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Adaptive Performance-Aware Distributed Memory Caching

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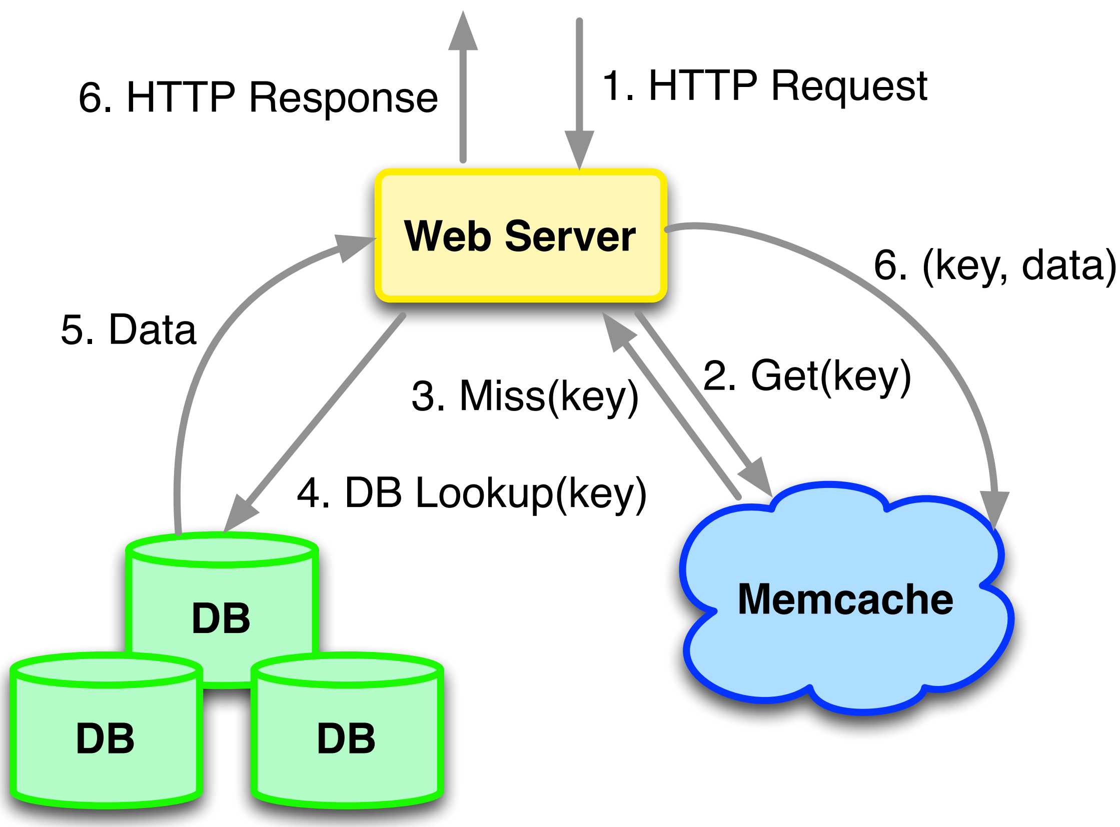
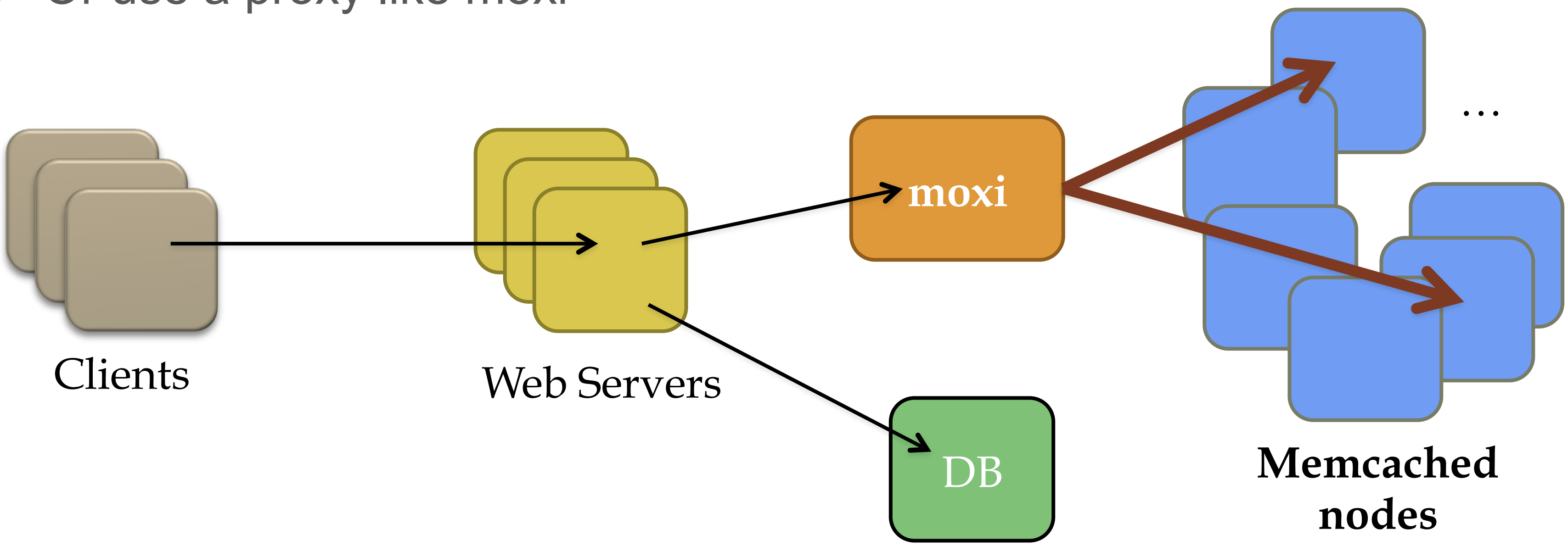
Background: Memory Caching

