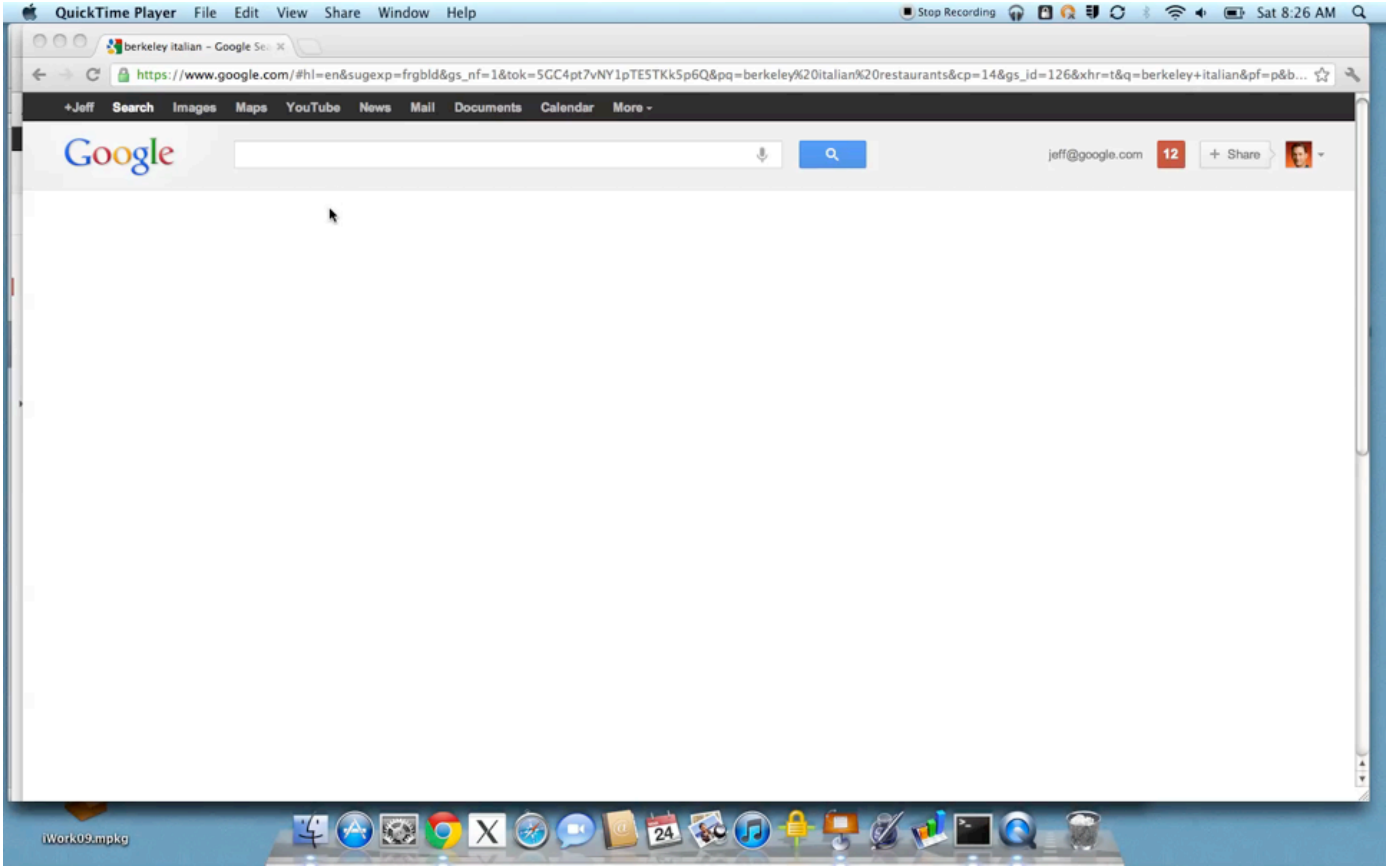
Achieving Rapid Response Times in Large Online Services

Jeff Dean
Google Fellow
jeff@google.com

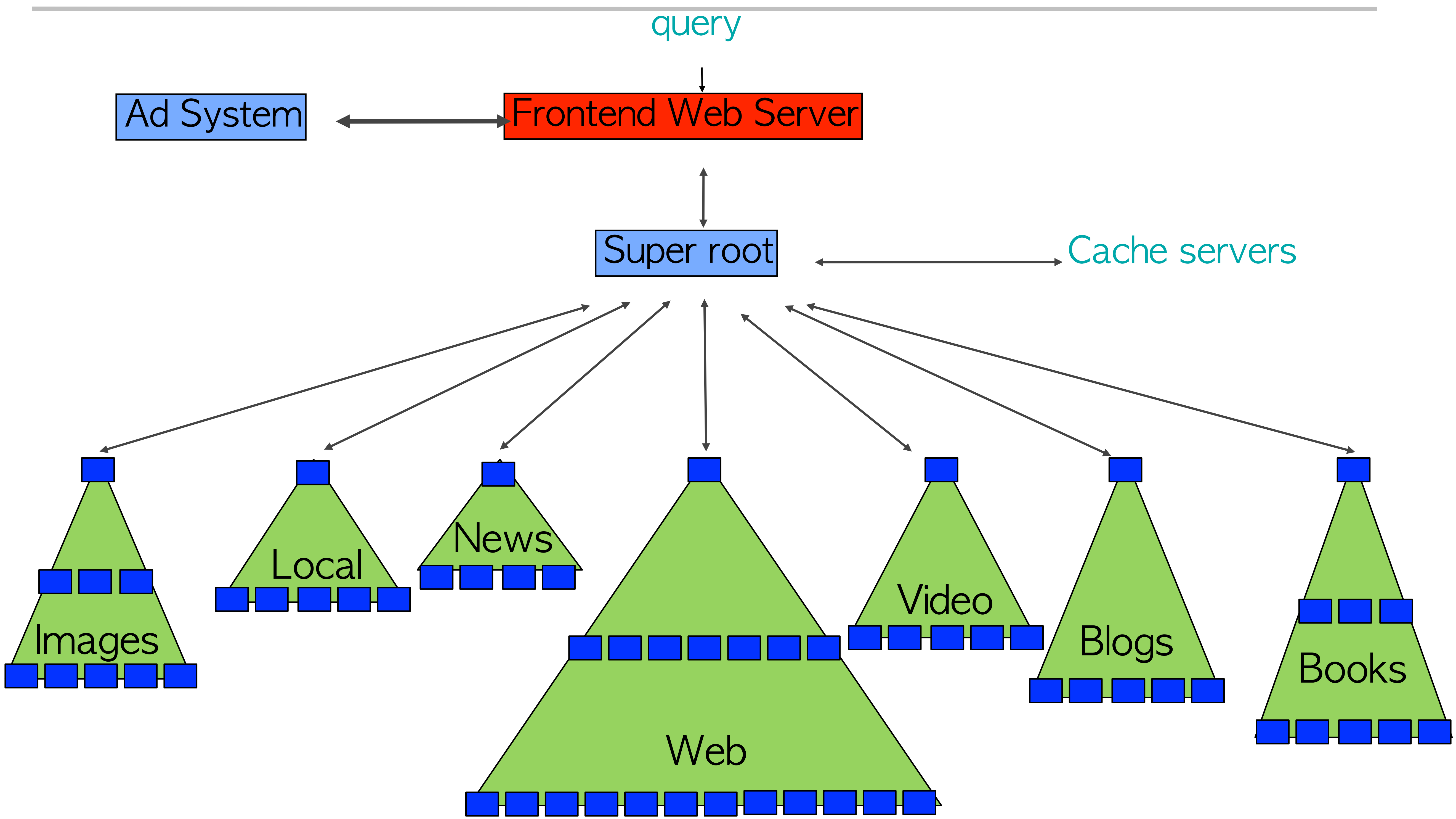
Faster Is Better

Google

Faster Is Better



Large Fanout Services



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

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

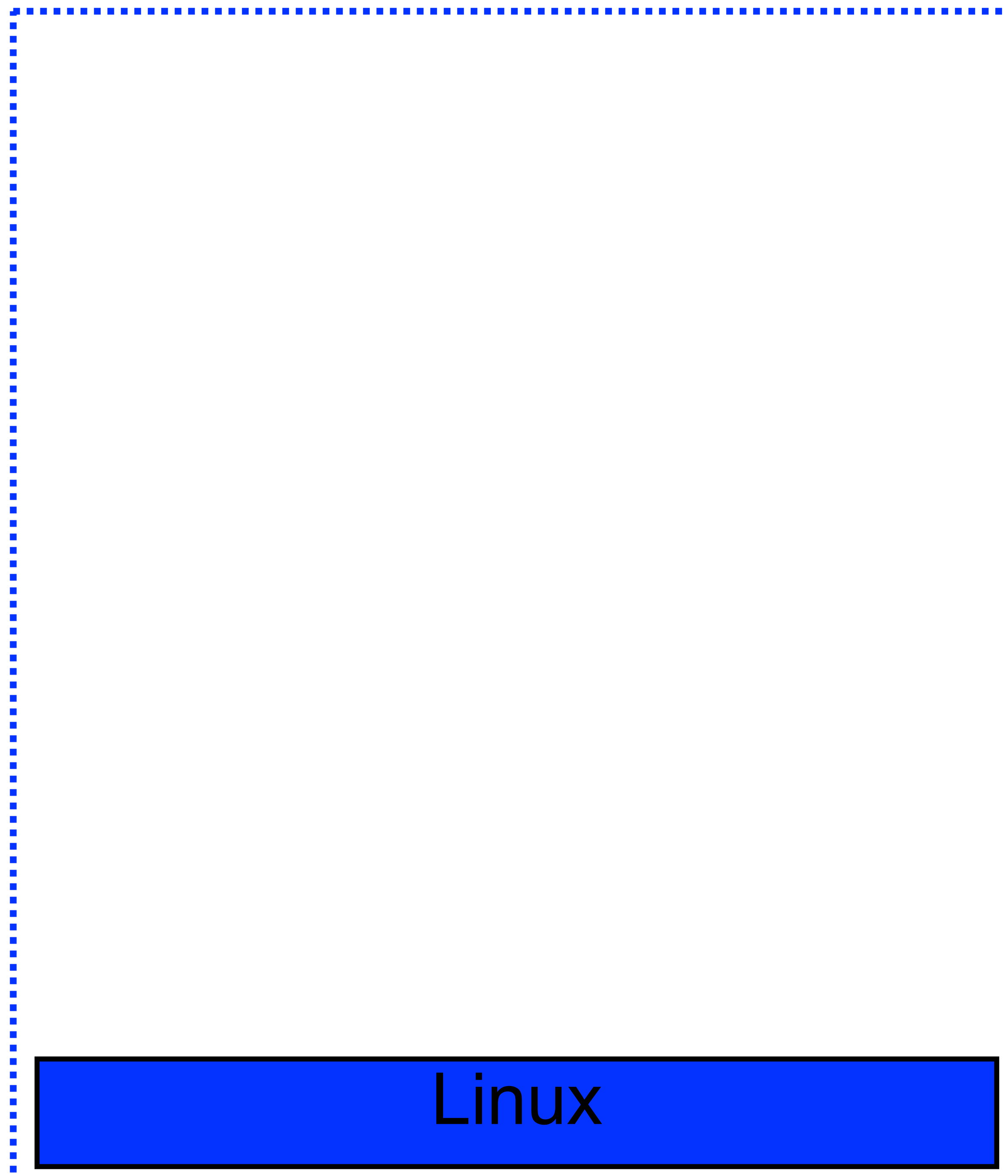
Google

Shared Environment

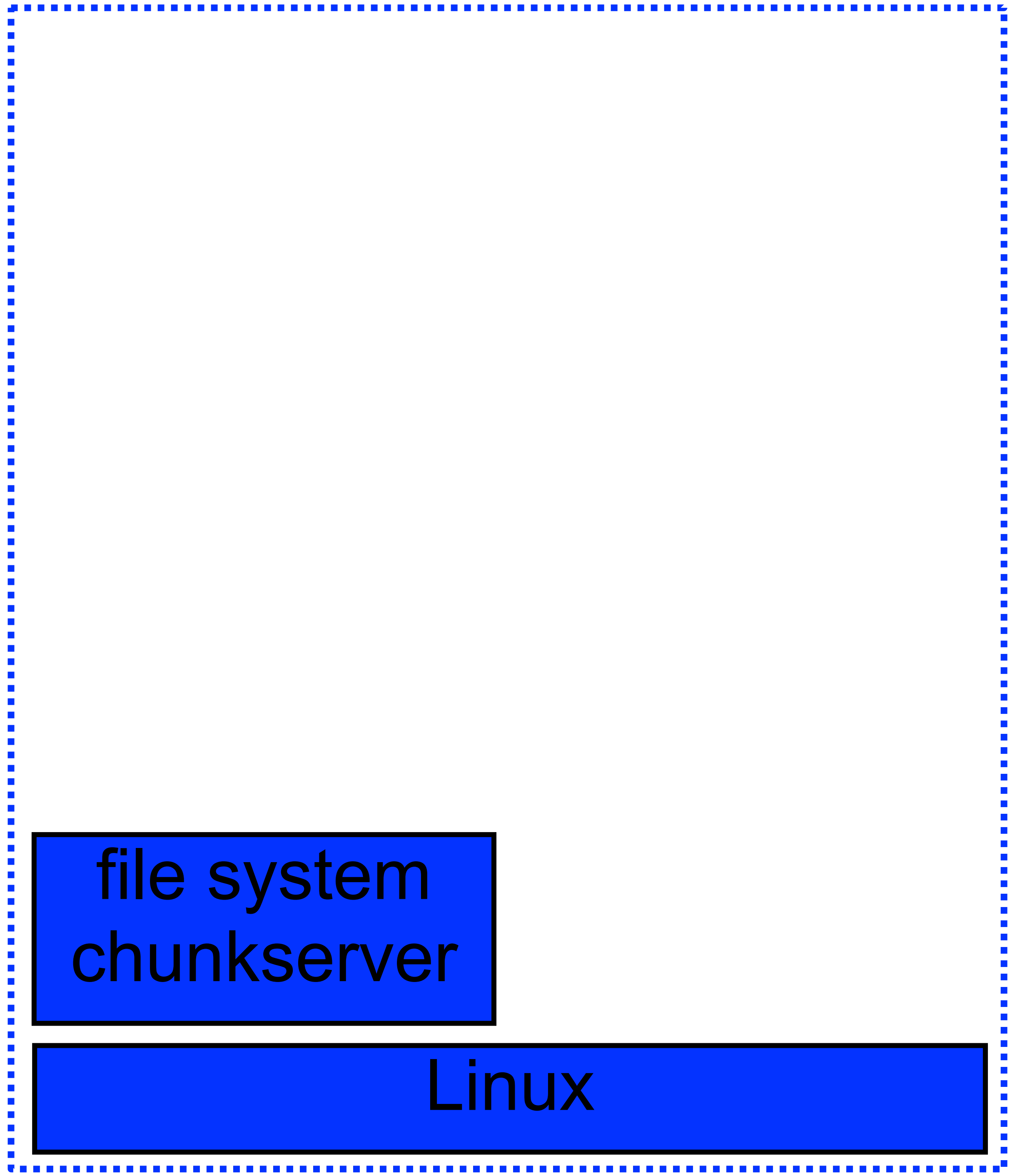
- Huge benefit: greatly increased utilization
- ... but hard to predict effects increase variability
  - network congestion
  - background activities
  - bursts of foreground activity
  - not just your jobs, but everyone else’s jobs, too
- Exacerbated by large fanout systems

