ElCached: Elastic Multi-Level Key-Value Cache

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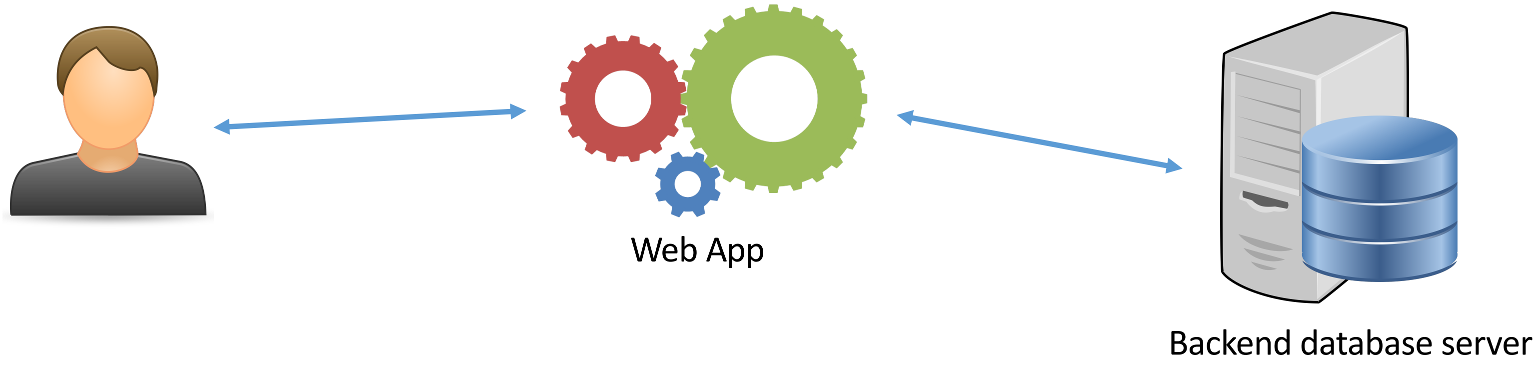
