清華大學

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Modeling and Analyzing Latency in the Memcached System

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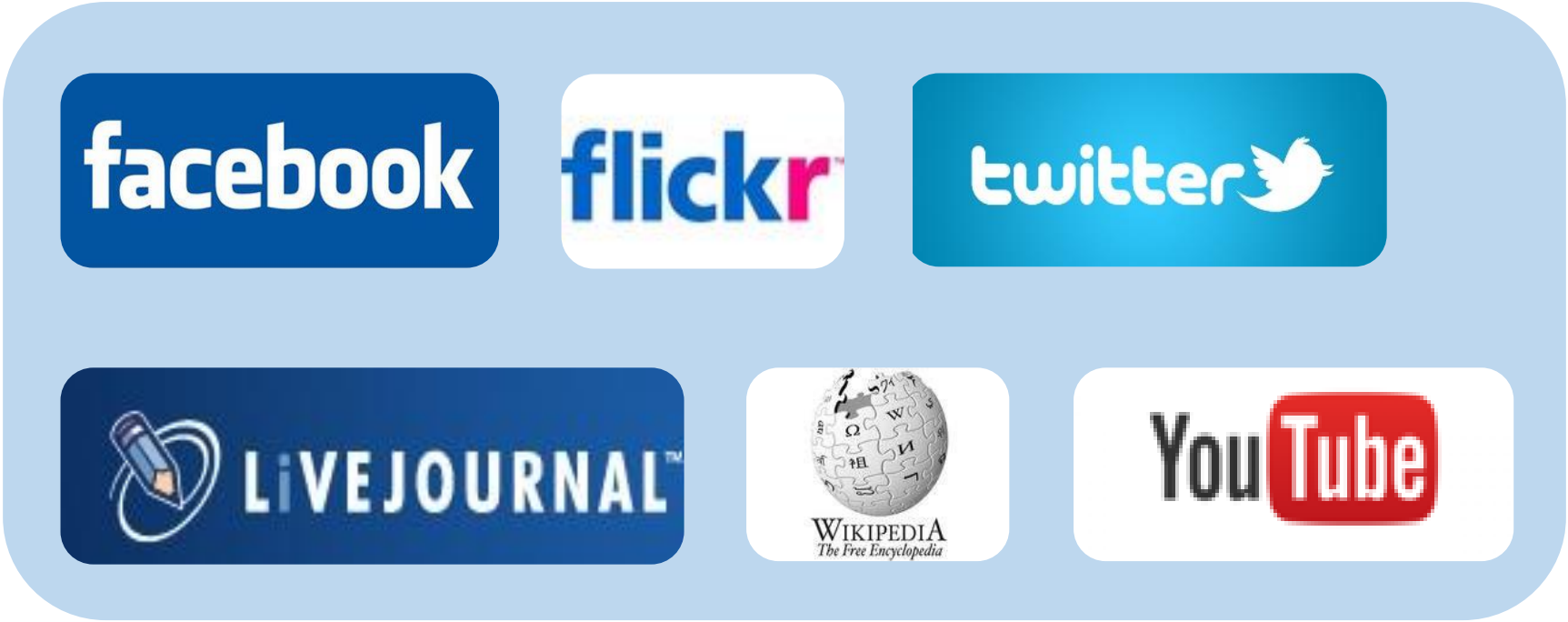
Background

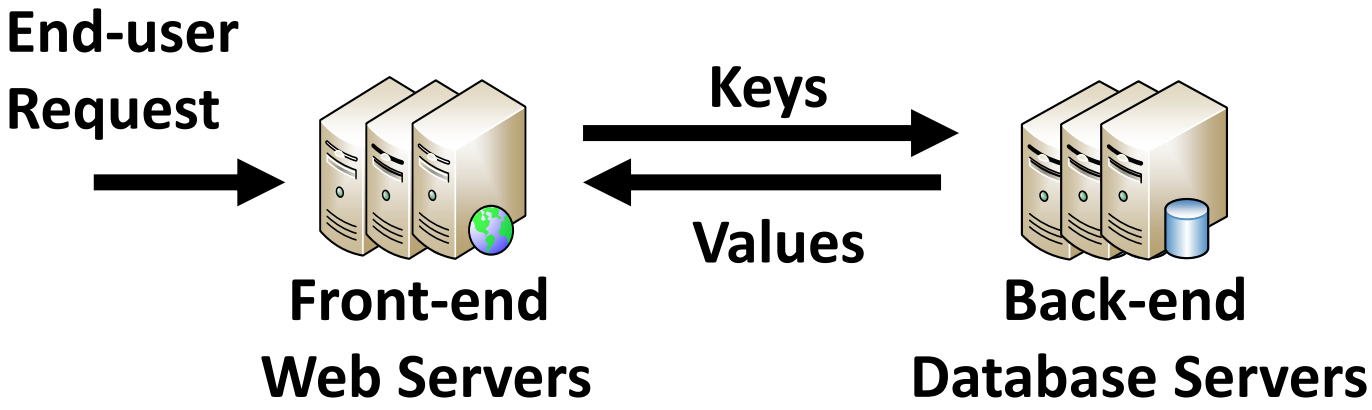
Memcached System

- Key-Value system
- In-memory caching solution
- Speed up searching applications



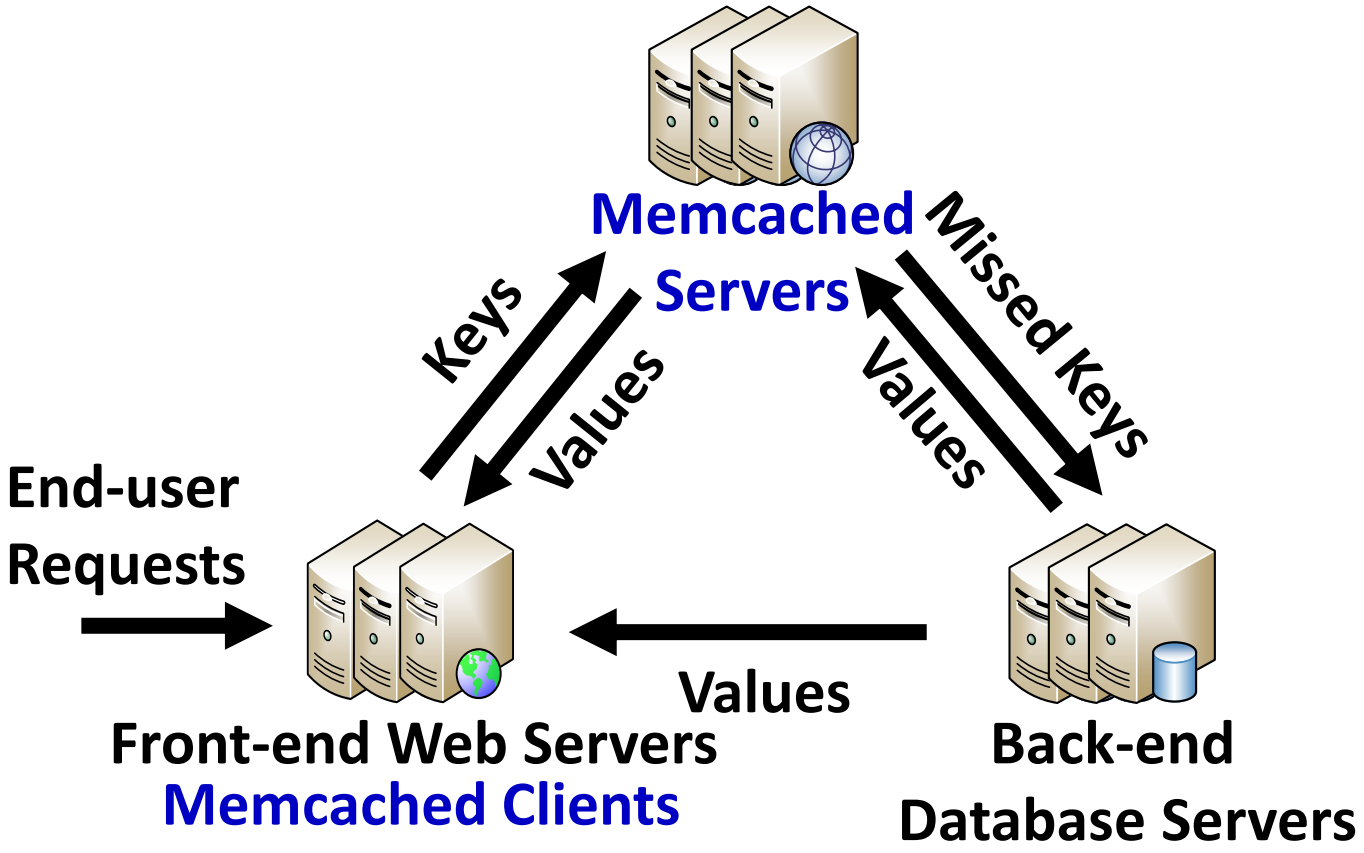
Background

Traditional Websites



Background

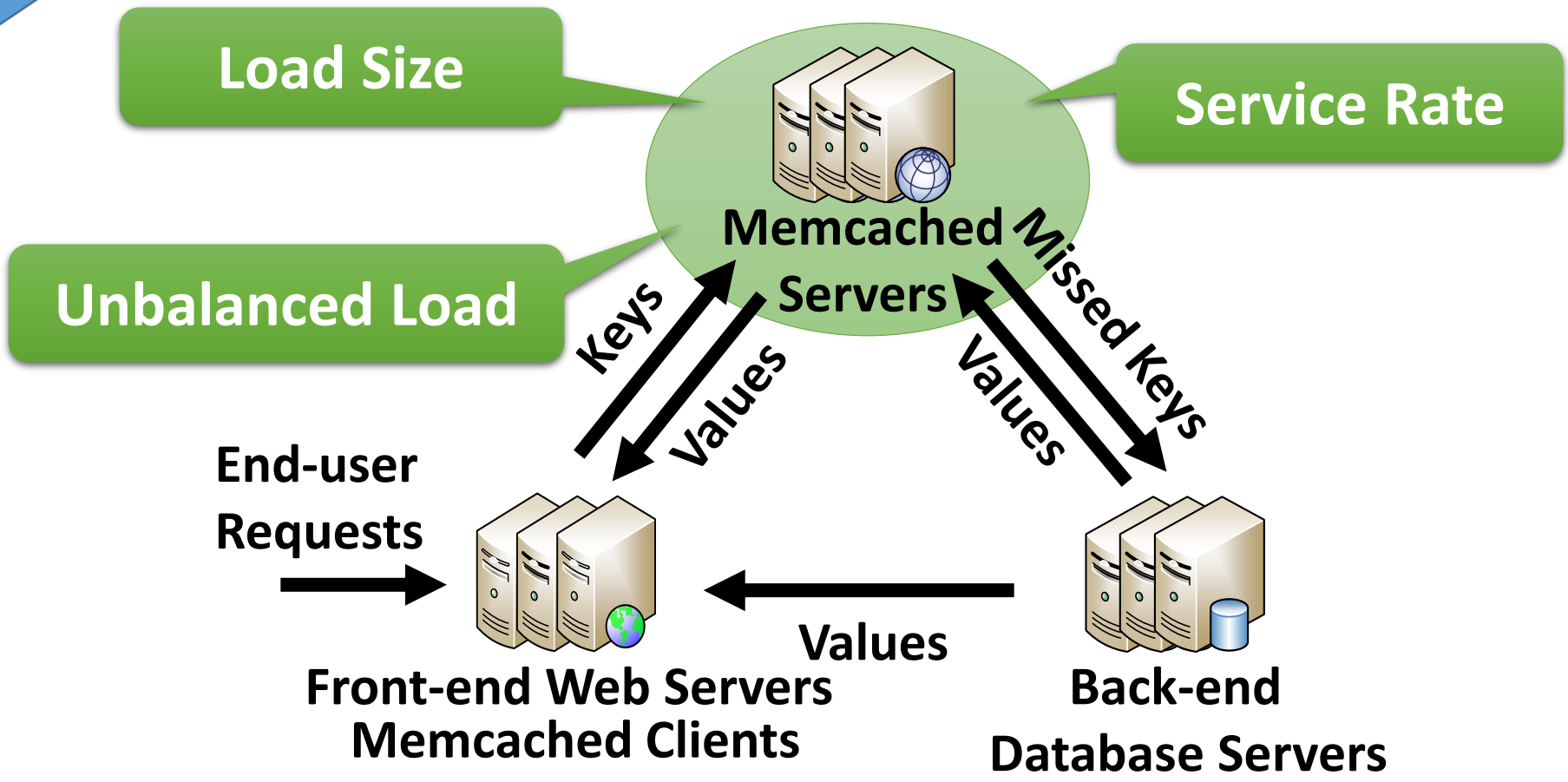
Memcached Architecture



Latency is the most pivotal performance metric.

