Improving Docker Registry Design based on Production Workload Analysis

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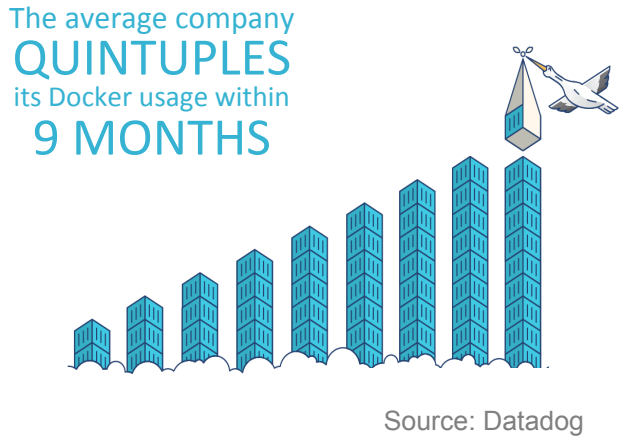
Containers will be a $2.7B market by 2020*

- Containers accelerate software development and distribution.
- In 2017 alone, Docker adoption went up by 40%.
- Containers use in enterprise and cloud infrastructure is expected to grow much faster.



Source: Datadog

*http://bit.ly/2uryjDI

Docker usage patterns remain a mystery

- How are Docker containers used and managed?
- How can we streamline Docker workflows?
- How do we facilitate Docker performance analysis?

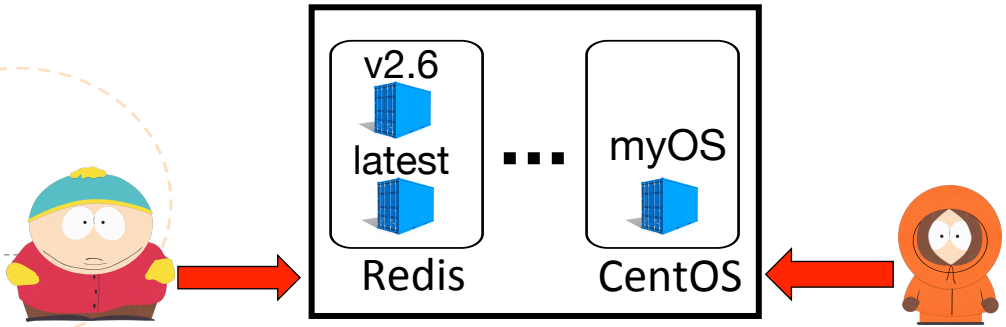
Our contribution: Characterization and optimization of Docker workflow

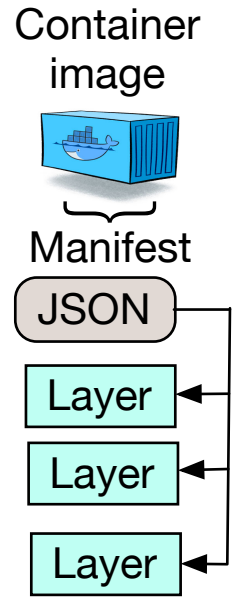
- Conduct a large-scale analysis of a real-world Docker workload from geo-distributed IBM container service
- Provide insights and develop heuristics to increase Docker performance
- Develop an open source Docker workflow analysis tool*

* https://dssl.cs.vt.edu/drtp/

Background: Docker container image

- Container images are divided into **layers.**
- The metadata file is called **manifest**.
- **Users** create **repositories** to store images.
- Images in a repository can have different **tags** (versions).





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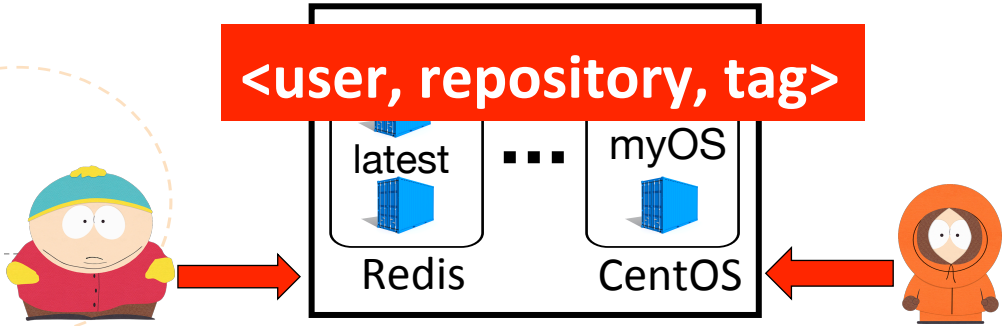
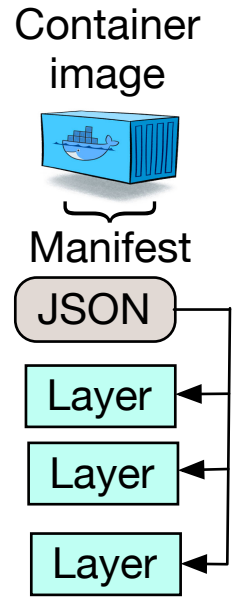
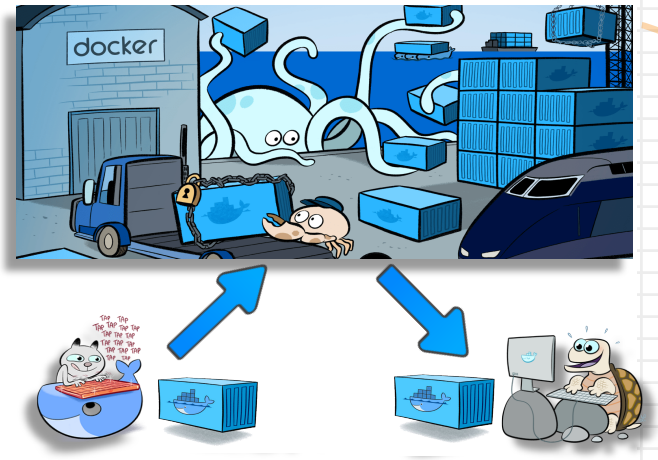




