D3N
A multi-layer cache for the rest of us

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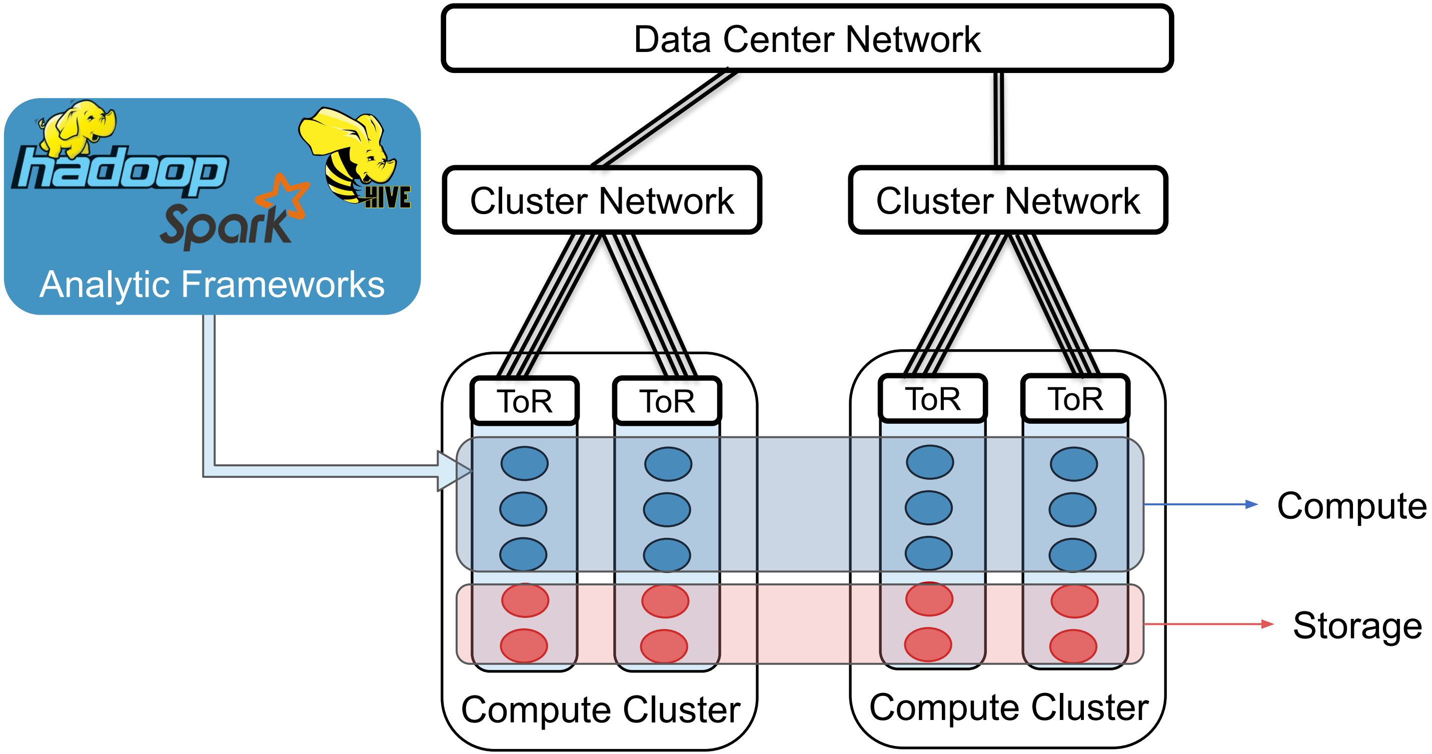
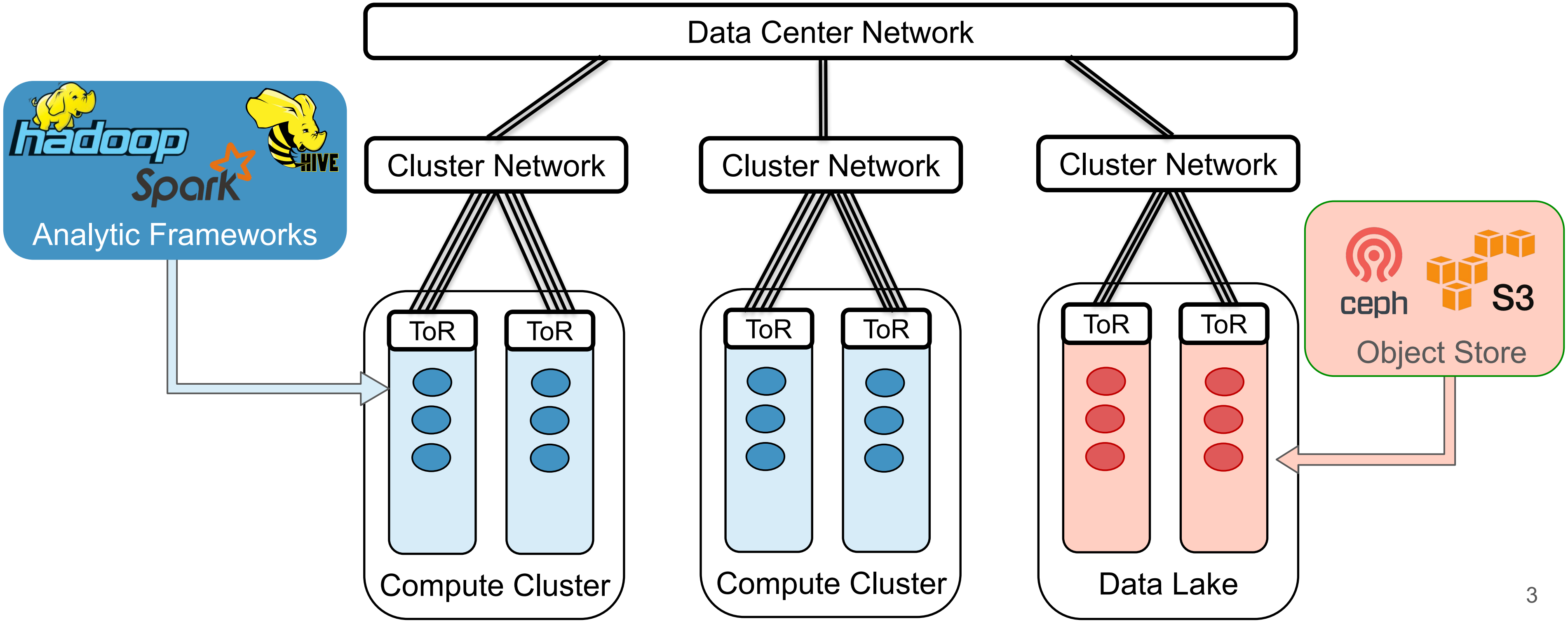
Motivation