Google

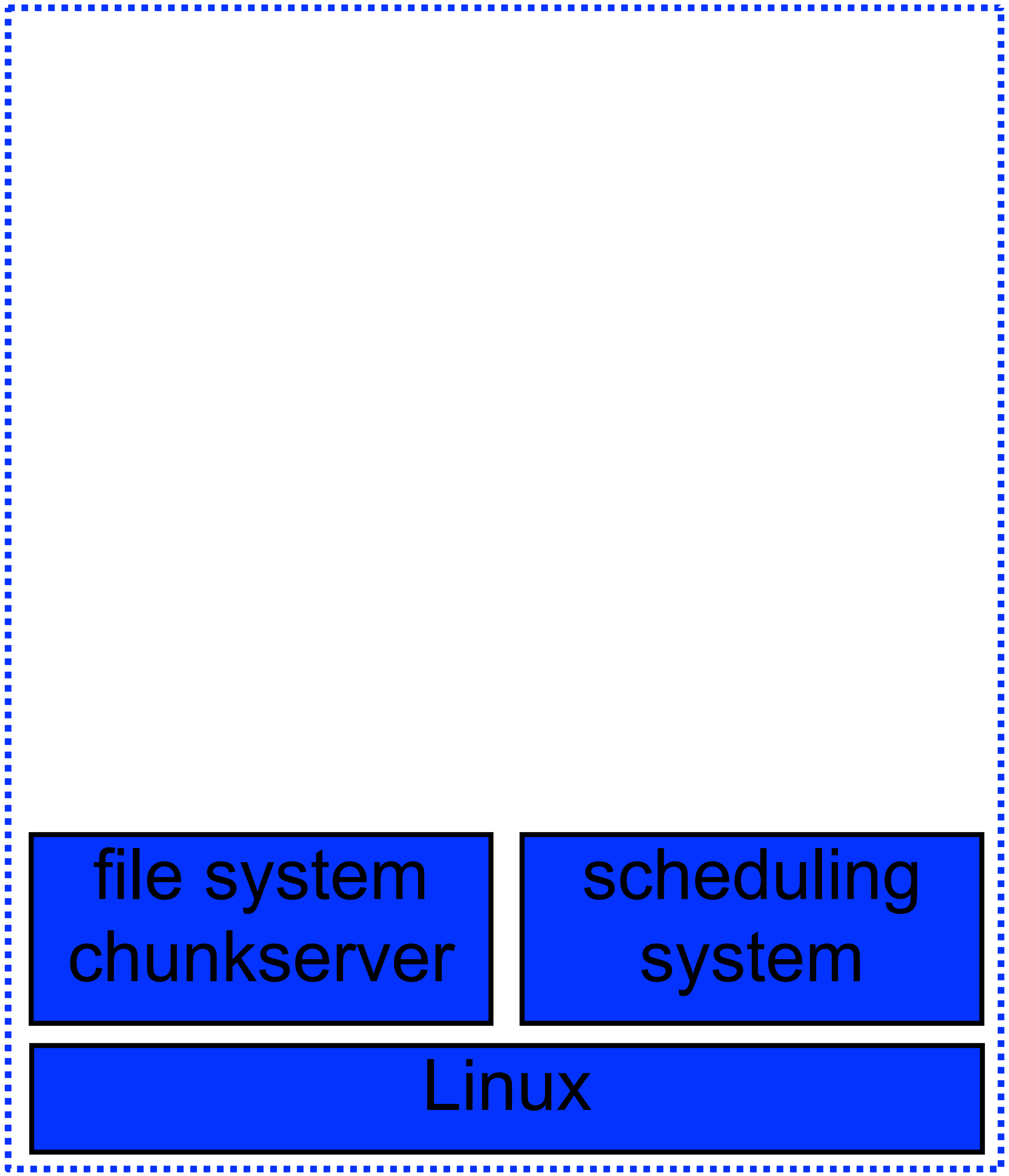
Shared Environment



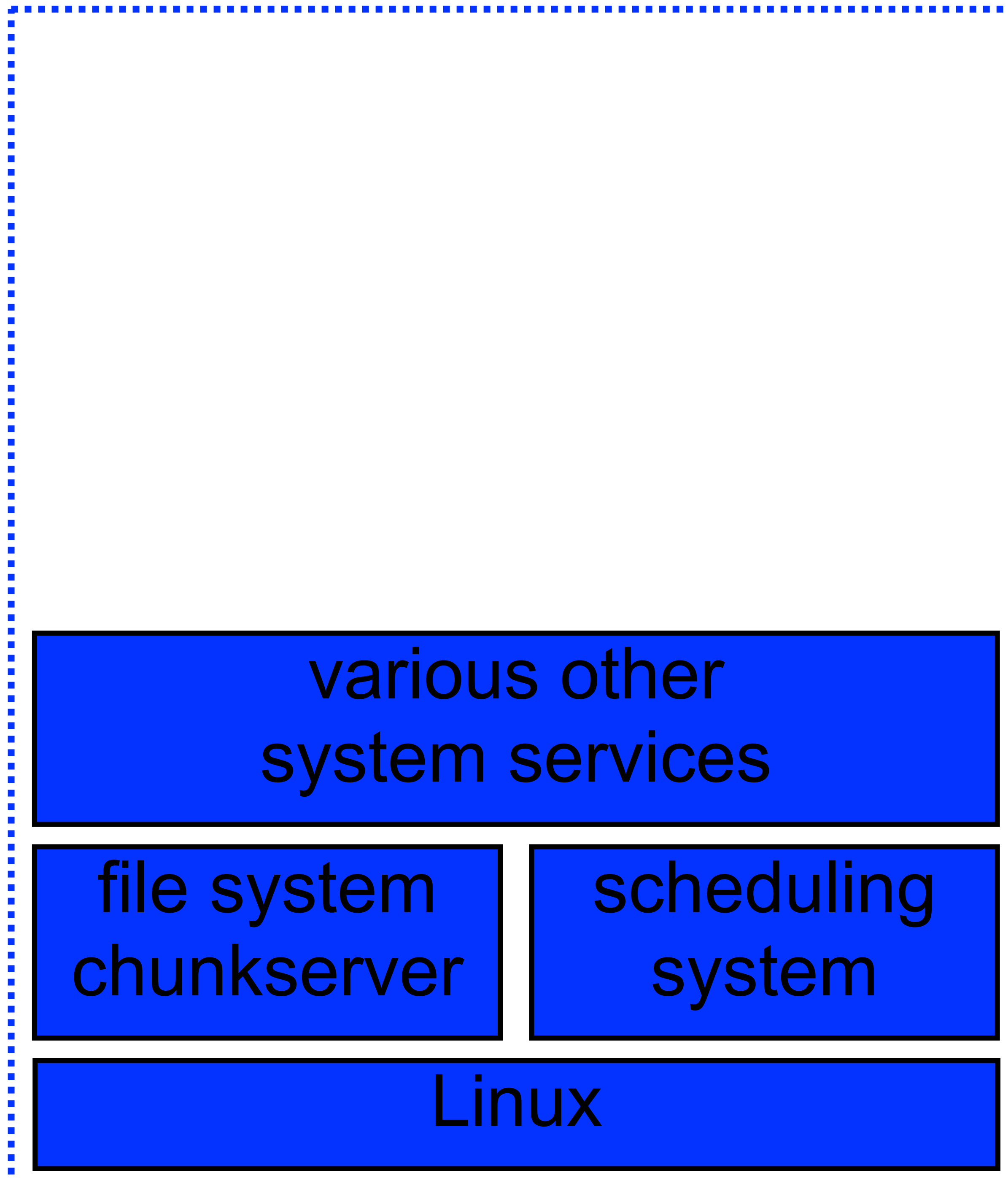
Shared Environment



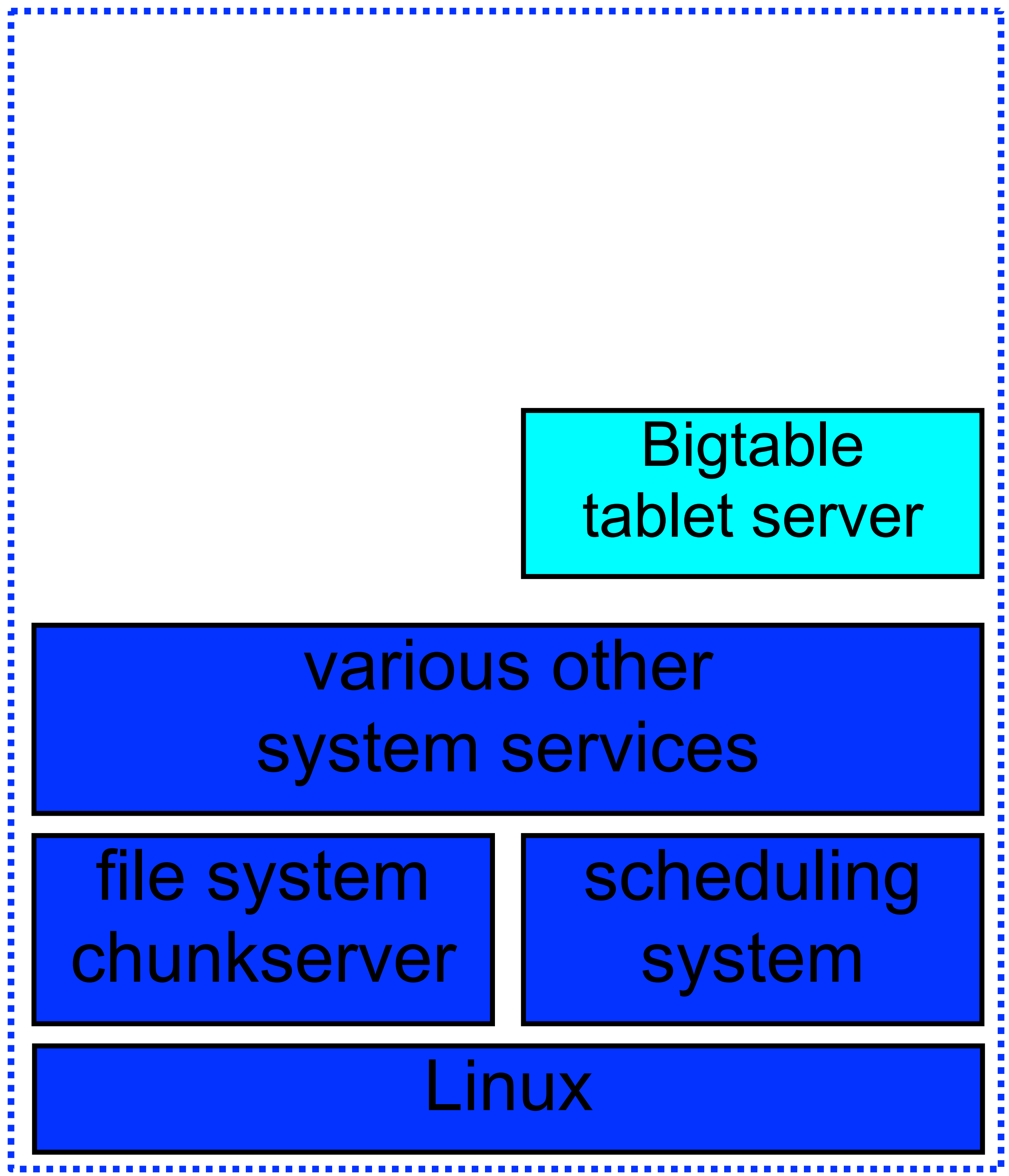
Shared Environment



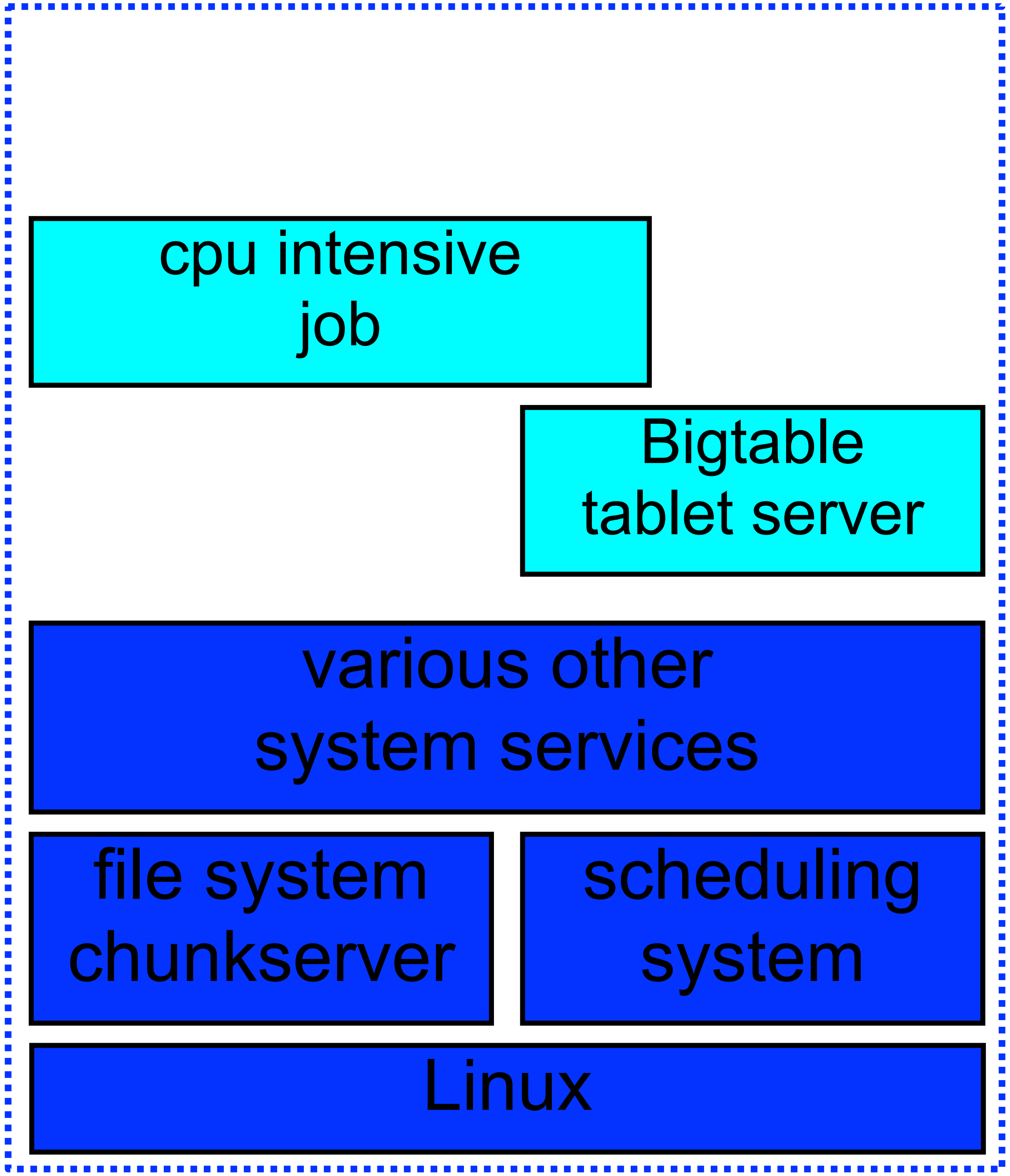
Shared Environment



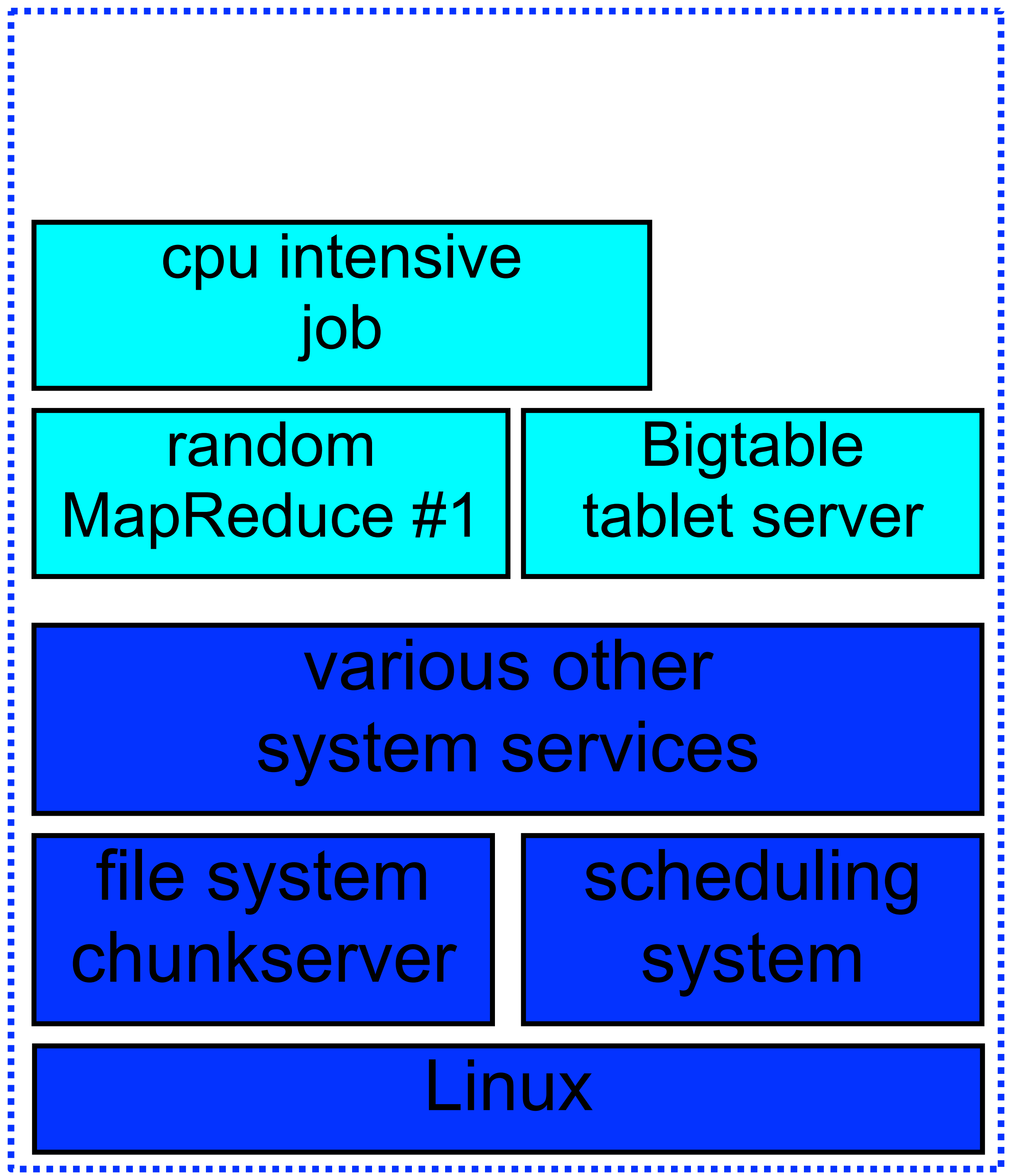
Shared Environment



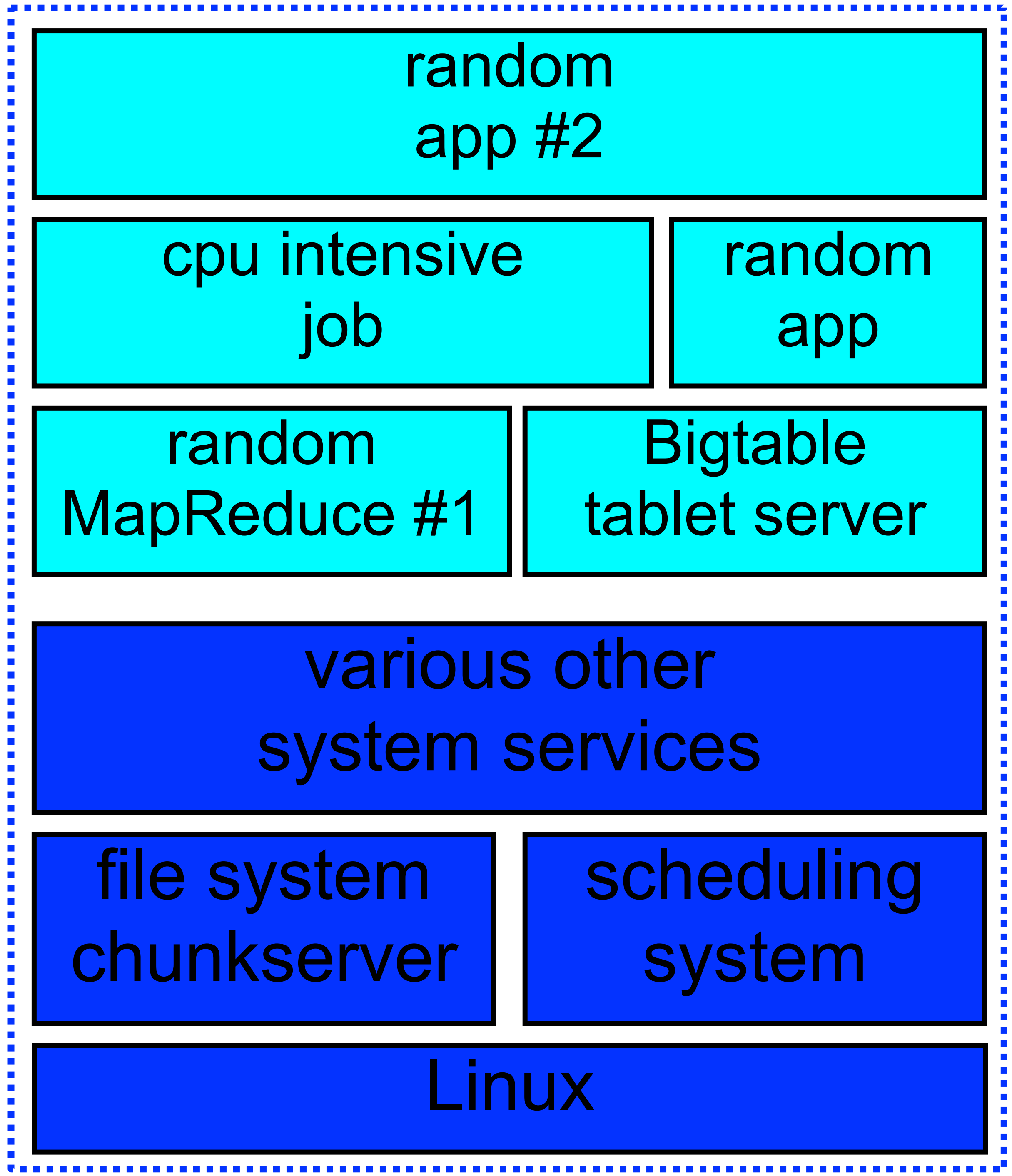
Shared Environment



Shared Environment



Shared Environment



Google

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

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

Google

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**

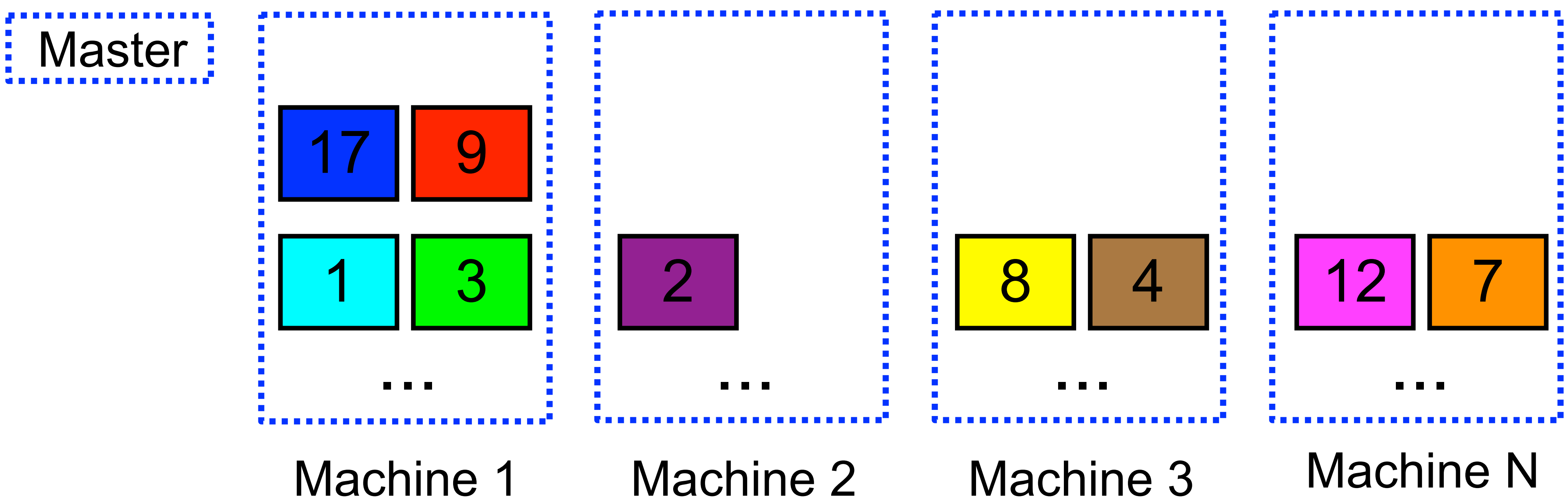
Latency Tolerating Techniques

- 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

Google

Fine-Grained Dynamic Partitioning

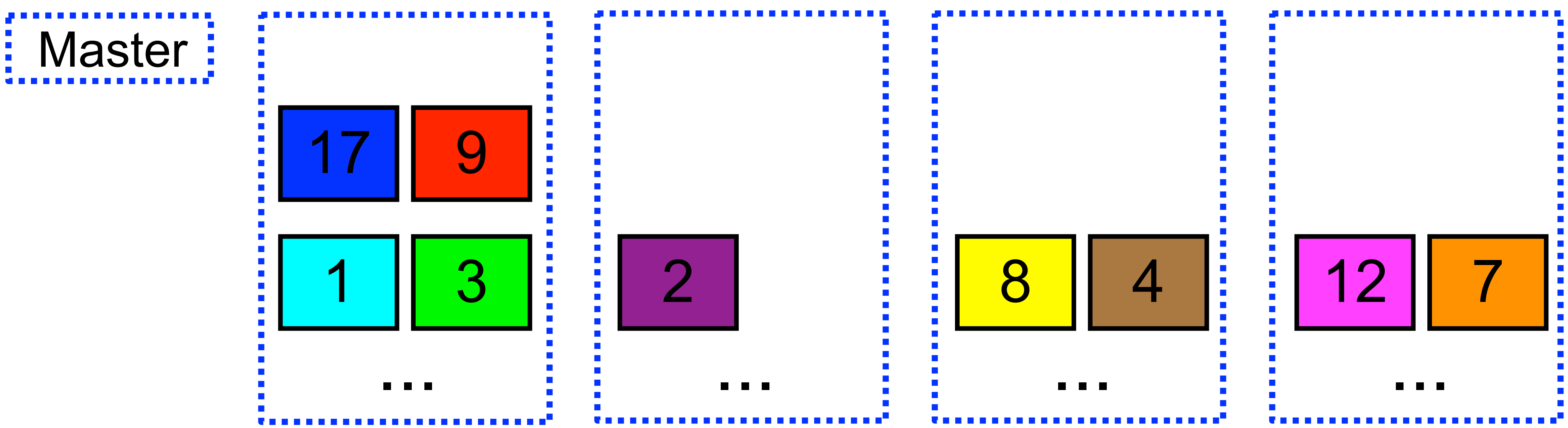
- Partition large datasets/computations
  - more than 1 partition per machine (often 10-100/machine)
  - e.g. BigTable, query serving systems, GFS, ...