Background: Docker container registry

- Docker container images are stored online in **Docker registry**.
  - Push image:
    1. HEAD layers
    2. POST/PUT layer
    3. PUT manifest
  - Pull image:
    1. GET manifest
    2. GET layers



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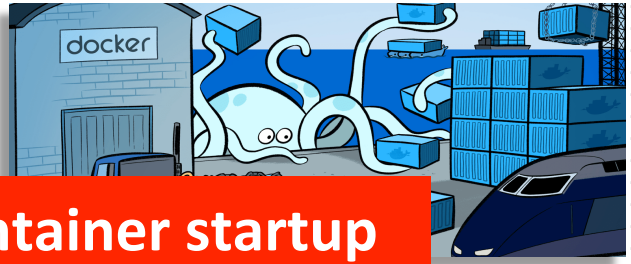
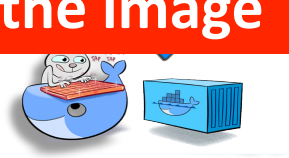
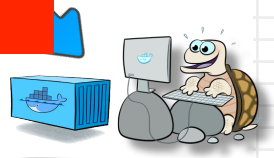


Significant amount of a container startup time is spent in pulling the image



docker push



docker pull

The IBM Cloud Docker registry traces

- Capture a diverse set of customers: individuals, small & medium businesses, government institutions
- Cover five geographical locations and seven availability zones
- Span 75 days and 38M requests that account for more than ~181TB of data transferred

IBM Docker registry service

Five geographical locations constitute seven Availability Zones (AZ):

Production

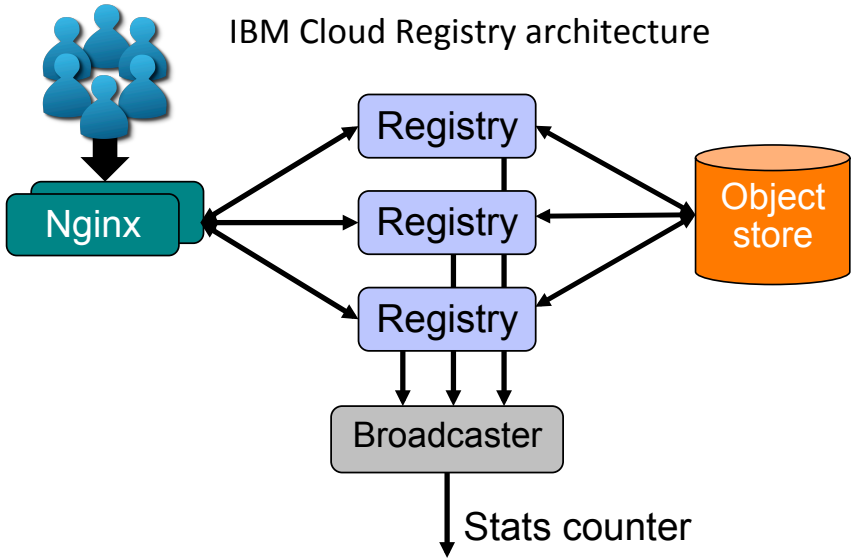
1. Dallas (**dal**)
2. London (**lon**)
3. Frankfurt (**fra**)
4. Sydney (**syd**)

IBM Internal

5. Staging (**stg**)

Testing*

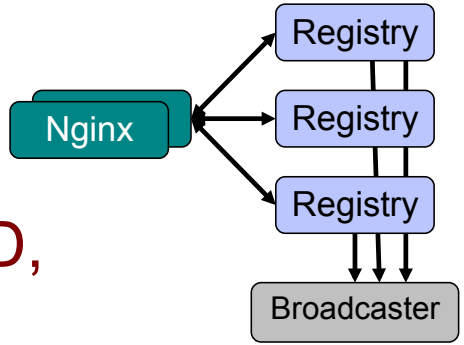
6. Prestaging (**prs**)
7. Development (**dev**)



*The registry setup is identical, except prs and dev are only half the size of the other Azs.

Tracing methodology

- Collected data from **Registry**, **Nginx**, and **Broadcaster**
- Studied requests: GET, PUT, HEAD, PATCH, POST
- Combined traces by matching the incoming HTTP request identifier across the components
- Removed redundant fields and anonymized the traces