Data Center Network
Cluster Network
Cluster Network
hadoop
HIVE
Spark
Analytic Frameworks
ToR
ToR
ToR
ToR
Compute Cluster
Compute Cluster
Compute
Storage

Motivation



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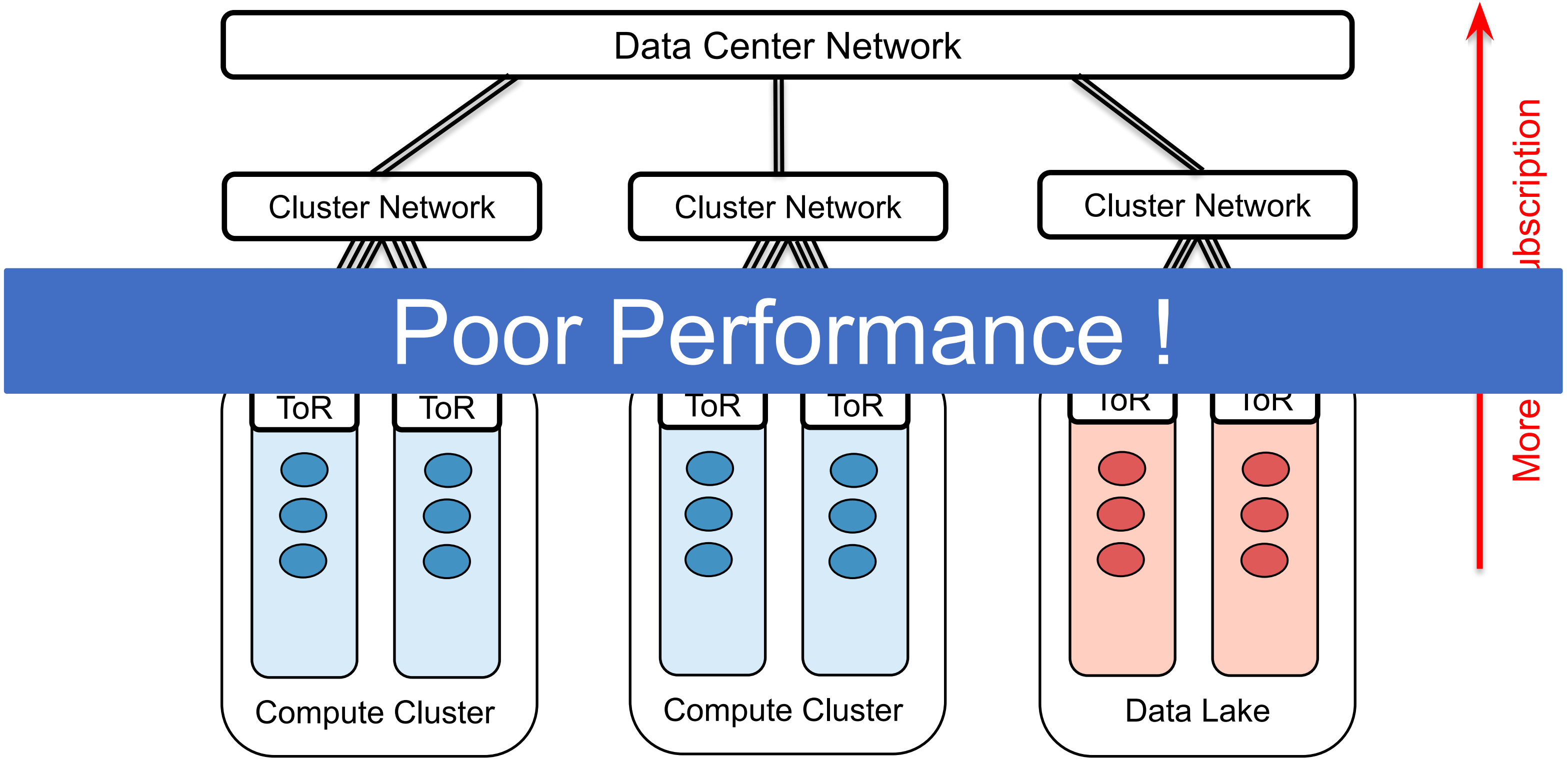
ceph
S3
Object Store