Background

Factors on Latency



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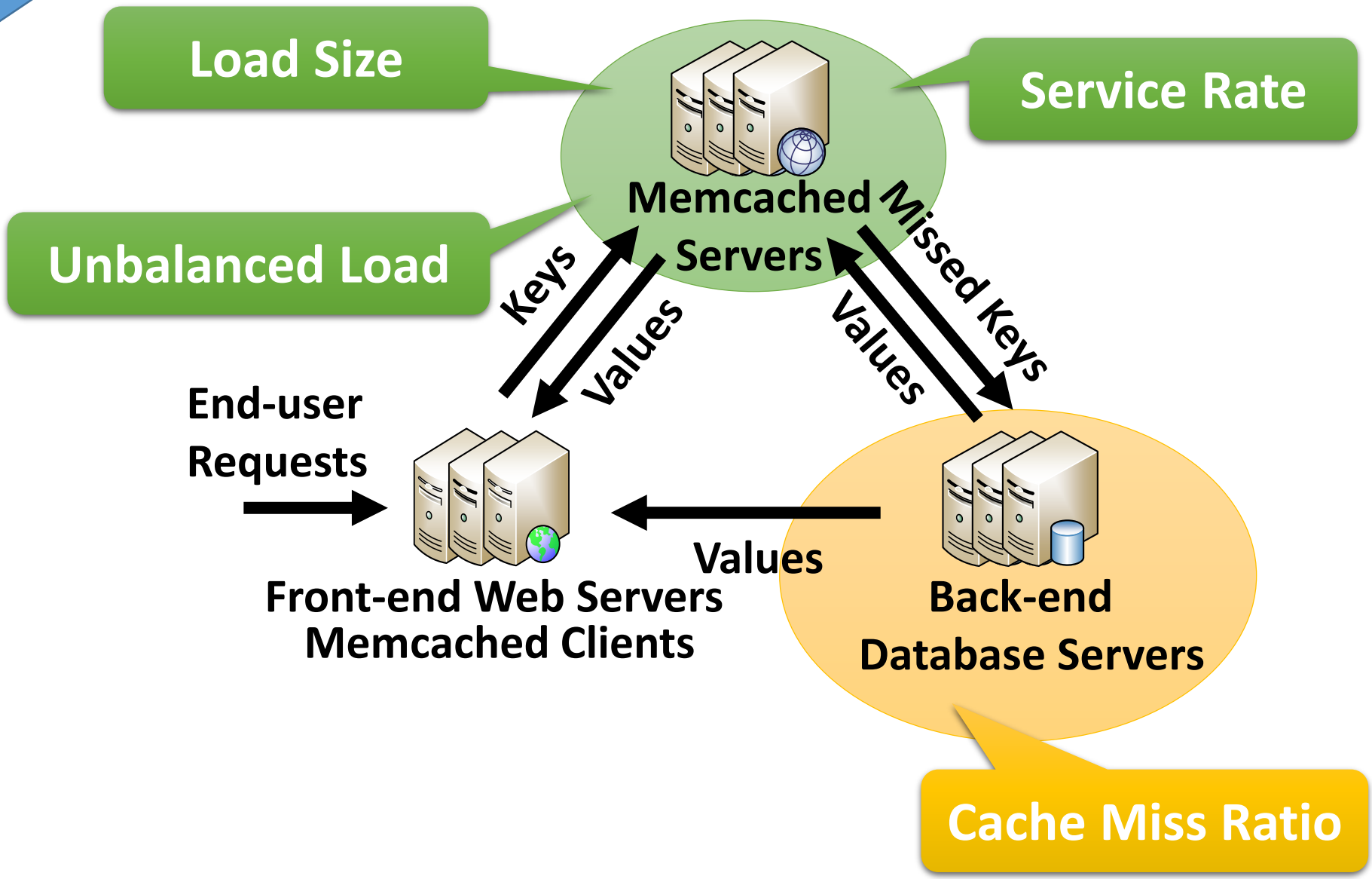
Factors on Latency



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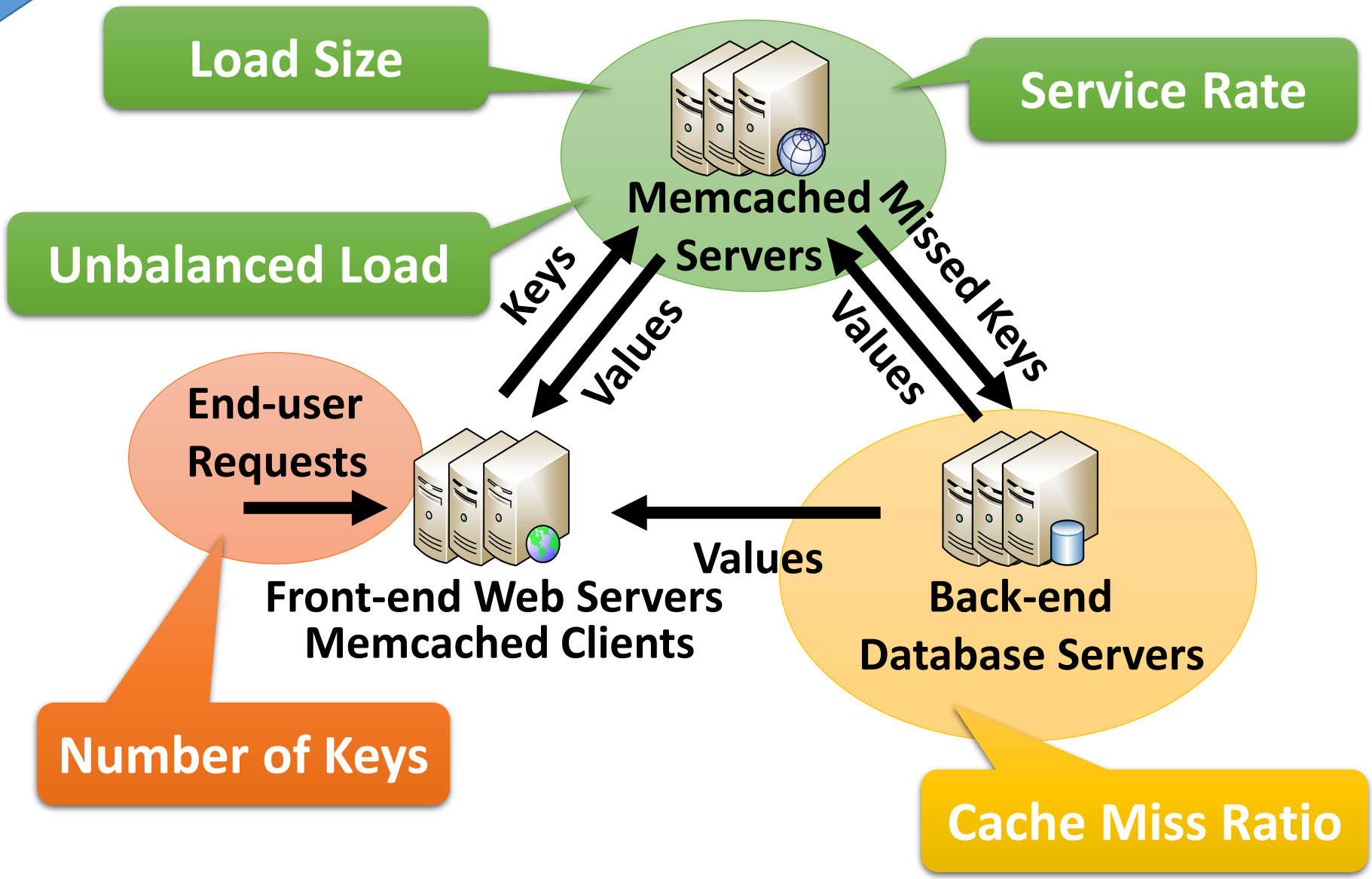
Factors on Latency



Background

Factors on Latency

Load Size

Service Rate

- How much improvement on latency can be achieved by optimizing each factor?

Values

Front-end Web Servers
Memcached Clients

Back-end
Database Servers

Number of Keys

Cache Miss Ratio

Background

Factors on Latency

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Service Rate

- How much improvement on latency can be achieved by optimizing each factor?