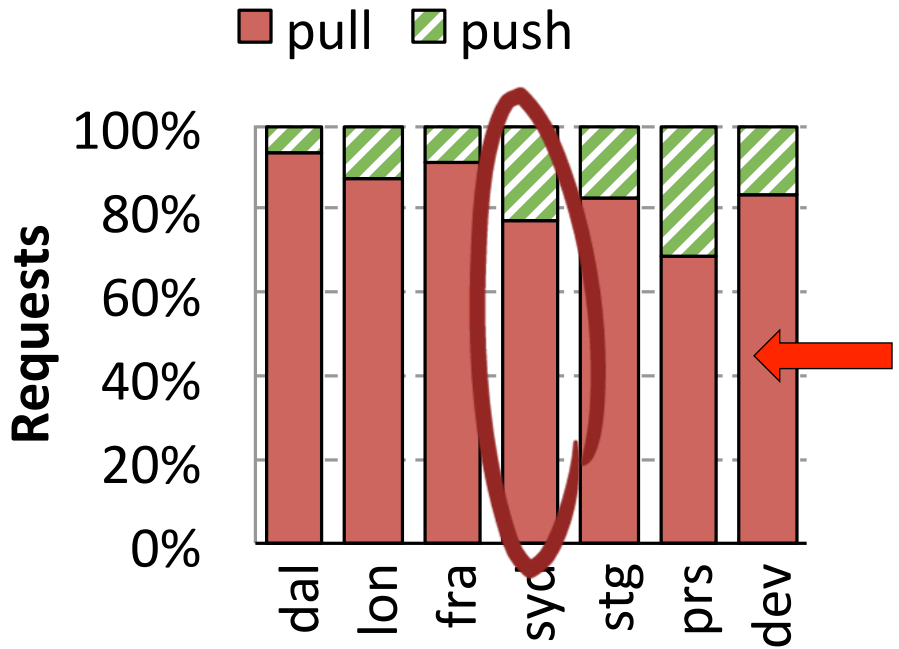


Anonymized log sample


```
{
    "host": "579633FD",
    "http.request.duration": 0.879271282,
    "http.request.method": "GET",
    "http.request.remoteaddr": "40535JF8",
    "http.request.uri": "v2/CA64KJ67/AS87D65G/blobs/B26S986D",
    "http.request.useragent": "docker/17.04.0-ce go/go1.7.5..)",
    "http.response.status": 200,
    "http.response.written": 1518,
    "id": "9F63984H",
    "timestamp": "2017-07-01T01:39:37.098Z"
}
```

Q1: What is the distribution of request types?

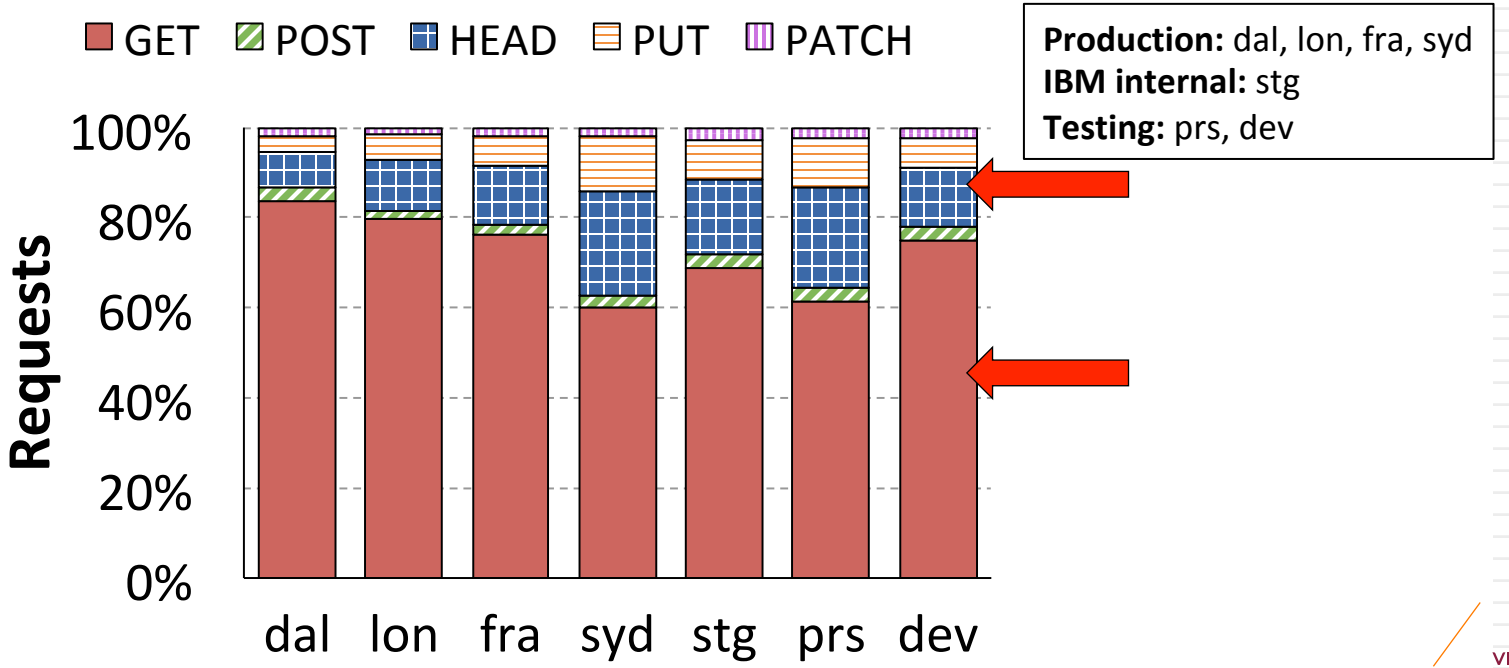
80%–95% of requests are reads (pulls)



Production: dal, lon, fra, syd
IBM internal: stg
Testing: prs, dev

Q1: What is the distribution of request types?