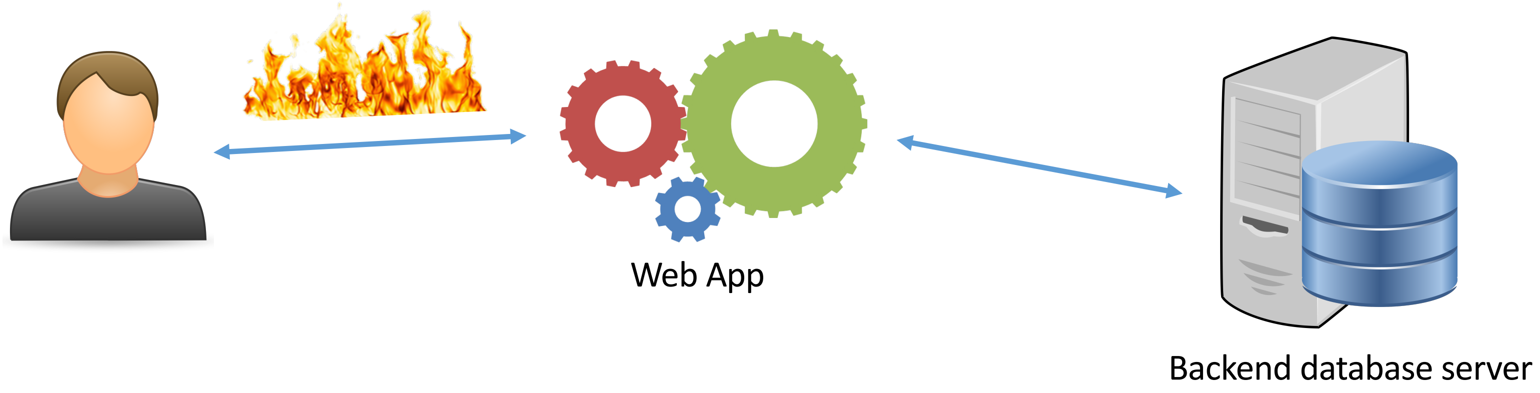
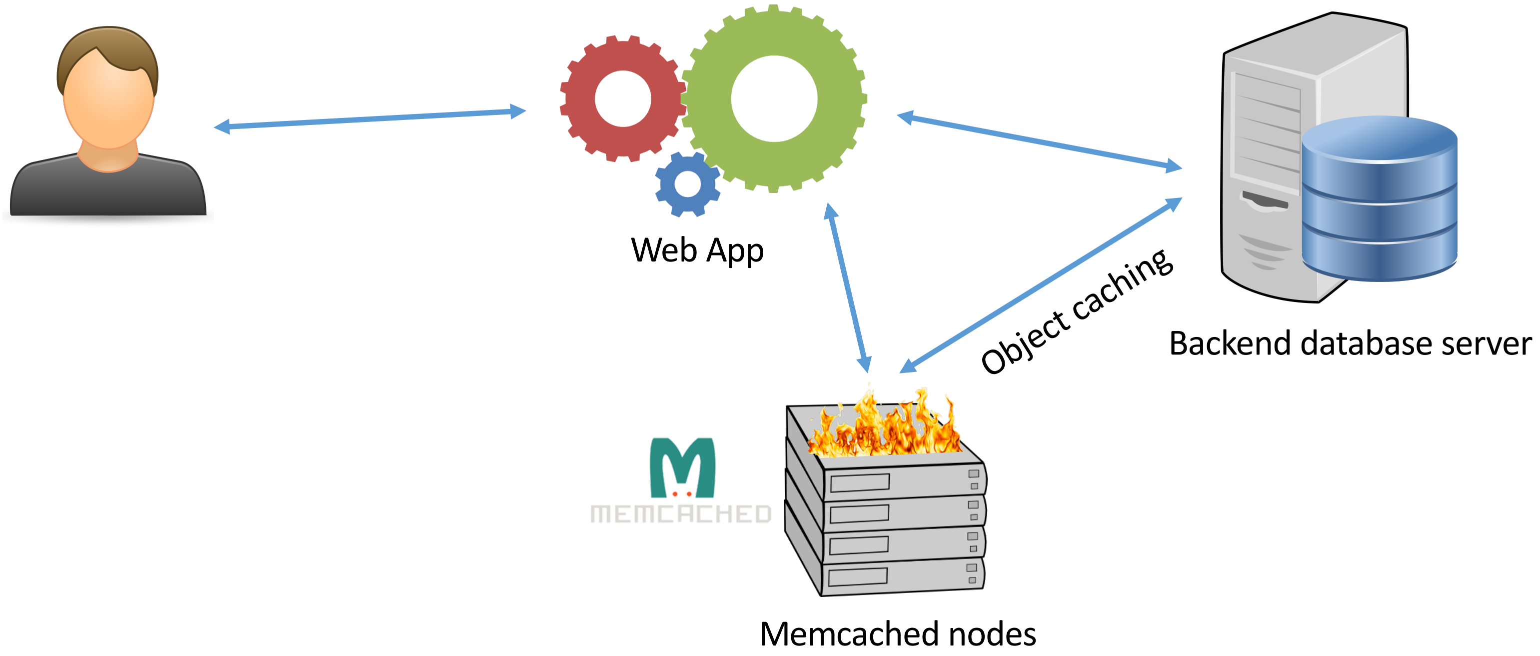
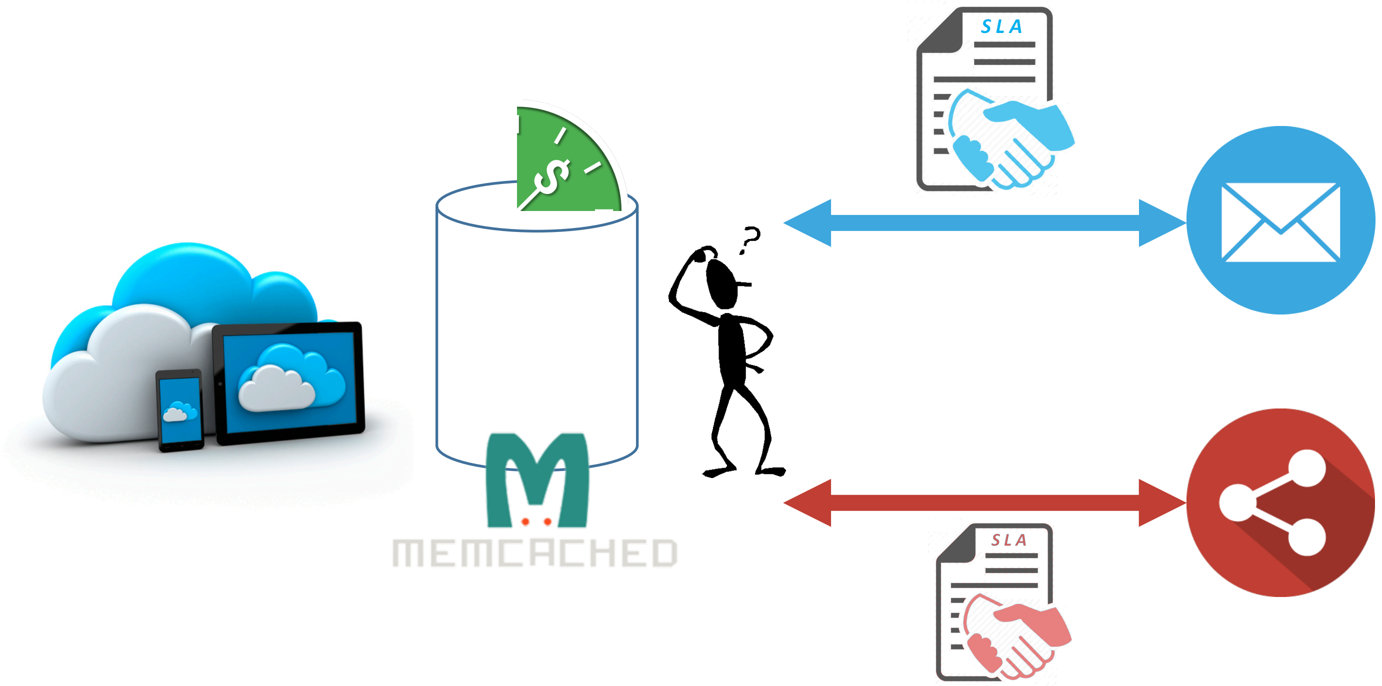