Network Limitations in Data Center



Caching for Big Data Analytics

Two Sigma [2018], Facebook [VLDB 2012], and **Yahoo [2010]** analytic cluster traces show that;

- High data input reuse
- Uneven Data Popularity
- File popularity changes over time
- Datasets accessed repeatedly by the same analytic clusters and between different analytic clusters

CACHING

Alluxio (formerly known as Tachyon[SOCC'14]), **HDFS-Cache**, **Pacman**[NSDI'12], **Adaptive Caching** [SOCC'16], **Scarlett**[Eurosys'11] , **Netco**[SOCC'19]

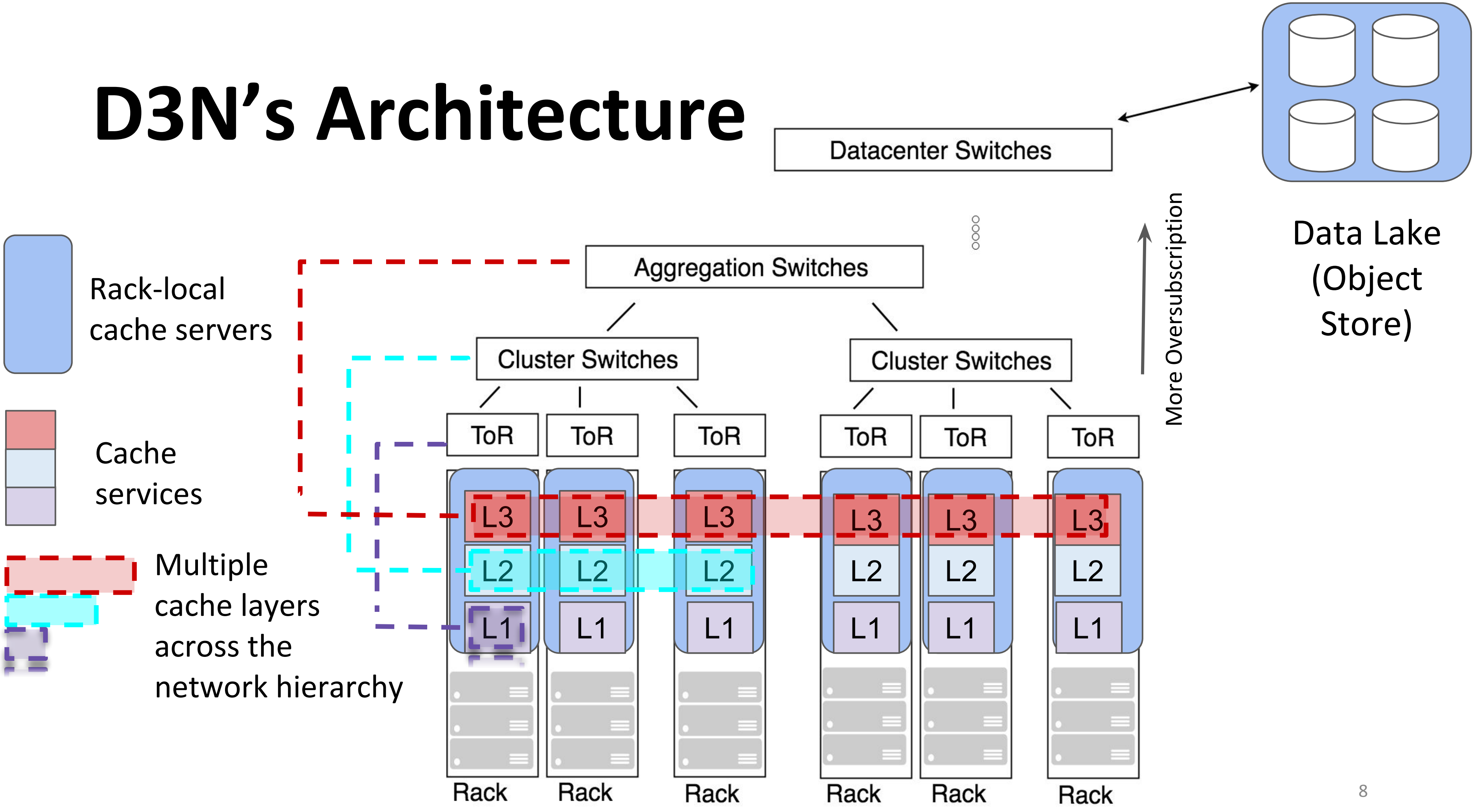
Fundamental Goals of D3N

- Extension of the data lake
- Reduce demand on network
- Automatically adjust to:
  - access pattern
  - network contention

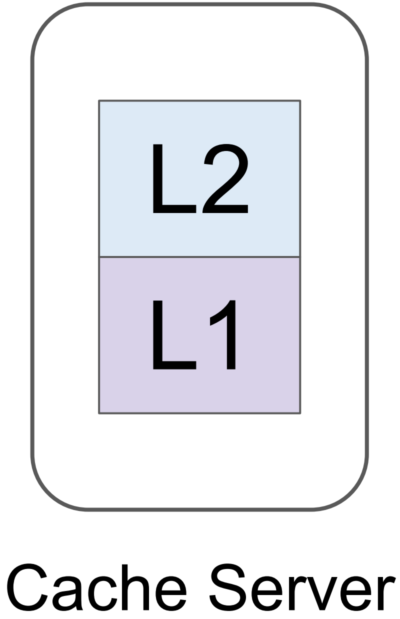
Design Principles

- Transparent to user
- Naturally scalable with the clusters that access it
