CloudCache: On-demand Flash Cache Management for Cloud Computing

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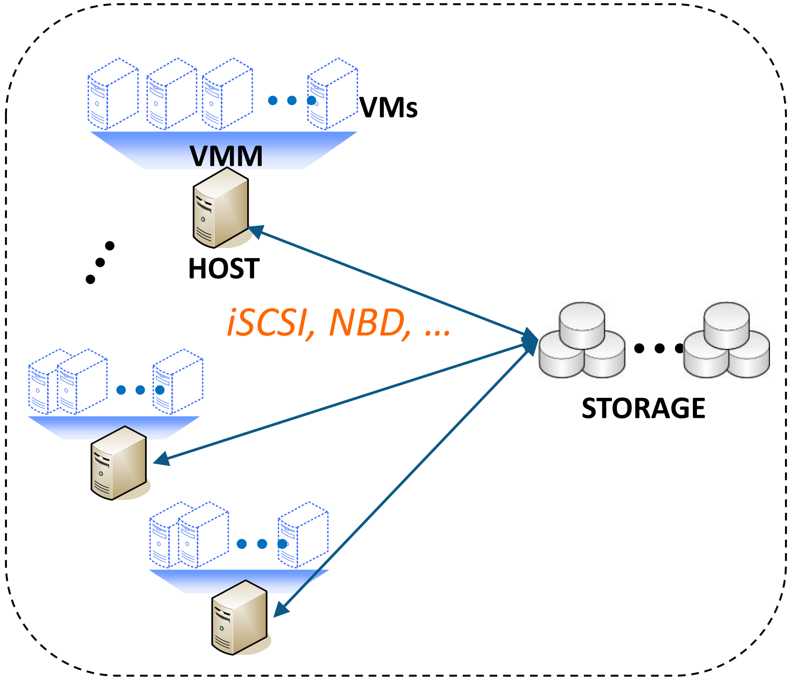
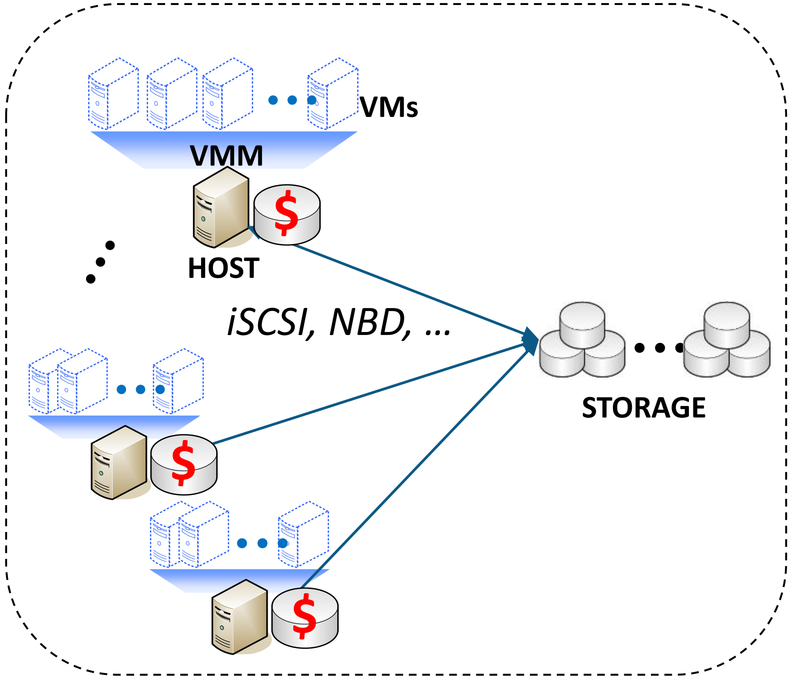
Background

- Networked storage systems are important building blocks for cloud computing
- Benefits
  - Efficient storage utilization
  - Reliable VM storage
  - Live VM migrations
- Challenge—scalability
  - Increasingly level of consolidation
  - Increasing data-intensive workloads



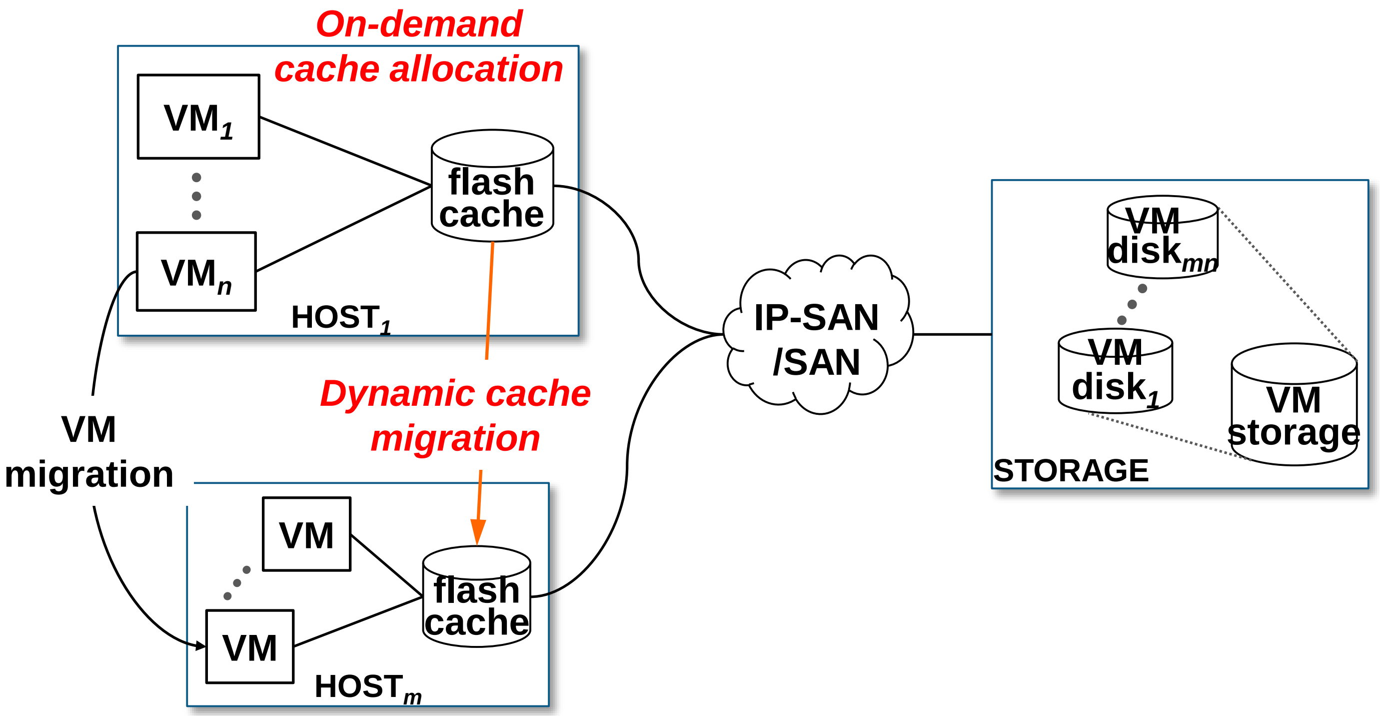
Flash caching to the rescue?