- Two orders of magnitude more reads than writes
- Solution: Deploy memcached hosts to handle the read capacity



Memcached at Scale

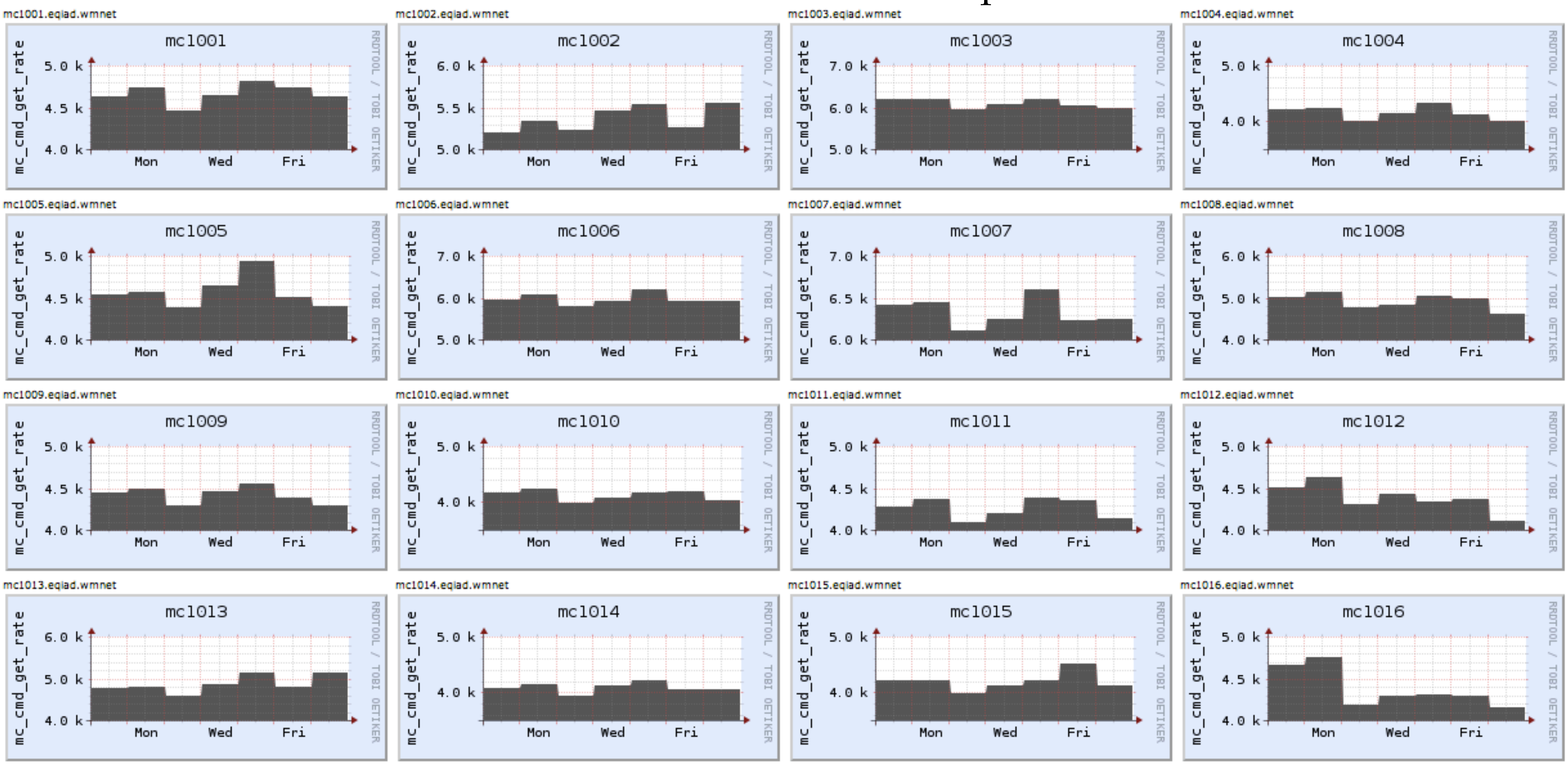
- Databases are hard to scale… Memcached is easy
  - Facebook has 10,000+ memcached servers
- Partition data and divide key space among all nodes
  - Simple data model. Stupid nodes.
- Web application must track where each object is stored
  - Or use a proxy like moxi



Scales easily, but loads are imbalanced

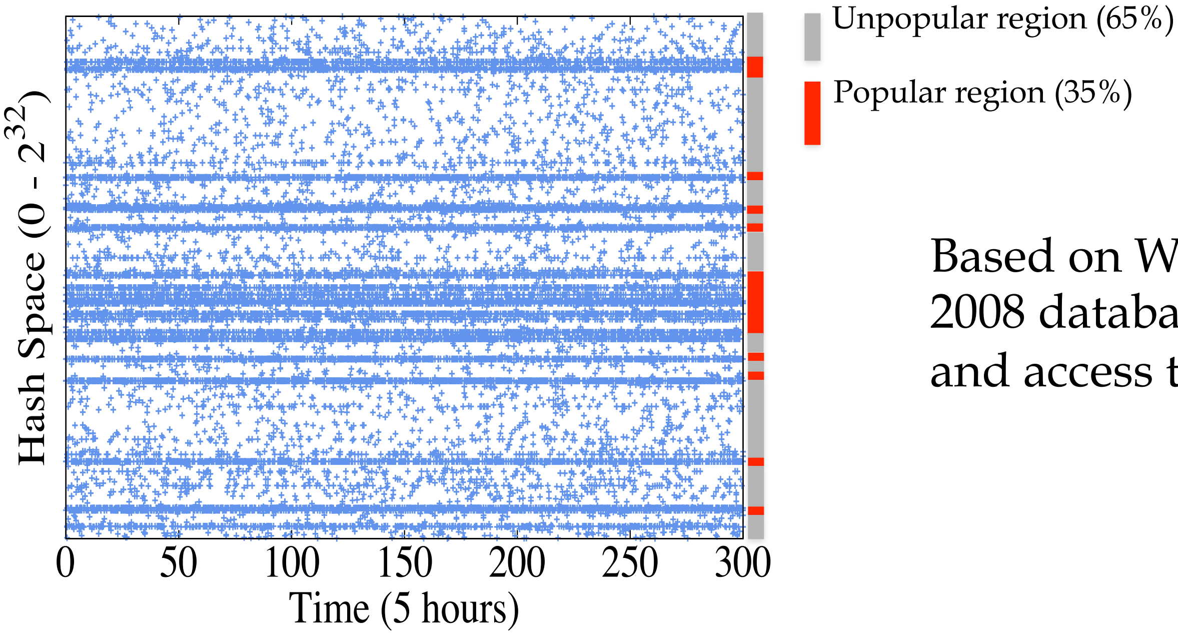
- Random placement…
- Skewed popularity distributions…

