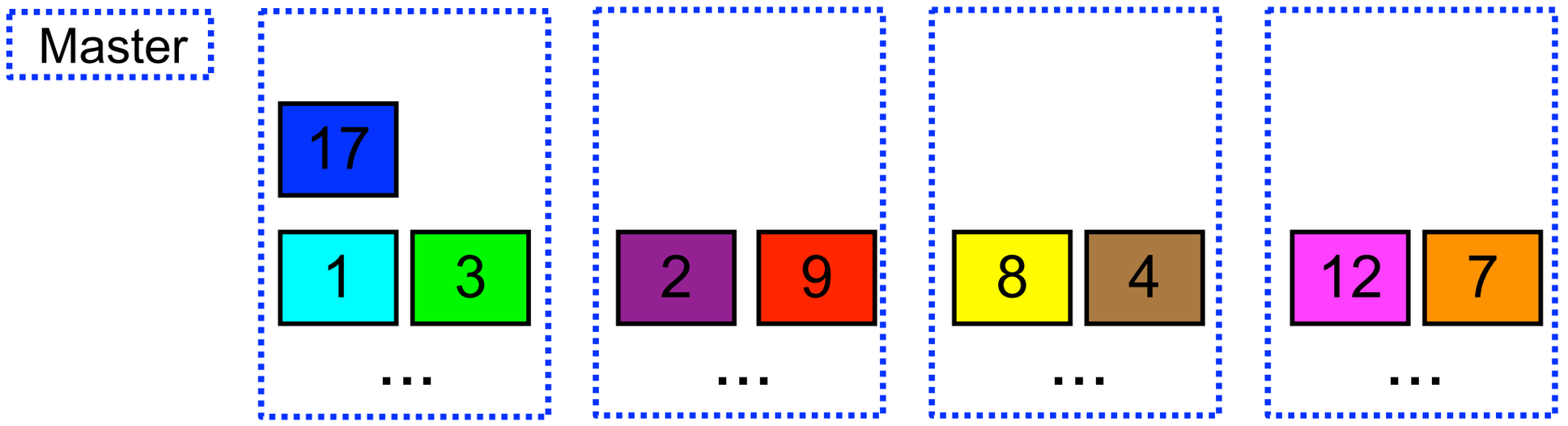
# Speeds Failure Recovery

- Many machines each recover one or a few partition
  - e.g. BigTable tablets, GFS chunks, query serving shards

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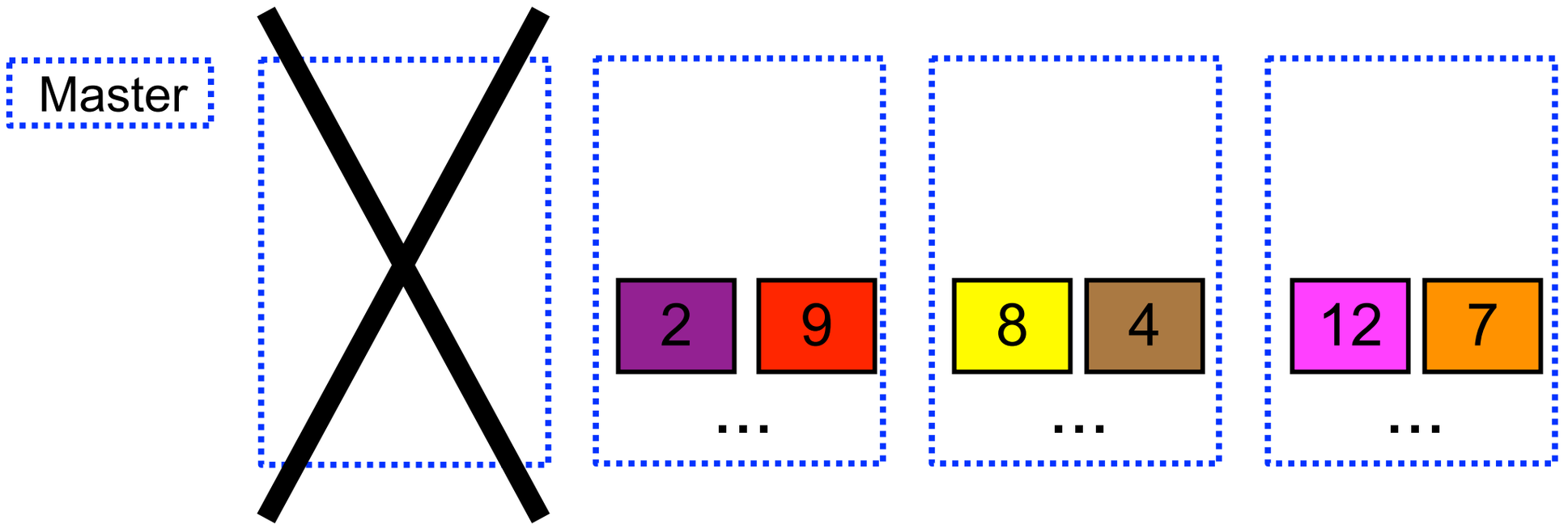


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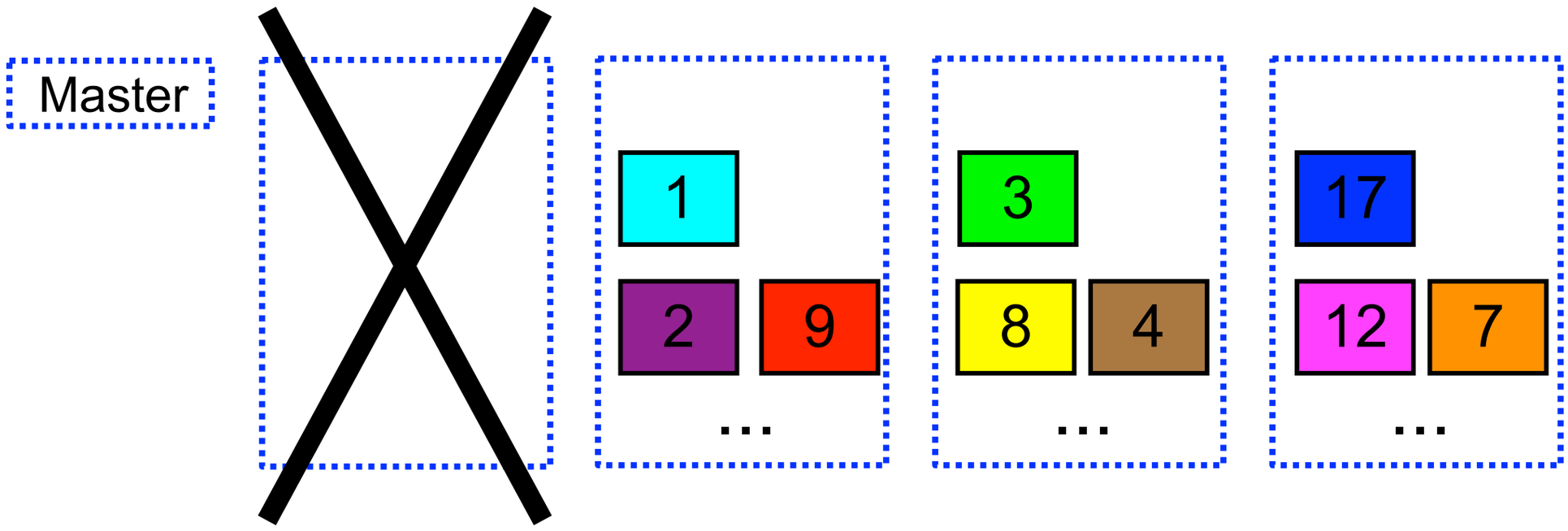


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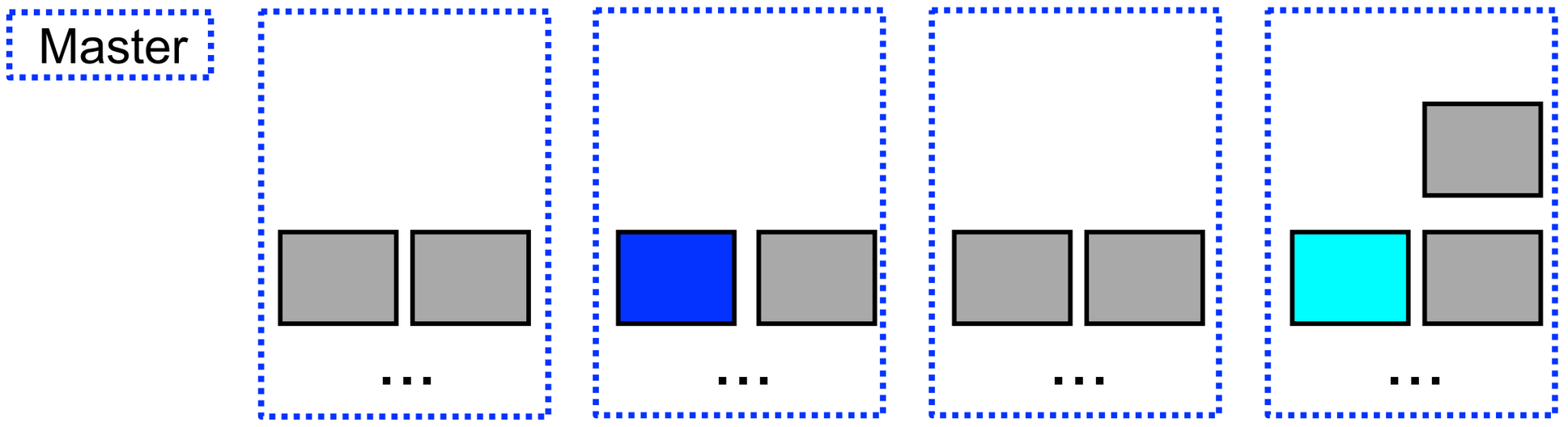
# Selective Replication

- Find heavily used items and make more replicas
  - can be static or dynamic
- Example: Query serving system
  - static: more replicas of important docs
  - dynamic: more replicas of Chinese documents as Chinese query load increases

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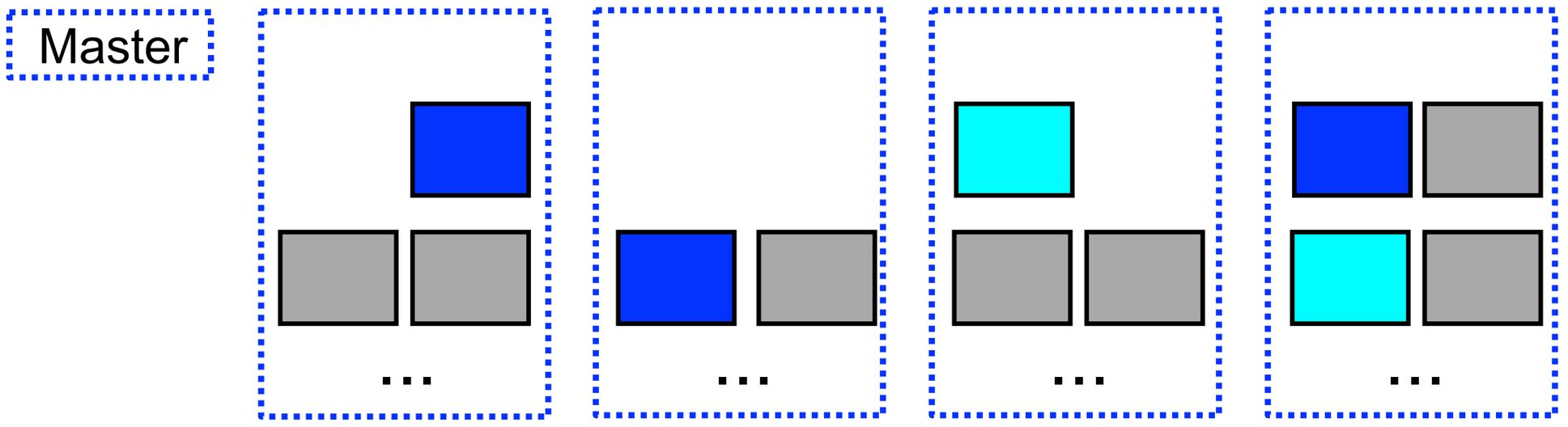


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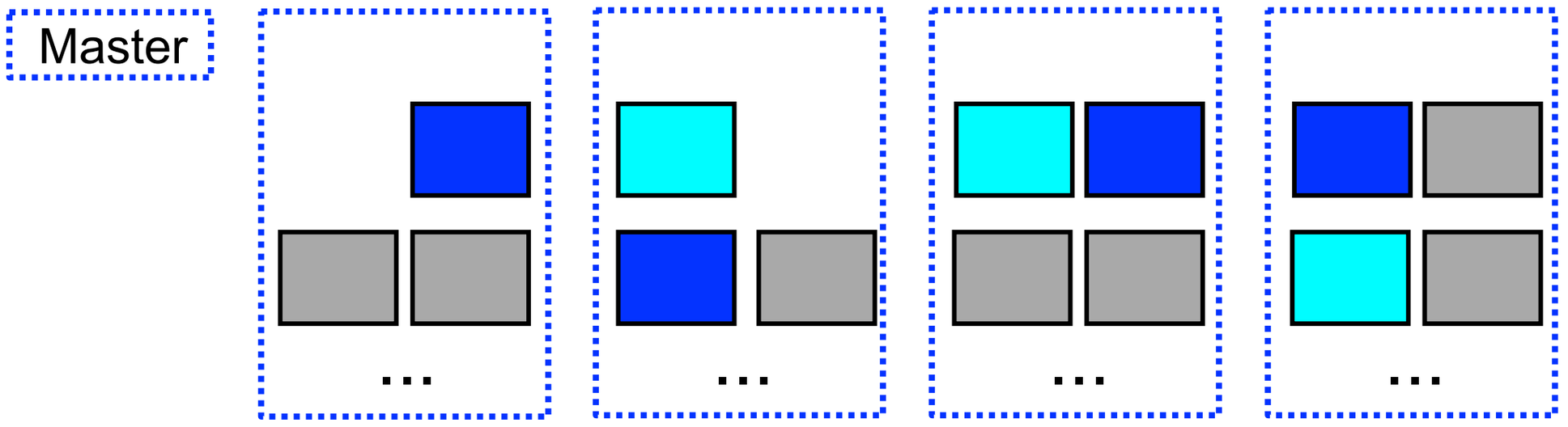


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# Latency-Induced Probation

- Servers sometimes become slow to respond
  - could be data dependent, but...
  - often due to interference effects
    - e.g. CPU or network spike for other jobs running on shared server
- Non-intuitive: remove capacity under load to improve latency (?!)
- Initiate corrective action
  - e.g. make copies of partitions on other servers
  - continue sending shadow stream of requests to server
    - keep measuring latency
    - return to service when latency back down for long enough

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# Handling Within-Request Variability

- Take action within single high-level request

- Goals:
  - reduce overall latency
  - don't increase resource use too much
  - keep serving systems safe

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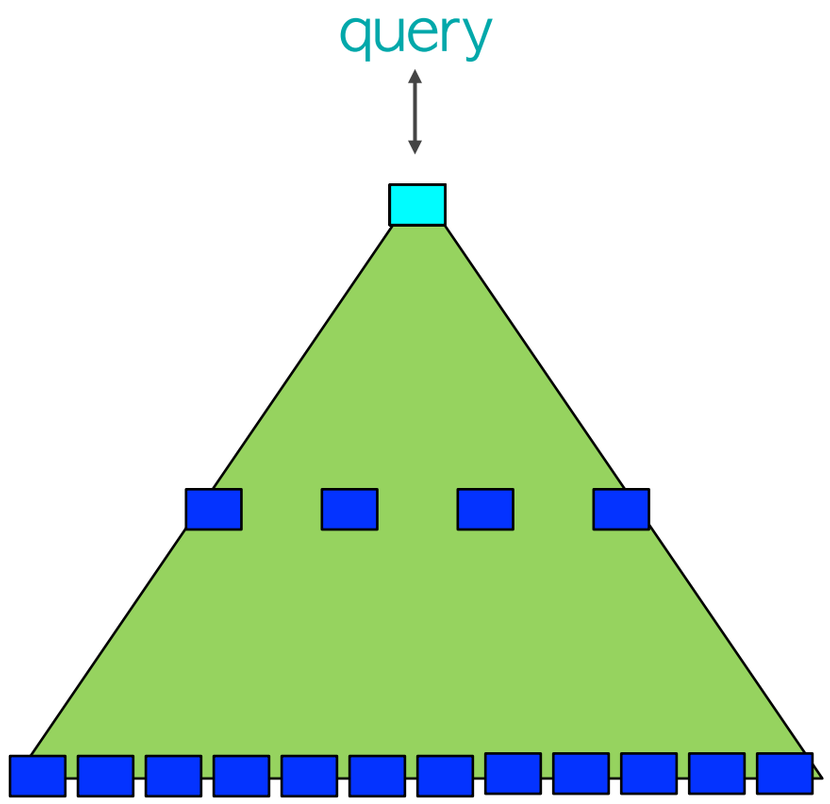
# Data Independent Failures