- Client-side caching
  - Exploit the locality in VM I/Os using the storage available on the client-side
- Flash-based cache devices
  - Exploit the high performance of flash storage
  - Avoid the long latency from the networked storage
- Challenges:
  - Limited cache capacity
    - Still small compared to dataset sizes
  - Limited device endurance
    - Caching makes it worse—both writes in the workloads and read misses cause wear-out
- Also applicable to other NVM based caches



Overview of CloudCache

- On-demand cache allocation
  - Allocate shared cache capacity to VMs according to their demands
- Dynamic cache migration
  - Balance cache load across hosts by migrating VMs and their cached data

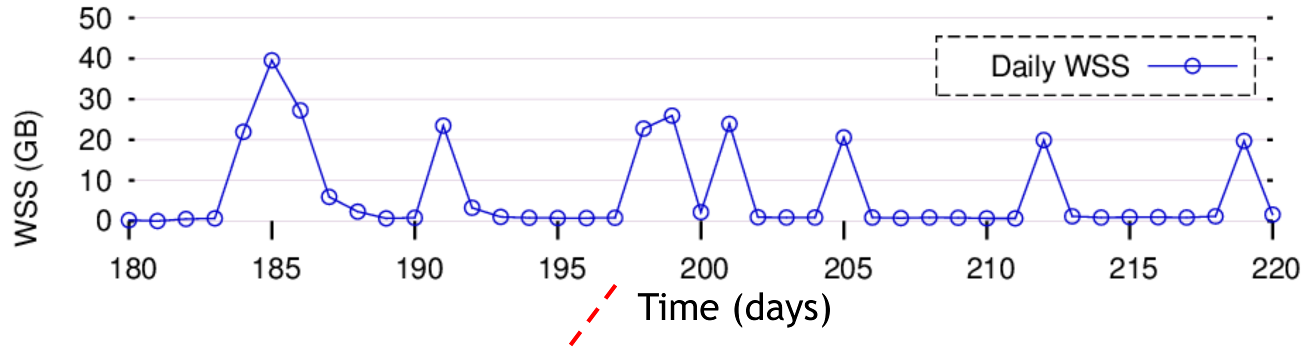


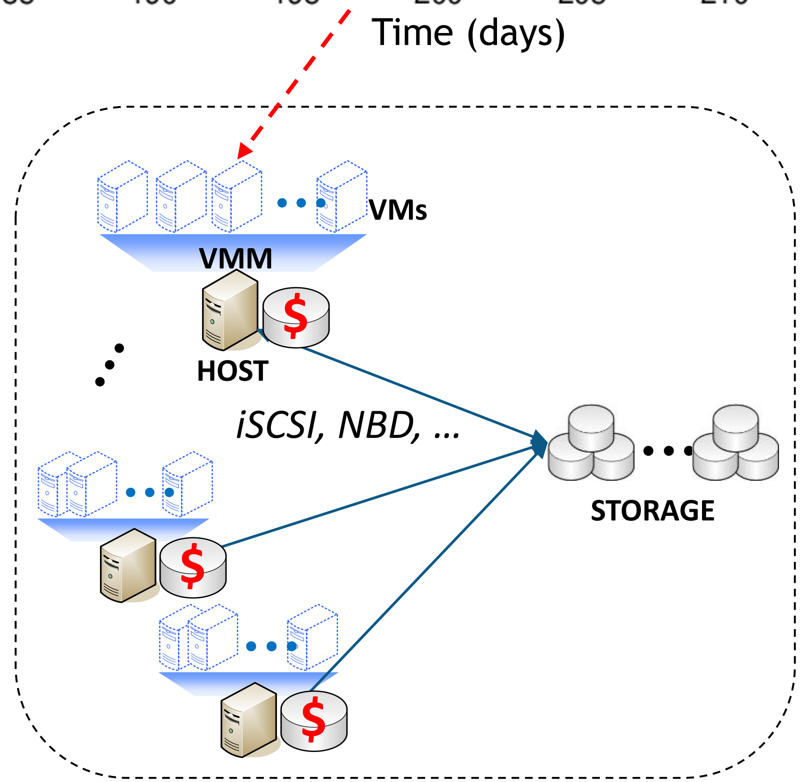
Outline

- Background
- **On-demand cache allocation**
- Dynamic cache migration
- Putting everything together

On-demand cache allocation

- Allocate cache capacity according to the workload cache demand
- How to model the cache demand of a workload?
- How to use the model to manage the cache?





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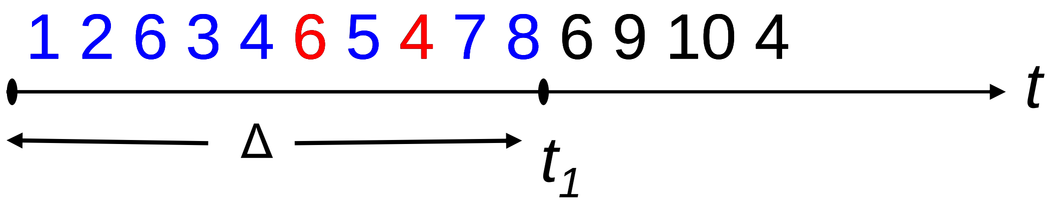
Working set and reuse working set

- Traditional Working Set *WS(t,T)* (Denning, 1968)
  - Set of distinct blocks referenced during [*t*-*T*, *t*]
  - Include data with low temporal locality
    - Waste cache space, hurt endurance
- Our proposed Reuse Working Set $RWS_N(t,T)$
  - Set of distinct blocks ***reused*** at least **N** times during [*t*-*T*, *t*]
  - Keep only the really useful data
    - Exclude low-temporal-locality data