- Cache policies based purely on local information
- Hierarchical multi-level cache

D3N's Architecture



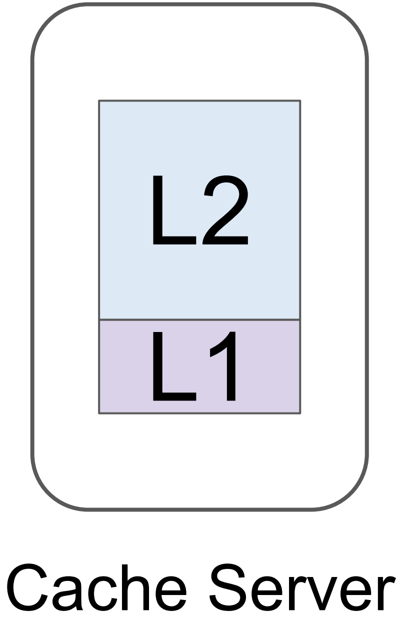
Dynamic Cache Size Management



The algorithm partitions the cache space based on:

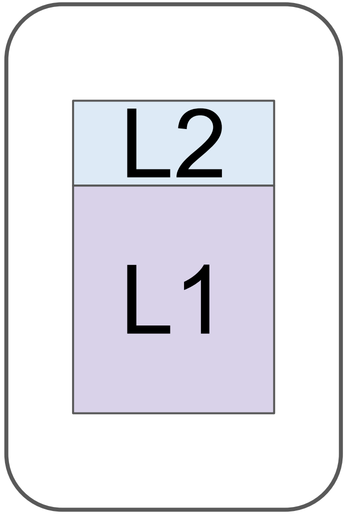
- Access Pattern
- Network Congestion

Dynamic Cache Size Management



- High rack locality with small working set size
- Congestion to storage network

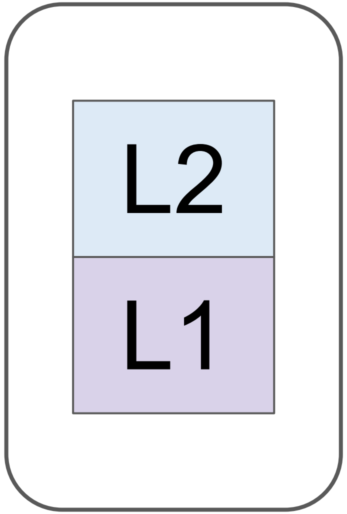
Dynamic Cache Size Management



Cache Server

- High rack locality
- Congestion within the cluster network

Dynamic Cache Size Management



Cache Server

The algorithm partitions the cache space based on:

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Dynamic Cache Size Management

The algorithm measures

- the reuse distance histogram
- mean miss latency

Find the optimal cache size split.

