Slacker: Fast Distribution with Lazy Docker Containers

Tyler Harter, Brandon Salmon†, Rose Liu†,
Andrea C. Arpaci-Dusseau, Remzi H. Arpaci-Dusseau

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Tintri †

Container Popularity

docker

Rocket

CoreOS

kubernetes by Google

Google

facebook

twitter

amazon

heroku

spoon.net

Theory and Practice

Theory: containers are lightweight

- just like starting a process!

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- **25 second** startup time [1]

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[1] Large-scale cluster management at Google with Borg.
http://static.googleusercontent.com/media/research.google.com/en//pubs/archive/43438.pdf

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Theory and Practice

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Practice: container startup is slow

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Startup time matters

- flash crowds
- load balance
- interactive development

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Contributions

HelloBench

- Docker benchmark for stressing startup
- based on **57** container workloads

Startup analysis

- **76%** of startup time spent copying/installing images
- startup requires only **6%** of that image data

Slacker: Docker storage driver

- lazily pull only needed data
- leverage extensions to Linux kernel and NFS server
- **5-20x** startup speedups

Slacker Outline

Background

- Containers: lightweight isolation
- Docker: file-system provisioning

Container Workloads

Default Driver: AUFS

Our Driver: Slacker

Evaluation

Conclusion

Why use containers?

Why use containers?

(it’s trendy)

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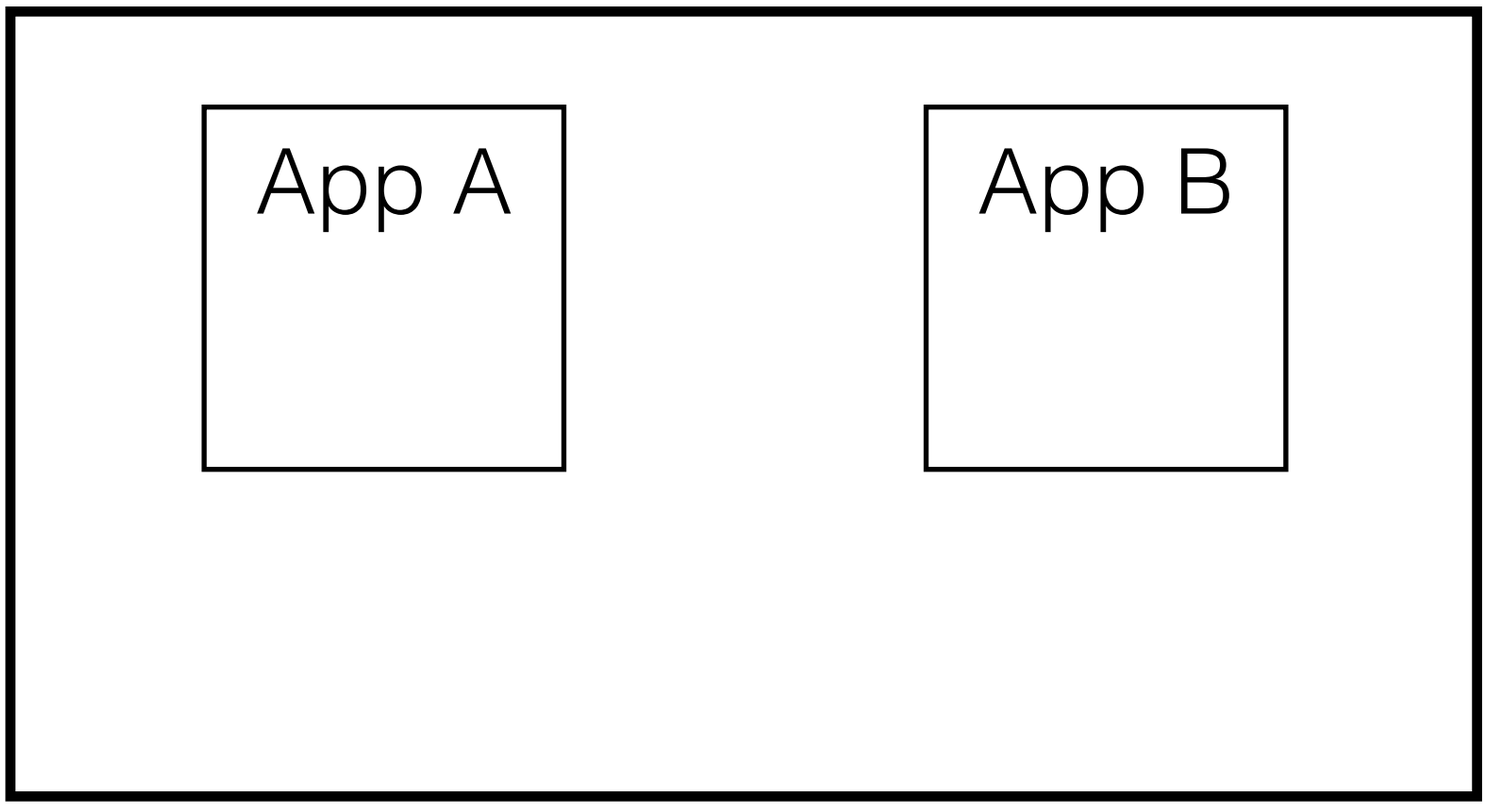
~~(it's trendy)~~

(efficient solution to classic problem)

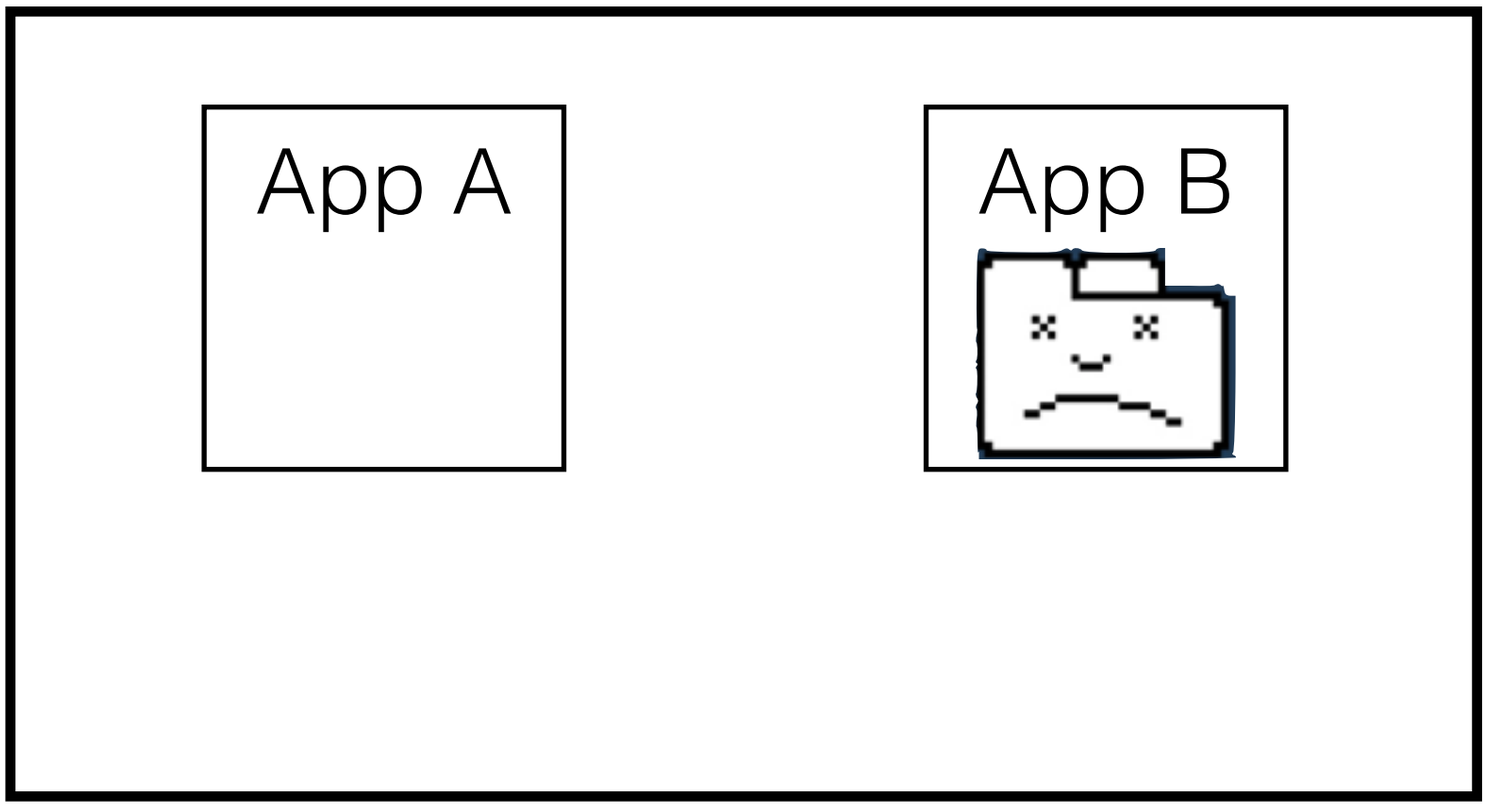
Big Goal: Sharing and Isolation



Physical Machine

want: multitenancy

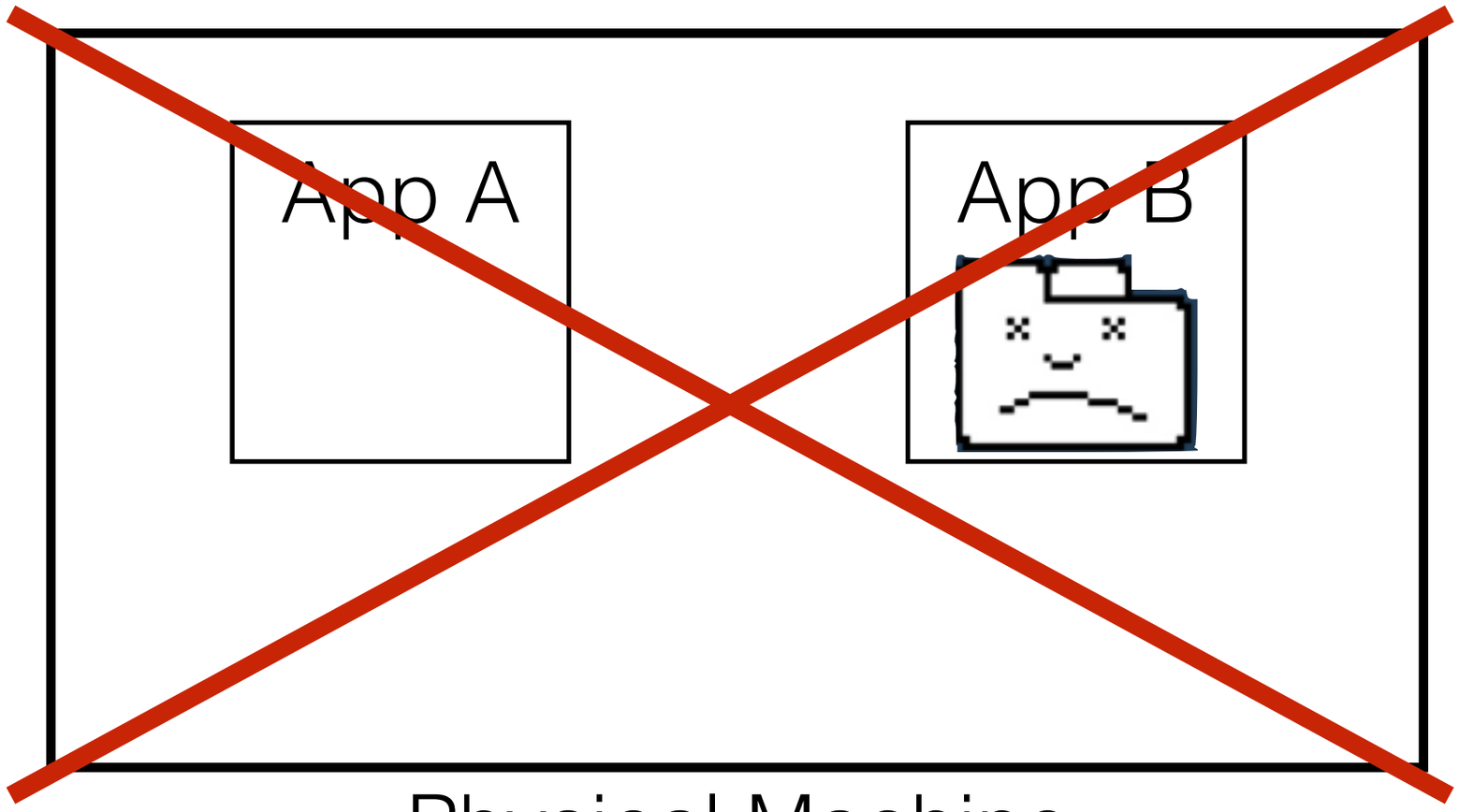
Big Goal: Sharing and Isolation



Physical Machine

don’t want: crashes

Big Goal: Sharing and Isolation



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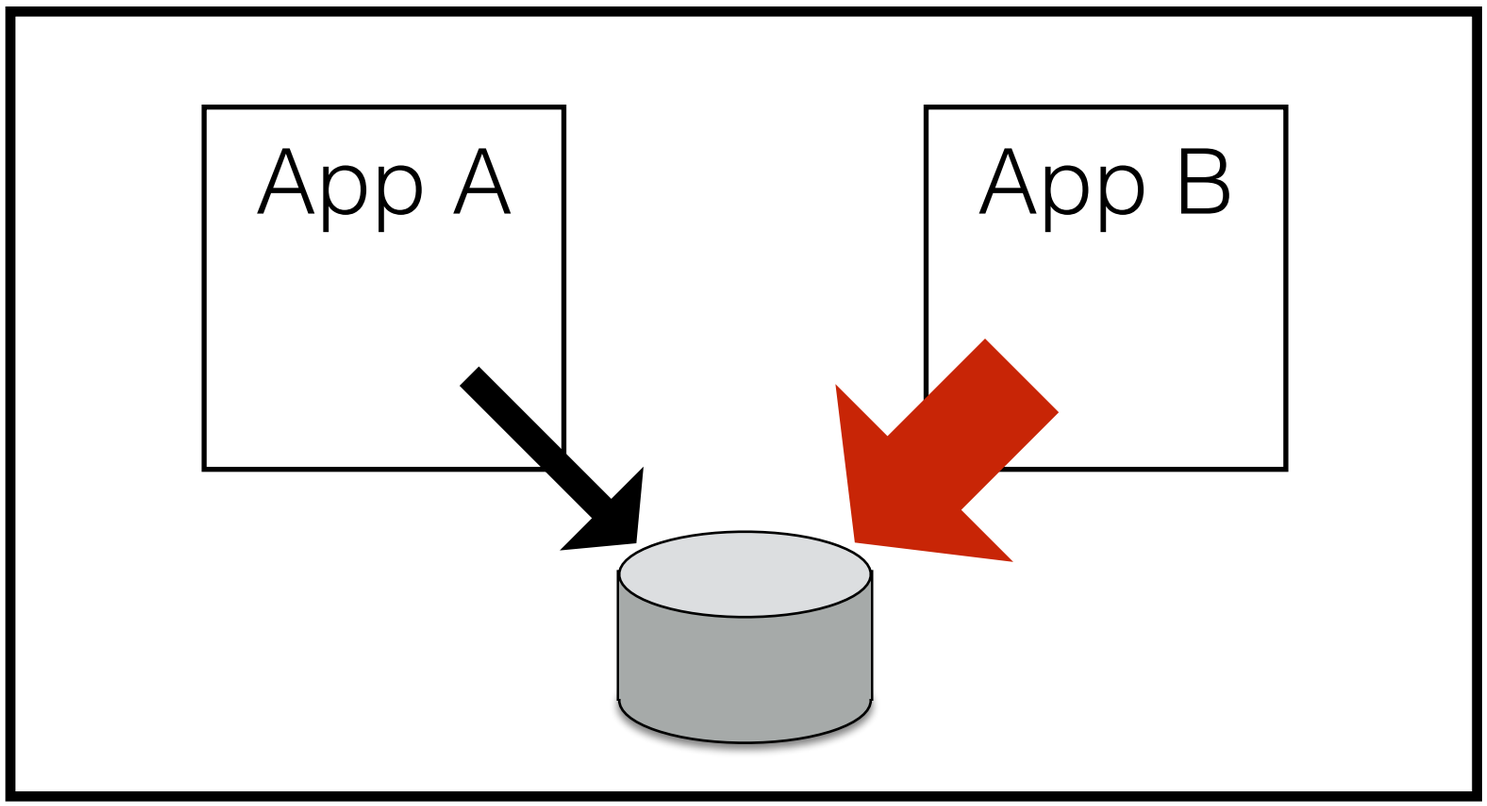
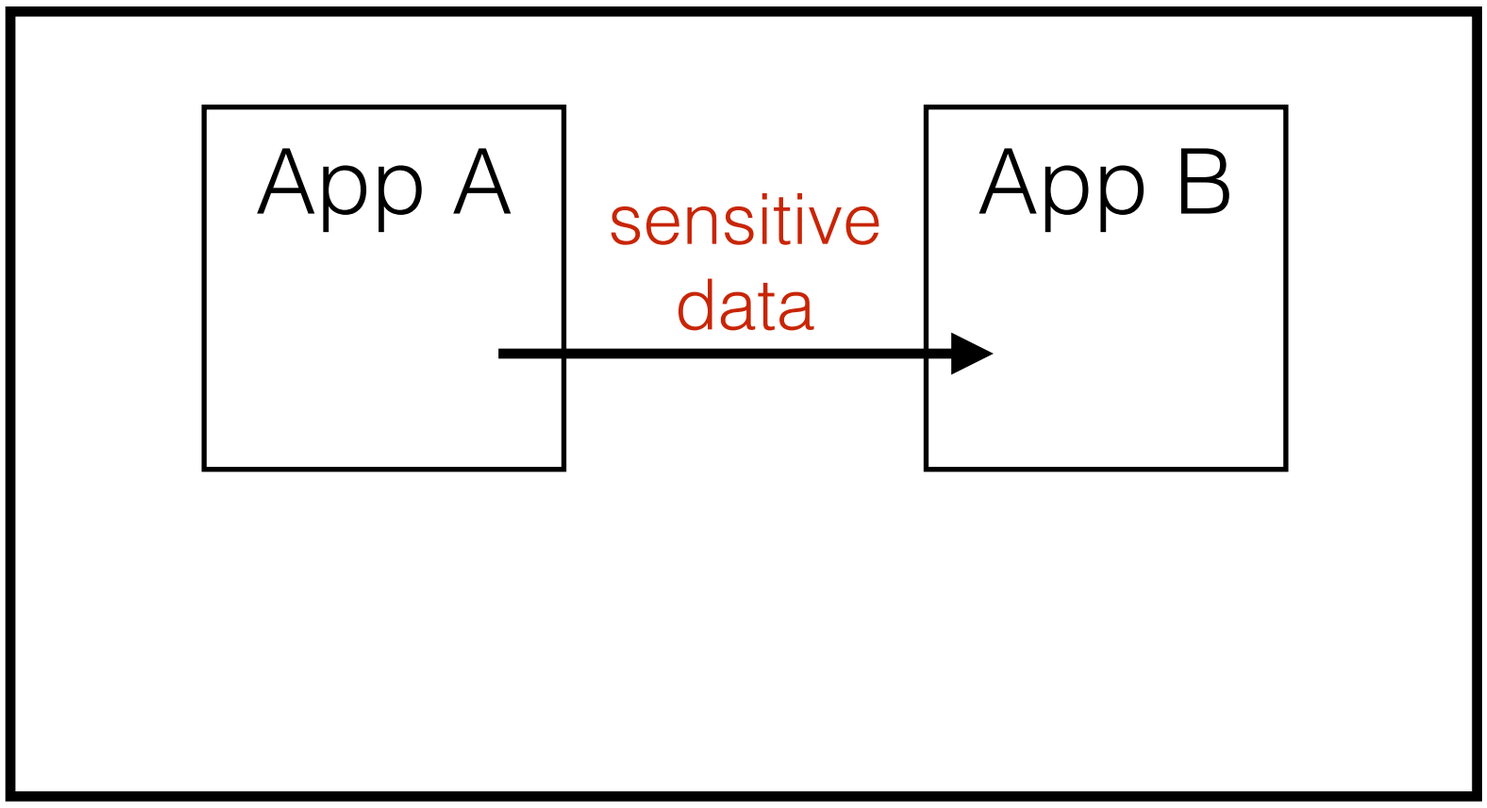


Physical Machine

don’t want: unfairness

Big Goal: Sharing and Isolation



Physical Machine

don’t want: leaks

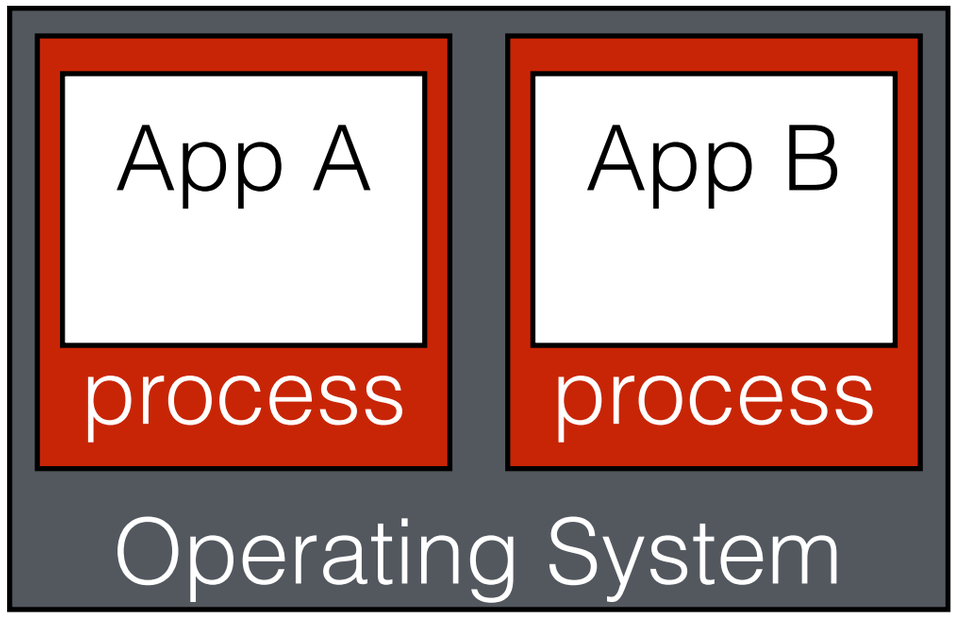
Solution: Virtualization

namespaces and **scheduling** provide illusion of private resources

Evolution of Virtualization

1st generation: process virtualization

- isolate within OS (e.g., virtual memory)
- **fast**, but incomplete (missing ports, file system, etc.)