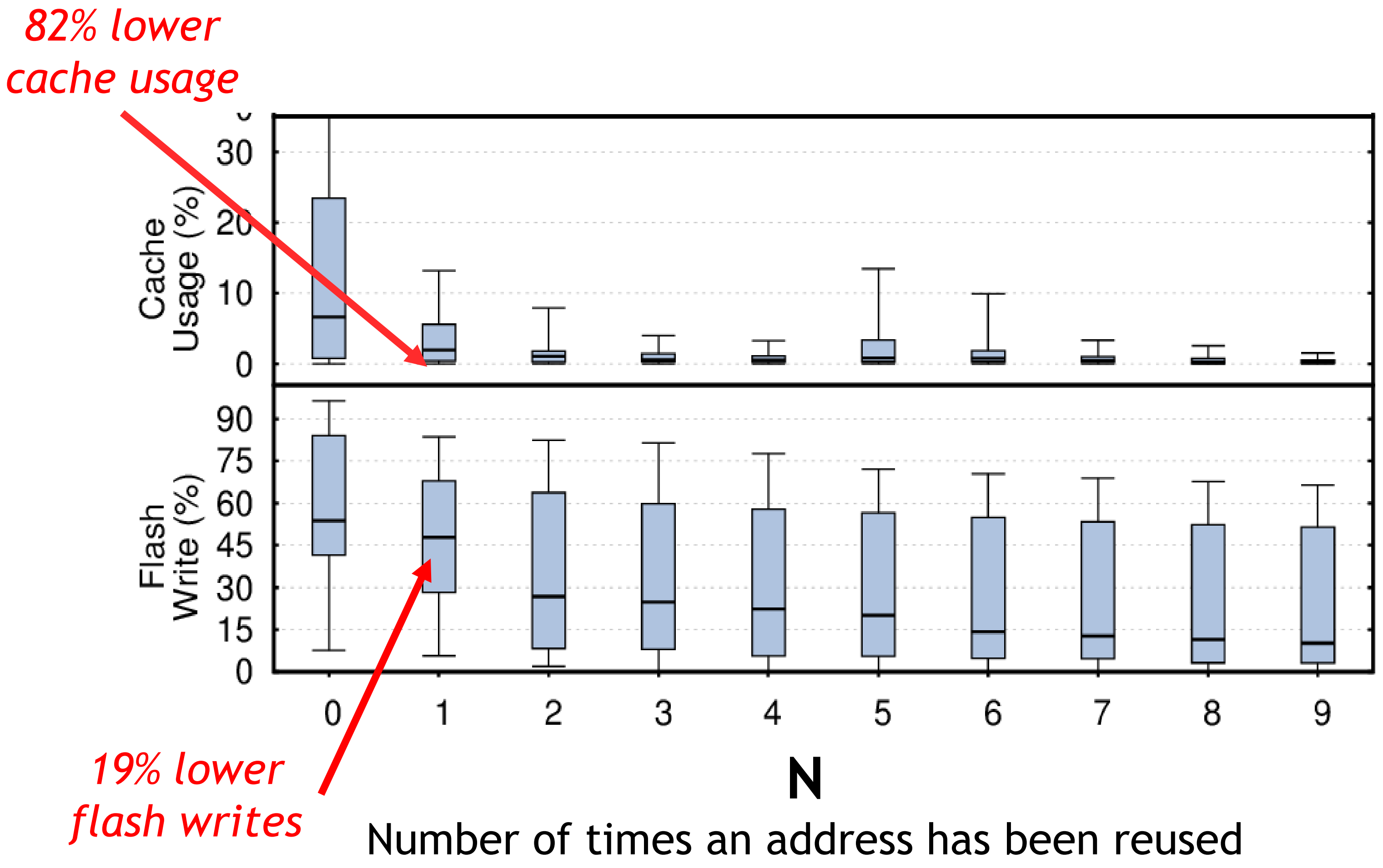


WS (Δ, t_1) = {1,2,6,3,4,5,7,8}   WSS = 8

RWS_1 (Δ, t_1) = {6,4} $RWSS_1$= 2

WS vs. RWS

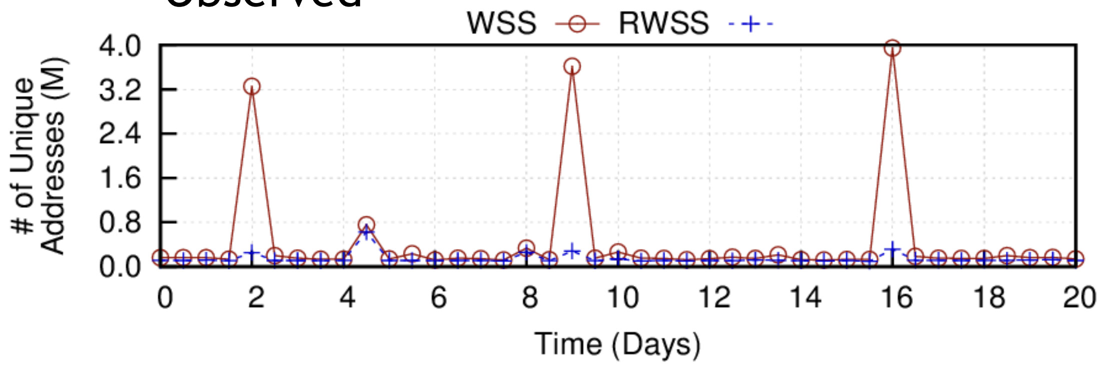
- Analysis of different *RWS*$_N$
  - 36 MSR traces
- RWS$_N$ — N is the number of times an address has been reused
- Flash write ratio: percentage of writes sent to the flash device
  - Indirect measurement of wear-out