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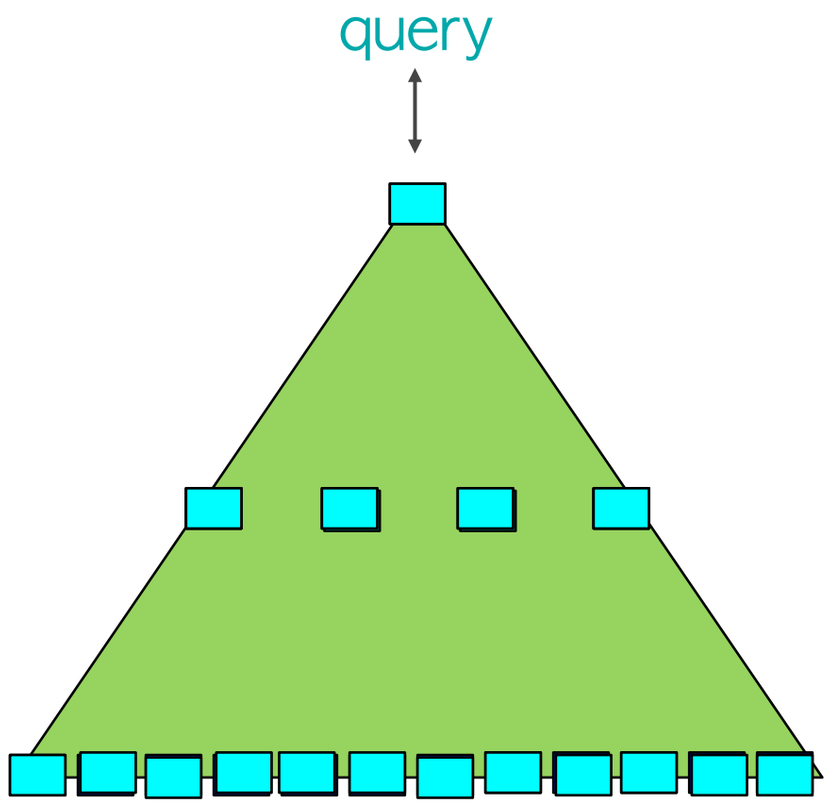

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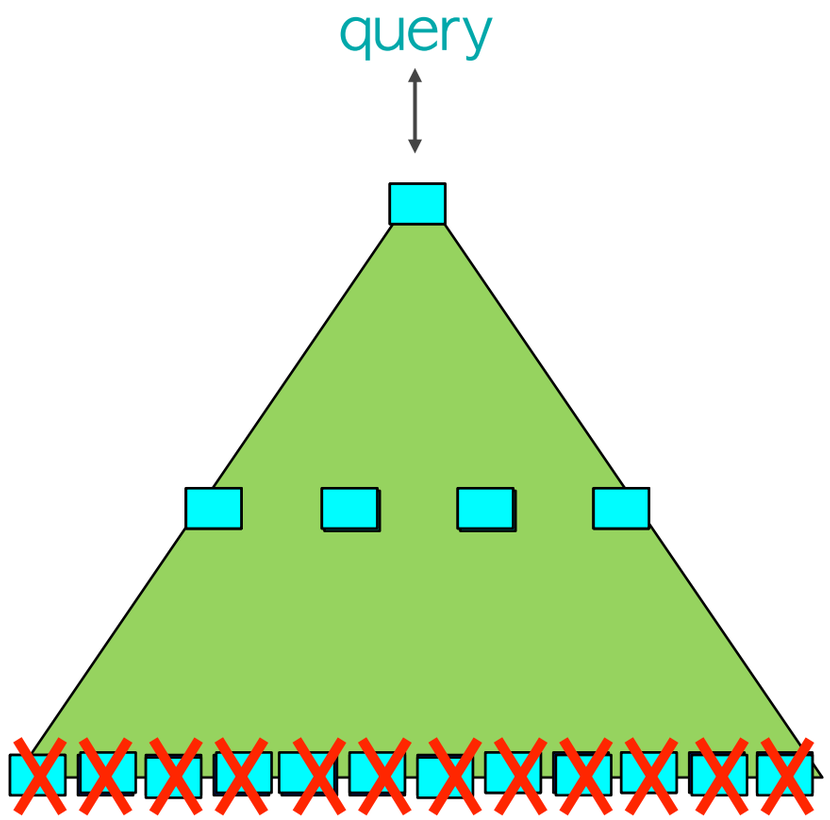


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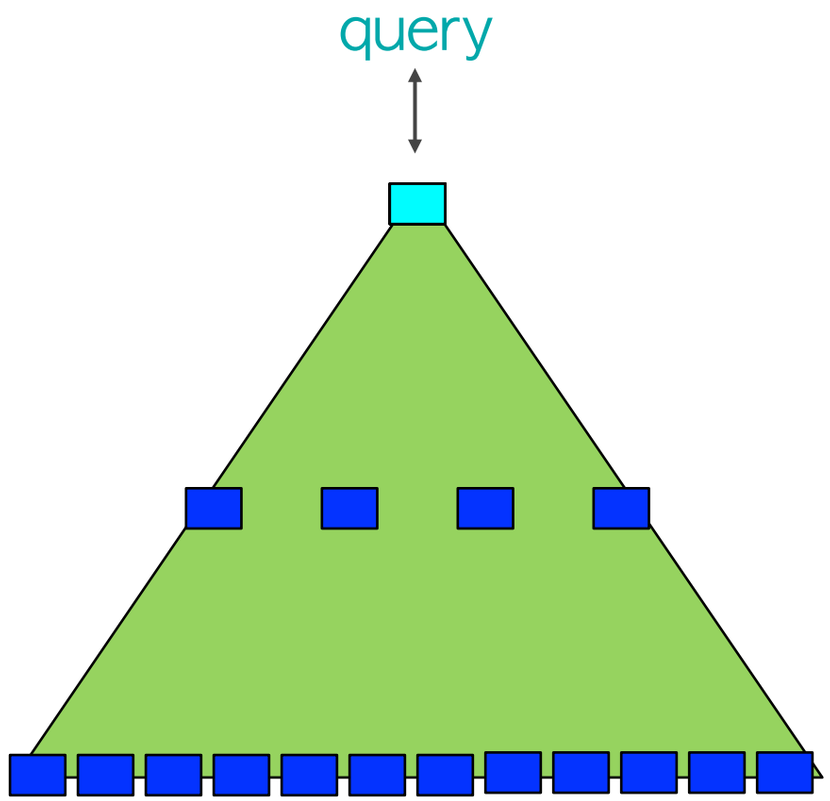

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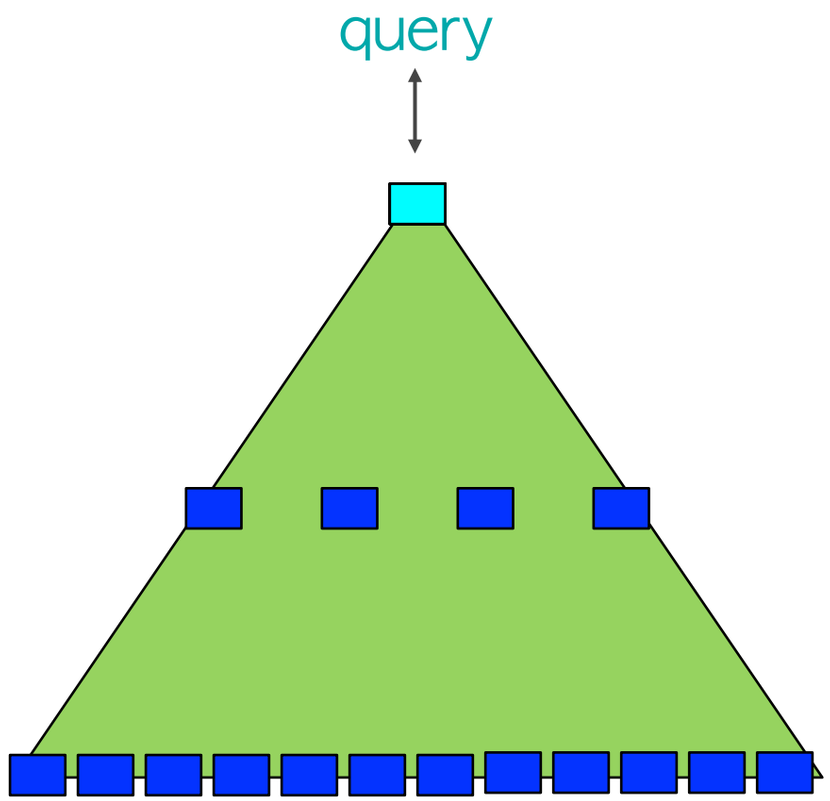

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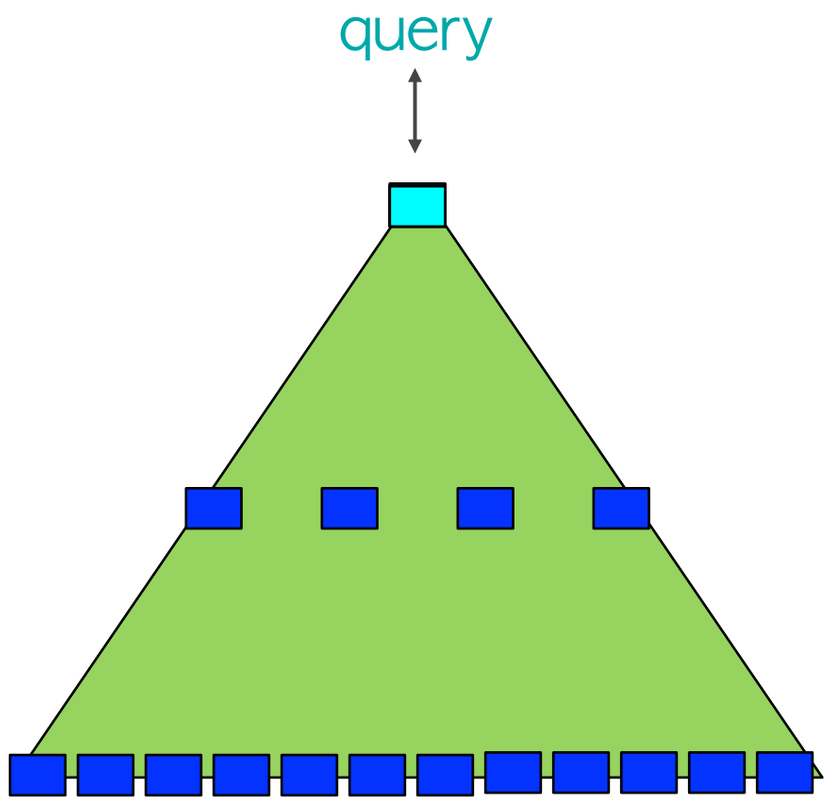

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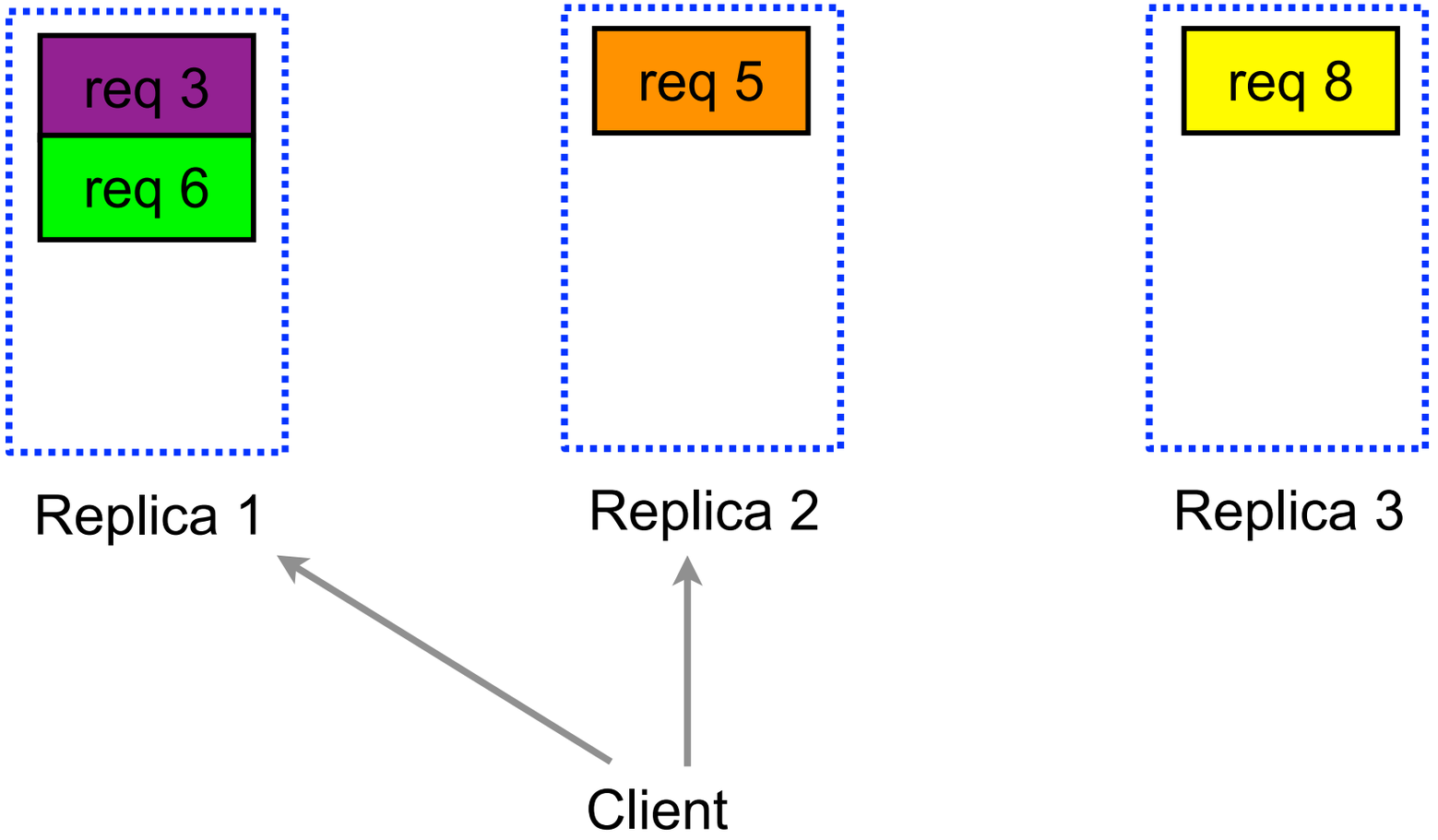

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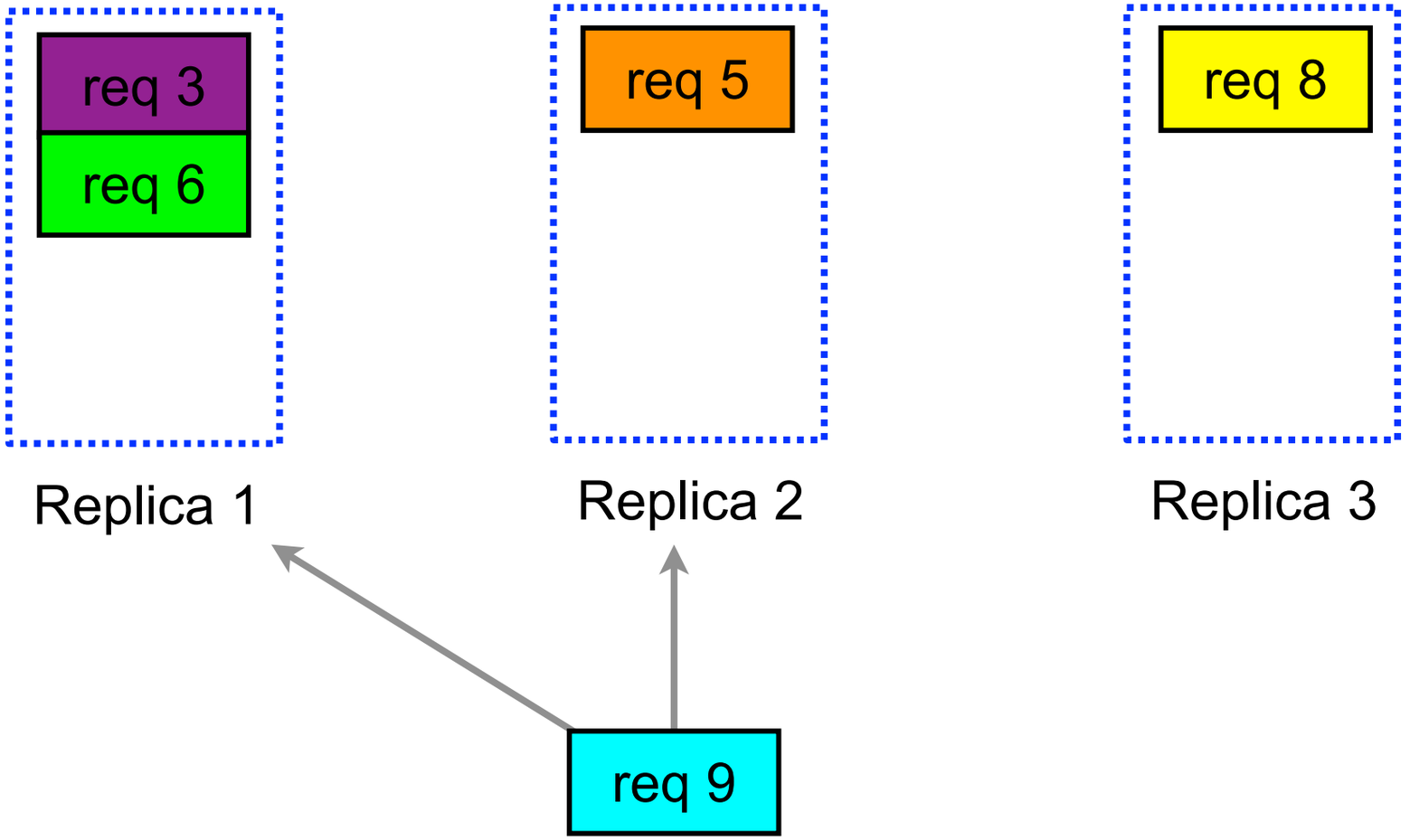