Google

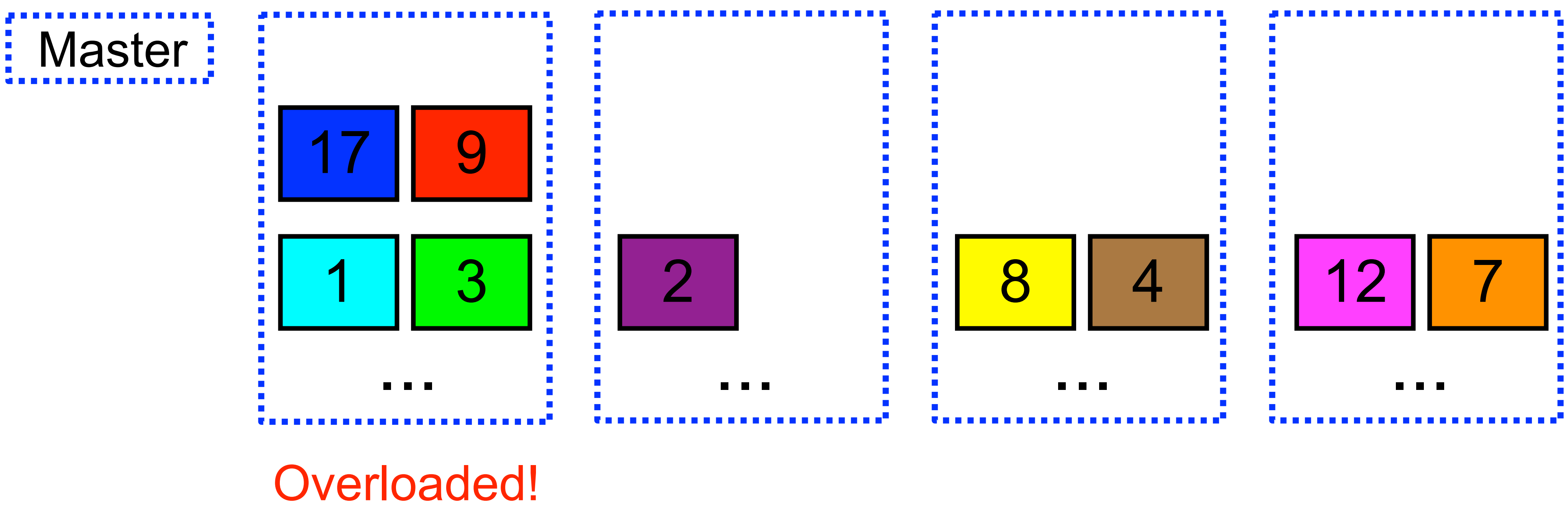
Load Balancing

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



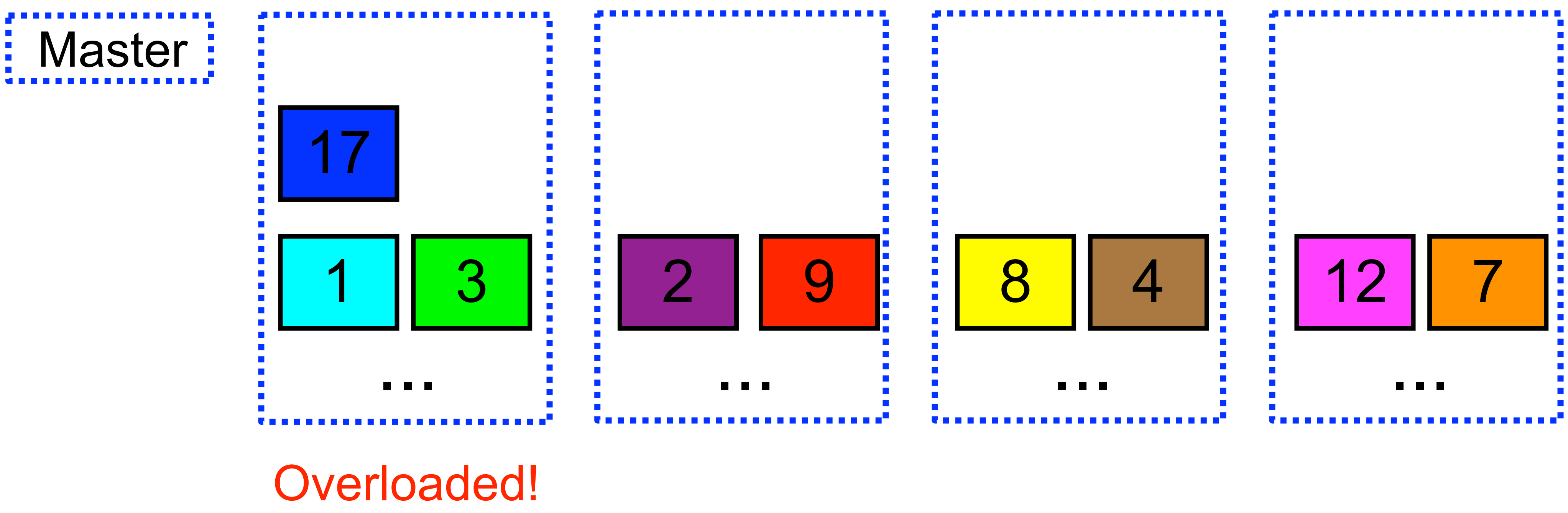
Load Balancing

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



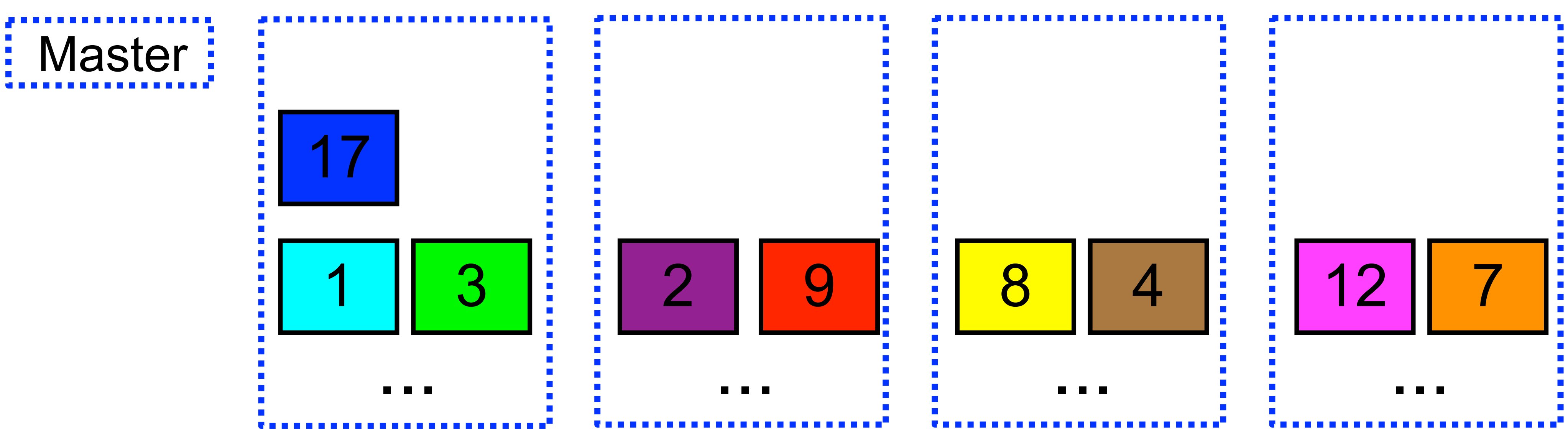
Load Balancing

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



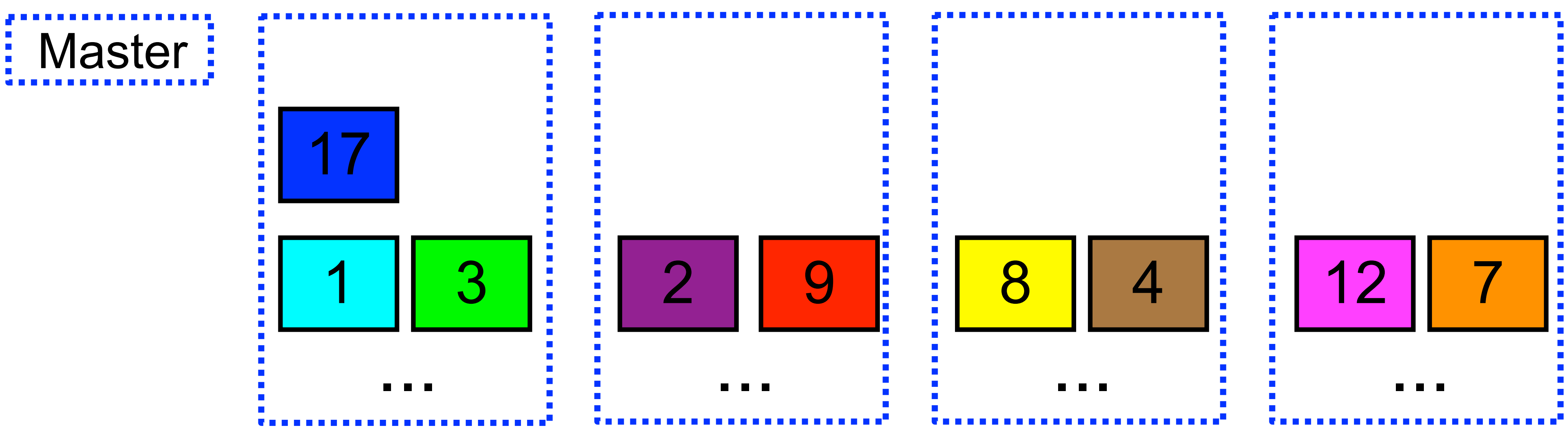
Load Balancing

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



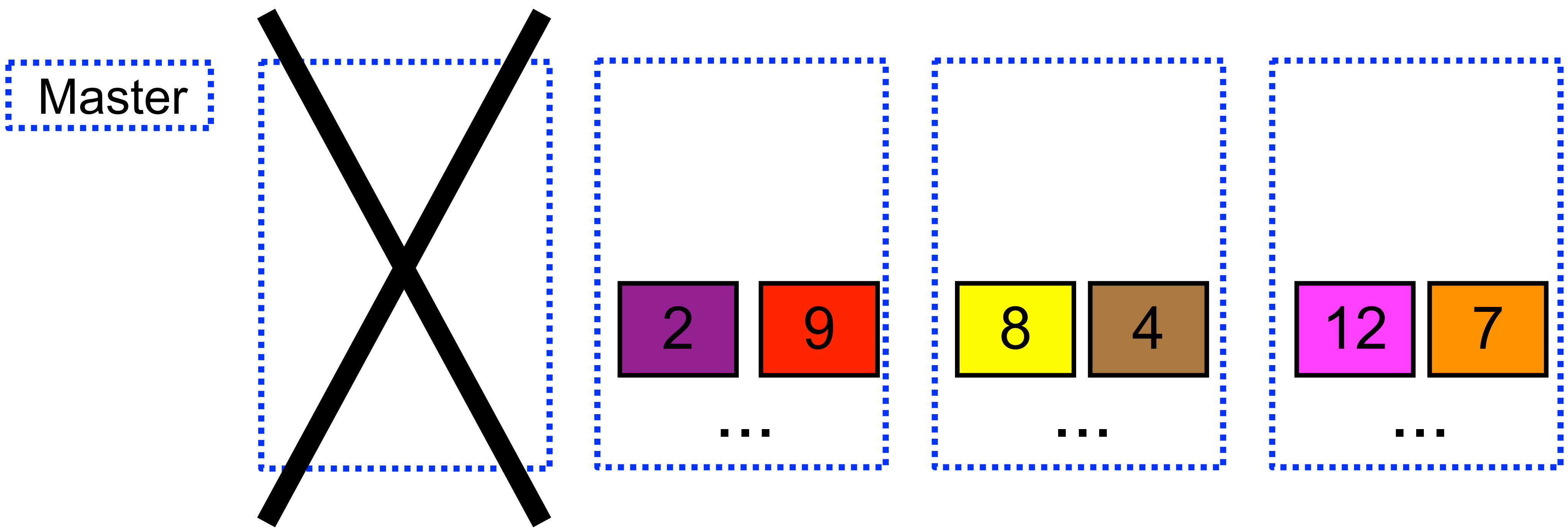
Speeds Failure Recovery

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



Speeds Failure Recovery

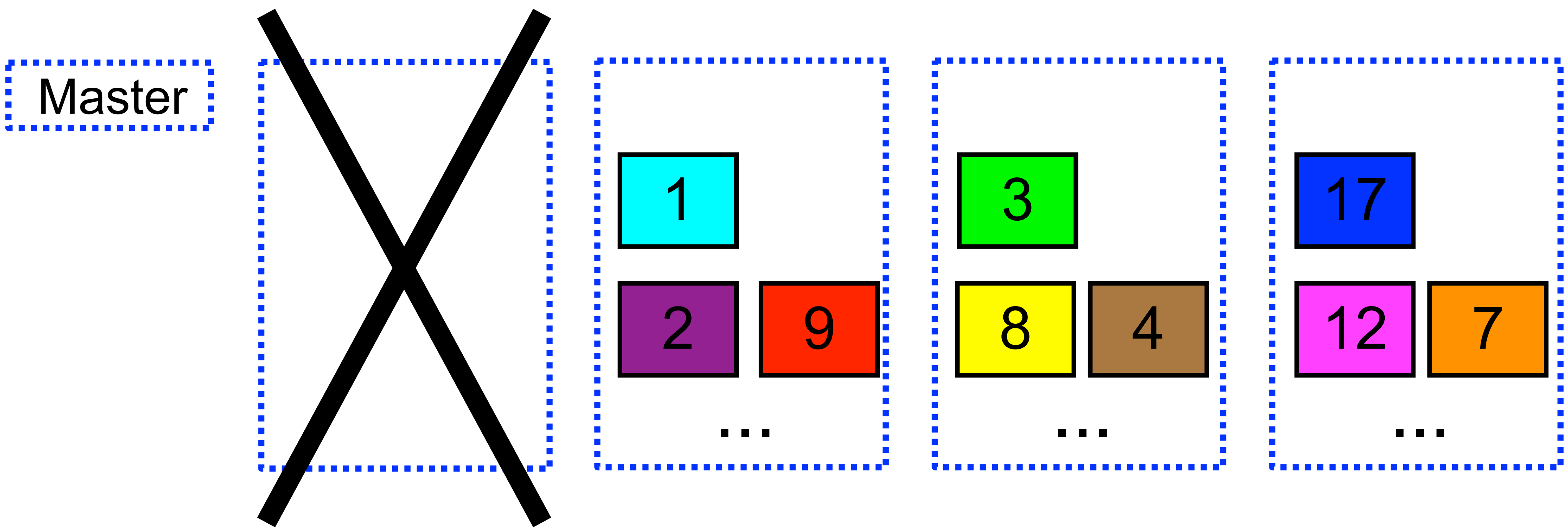
- Many machines each recover one or a few partition
  - e.g. BigTable tablets, GFS chunks, query serving shards



Google

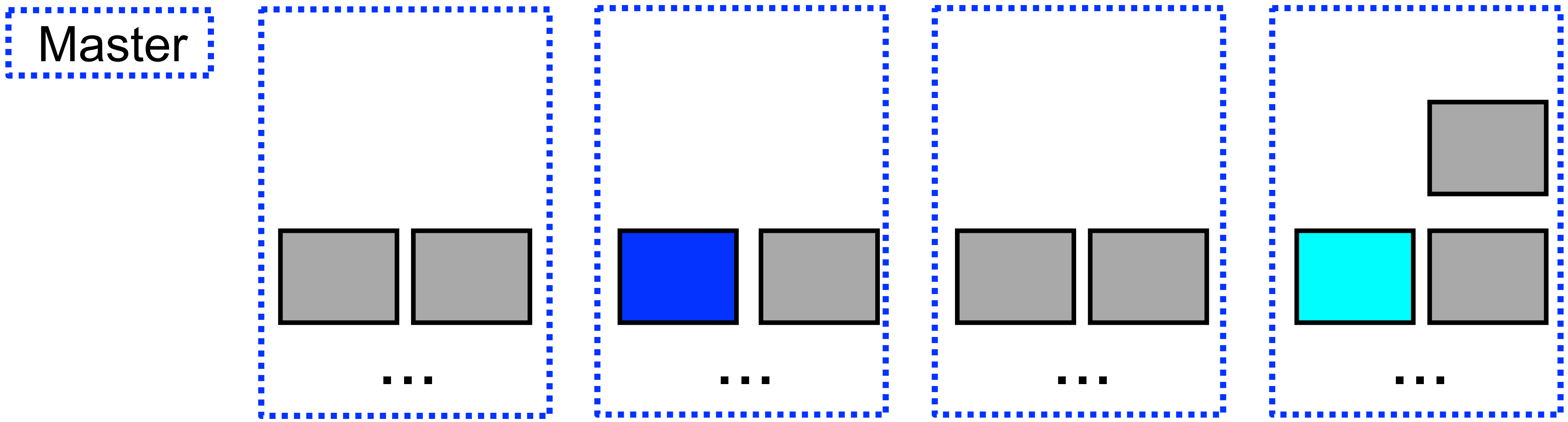
Speeds Failure Recovery

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



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

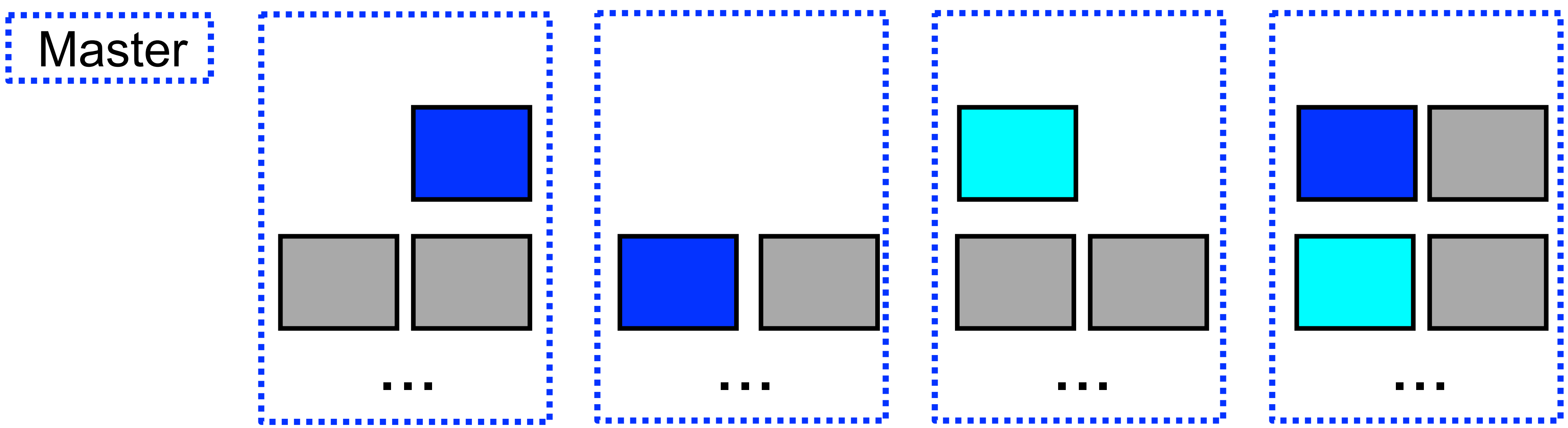


Google

Selective Replication

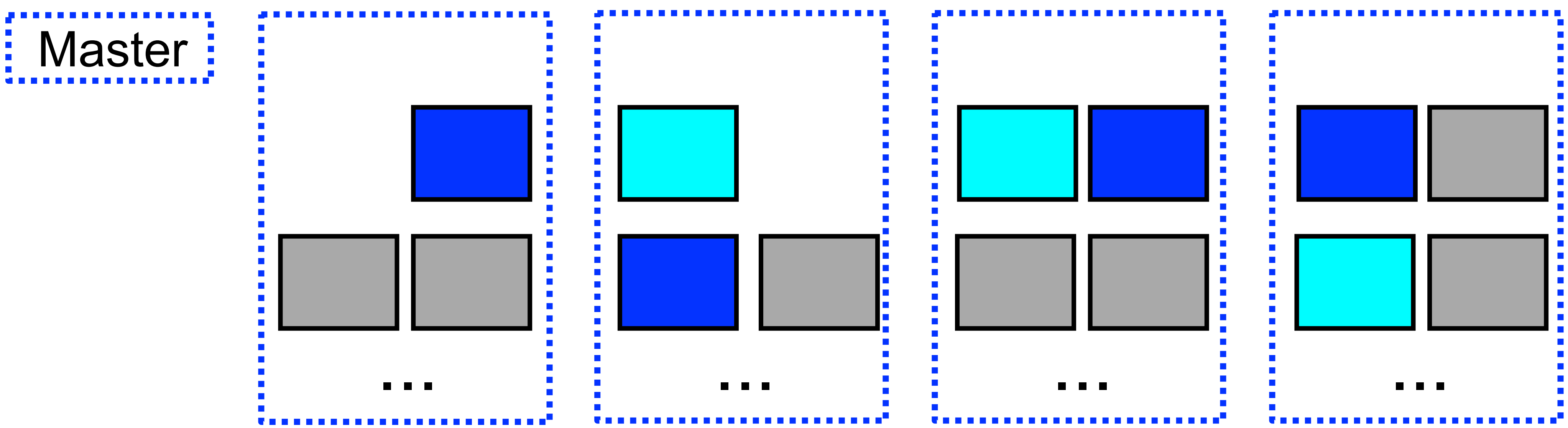
- Find heavily used items and make more replicas
  – can be static or dynamic

- Example: Query serving system
  – static: more replicas of important docs
  – dynamic: more replicas of Chinese documents as Chinese query load increases