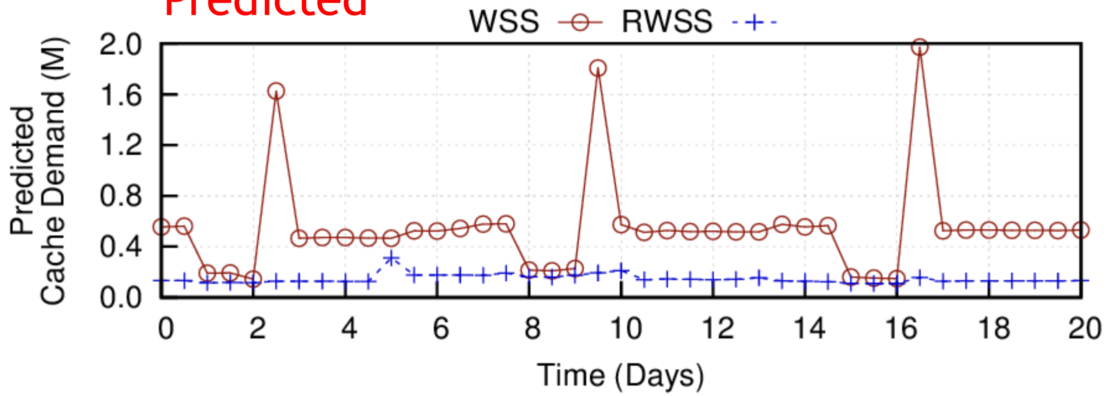
RWS-based cache allocation

- Measure the RWS size (RWSS) of each workload online
  - Window size typically set to days
- Predict the workload cache demands using observed RWSSes
  - Exponential smoothing with self-tuning smoothing factor
- Allocate cache capacity according to the predicted RWSSes
- Reduces cache usage up to 76%

Observed

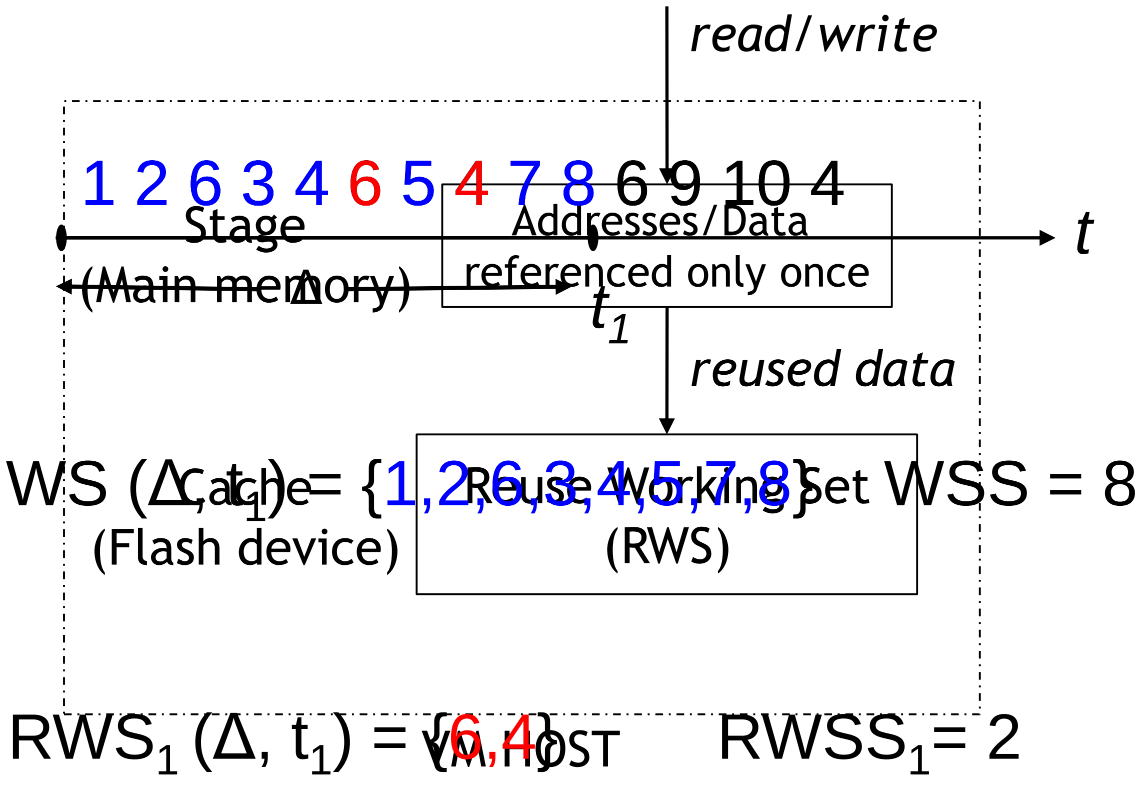


Predicted



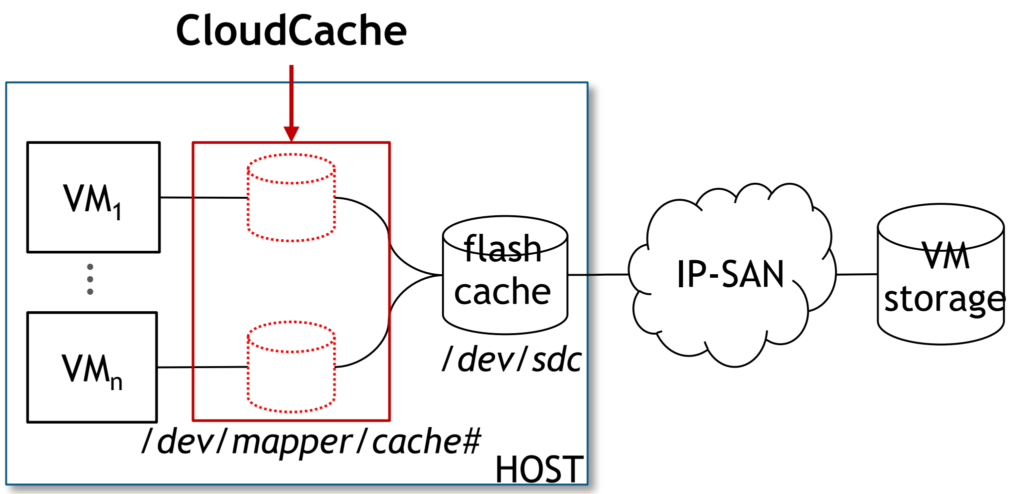
Cache admission

- Admit only reused data into cache
  - Avoid low-temporal-locality data from polluting the cache and causing unnecessary wear-out
- Staging—store candidates in memory before admitting them into cache
  - **Address staging**—stage only addresses of the candidates
  - **Data staging**—stage both addresses and data of the candidates
    - Reduce second-access misses
  - **Hybrid staging**—separate areas for staging addresses and data
    - Can stage more addresses than data items