60% of the requests are GET and 10%–22% are HEAD requests



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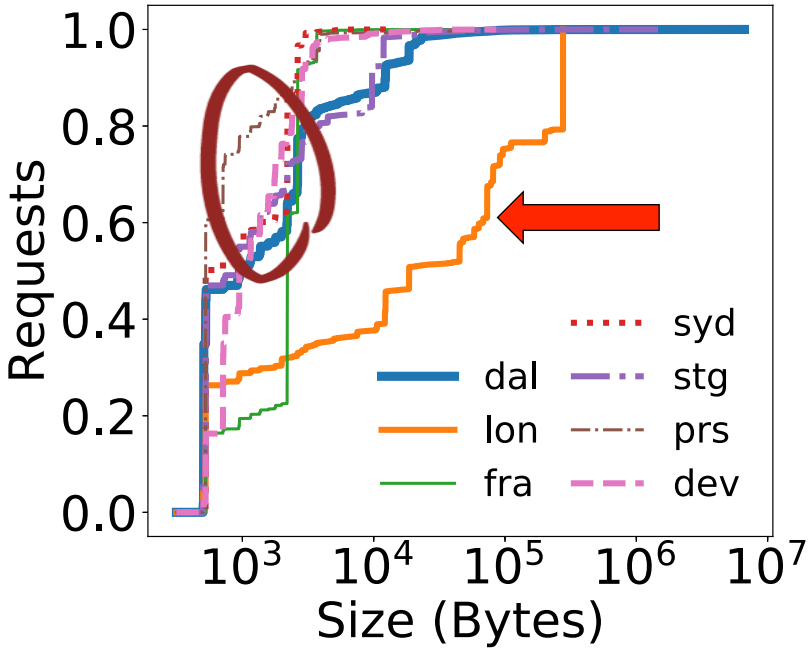
Q2: What is the manifest size distribution?

Typical manifest size is around 1 KB



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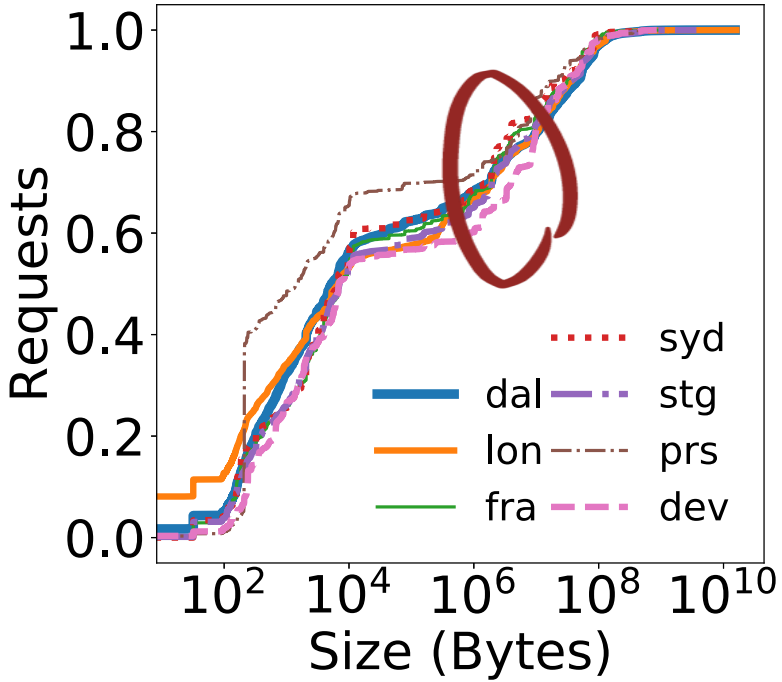
Q3: What is the layer size distribution?

65% of the layers are smaller than 1 MB and around 80% are smaller than 10 MB



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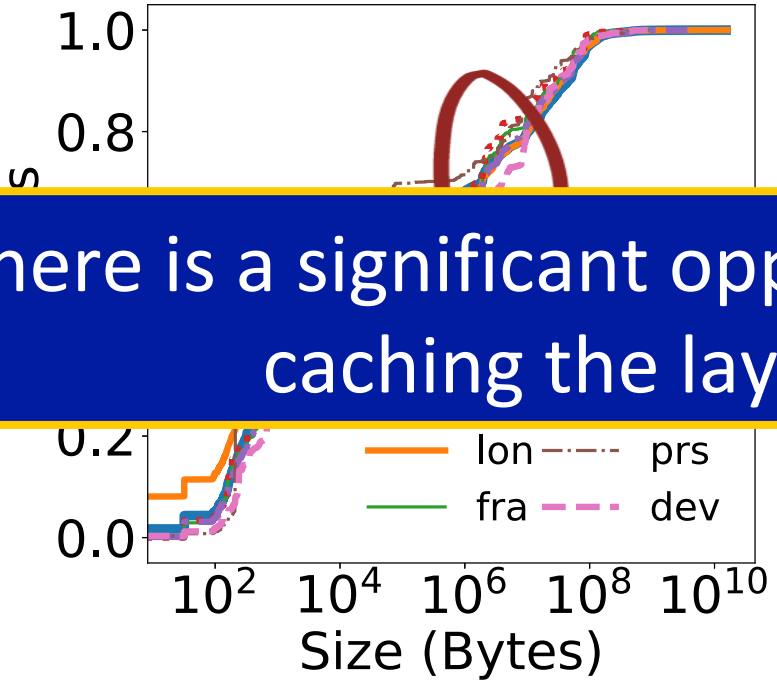