Theoretical Model & Quantitative Analysis

Values

Front-end Web Servers
Memcached Clients

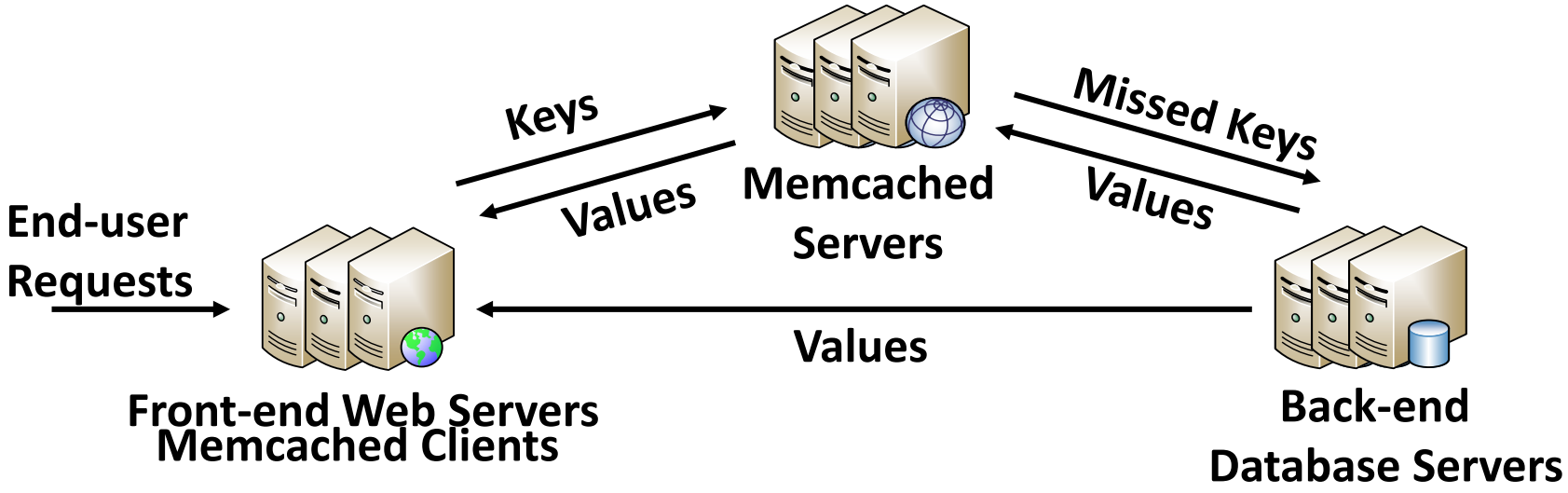
Back-end
Database Servers

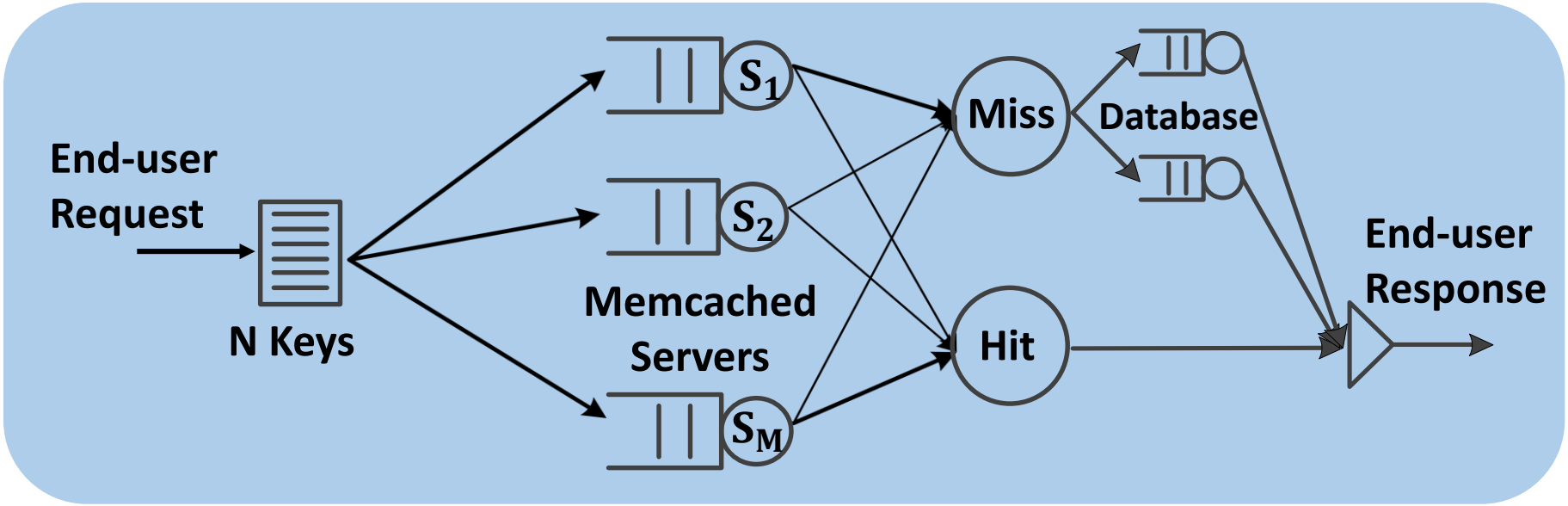
Number of Keys

Cache Miss Ratio

Model

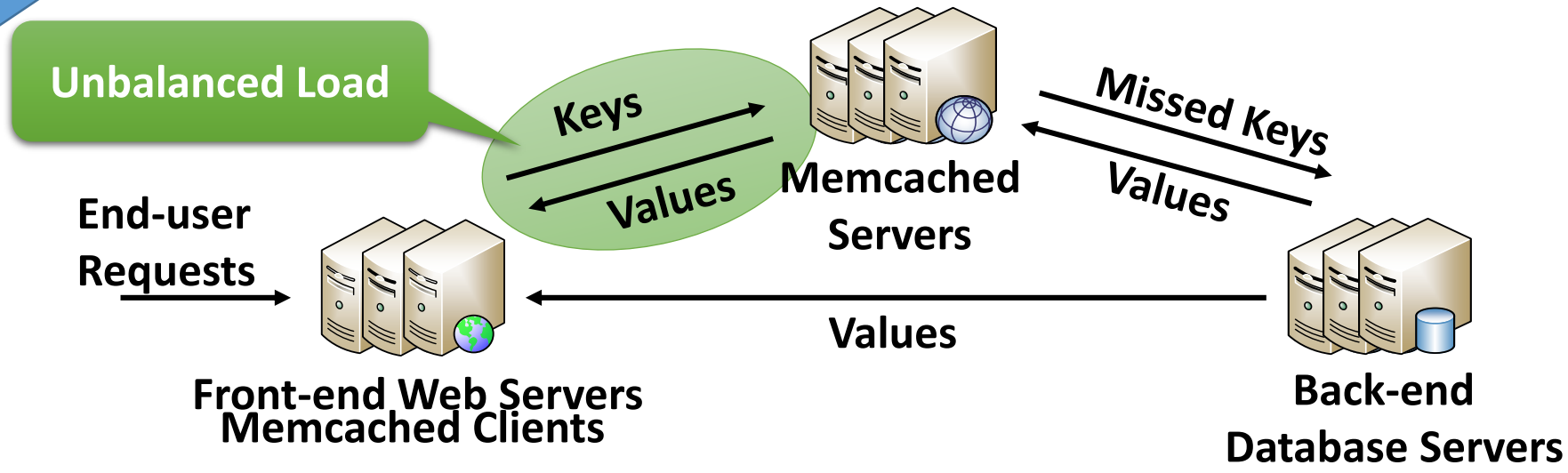
Model for Memcached

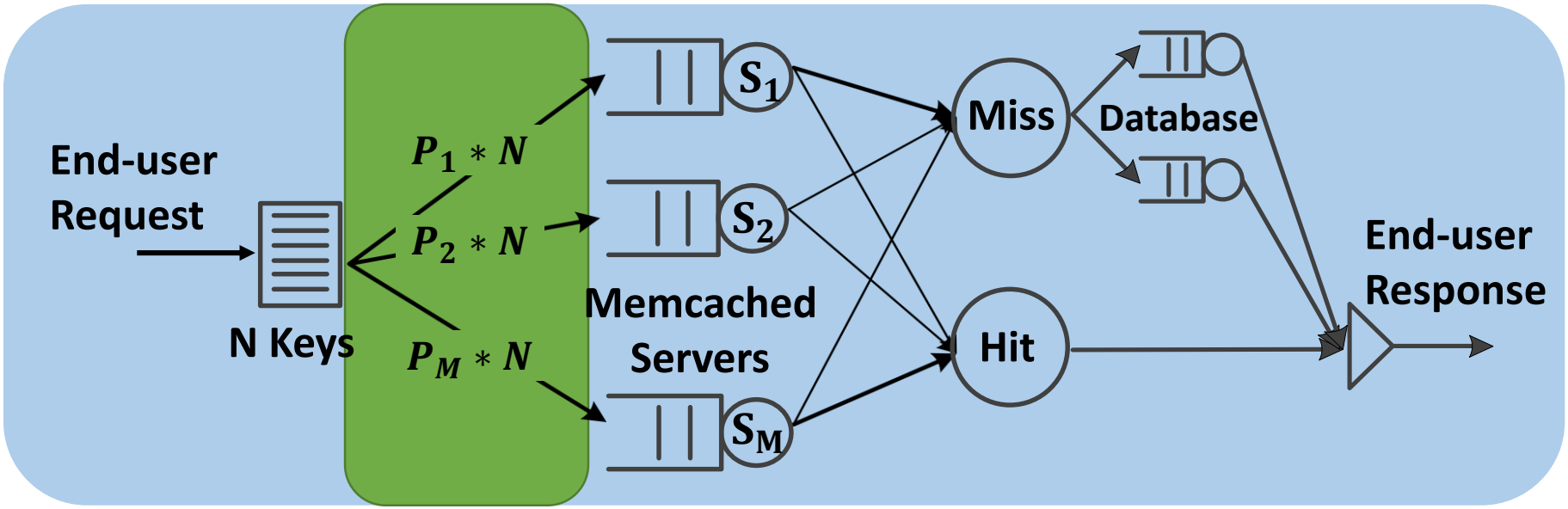




Model

Specific Features





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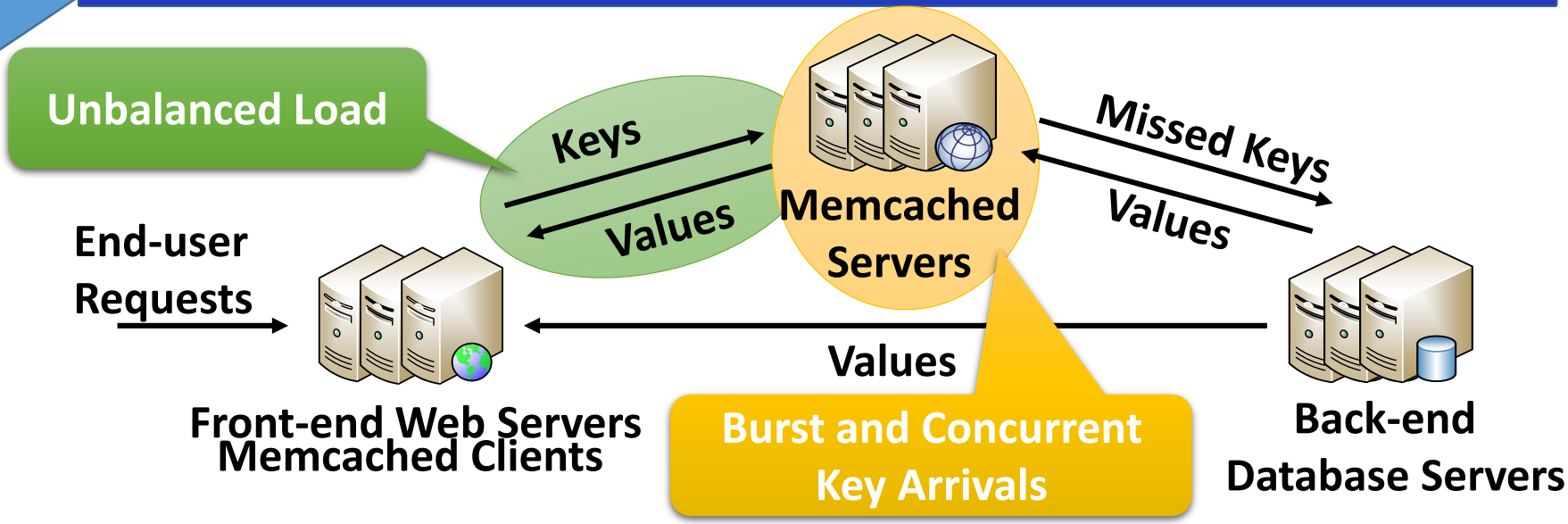

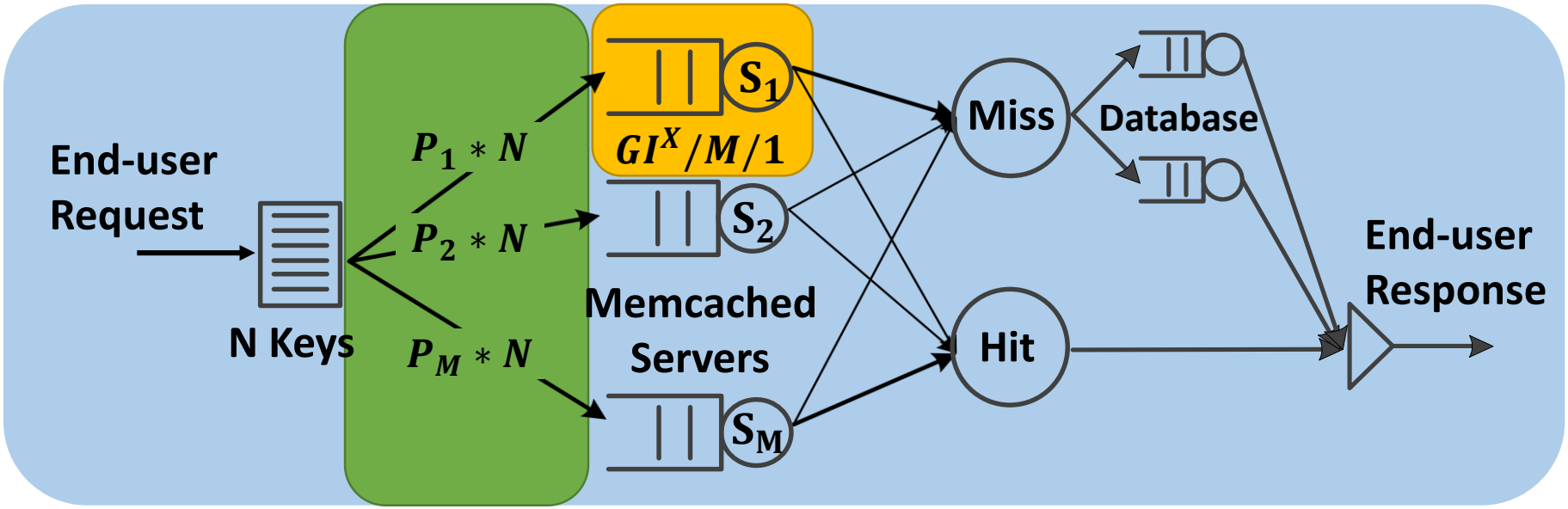

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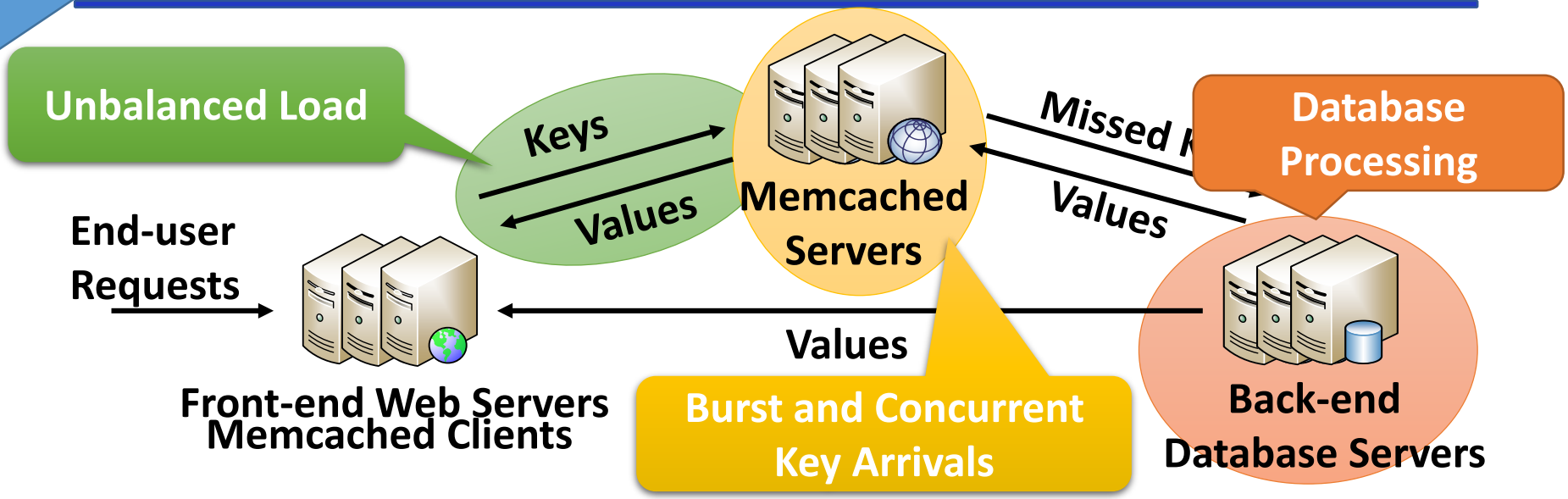
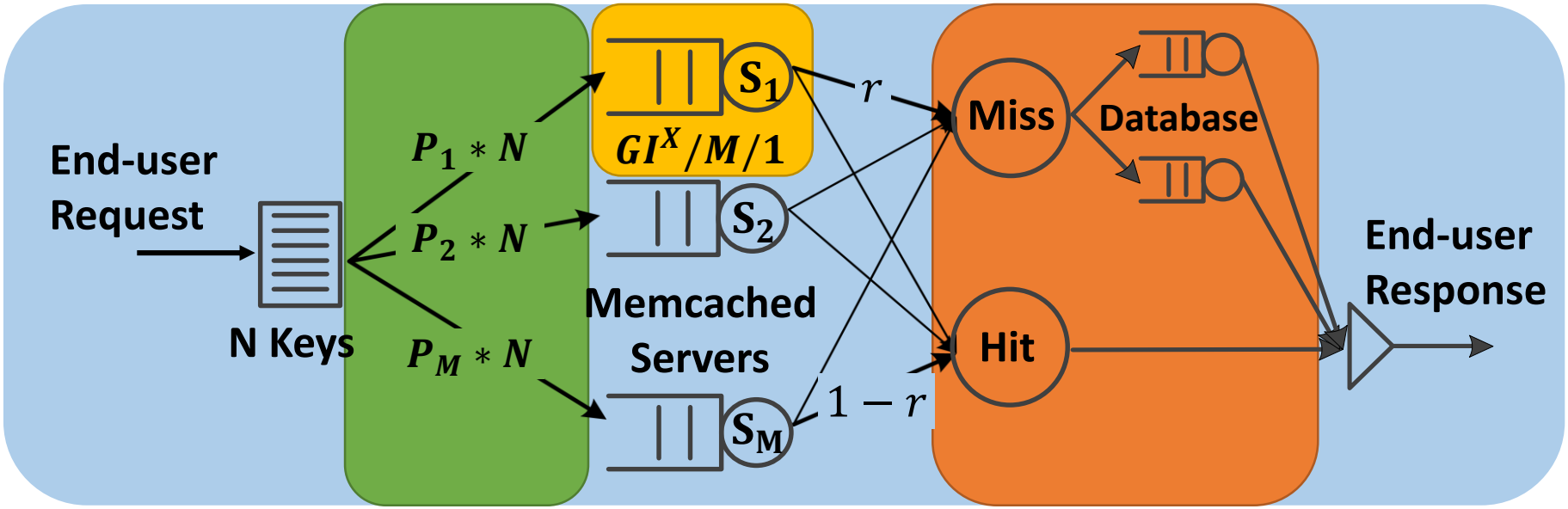
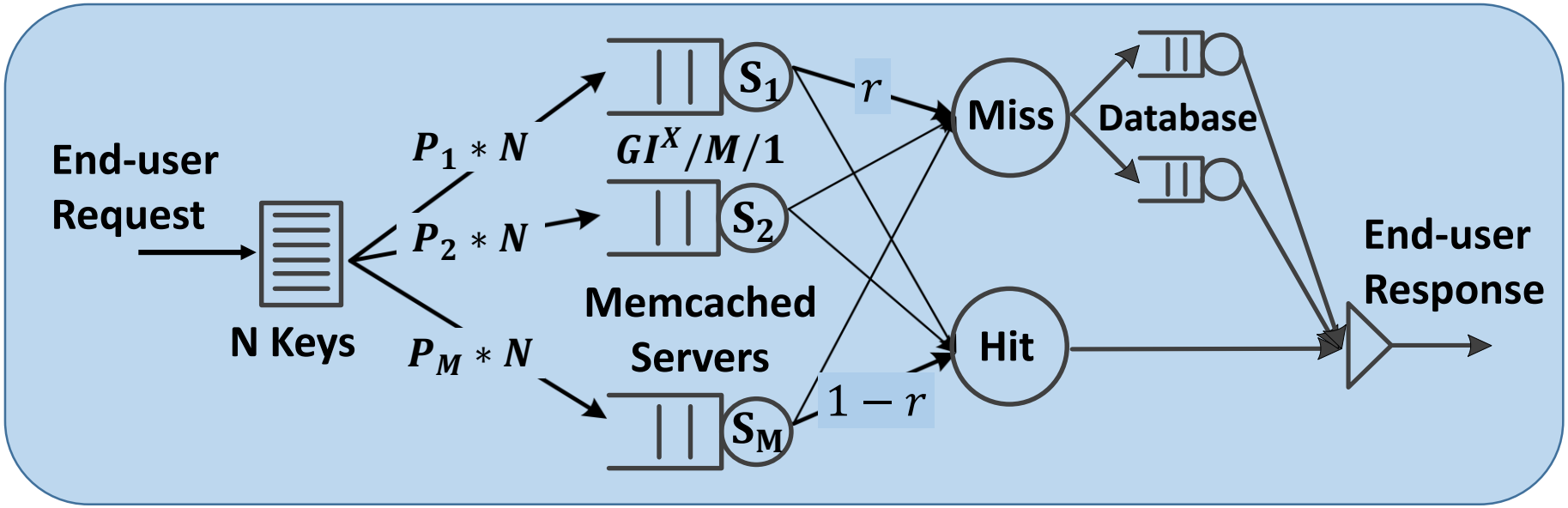