Evaluation

- Prototype
  - Based on block device virtualization (dm-cache, visa.lab.asu.edu/dmcache)
  - Transparent support for Linux-based (virtualized) environments
- Traces
  - Collected from several departmental servers
  - visa.lab.asu.edu/traces ([Systor'14])
- Testbed
  - iSCSI; Intel 120GB MLC SSD; XEN 4.1



Name	Time (days)	Write (%)	WSS (GB)
Webserver	281	51	110
Moodle	161	13	226
Fileserver	152	22	1037

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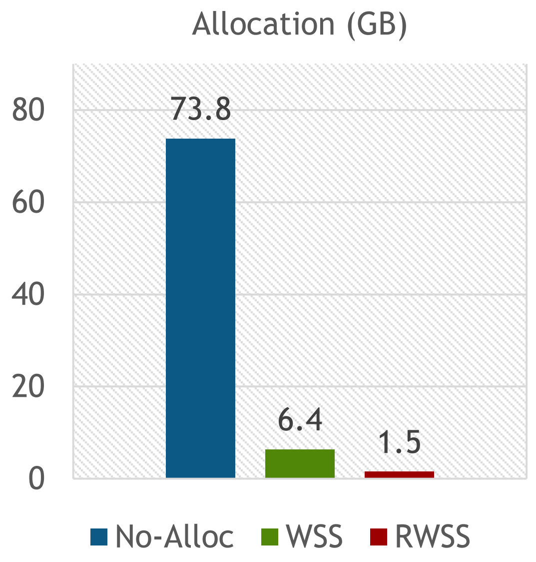
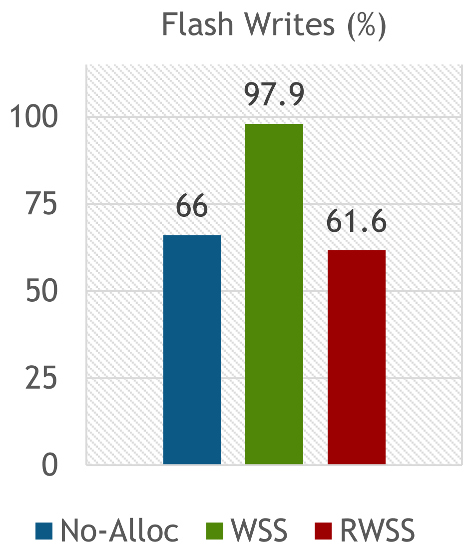
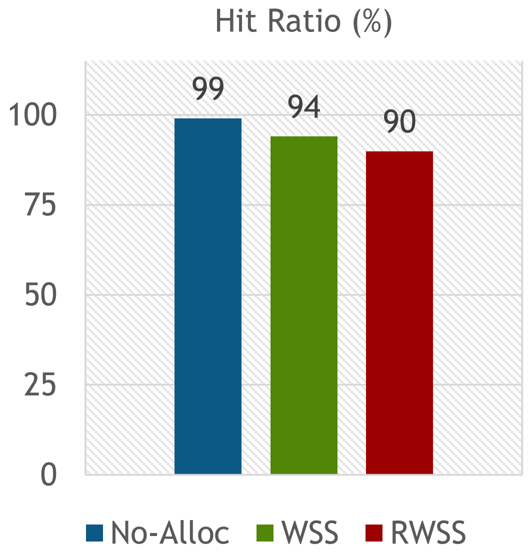
RWSS vs. WSS based allocation

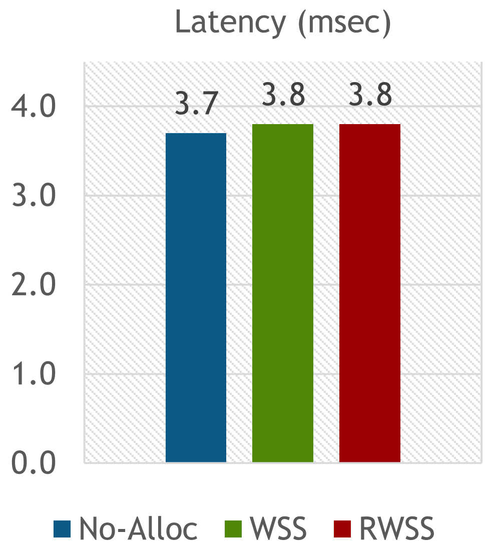




- Cache usage
  - Up to 72GB less than *No Allocation*
  - Up to 5GB less than *WSS*
- Flash write ratio
  - Up to 6% lower than *No Allocation*
  - Up to 37% lower than *WSS*

- Hit ratio
  - Up to 9% lower than *No Allocation*
  - Up to 4% lower than *WSS*
- Latency
  - 1% higher than *No Allocation*
  - Similar to *WSS*





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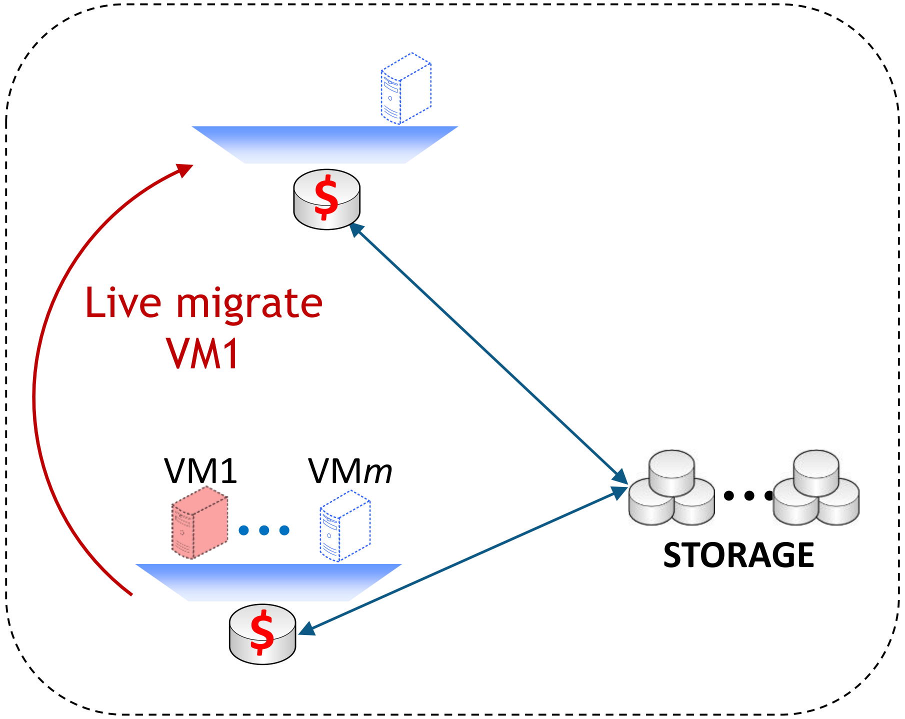
Dynamic cache migration

- CloudCache allocates cache according to VMs’ cache demands (RWSSes)
  - How to handle situations where the cache capacity is insufficient?
- Live VM migration can be used to balance the cache load across hosts
  - How to handle the cached (possibly dirty) data?