Web App
Backend database server


Web App
Backend database server

Web Caching

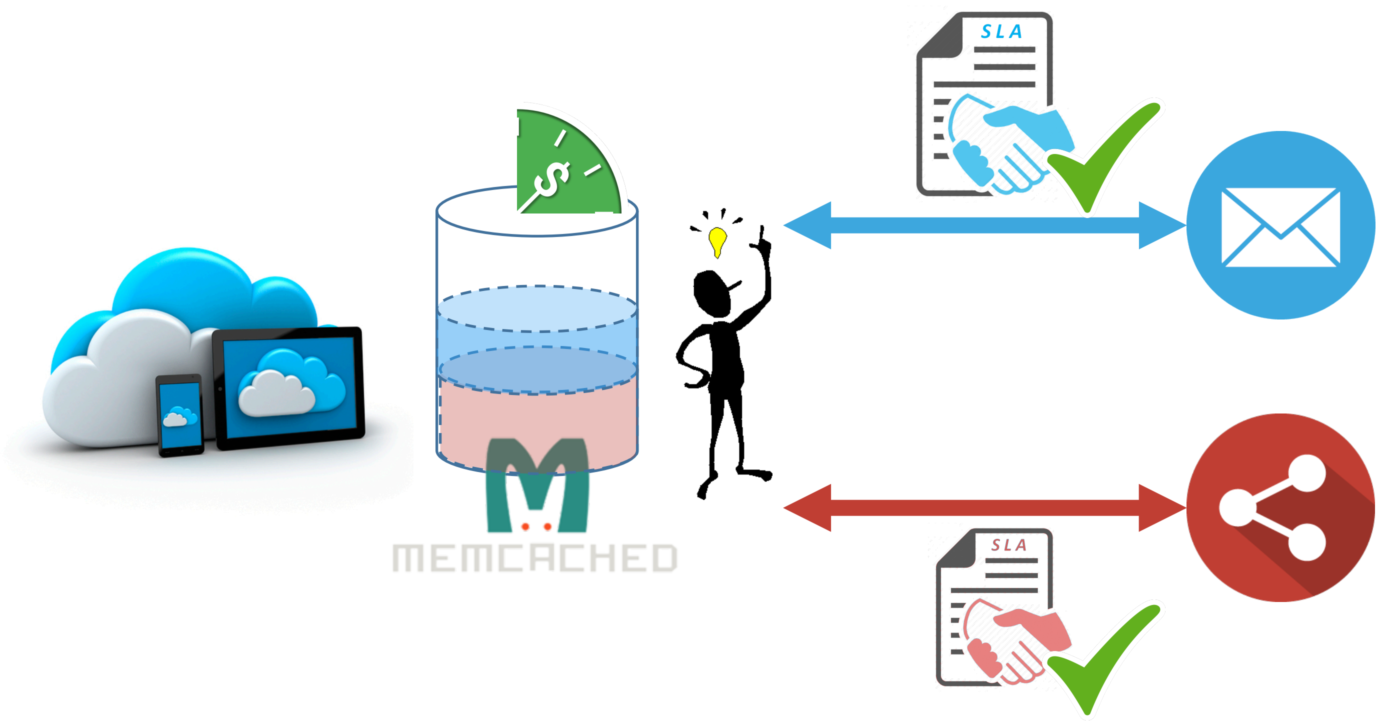

Web App
Object caching
Backend database server
MEMCACHED
Memcached nodes

Resource Provisioning for Memcached



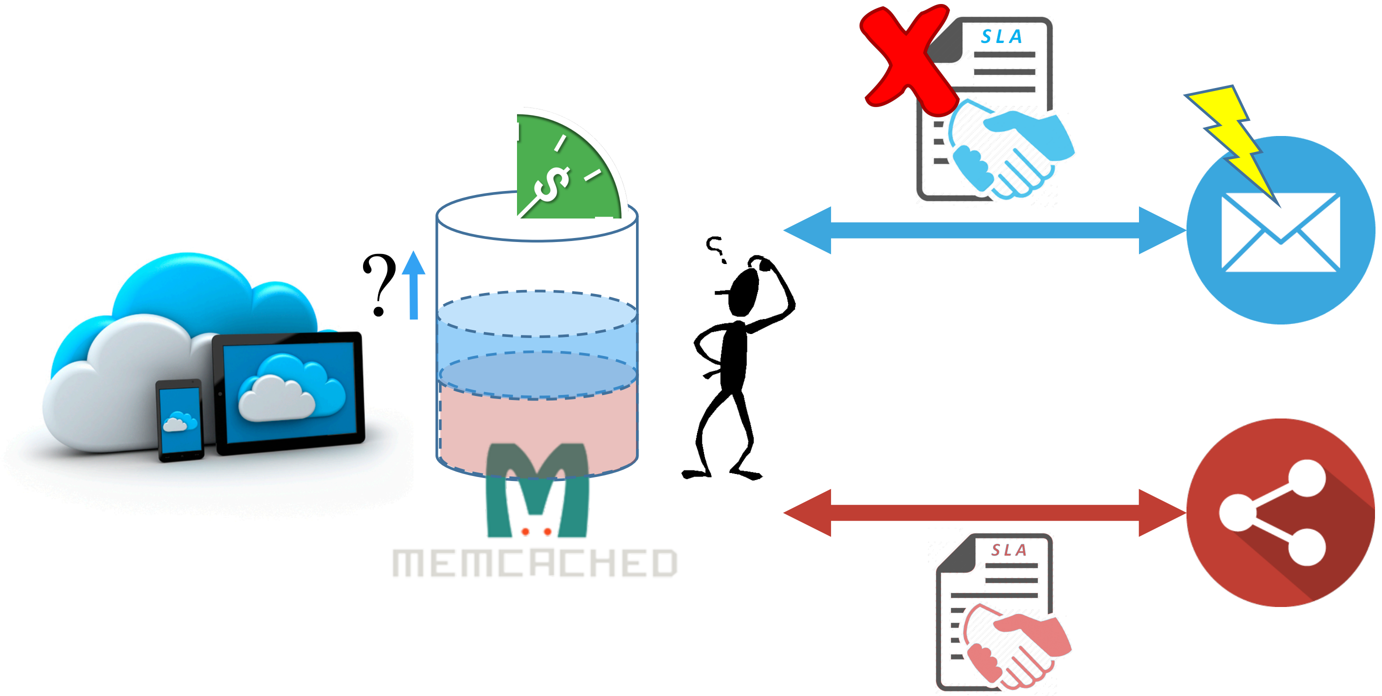
Resource Provisioning for Memcached

- The service provider must wisely allocate the resource to guarantee each tenant's SLA, while minimizing TCO.