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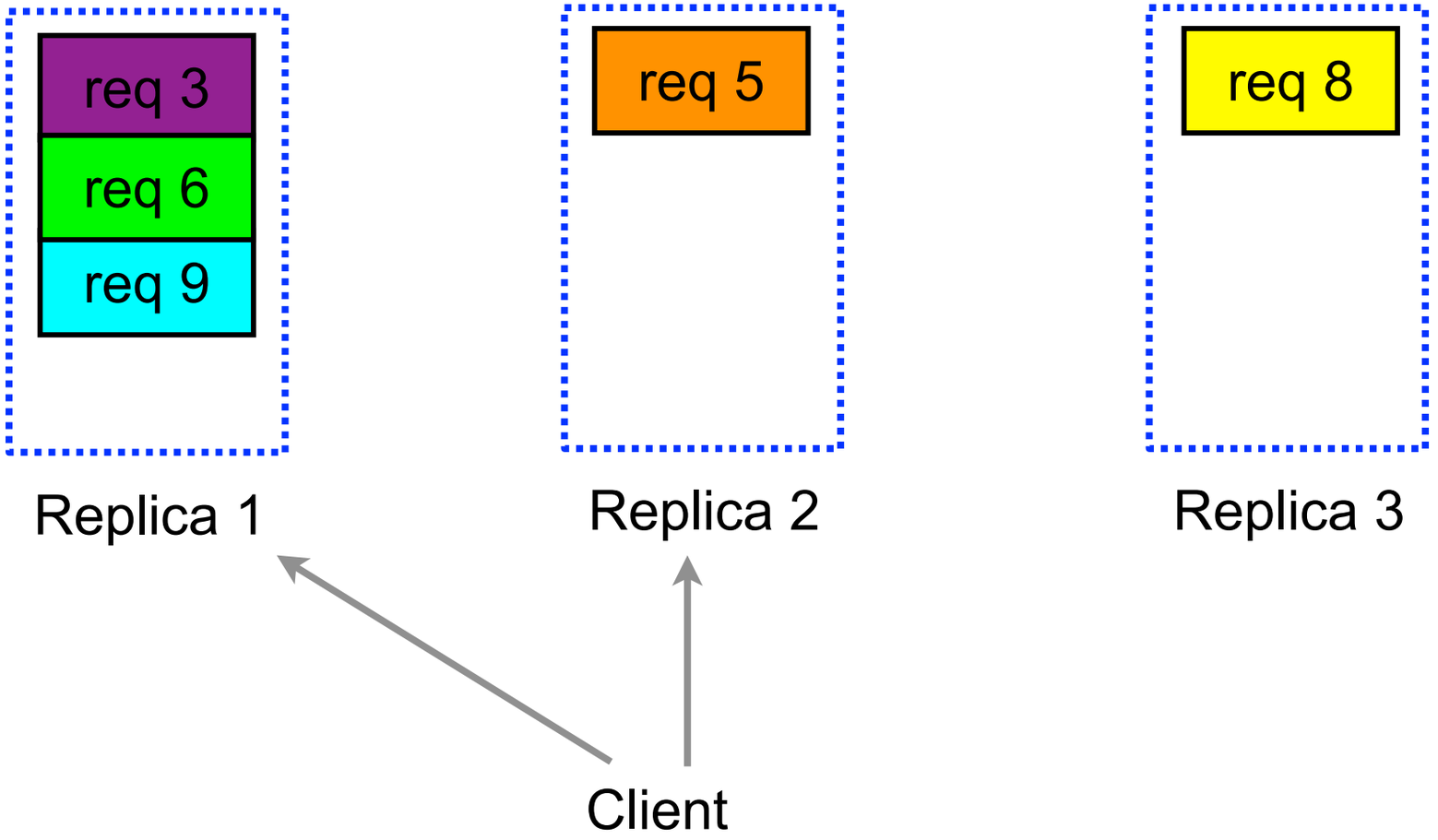


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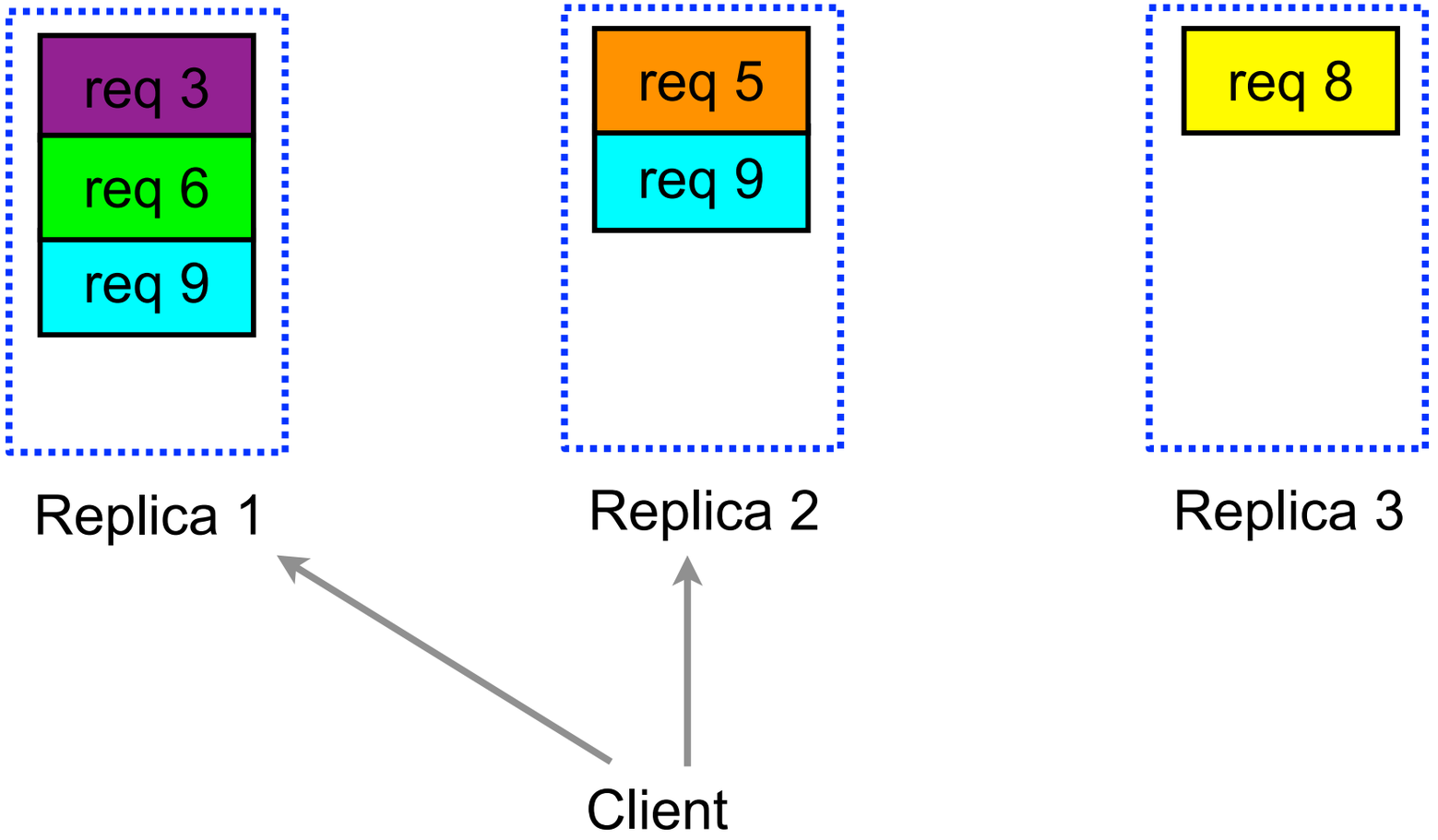


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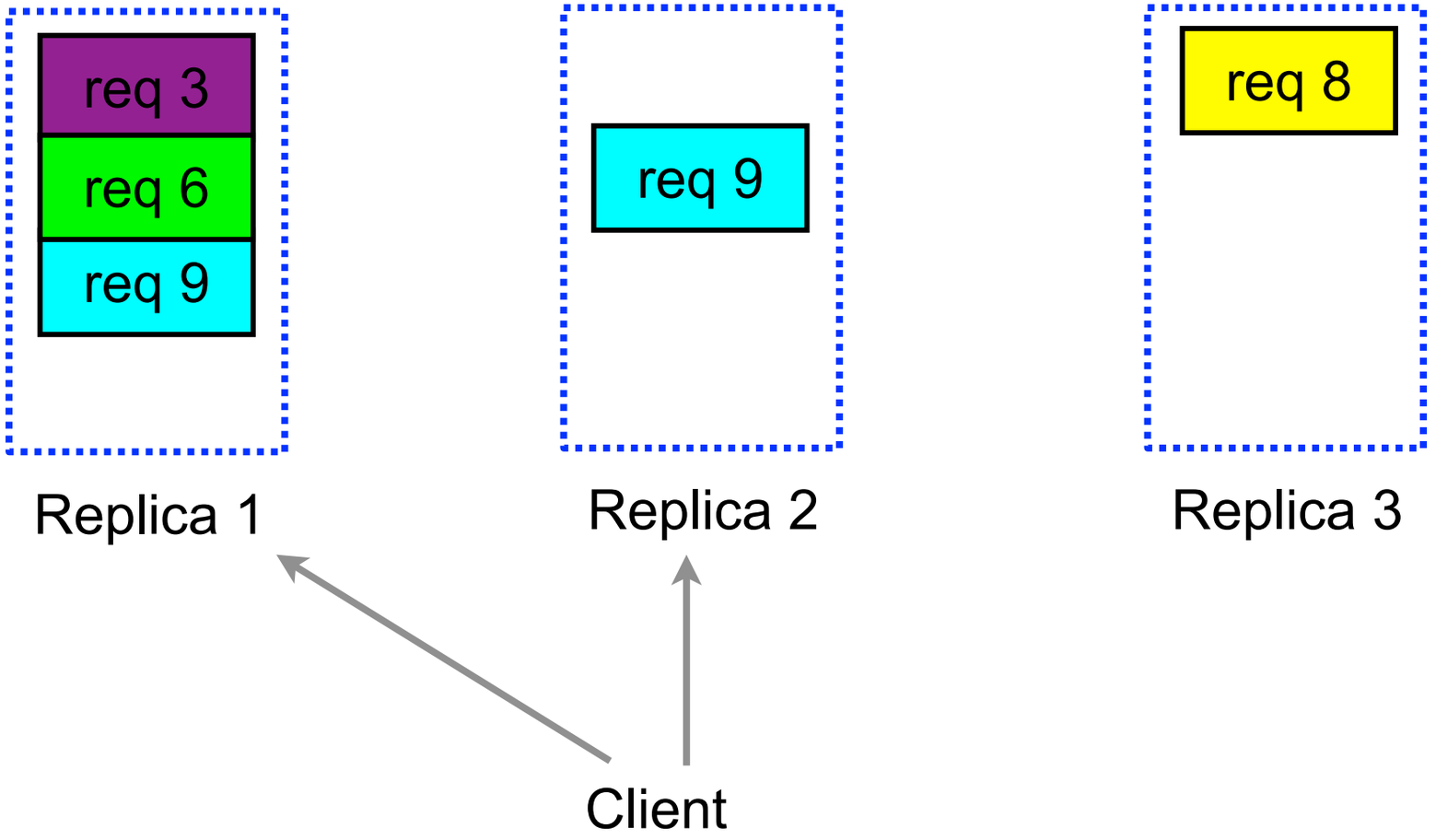


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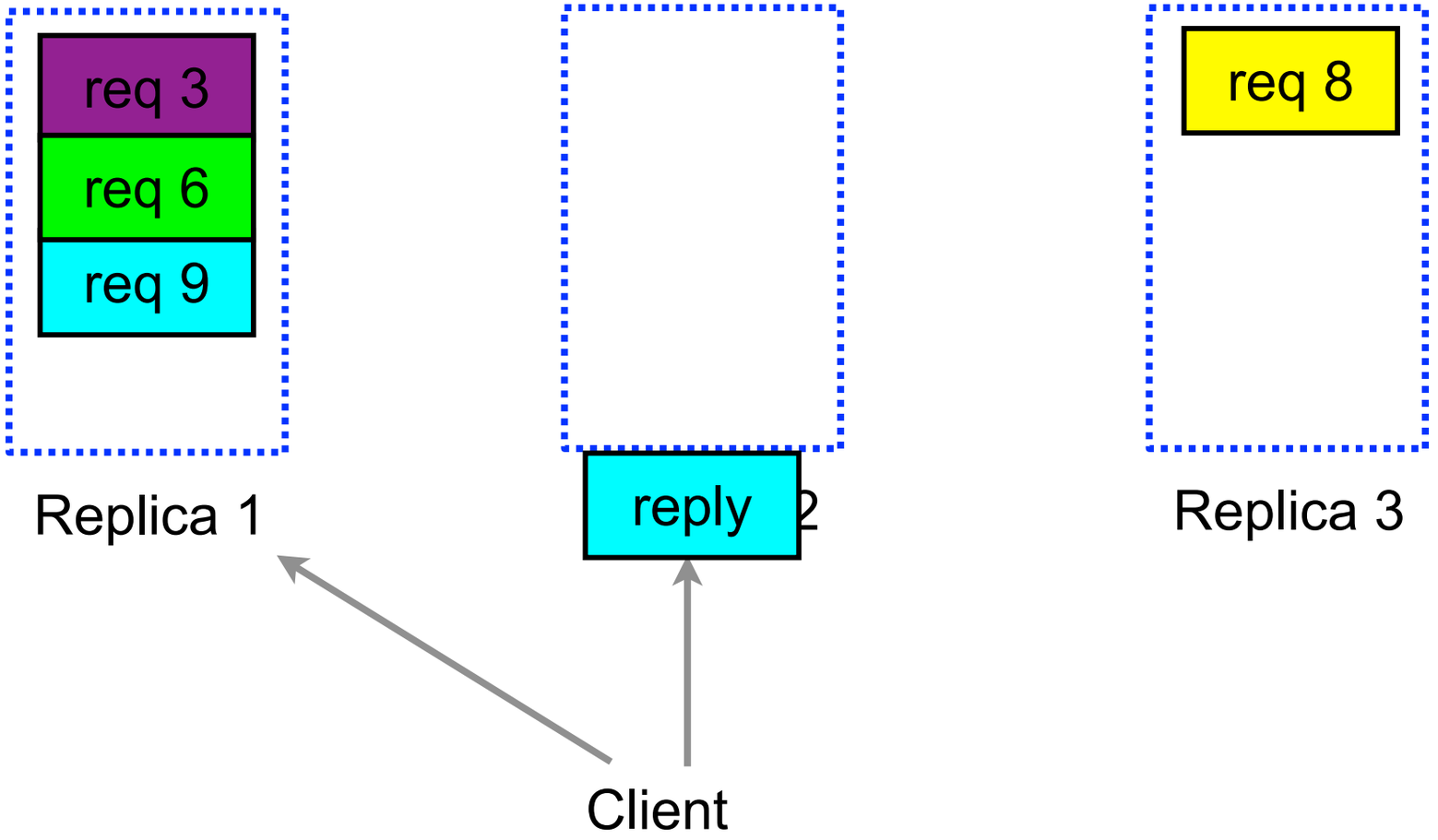

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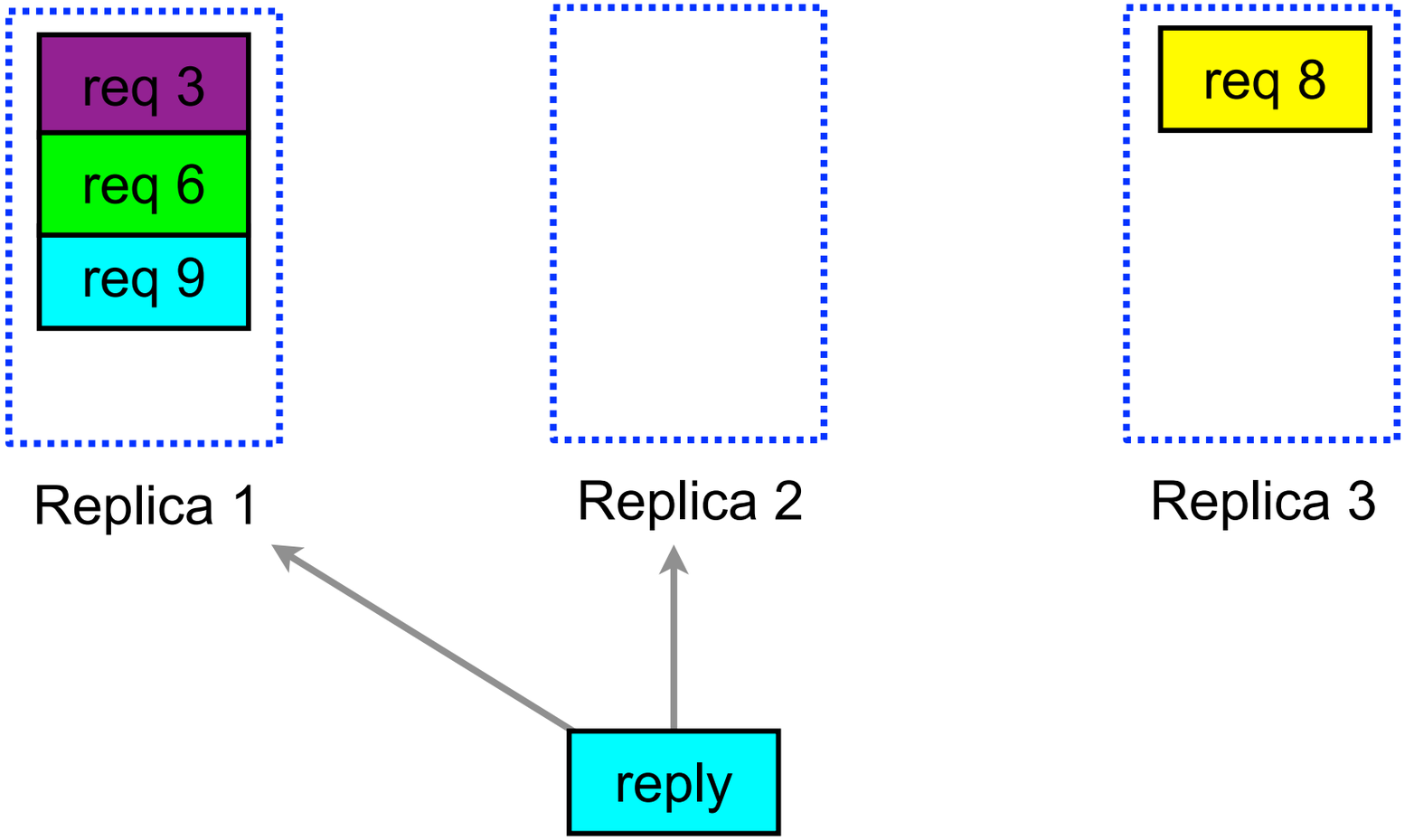