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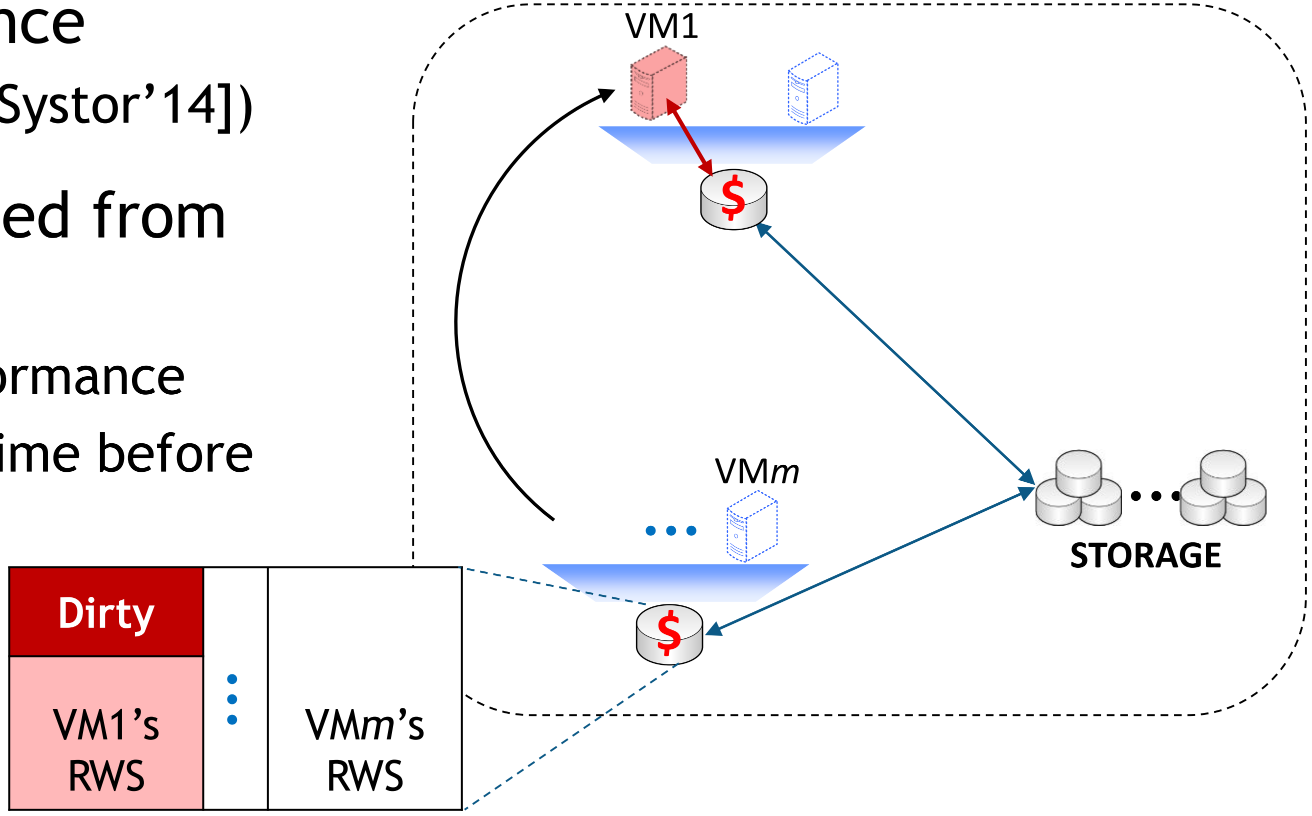
Challenges

- Cached data is critical to performance
  - Warmup may take a long time ([ATC'13, Systor'14])
- Dirty pages on cache must be synched from source to destination
  - Write-back caching provides better performance
  - But flushing dirty data may take a long time before migration