Algorithm 1 Re-use distance measurement

b: requested block
ℓ: layer (1 or 2)
S_t: total cache size (in blocks)
SL_ℓ: shadow LRU list (length S_t)
HC_ℓ: re-use distance histogram
$\overrightarrow{s} = (s_1, s_2)$: cache distribution, $s_1 + s_2 = S_t$

▷ Measure re-use distance for access to block b, layer ℓ
procedure MEASURE(b,ℓ)
  if $b \in SL_\ell$ **then**
    find i s.t. $SL_\ell(i) = b$ ▷ LRU position
    $HC_\ell(i)$++
  reorder SL_ℓ LRU due to access to b

Algorithm 2 Cache distribution adaptation

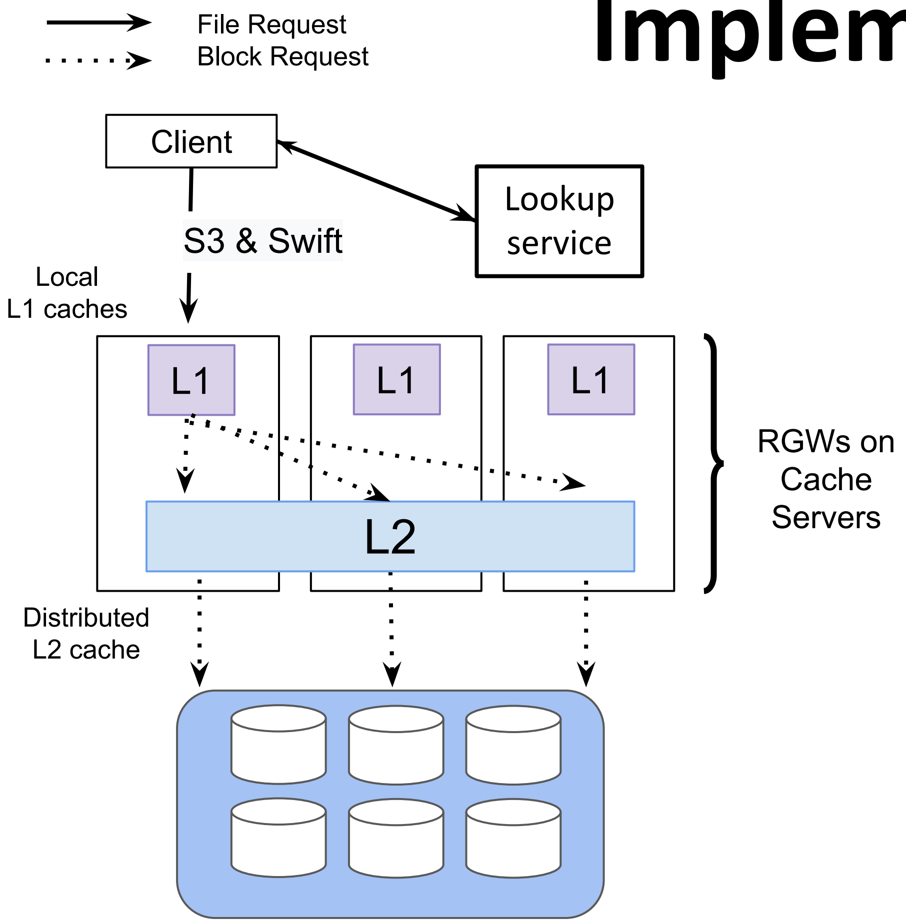
$b, \ell, S_t, \overrightarrow{s}, HC_\ell$: As in Algorithm 1
MR_ℓ: miss rate (i.e. miss ratio Curve)
L_ℓ: measured miss latency
q: adaptation limit (maximum assignment change in blocks)

▷ Calculate updated $L_1 L_2$ cache distribution $\overrightarrow{s}_{new}$
procedure ADAPT
  for ℓ in 1, 2 **do**
    $MR_\ell(i) = _{k=i}^{S_t} HC_\ell(k)$ ▷ Calculate miss ratio curve
  $C_{min} = \inf$
  $s_{new} = \emptyset$
  for $\overrightarrow{s}'$ in $(s_1 - q, s_2 + q) \ldots (s_1 + q, s_2 - q)$ **do**
    $\overrightarrow{m} = (MR_1(s_1) + MR_2(s_2))$ ▷ Predicted miss rate
    $C = m_1 L_1 + m_2 L_2$ ▷ Expected latency
    if $C < C_{min}$ **then**
      $C_{min} = C$
      $s_{new} = s'$

Edge Conditions and Failures

- VM Migration
  - Anycast to DNS lookup server.
  - TCP session keep active until a request is completed.
- Failure of cache server
  - Heartbeat service is used to keep track of active caches.
  - During a failure
    - lookup service will direct new requests to second nearest L1.
    - Consistent hashing algorithm remove the failed node from its map.