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



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

Google

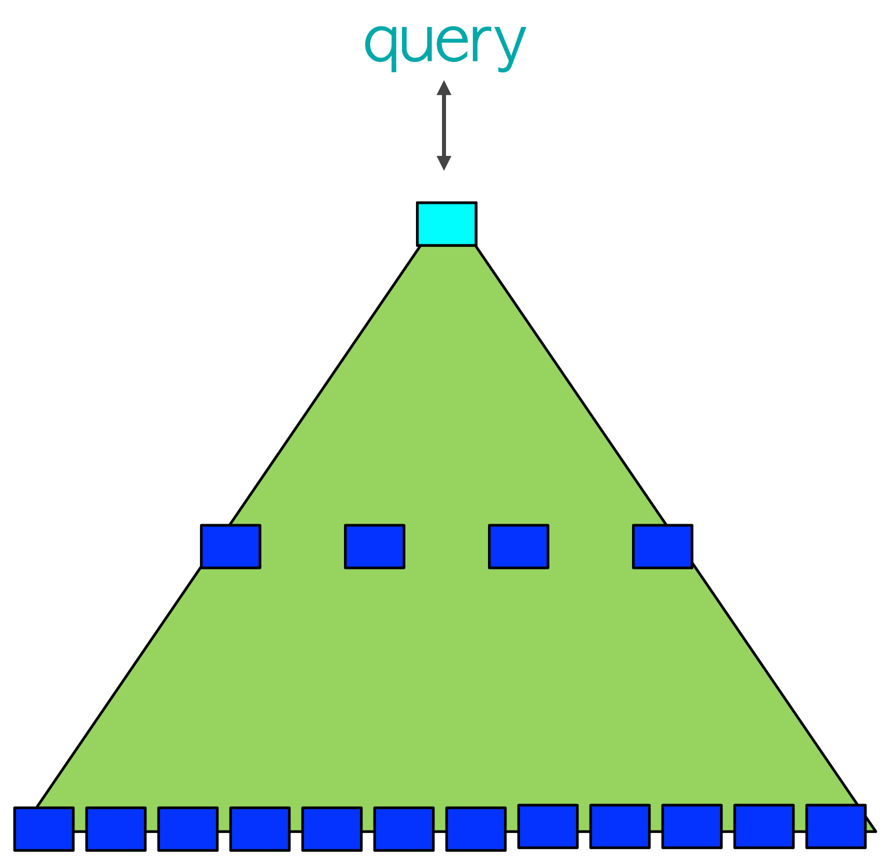
Handling Within-Request Variability

- Take action within single high-level request

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

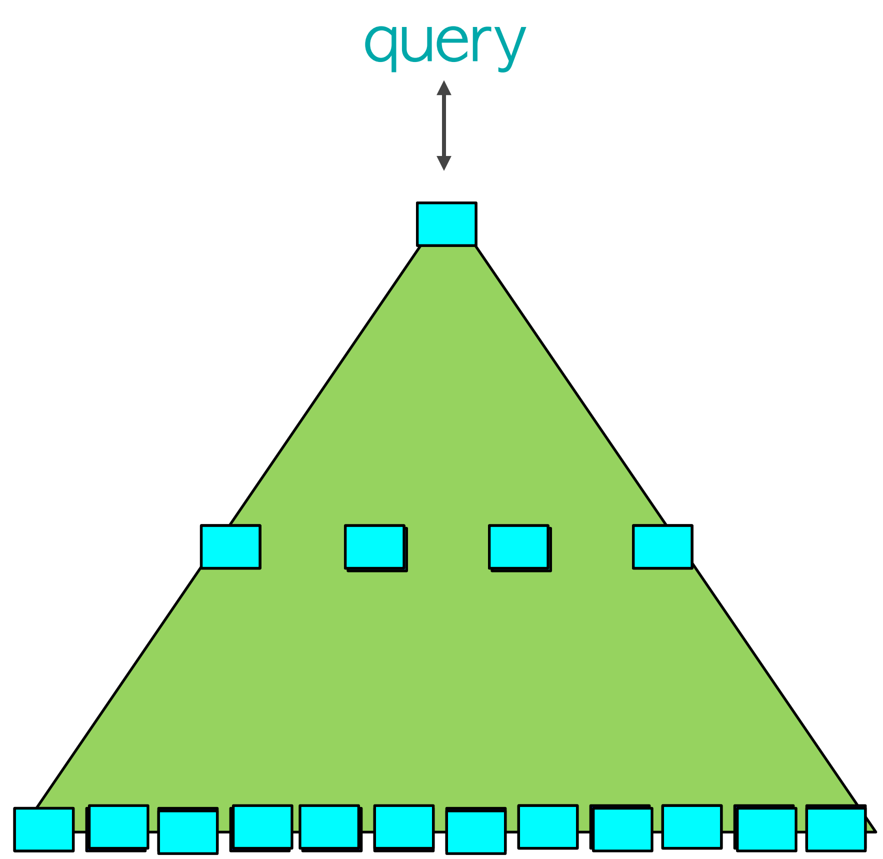
Google

Data Independent Failures

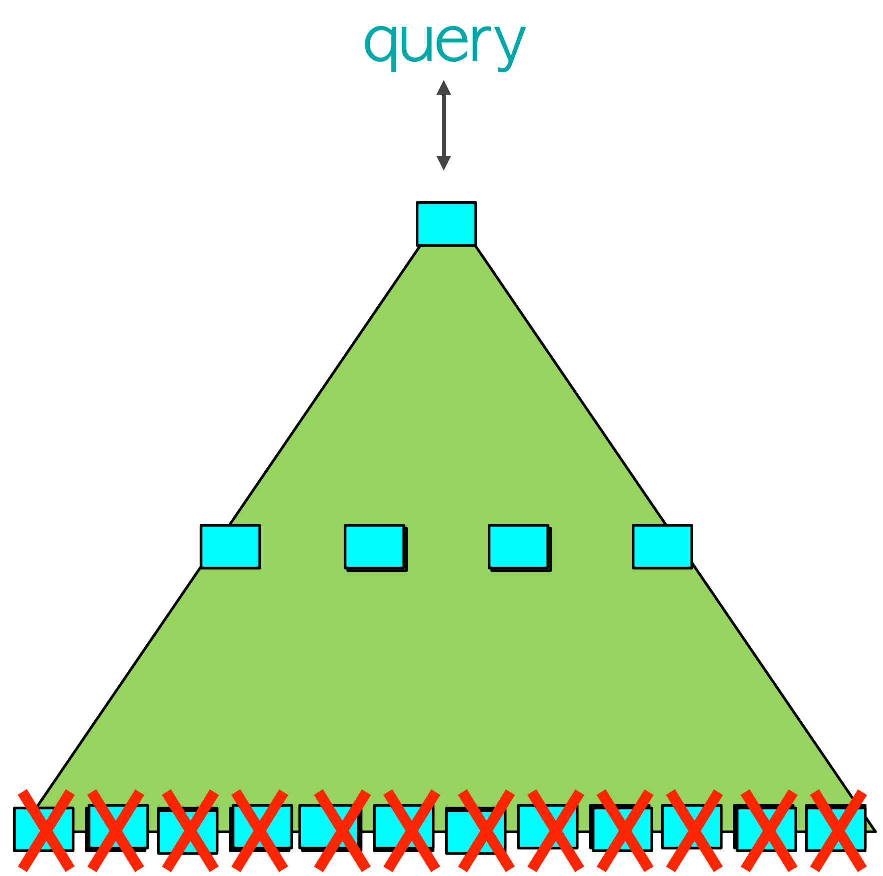


Google

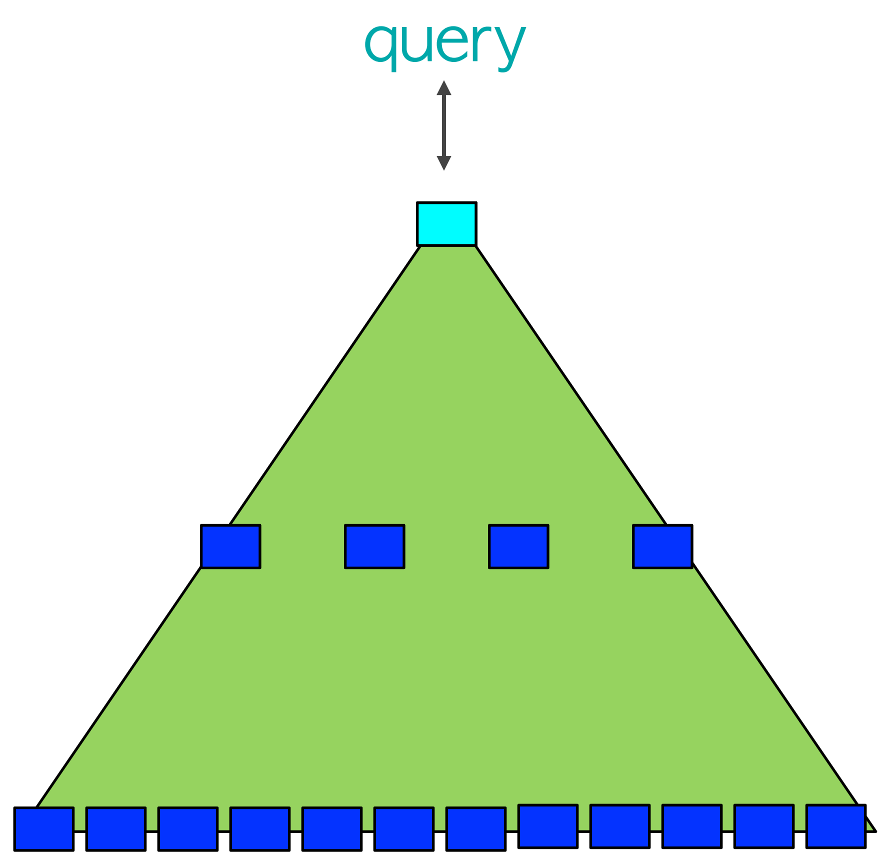
Data Independent Failures



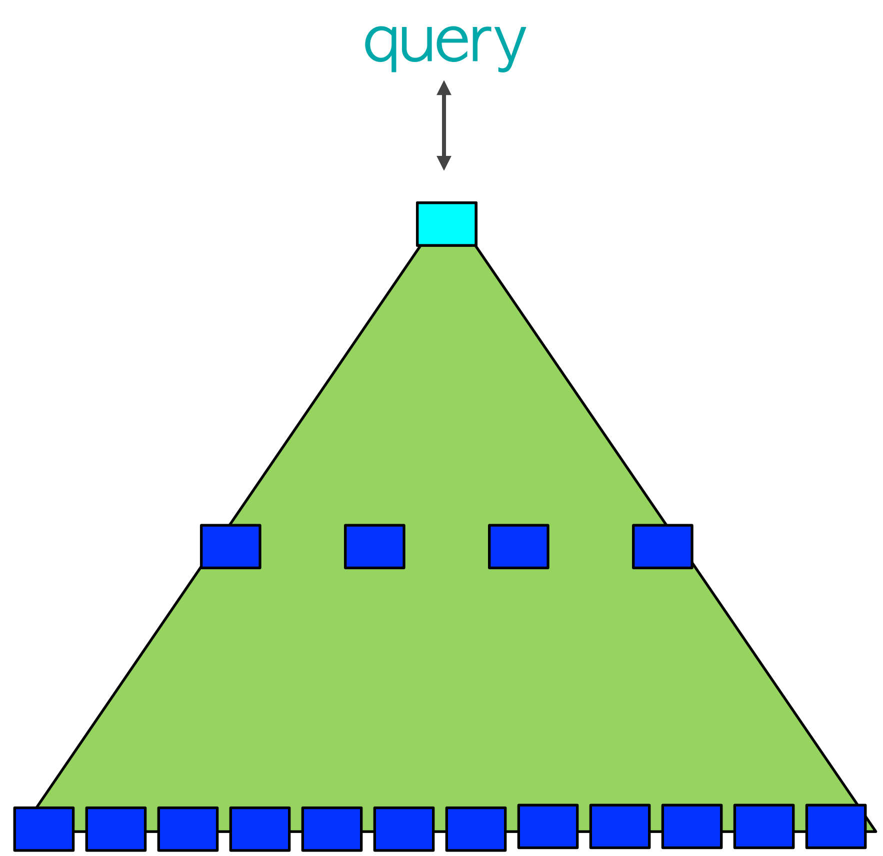
Data Independent Failures



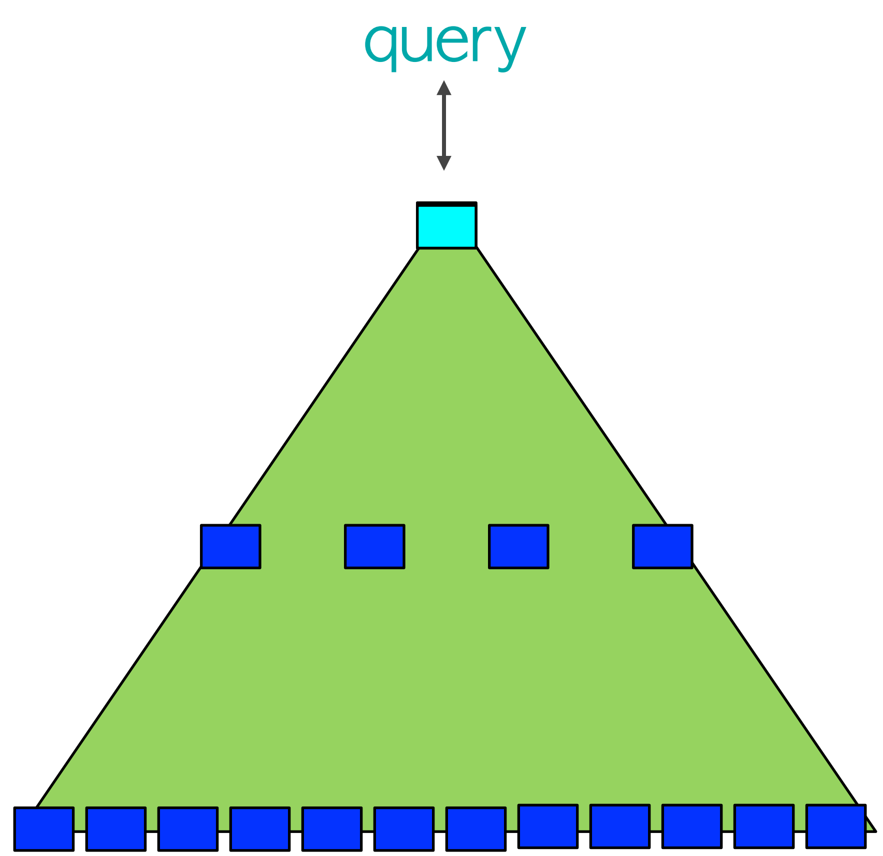
Canary Requests (2)



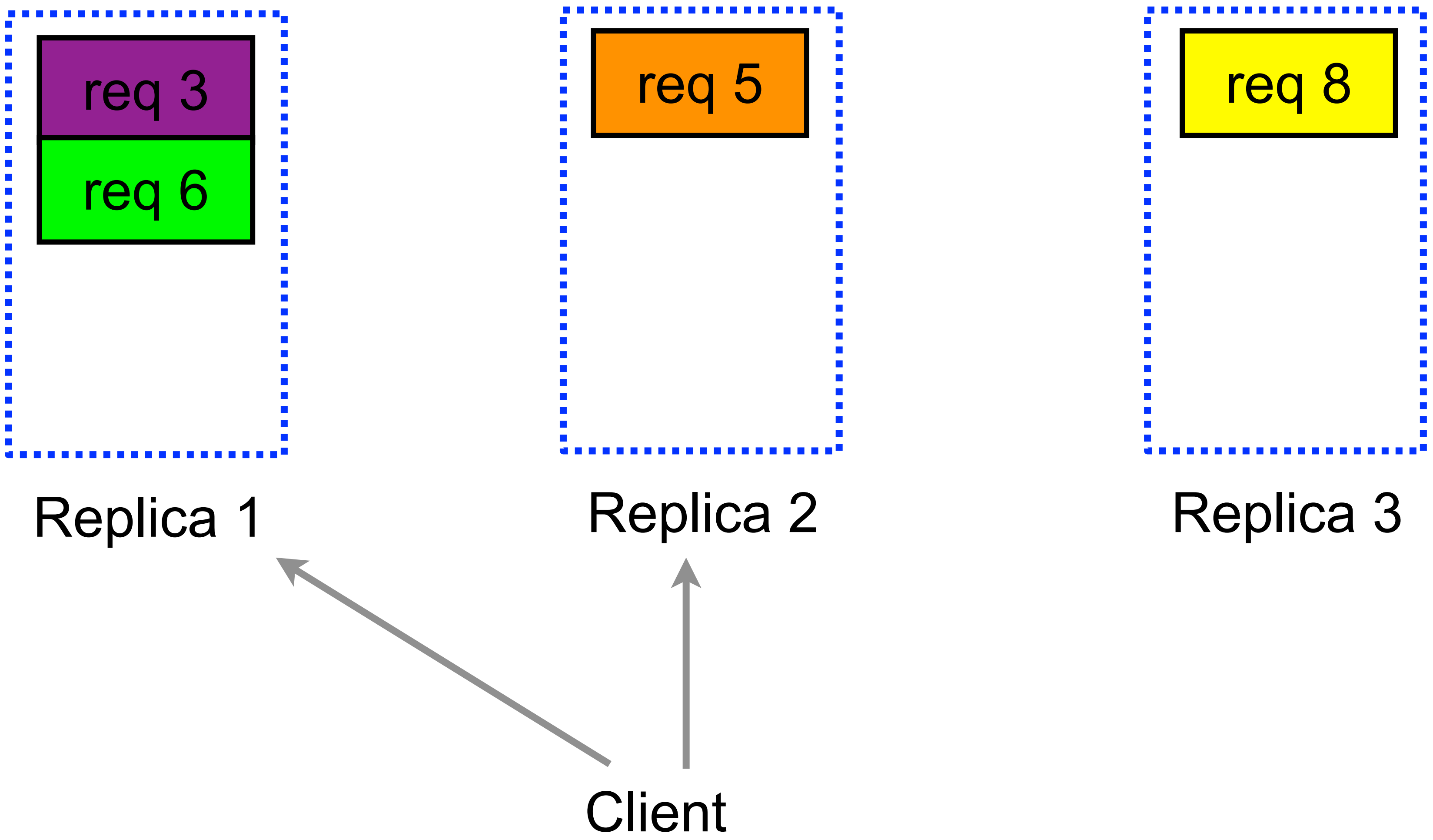
Canary Requests (2)



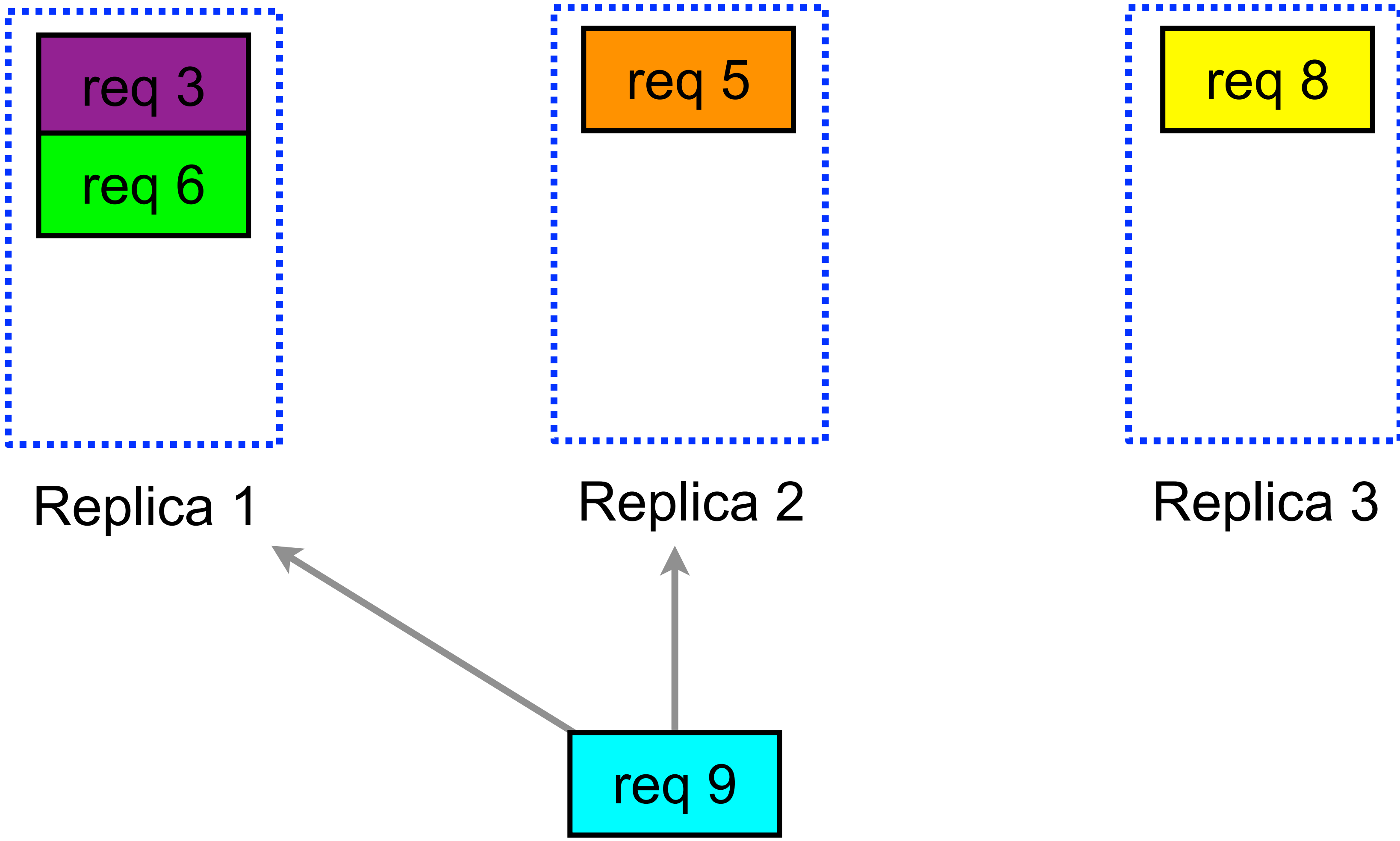
Canary Requests (2)