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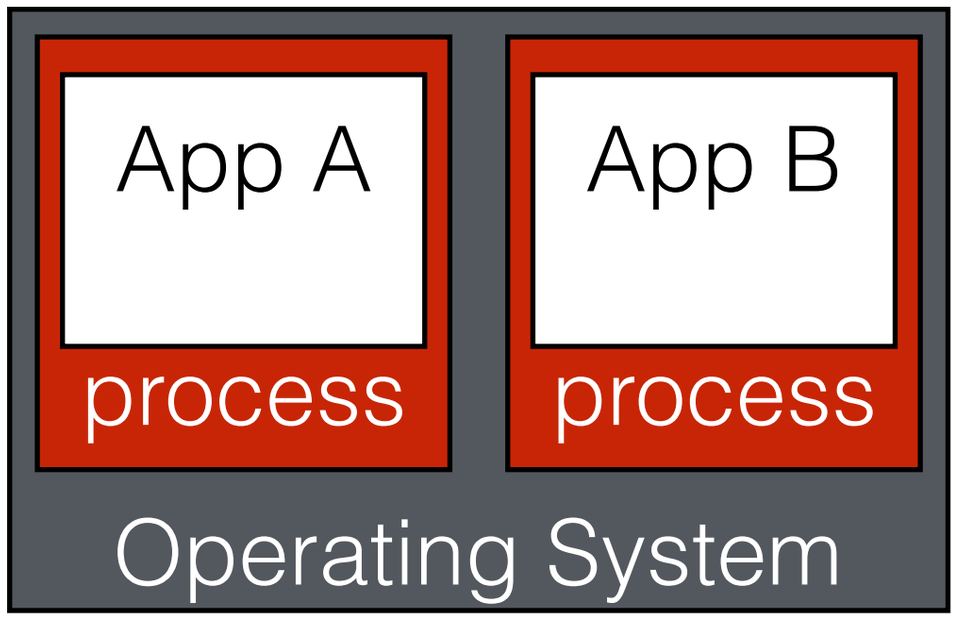

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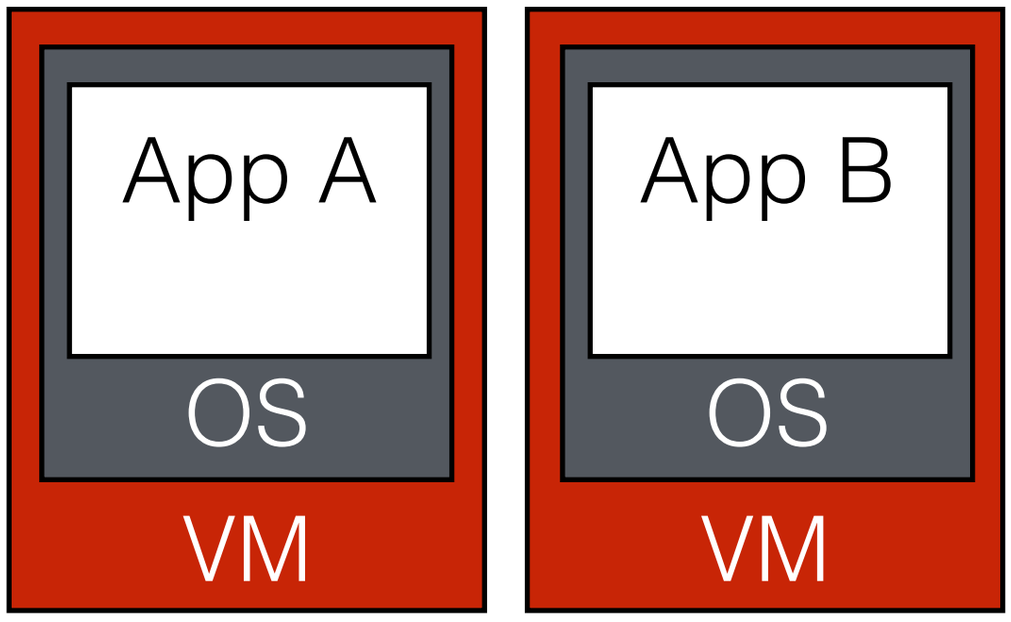

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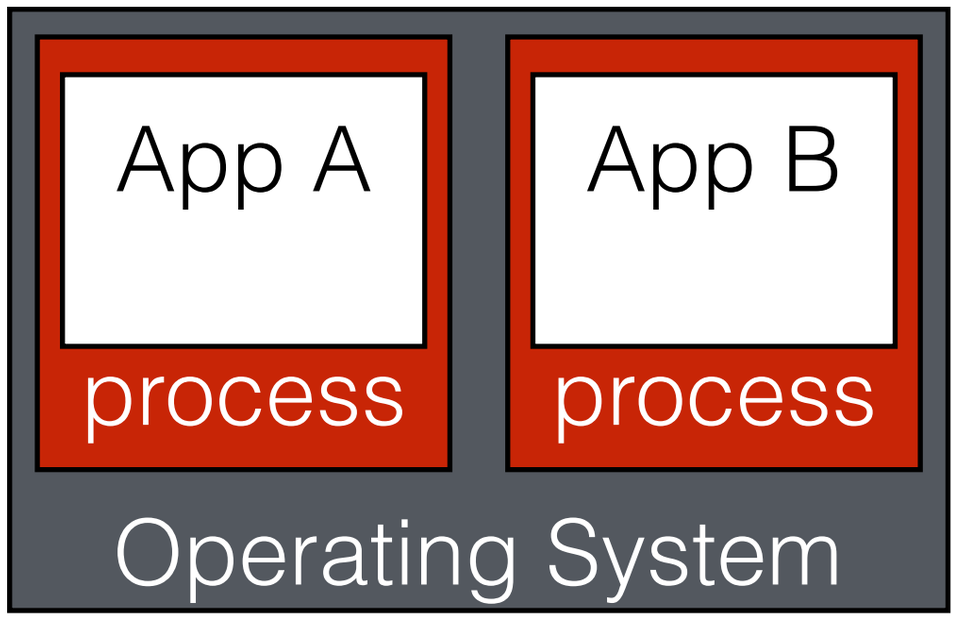

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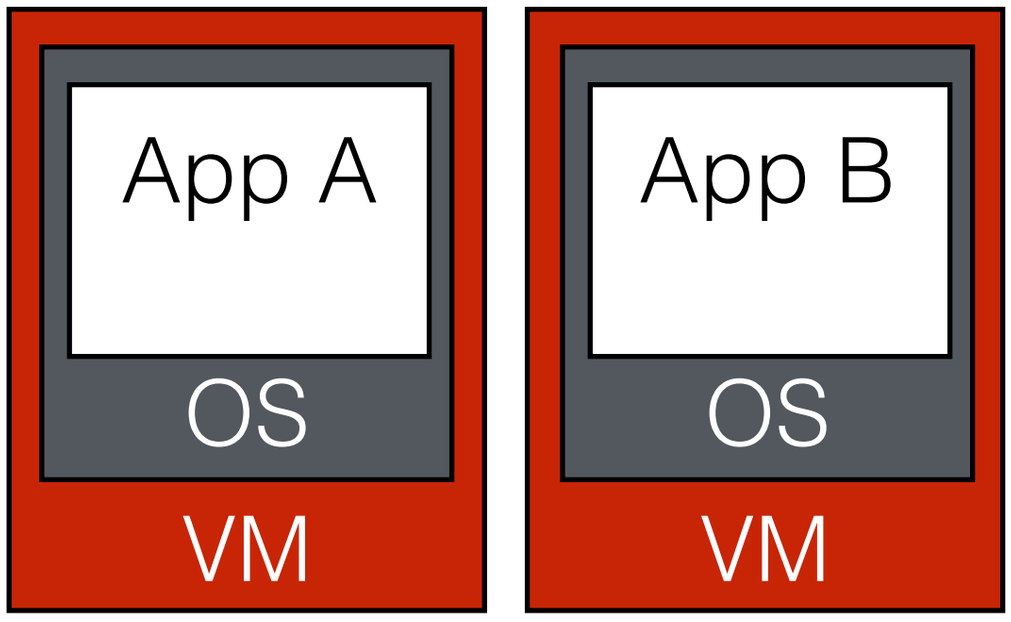

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3rd generation: container virtualization

- extend process virtualization: ports, file system, etc.
- **fast** and **complete**

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3rd generation: container virtualization

- extend process virtualization: ports, file system, etc.
- **fast** and **complete**???

many storage challenges

New Storage Challenges

Crash isolation

Physical Disentanglement in a Container-Based File System.
Lanyue Lu, Yupu Zhang, Thanh Do, Samer Al-Kiswany,
Andrea C. Arpaci-Dusseau, Remzi H. Arpaci-Dusseau. **OSDI '14.**

Performance isolation

Split-level I/O Scheduling For Virtualized Environments.
Suli Yang, Tyler Harter, Nishant Agrawal, Salini Selvaraj Kowsalya, Anand Krishnamurthy, Samer Al-Kiswany, Andrea C. Arpaci-Dusseau,
Remzi H. Arpaci-Dusseau. **SOSP '15.**

File-system provisioning

Slacker: Fast Distribution with Lazy Docker Containers.
Tyler Harter, Brandon Salmon, Rose Liu,
Andrea C. Arpaci-Dusseau, Remzi H. Arpaci-Dusseau. **FAST '16.**

today

Slacker Outline

Background

- Containers: lightweight isolation
- Docker: file-system provisioning

Container Workloads

Default Driver: AUFS

Our Driver: Slacker

Evaluation

Conclusion

Docker Background

Deployment tool built on containers

An application is defined by a file-system image

- application binary
- shared libraries
- etc.

Version-control model

- **extend** images by committing additional files
- **deploy** applications by pushing/pulling images

Containers as Repos

LAMP stack example

- commit 1: **L**inux packages (e.g., Ubuntu)
- commit 2: **A**pache
- commit 3: **M**ySQL
- commit 4: **P**HP

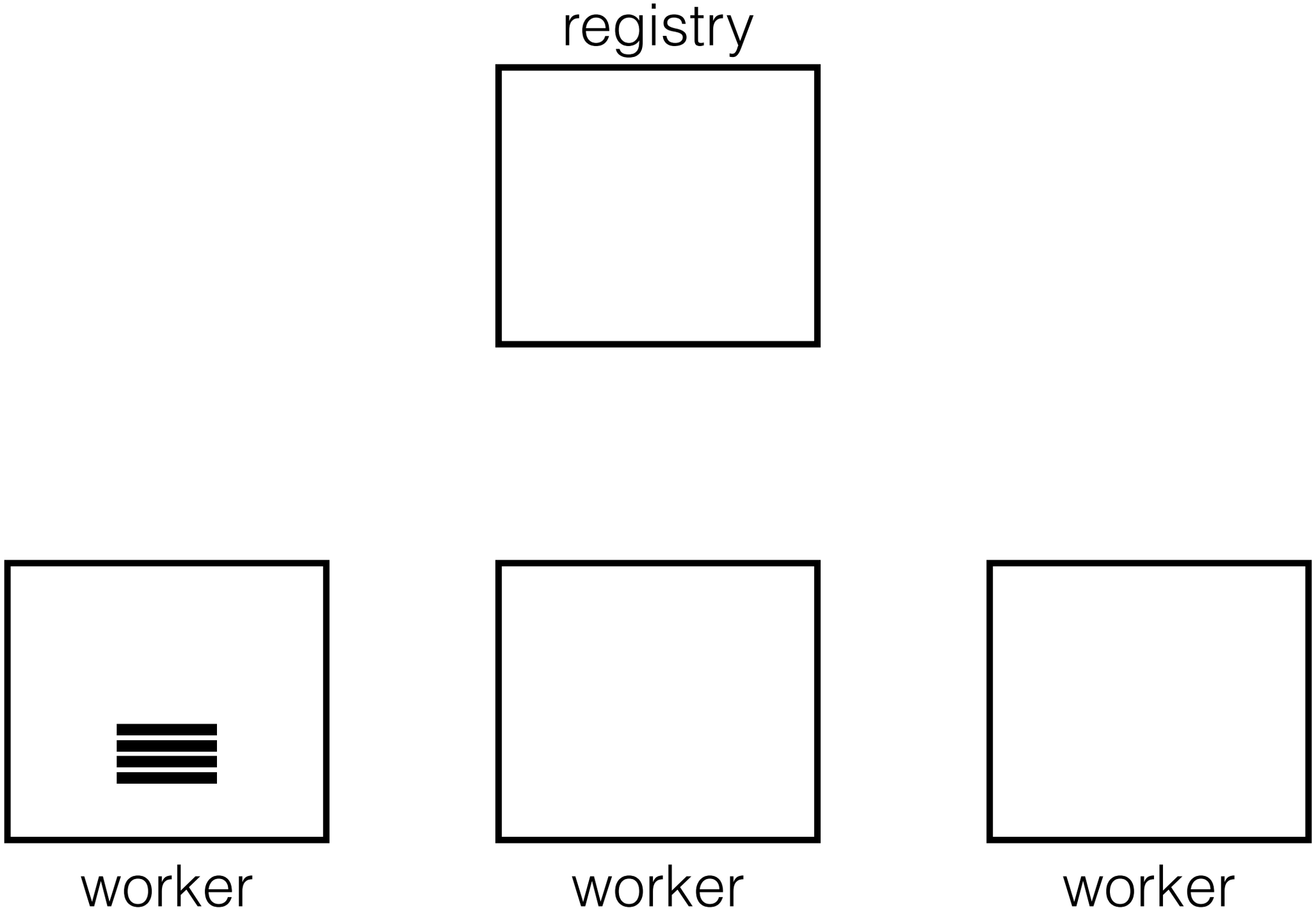
Central registries

- Docker HUB
- private registries

Docker “layer”

- commit
- container scratch space

Push, Pull, Run



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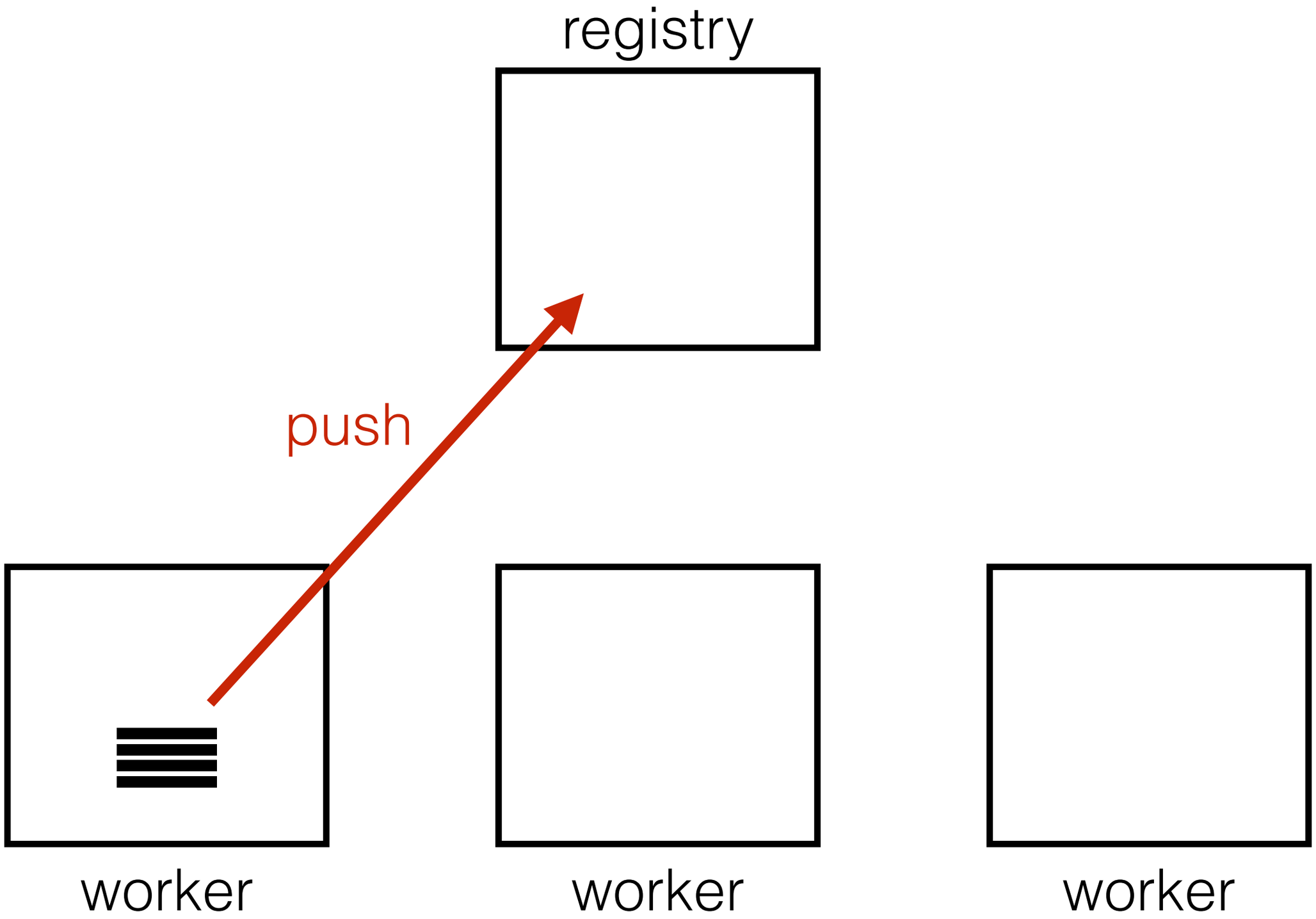

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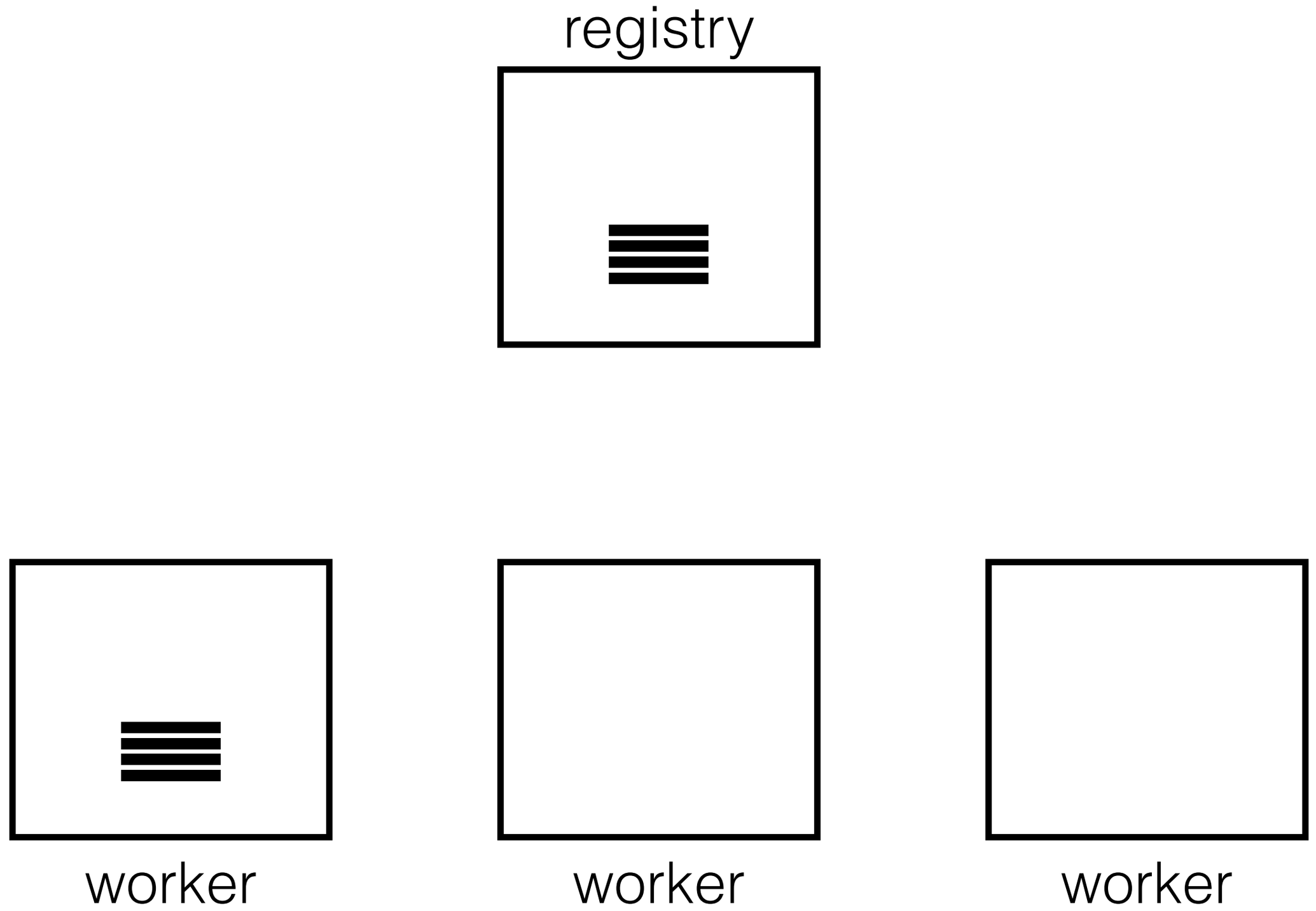

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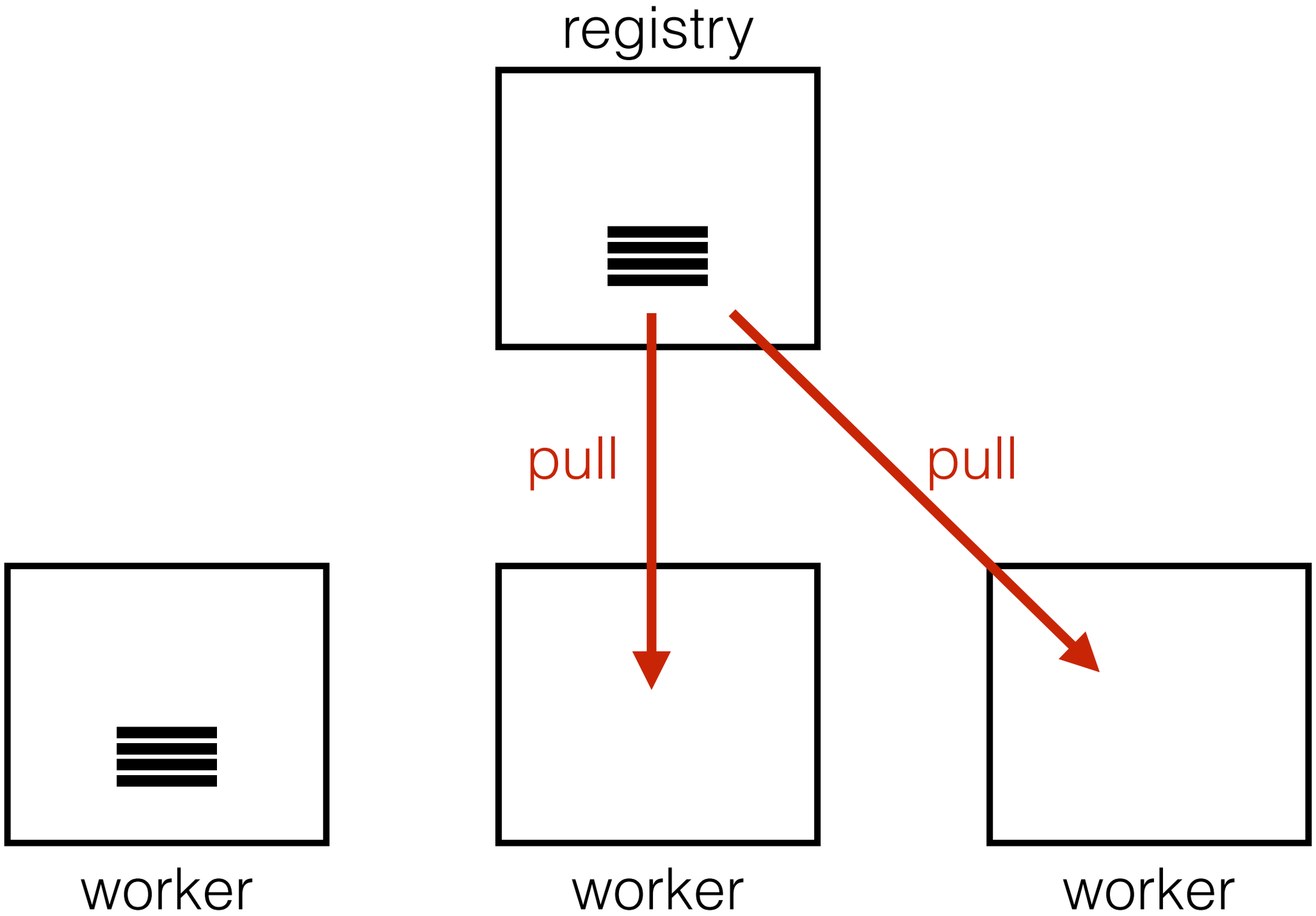