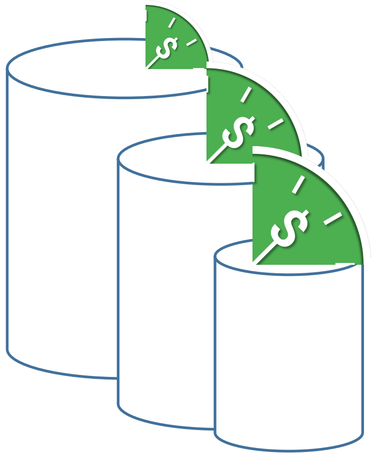
Elastic Resource Provisioning

- Optimal resource provisioning requires **elasticity**
  - capability to adapt to workload changes by dynamic resource provisioning.



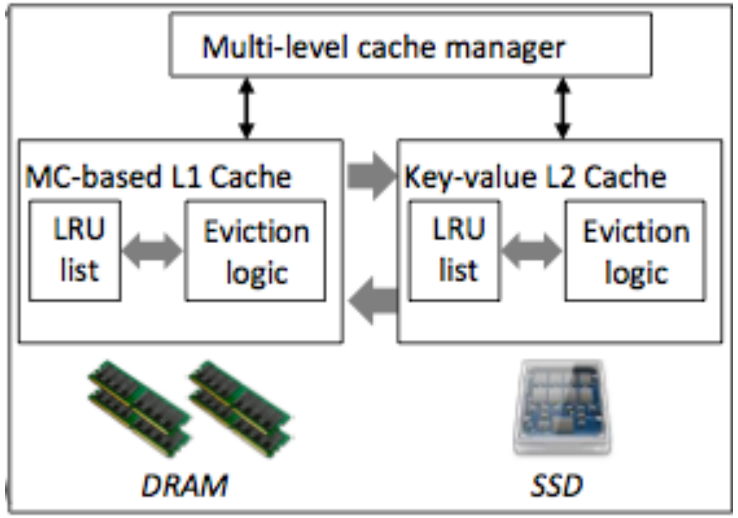
Multitenant Resource Provisioning

- The problem becomes more complex as
  - more tenants are added to the system.
  - more web caching layers are used.



MlCached [HotCloud'16]

- A multi-level **key-value** caching system.
  - L1: DRAM-based Memcached
  - L2: exclusive NAND-flash-based key-value cache (SSD).

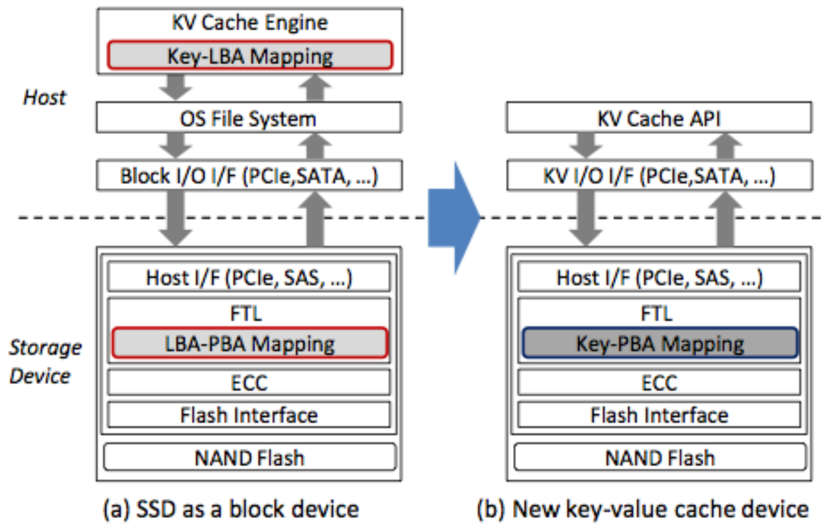


Mlcached

- MlCached implements direct key-to-PBA mappings on SSD.
  - Independent resource provisioning
- In this work, we extend MlCached by adding the elasticity feature.

Independent Resource Provisioning in MlCached

- MlCached implements direct key-to-PBA mappings on SSD.
- This removes the need for storing redundant key-to-LBA mapping tables in memory



Performance Model

Latency Model

$$Lat = l_m + l_s . \mathrm{M_m} + l_{db} . M_s$$

l_m	Latency of Memcached server
l_s	Latency of SSD
l_{db}	Latency of backend DB server

$\mathrm{M_m}$	Miss rate of Memcached
M_s	Miss rate of SSD

Cost Model

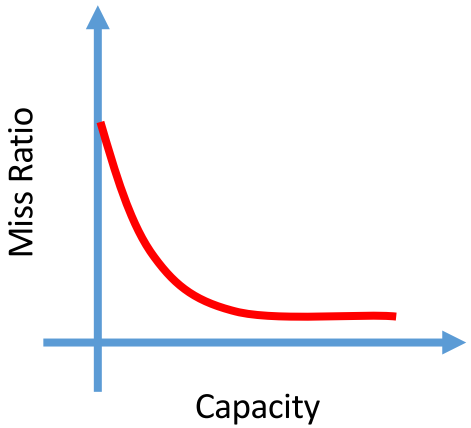
$$Cost = c_m . p_m + c_s . p_s$$

c_m	Size of DRAM
c_s	Size of SSD

p_m	Price per unit of DRAM
p_s	Price per unit of SSD

Latency Based on Miss Ratio Curve

- The key to optimal resource provisioning is to find the miss ratio curve (MRC).



$$Lat = l_m + l_s.mr(\mathrm{c_m}) + l_{db}.mr(c_s)$$

How to compute the MRC?