Load on Wikipedia's memcached servers



Motivation

- Consistent hashing does not evenly load data across memory cache servers
  - Variation in number of keys assigned to each server
  - Key popularity is skewed and changes over time



Based on Wikipedia 2008 database dump and access trace

- Solution: dynamically balance load according to the performance

Contributions

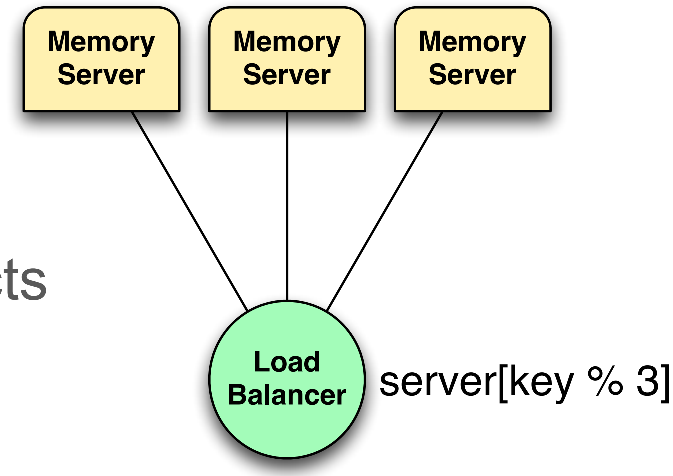
- A hash space allocation scheme
  - allows for targeted load shifting between unbalanced servers
- Adaptive partitioning of the cache's hash space
  - automatically meet hit rate and server utilization goals
- An automated replica management system
  - adds or removes cache replicas based on overall cache performance

Outline

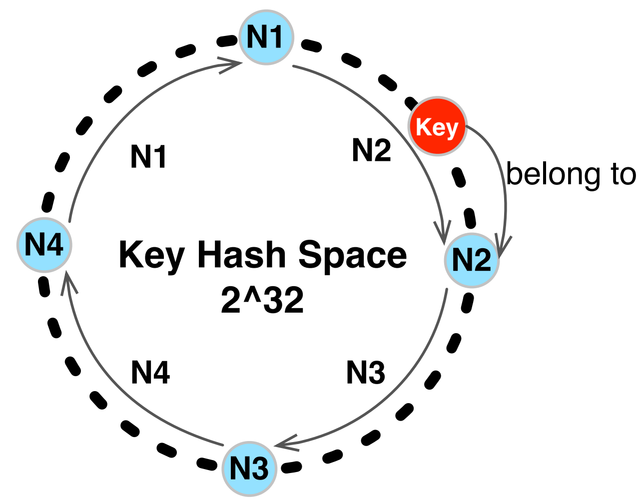
- Background and Motivation
- Initial Hash Space Partitioning
- Dynamic Adaptation
- Evaluation
- Conclusions

Background: Hash Space Allocation

- Simple Hashing
  - hash(key) % [# of server]
  - Once assigned, never changes
  - If node added or removed, all objects need to be rearranged



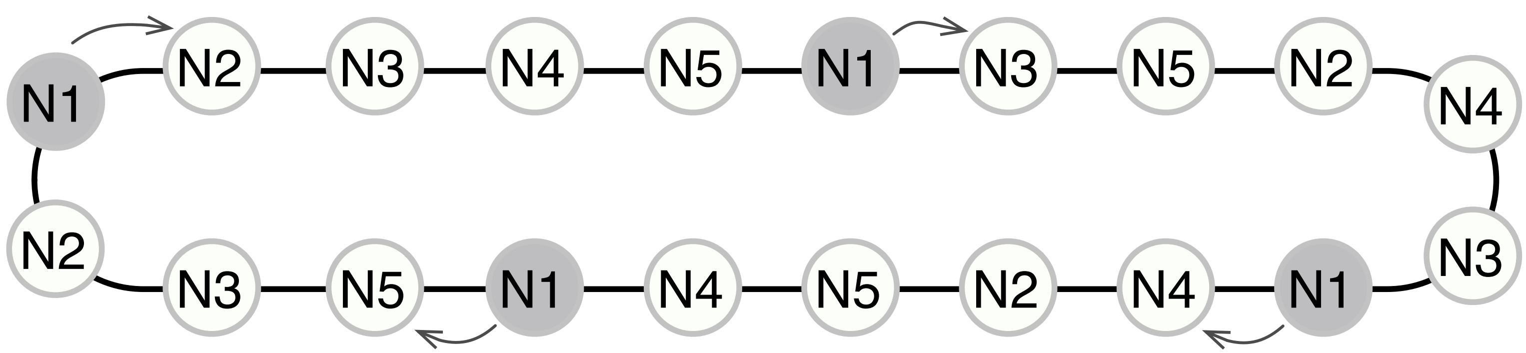
- Consistent hashing
  - Treat hash space as ring with nodes assigned to each region
  - Node addition / removal only affects adjacent nodes
  - Used in P2P systems and by popular memcached proxy system Moxi