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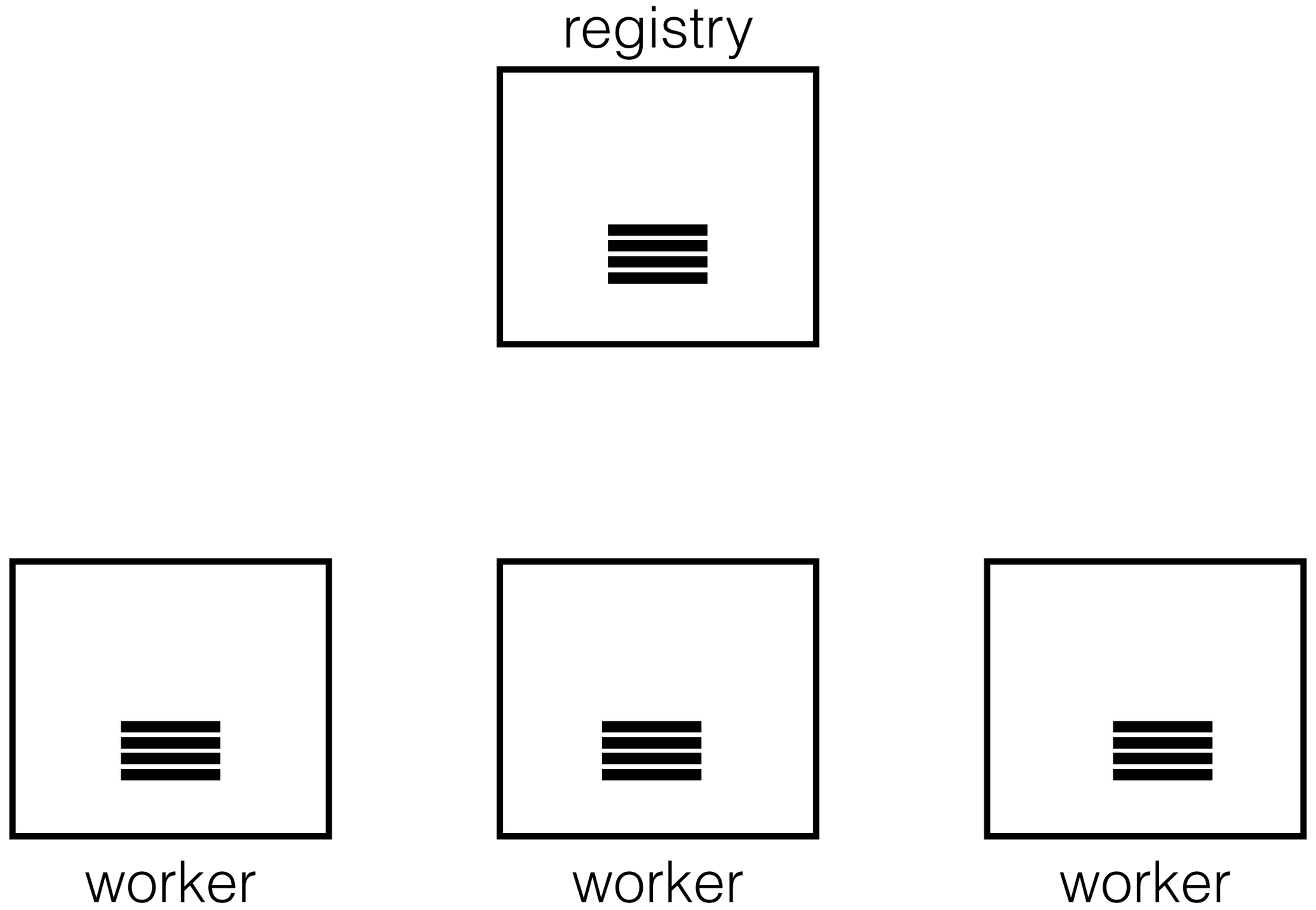

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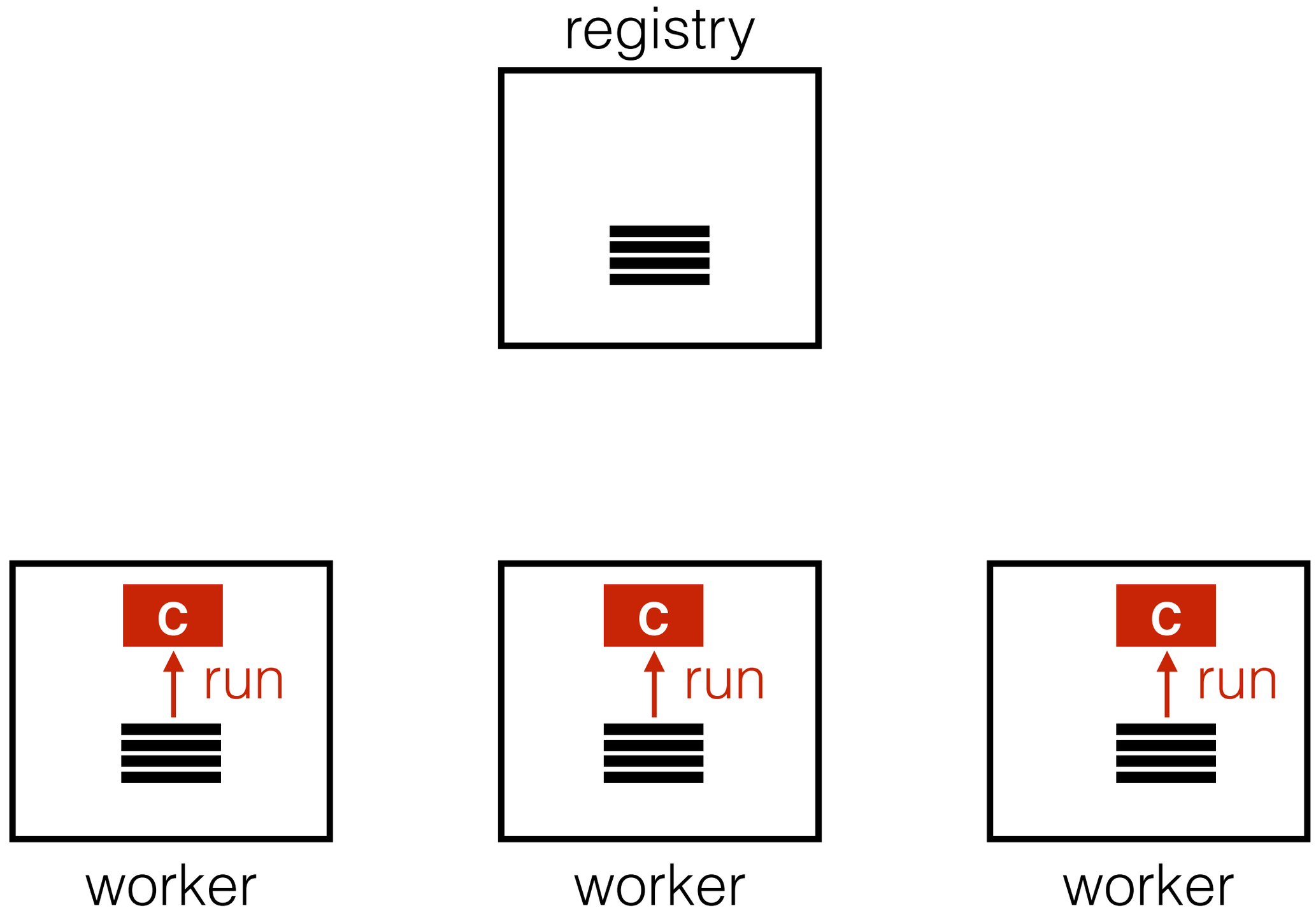

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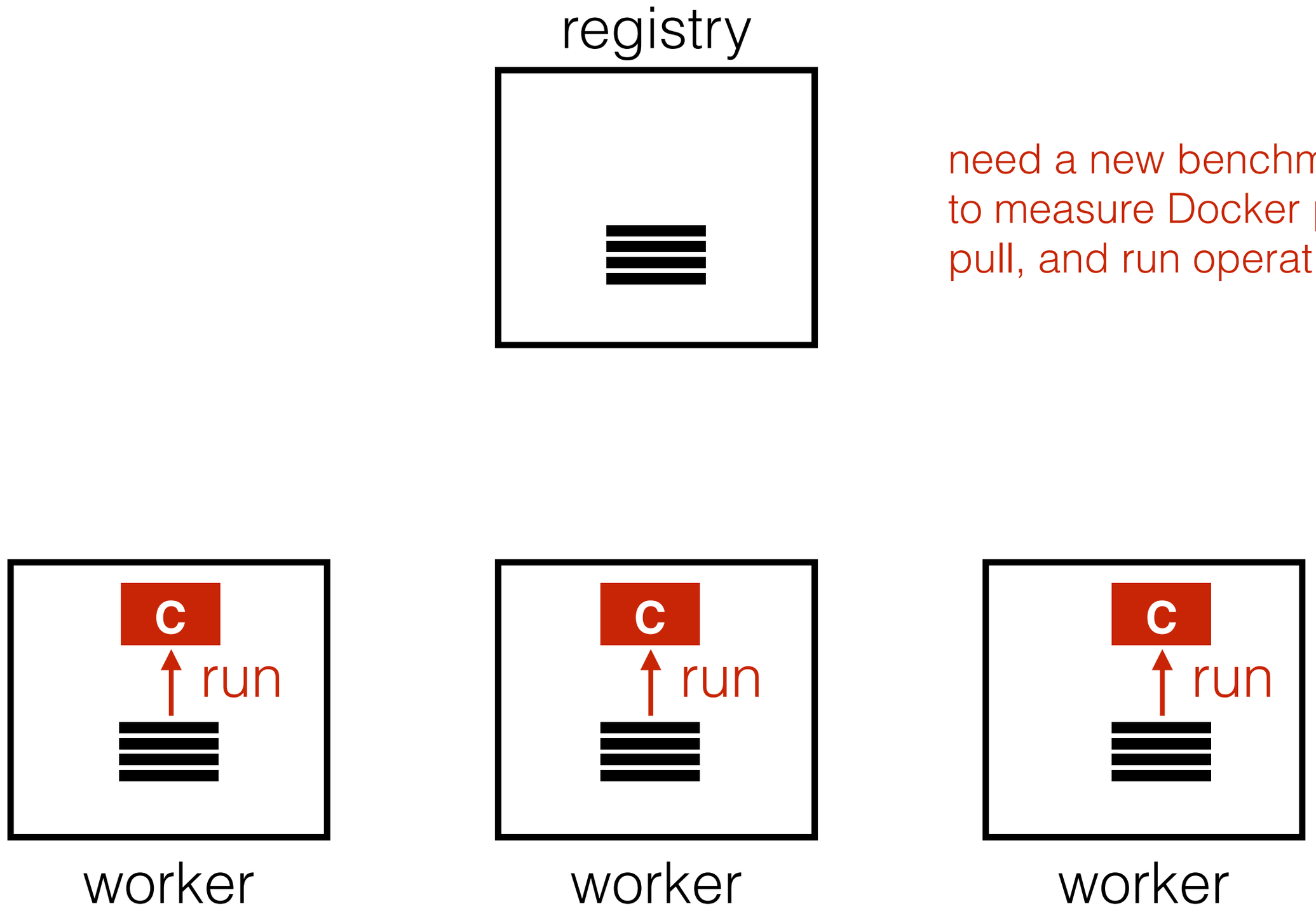

need a new benchmark
to measure Docker push,
pull, and run operations.

Slacker Outline

Background

Container Workloads

- HelloBench
- Analysis

Default Driver: AUFS

Our Driver: Slacker

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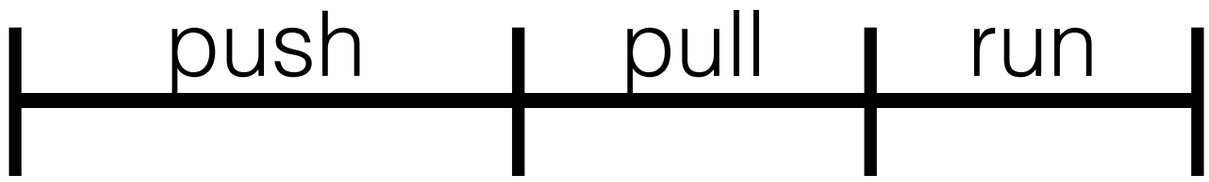
HelloBench

Goal: stress container startup

- including push/pull
- **57 container images** from Docker HUB
- run simple “hello world”-like task
- wait until it’s done/ready



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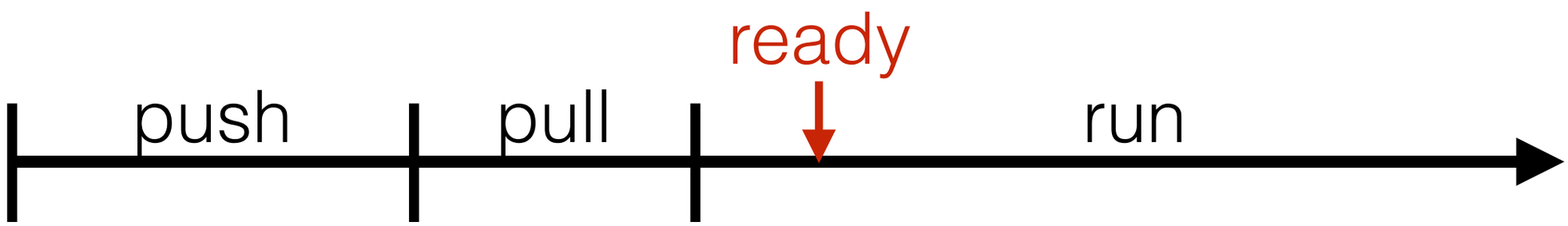

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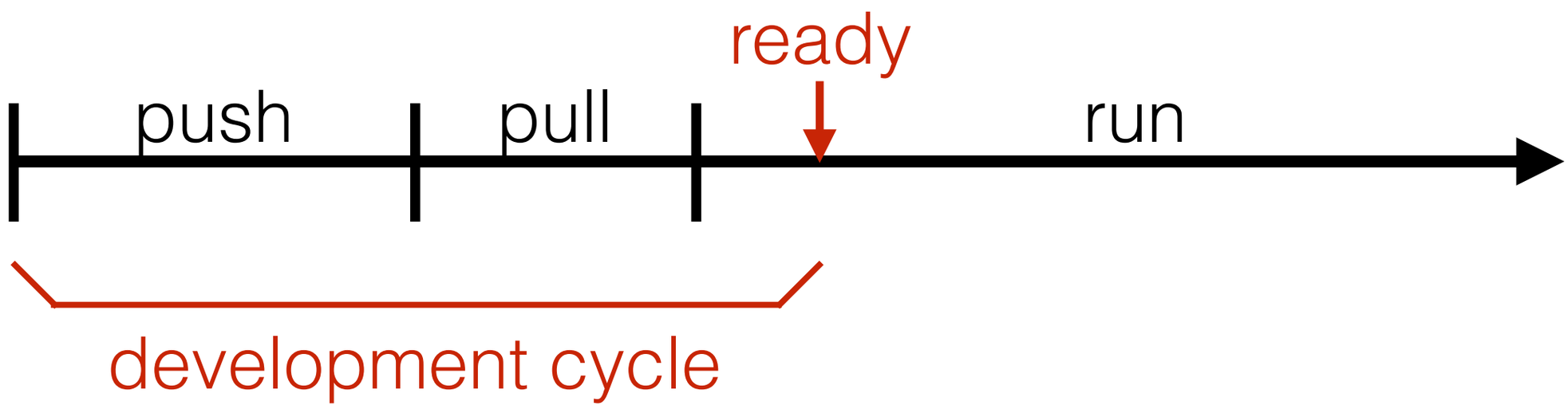

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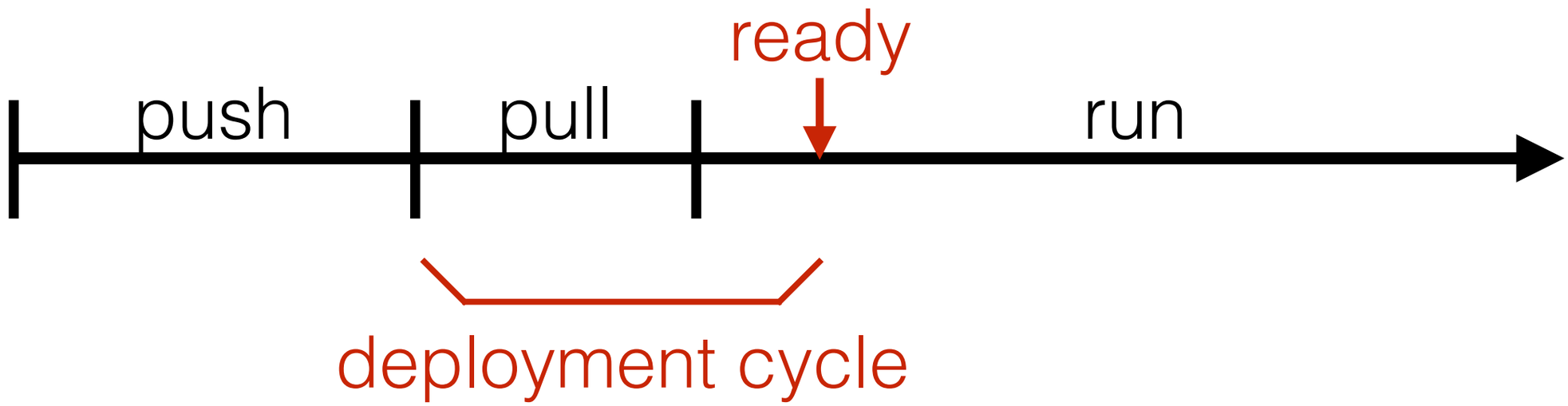
Deployment cycle

- flash crowds, rebalance



Workload Categories

Language
clojure
gcc
golang
haskell
hylang
java
jruby
julia
mono
perl
php
pypy
python
r-base
rakudo-star
ruby
thrift

Linux Distro
alpine
busybox
centos
cirros
crux
debian
fedora
mageia
opensuse
oraclelinux
ubuntu
ubuntu-debootstrap
ubuntu-upstart

Database
cassandra
crate
elasticsearch
mariadb
mongo
mysql
percona
postgres
redis
rethinkdb

Web Framework
django
iojs
node
rails

Web Server
glassfish
httpd
jetty
nginx
php-zendserver
tomcat

Other
drupal
ghost
hello-world
jenkins
rabbitmq
registry
sonarqube

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How is data distributed across Docker layers?

How much image data is needed for container startup?

How similar are reads between runs?

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HelloBench images

- **circle**: commit
- **red**: image

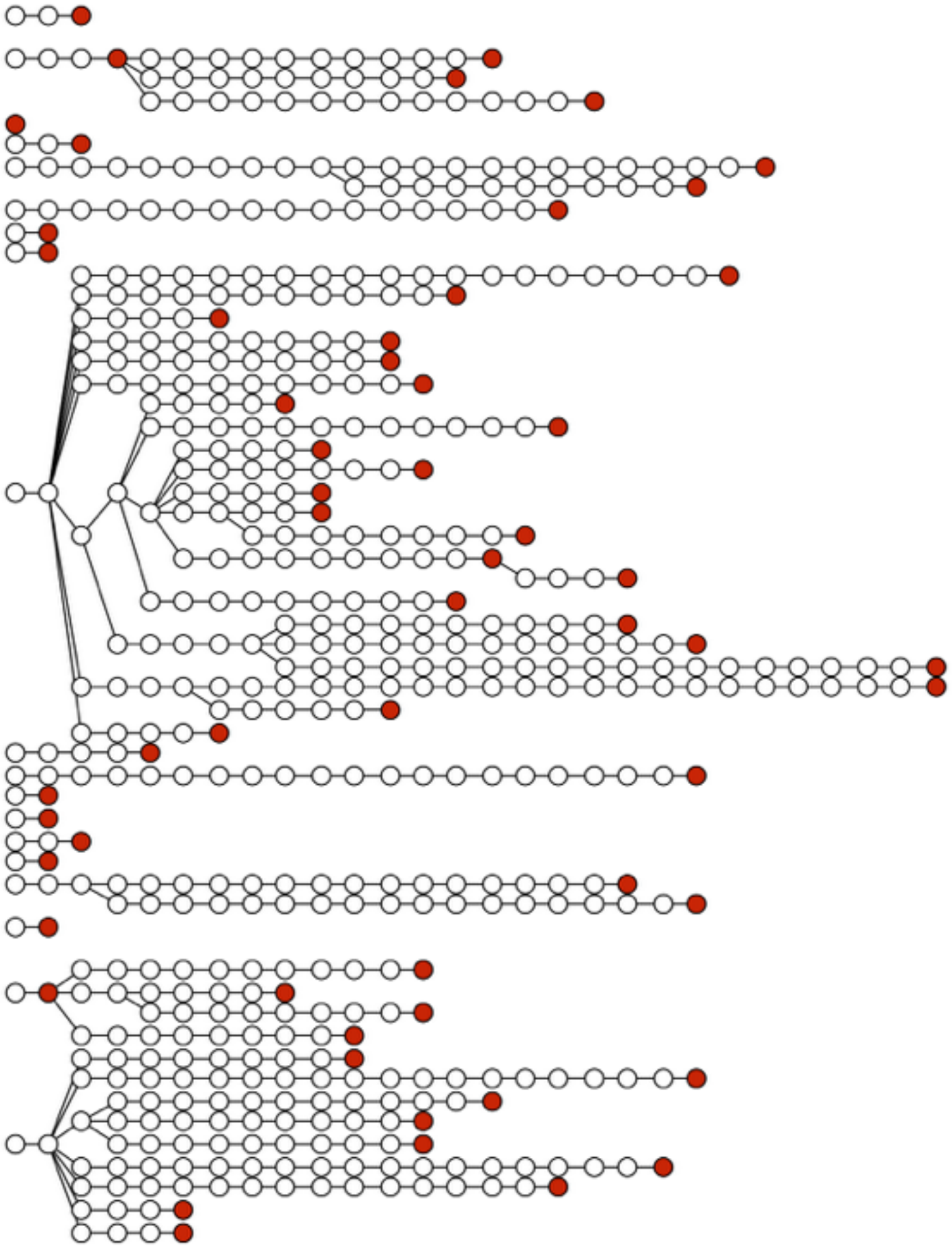
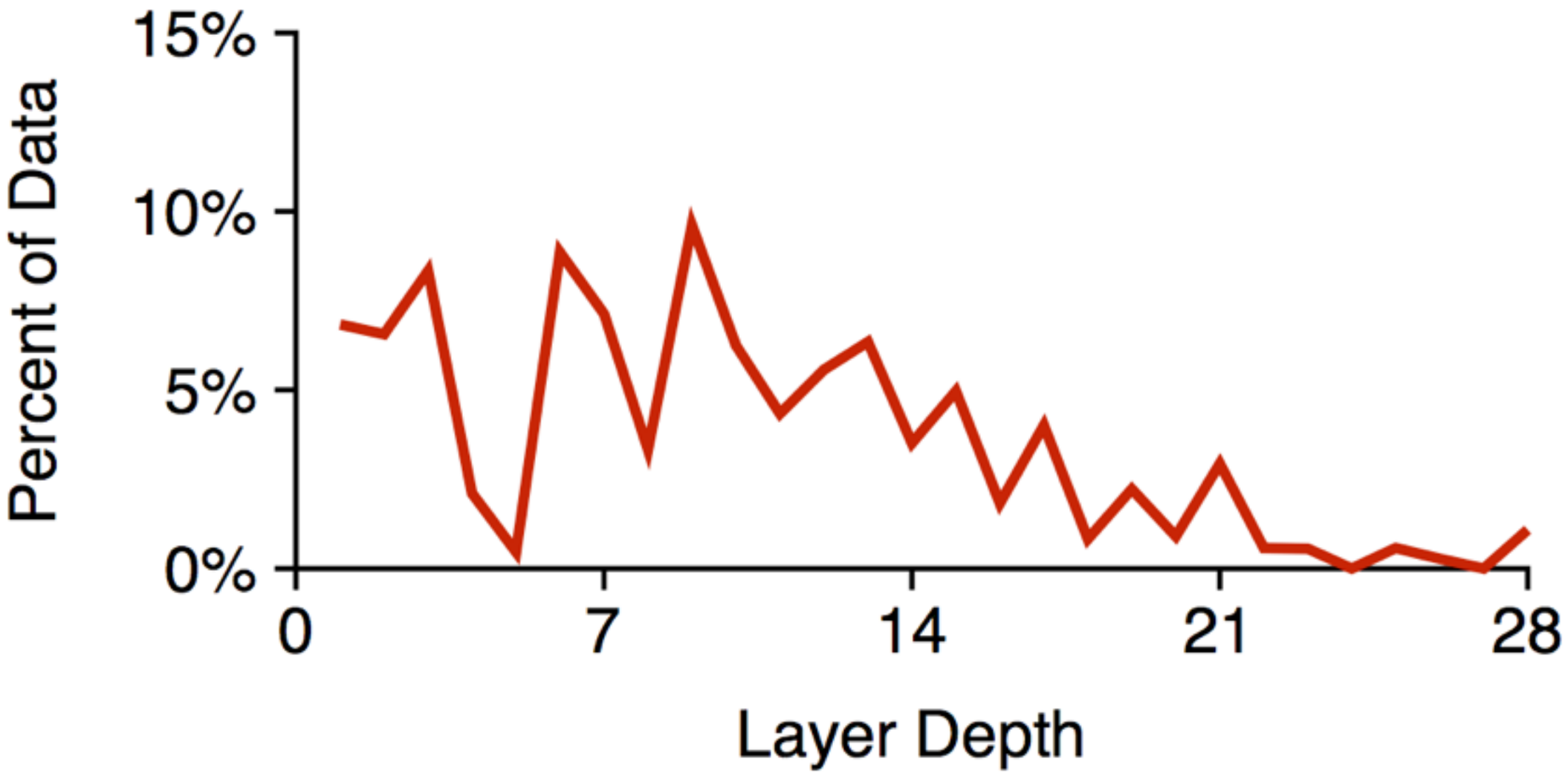