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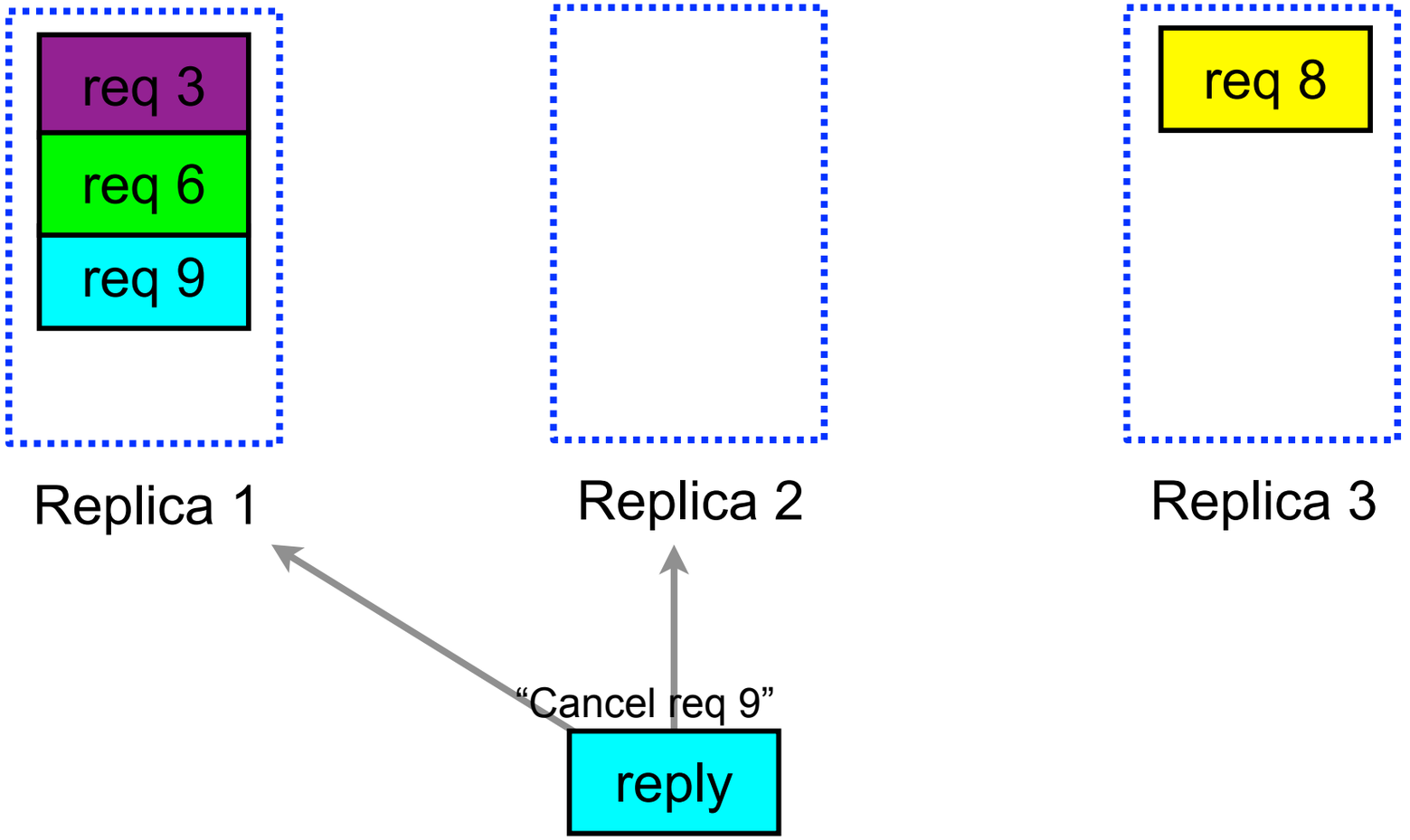

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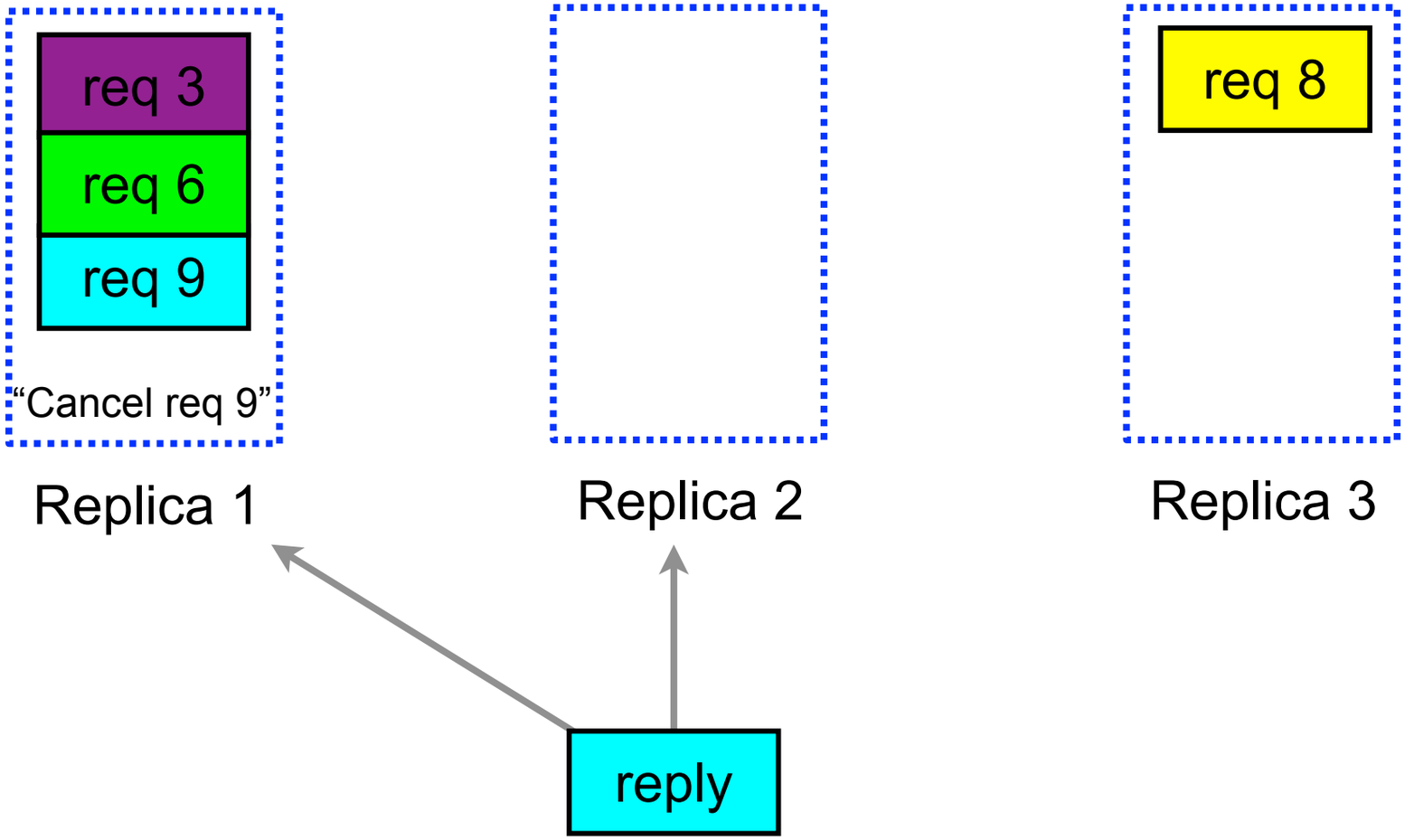


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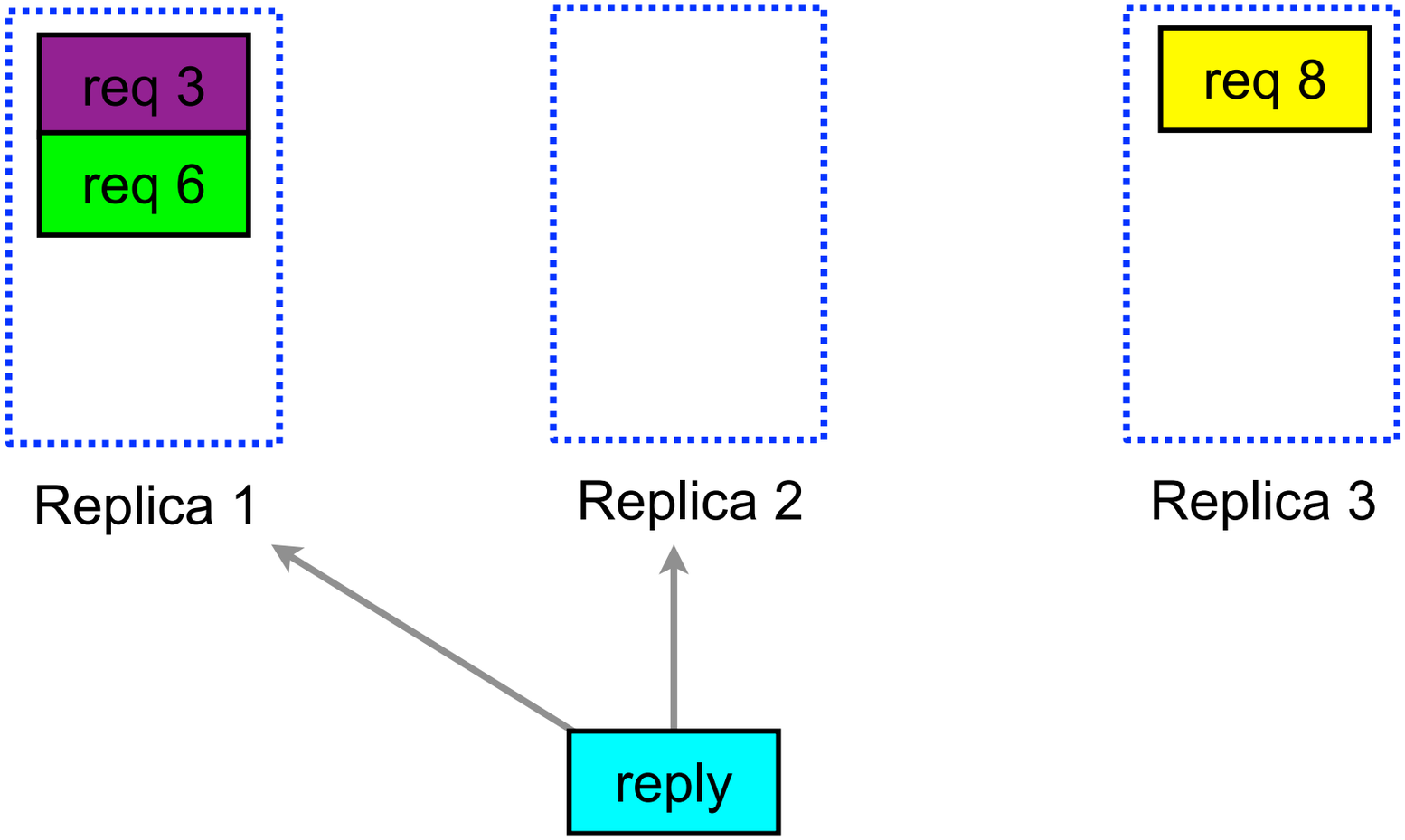


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# Backup Requests Effects

- In-memory BigTable lookups
  - data replicated in two in-memory tables
  - issue requests for 1000 keys spread across 100 tablets
  - measure elapsed time until data for last key arrives

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| | Avg | Std Dev | 95%ile | 99%ile | 99.9%ile |
|---|---|---|---|---|---|
| No backups | 33 ms | 1524 ms | 24 ms | 52 ms | 994 ms |
| Backup after 10 ms | 14 ms | 4 ms | 20 ms | 23 ms | 50 ms |
| Backup after 50 ms | 16 ms | 12 ms | 57 ms | 63 ms | 68 ms |

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- Modest increase in request load:
  - 10 ms delay: <5% extra requests; 50 ms delay: <1%

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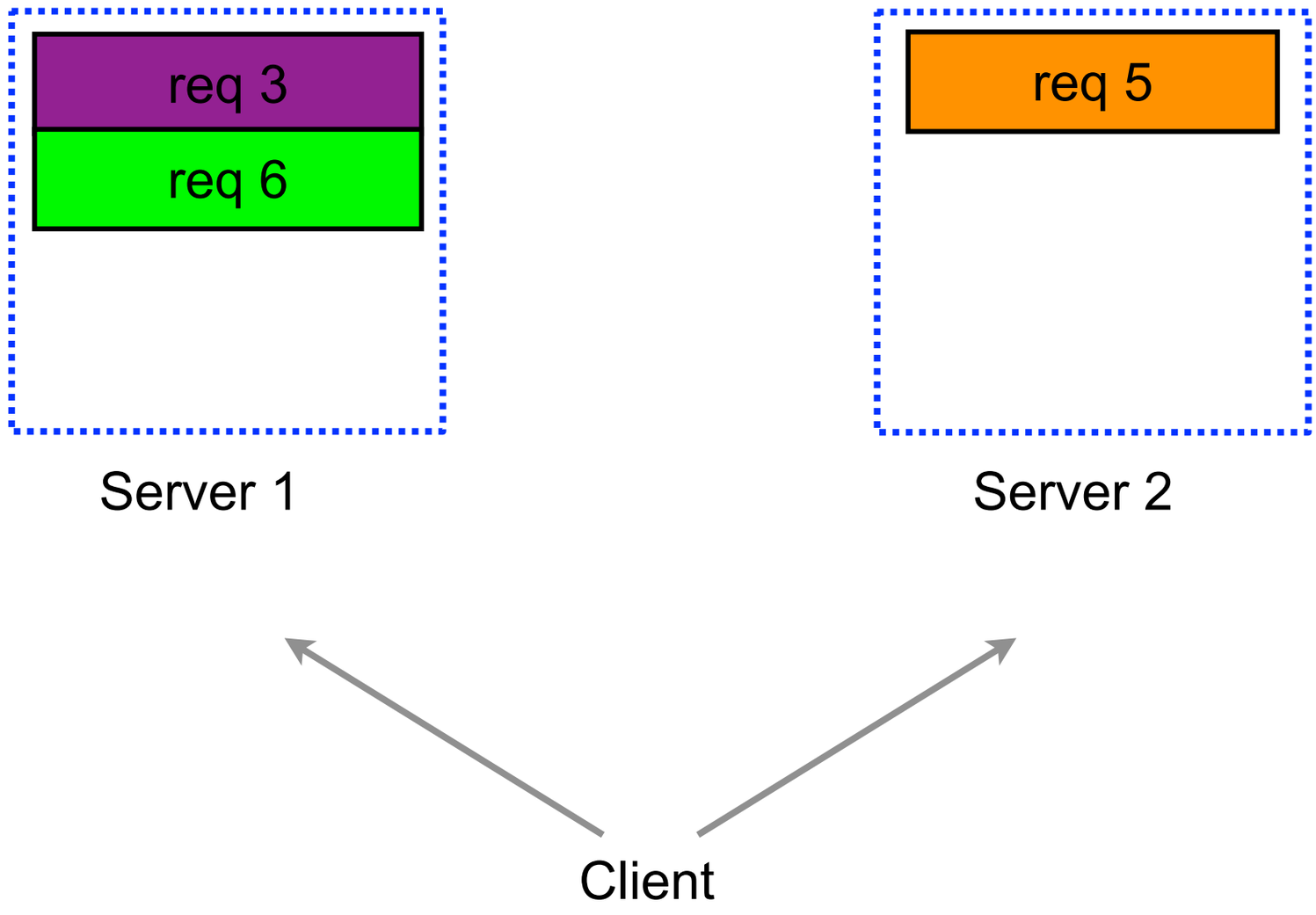
# Backup Requests w/ Cross-Server Cancellation