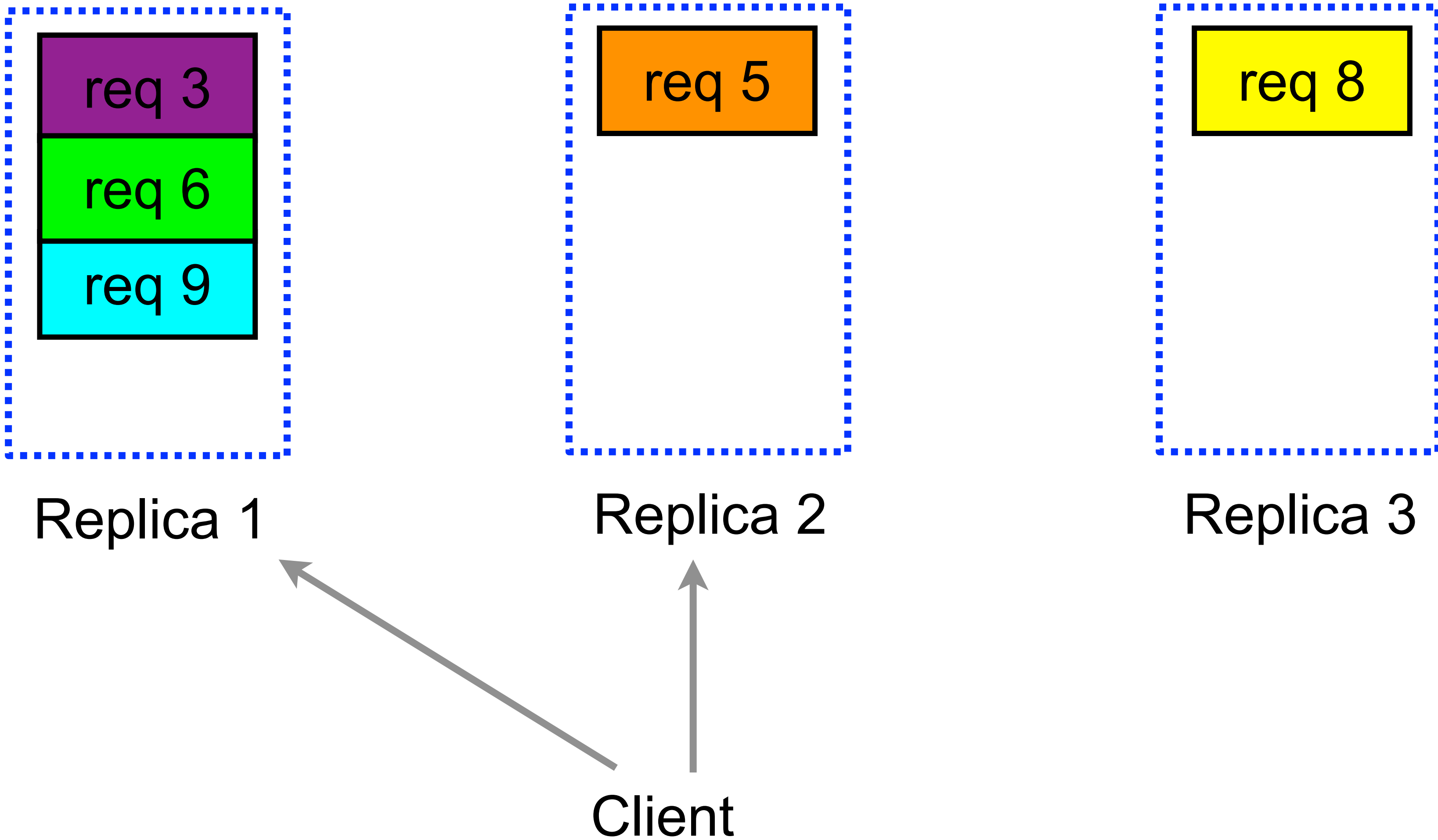
Backup Requests



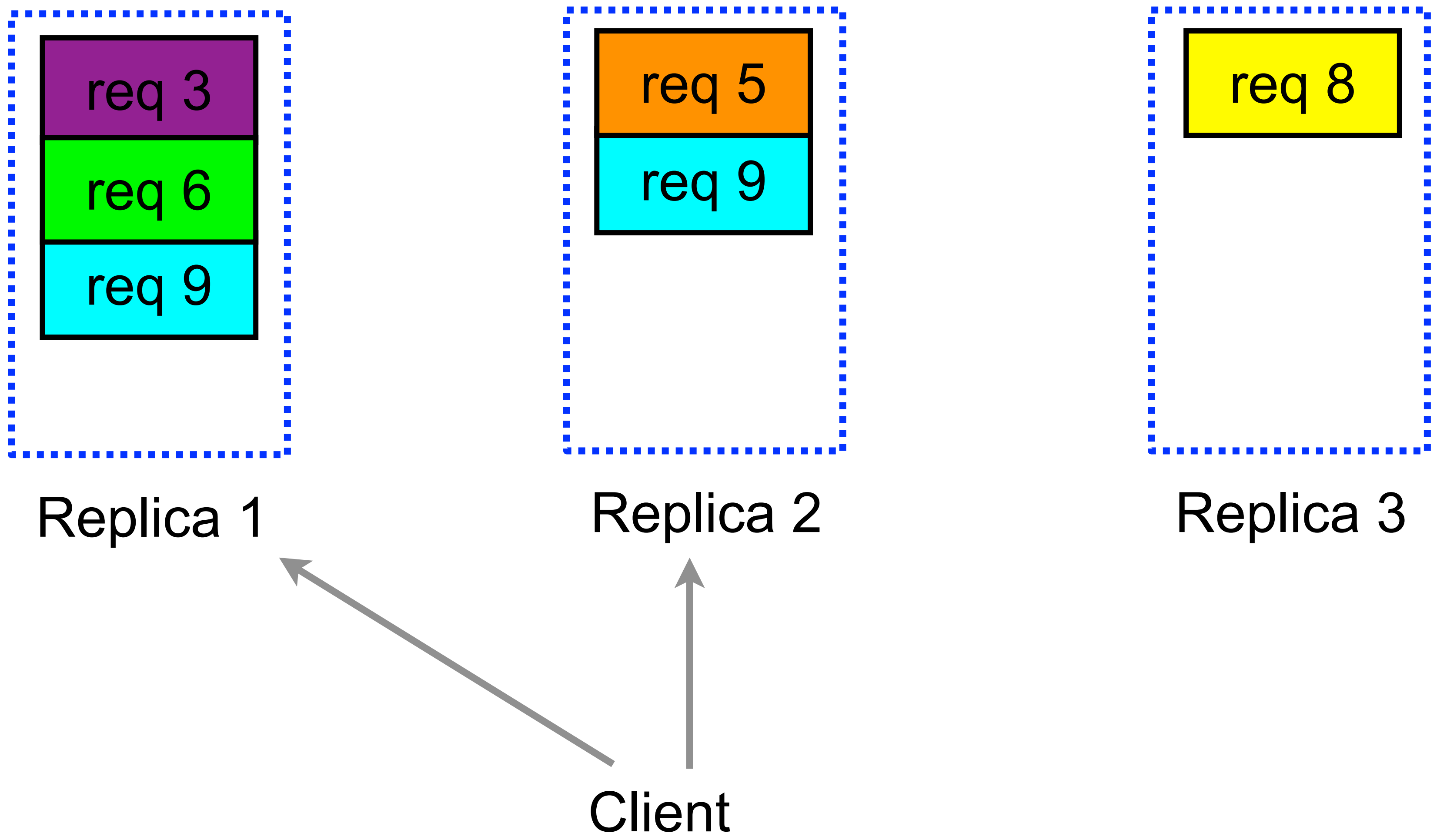
Backup Requests



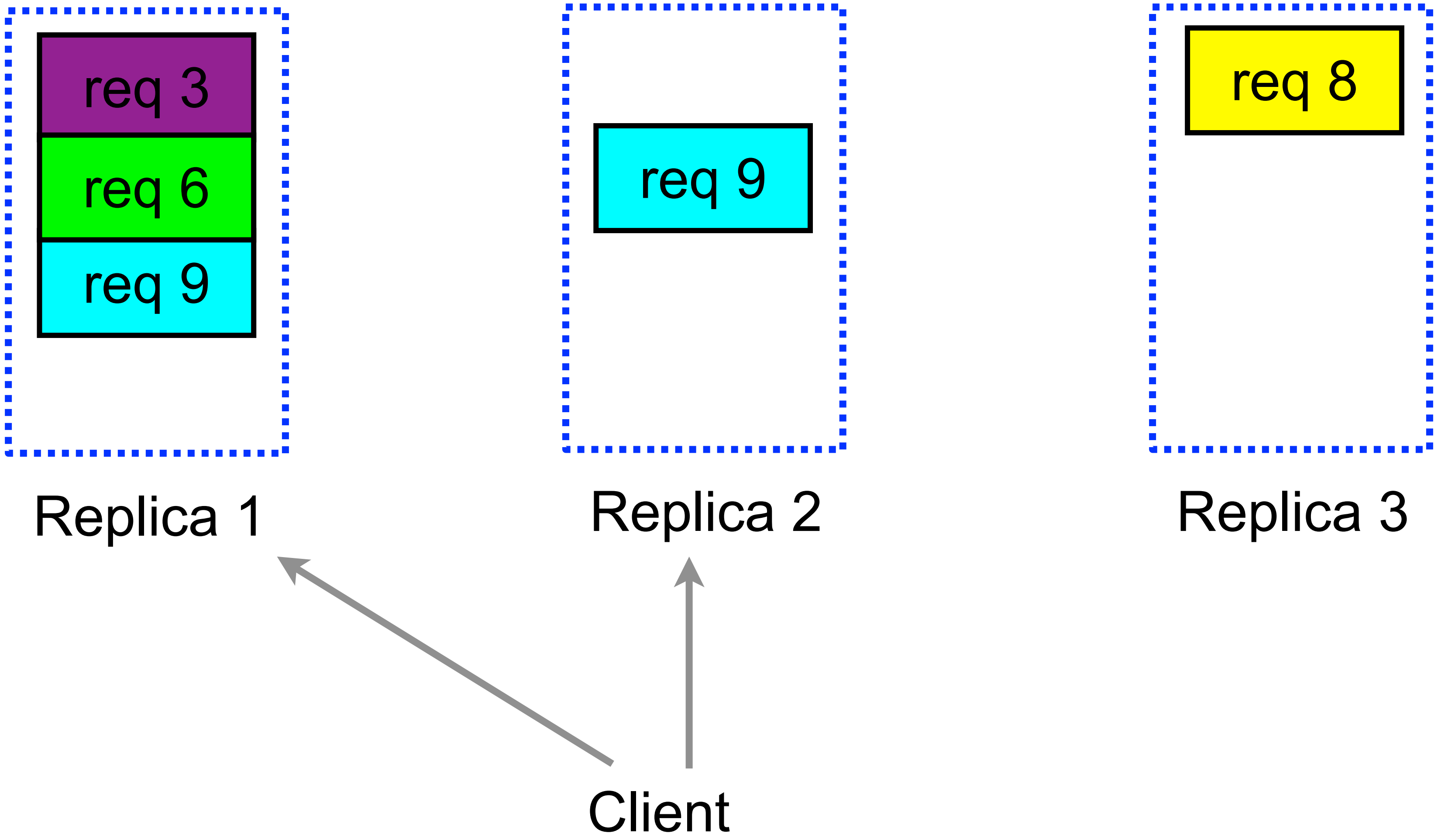
Backup Requests



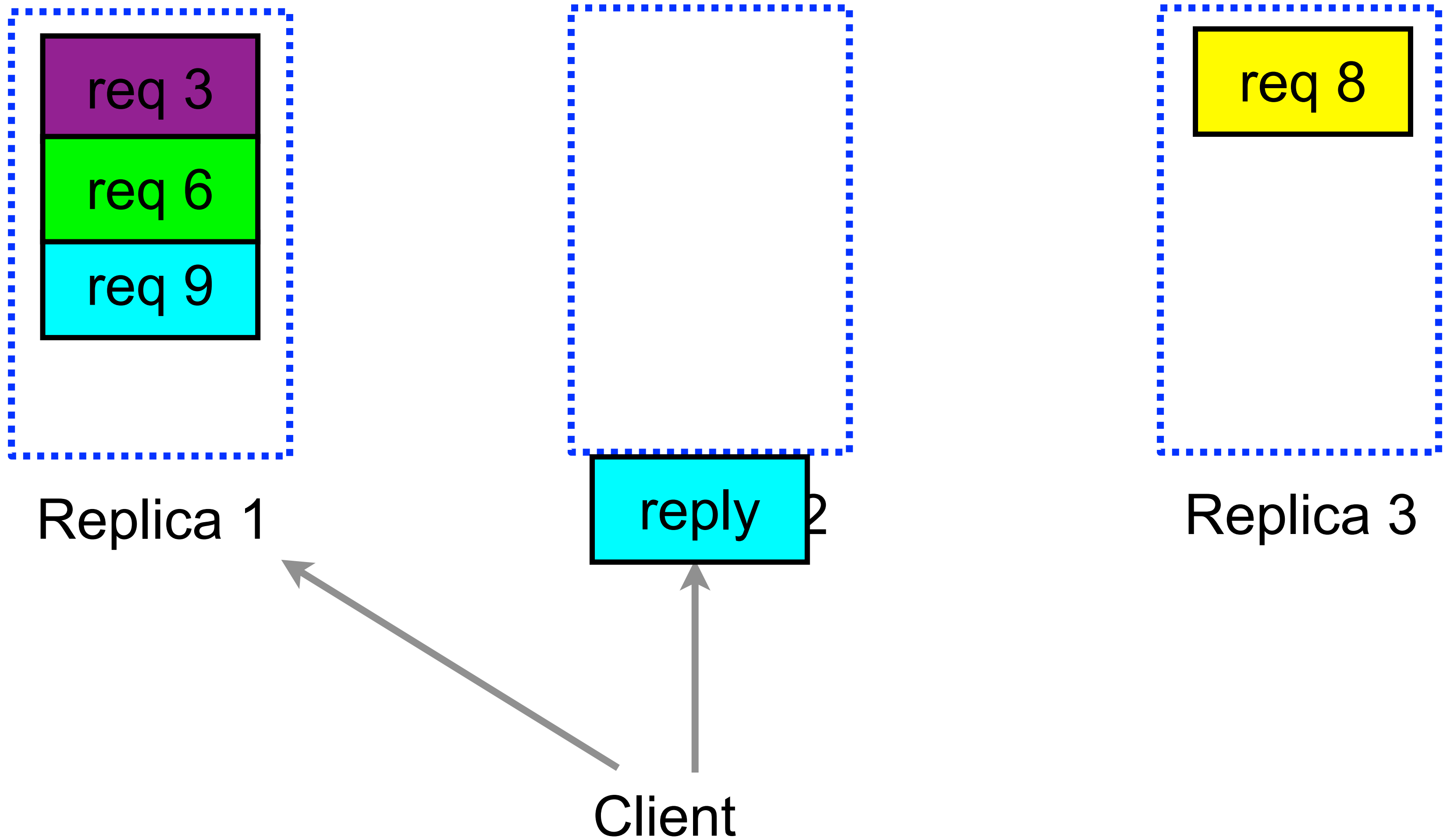
Backup Requests



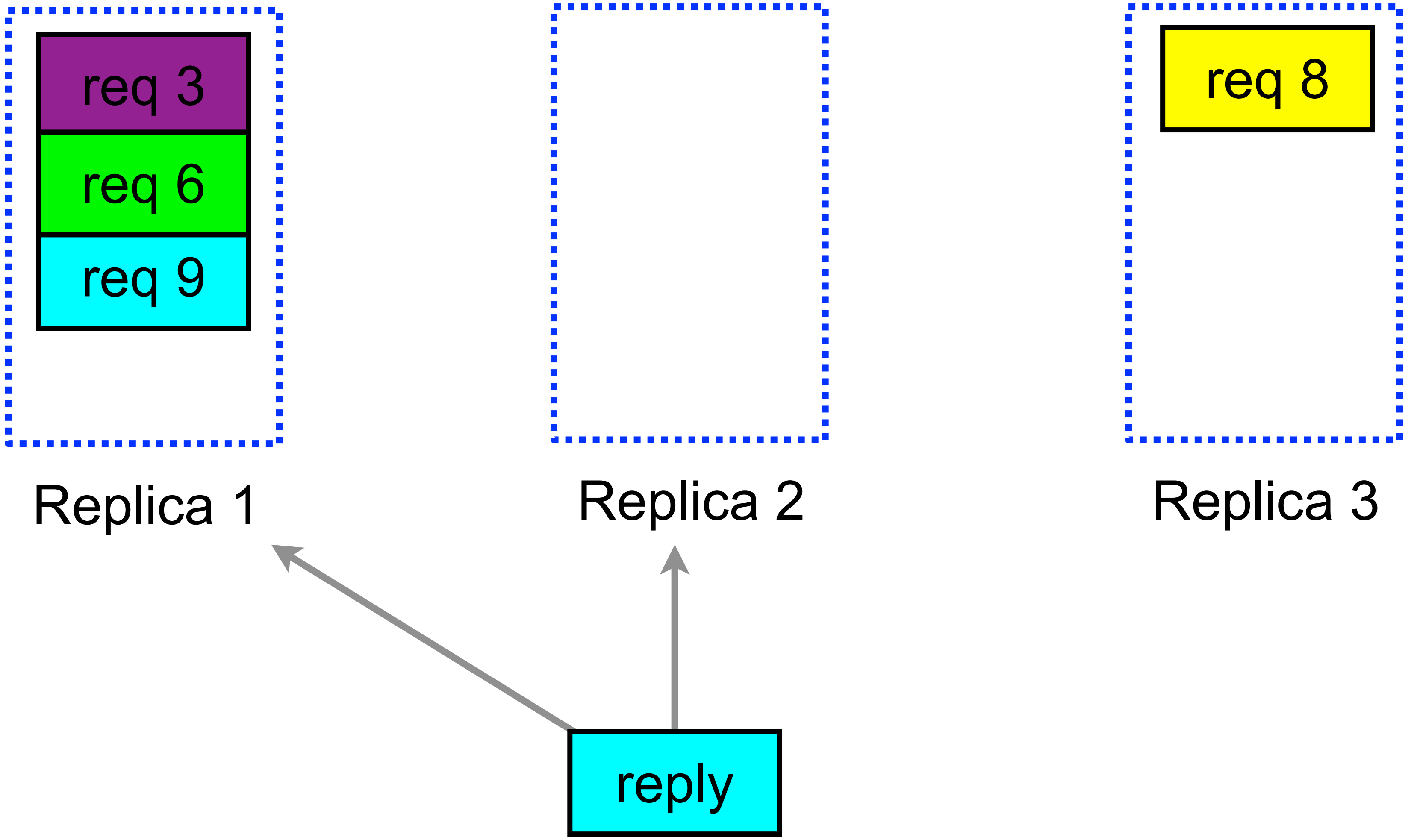
Backup Requests



Backup Requests

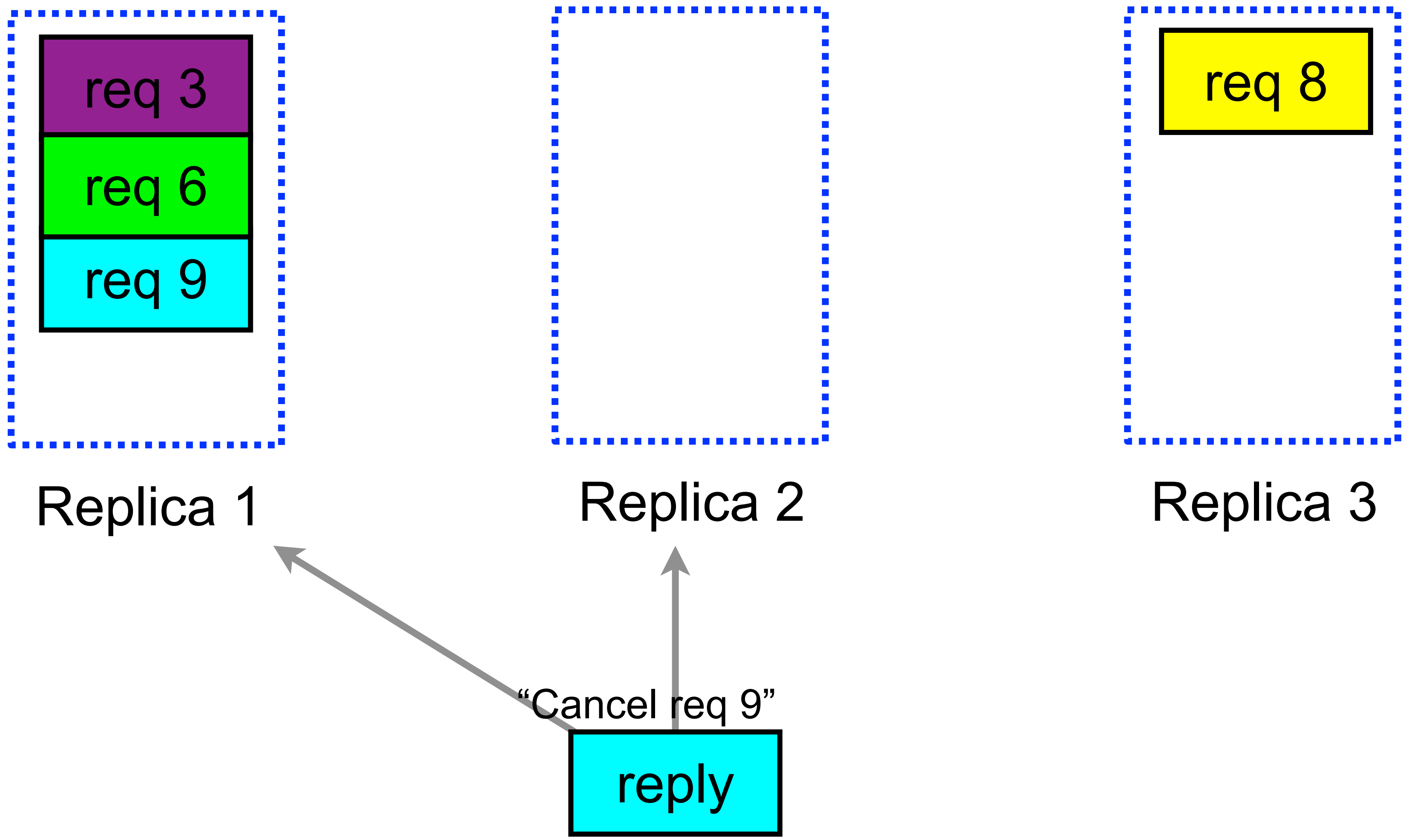


Backup Requests

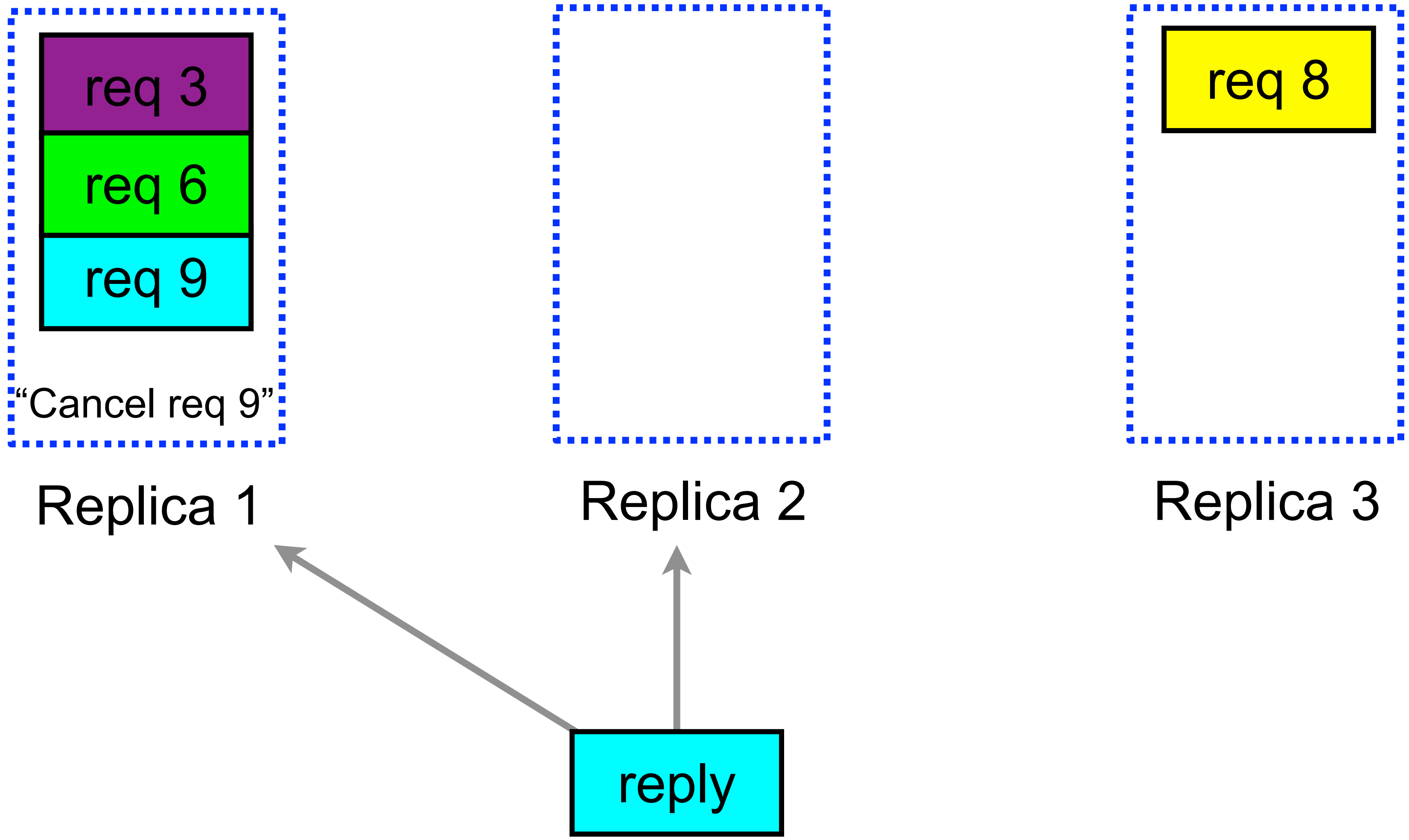


Google

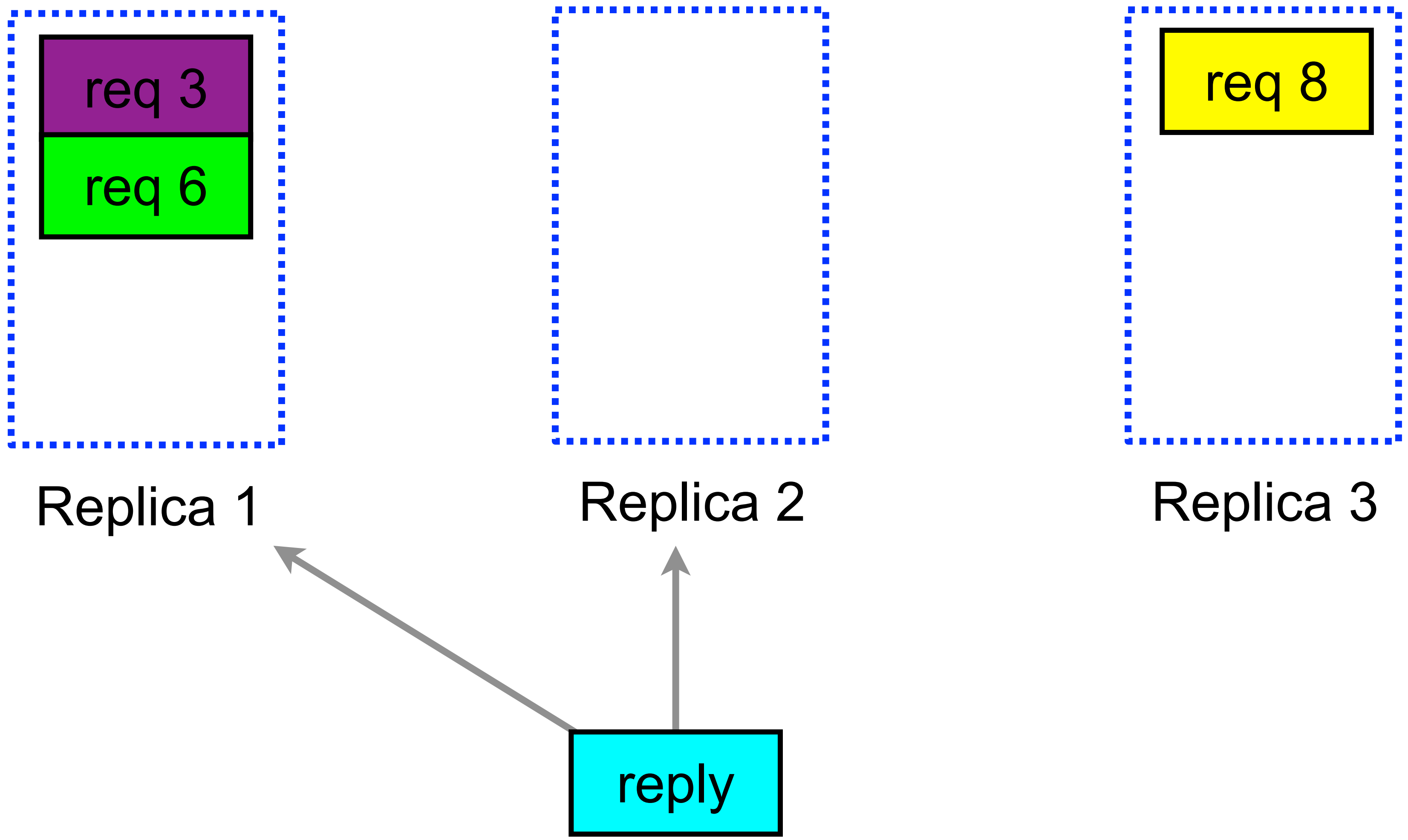
Backup Requests



Backup Requests



Backup Requests



Google

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

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

	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

Google

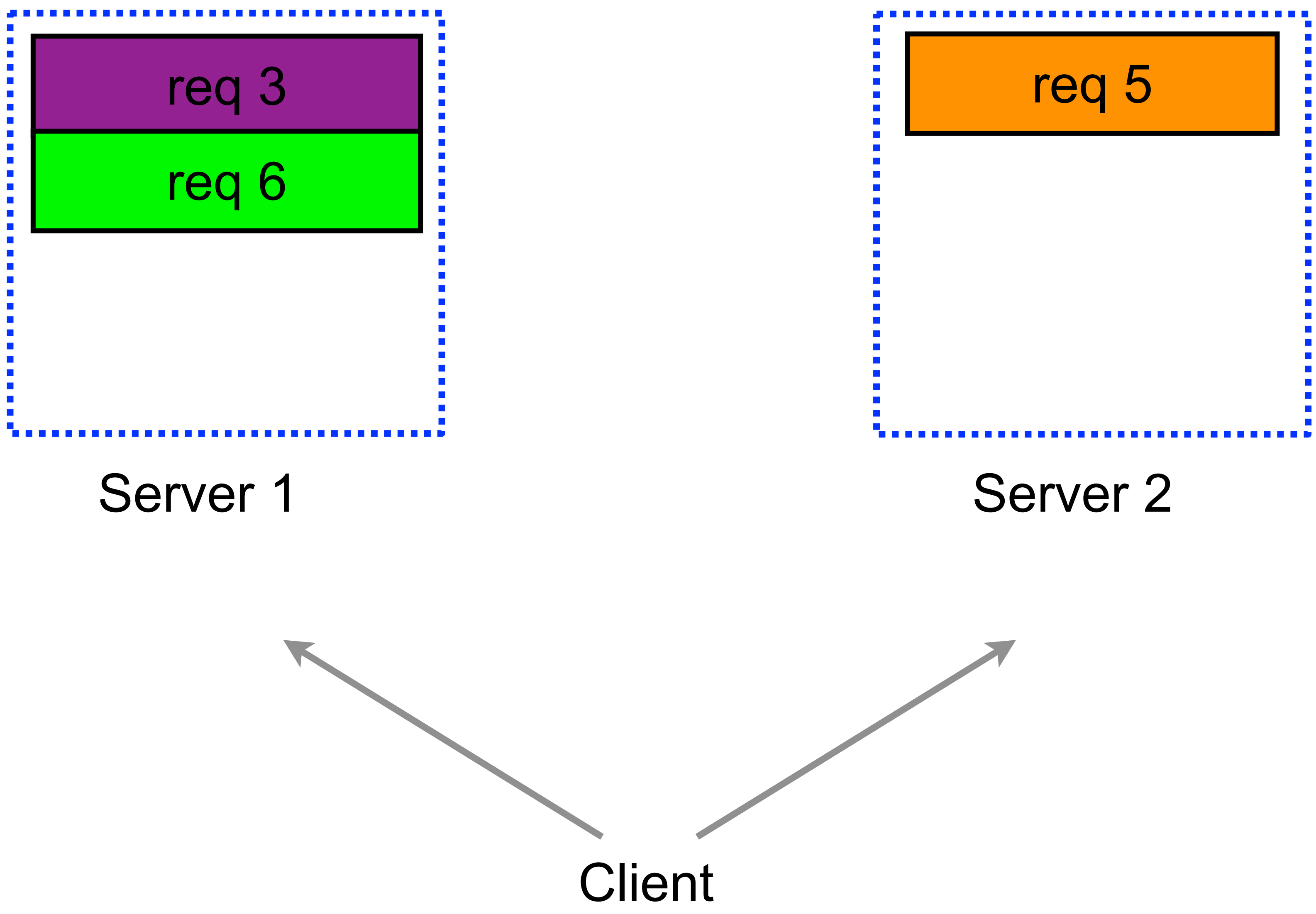
Backup Requests Effects

- 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

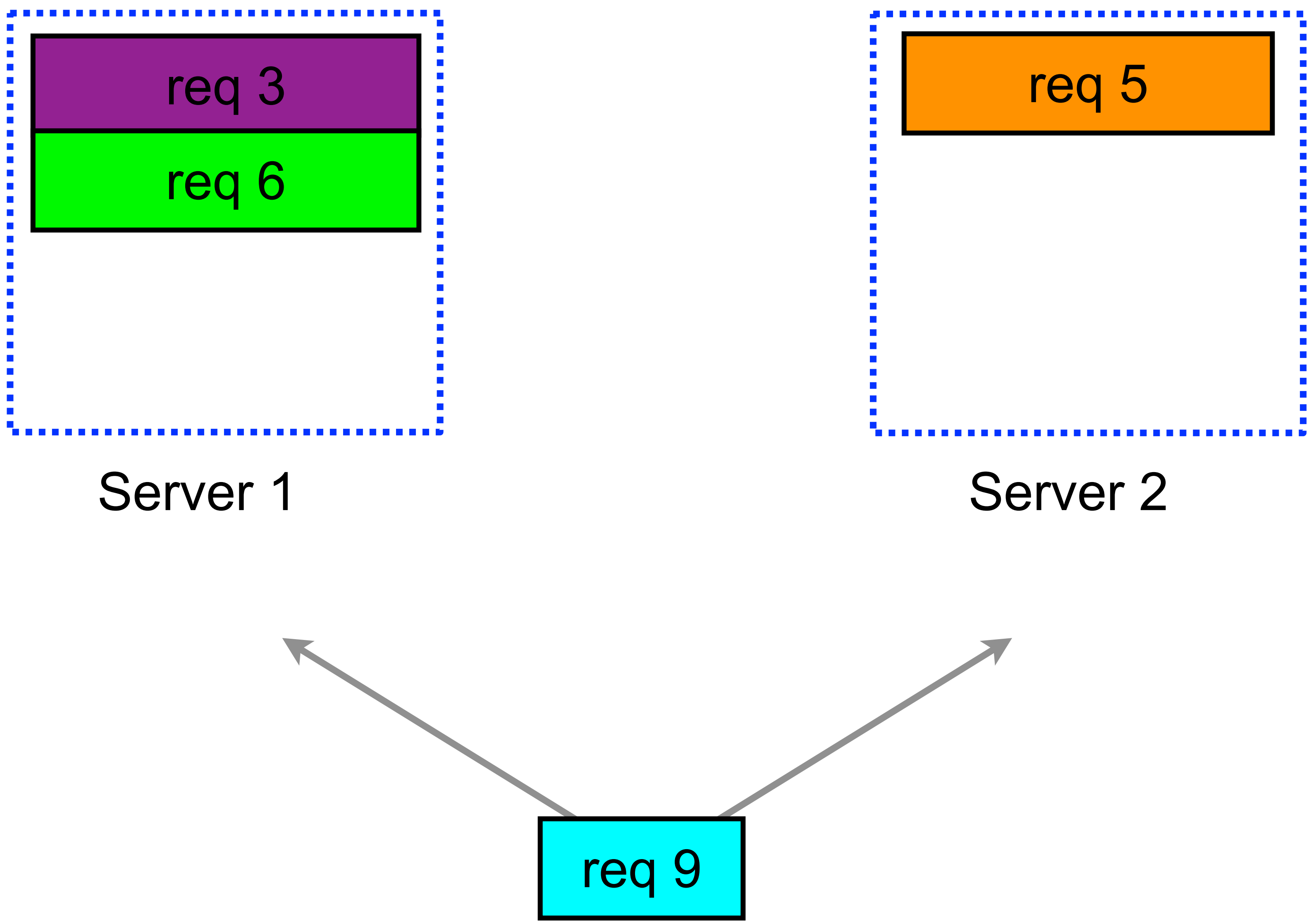
	Avg	Std Dev	95%ile	99%ile	99.9%ile