Model

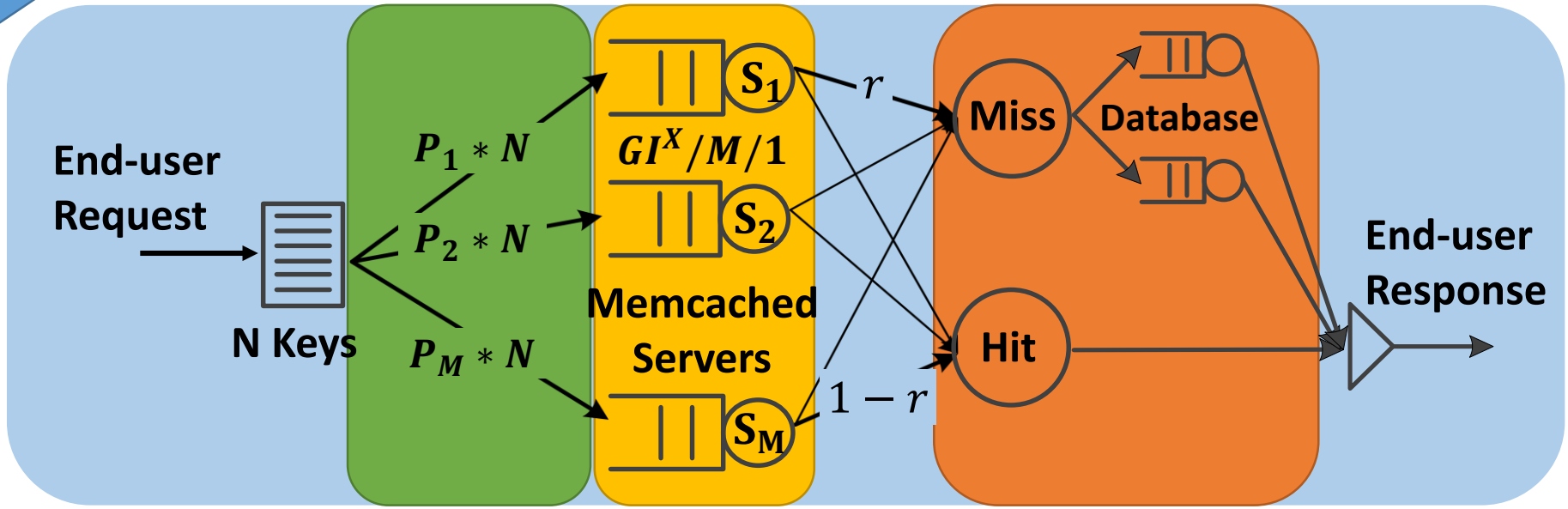
Assumptions

- One end-user request simultaneously generates multiple independent keys.
- Service times are exponential, both at Memcached servers and database.[CoNEXT'13][NSDI'15]



Estimation

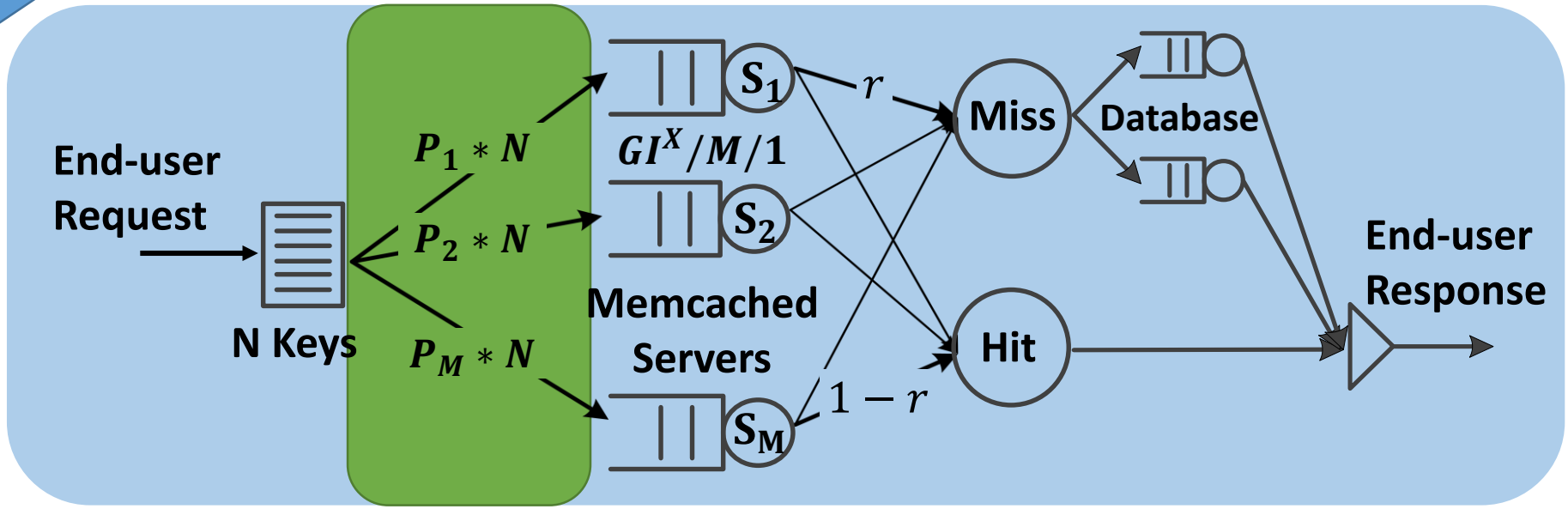
Latency Composition



- Network Latency
- Processing Latency at Memcached Servers
- Processing Latency at Database

Estimation

Network Latency



- Network Utilization << 10% ➔ No queueing in network transmission
  - Request rate: $10^5/s$
  - Request size: Key < 200B, Value < 1KB[SIGMETRICS'12]