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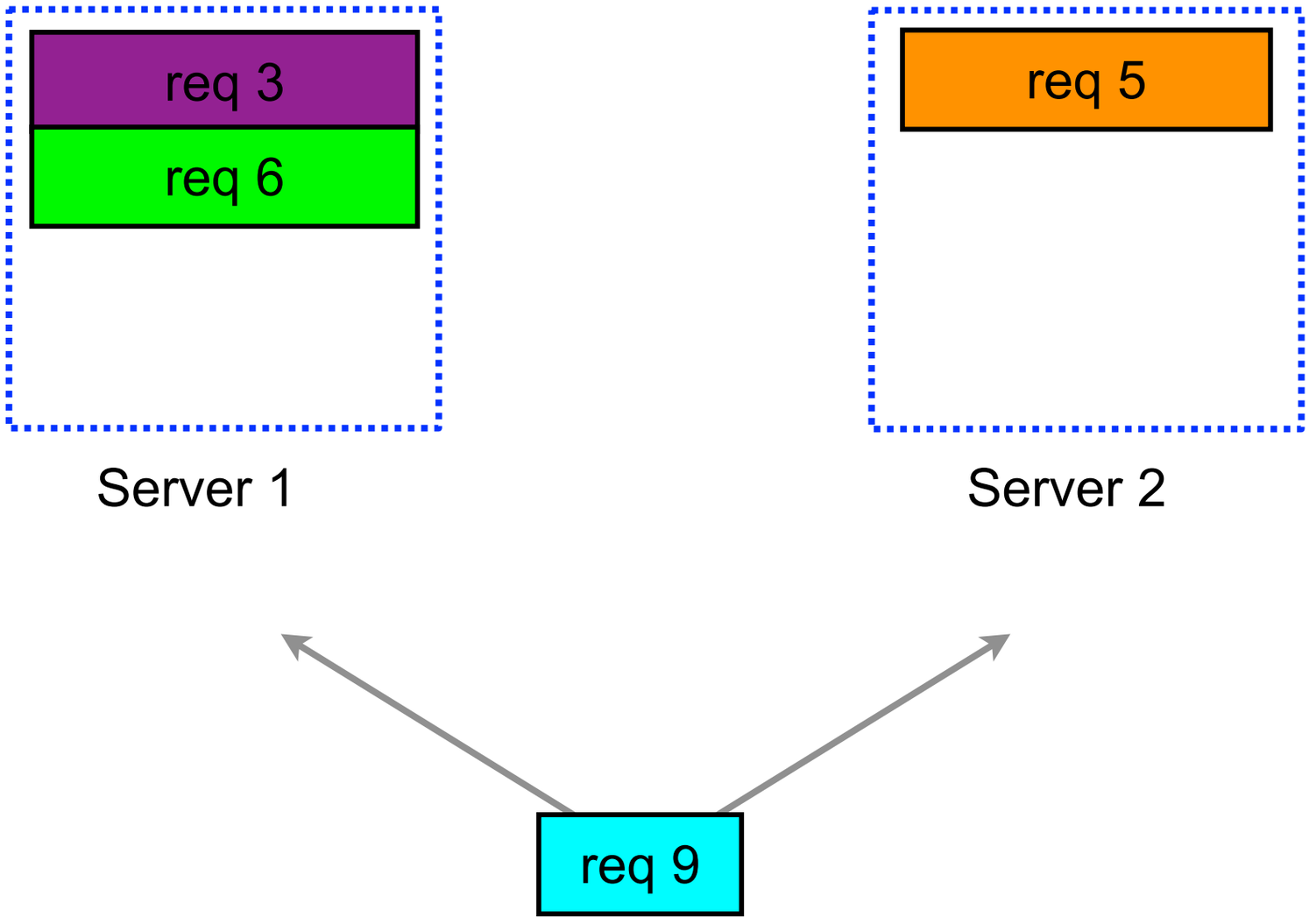

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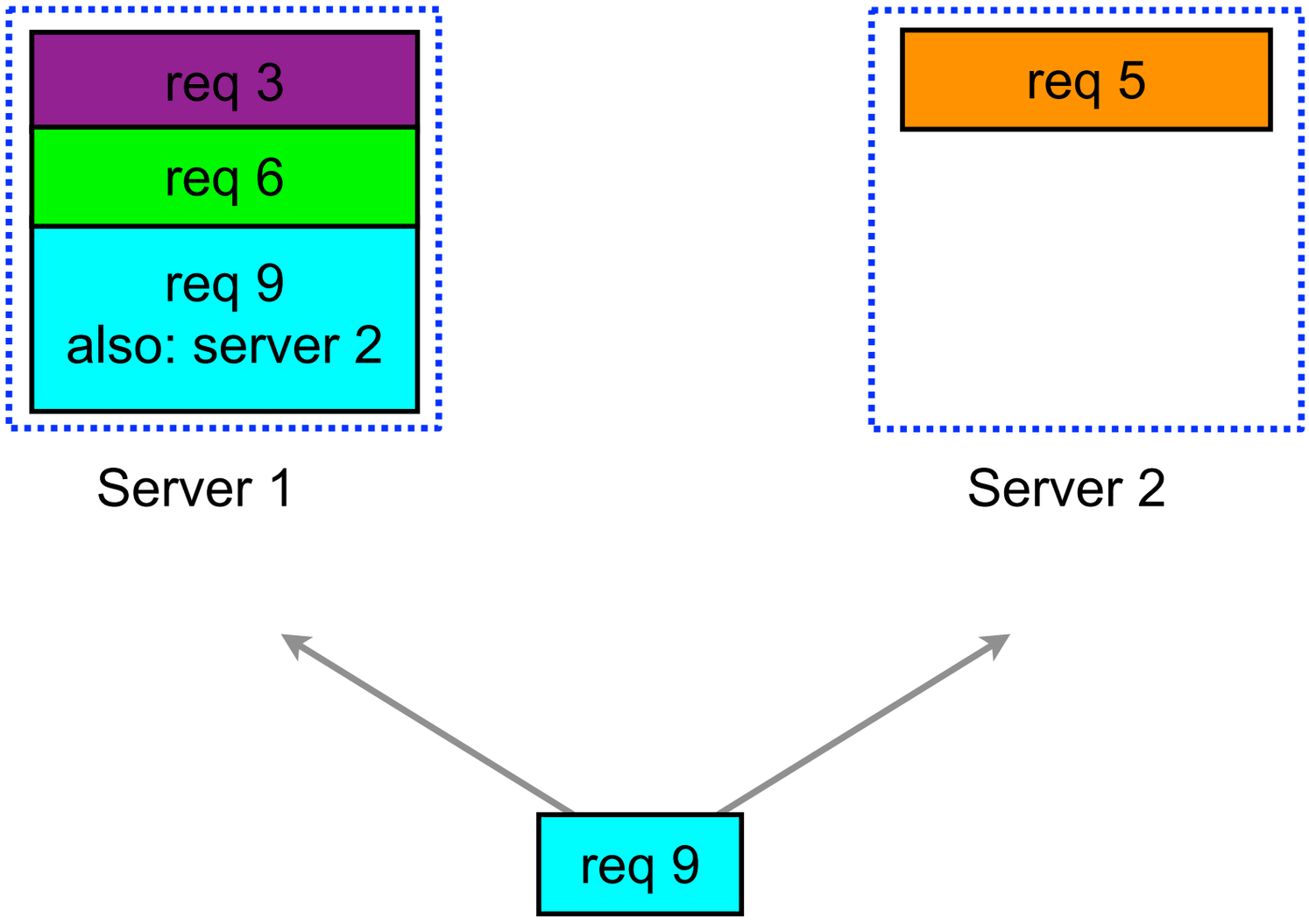


Each request identifies other server(s) to which request might be sent

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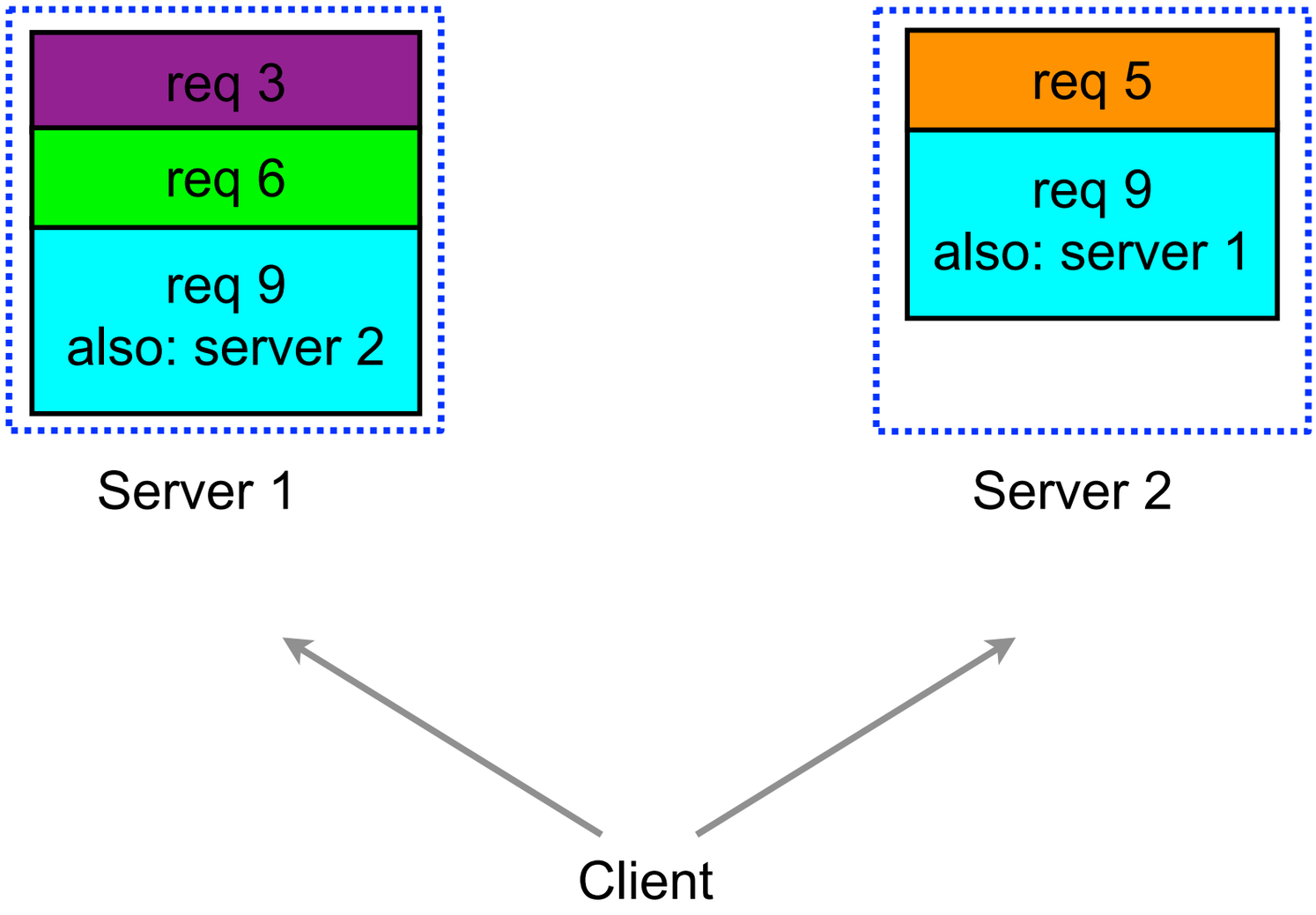


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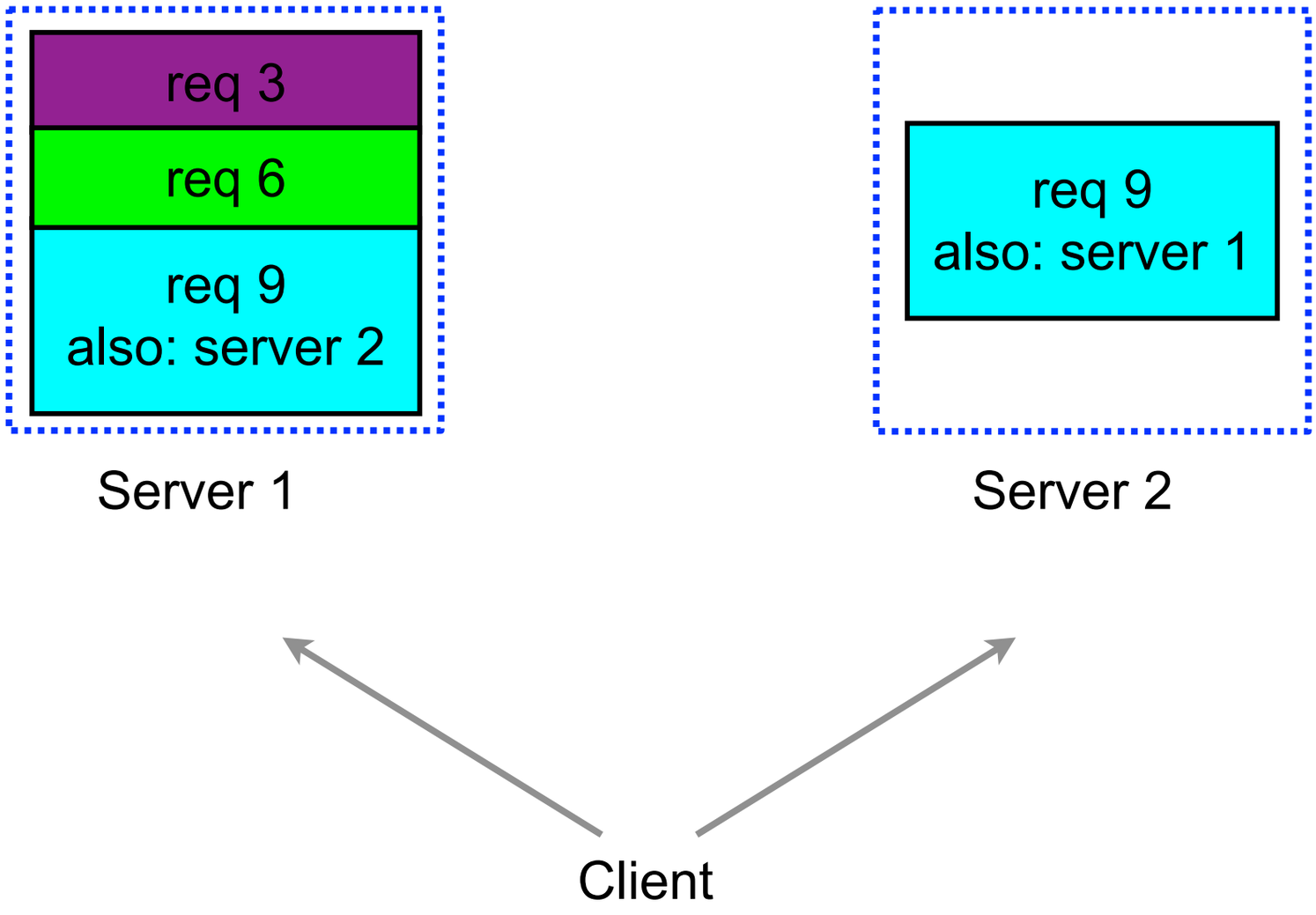


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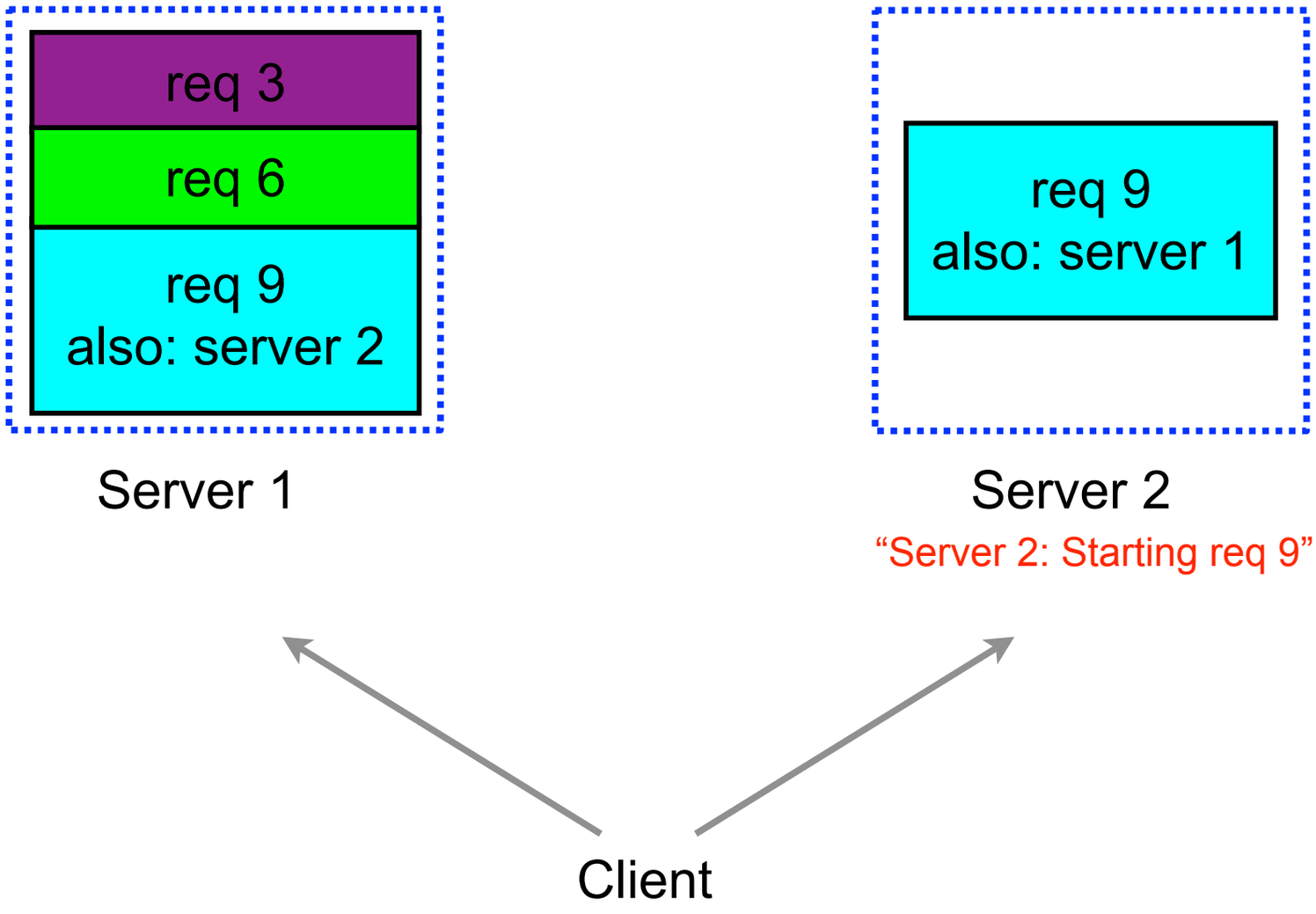