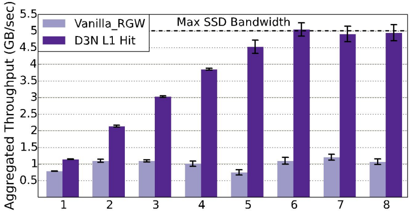
Implementation

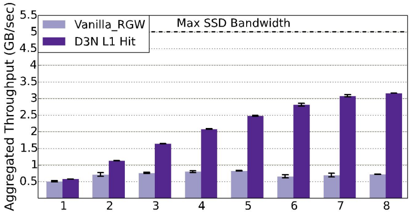


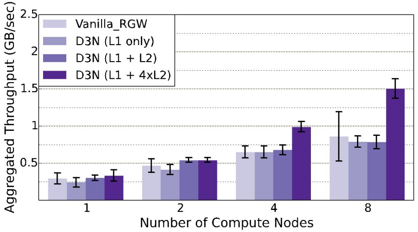
- Modification to **Ceph's RADOS gateway**. We add 2500 lines of code.
- Implements **two level cache,** L1 and L2.
- Read Cache
- Write Cache
  - Write-through
  - Write-back (today no redundancy)
- Stores cached data in 4 MB blocks as individual files on an SSD-backed file system.

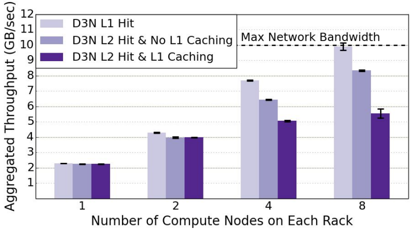
Evaluation of D3N

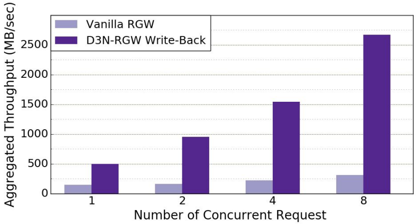
Micro Benchmarks

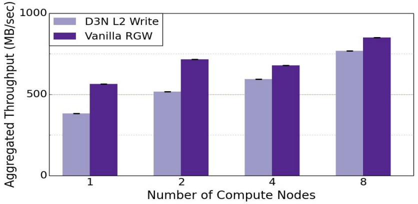




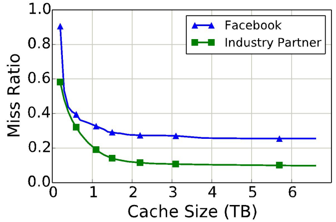


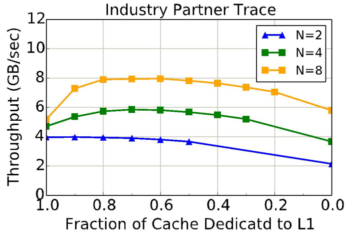


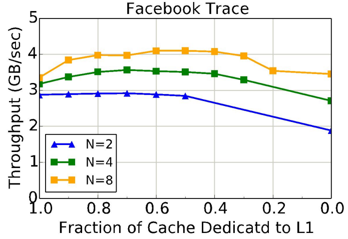




Value of Multi-level

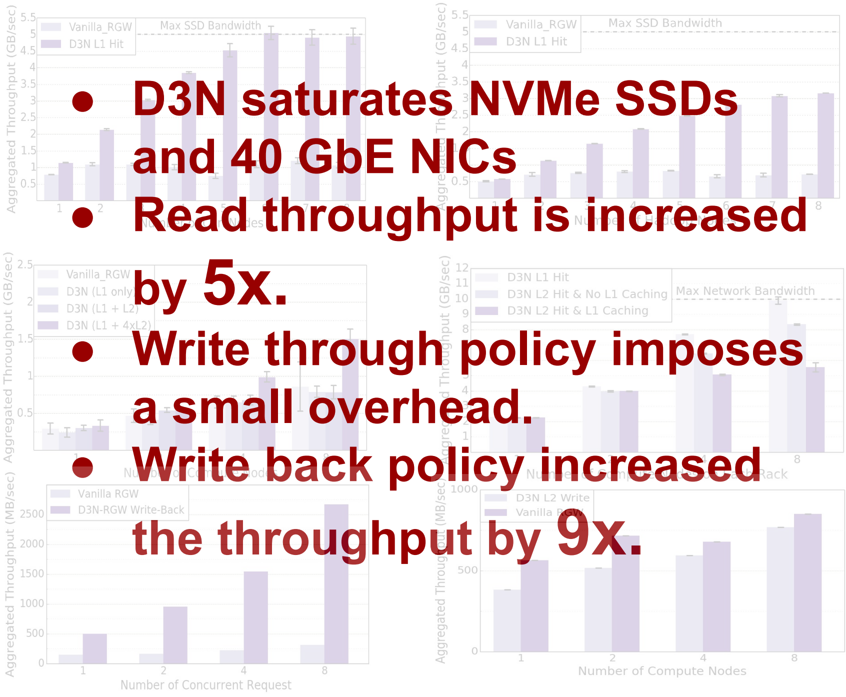






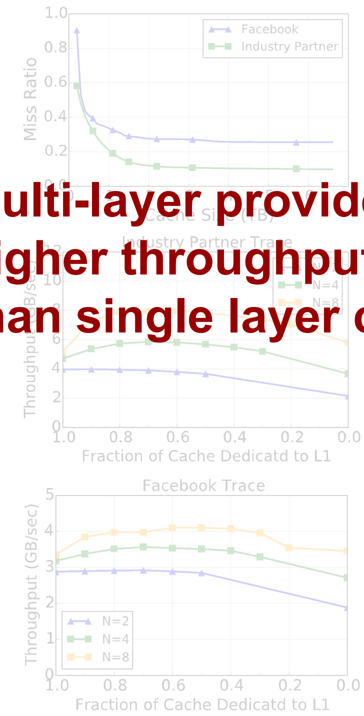
Evaluation of D3N

Micro Benchmarks



- **D3N saturates NVMe SSDs and 40 GbE NICs**
- **Read throughput is increased by 5x.**