No backups	33 ms	1524 ms	24 ms	52 ms	994 ms
Backup after 10 ms	14 ms	4 ms	20 ms	23 ms	50 ms
Backup after 50 ms	16 ms	12 ms	57 ms	63 ms	68 ms

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

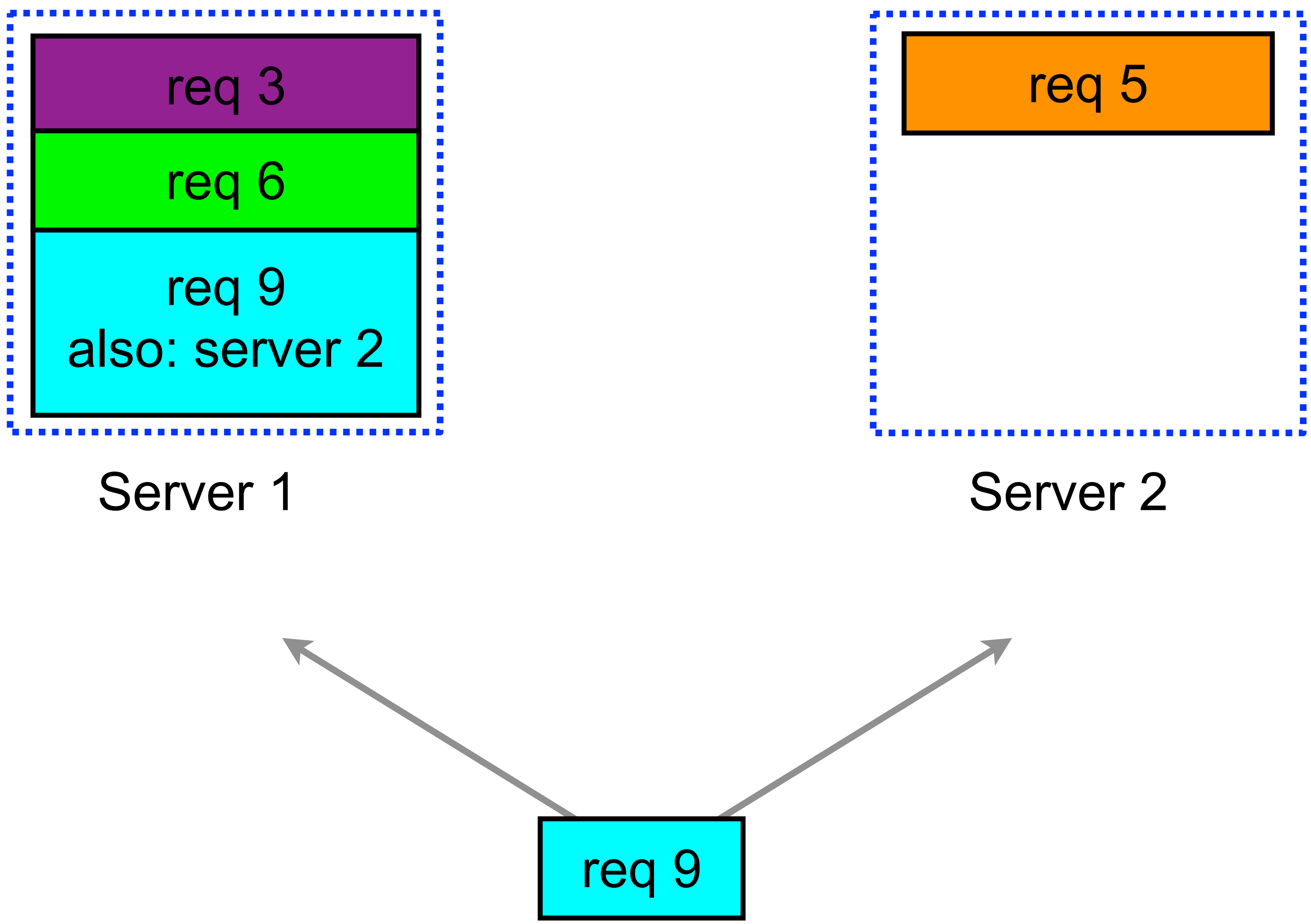
Backup Requests w/ Cross-Server Cancellation



Backup Requests w/ Cross-Server Cancellation

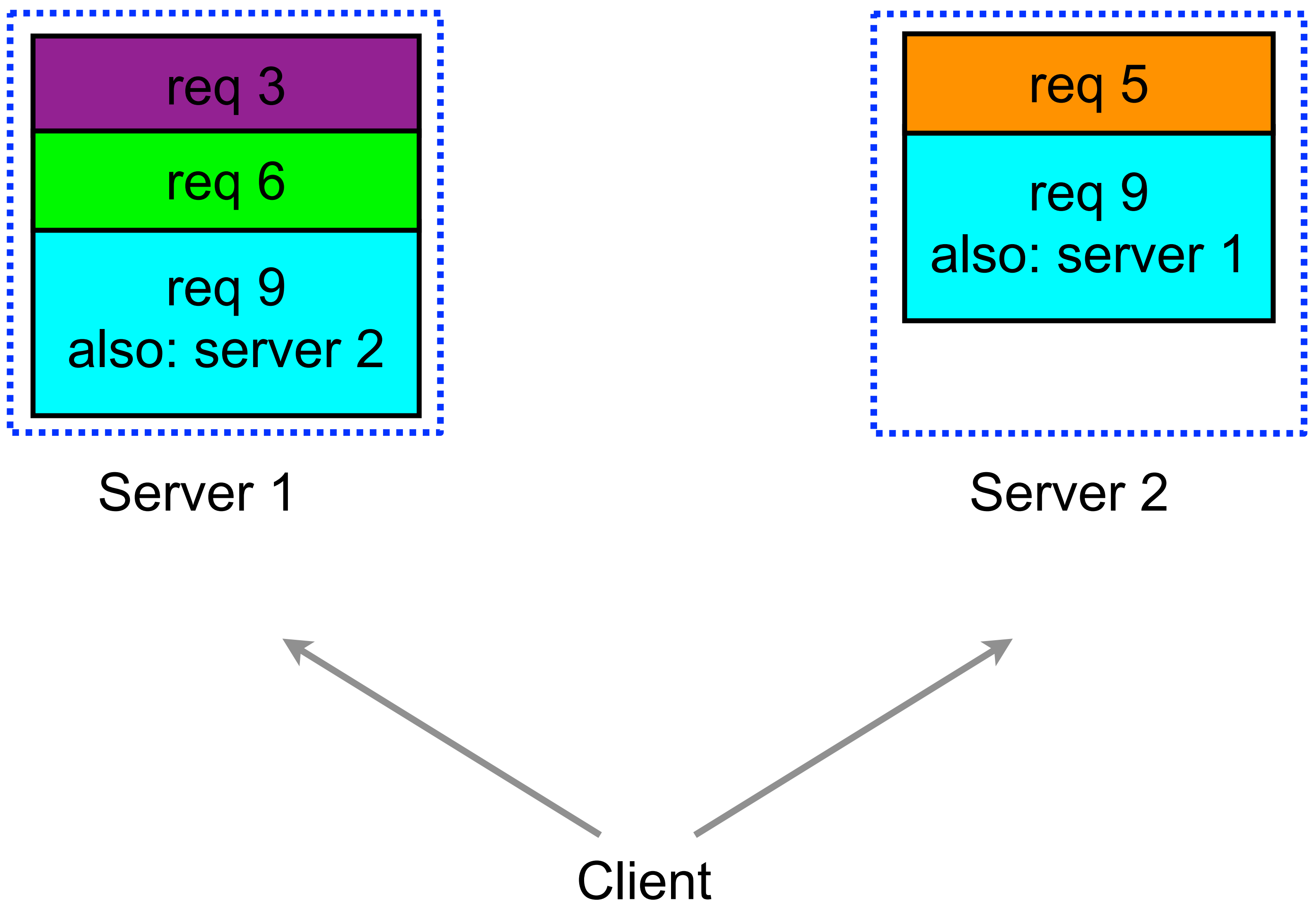


Backup Requests w/ Cross-Server Cancellation



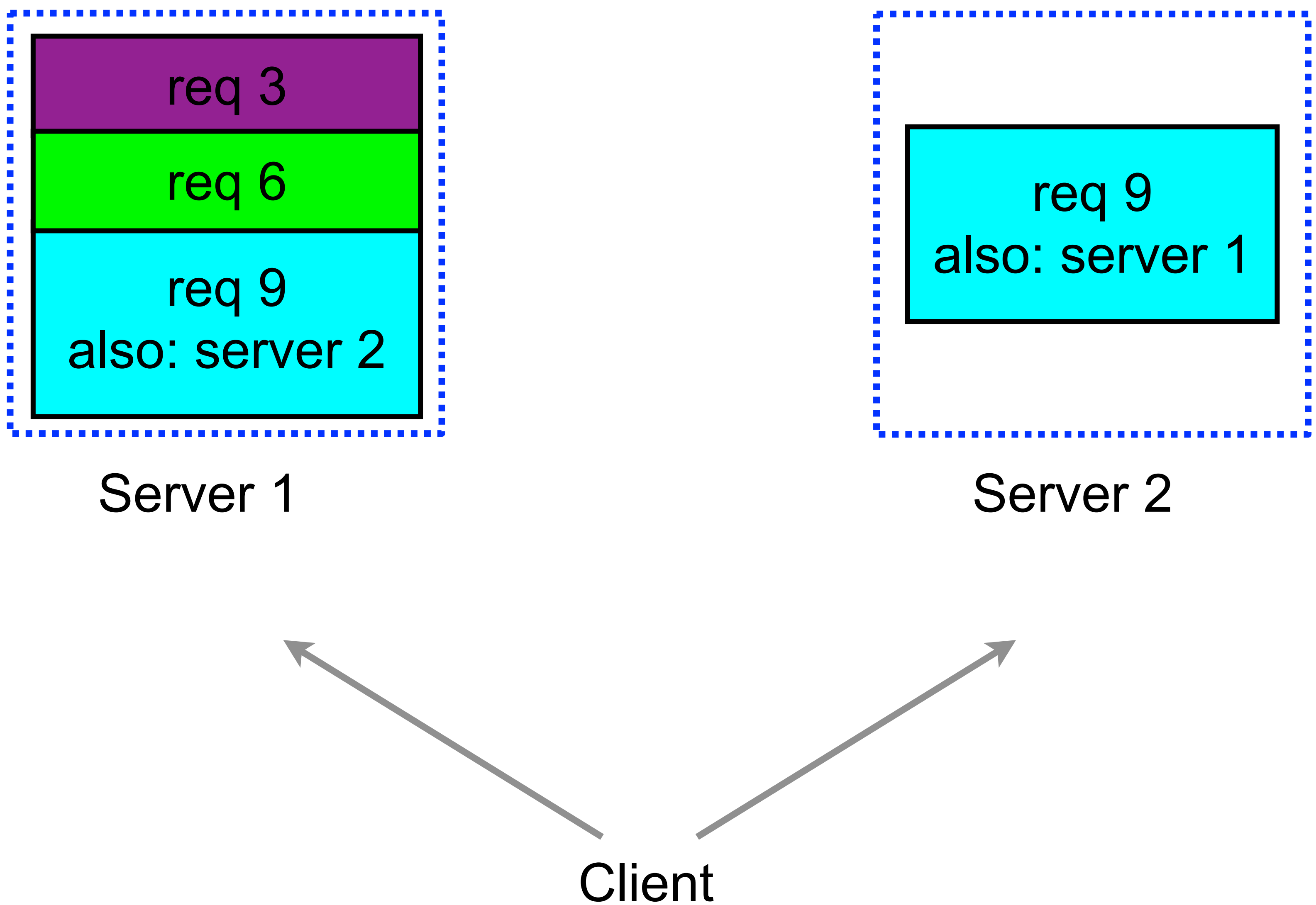
Each request identifies other server(s) to which request might be sent

Backup Requests w/ Cross-Server Cancellation



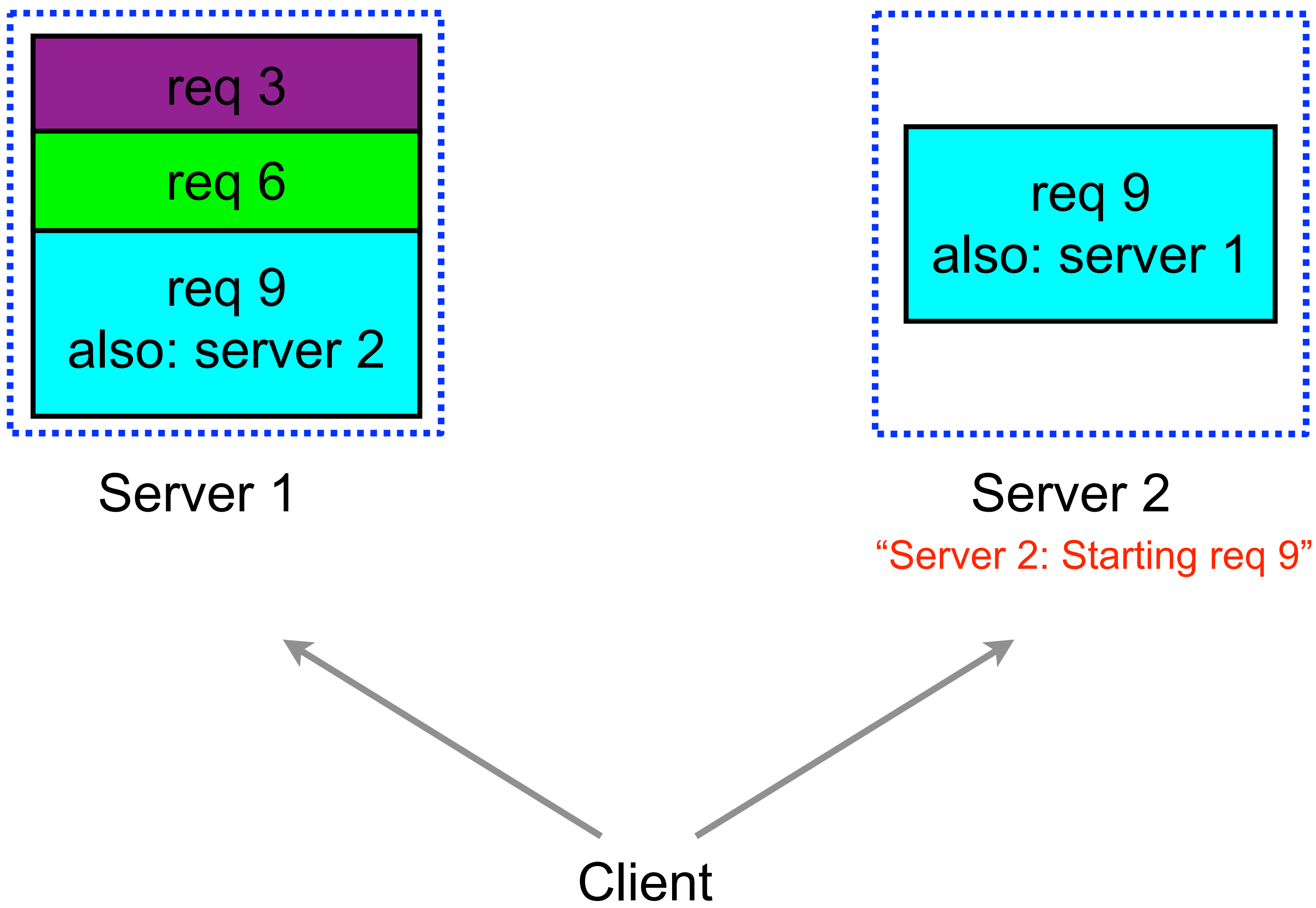
Each request identifies other server(s) to which request might be sent

Backup Requests w/ Cross-Server Cancellation



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

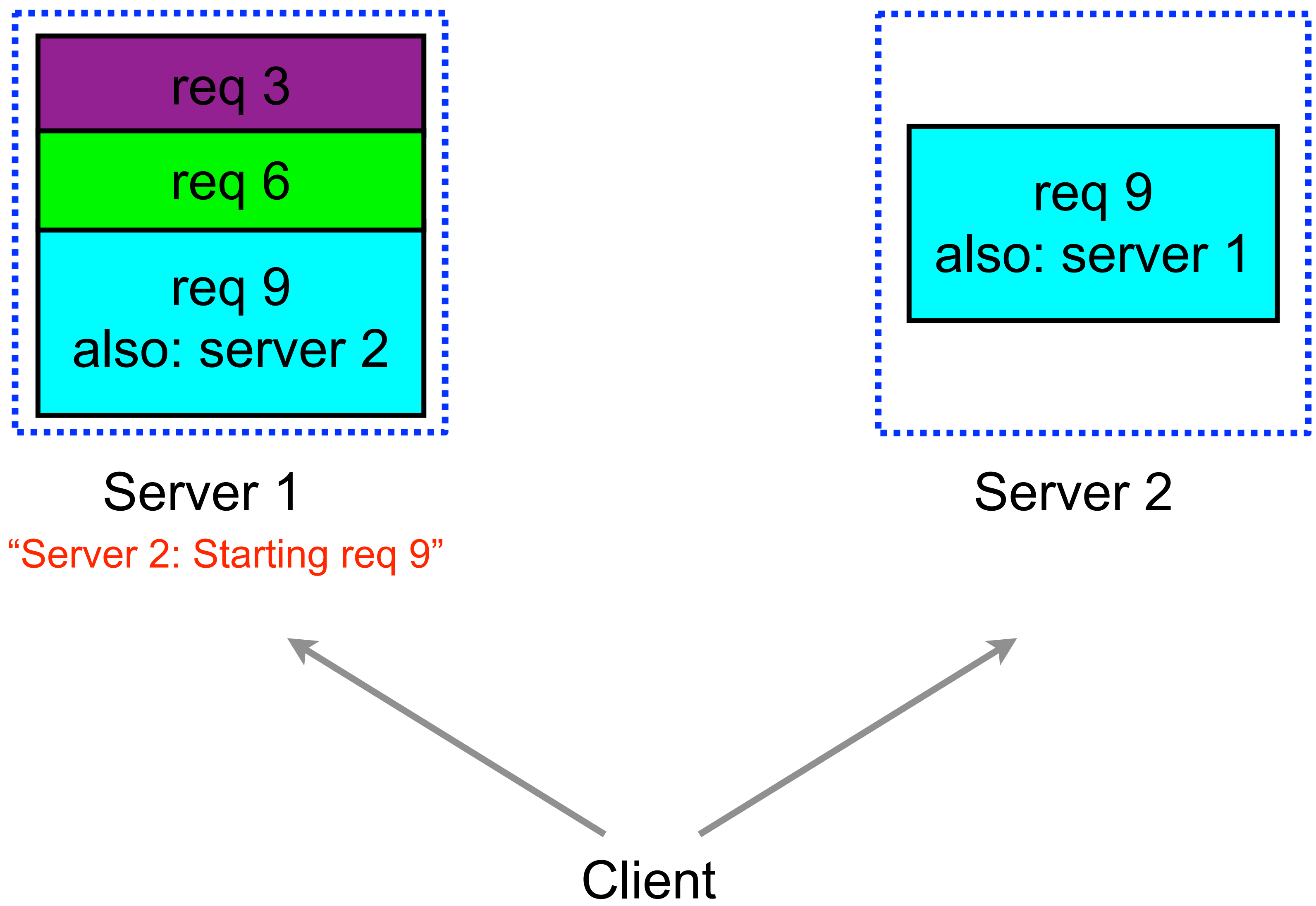
Backup Requests w/ Cross-Server Cancellation