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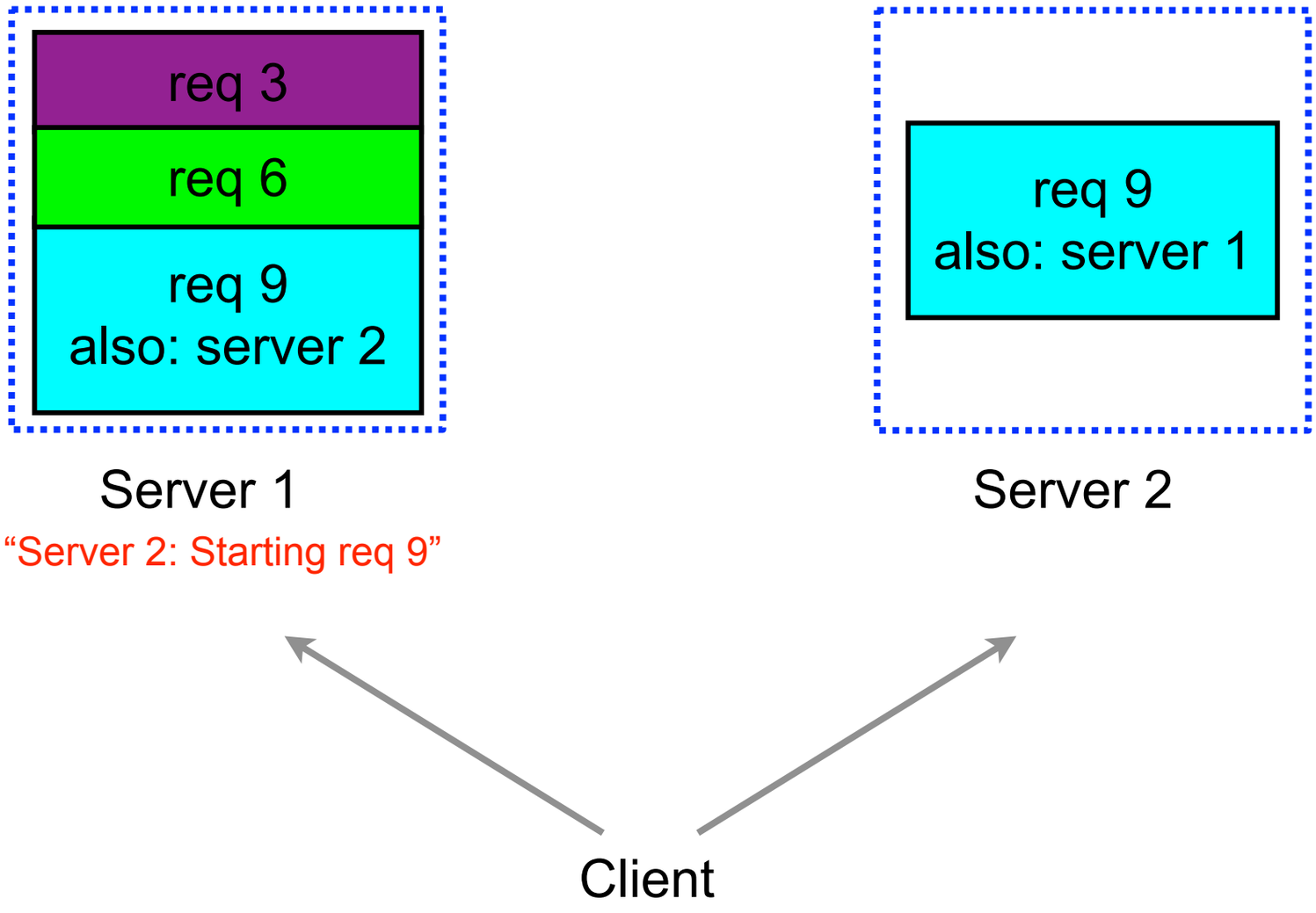


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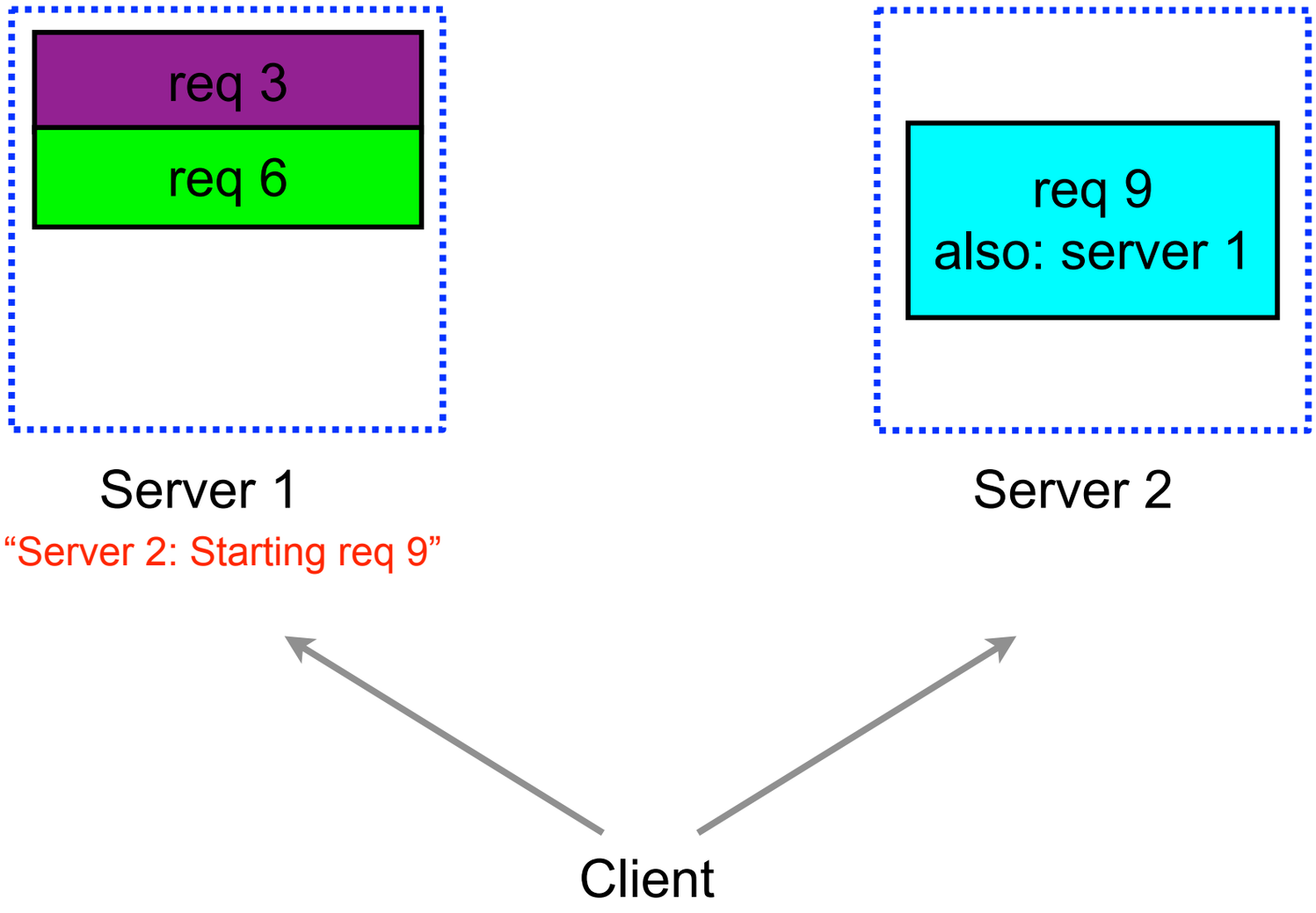


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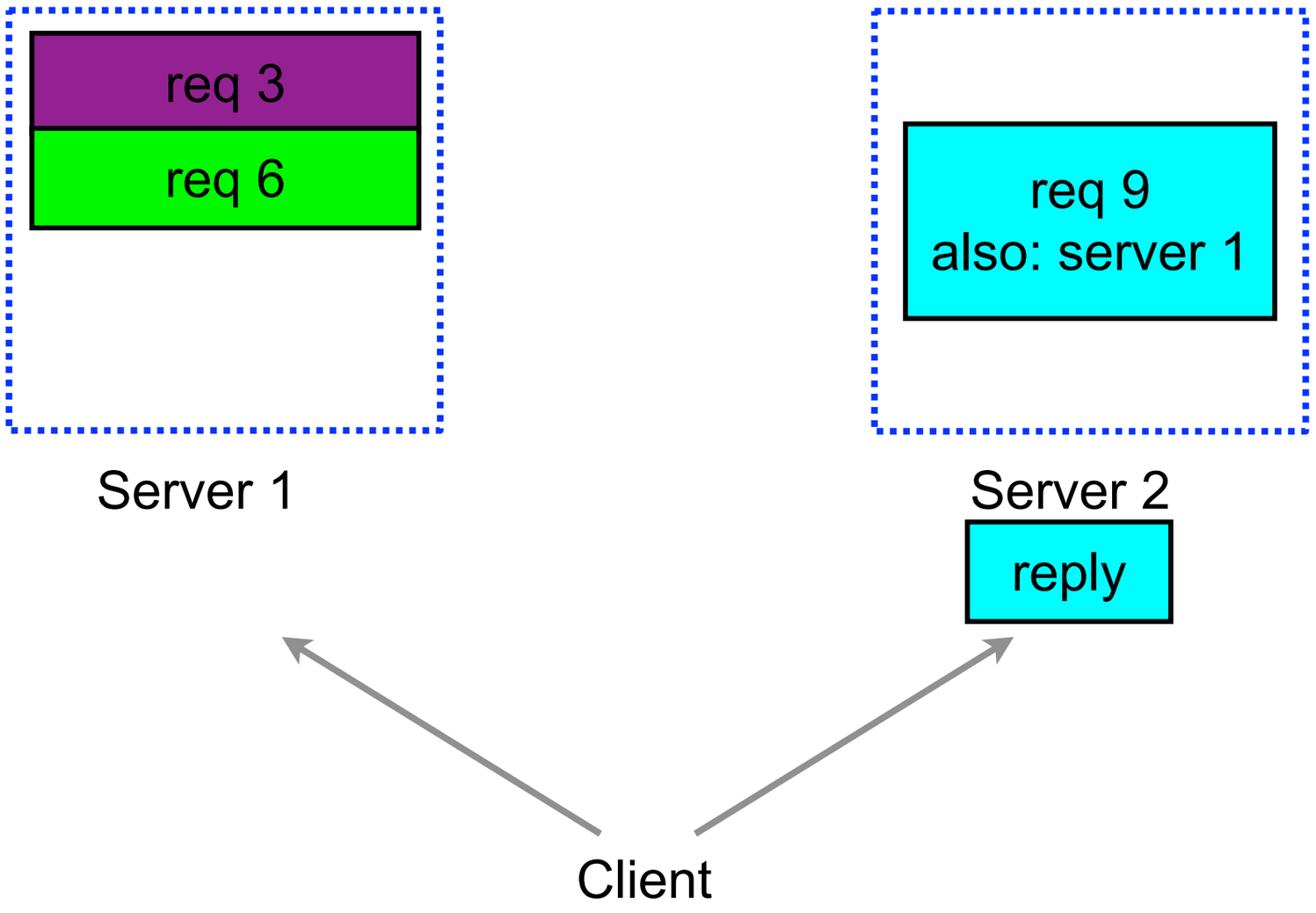
# Backup Requests w/ Cross-Server Cancellation

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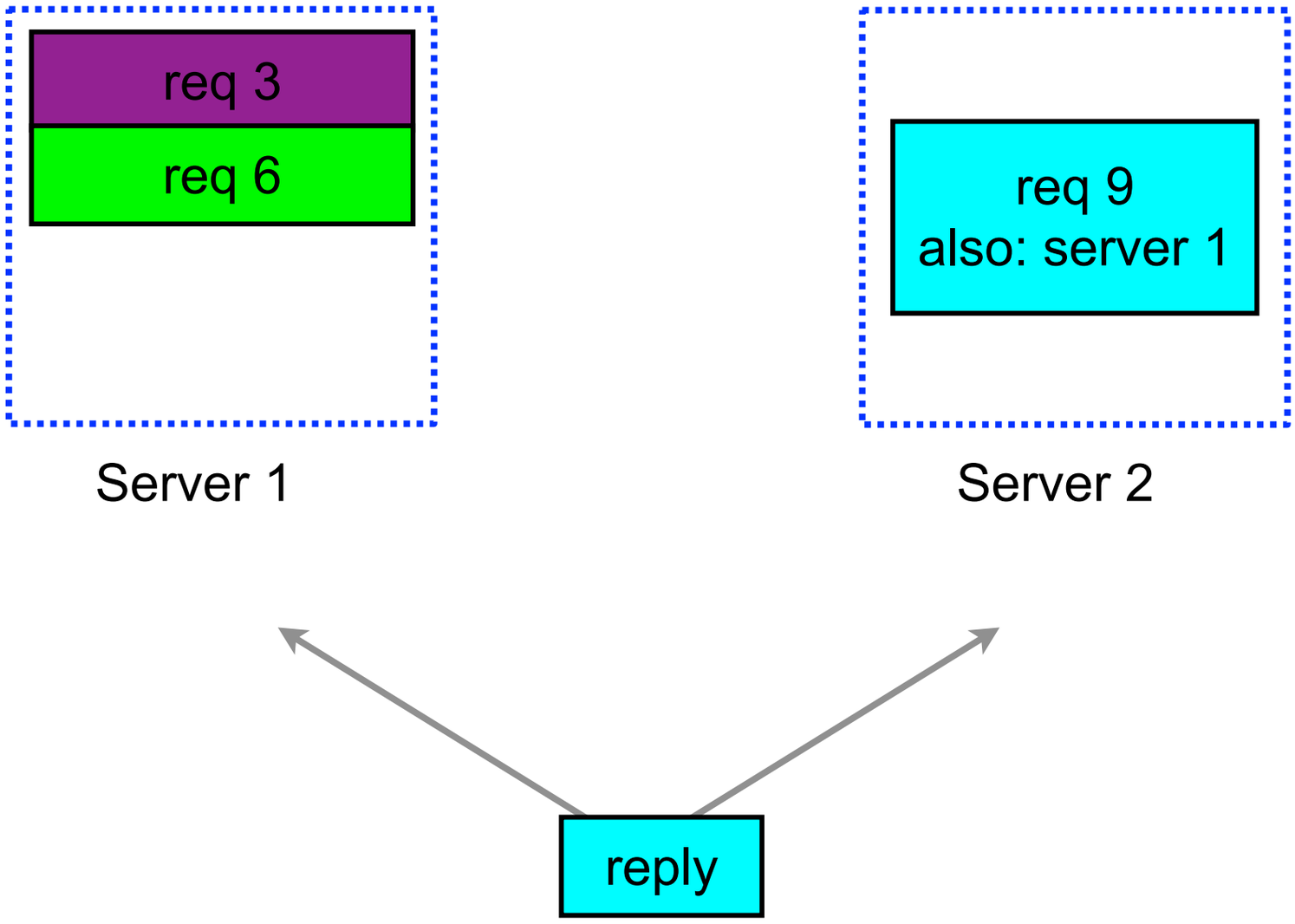