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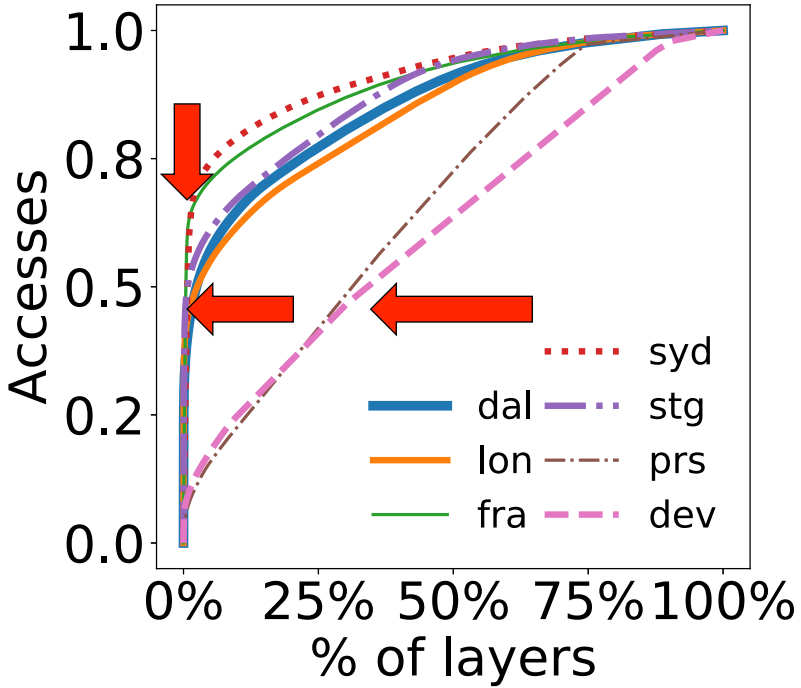
There is a significant opportunity for caching the layers

Q4: Is there spatial locality?

1% of most accessed layers account for 42% and 59% of all requests in dal and syd, respectively



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Q4: Is there spatial locality?

The popularity rate drops rapidly as we move from most popular to tenth most popular layer

Production: dal, lon, fra, syd
IBM internal: stg
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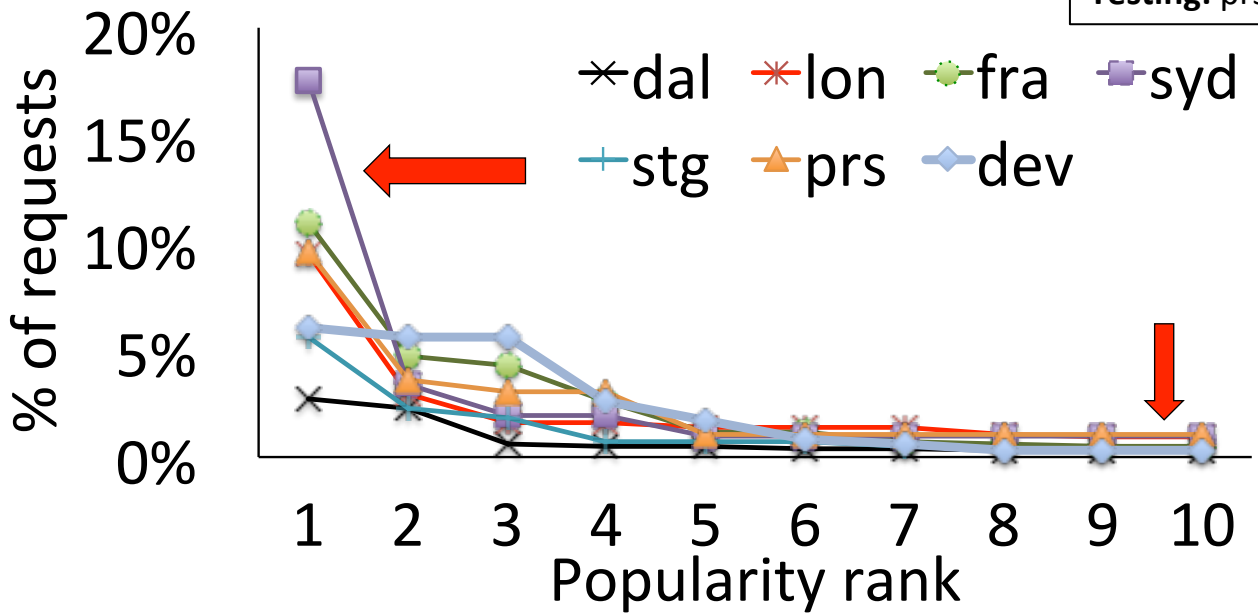

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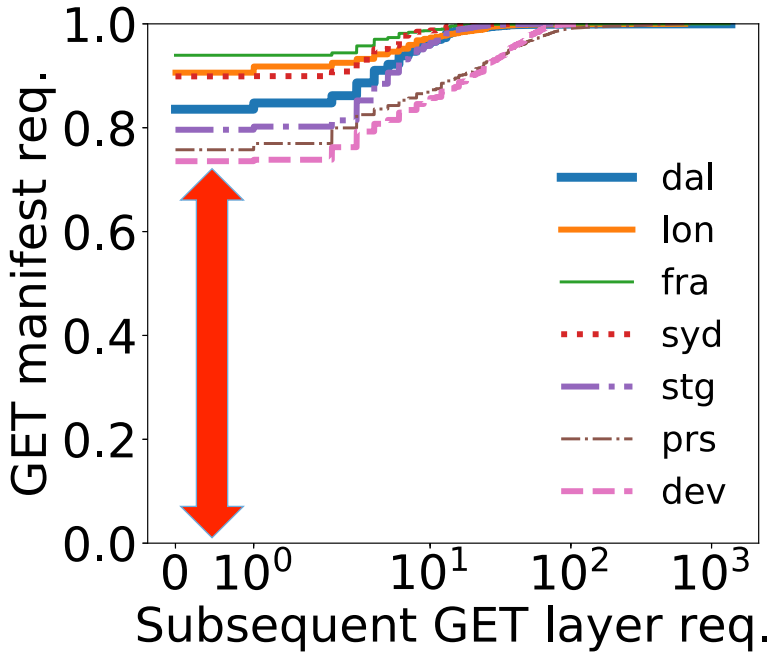
Q5: Can future requests be predicted?