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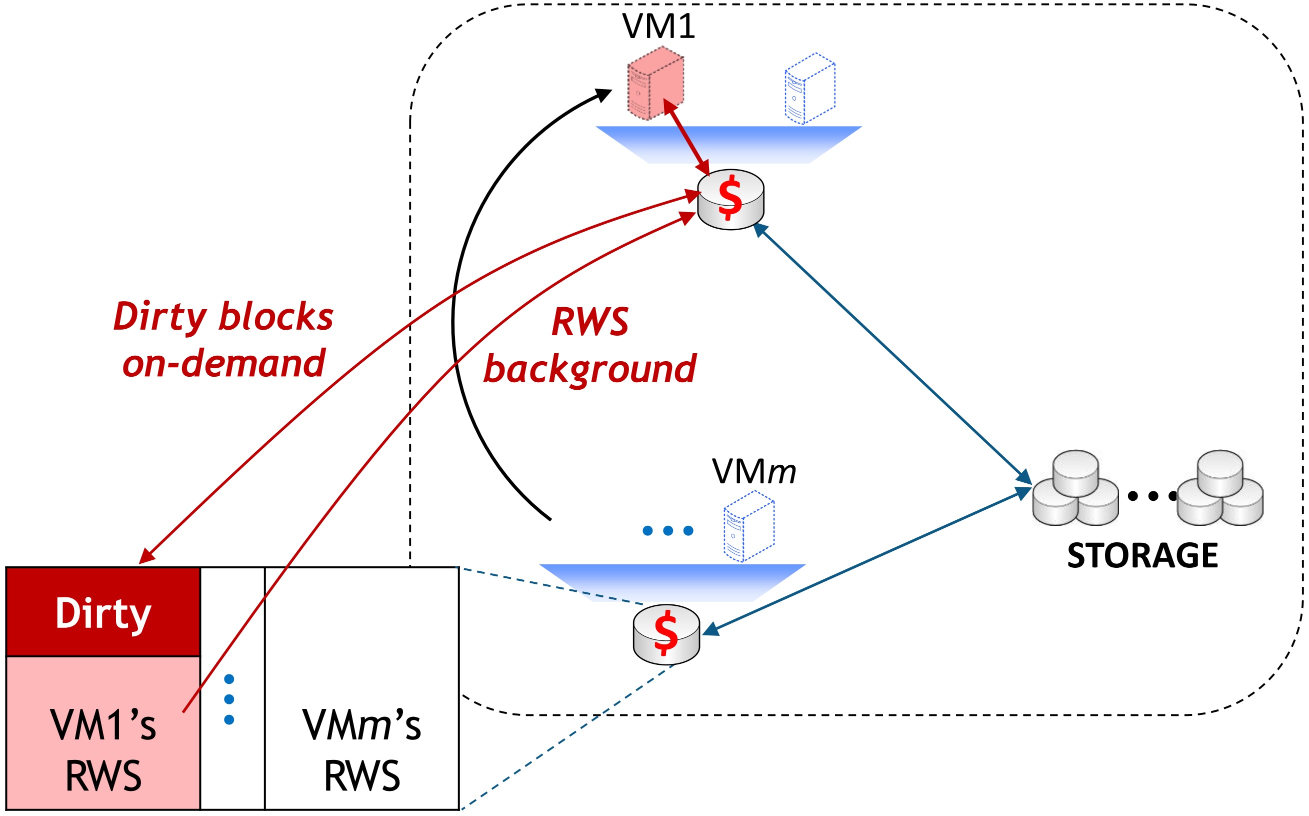
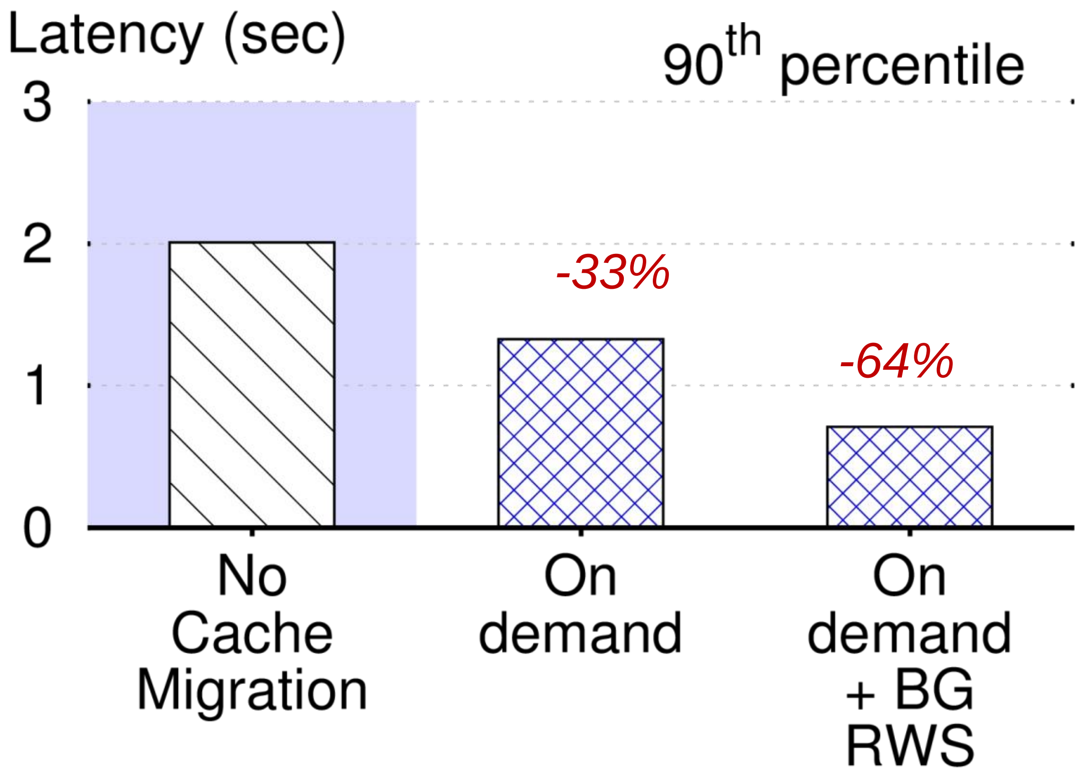
Dynamic cache migration

- **On-demand migration** of dirty data
  - Zero downtime to migrated VM
  - Cache immediately available to the VM
- **Background migration** of RWS
  - Quickly warmup the cache
  - Migrate only the useful data
- Rate limiting
  - Limit number of blocks transferred per period of time
  - Limit the impact to co-hosted VMs



Evaluation

- A day-long moodle trace
  - Read intensive
  - RWS: 5GB, 15% dirty
- On-demand migration enables zero downtime
  - 54s downtime otherwise
- Background migration allows fast cache warm-up