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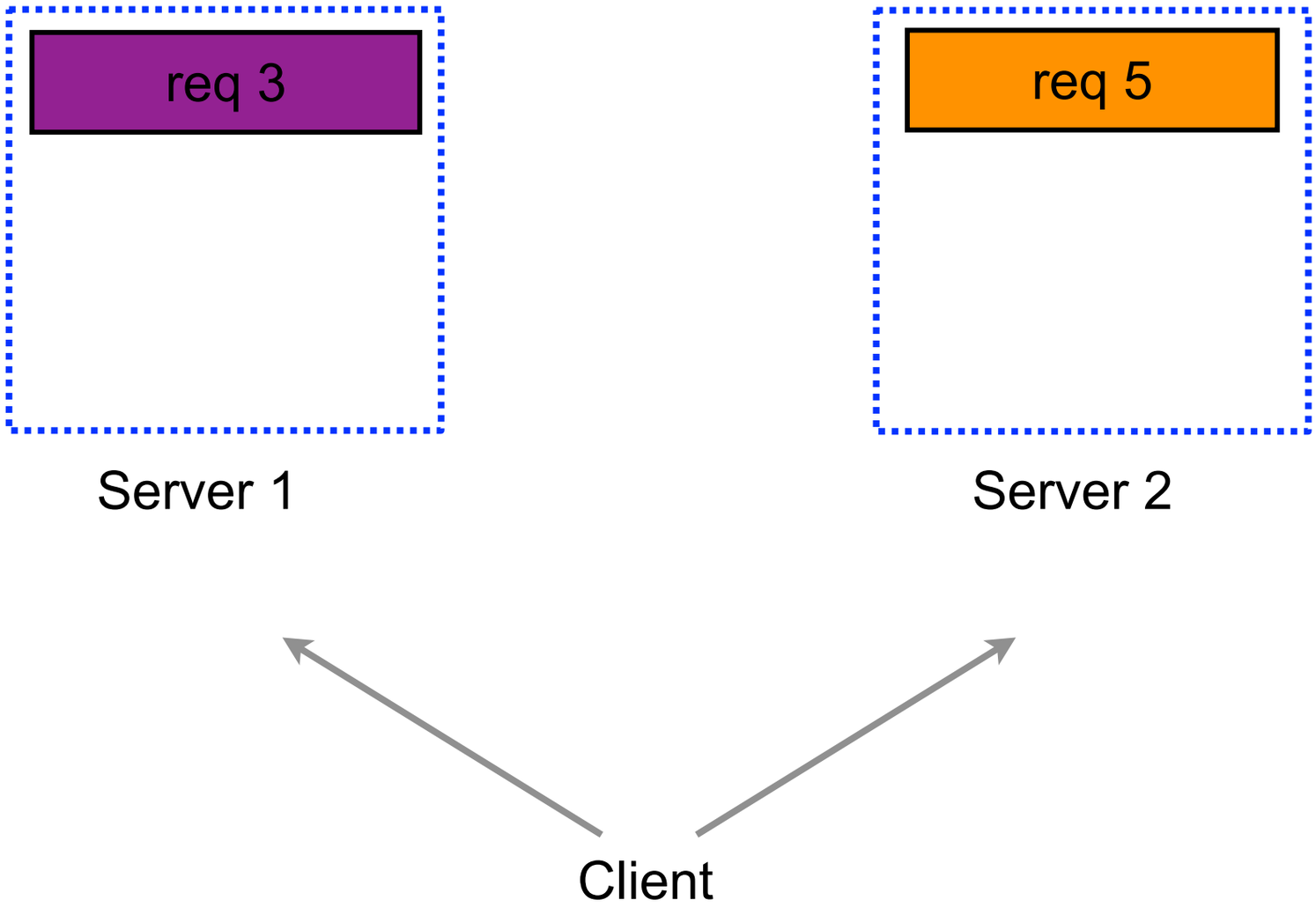
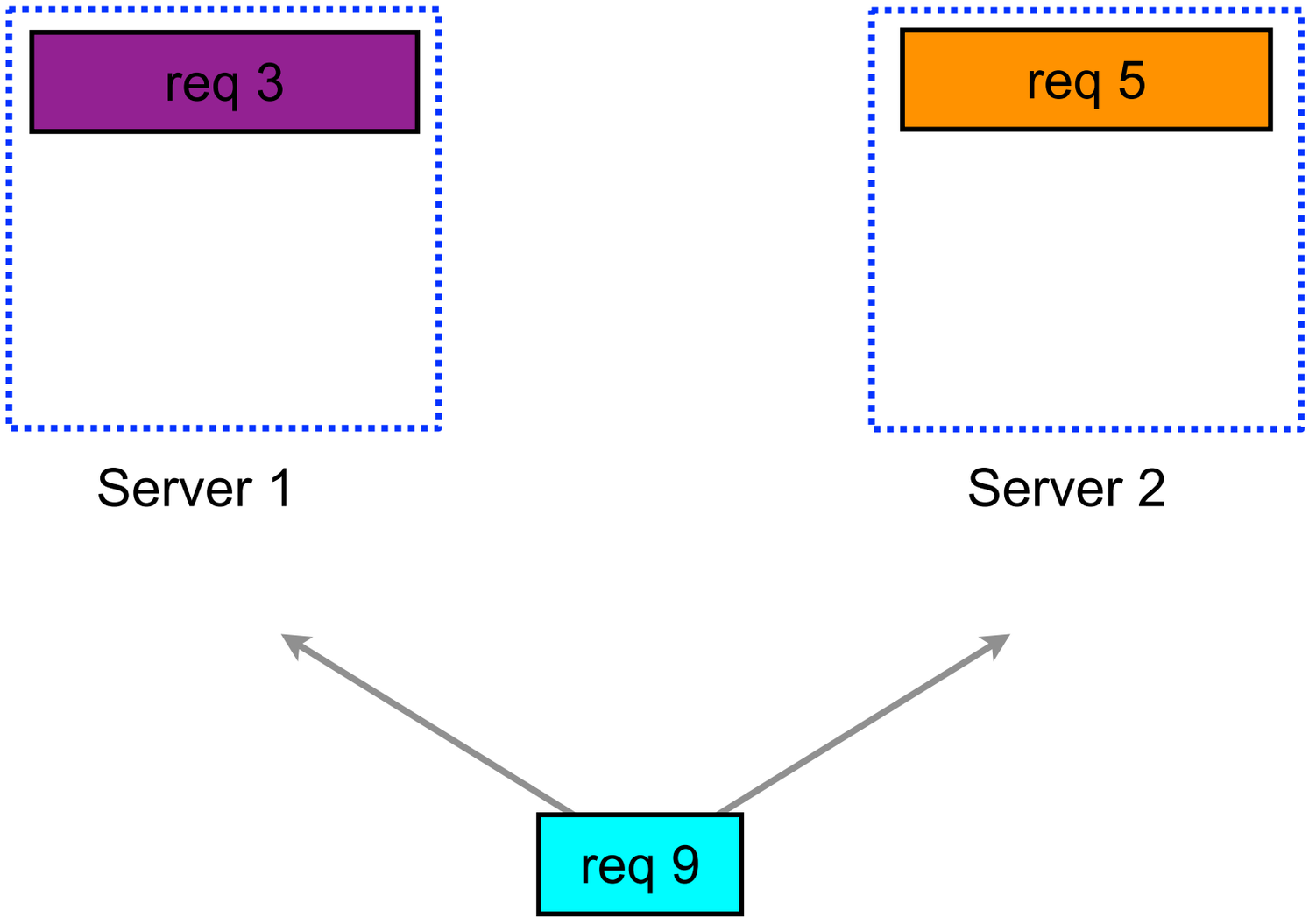
Google

# Backup Requests: Bad Case




Google

# Backup Requests: Bad Case




Google

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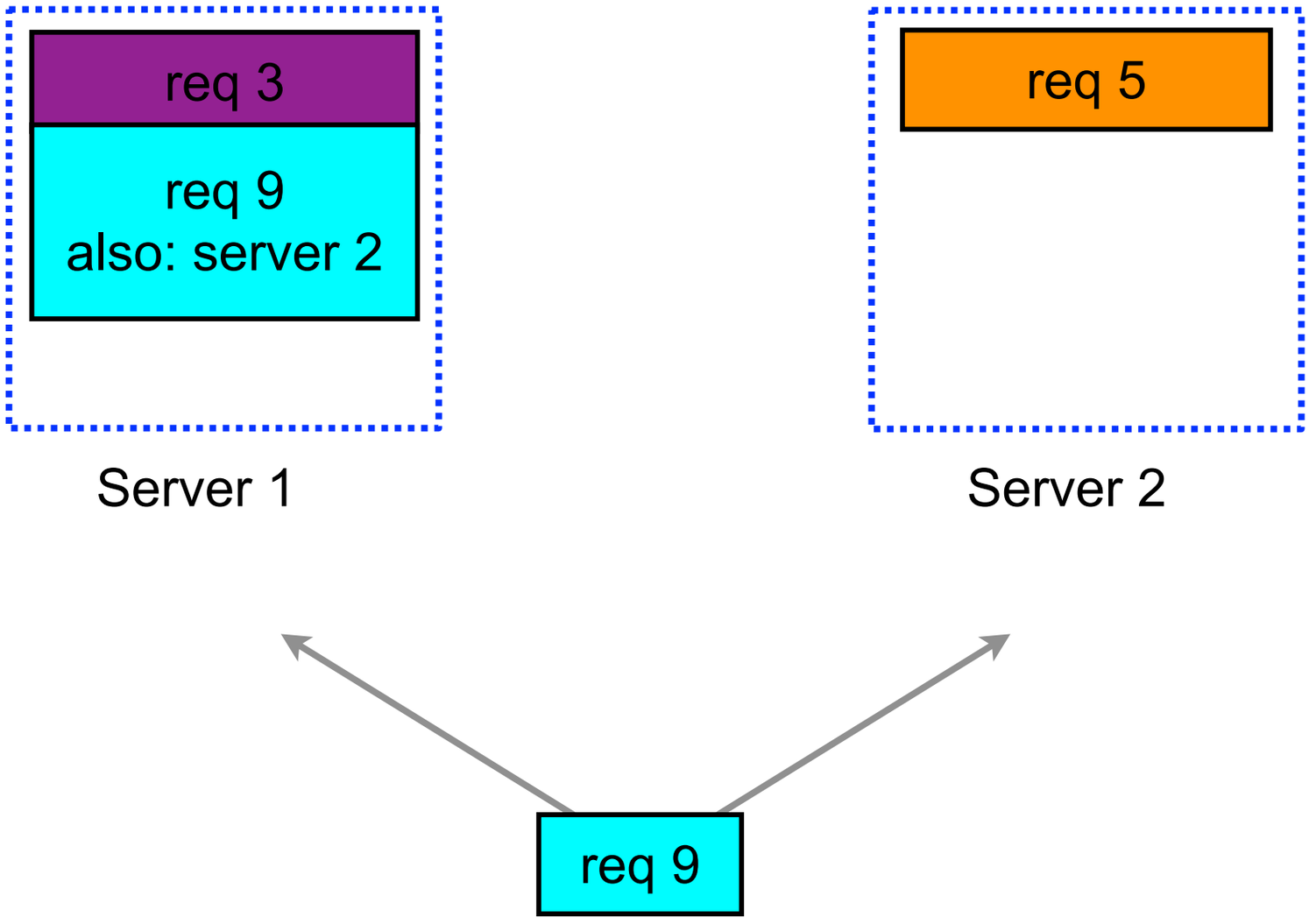

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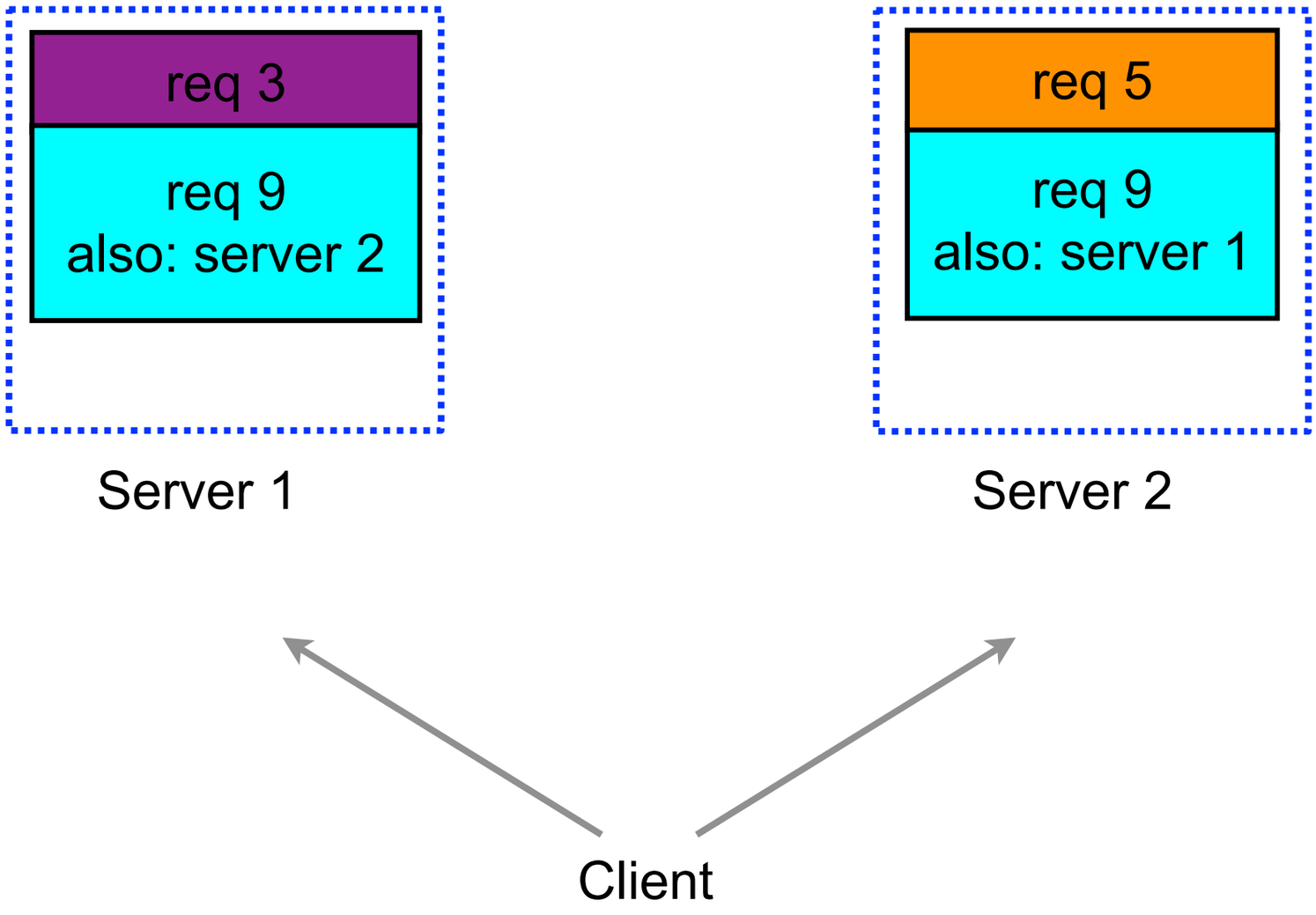


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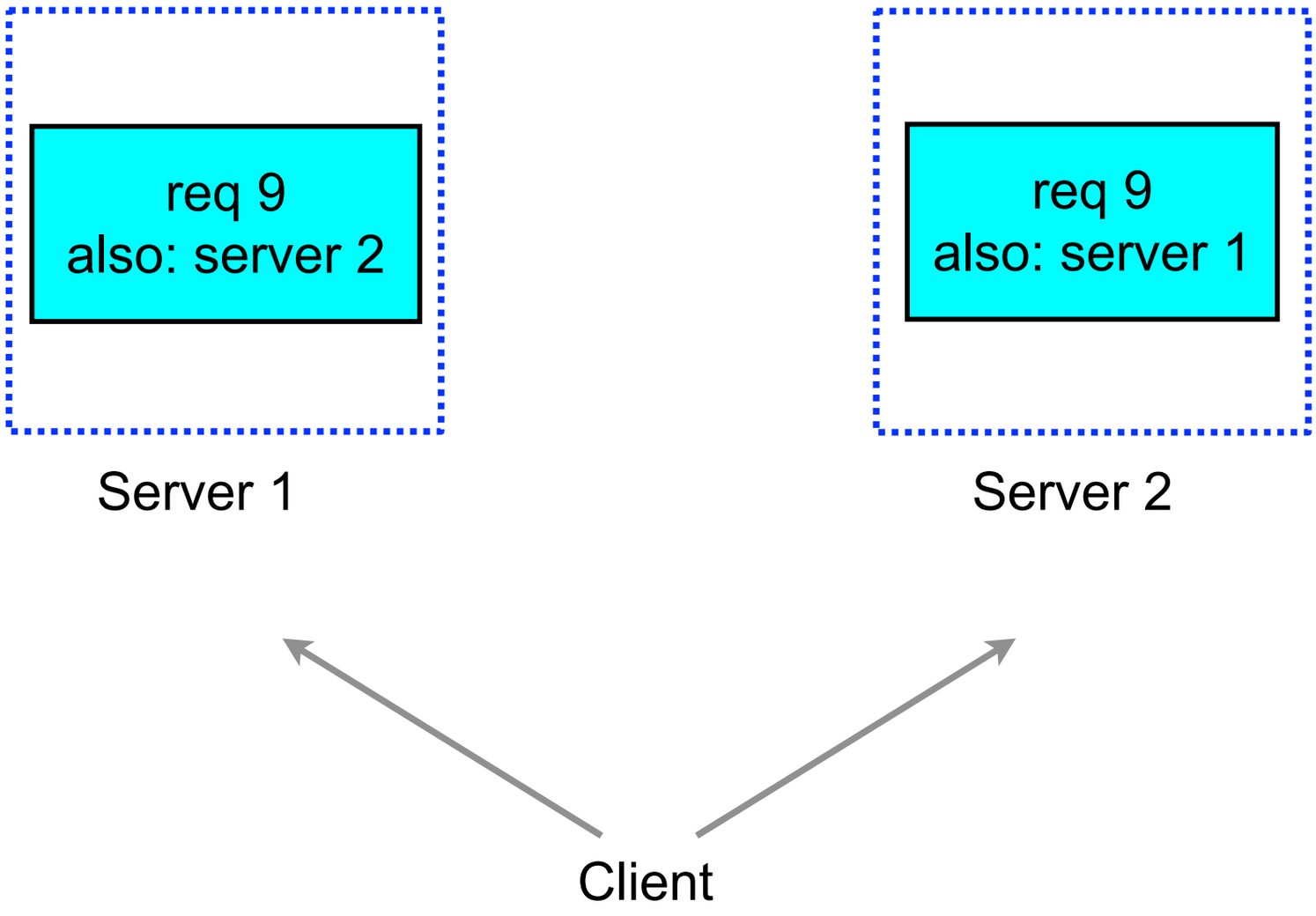