GET manifest requests are not followed by any subsequent GET layer request



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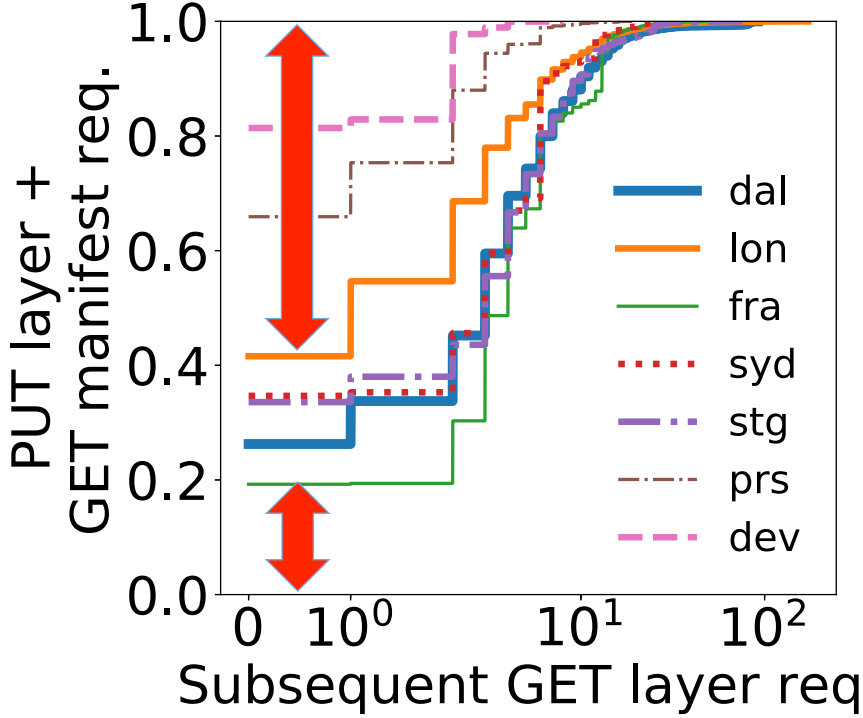
Significant increase in subsequent GET layer requests within a session



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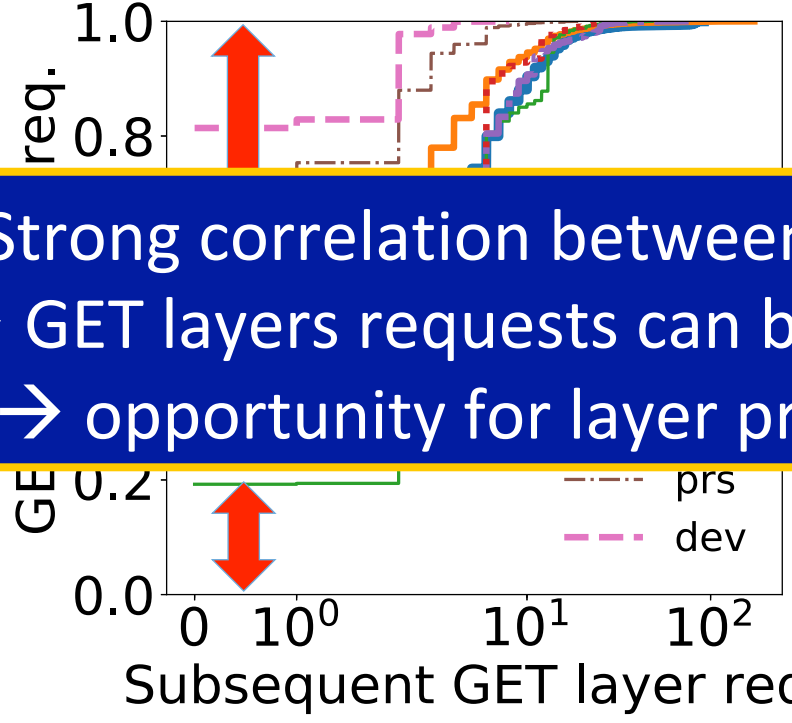

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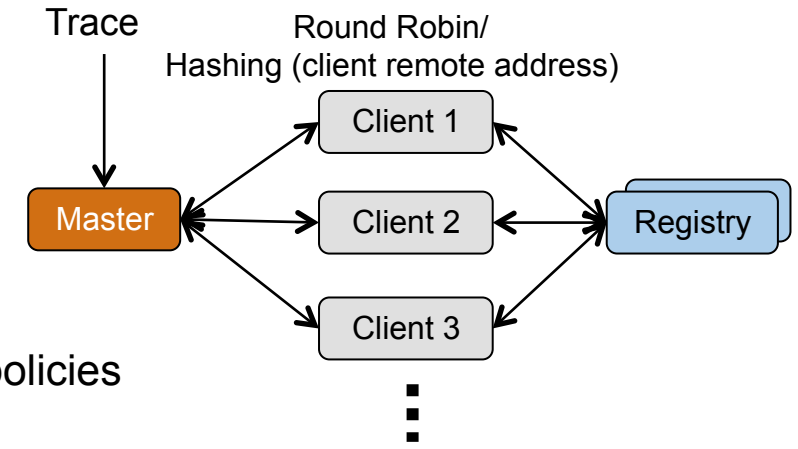
Strong correlation between requests
→ GET layers requests can be predicted
→ opportunity for layer prefetching

Enabling further analysis: Trace re-player

Performance analysis mode

- Study throughput and latency
- Understand effect of CPU, Memory, Storage, Network