Reuse Distance

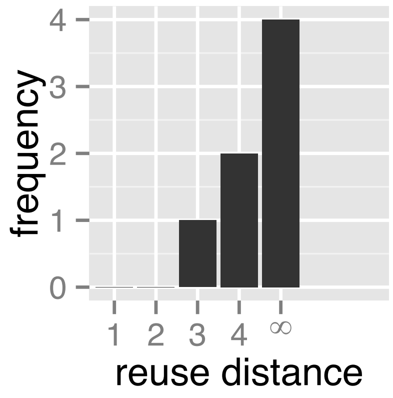
- We use the reuse distance theory to compute the miss ratio curve.
- Reuse distance is the number of distinct memory locations accessed between two consecutive uses of the same memory location.

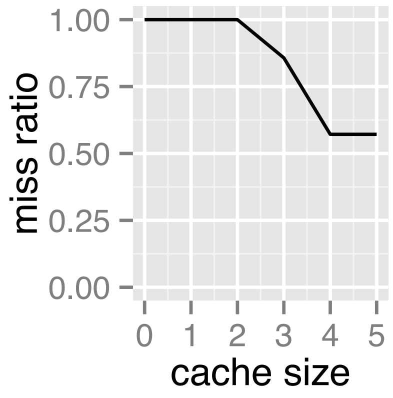
a	b	c	d	b	a	c
∞	∞	∞	∞	3	4	4

Reuse Distance Histogram

- The reuse distance information is best represented by the reuse distance histogram, which shows the frequency for every reuse distance.
- The MRC can be computed from this histogram.

a	b	c	d	b	a	c
∞	∞	∞	∞	3	4	4





Reuse Distance Computation

- Olken tree [Olken 1981]
- Approximate reuse distance [Ding+ 2001]
- Footprint estimation [Xiang+ 2011]
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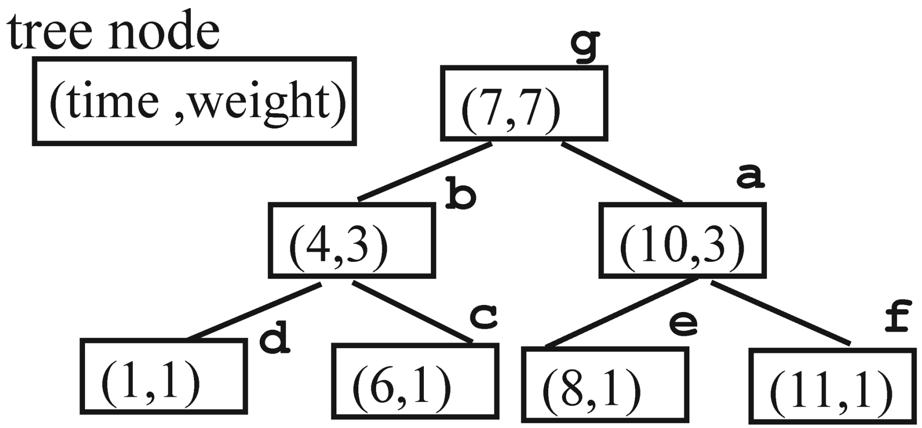
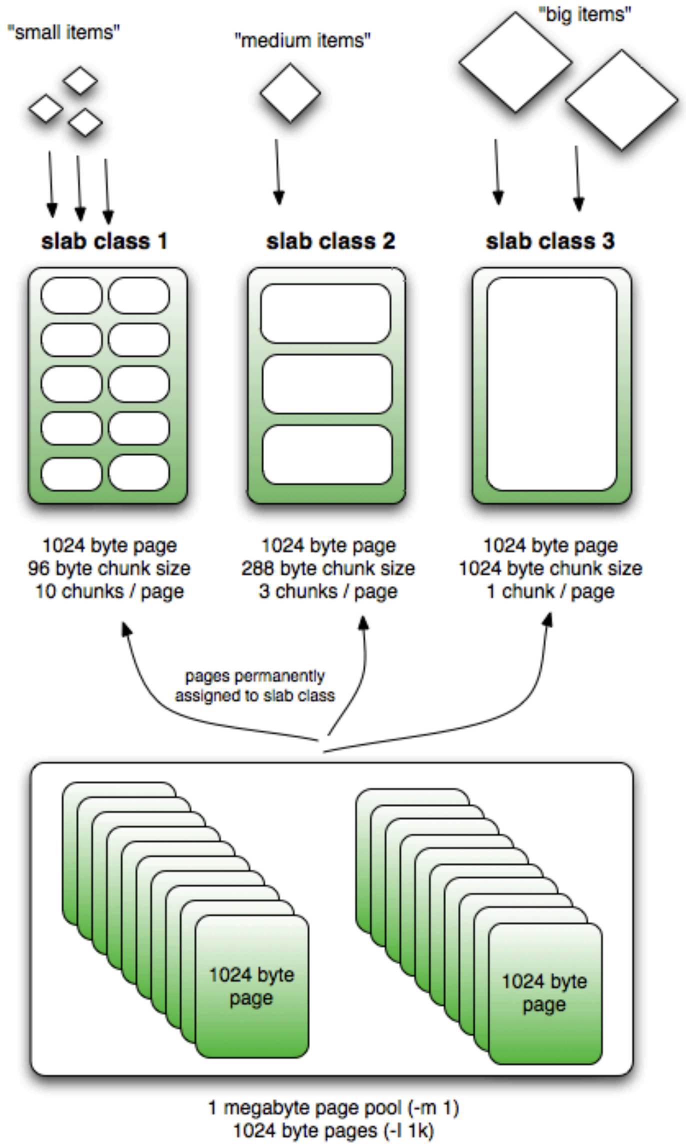