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

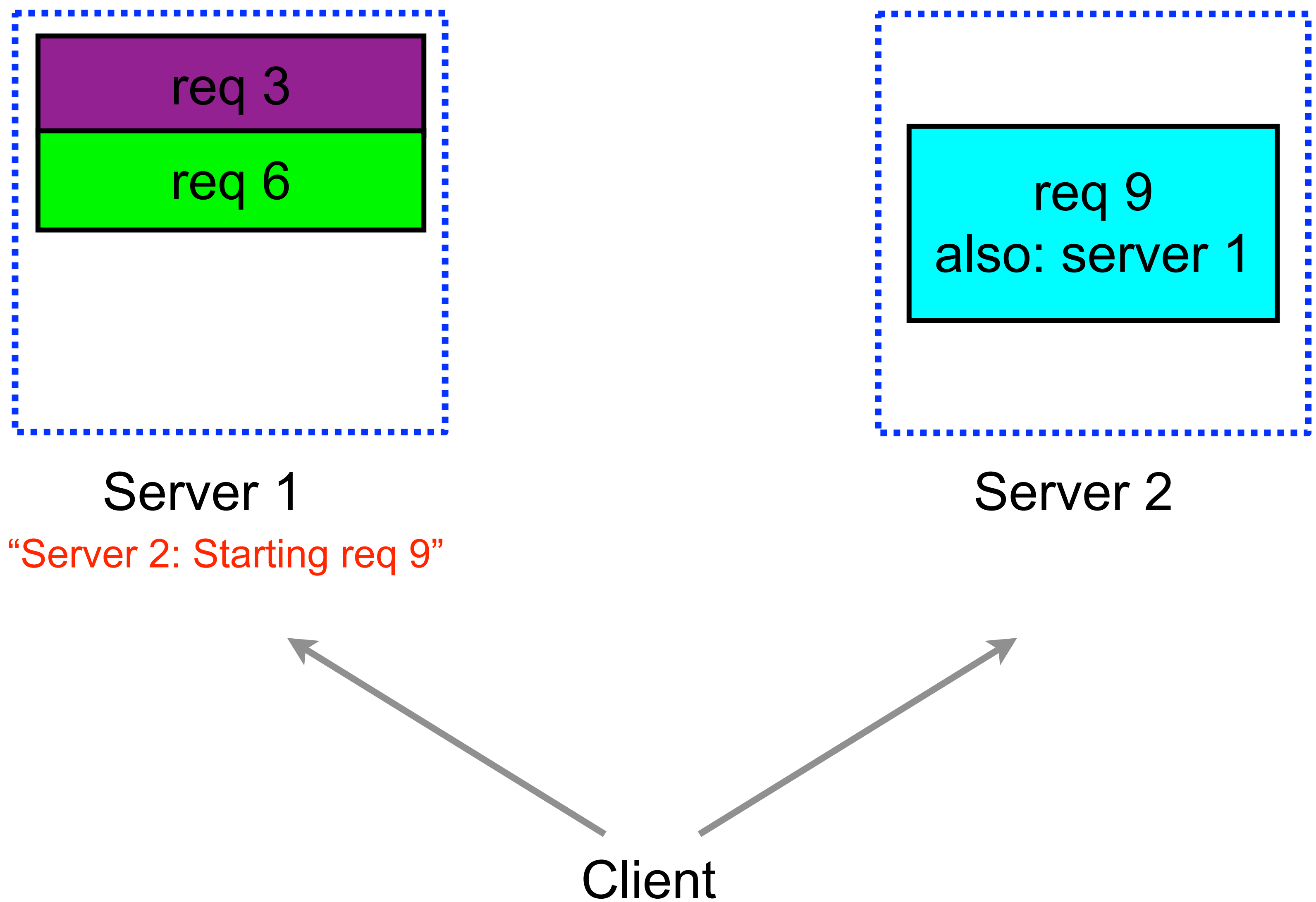
Google

Backup Requests w/ Cross-Server Cancellation



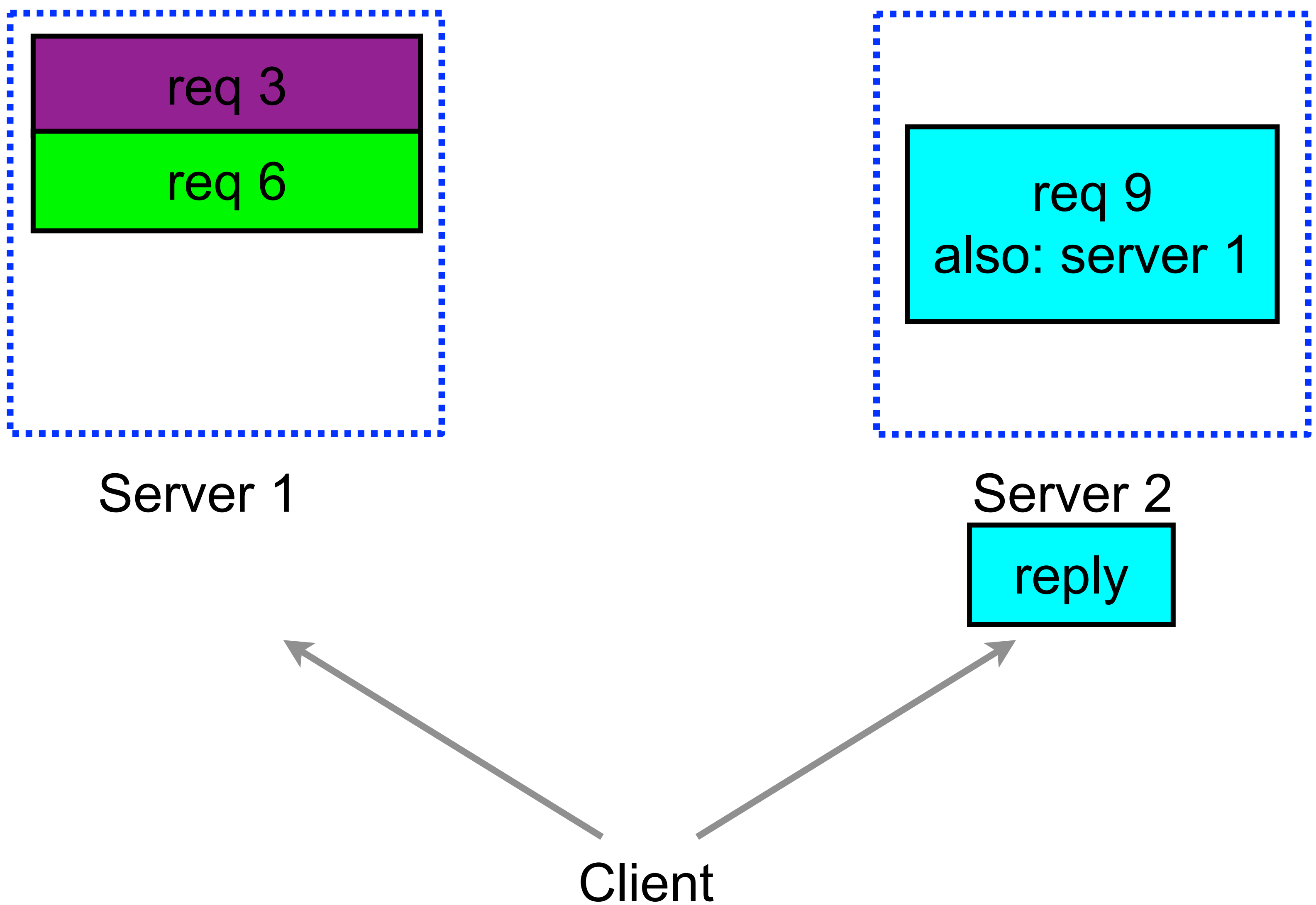
Each request identifies other server(s) to which request might be sent

Backup Requests w/ Cross-Server Cancellation



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

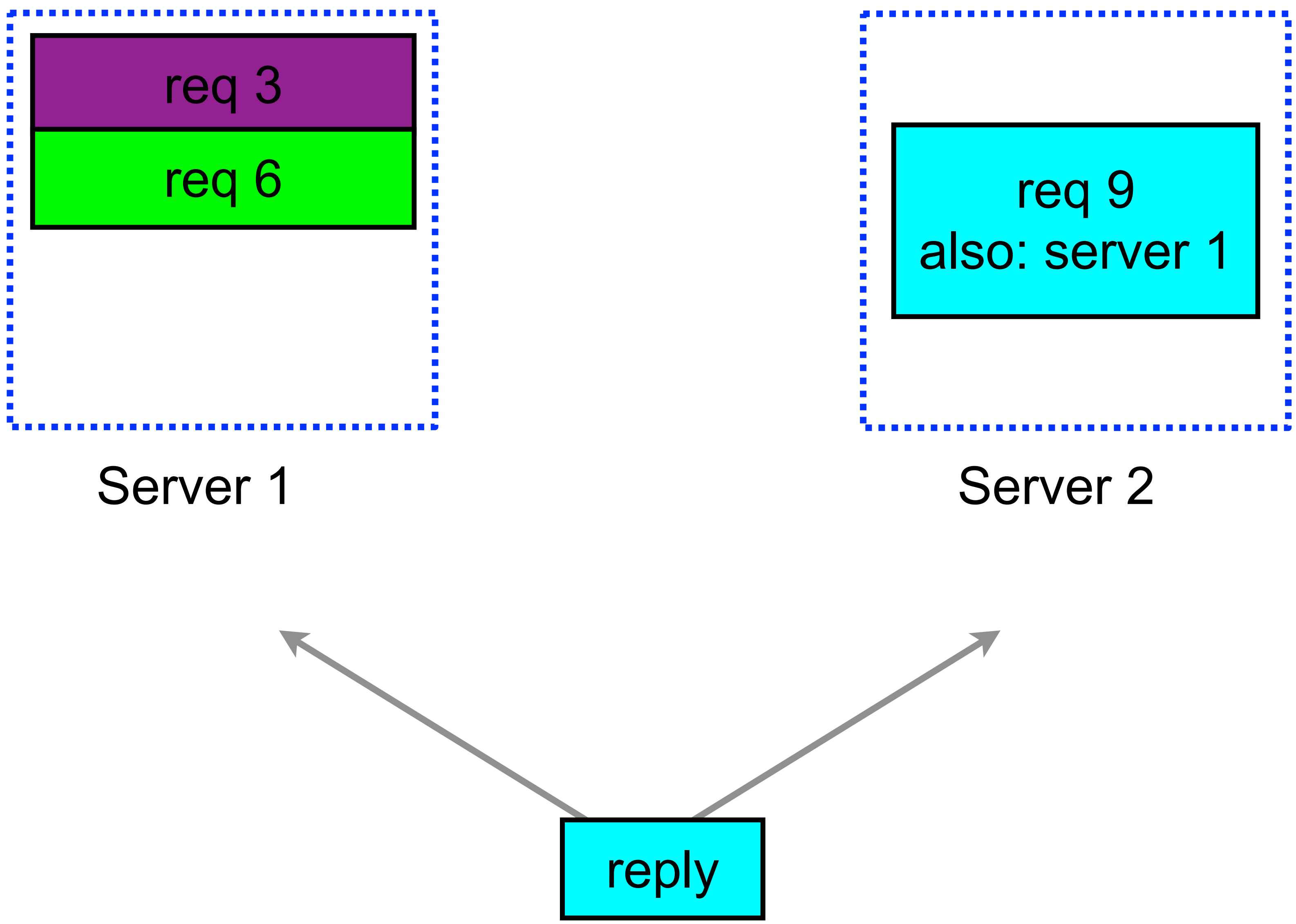
Backup Requests w/ Cross-Server Cancellation