Initial Assignment

- To enable efficient repartitioning of the hash space:
  - Every node is adjacent to every other node
  - This allows a simple transfer of load between two nodes by adjusting just one boundary

- Required number of duplicate nodes = $v \geq \frac{{}^{n_0}P_2}{n_0} = n_0 - 1,$
- Total number of nodes = $n_0 \times (n_0 - 1)$
- Multiply number of virtual nodes



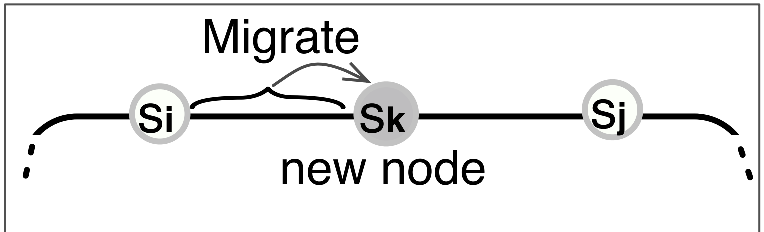
Dynamic Hash Space Scheduling

- Two factors to measure server performance:
  - Hit rate: enough memory for popular data
  - Usage ratio: server processing
- Minimize {cost = $\overline{\text{hit rate}}$ + usage ratio}

- Scheduling decision: $\alpha \in [0,1]$
  - Find the most different two memory servers
  - Find the most different two adjacent virtual nodes
- Size of hash space moved at each scheduling decision
  - Determine the speed of adaptability, but more fluctuation
  - Using ratio value: $\beta \in (0,1]$

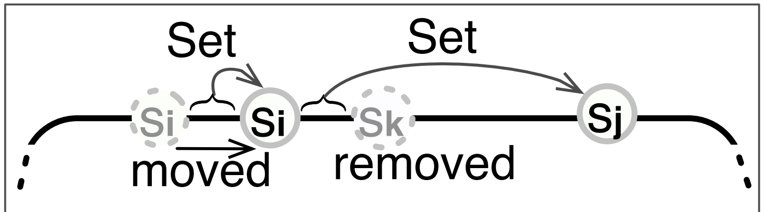
Node Addition / Removal

- Balance out the requests across replicas that overall performance improves
- Highly overloaded server(s) sustaining a certain period of time should be backed by new server(s)
- Find the most costly memory server, and its virtual node



Node Addition

- Find the least costly memory server, and its virtual node



Node Removal

Outline

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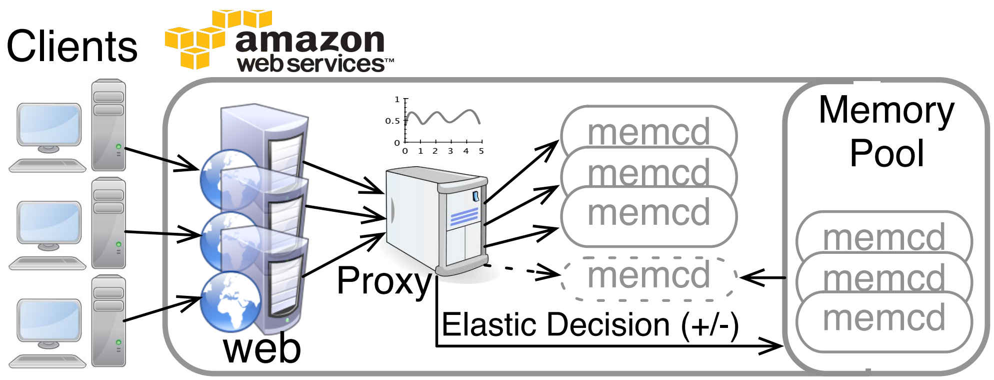
Experimental Setup

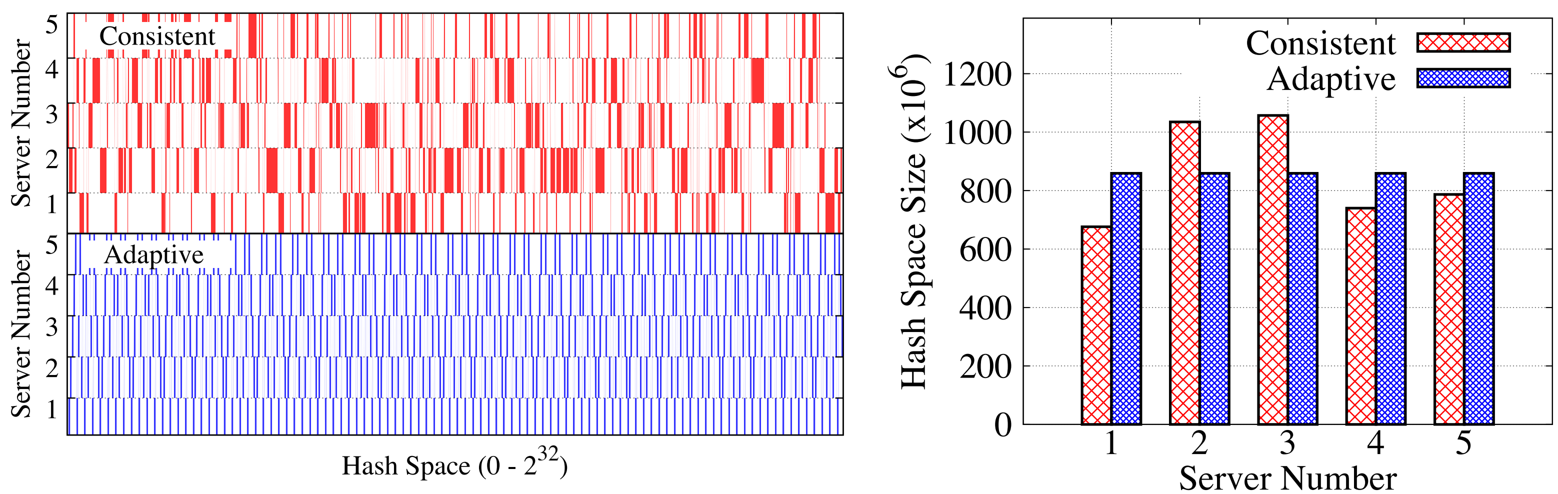
- Lab setup
  - Five experimental servers(4× Intel Xeon X3450 2.67GHz processor, 16GB, and a 500GB 7200RPM hard drive)
- Amazon setup
  - 15 medium instances