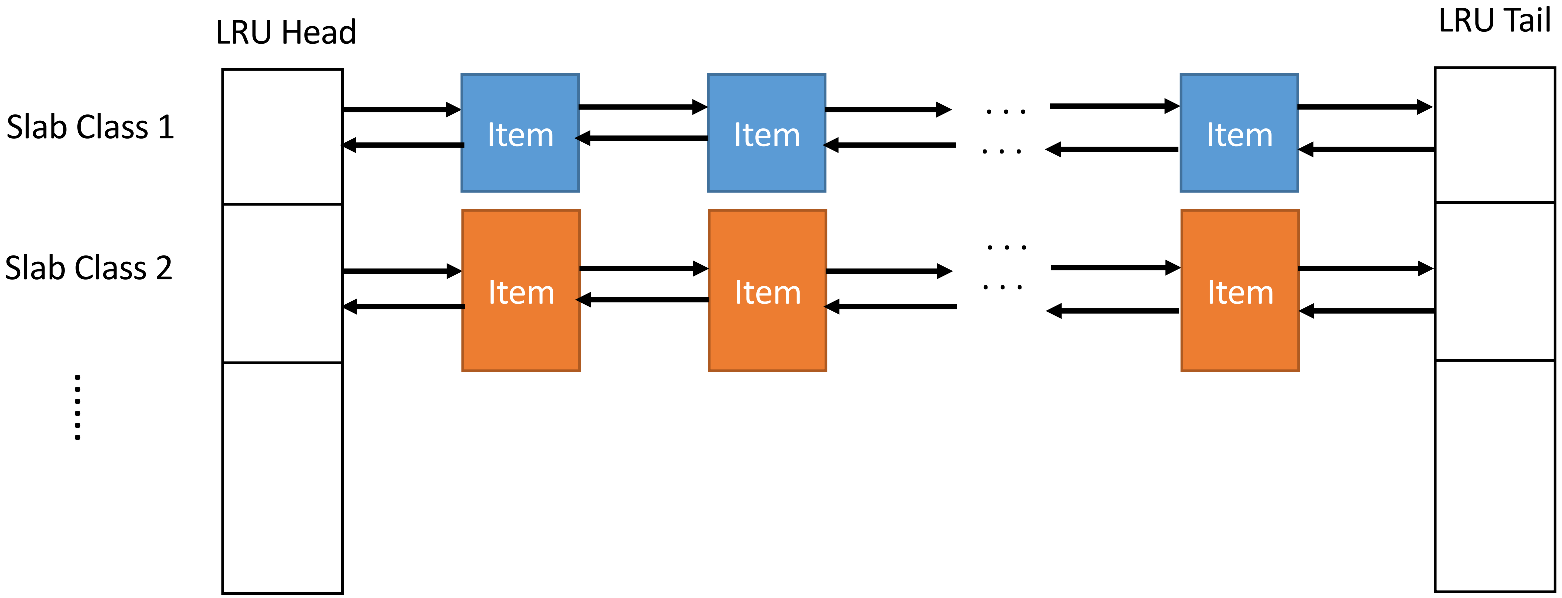
Reuse Distance for Memcached

- Memcached distributes items among different slab classes, according to their sizes.
- Slab allocation is done during the cold start.



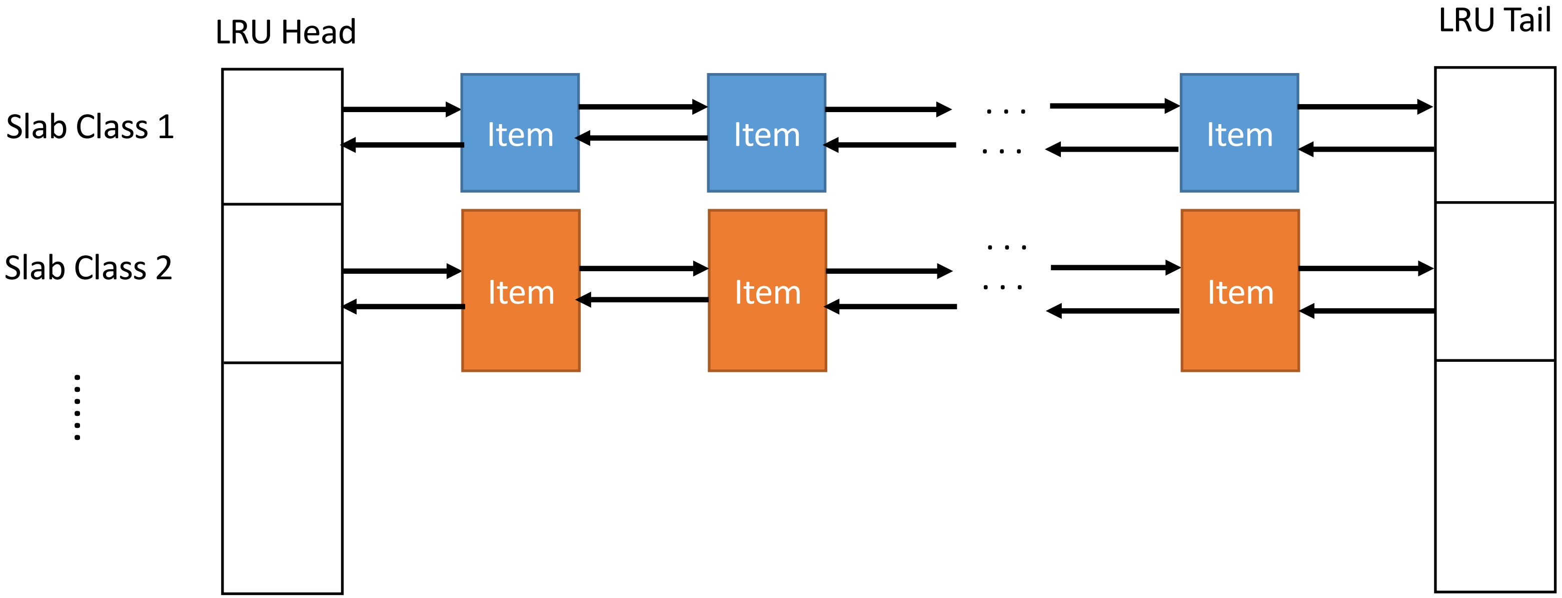
LRU Replacement in Memcached

- Once the Memcached system reaches its memory limit, LRU replacement is done separately for every slab class.