Image Data Depth



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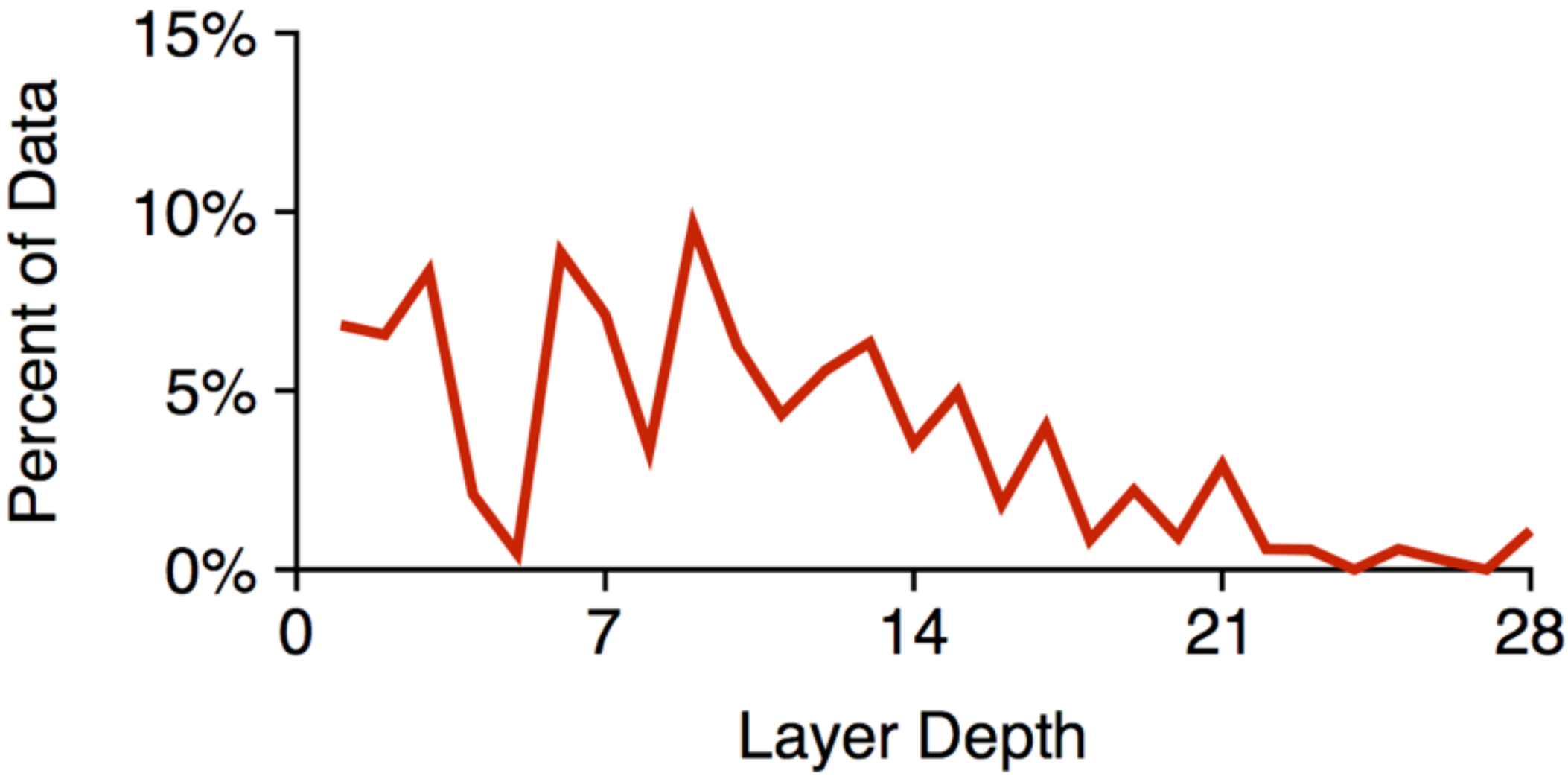

half of data is at depth 9+

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- **design implication**: flatten layers at runtime

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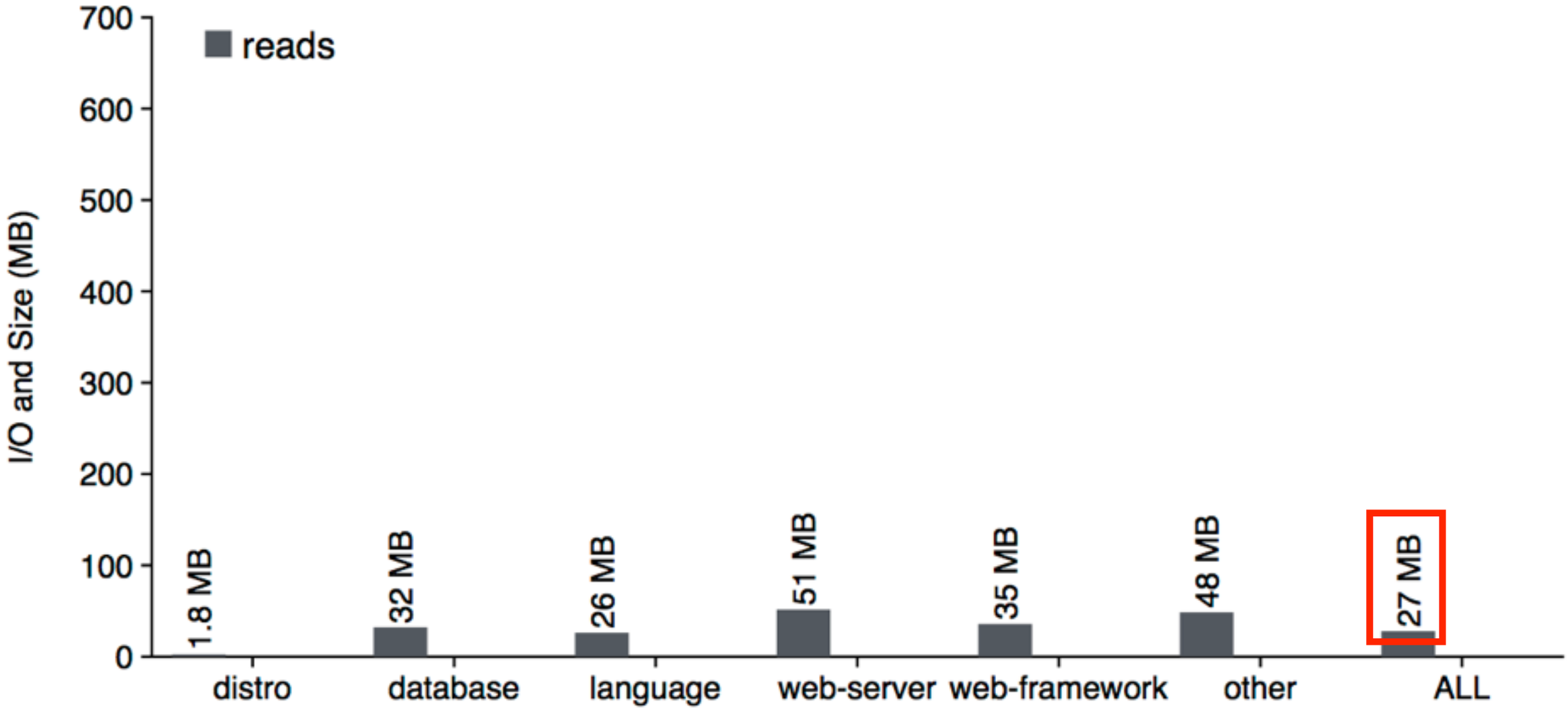

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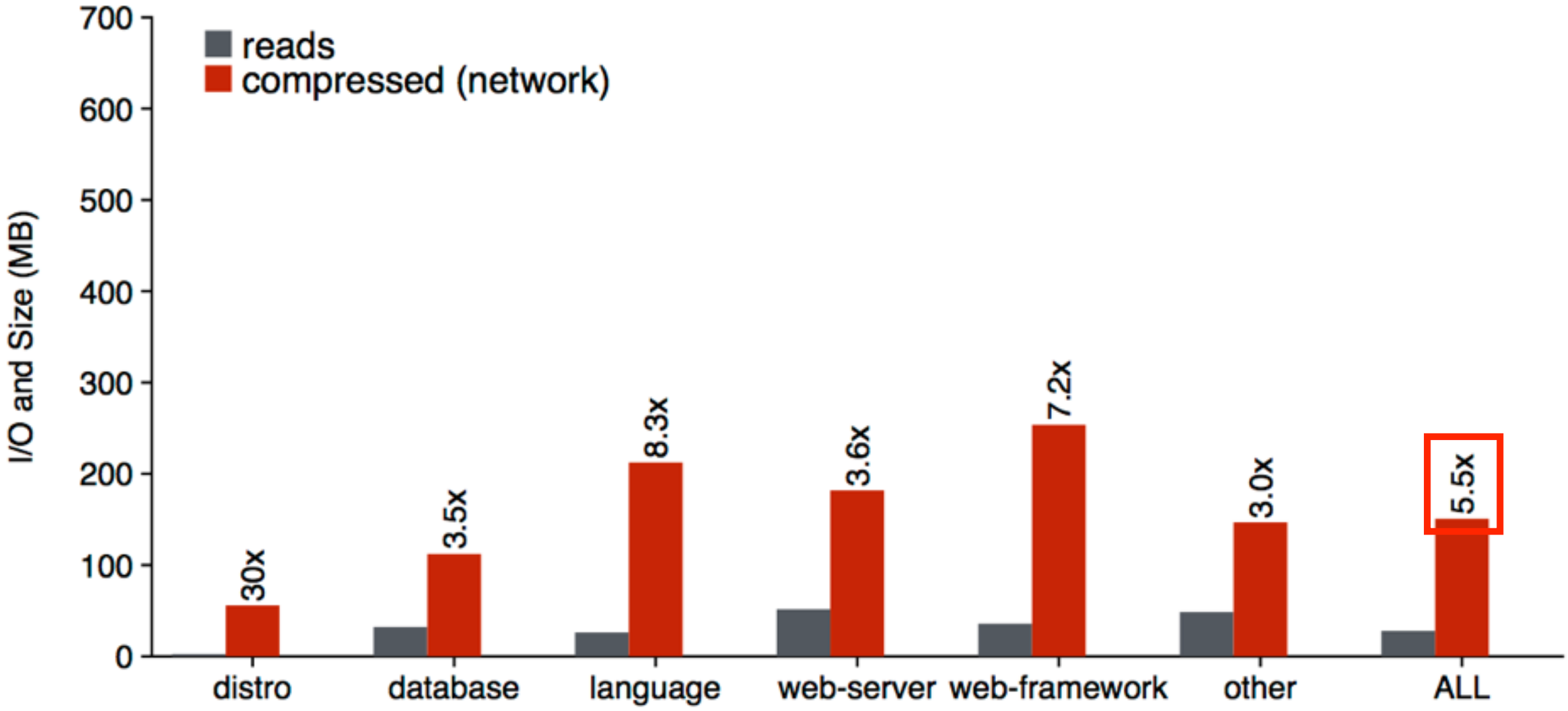

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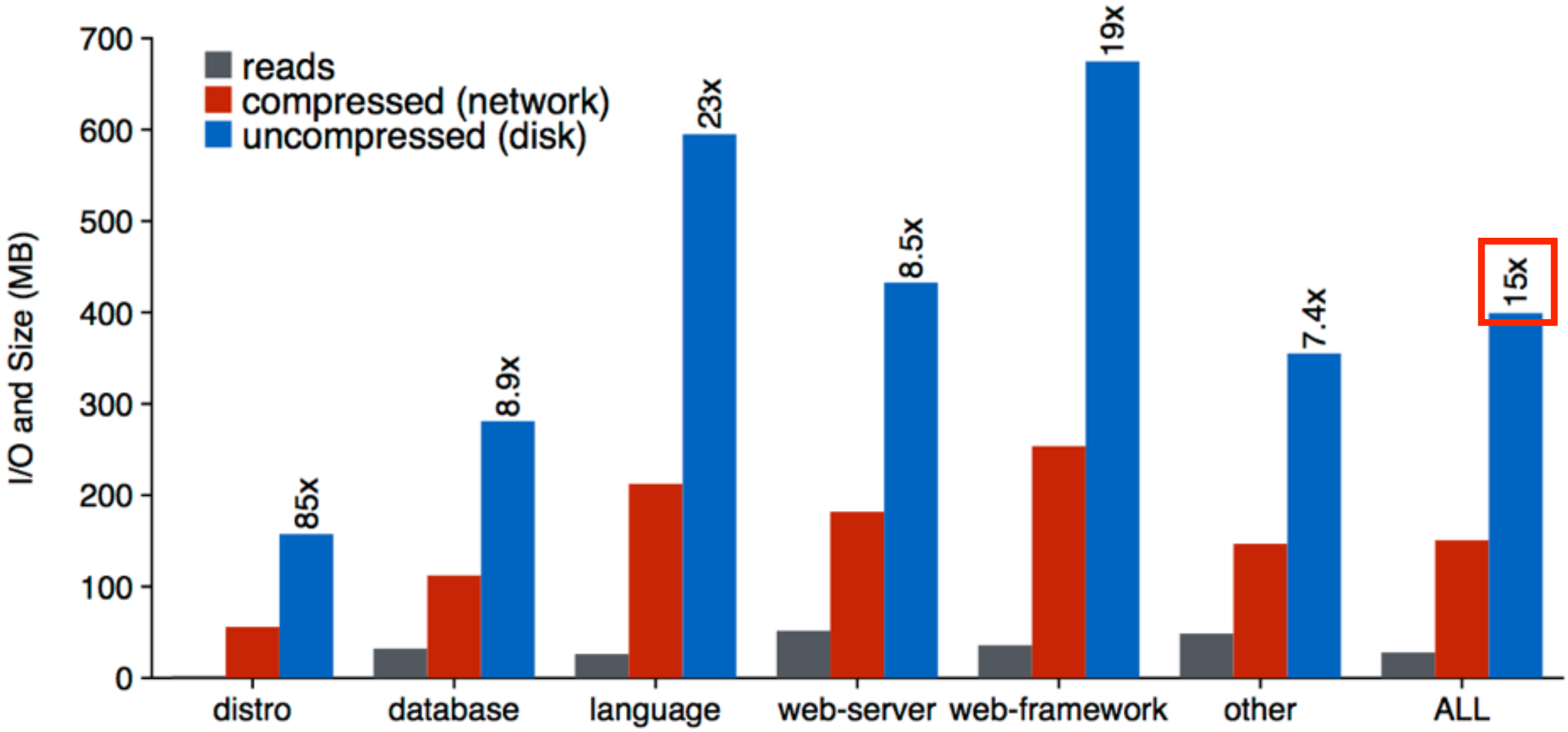

only 6.4% of data needed during startup

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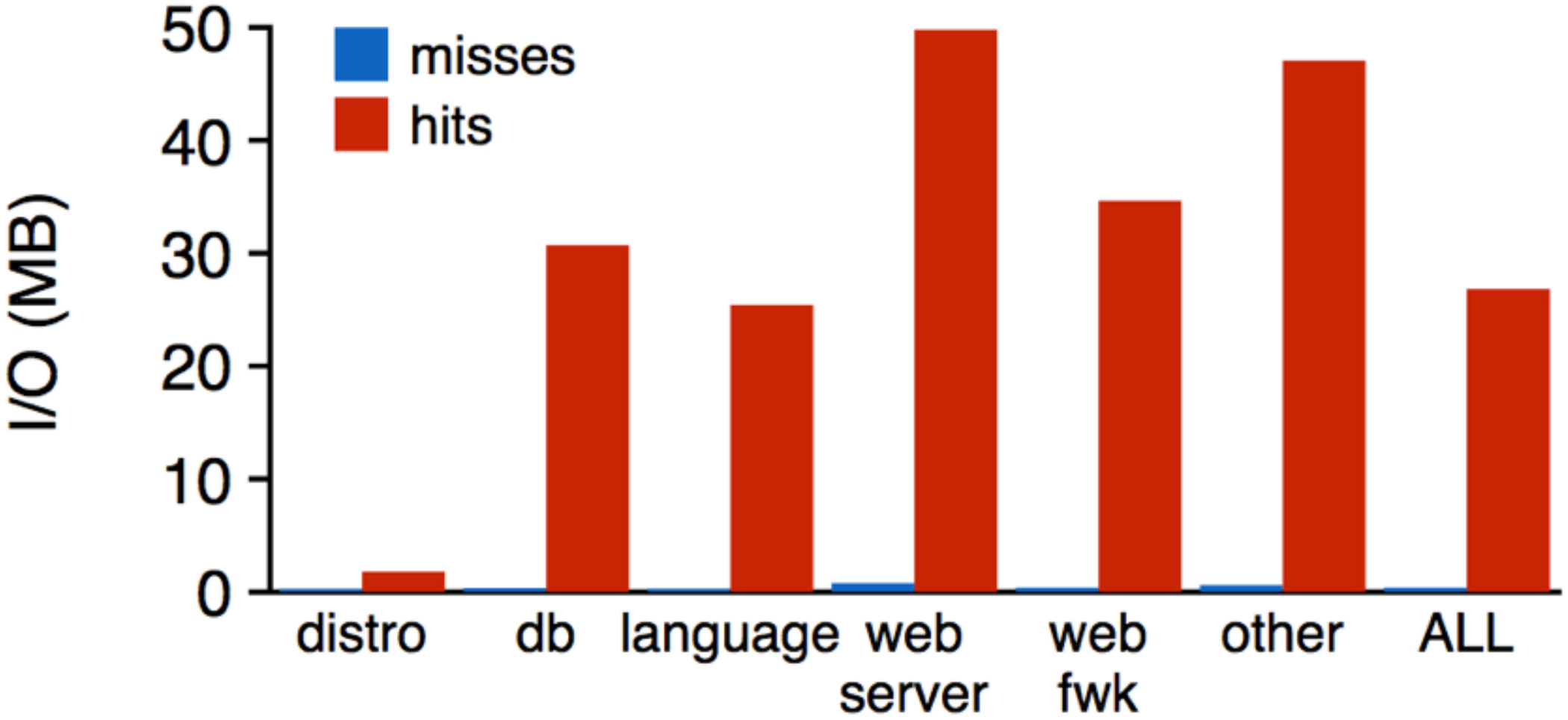
Repeat Runs

measure hits/misses for second of two runs



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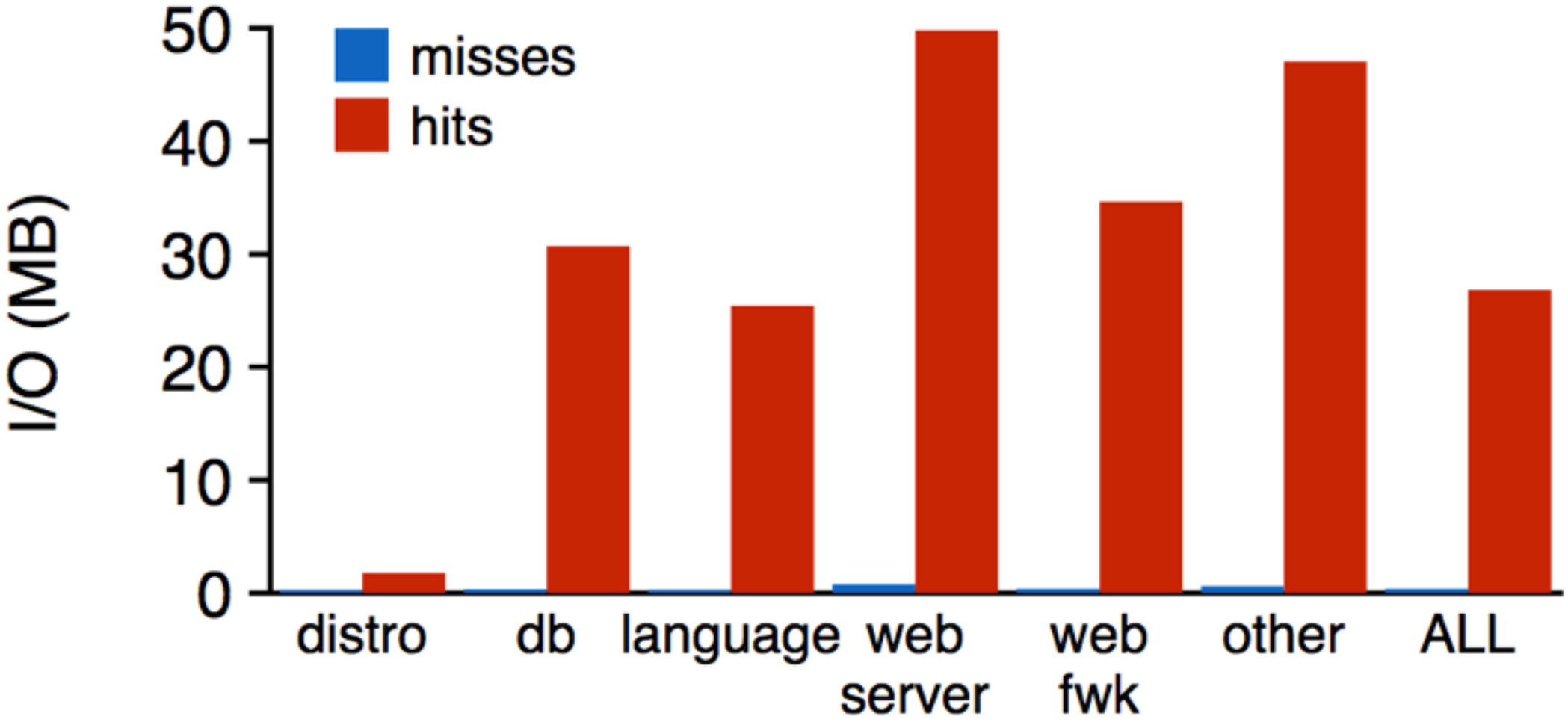

up to 99% of reads could be serviced by a cache

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How similar are reads between runs?