Offline analysis mode

- Simulate prefetching and caching policies
- Explore cache efficacy

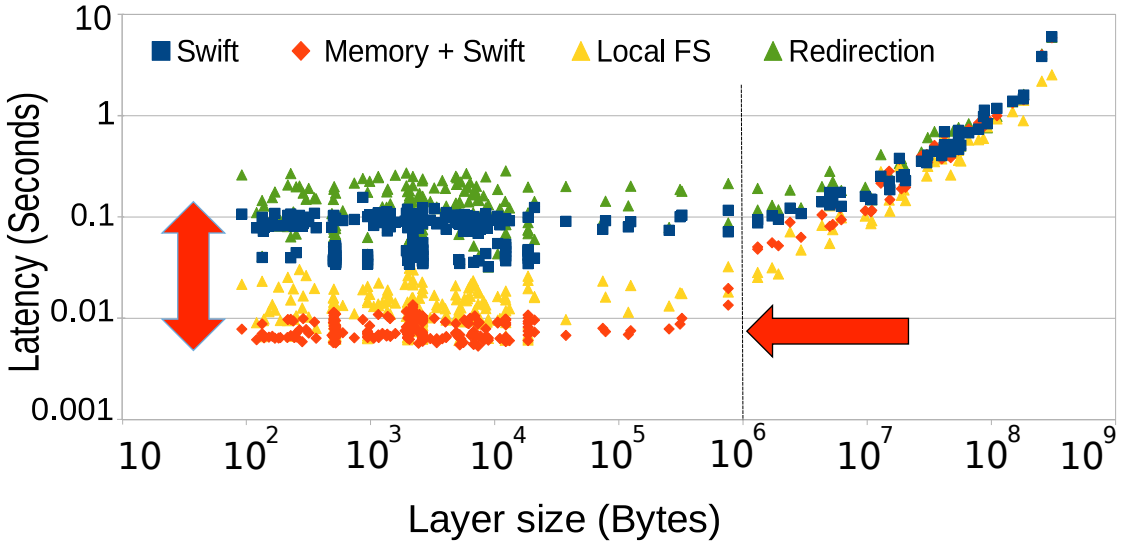
Additional analysis

- Analyze request arrival rate at user define granularity
- Study effect of deduplication on registry size

Effect of backend storage technologies

Experimental setup:

- Registry on 32 core machine with 64 GB RAM and 512 GB SSD
- Swift object store on **10** similar nodes
- Trace re-player on **6** additional nodes

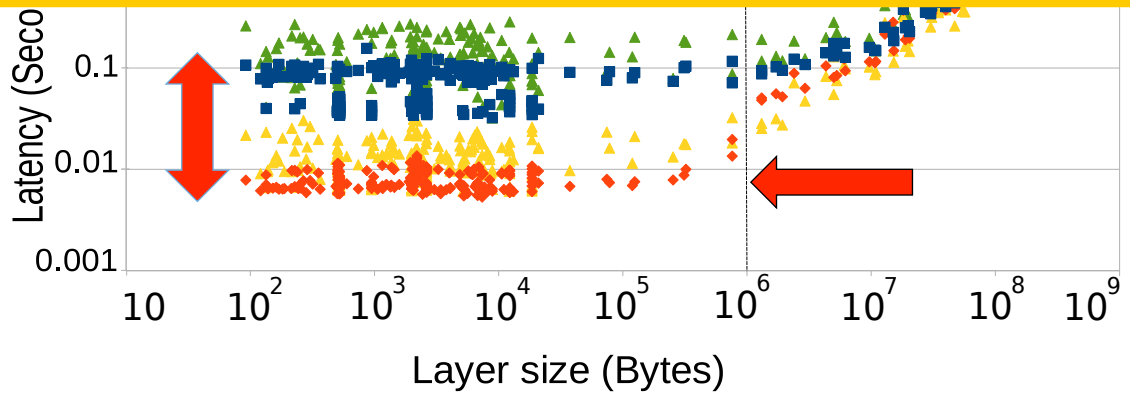


Effect of backend storage technologies

Experimental setup:

- Registry on 32 core machine with 64 GB RAM and 512 GB SSD

Fast backend storage/cache for the registry can significantly improve the overall performance