- All workloads are from Wikipedia data and access traces

Initial Hash Space Assignment

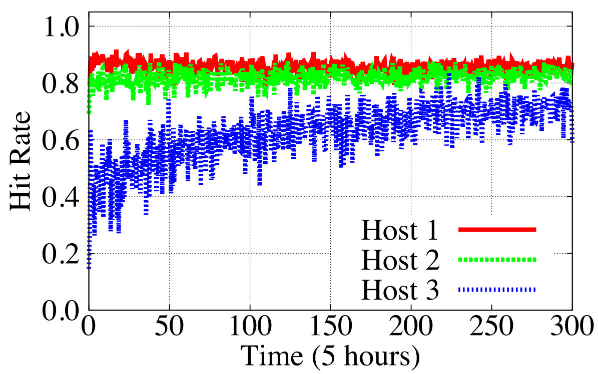
- 5 memory servers used (total 500 virtual nodes)
  - For consistent hashing, 100 virtual nodes per each server
  - For our scheme, the initial set is 5 x 4 = 20, and 25 virtual nodes per node

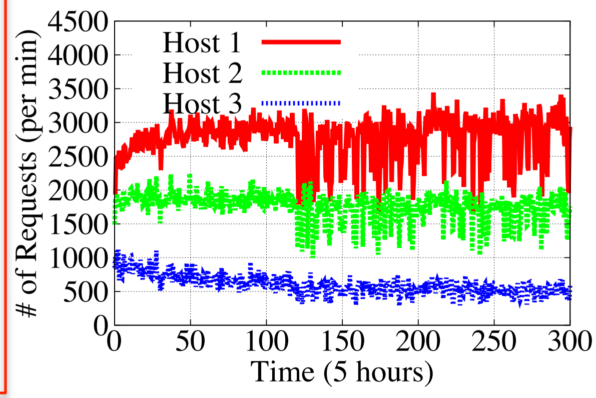


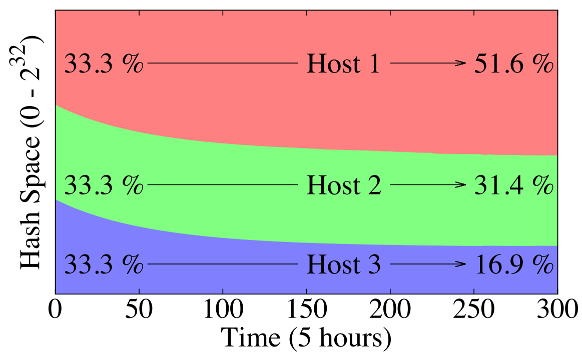
- The largest gap between the biggest hash size and the smallest hash size is 381,114,554 (≅ 20% more)

Dynamic Partitioning

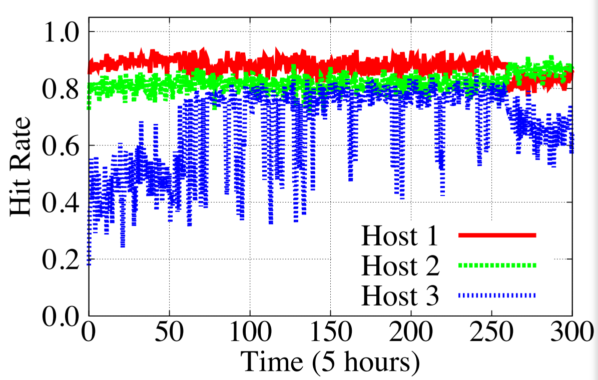
- α = 1.0 (only hit rate)

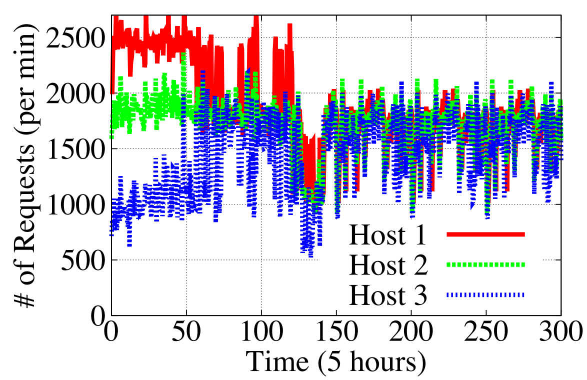


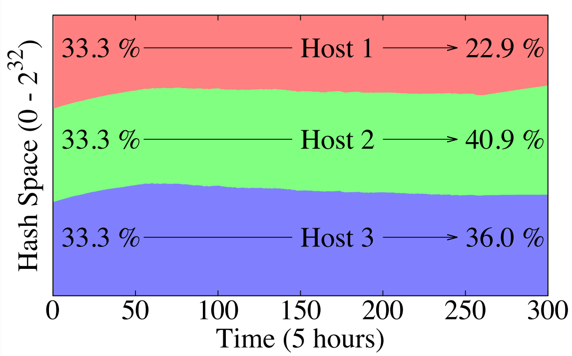




- α = 0 (only usage ratio)