- **Write through policy imposes a small overhead.**
- **Write back policy increased the throughput by 9x.**

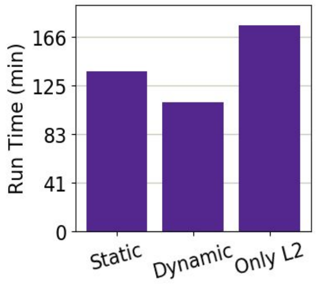
Value of Multi-level

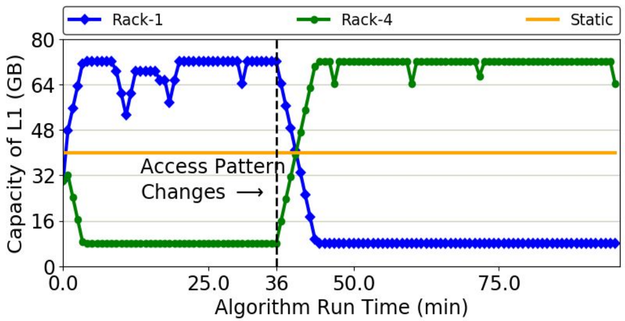


Multi-layer provides higher throughput than single layer cache.

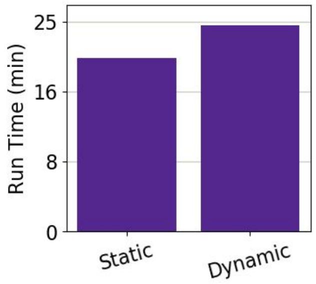
Evaluation of Cache Management

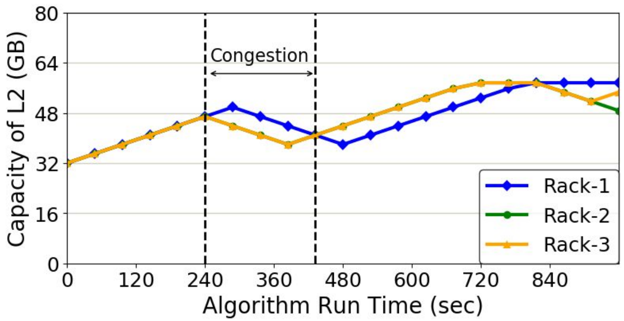
Adaptability to different access patterns





Adaptability to network load changes





Evaluation of Cache Management

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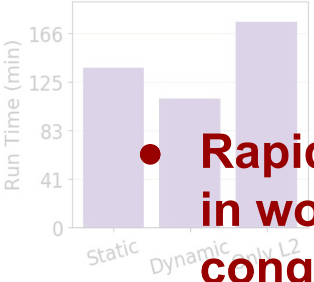

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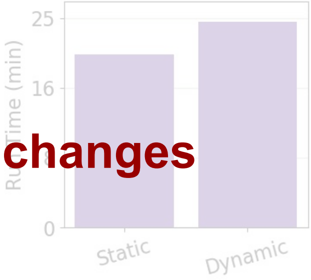


- **Rapidly and automatically adjust changes in workload access pattern and congestion on network links.**

Impact of D3N on Realistic Workload

Workloads: Facebook Traces

- 75% reuse
- 40TB data
- Requests were randomly assigned

Benchmark:

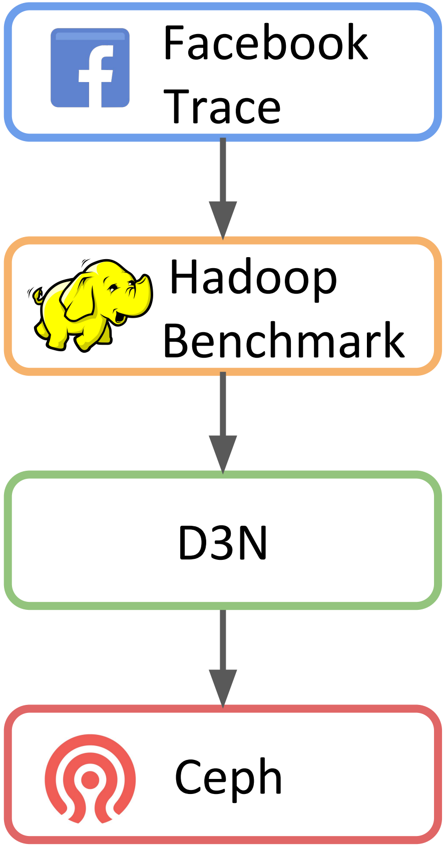
- Mimic the hadoop mappers oncurrent
- Concurrent 144 read requests using “curl”

D3N: 2 cache servers each have

- 1.5 TB NVMe SSDs (RAID 0)
- Fast NIC: 2 x40 Gbit & Slow NIC: 2 x6 Gbit

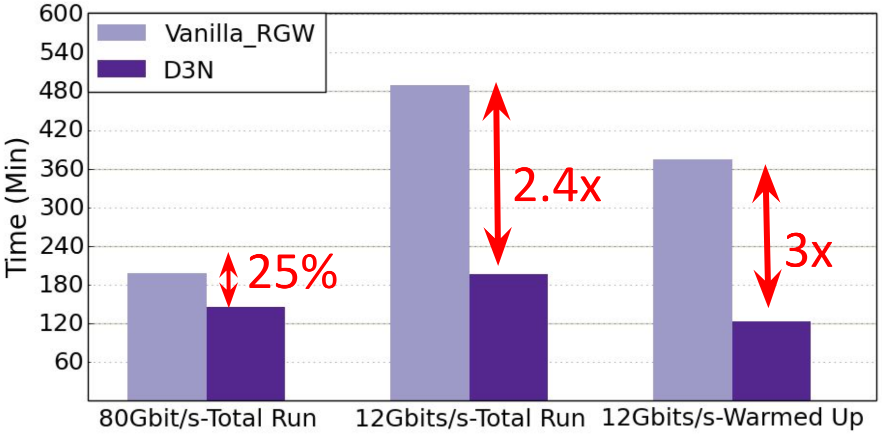
Data lake:

- Ceph (90 HDDs)



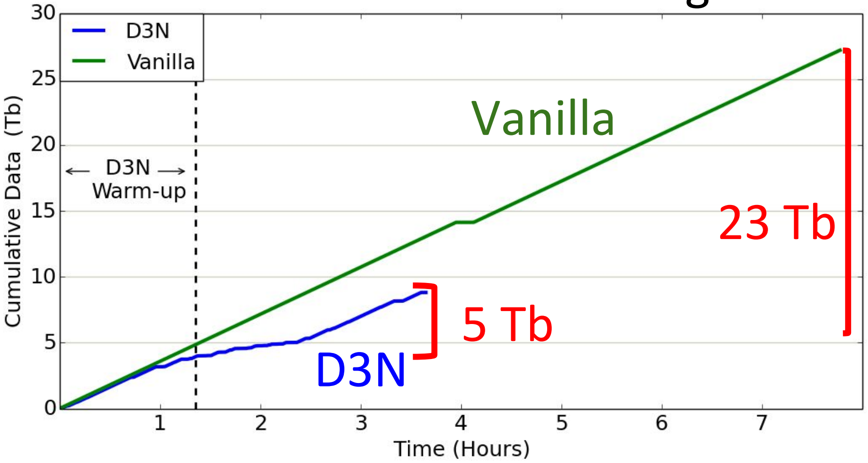
Impact of D3N on Realistic Workload

The trace completion time



D3N improves performance significantly.

Cumulative data transferred from back-end storage



More than 4x reduction to backend traffic.

Concluding Remarks

Proposed a transparent multi layer caching

- Extension of the data lake
- Implemented two layer prototype

Results:

- Cache partitioning algorithm dynamically adapt changes
- Reduces demand datacenter wide
- Improve the analytic workloads performance

Red Hat is currently productizing D3N.

- https://github.com/ekaynar/ceph

Project Websites

- https://www.bu.edu/rhcollab/projects/d3n/
- https://massopen.cloud/d3n/

Thank you