- containers from same image have similar read patterns
- **design implication**: share cache state between containers

Slacker Outline

Background

Container Workloads

Default Driver: AUFS

- Design
- Performance

Our Driver: Slacker

Evaluation

Conclusion

AUFS Storage Driver

Uses AUFS file system (Another Union FS)

- stores data in an underlying FS (e.g., ext4)
- layer ⇒ directory in underlying FS
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Operations

- push
- pull
- run

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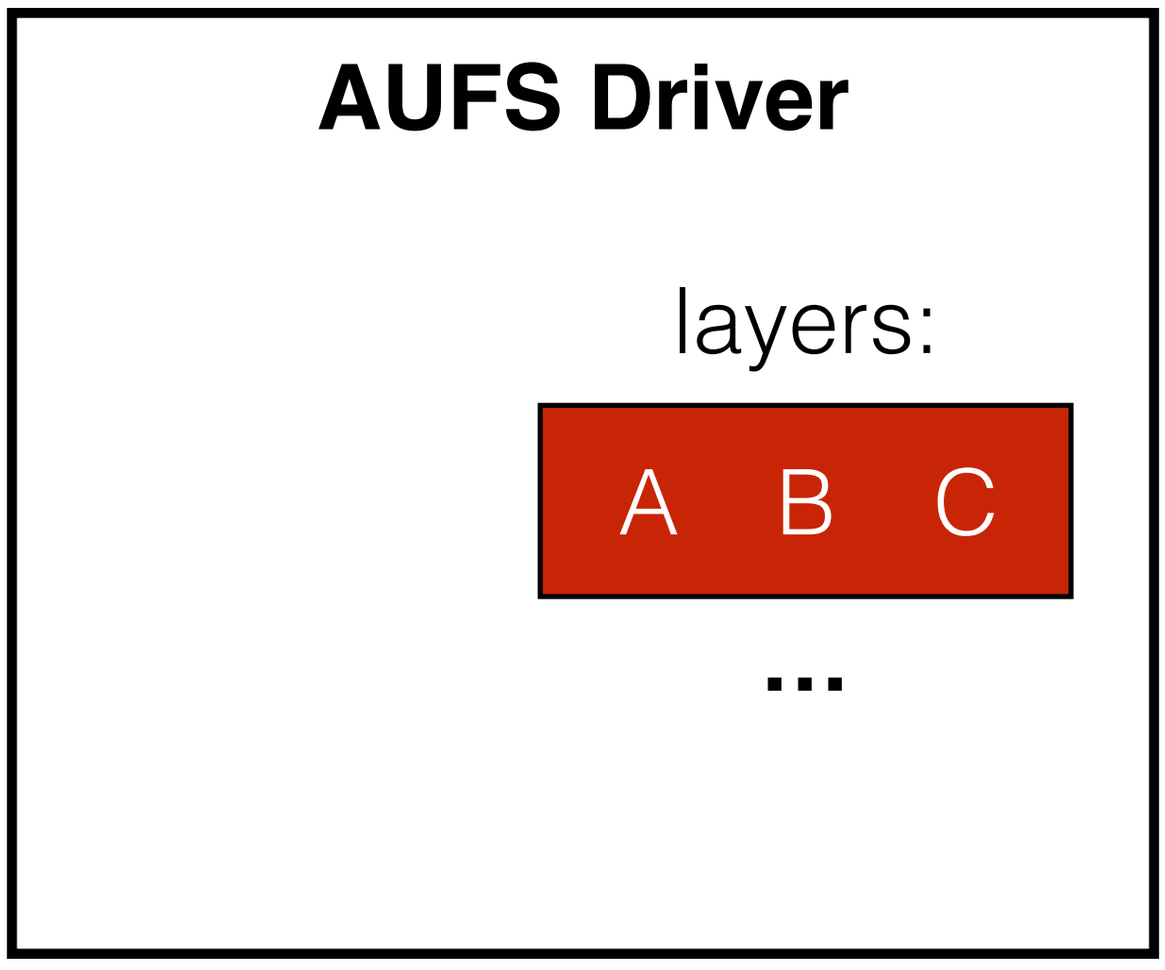

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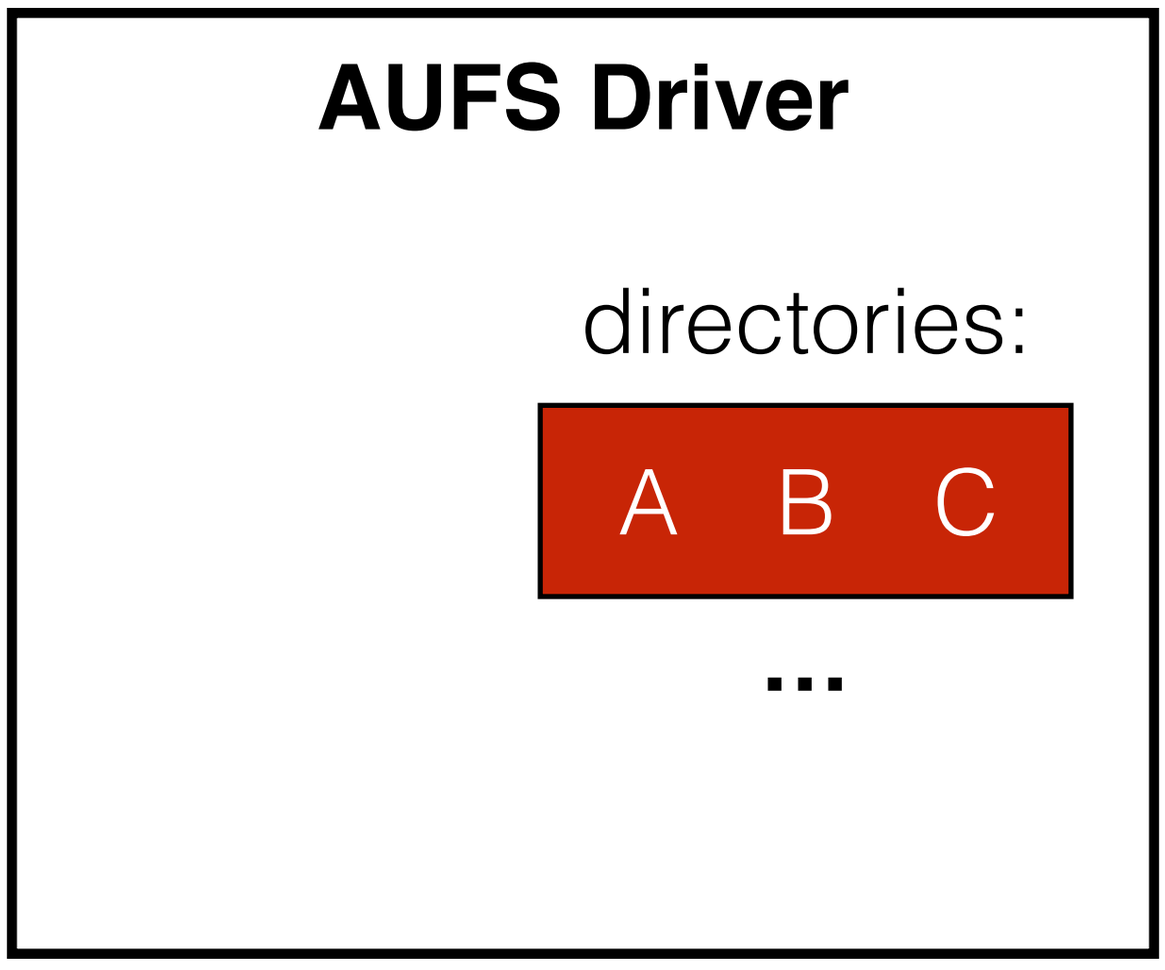

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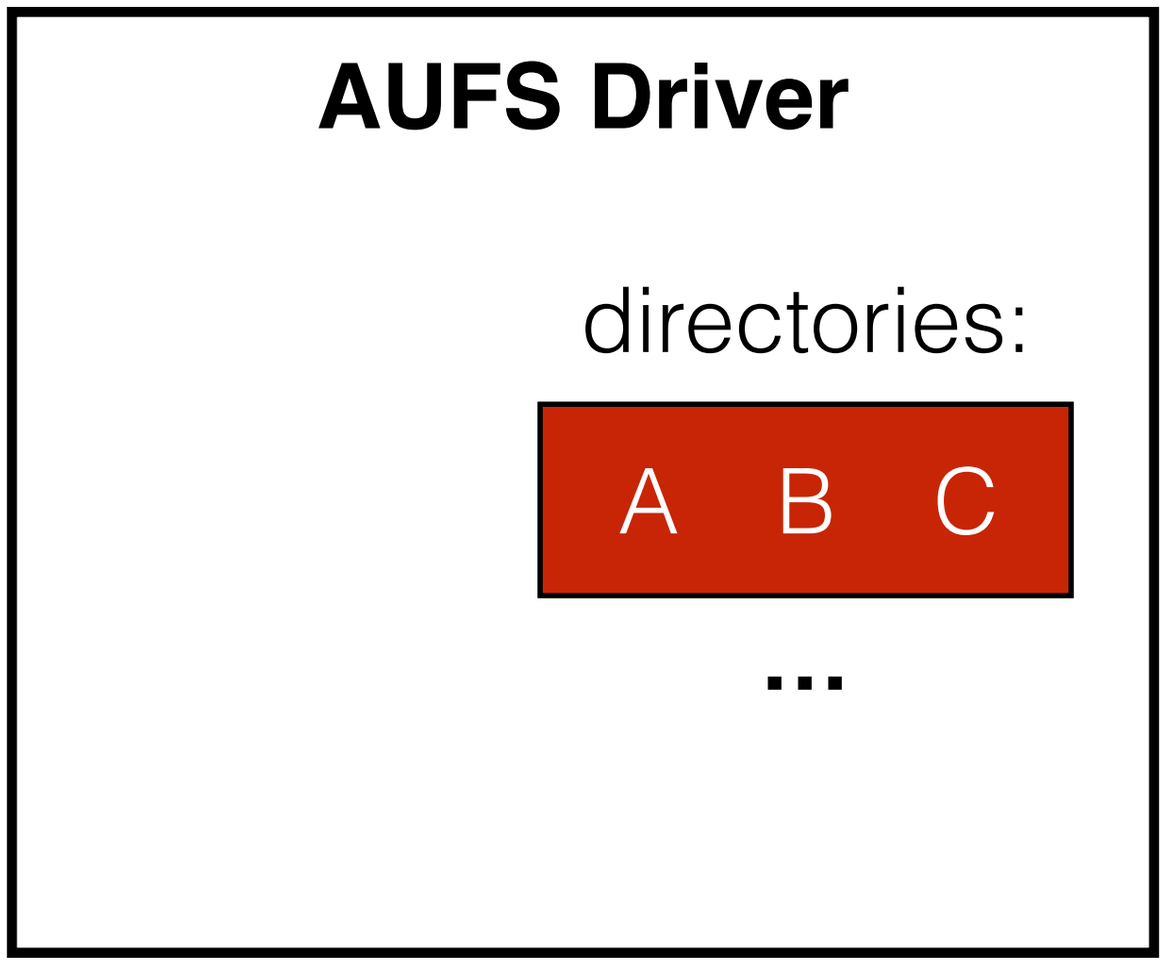

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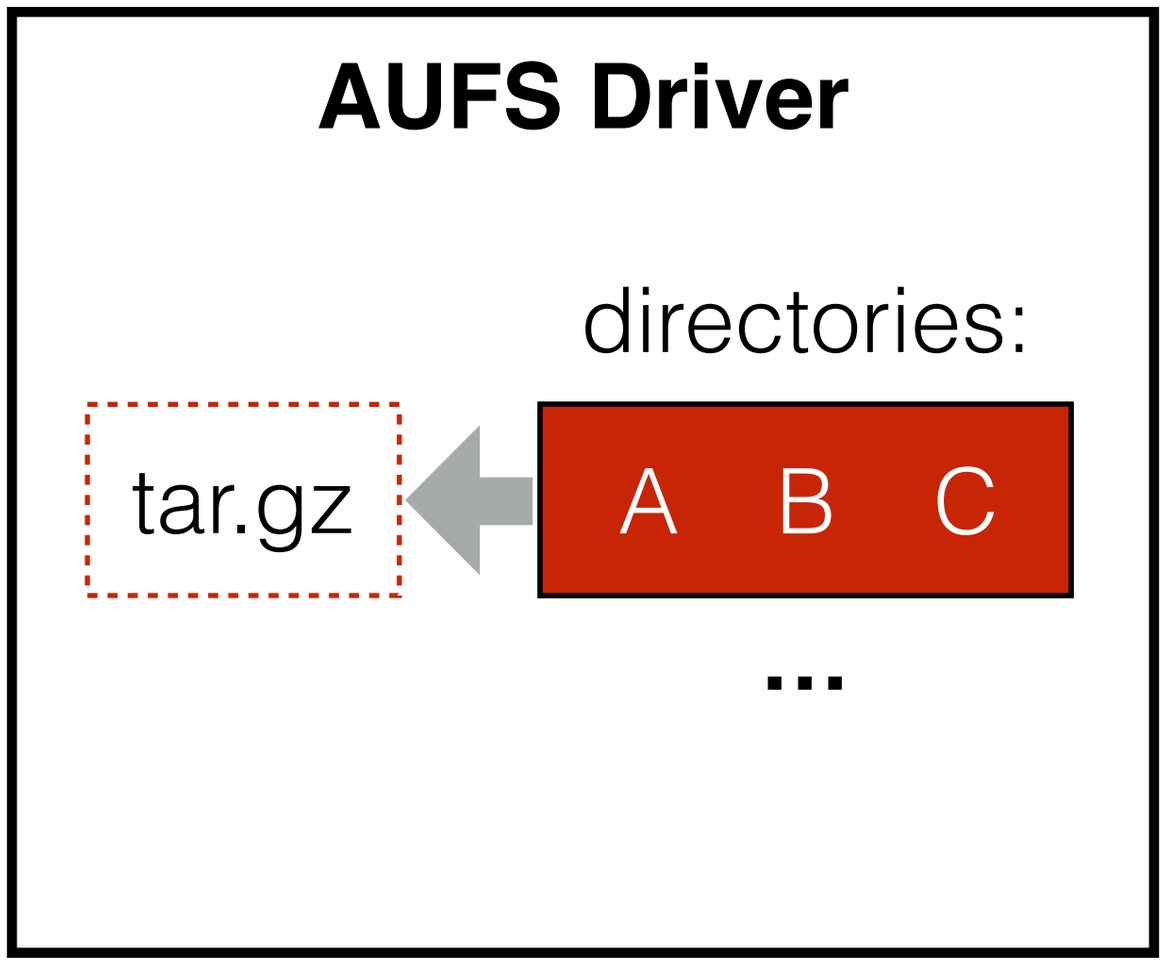

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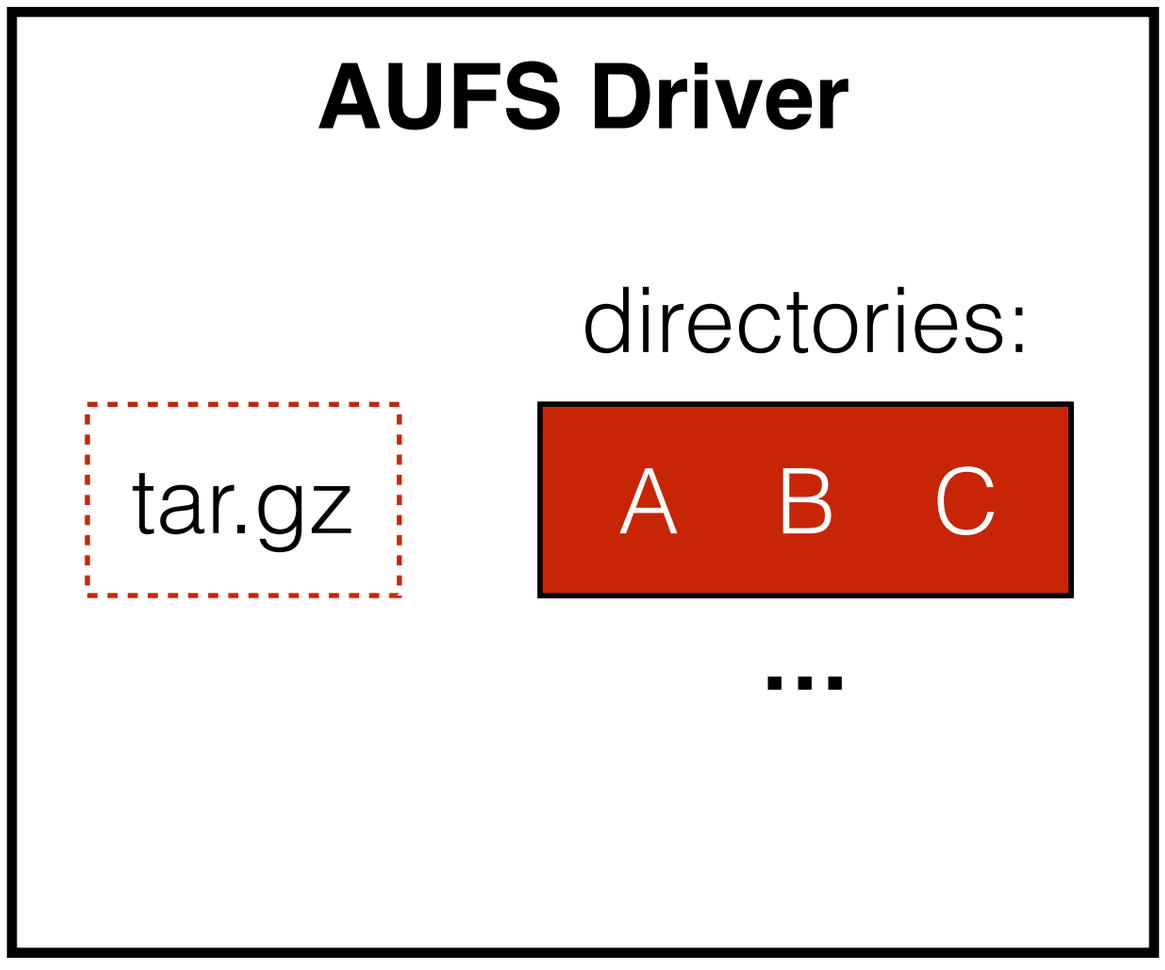

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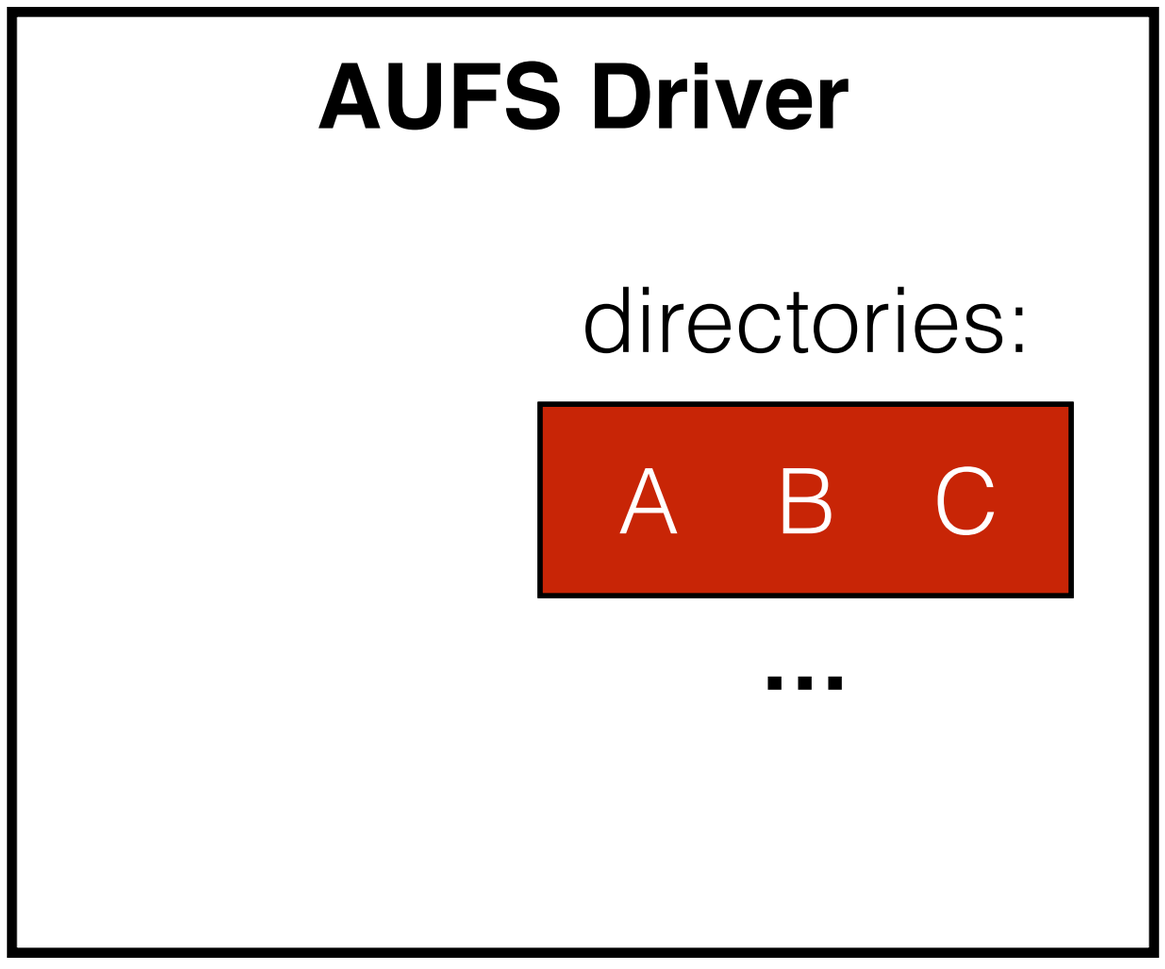