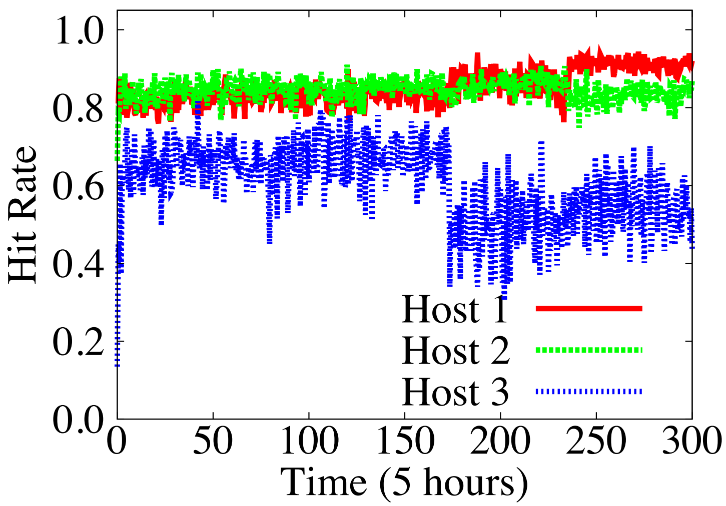


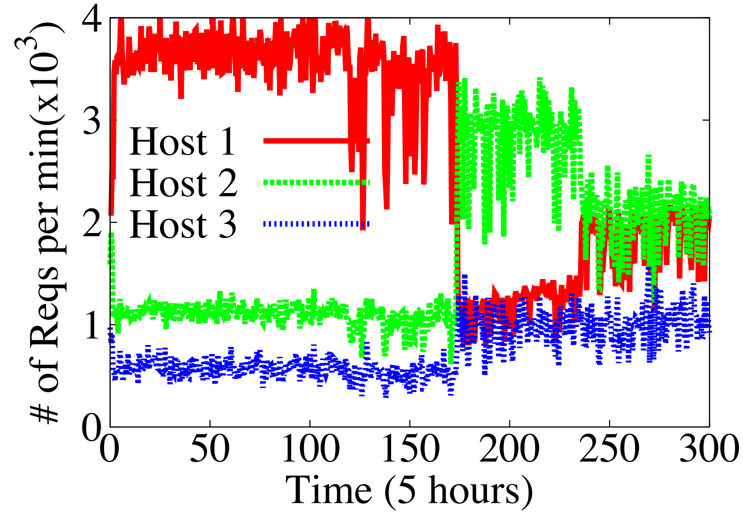


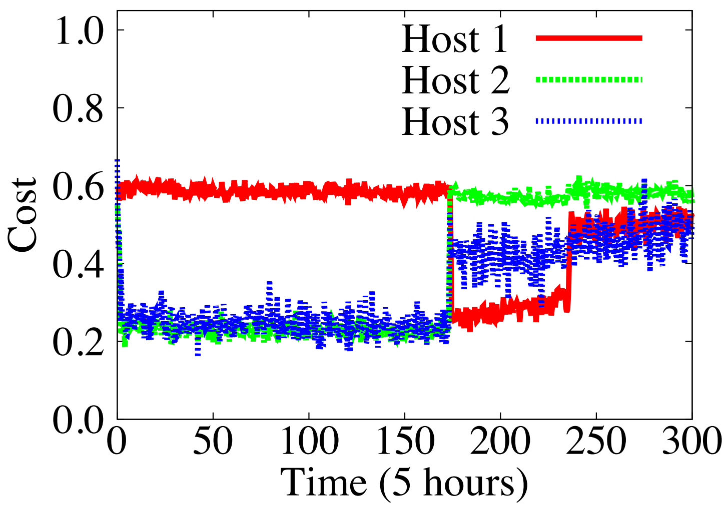


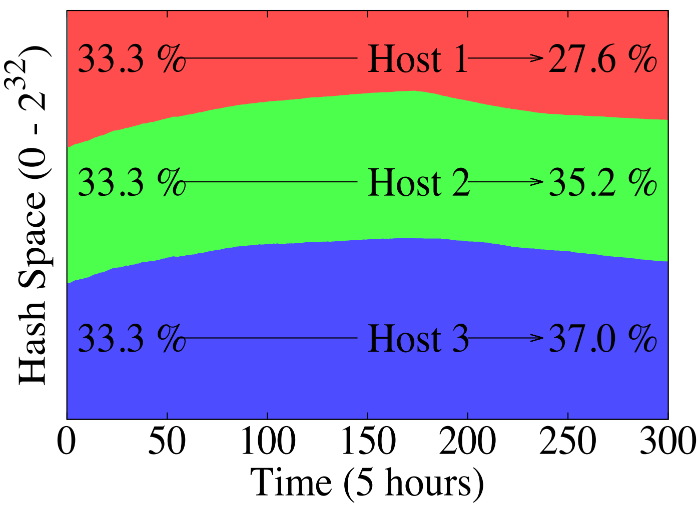
α Behavior

- When α = 0.5, β = 0.01

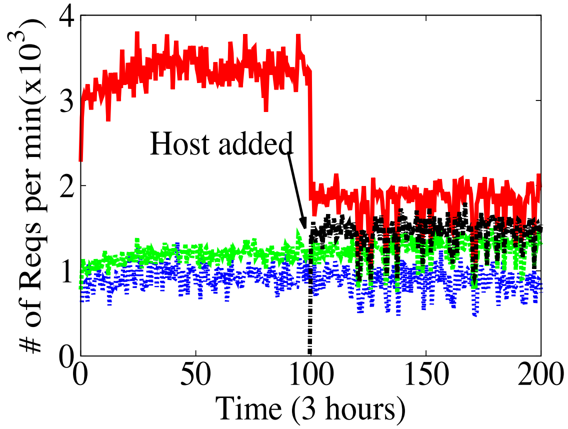


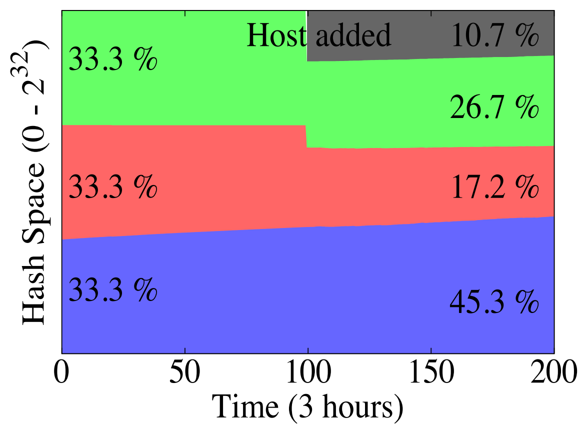




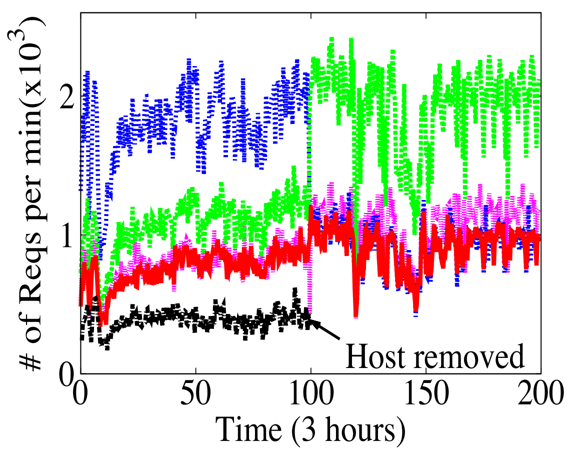


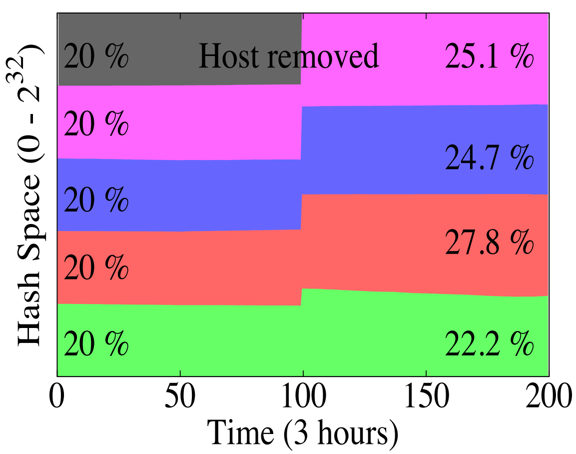
Node Addition / Removal