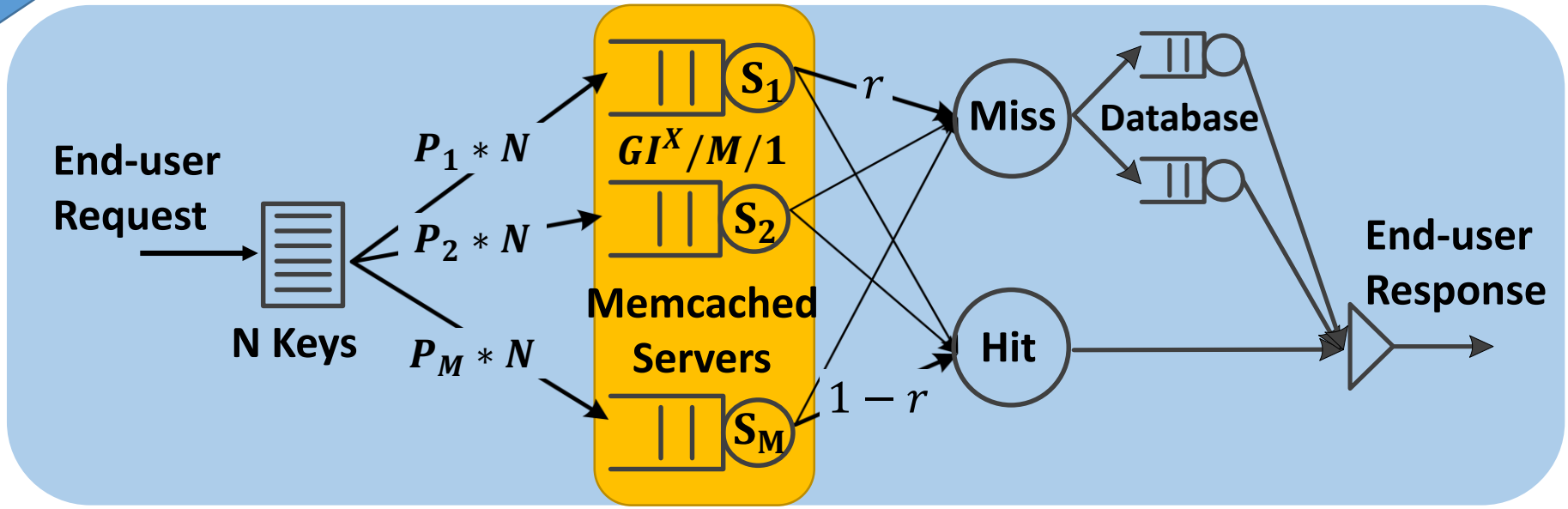
➔Workload << 1Gbps

➔Network bandwidth 10Gbps

Network latency is almost constant

Estimation

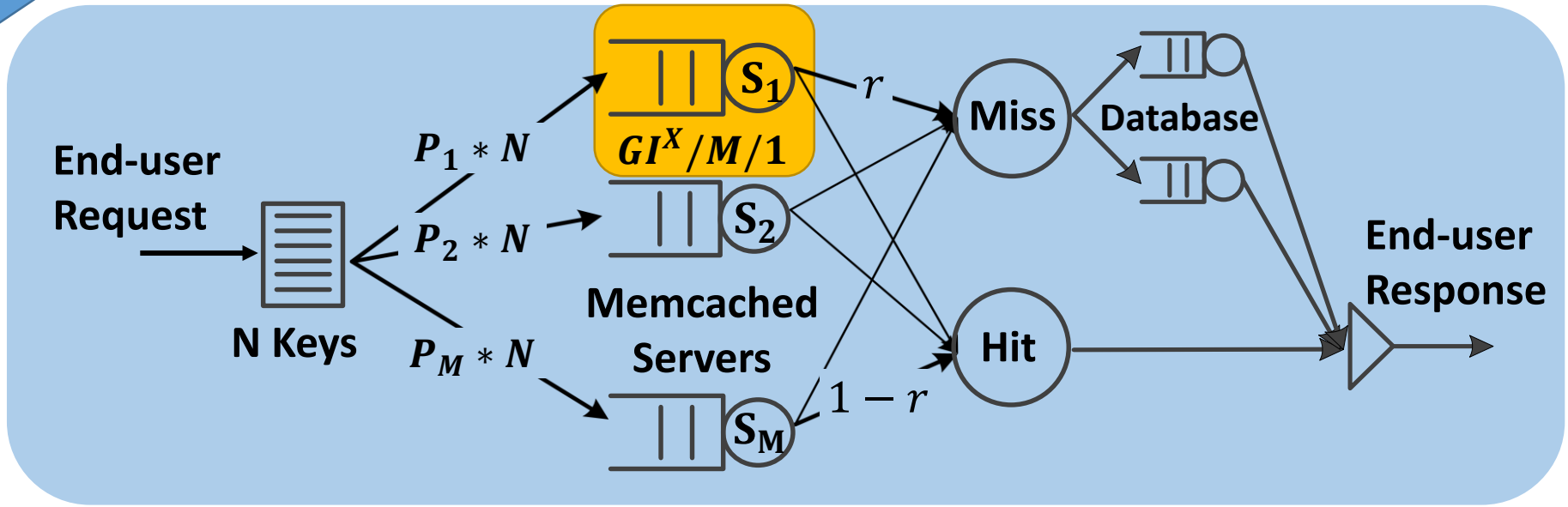
Latency at Memcached servers



- Latency for 1 Key → Maximum Latency for N Keys

Estimation

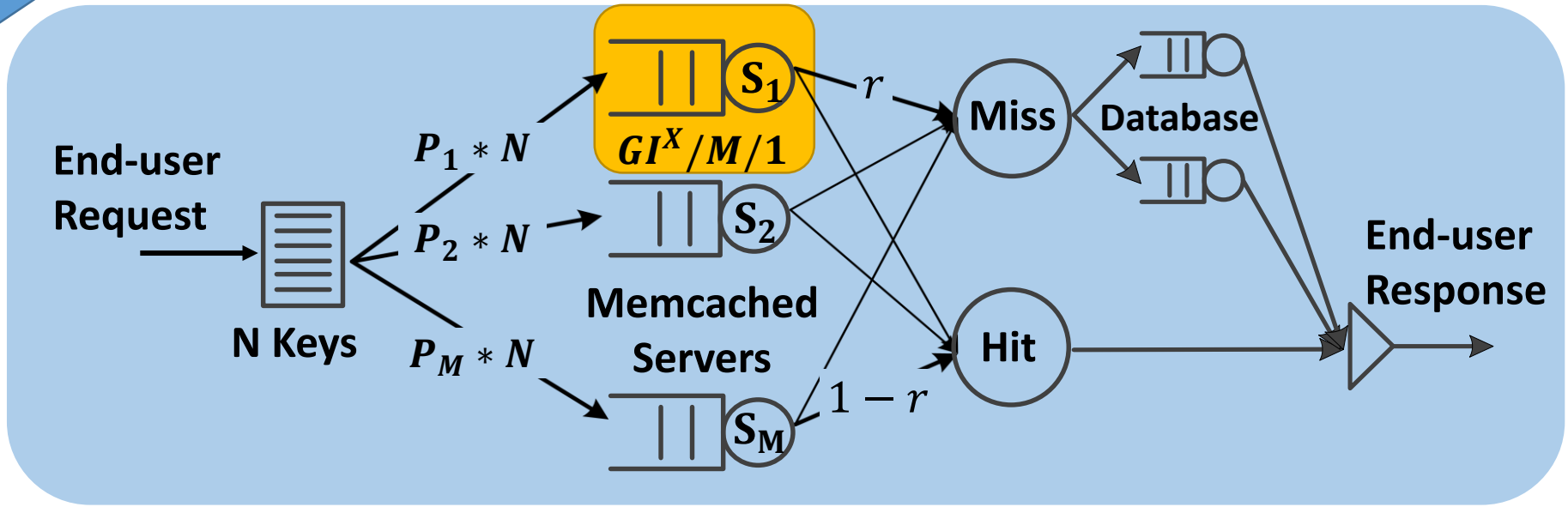
Latency at Memcached servers



- Latency for 1 Key
  - Queuing at each Memcached server : $GI^X/M/1$
    - GI: Any distribution ➔ Burst arrival of keys
    - X: Batch blocks ➔ Concurrent arrival of keys
  - $GI^X/M/1$ ➔ $GI/M/1$
    - Response time for a batch < Latency for 1 Key ≤ Response time for a batch

Estimation

Latency at Memcached servers



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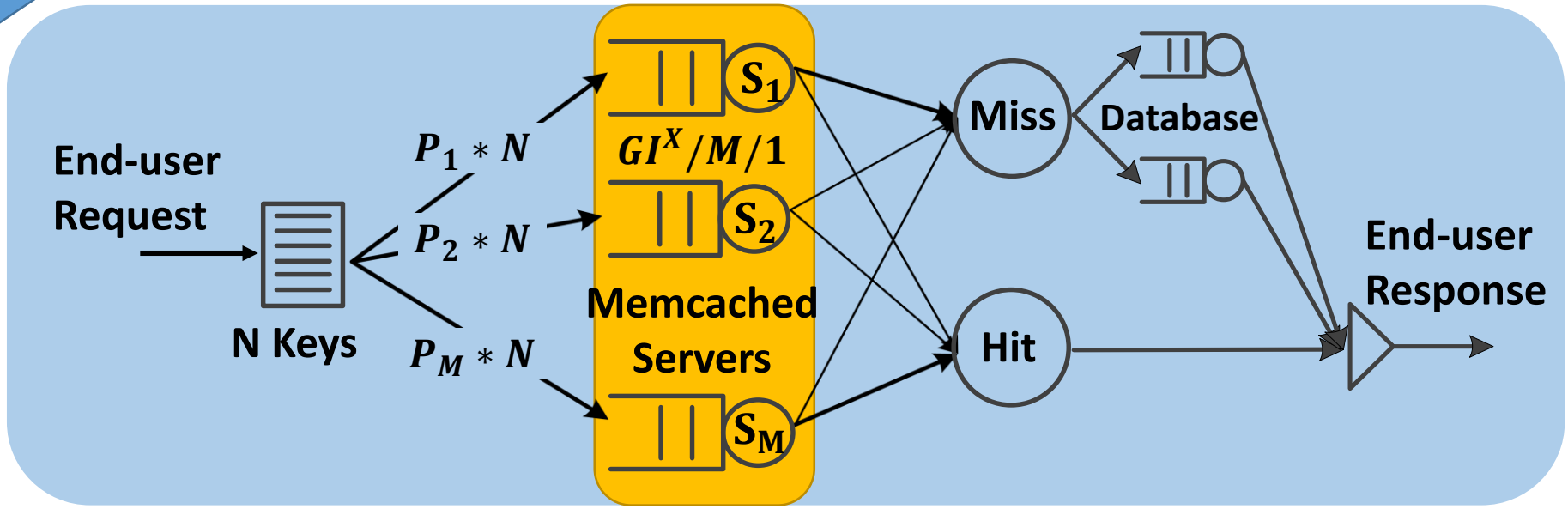
Estimation

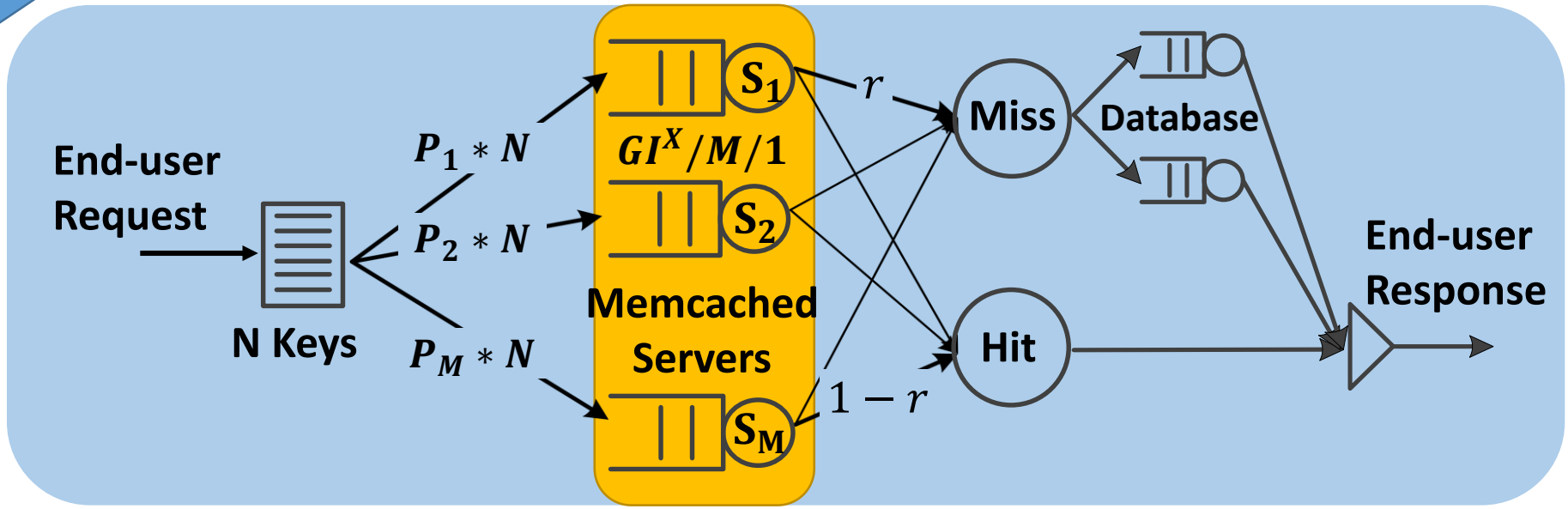
Latency at Memcached servers



- Maximum Latency for N Keys
  - Balanced load ➔ $\approx \left(\frac{N}{N+1}\right)_{th}$ of latency for 1 key
  - Unbalanced load among Memcached servers : $\{P_j\}_{j=1}^{M}$
    - $\in \left[\left(\frac{N}{N+1}\right)^{\frac{1}{p_{max}}}, \left(\frac{N}{N+1}\right)\right]_{th}$ of latency for a key at the heaviest server

Estimation

Latency at Memcached servers



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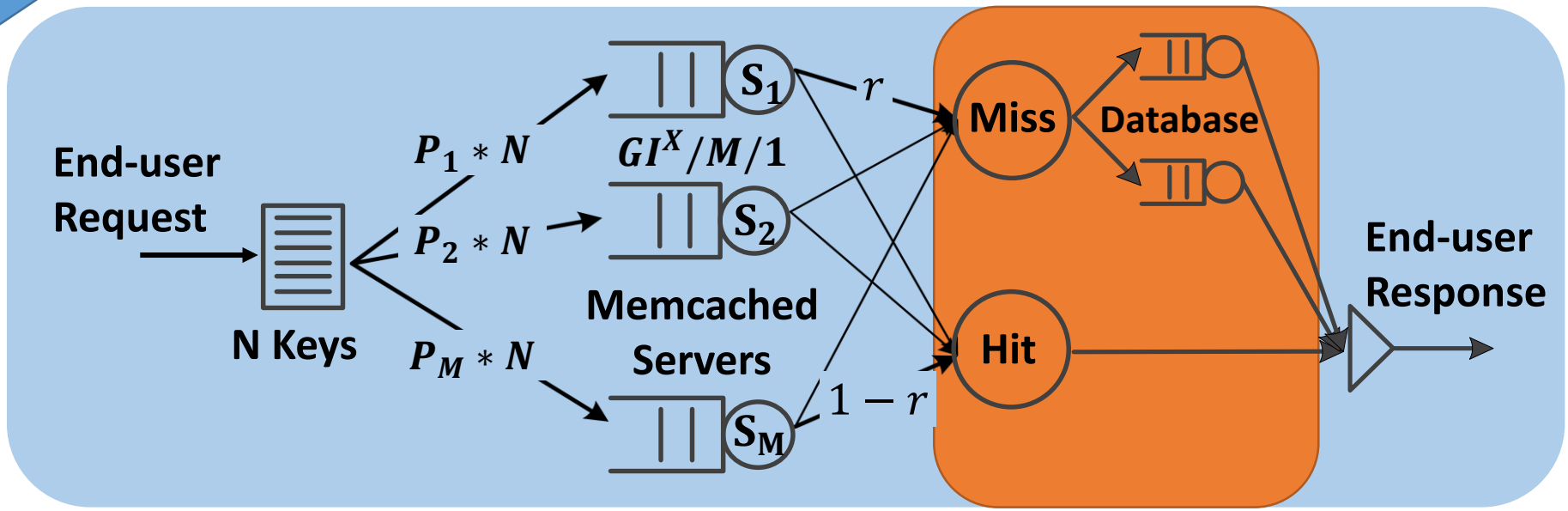
Estimation

Latency at Database



- Depends on the number of keys N and cache miss ratio r
  - $(1-r)^N$: All-hit cases➔ Zero latency.
  - $1-(1-r)^N$: Miss cases ➔ Large latency.

Estimation

Symbols

Symbol	Definition
N	Number of keys generated from an end user request.
M	Number of Memcached servers.
$\{p_j\}_{j=1}^{M}$	Load distribution among Memcached servers.
q	Concurrent probability of keys.
X	Batch size for concurrent keys.
T_X	Inter-arrival gap of batches.
λ	Arrival rate of keys.
μ_S	Service rate of one Memcached server.
r	Cache miss ratio.
μ_D	Service rate at database.