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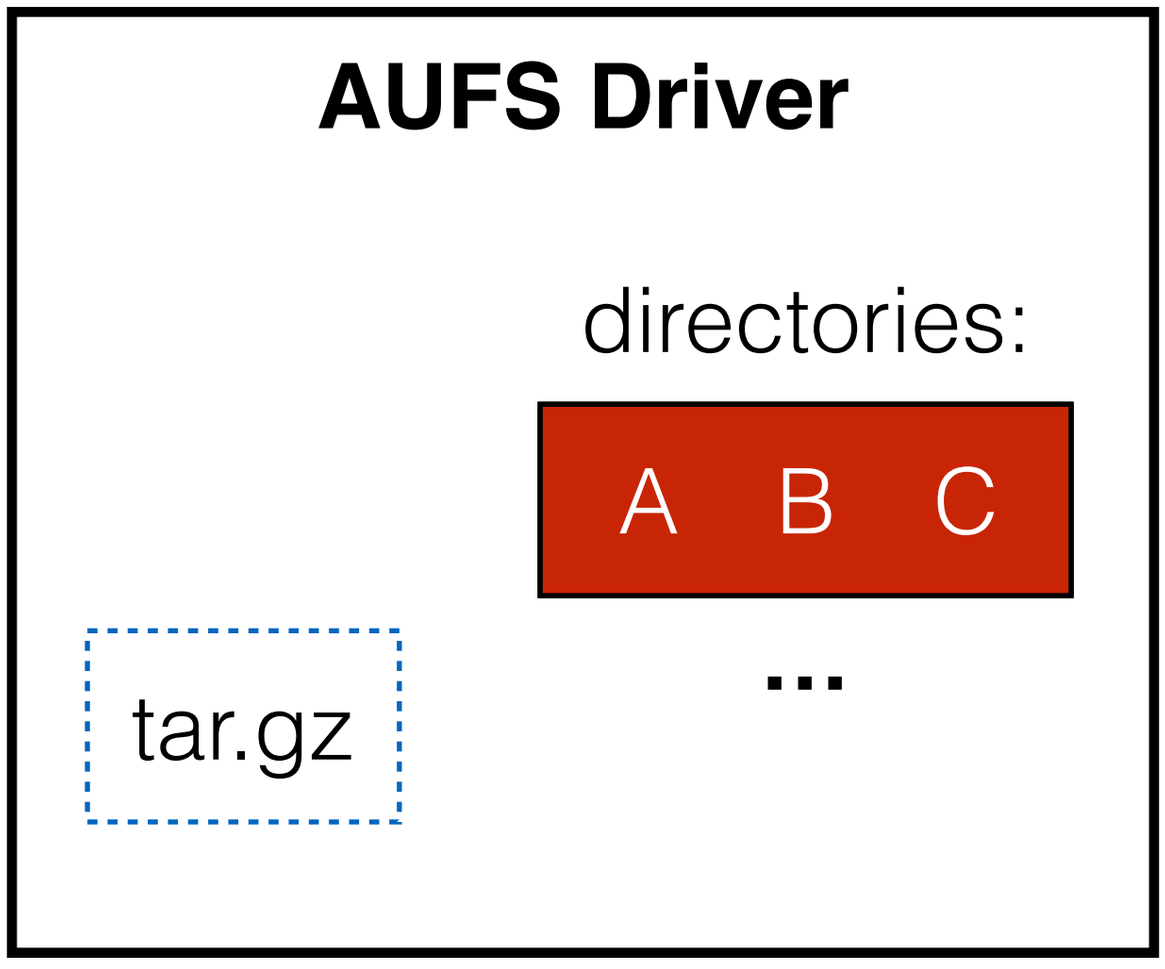

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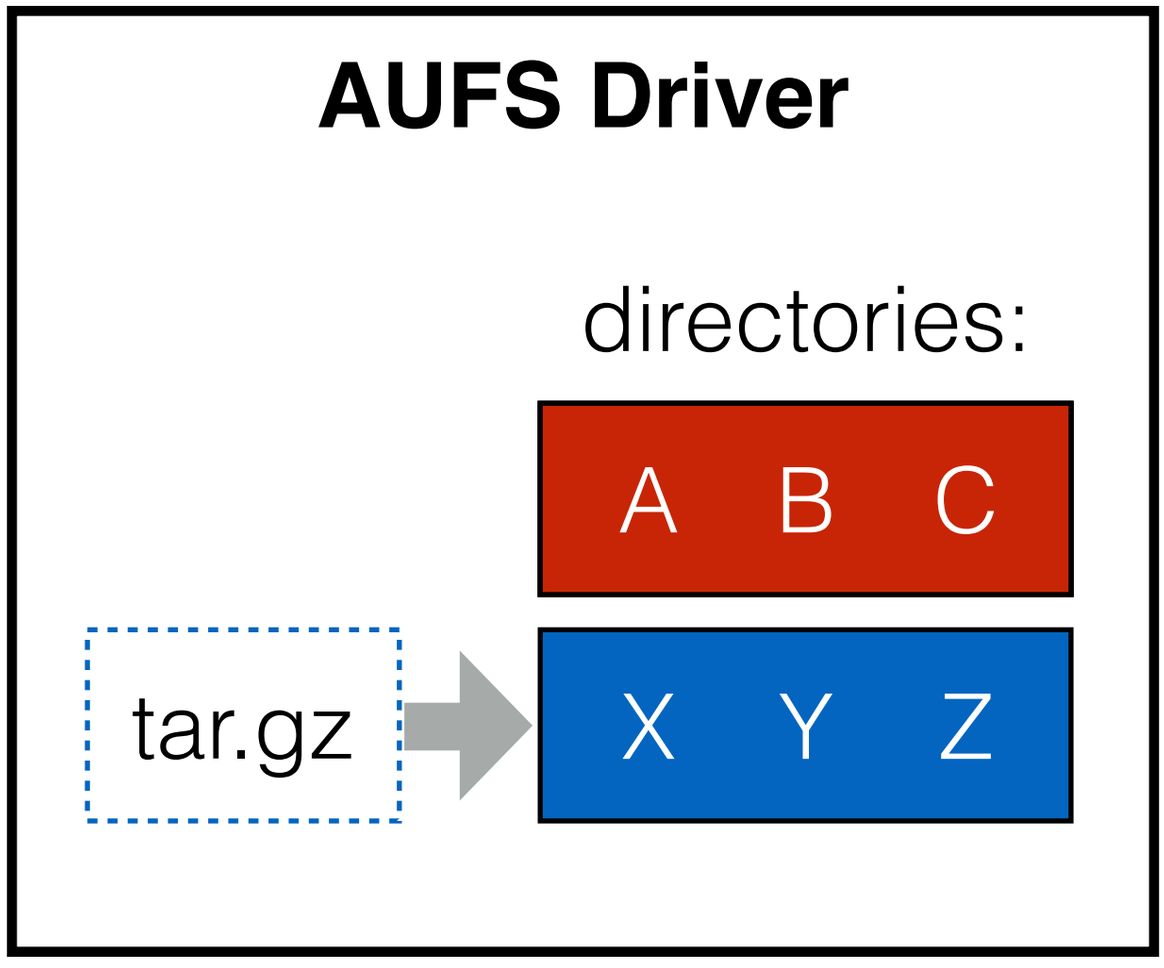

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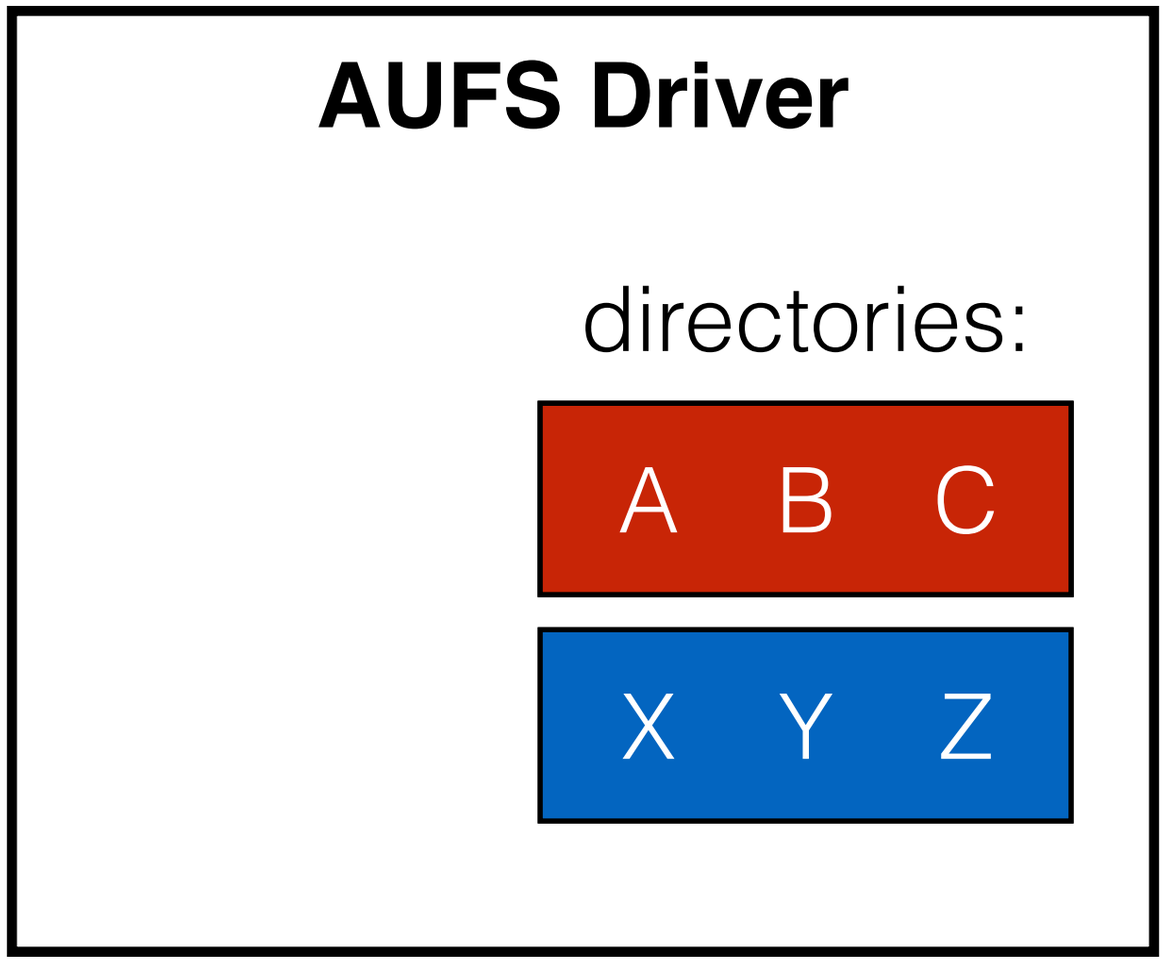

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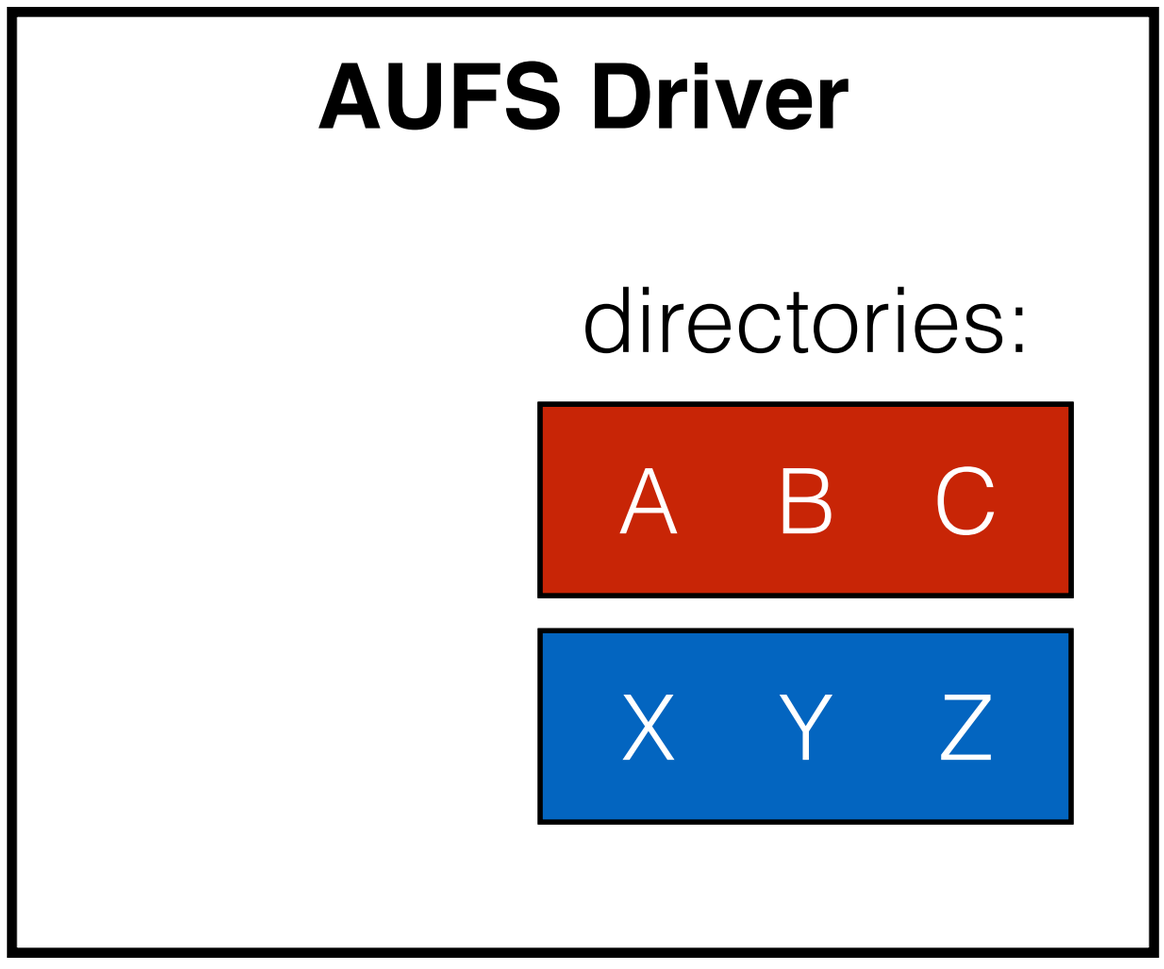

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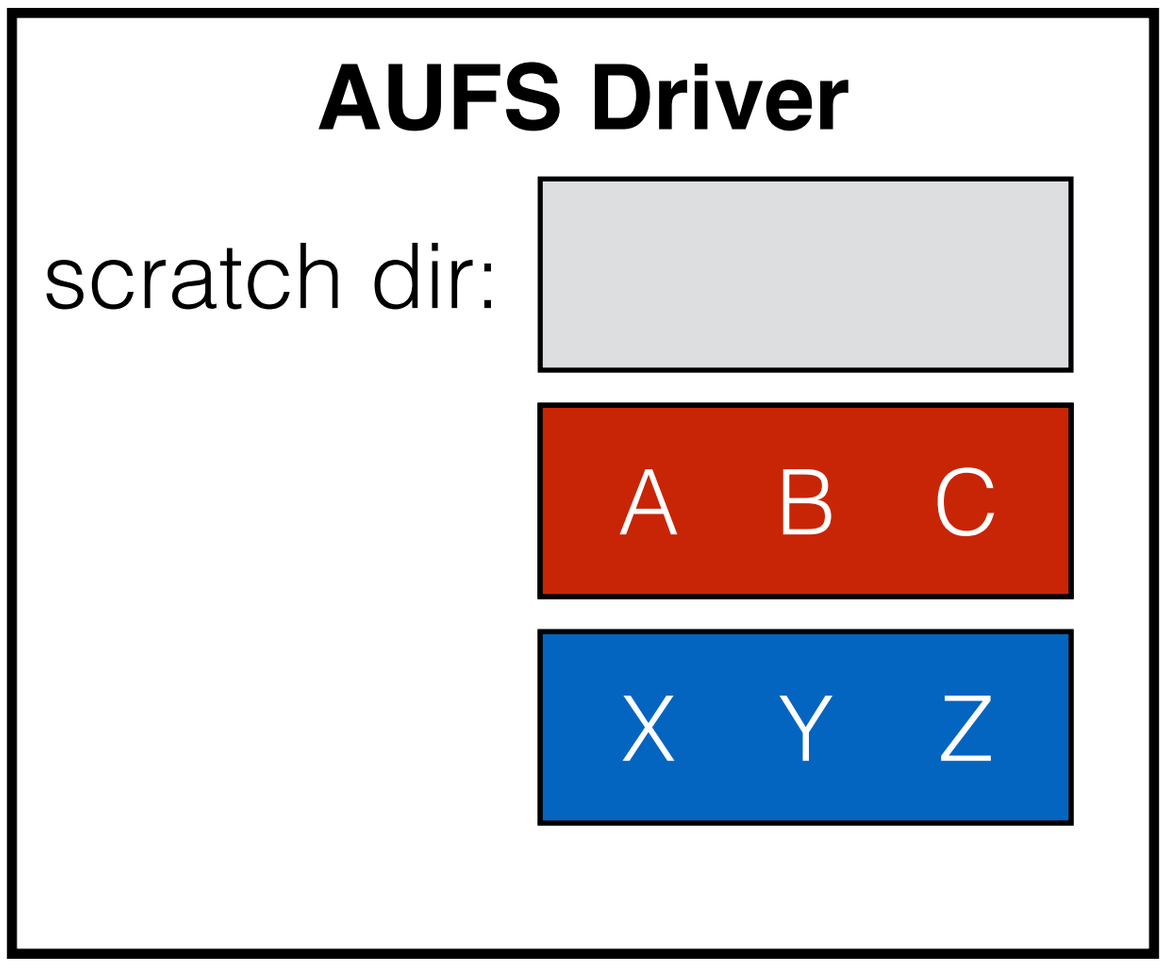

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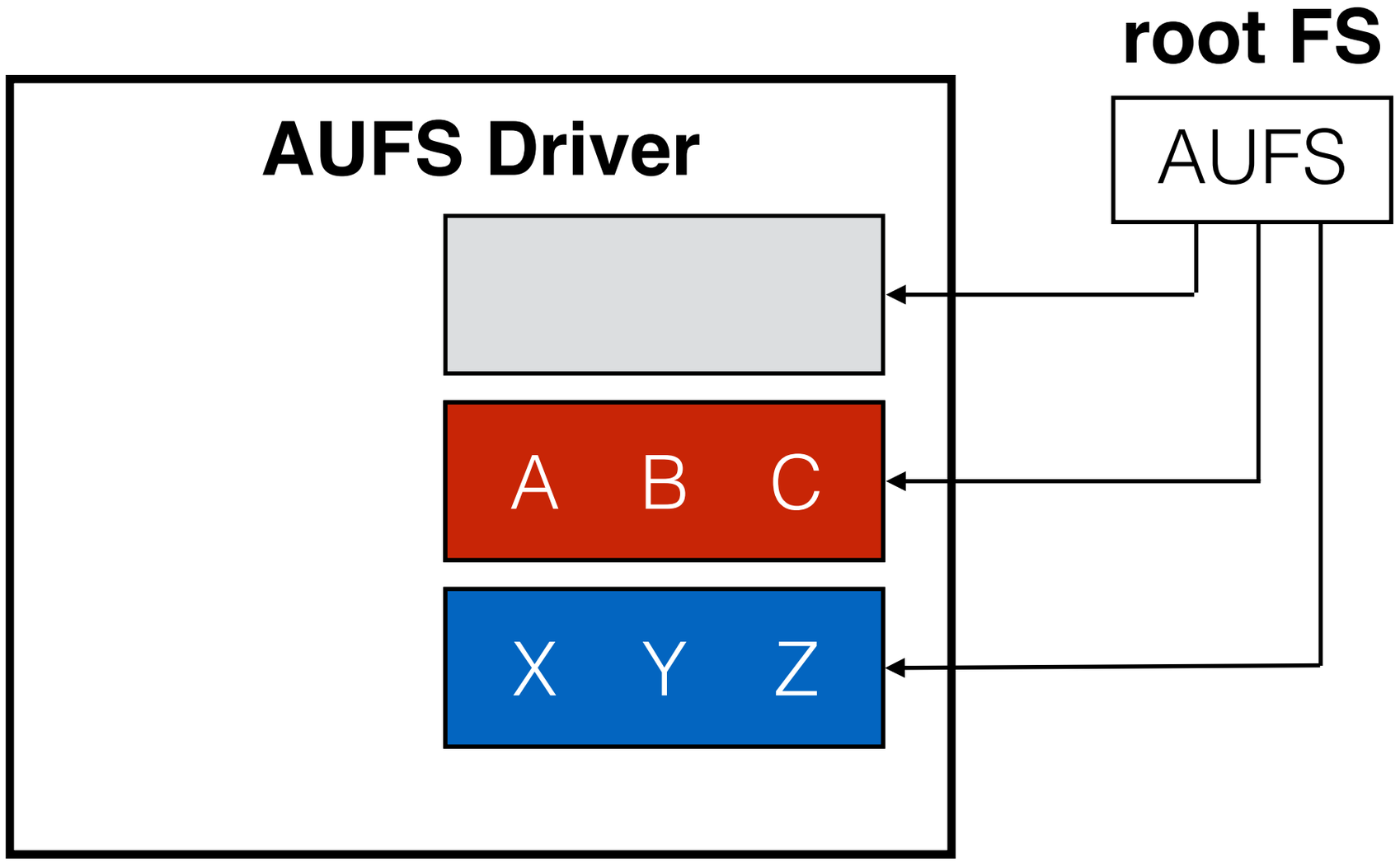

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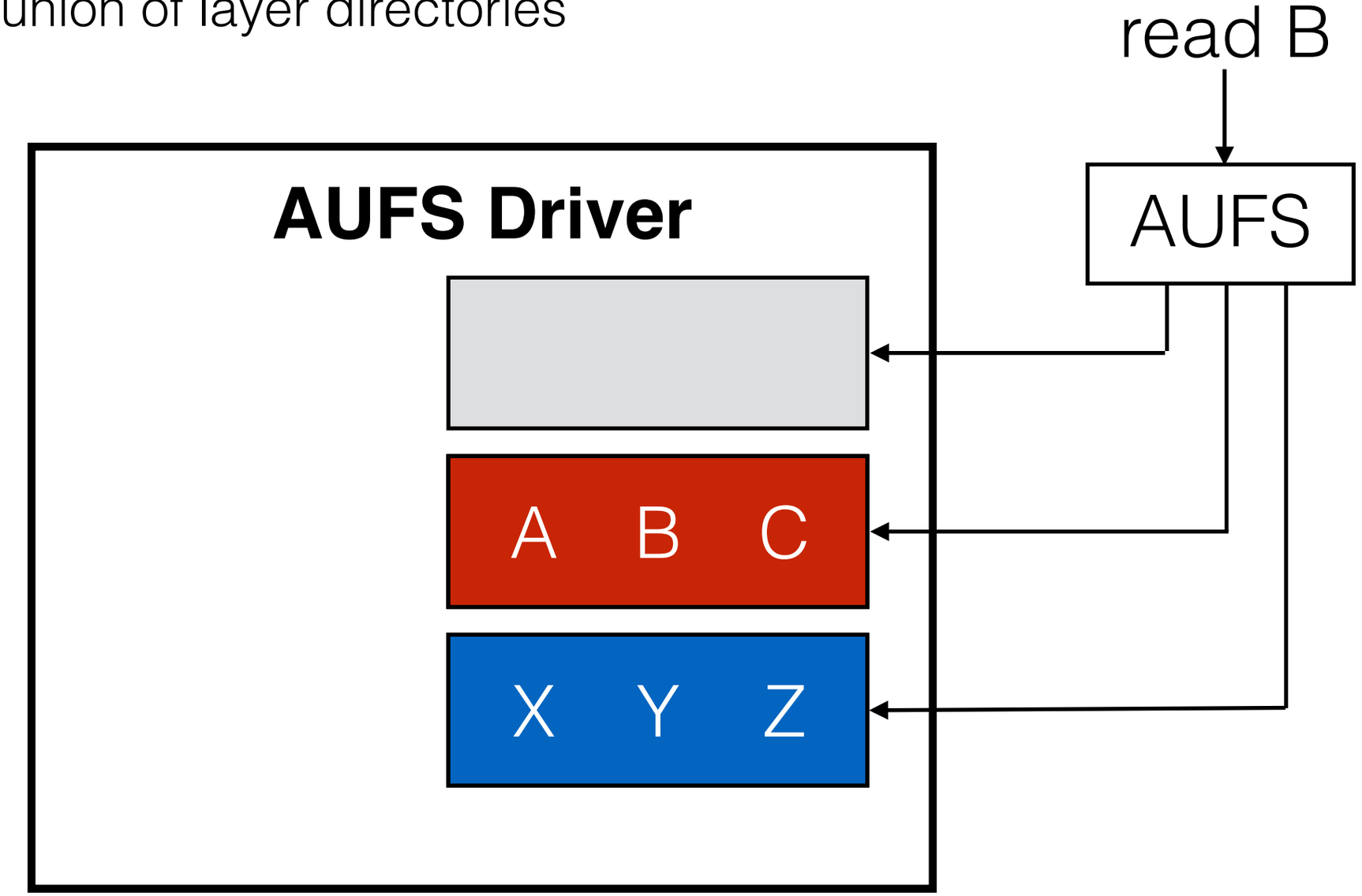