Slab-Aware Reuse Distance Profiling

- Rather than analyzing the whole Memcached system in a single reuse distance model, we model each slab class separately.
- We compose the MRCs from different slab classes.



How To Solve
Resource Provisioning?

Resource Provisioning as a Linear Program

- The resource provisioning problem can be described in one of the two ways.
  - Minimize *Cost* such that *Lat ≤ SLA*.
  - Minimize *Lat* such that *Cost ≤ TCO*.

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Linear Program?

- Cost is already linear in terms of DRAM/SSD capacities. ✓

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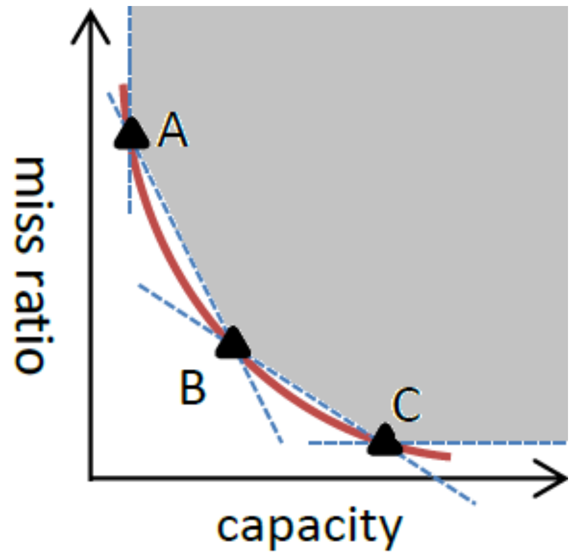
  - Minimize *Lat* such that *Cost ≤ TCO*.

Linear Program?

- Cost is already linear in terms of DRAM/SSD capacities. ✓
- Latency is linear only in terms of the miss ratio function. ✗

Resource Provisioning as a Linear Program

- We observe that the miss ratio curves in our workloads are always convex.
- We formulate the miss ratio curve using linear constraints.



Evaluation

- We compare ElCached against a proportional approach that fixes the ratio between DRAM and SSD capacities to 1:4 (Pareto principle).

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cost ($/GB)		latency	
DRAM	10	Memcached	100μs
SSD	0.68	KVD	200μs
		Back-end DB	10ms

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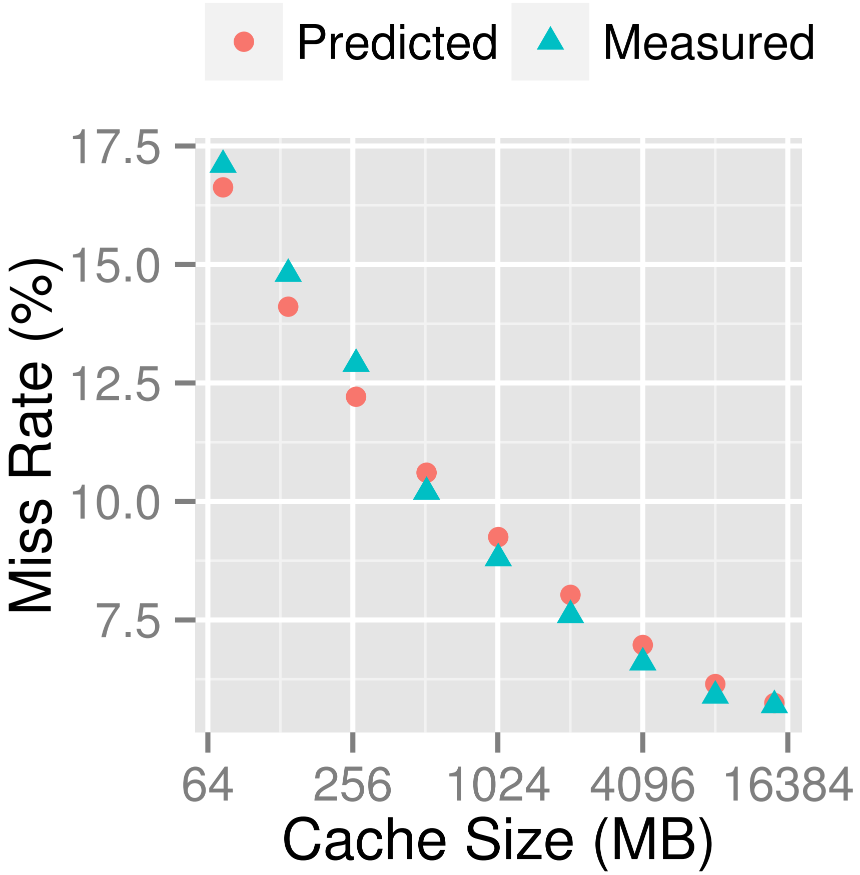
SSD	0.68	KVD	$200\mu s$
		Back-end DB	10ms

- Workloads:
  - Zipfian key distribution with $\alpha = 1.15$
  - Exponential key distribution with $\lambda = 10^{-6}$
  - Both workloads issue 800 million requests to a range of 4 billion keys.