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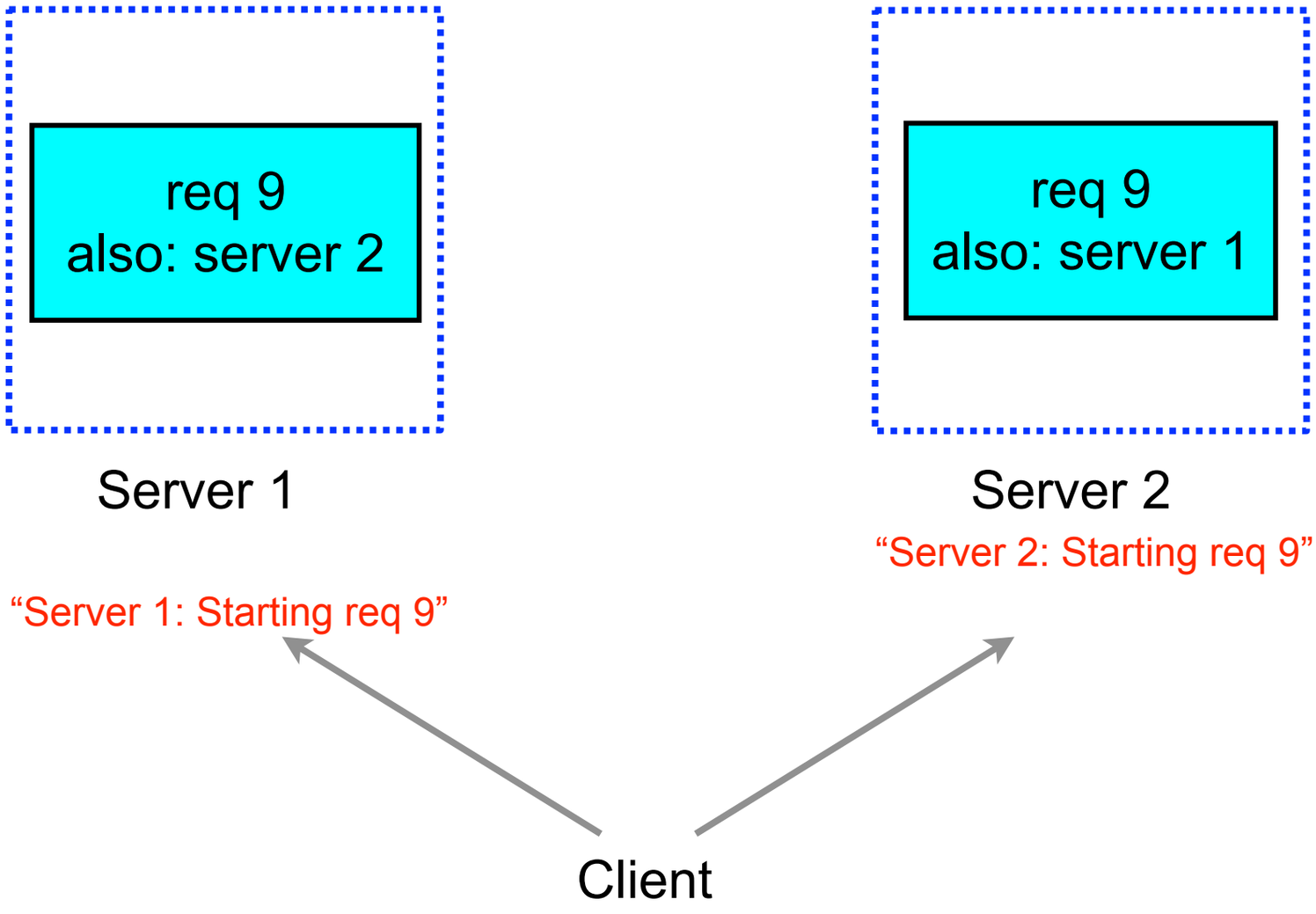


Google

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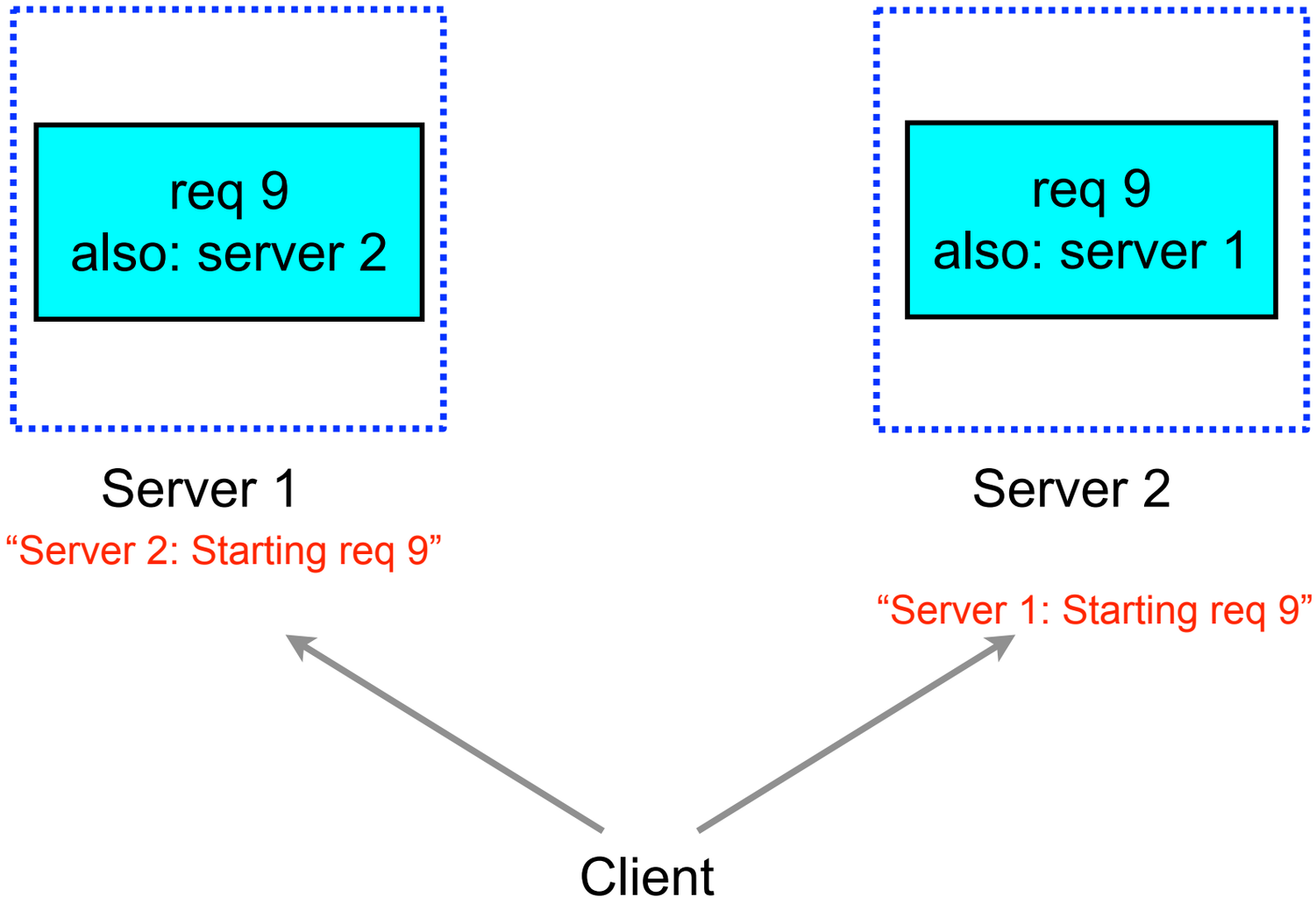


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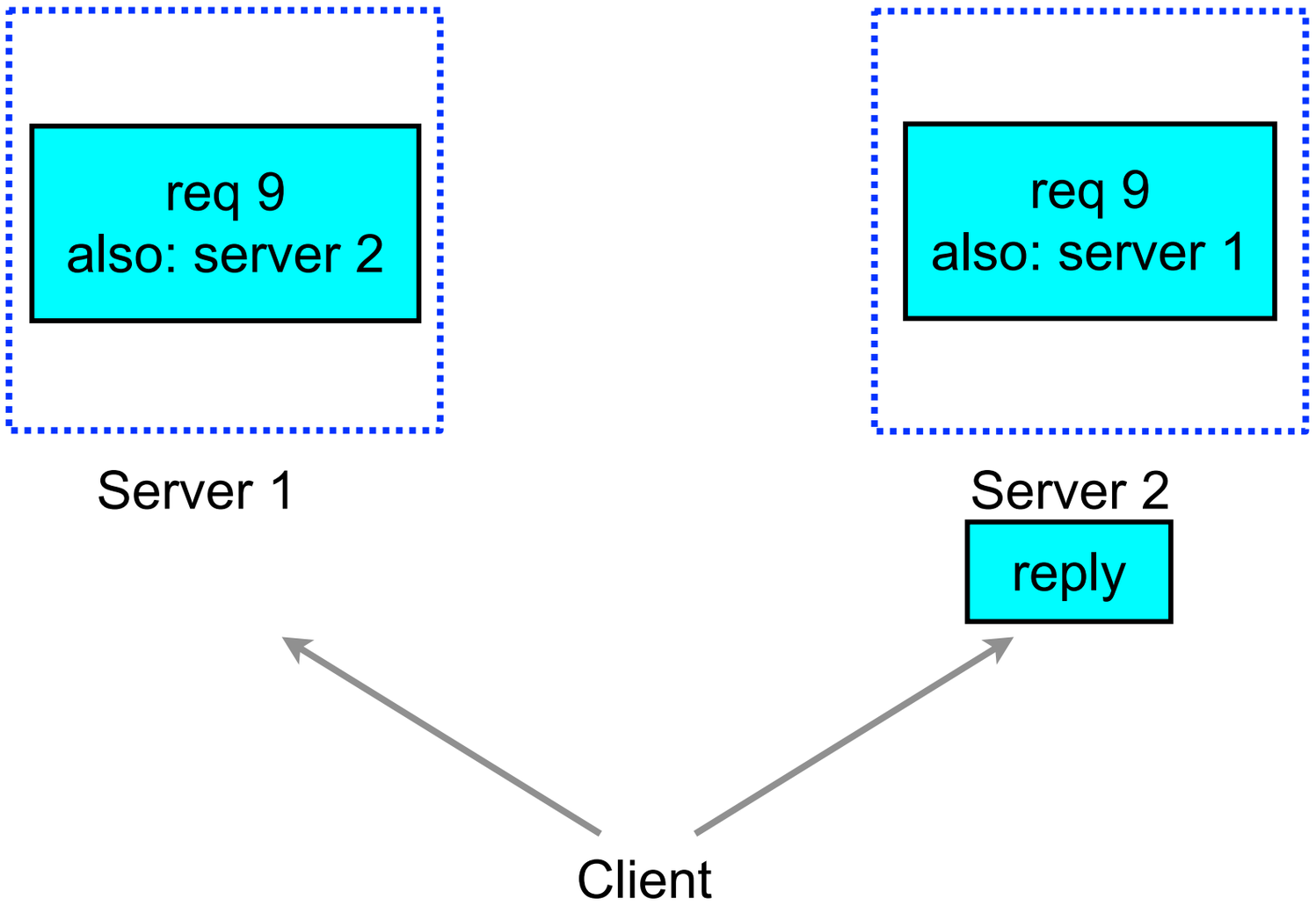


Google

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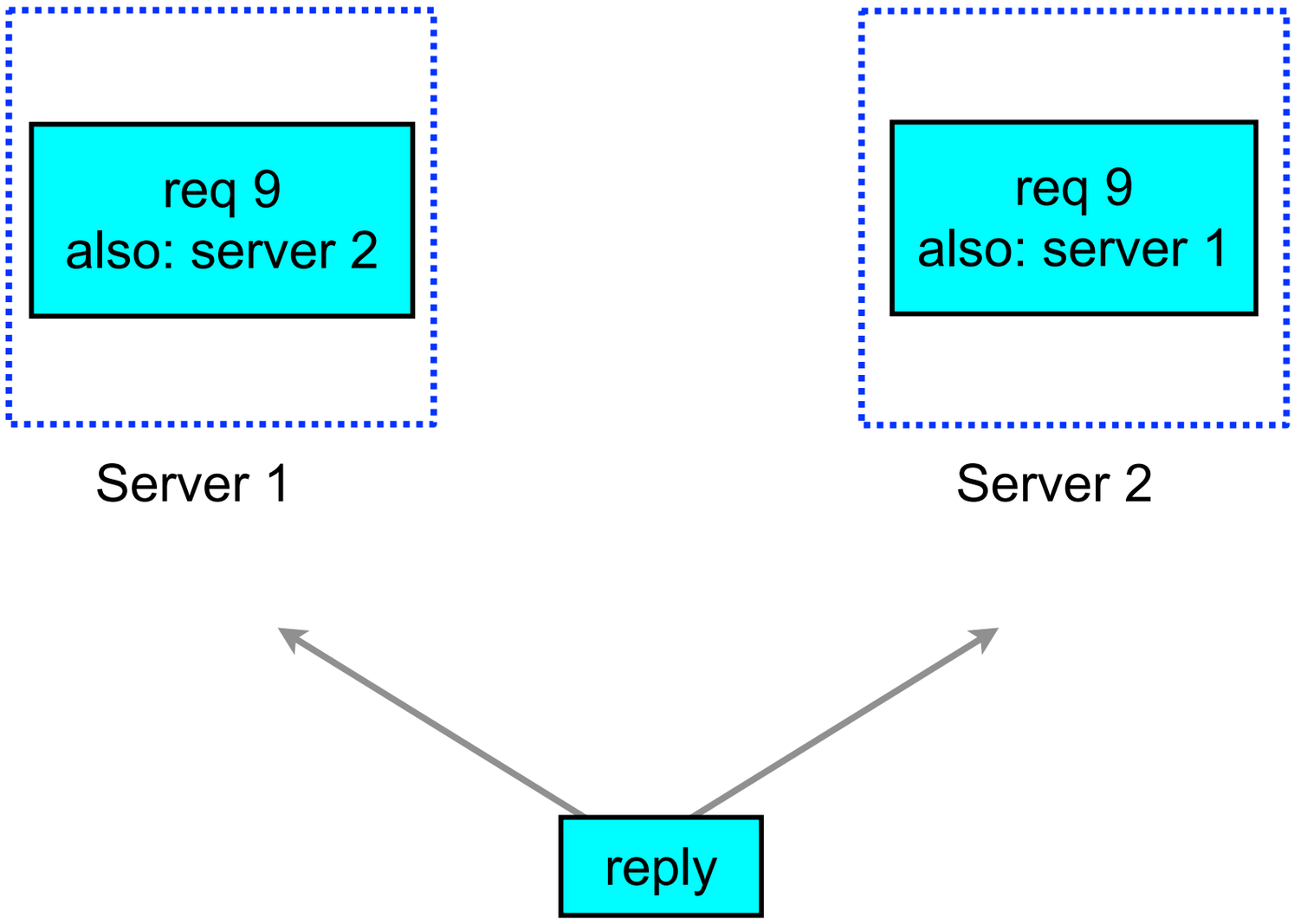

# Backup Requests w/ Cross-Server Cancellation

- Read operations in distributed file system client
  - send request to first replica
  - wait 2 ms, and send to second replica
  - servers cancel request on other replica when starting read
- Time for bigtable monitoring ops that touch disk

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| Cluster state | Policy | 50%ile | 90%ile | 99%ile | 99.9%ile |
|---|---|---|---|---|---|
| Mostly idle | No backups | 19 ms | 38 ms | 67 ms | 98 ms |
| | Backup after 2 ms | 16 ms | 28 ms | 38 ms | 51 ms |

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-43%

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Google

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Backups cause about ~1% extra disk reads

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Backups w/big sort job gives same read latencies as no backups w/ idle cluster!

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# Backup Request Variants

- Many variants possible:
- Send to third replica after longer delay
  - sending to two gives almost all the benefit, however.
- Keep requests in other queues, but reduce priority
- Can handle Reed-Solomon reconstruction similarly

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# Tainted Partial Results

- Many systems can tolerate inexact results
  - information retrieval systems
    - search 99.9% of docs in 200ms better than 100% in 1000ms
  - complex web pages with many sub-components
    - e.g. okay to skip spelling correction service if it is slow

- Design to proactively abandon slow subsystems
  - set cutoffs dynamically based on recent measurements
    - can tradeoff completeness vs. responsiveness
  - important to mark such results as tainted in caches

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# Hardware Trends

- Some good:
  - lower latency networks make things like backup request cancellations work better

- Some not so good:
  - plethora of CPU and device sleep modes save power, but add latency variability
  - higher number of “wimpy” cores => higher fanout => more variability

- Software techniques can reduce variability despite increasing variability in underlying hardware

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# Conclusions

- Tolerating variability
  - important for large-scale online services
  - large fanout magnifies importance
  - makes services more responsive
  - saves significant computing resources

- Collection of techniques
  - general good engineering practices
    - prioritized server queues, careful management of background activities
  - cross-request adaptation
    - load balancing, micro-partitioning
  - within-request adaptation
    - backup requests, backup requests w/ cancellation, tainted results

Google

# Thanks

- Joint work with Luiz Barroso and many others at Google

- Questions?