Estimation

Latency Estimation

Latency $T(N)$ of an end-user request that generates N keys is separately bounded by three parts,

$$\max\{T_N(N), T_S(N), T_D(N)\} \leq T(N) \leq T_N(N) + T_S(N) + T_D(N)$$

- The network latency $T_N(N)$ is almost constant.
- The processing latency at Memcached servers $T_S(N)$ satisfies

$$\max\left\{\frac{\ln\delta + \frac{1}{p_{max}}\ln(N+1)}{(1-\delta)(1-q)\mu_S}, 0\right\} \leq E[T_S(N)] \leq \frac{\frac{1}{p_{max}}\ln(N+1)}{(1-\delta)(1-q)\mu_S}$$

- The processing latency at database $T_D(N)$ can be estimated by

$$E[T_D(N)] \approx \frac{1-(1-r)^N}{\mu_D} * \ln\left(\frac{N*r}{1-(1-r)^N} + 1\right)$$

Validation

Basic Validation

- Experimental Setup
  - 2 client machines and 4 server machines
    - Intel CoreTM i5-5200U CPU and 8GB memory
    - Same Rank, 1Gbps links
  - Workload
    - Mutilate: 512 connections
    - Measurements of Facebook [Sigmetrics'12]

Latency	Estimation	Experiment	Confidence Interval
Network	$20\mu s$	$20\mu s$	$[18.12\mu s, 21.68\mu s]$
Memcached Servers	$351\mu s \sim 366\mu s$	$368\mu s$	$[362\mu s, 373\mu s]$
Database	$836\mu s$	$867\mu s$	$[855\mu s, 879\mu s]$
Total	$\mathbf{836\mu s \sim 1222\mu s}$	$\mathbf{1144\mu s}$	$[\mathbf{1128\mu s}, \mathbf{1160\mu s}]$

Background

Factors on Latency

Load Size

Service Rate

- How much improvement on latency can be achieved by optimizing each factor?

Quantitative Analysis

Values

Front-end Web Servers
Memcached Clients

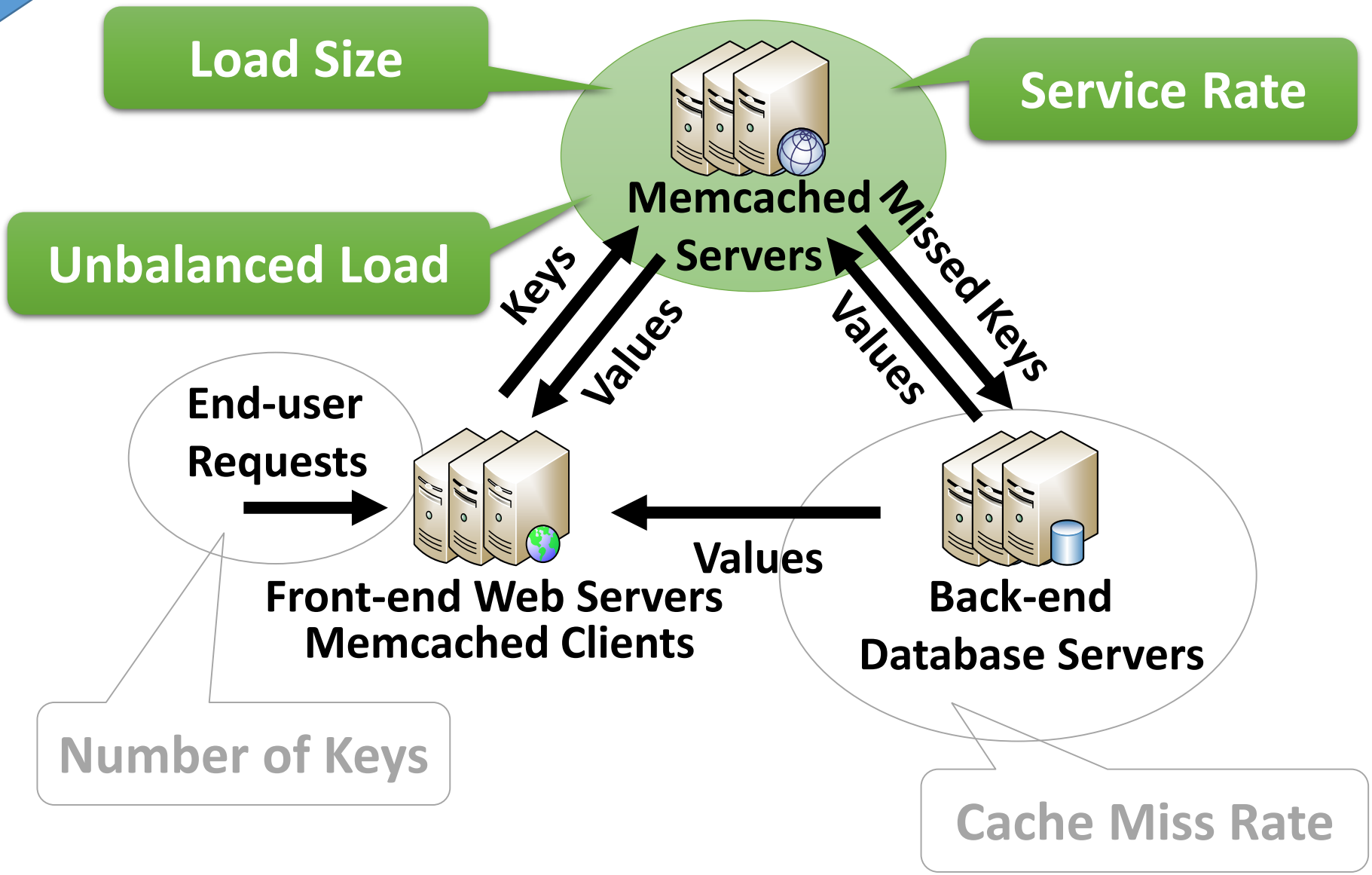
Back-end
Database Servers

Number of Keys

Cache Miss Ratio

Analysis

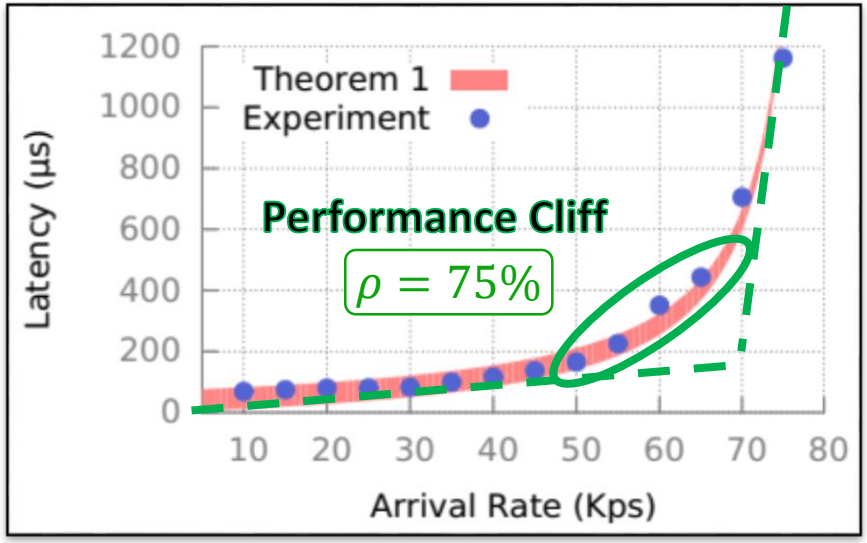
Factors on Latency

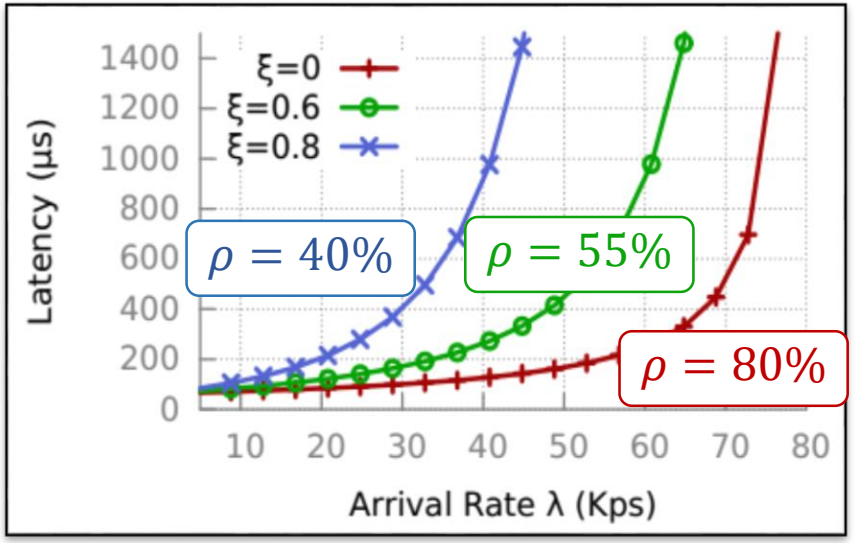


Analysis

Load Size

- Workload: Generalized Pareto Distribution
  - Arrival rate: $\lambda(\text{default} = 62.5Kbps)$
  - Burst degree: ξ $(\text{default} = 0.15)$
- Service rate: $\mu_s(\text{default} = 80Kps)$





Analysis

Service Rate

- Workload: Generalized Pareto Distribution
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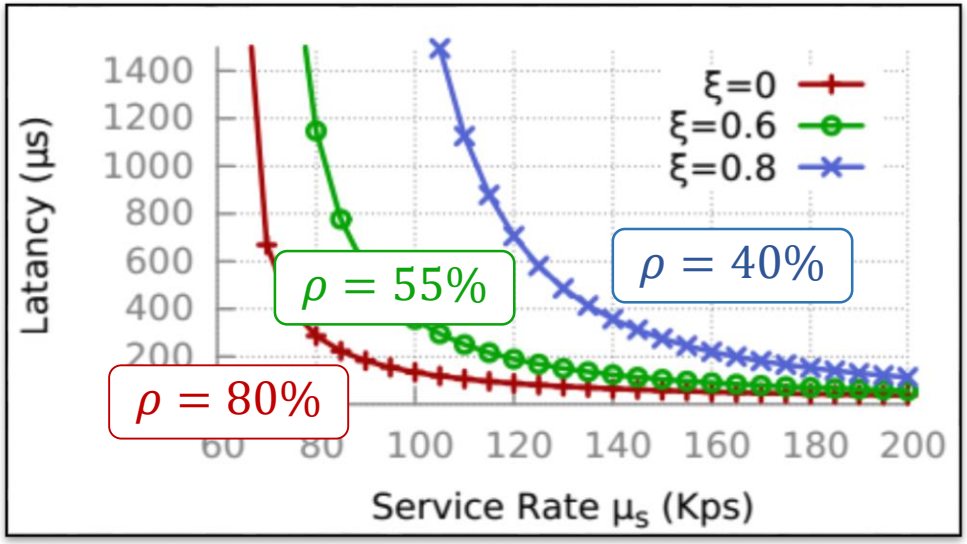
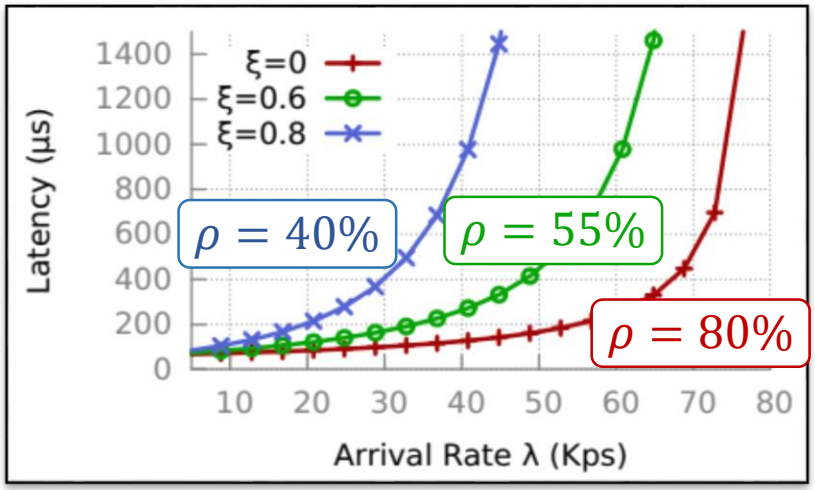
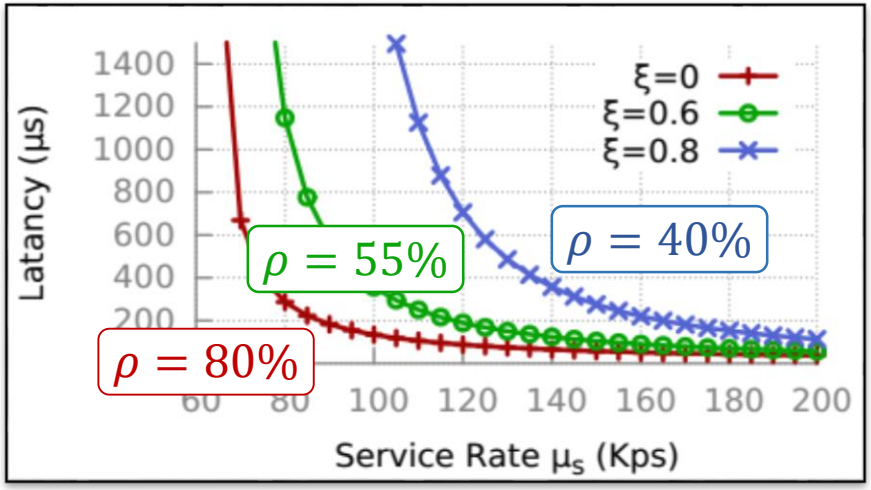