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

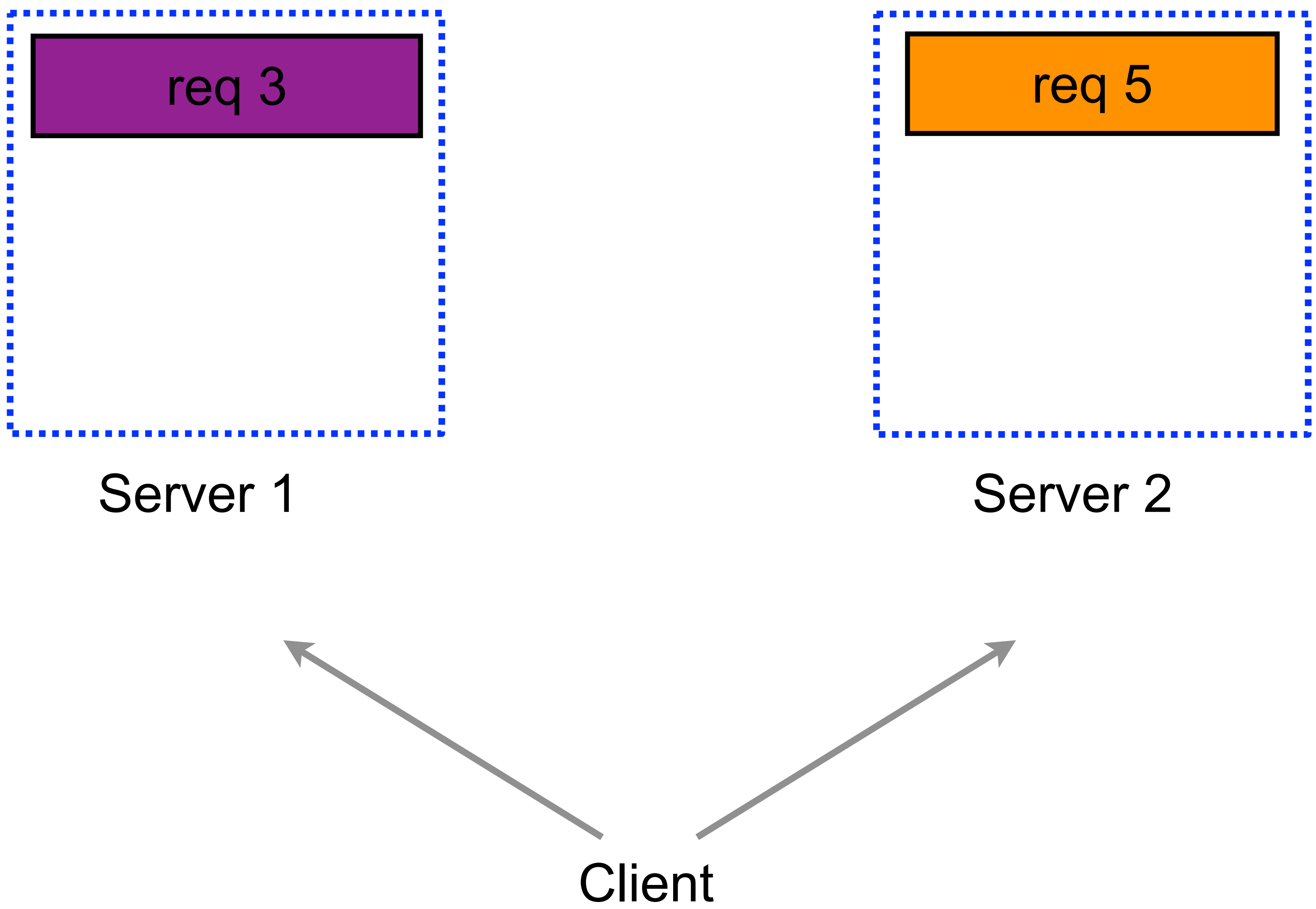
Google

Backup Requests w/ Cross-Server Cancellation

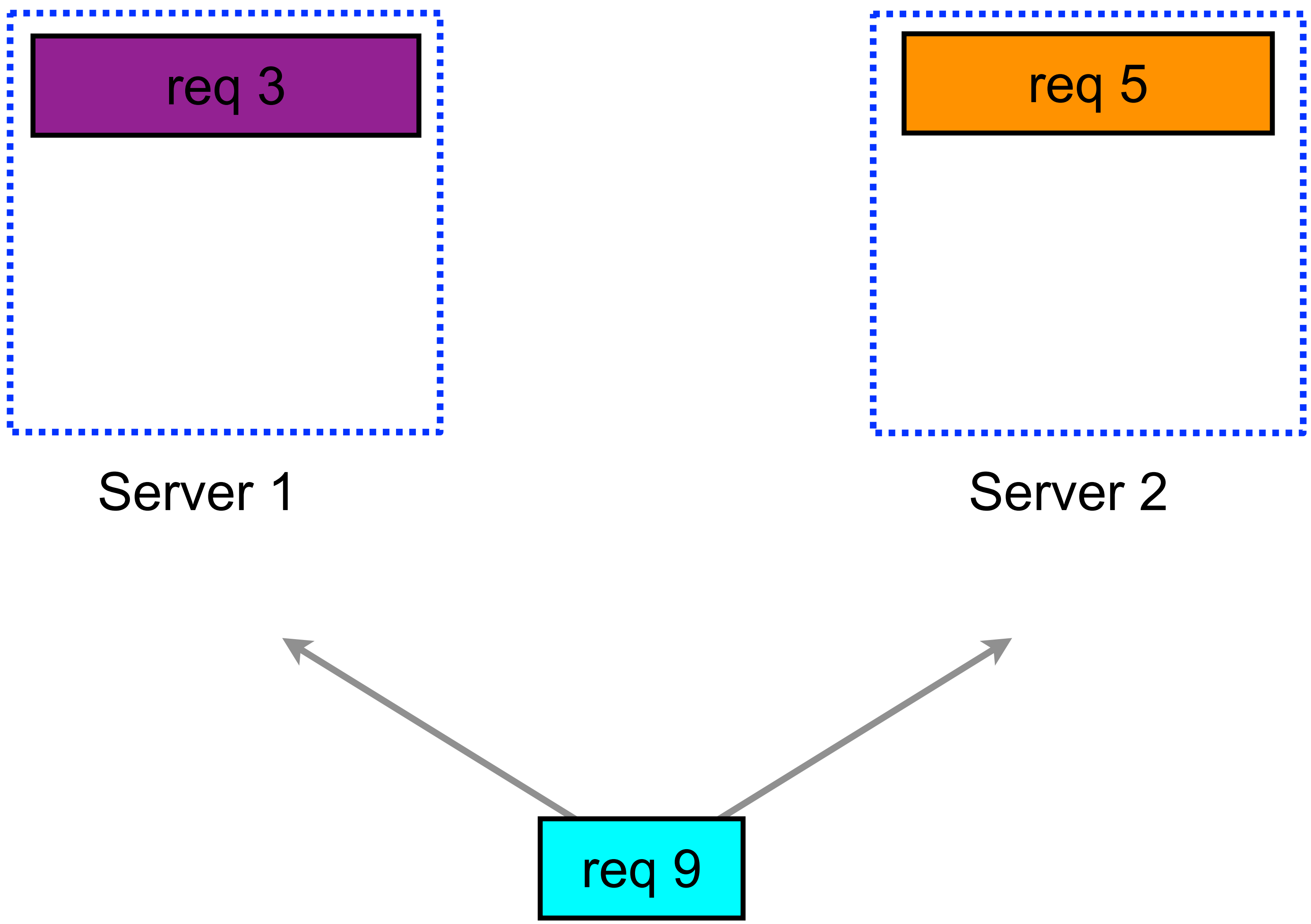


Each request identifies other server(s) to which request might be sent

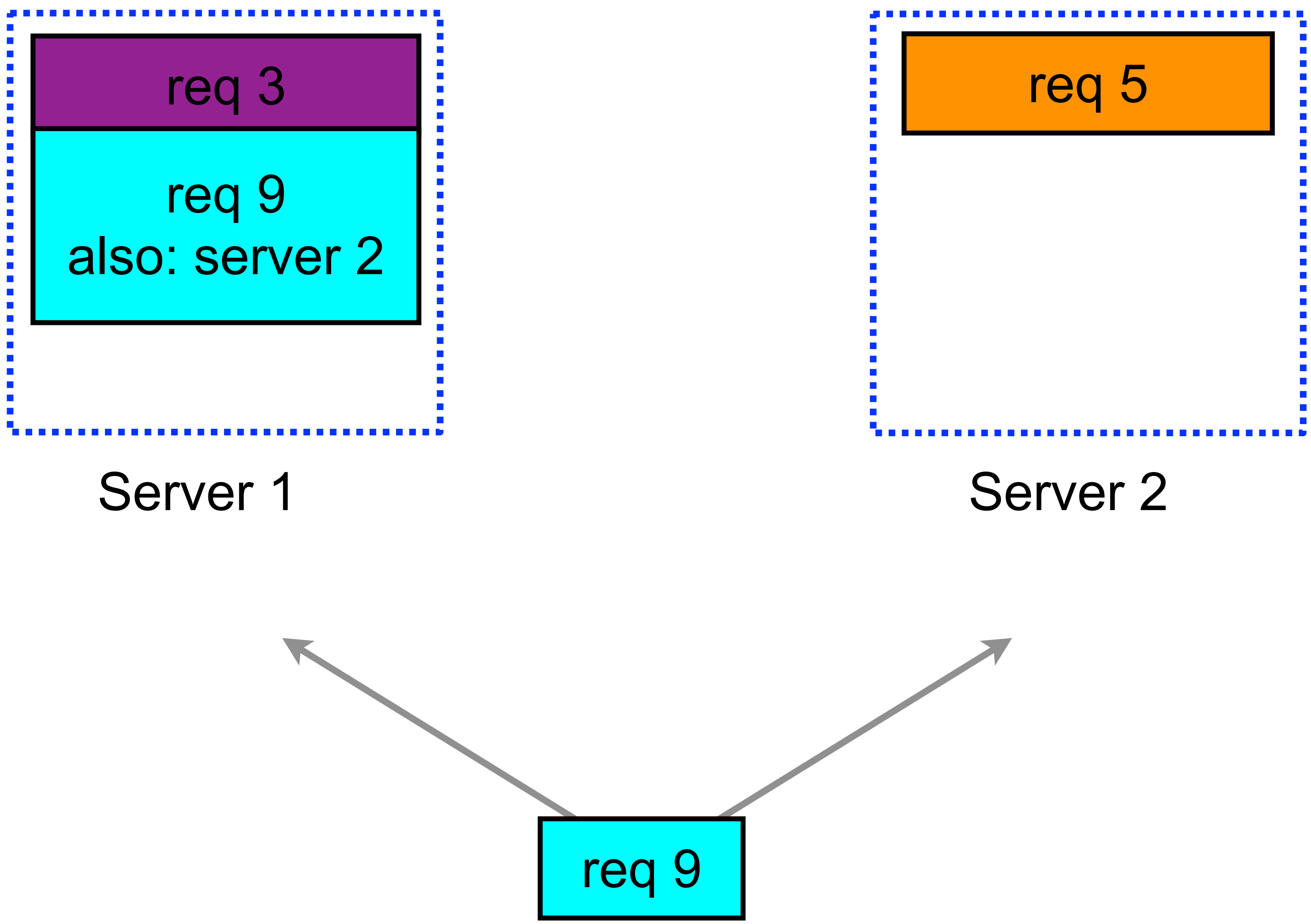
Backup Requests: Bad Case



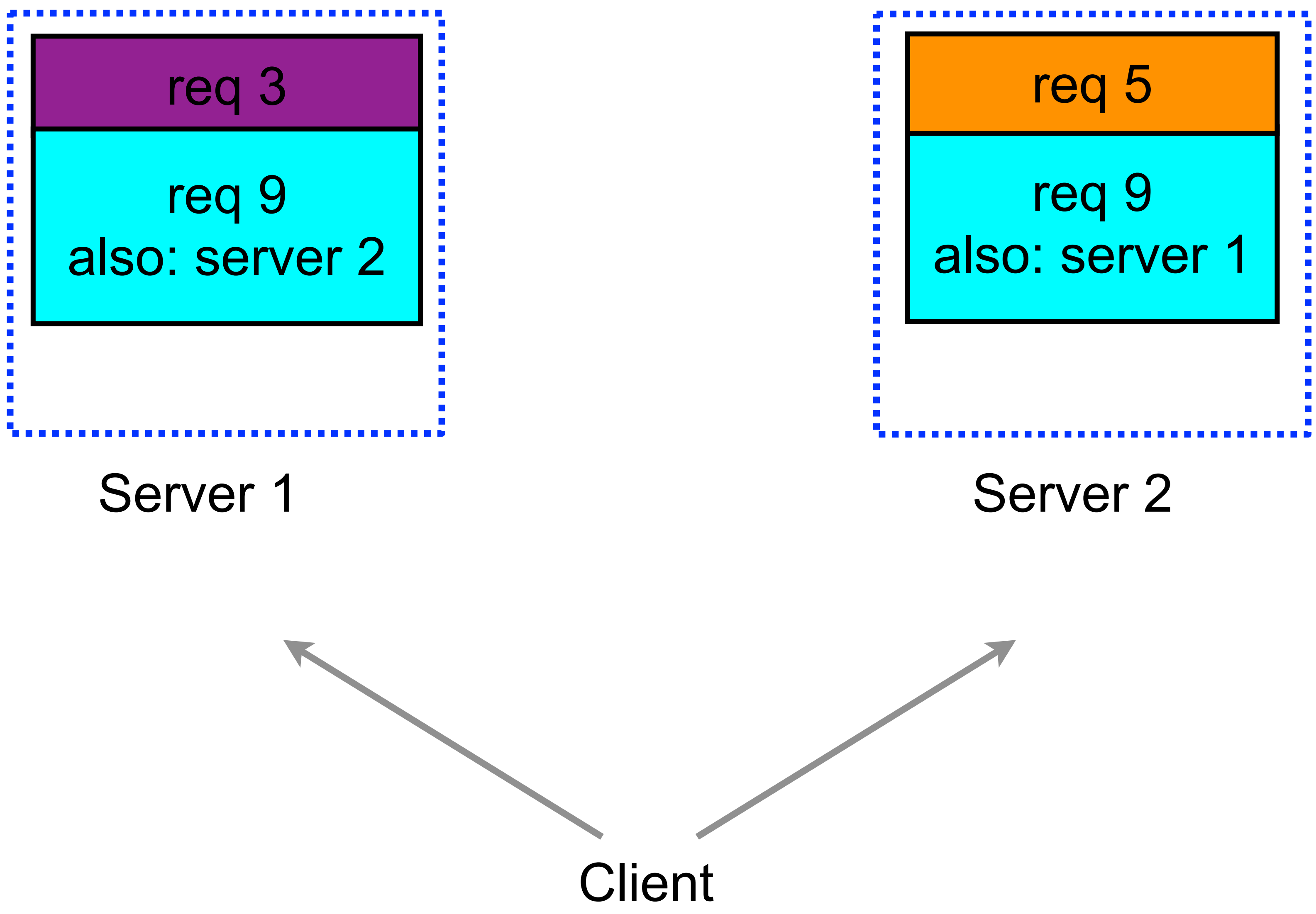
Backup Requests: Bad Case



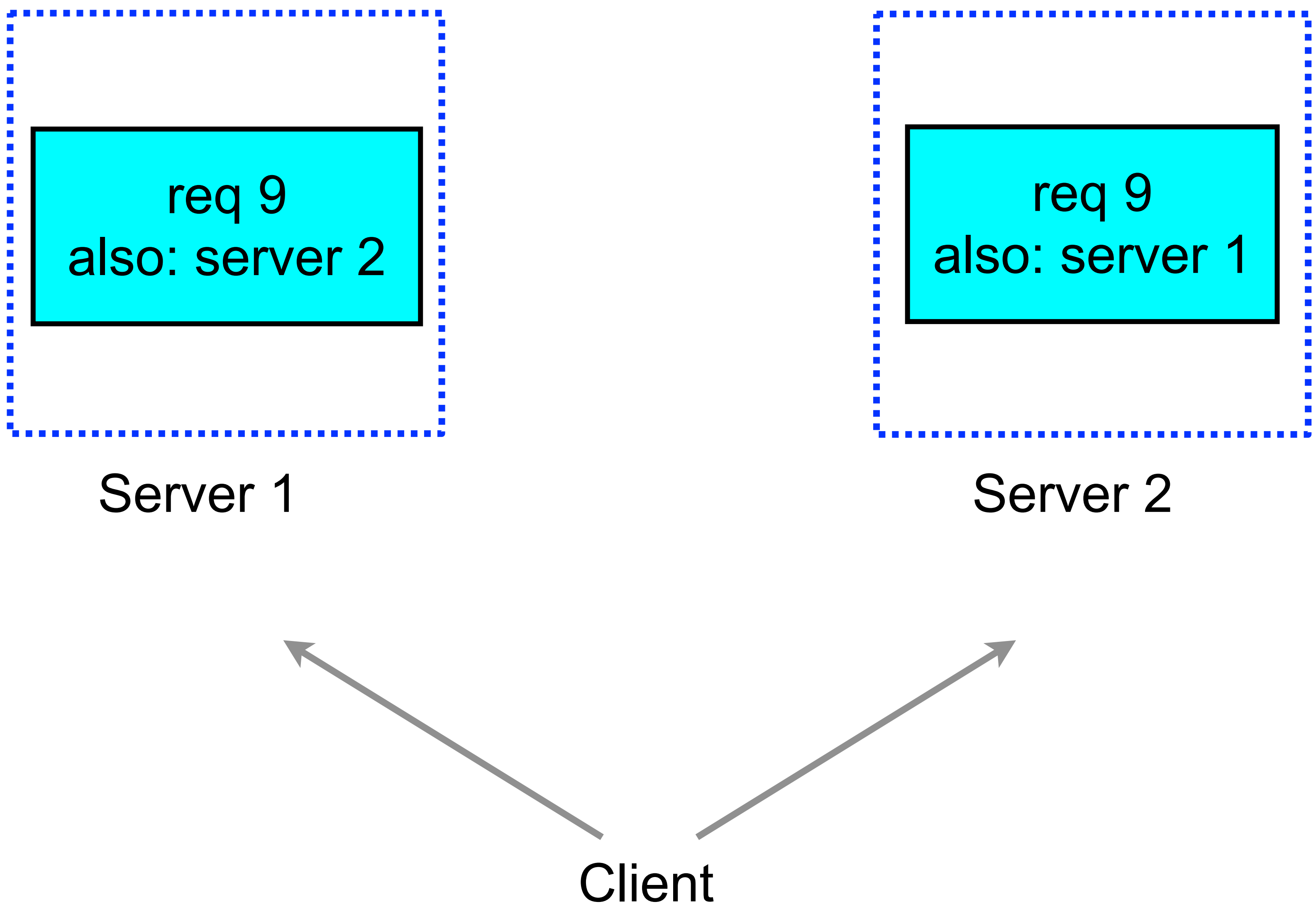
Backup Requests: Bad Case



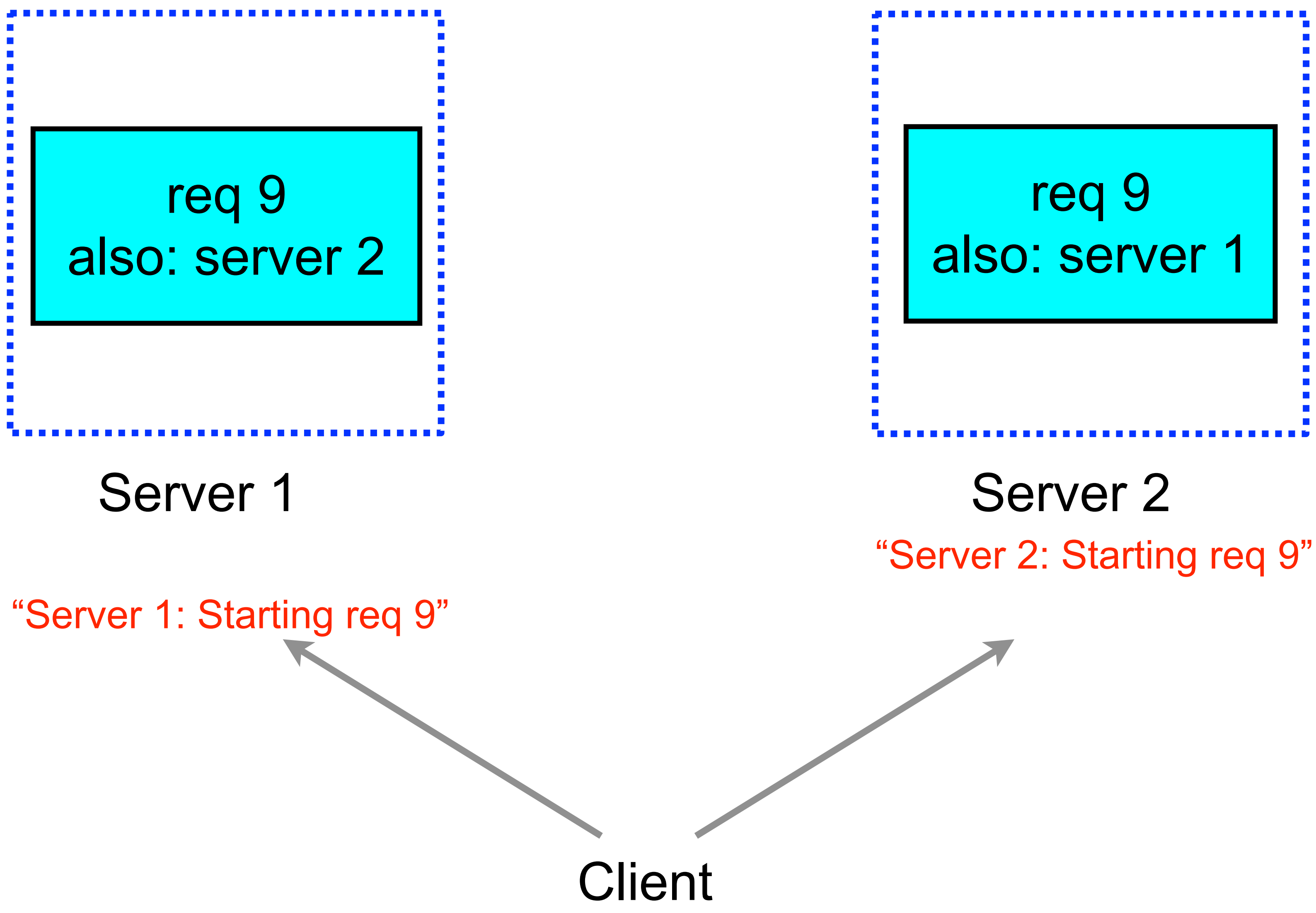
Backup Requests: Bad Case



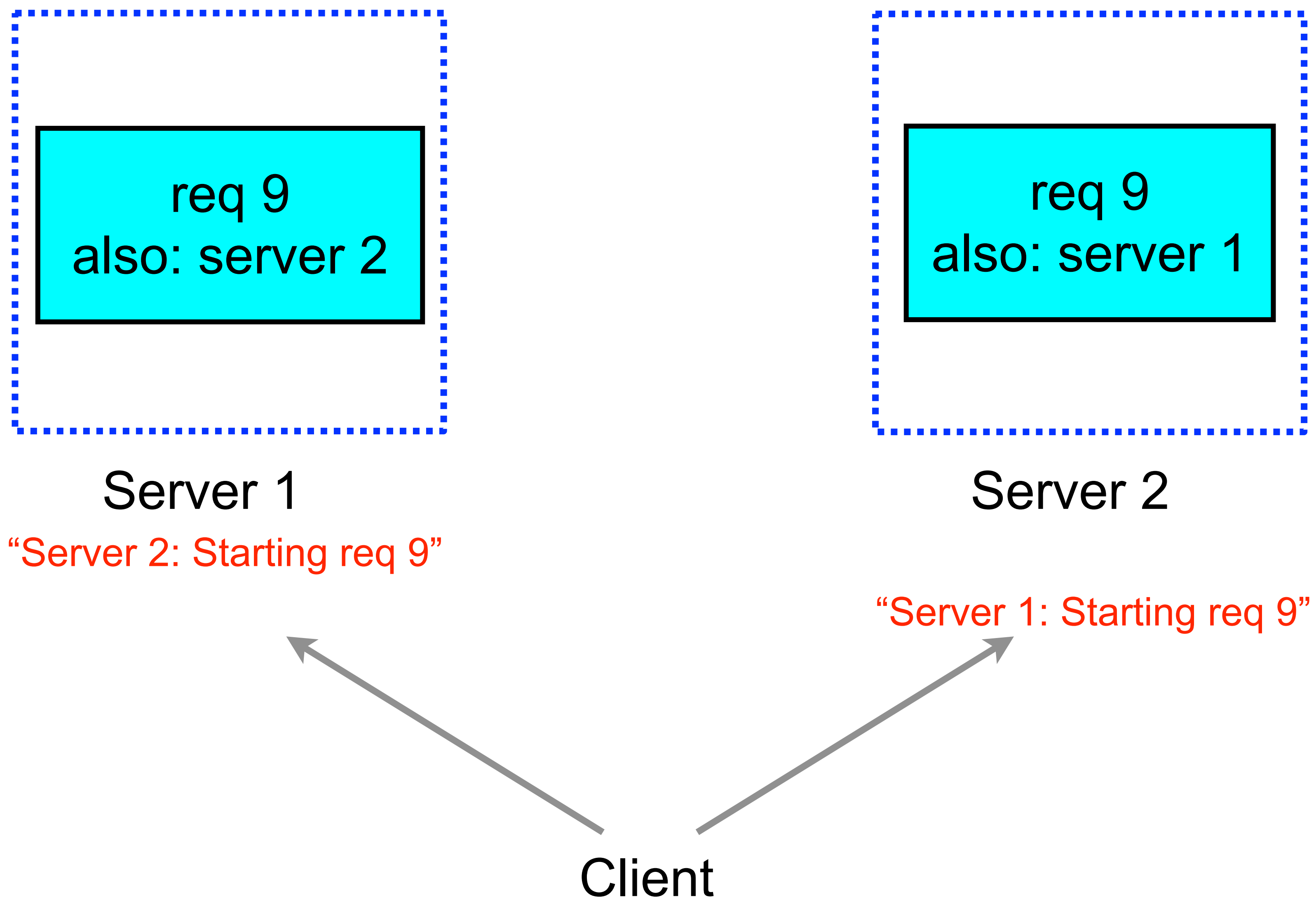
Backup Requests: Bad Case



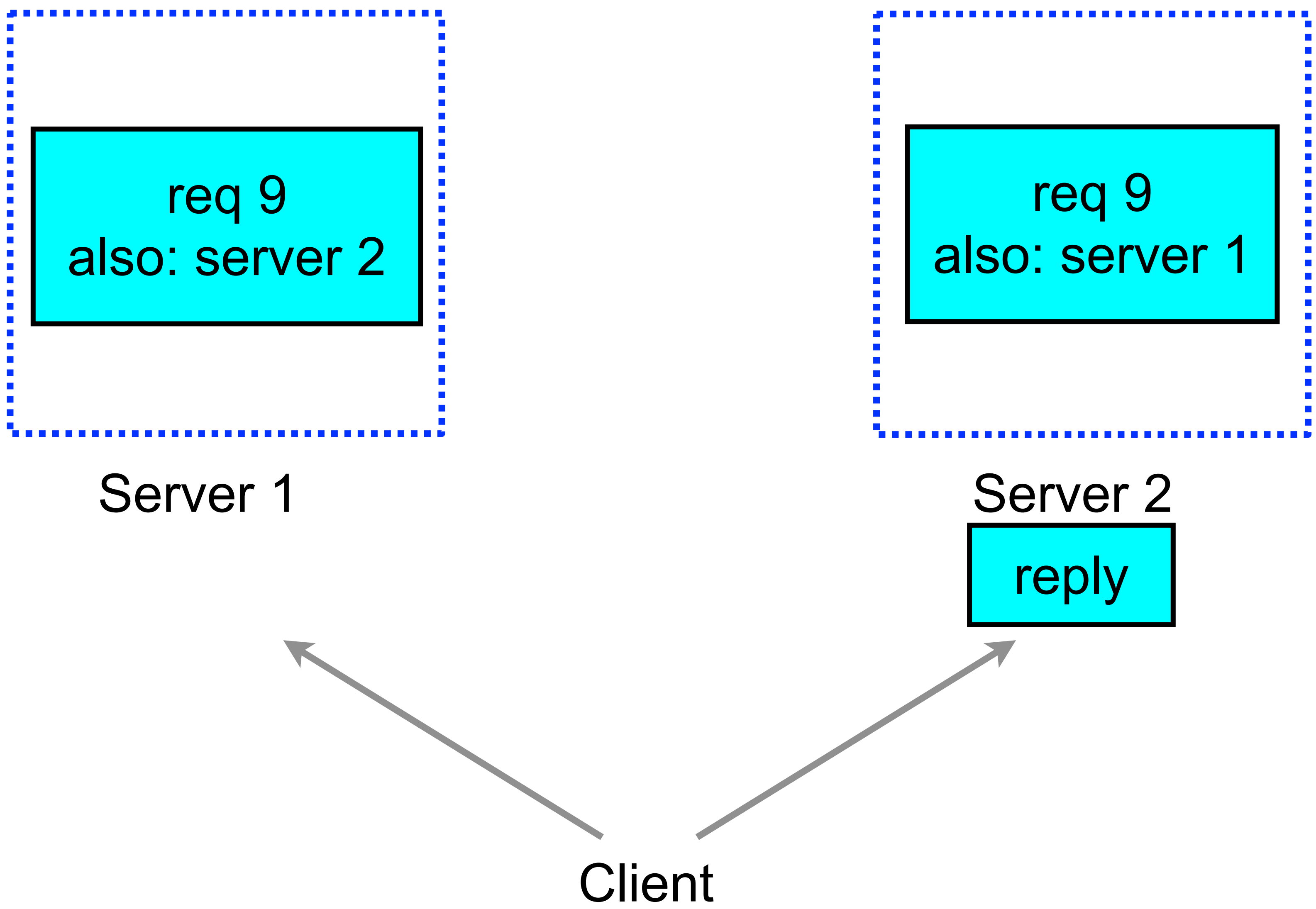
Backup Requests: Bad Case



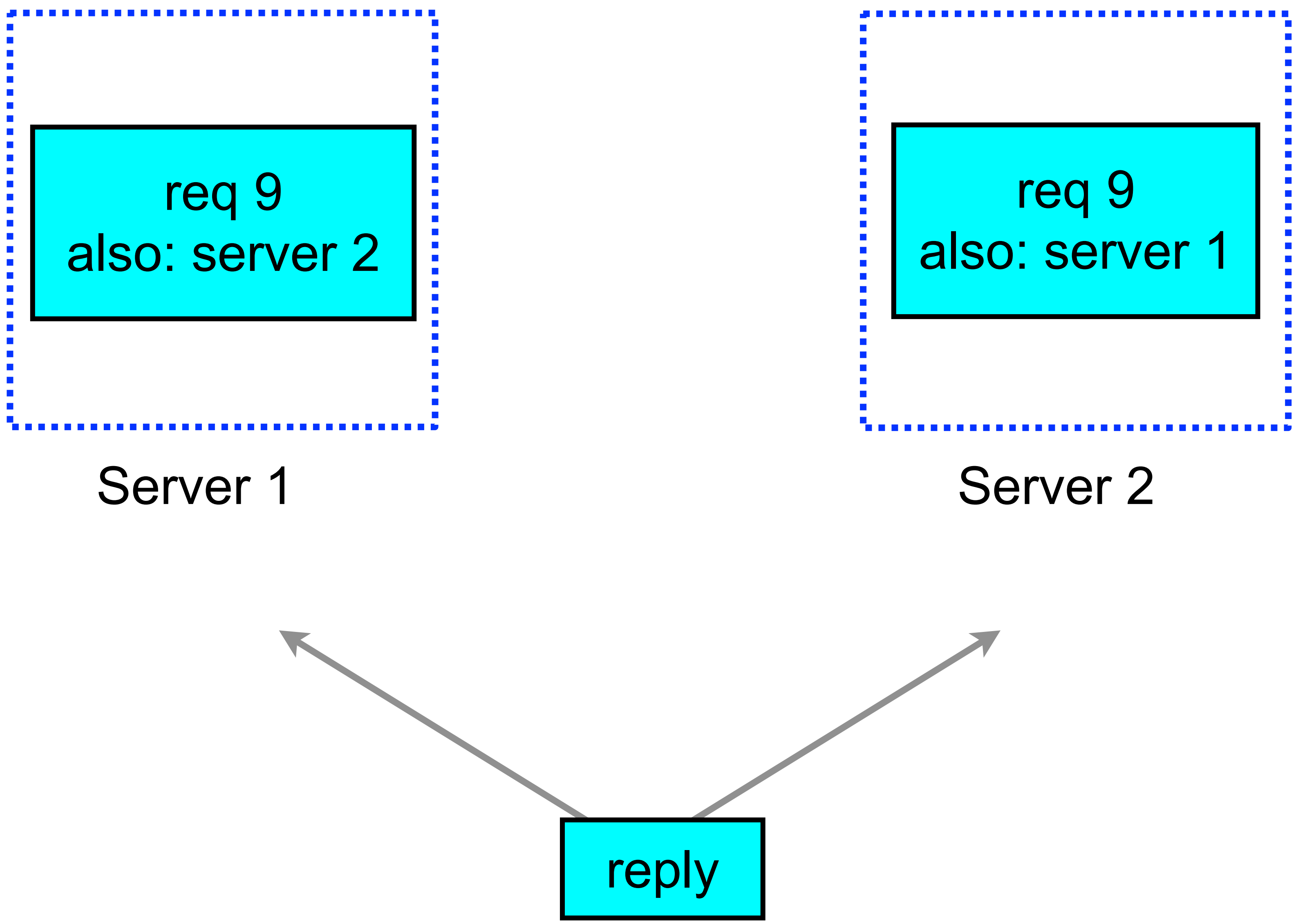
Backup Requests: Bad Case



Backup Requests: Bad Case



Backup Requests: Bad Case



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

Google

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

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

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

-43%

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

Google

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

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
+Terasort	No backups	24 ms	56 ms	108 ms	159 ms
	Backup after 2 ms	19 ms	35 ms	67 ms	108 ms

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

-38%

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
+Terasort	No backups	24 ms	56 ms	108 ms	159 ms
	Backup after 2 ms	19 ms	35 ms	67 ms	108 ms

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

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
+Terasort	No backups	24 ms	56 ms	108 ms	159 ms
	Backup after 2 ms	19 ms	35 ms	67 ms	108 ms

Backups cause about ~1% extra disk reads

Google

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

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
+Terasort	No backups	24 ms	56 ms	108 ms	159 ms
	Backup after 2 ms	19 ms	35 ms	67 ms	108 ms

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

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
+Terasort	No backups	24 ms	56 ms	108 ms	159 ms
	Backup after 2 ms	19 ms	35 ms	67 ms	108 ms

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

Google

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

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

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

Google

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?