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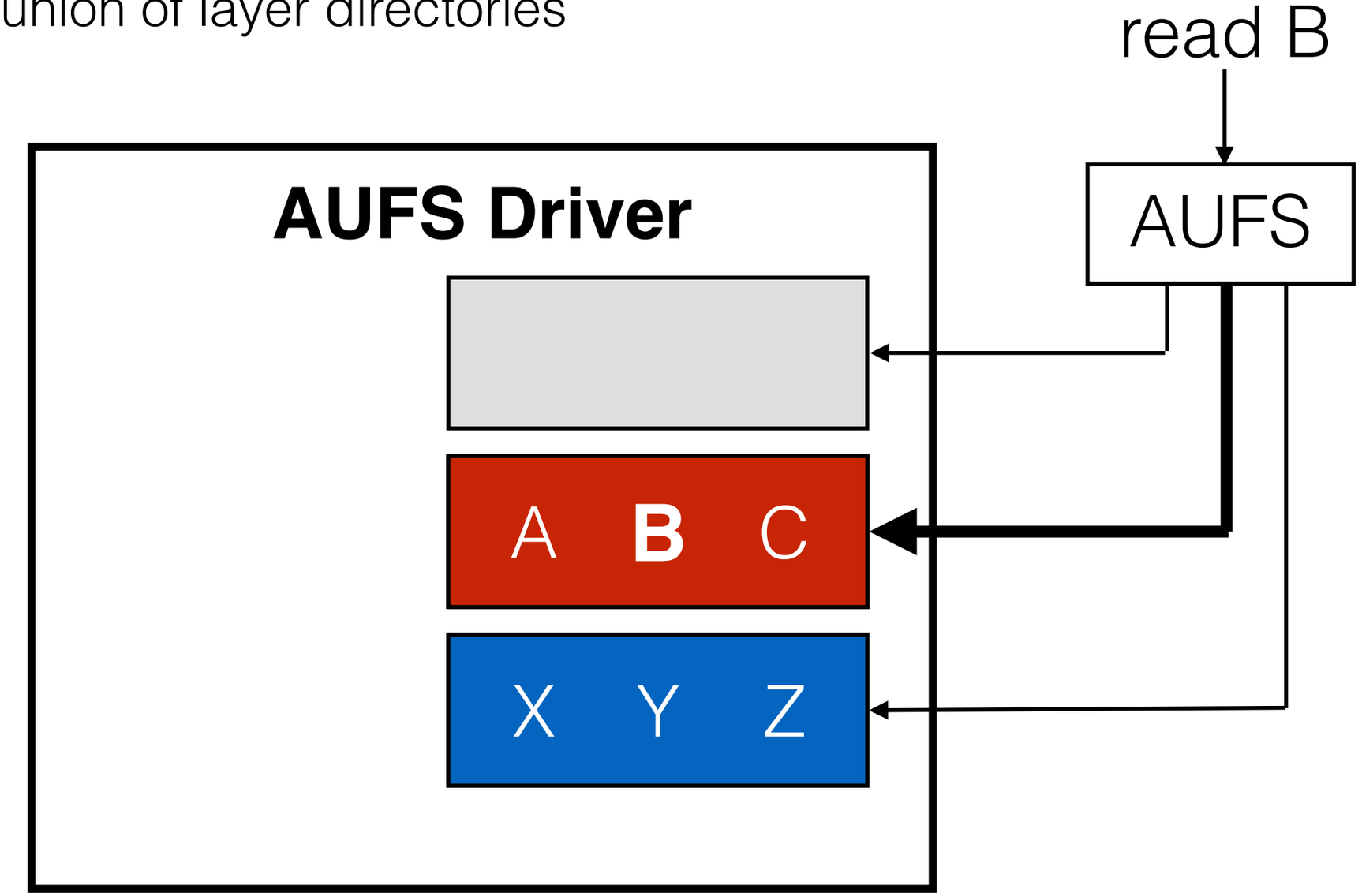

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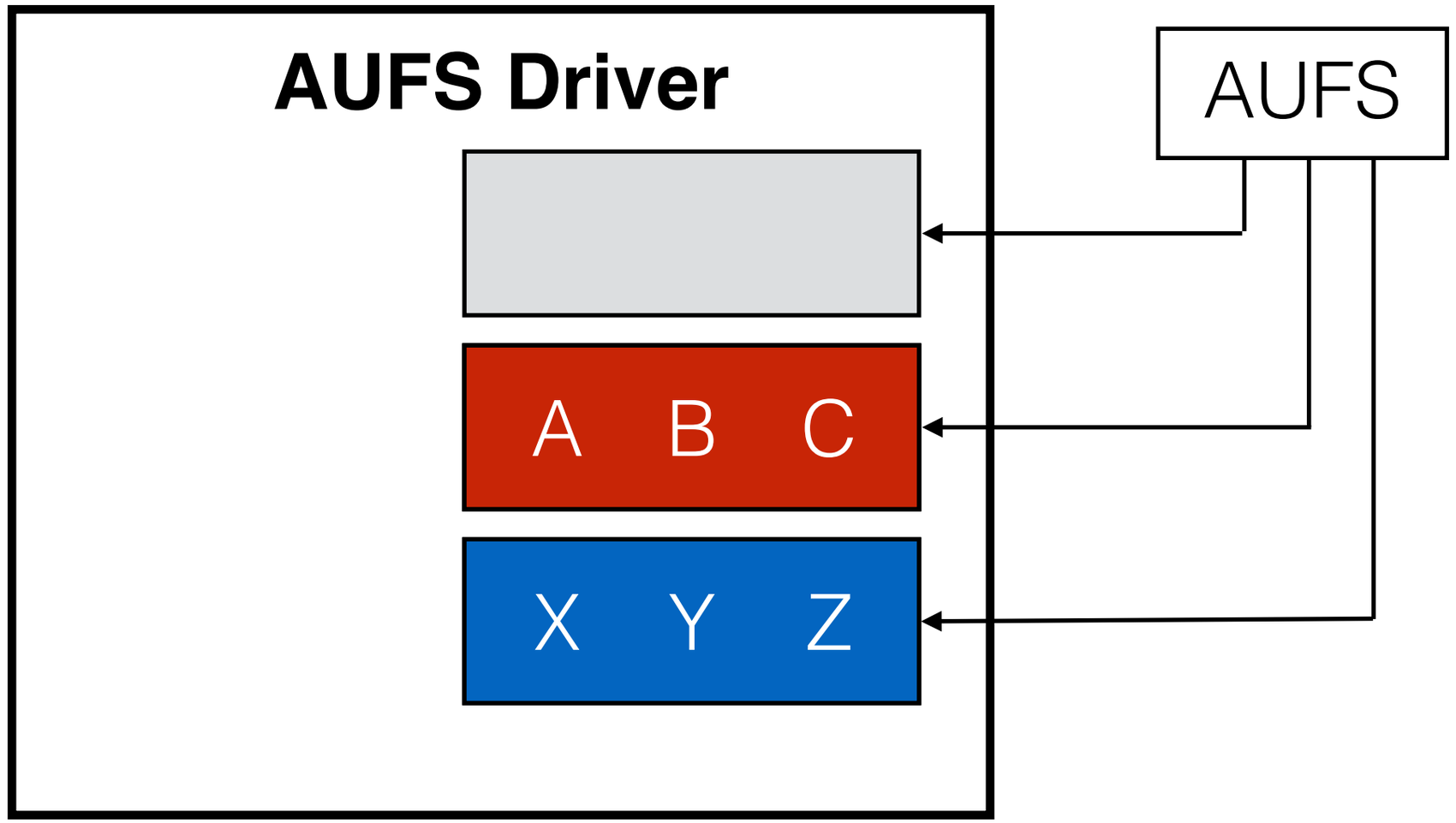

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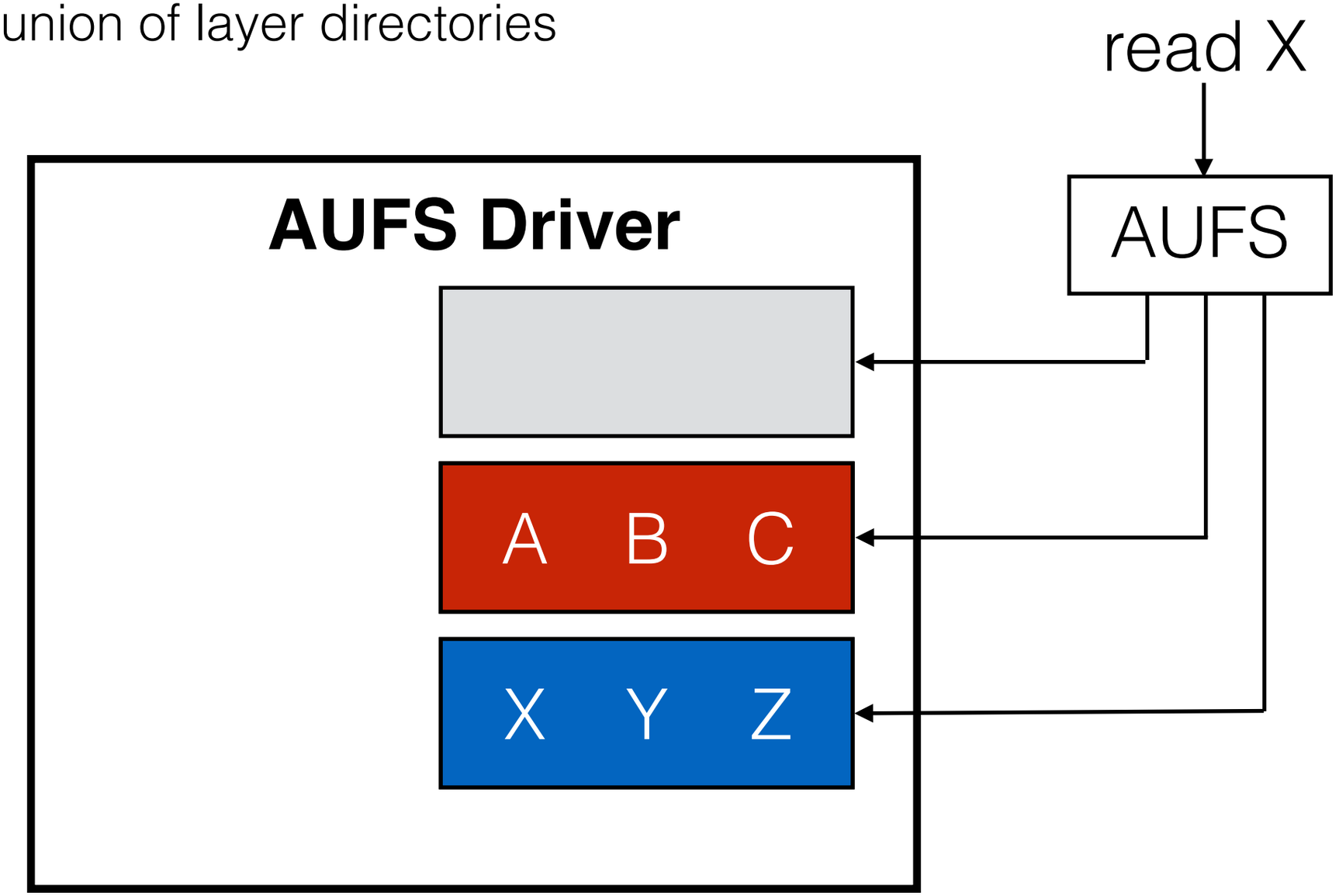

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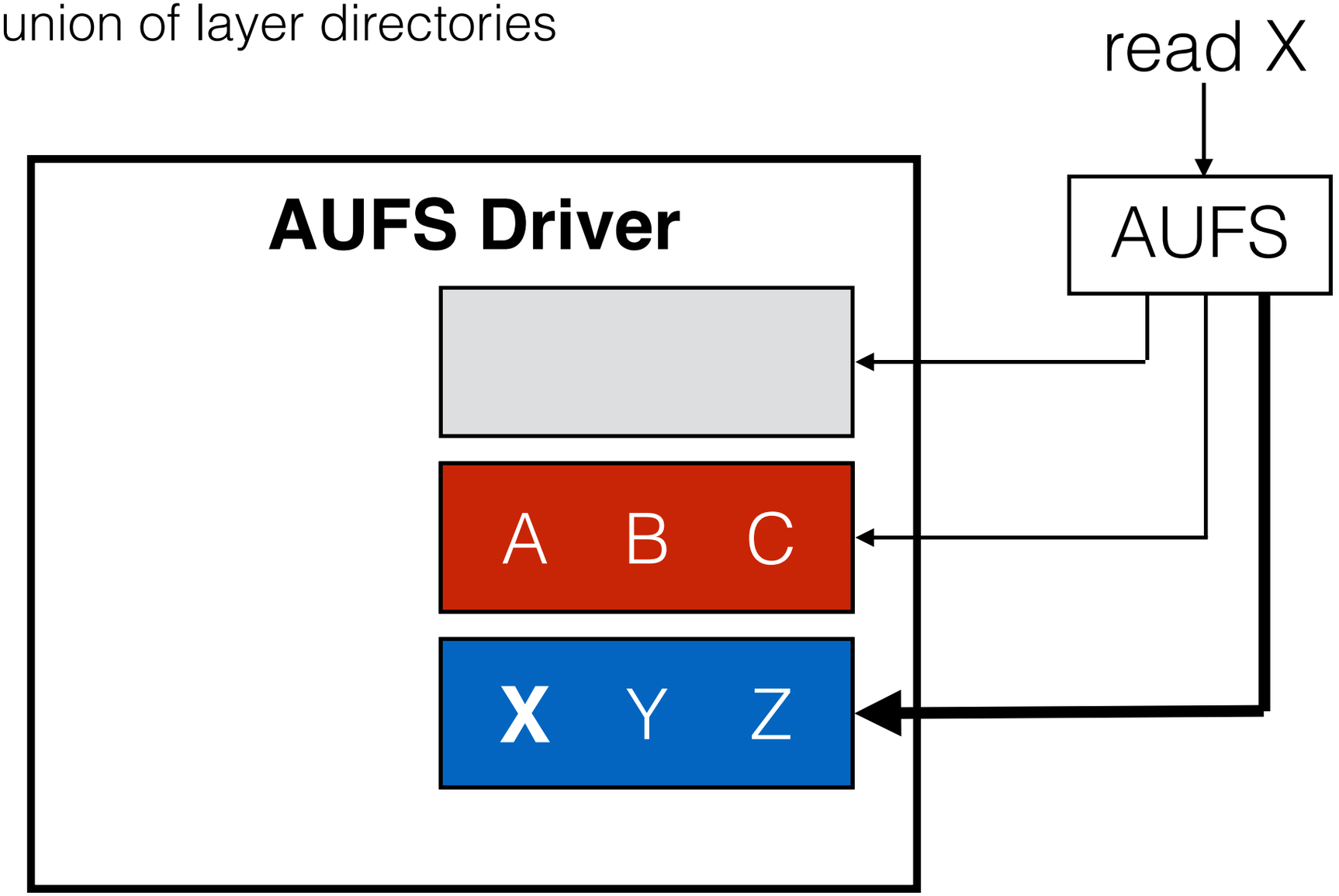

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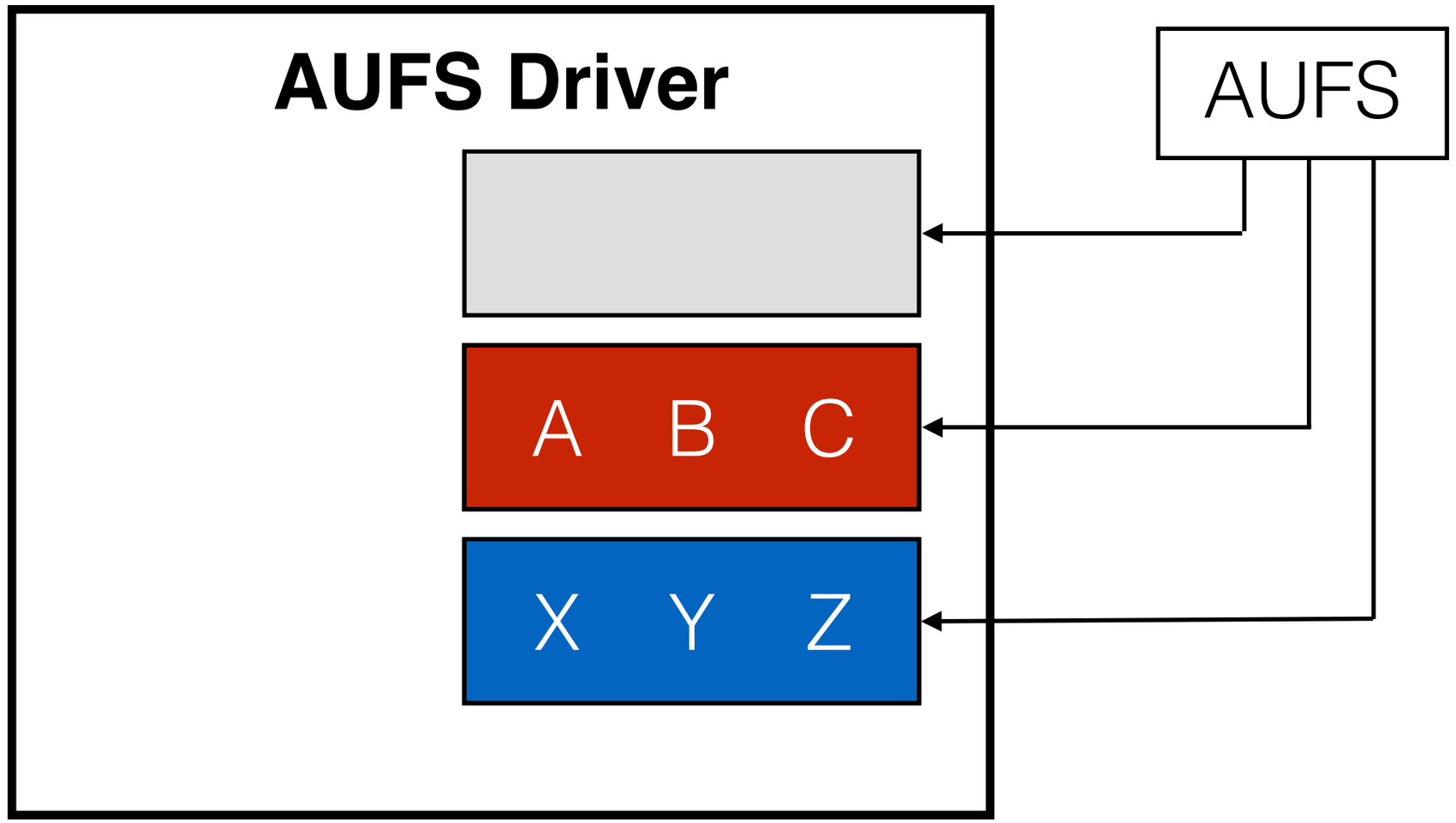

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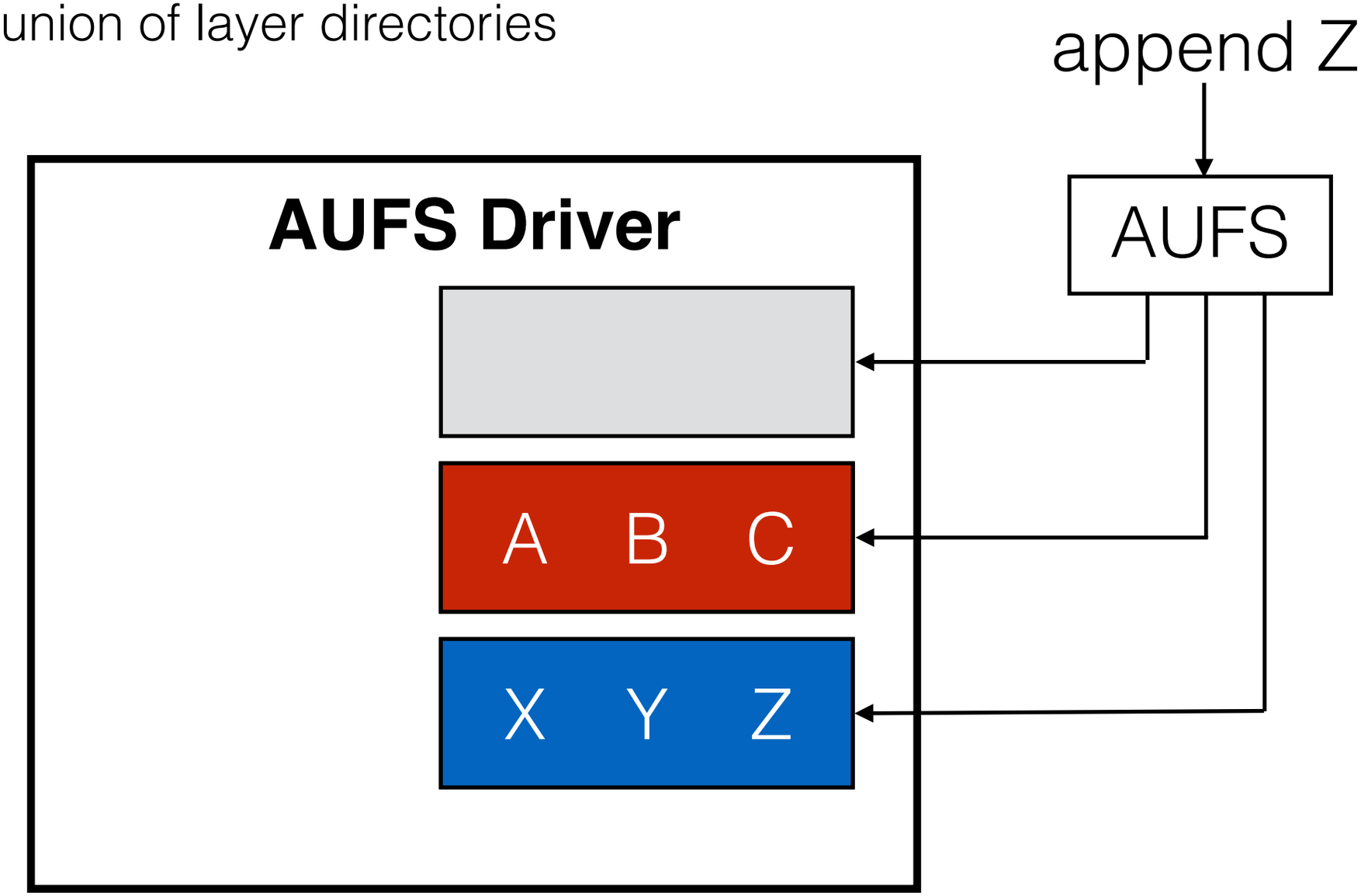