Analysis

Load Size & Service Rate

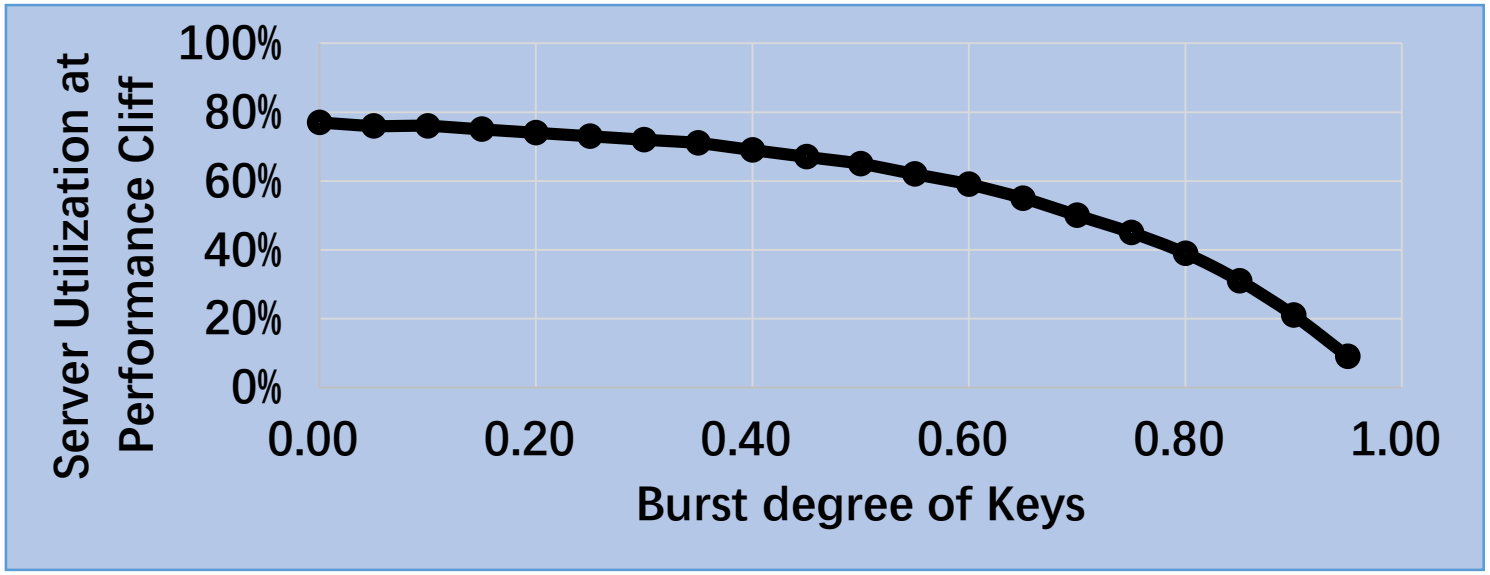




- *Latency reaches a **cliff point** when the Memcached **server utilization** gets to a specific value.*
- *This specific utilization is only determined by the **burst degree** of workload.*

Analysis

Server Utilization



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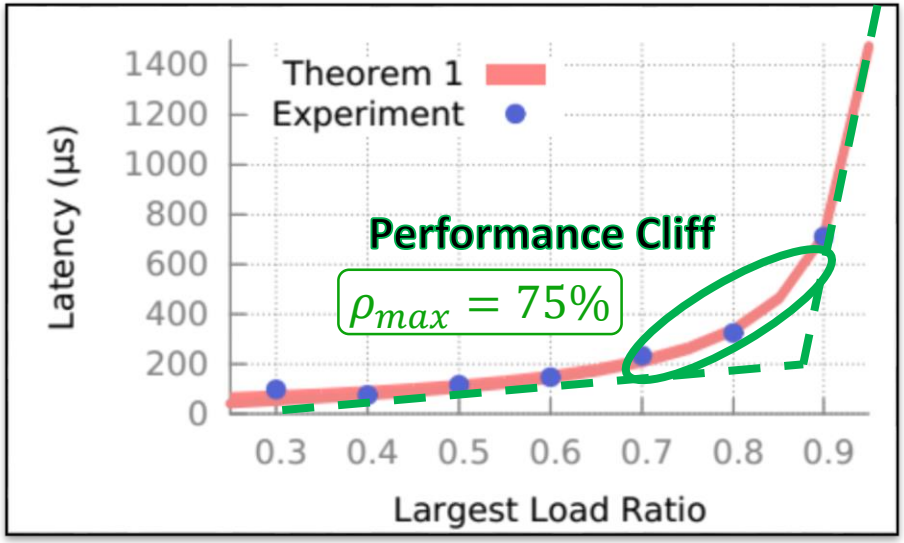
- *This specific utilization is only determined by the **burst degree** of workload.*

Analysis

Unbalanced Load

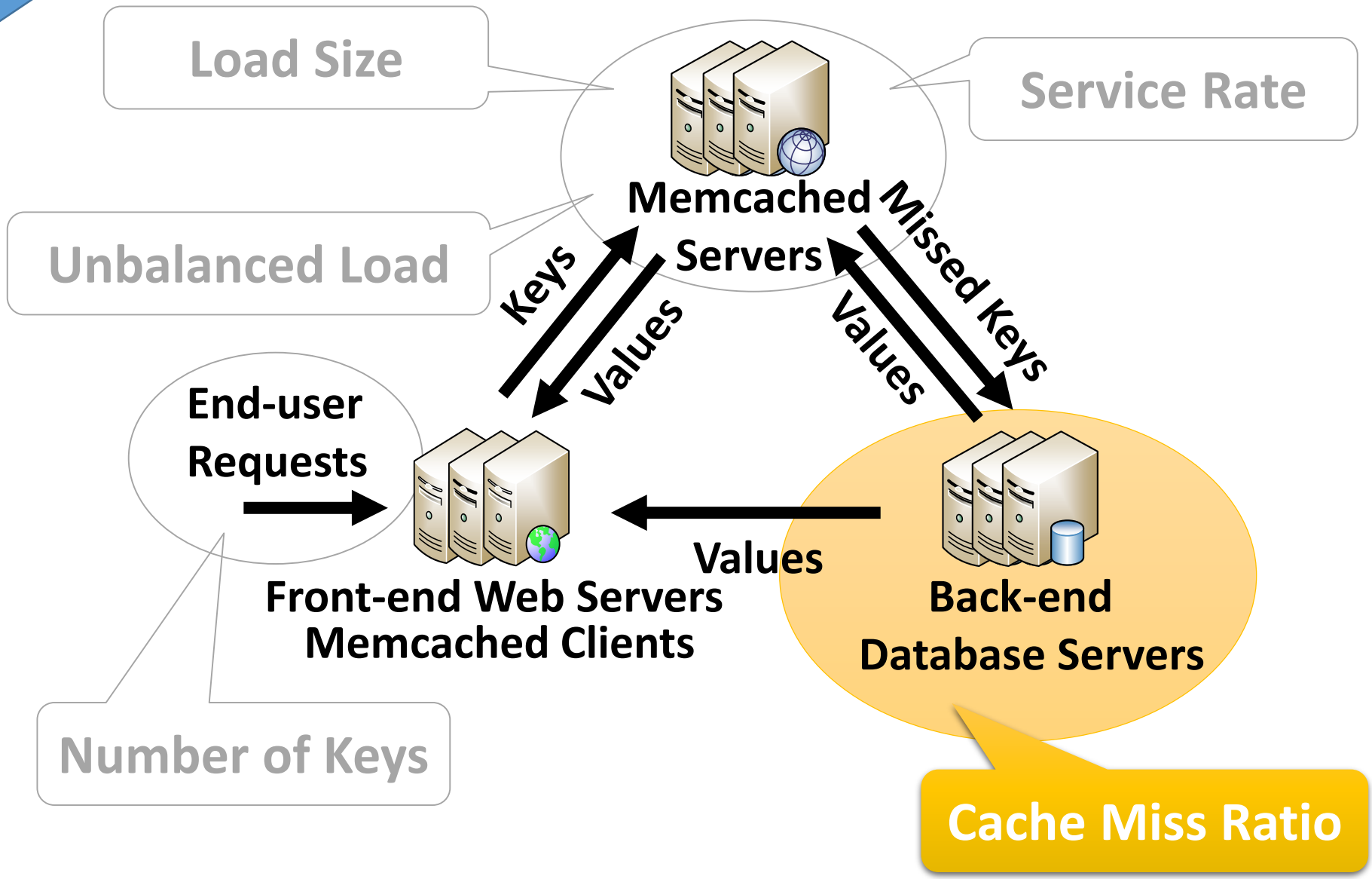
- 4 Memcached servers: Largest load ratio
  - Total load size: $\Lambda = 80Kbps$
  - Burst degree: $\xi = 0.15$
  - Service rate: $\mu_s = 80Kbps$



- Latency still reaches a **cliff point** when the **heaviest** server gets to the **specific utilization**.