- **Addition**
- A new node takes reduces load on the overloaded server

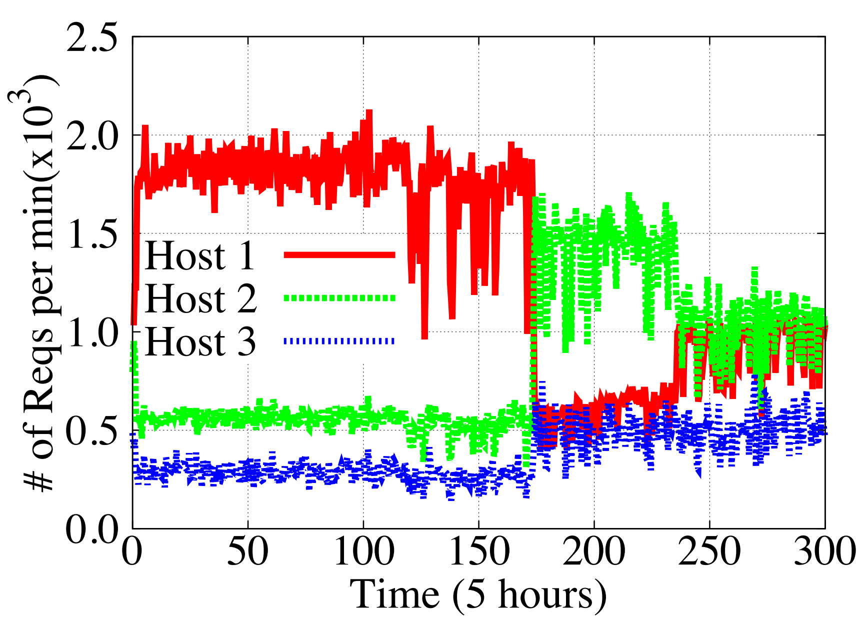




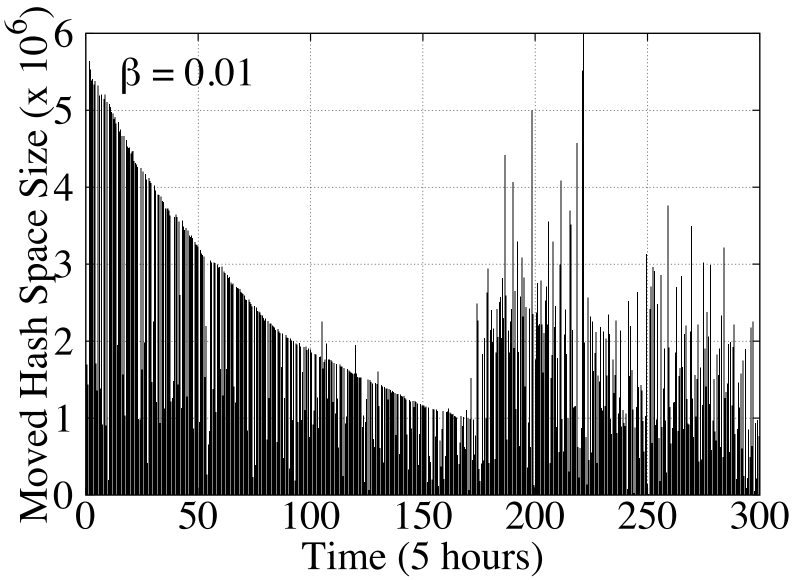
- **Removal**
- Removing an underloaded server gives cost benefits while maintaining performance

β Behavior

- Amount ratio of hash space movement
- Determine the speed of adaptability
- Use β = 0.01 (1%) to show the behavior