Miss Ratio Prediction Accuracy

- Mean relative error on Zipfian workload: 4%



Experiment 1:
Elastic Resource Provisioning

- For each workload
  - For each latency limit, we find the minimum cost resource provisioning.

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- For each workload
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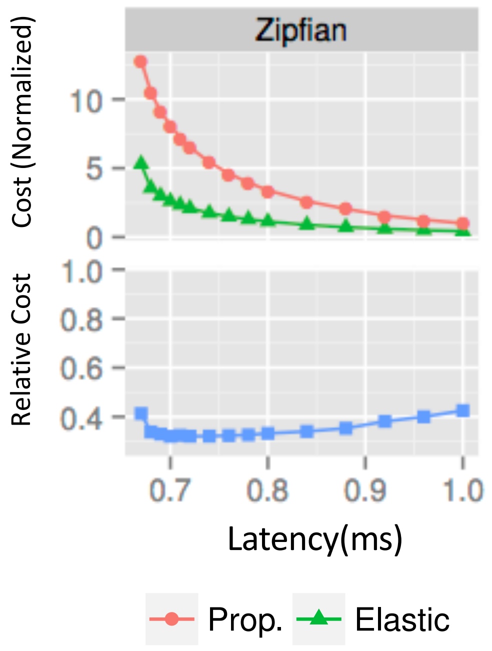
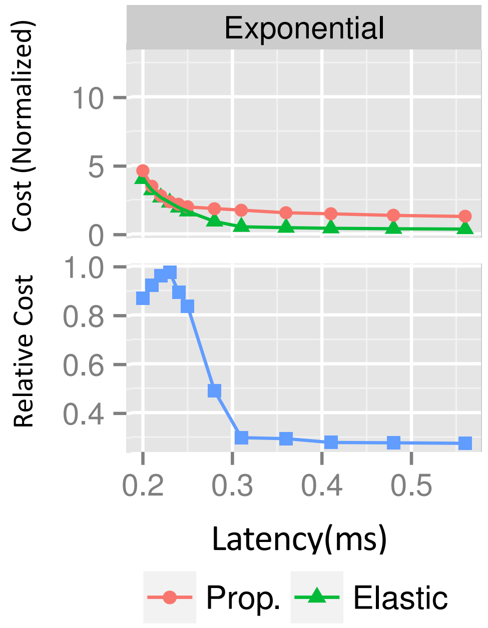
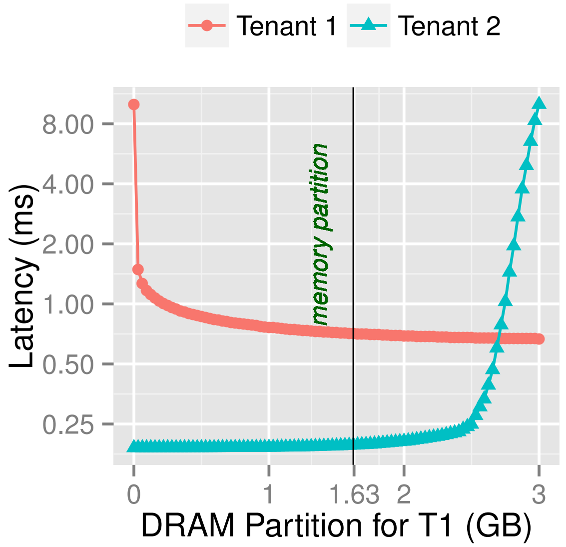
- Elastic saves cost by around 60% for both workloads.





Experiment 2:
Multitenant Resource Provisioning

- First, we use the proportional scheme to partition a fixed 3GB memory between the two tenants.



Proportional

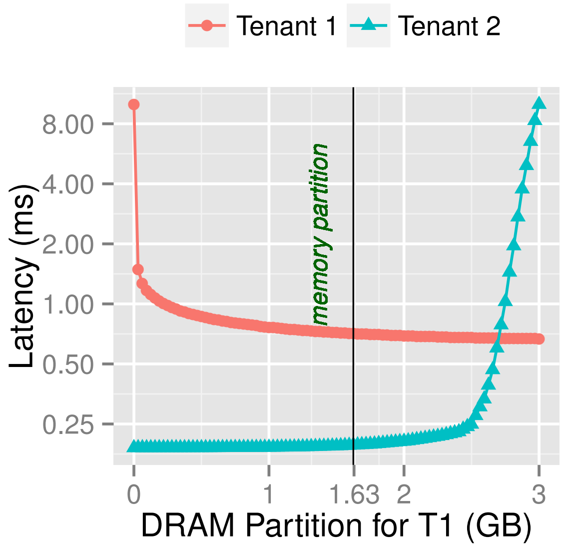
	T1	T2
DRAM	1.63	1.37
Lat.	0.71	0.20
Cost	7.20	5.41

Experiment 2:
Multitenant Resource Provisioning

- Then, we use ElCached to find the latency-optimal DRAM/SSD partitioning.

Elastic

	T1	T2
DRAM	0.46	1.17
Lat.	0.67	0.20
Cost	5.30	4.01



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DRAM	1.63	1.37
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Cost	7.20	5.41

Experiment 2: Multitenant Resource Provisioning

- Elasticity improves
  - tenant 1's latency by 5%,
  - both tenants' cost by 26%, and
  - total memory consumption by 46%.

Summary

- ElCached is a multi-level key-value caching system.
- It uses a **reuse distance profiler** to estimate the miss rate curve across all capacity limits.
- It reduces the total **cost** by up to around 60% compared to a proportional scheme.
- Multi-tenant experiment indicates that we can improve **latency**, **cost**, and total **DRAM usage**, compared to the proportional scheme.

Thank You

Any Questions?