Analysis

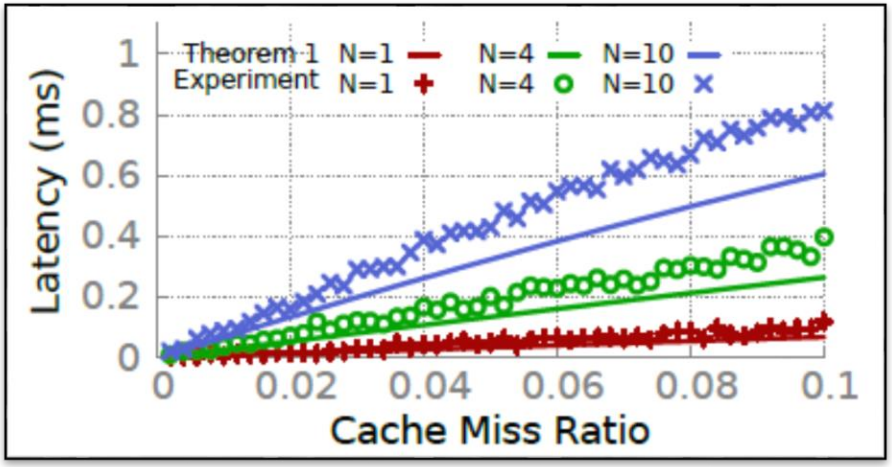
Factors on Latency

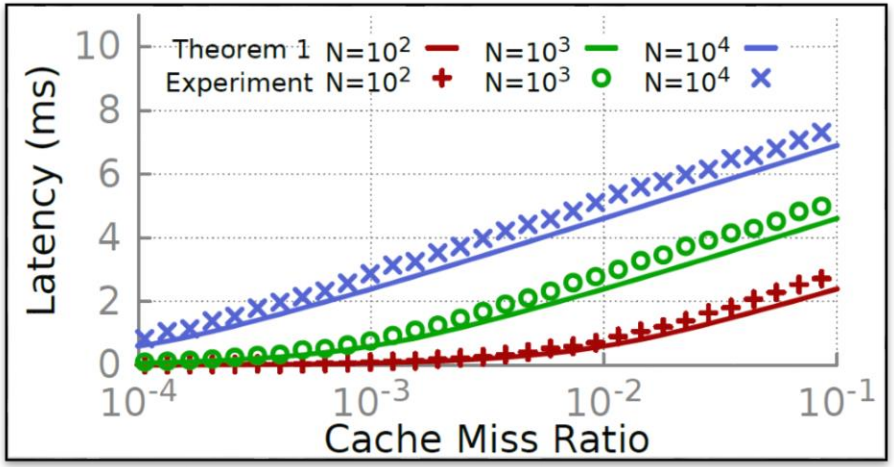


Analysis

Cache Miss Ratio

- Average cost at database: $\frac{1}{\mu_D} = 1ms$



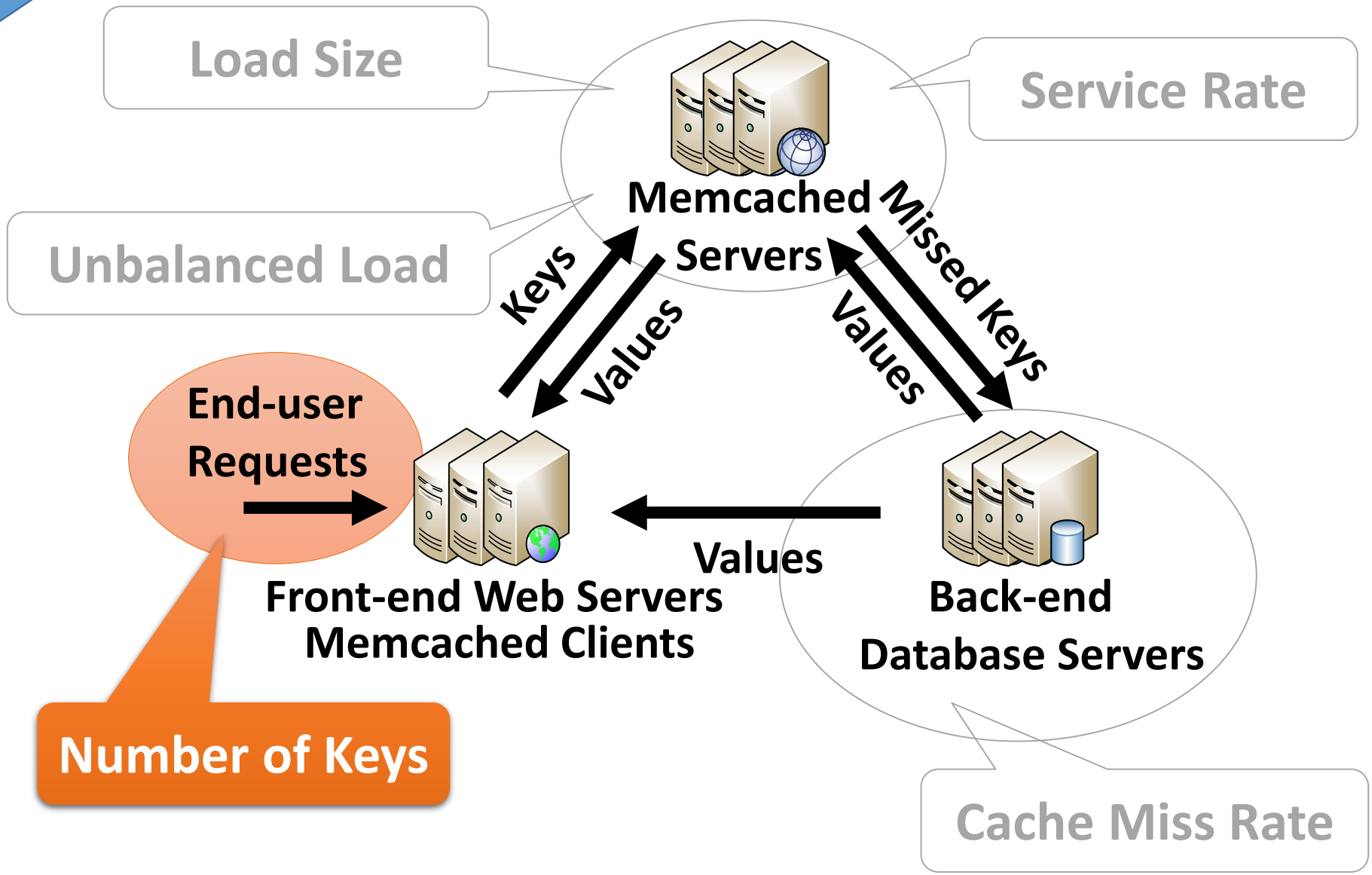


- $r = 0.1 \rightarrow 0.01$
  - $N = 1$ ➔ latency: 0.8ms → 0.08ms, ↓ 90%
  - $N = 10^4$ ➔ latency: 7.2ms → 4.3ms, ↓ 40%

- Latency grows **logarithmically** with the increase of the **cache miss ratio**.

Analysis

Factors on Latency

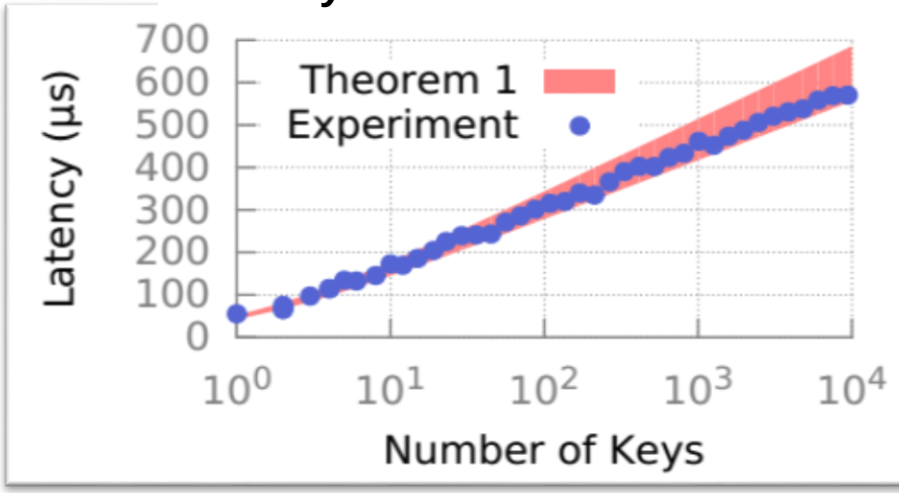


Analysis

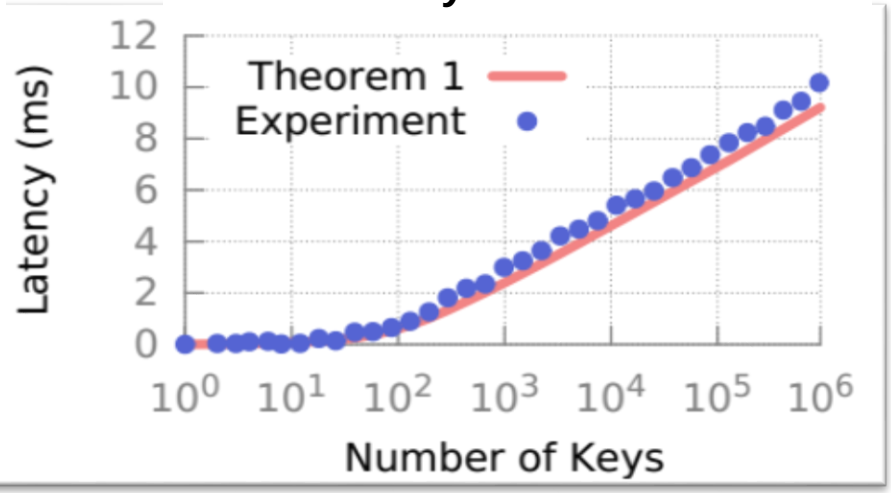
Number of Keys

- Workload burst degree $\xi = 0.15$
- Memcached server utilization $\rho = 0.75$
- Cache miss rate $r = 0.01$

Latency at Memcached Servers



Latency at Database



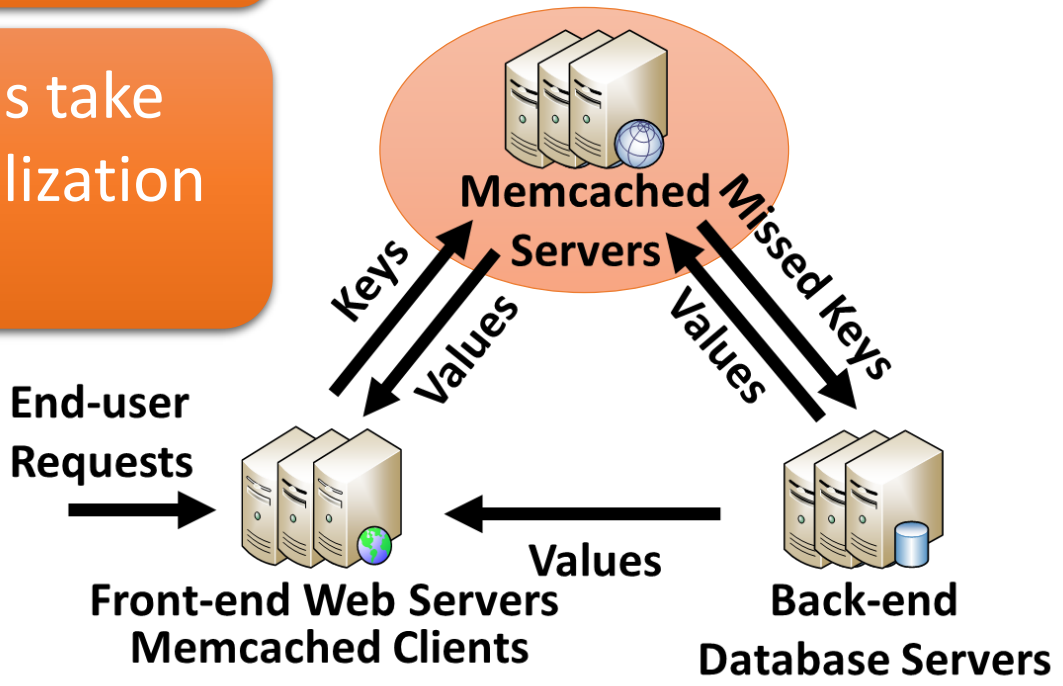
- Latency grows **logarithmically** with the increase of the **number of keys.**

Analysis

Recommendations

Server utilization should not exceed a specific value.

Load-balancing mechanisms take effect before the largest utilization extends the specific value.



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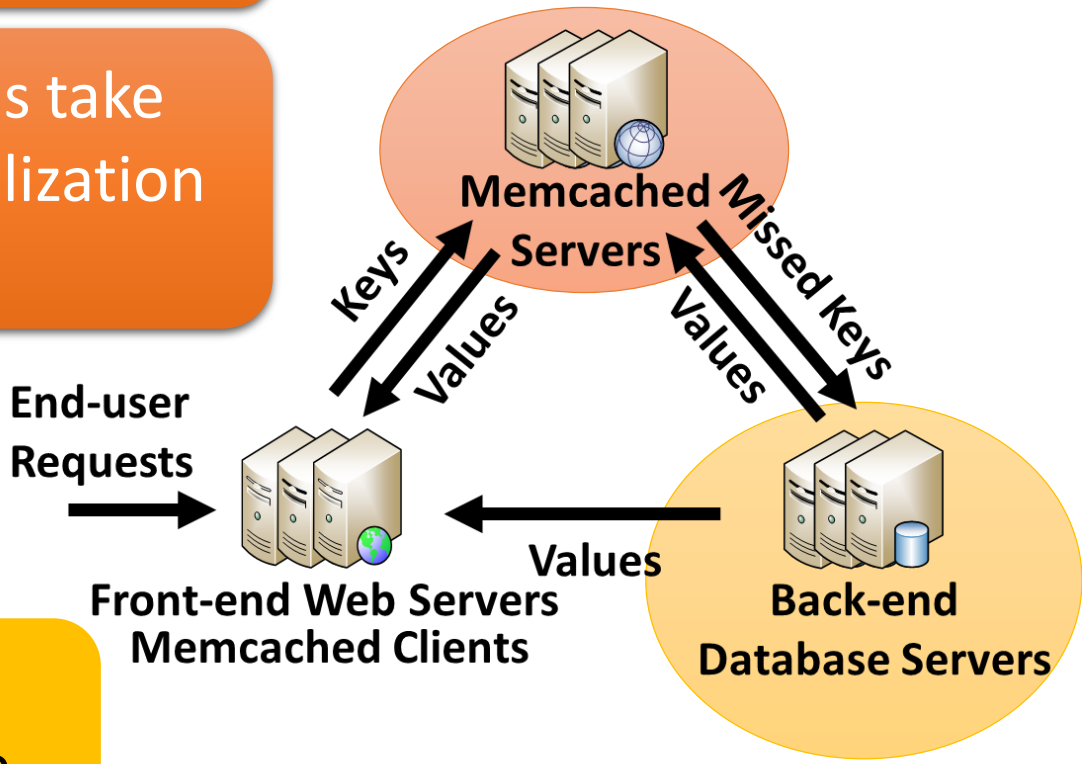
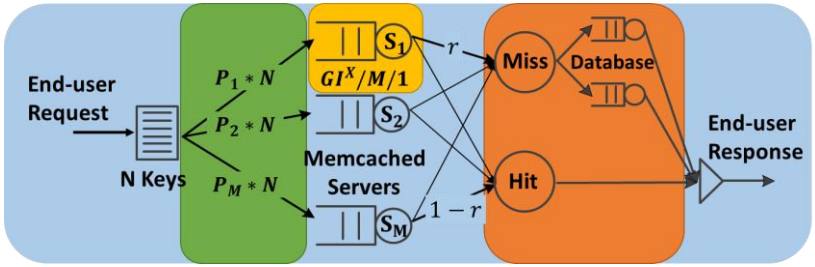


Minimizing the number of keys instead of reducing the cache miss ratio.

Conclusion

- Specific model for Memcached
  - Unbalanced load distribution
  - Burst and concurrent key arrivals
  - Database processing



- Latency estimation, validation & Analysis
  - Network latency is almost constant
  - Latency at Memcached servers is determined by server utilization
  - Latency at database is determined by the number of keys and cache miss ratio
- Recommendations
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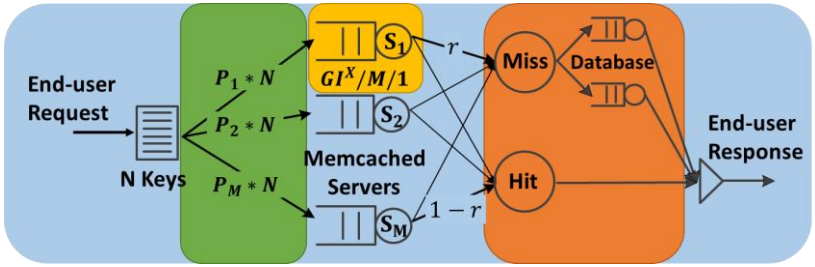

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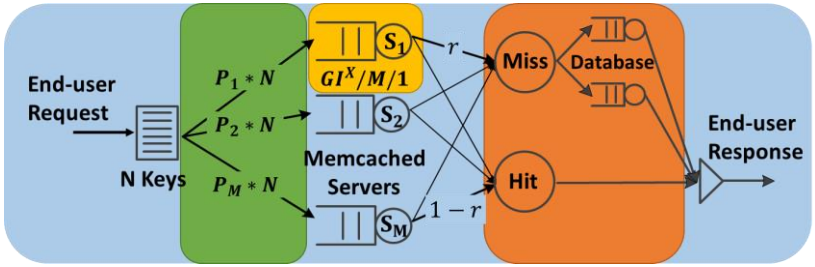
  - Burst and concurrent key arrivals
  - Database processing



- Latency estimation, validation & Analysis
  - Network latency is almost constant
  - Latency at Memcached servers is determined by server utilization
  - Latency at database is determined by the number of keys and cache miss ratio
- Recommendations
  - Server utilization should not exceed a specific value.
  - Load-balancing mechanisms take effect before the largest utilization extends the specific value.
  - Minimizing the number of keys instead of reducing the cache miss ratio.

Thanks!