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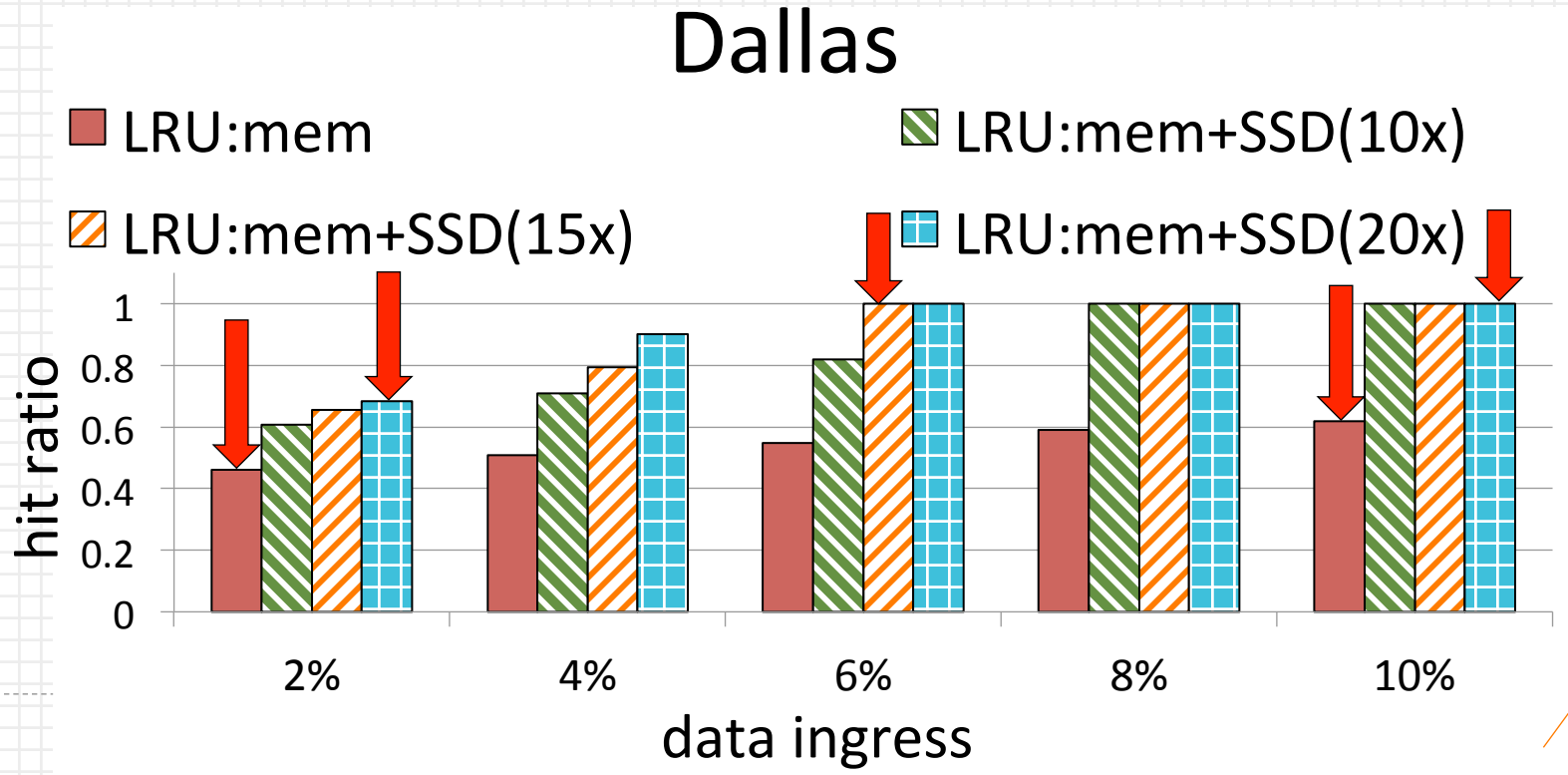
Effect of a two-level Main Memory+SSD cache

Experimental setup:

- Small layers (<100 MB) are stored in the main memory
- Replacement policy for both cache level is LRU
- Studied cache sizes:
  RAM: 2%, 4%, 6%, 8%, and 10% of the data ingress
  SSD: 10x, 15x, 20x the size of RAM cache

- Layers are content addressable
  → cache invalidation is not a problem

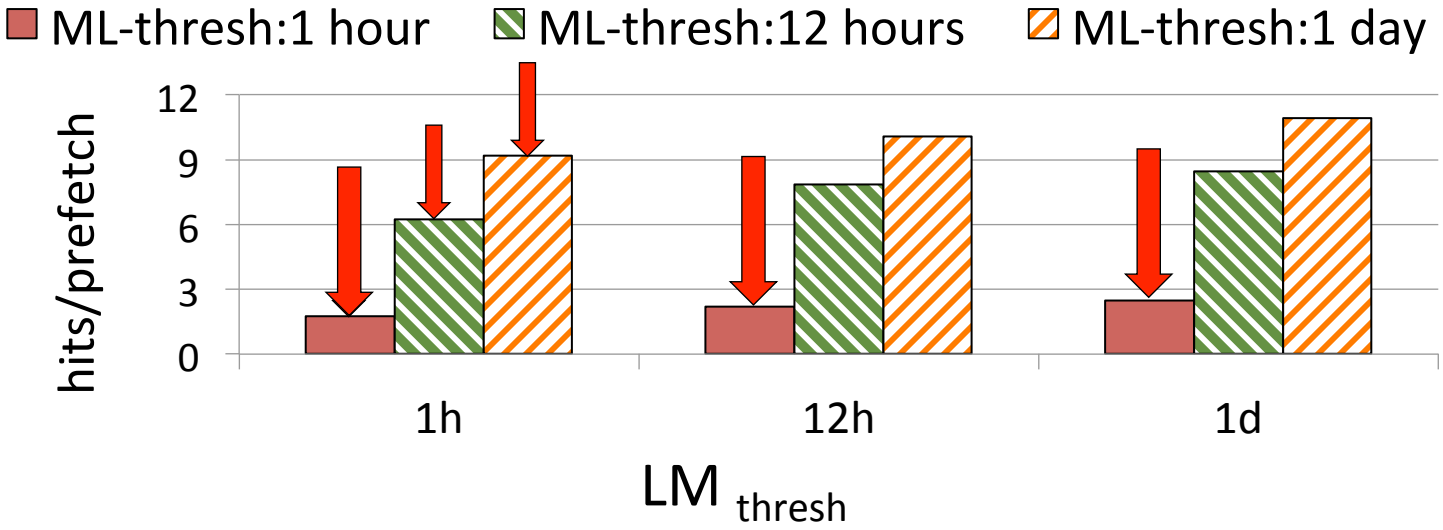
Two-level cache: Main memory+SSD



Benefit of layer prefetching

PUT layer → GET manifest → GET layer

LM_{thresh} ML_{thresh}



Summary

- We perform a quantitative characterization of a production Docker registry deployment
  - Registry workload is read intensive
  - Layers sizes are small
  - Strong correlation exists between layer requests
- We propose effective caching and prefetching strategies for container layers
- We enable further Docker investigation and optimization by making our traces and the trace re-player tool open source*

* https://dssl.cs.vt.edu/drtp/

Thank You!

Questions & contact: Ali Anwar, ali@vt.edu

https://dssl.cs.vt.edu/