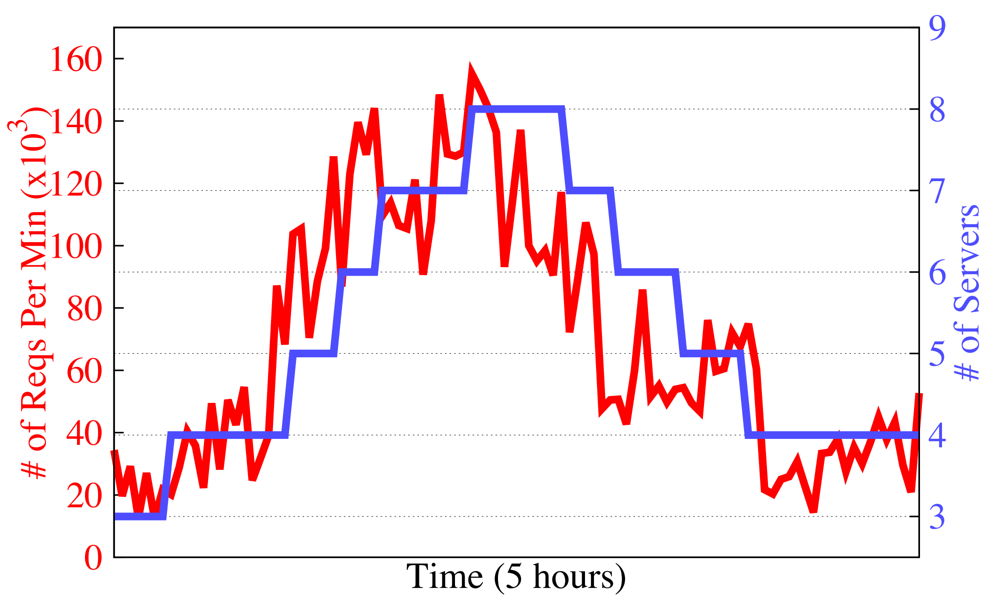
Traffic changes over 5 hours



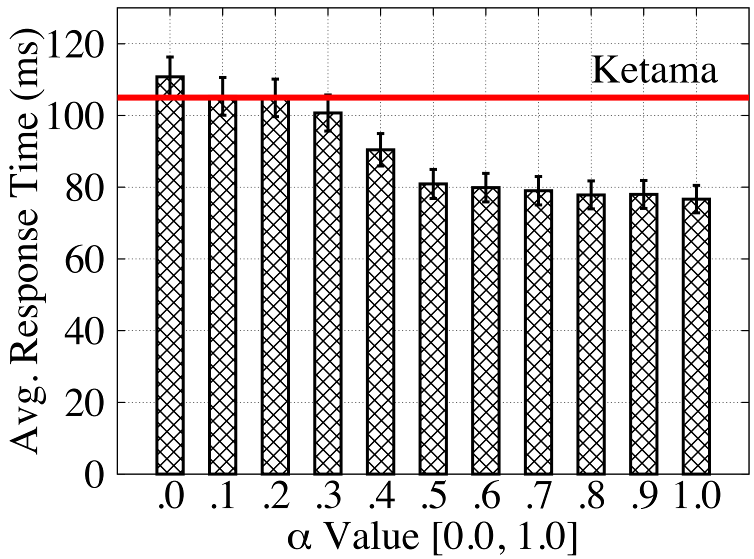
Moved hash space per each scheduling

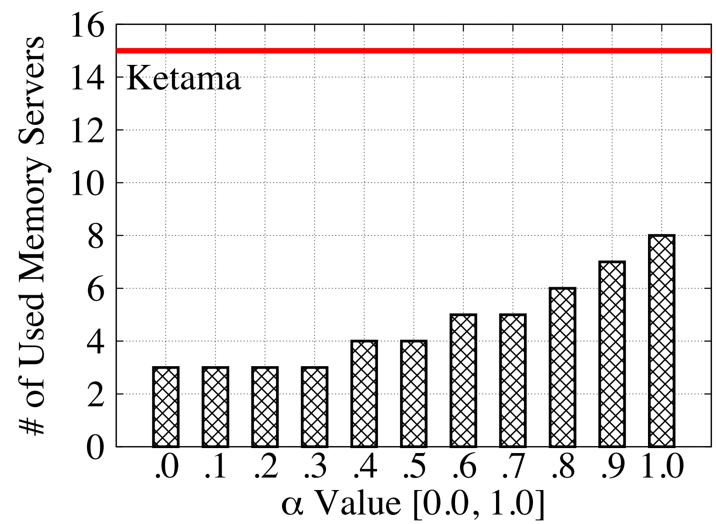
Scaling Up / Down

- Dynamically add / remove server(s) depending on amount of load intensity
- Watch each server for a period of time (5 min) to check high load sustainability
- To maximize variation, α = 1 (hit rate only)
- 5 Wikipedia traffic generators used



QoE Improvement





Usage rate ⟷ Hit rate

- Wikipedia workload achieves better response time as hit rate increases (≈ 45% increase)
- But the number of servers used increases as well
- As recommendation, the combination of hit rate and usage rate ($\alpha = 0.5$) is a good administrative choice

Related Work

- [Stoica, ToN 03] Chord Peer-to-Peer architecture
- [Nishtala, NSDI 13] Scaling Memcached at Facebook
- [Zhu, HotCloud 12] Shrinking memcached to save $$
- Ideas may apply to many other key-value based storage systems: couchebase, redis, SILT, FAWN, etc

Conclusion

- Summary
  - A hash space allocation scheme

    Carefully place nodes to ensure adjacency

  - Adaptive partitioning of the cache's hash space

    Maximize hit rate and minimize difference in utilization rate

  - An automated replica management system

    Detect sustained overload and add or remove nodes

- Future works
  - Automatic α value adjustment to minimize response time
  - Targeted management of hot objects without impacting application performance