Migrated VM's latency

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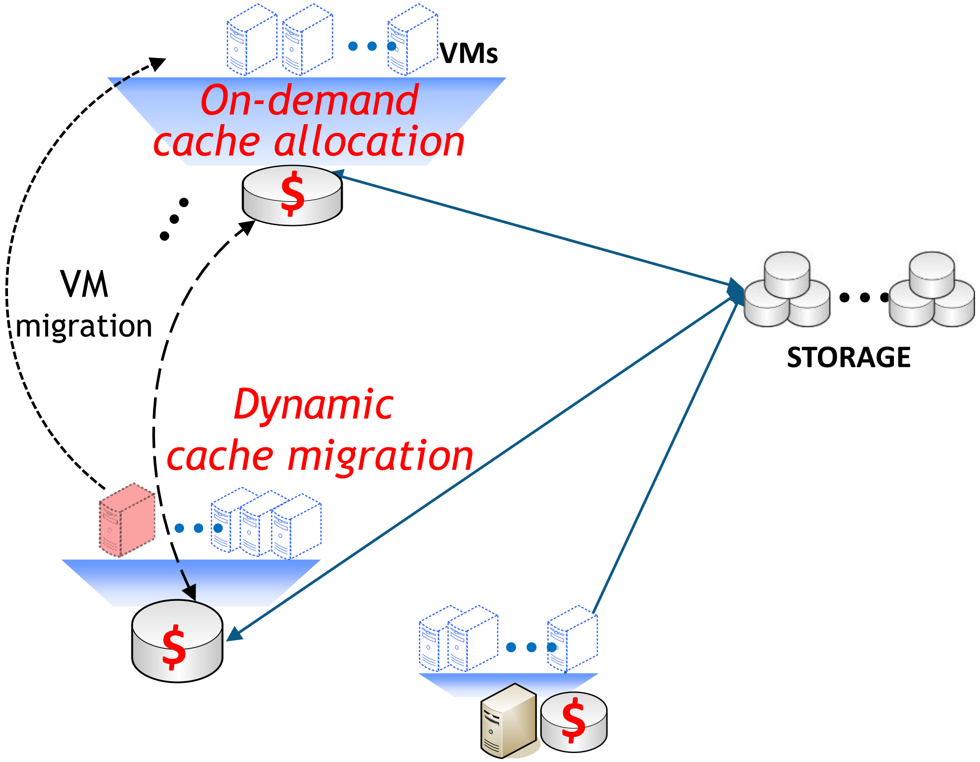
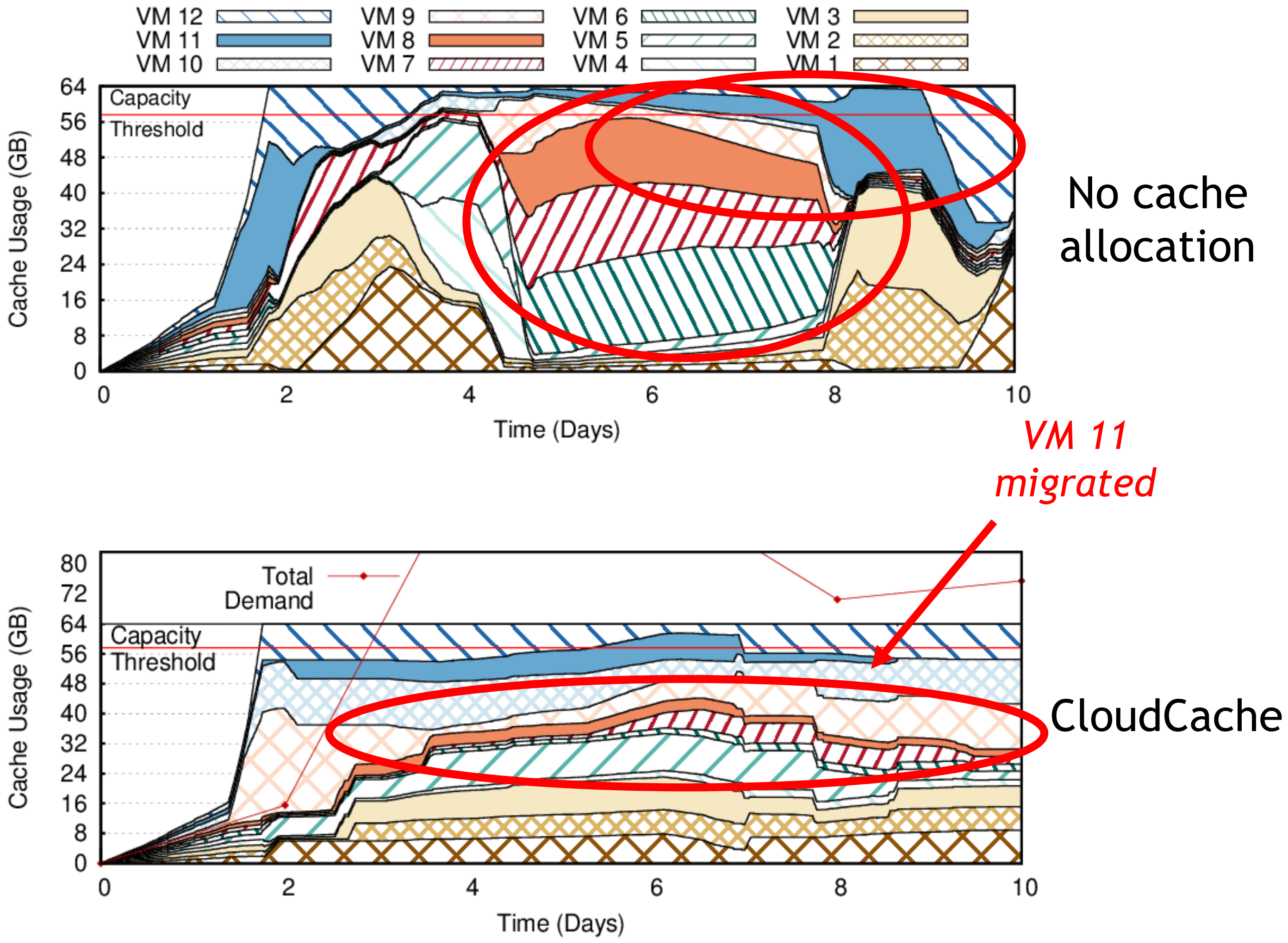
Putting everything together

- Allocate cache capacity proportionally to RWSSes
- Migrate VMs and their cached data when a cache is overloaded
  - After exceeding the 90% watermark for 3 consecutive periods
- Choose the destination host by minimizing the cache load imbalance



Evaluation

- Setup
  - 2 hosts each w/ 64GB cache
  - 10-day Webserver trace
  - 12 VMs
- RWS-based allocation allows every VM got a fair share
- Dynamic cache migration balances cache load
- 28% higher hit ratio, 27% lower a latency



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Related work

- Cache allocation (S-CAVE, vCacheShare, Centaur)
  - Admit all referenced data into cache
  - Do not consider dynamic cache migration to deal with overloaded cache
- Cache admission (HEC, LARC)
  - Do not consider how to allocate shared cache to concurrent workloads
  - RWSS-based cache admission achieves better reduction in cache footprint and wear-out
- Processor and memory cache allocation ([ICPADS’01, ASPLOS’04, ASPLOS’09, MICRO’08, FAST’03])
  - Flash cache presents different challenges and opportunities
  - Low-locality data are detrimental to performance and endurance

Conclusions

- The RWS model can capture data with good temporal locality
- Allocation based on RWSS can efficiently meet workload cache demands
- Dynamically migrating VMs and cached data can effectively balance cache load across host with minimal performance impact
- Our results show:
  - Single VM: Up to 76% reduction in cache usage and up to 37% in flash writes
  - 12 concurrent VMs: 28% higher hit ratio and 27% lower latency, on average

Acknowledgements

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  - http://visa.lab.asu.edu

- *Thank you!*