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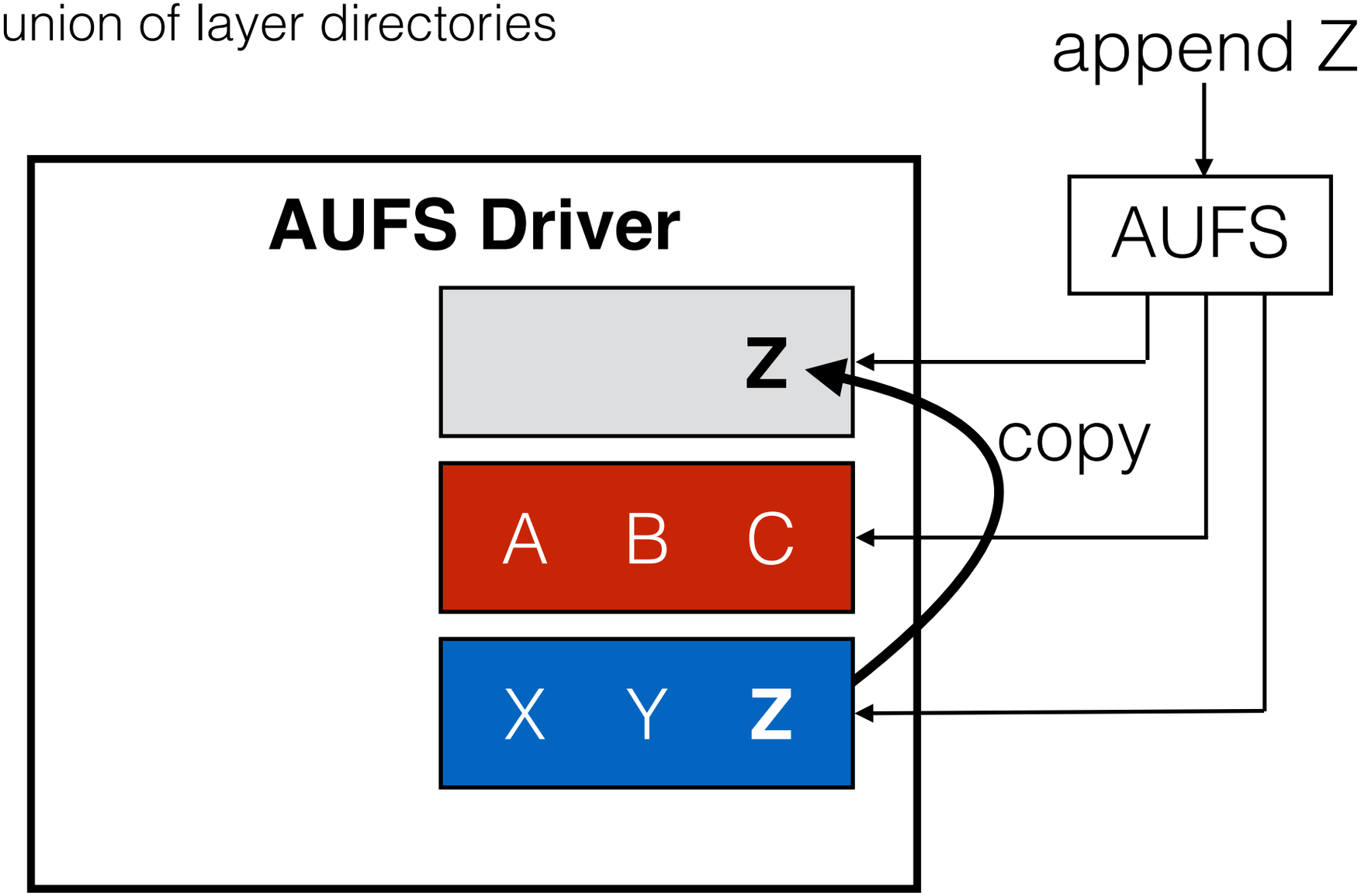

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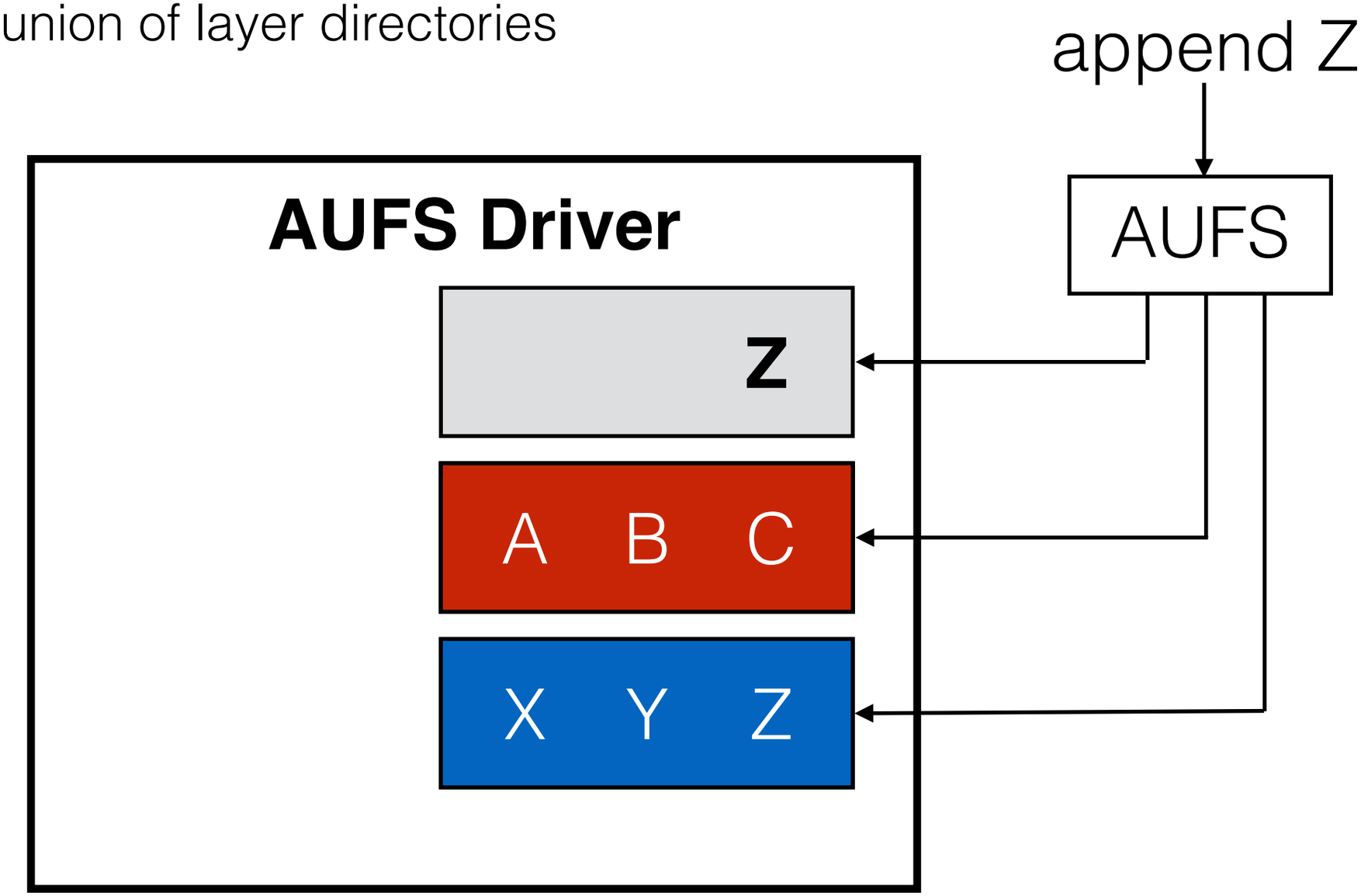

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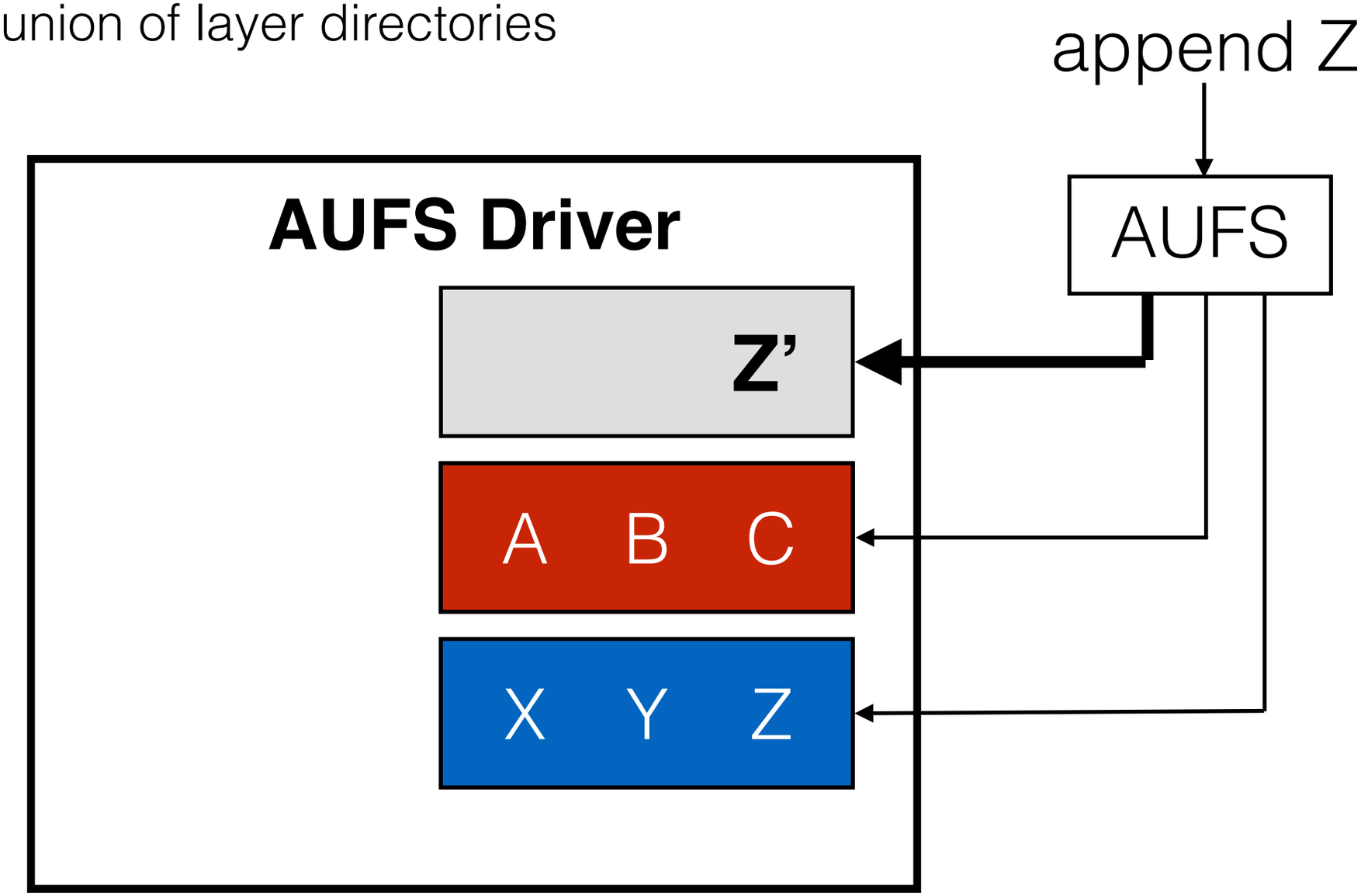

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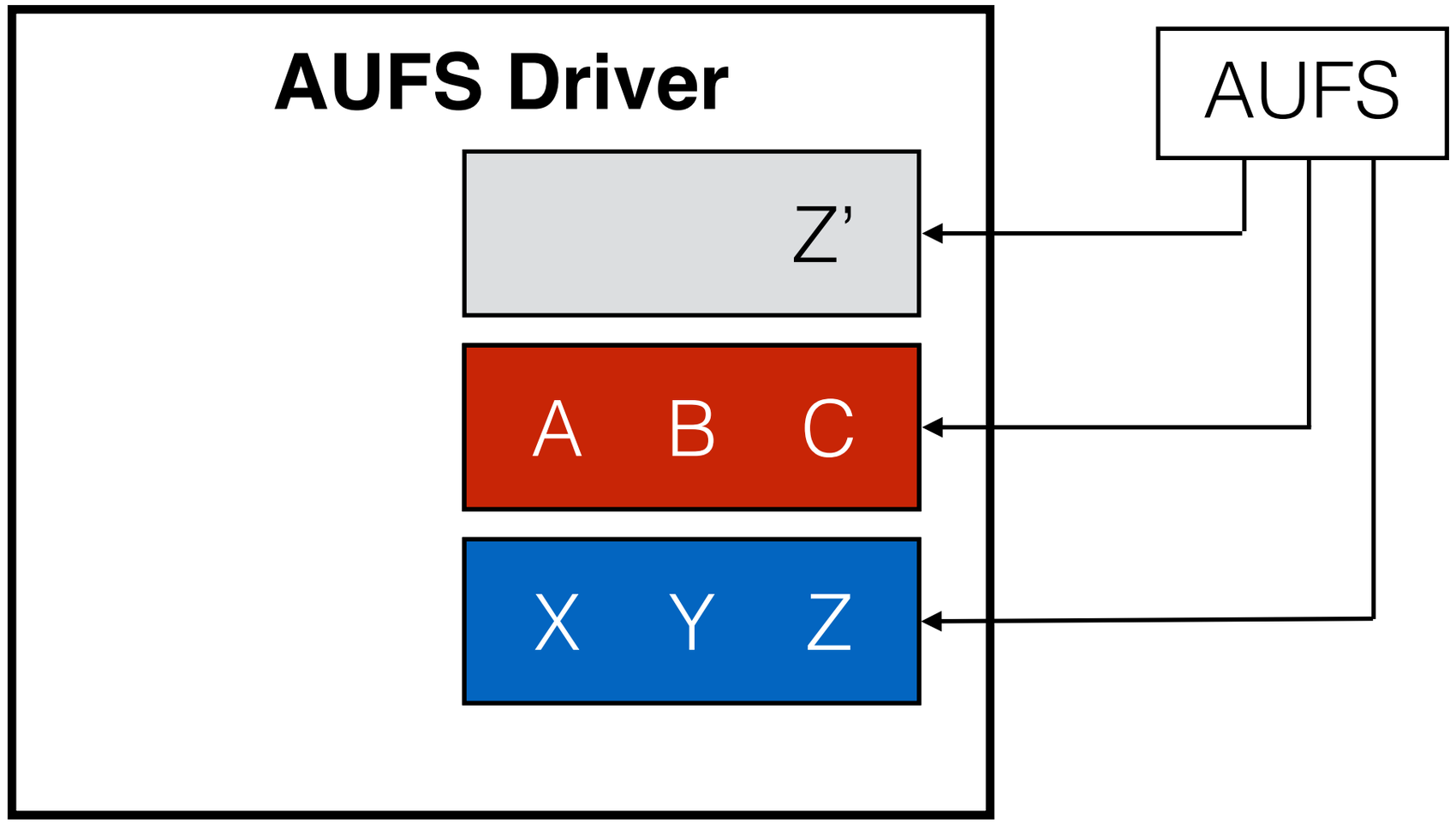


Slacker Outline

Background

Container Workloads

Default Driver: AUFS

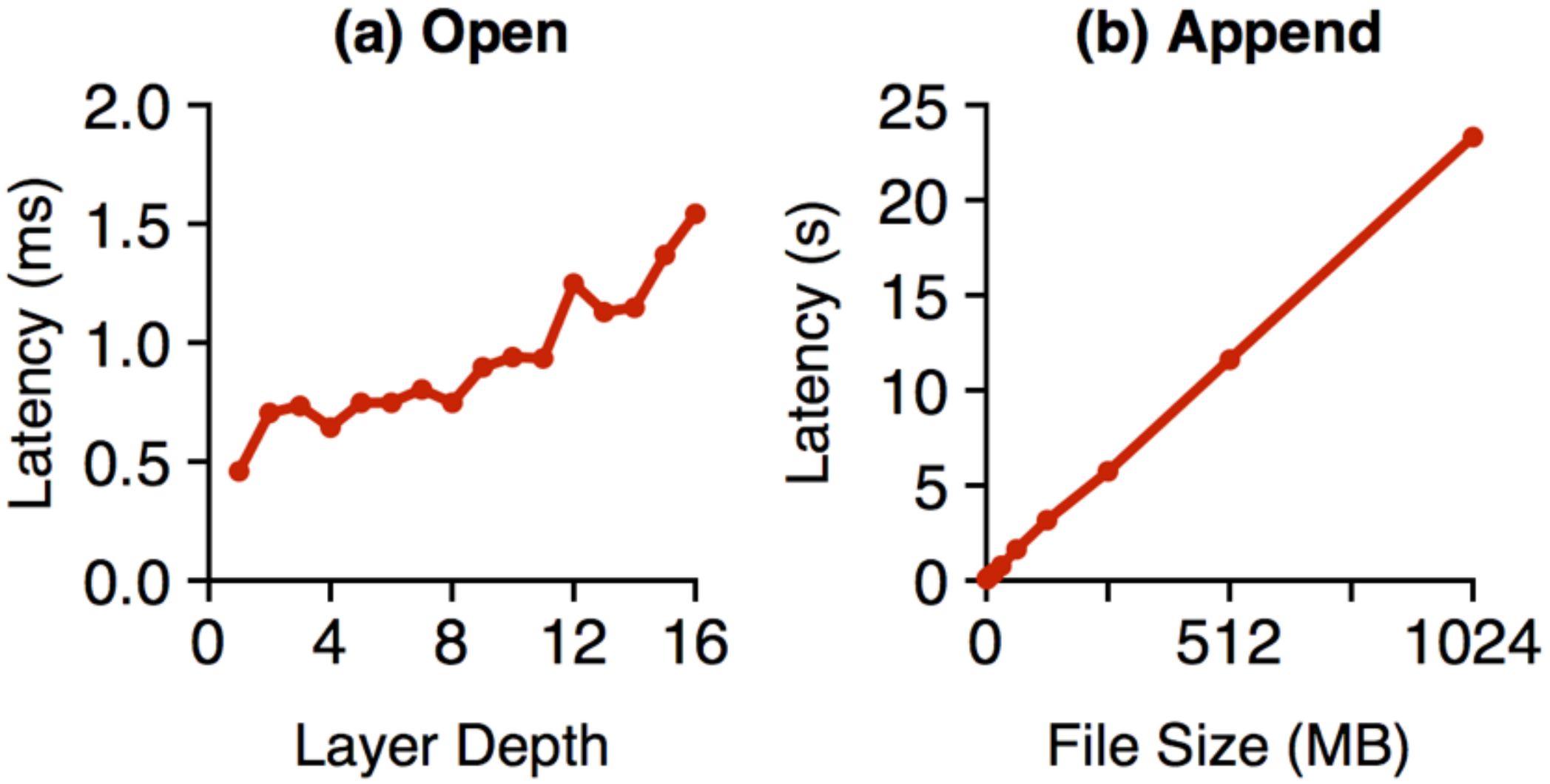
- Design
- Performance

Our Driver: Slacker

Evaluation

Conclusion

AUFS File System



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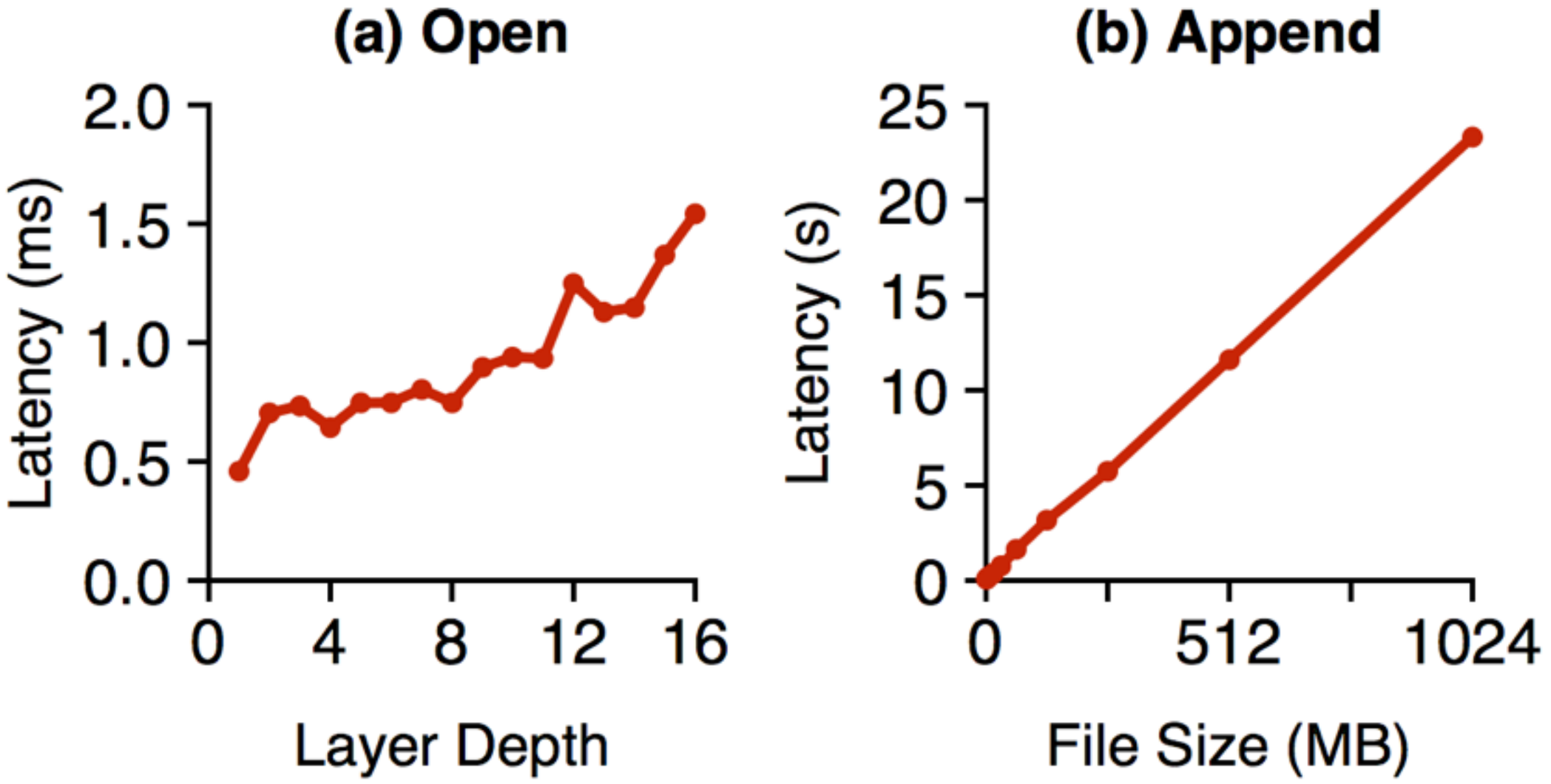
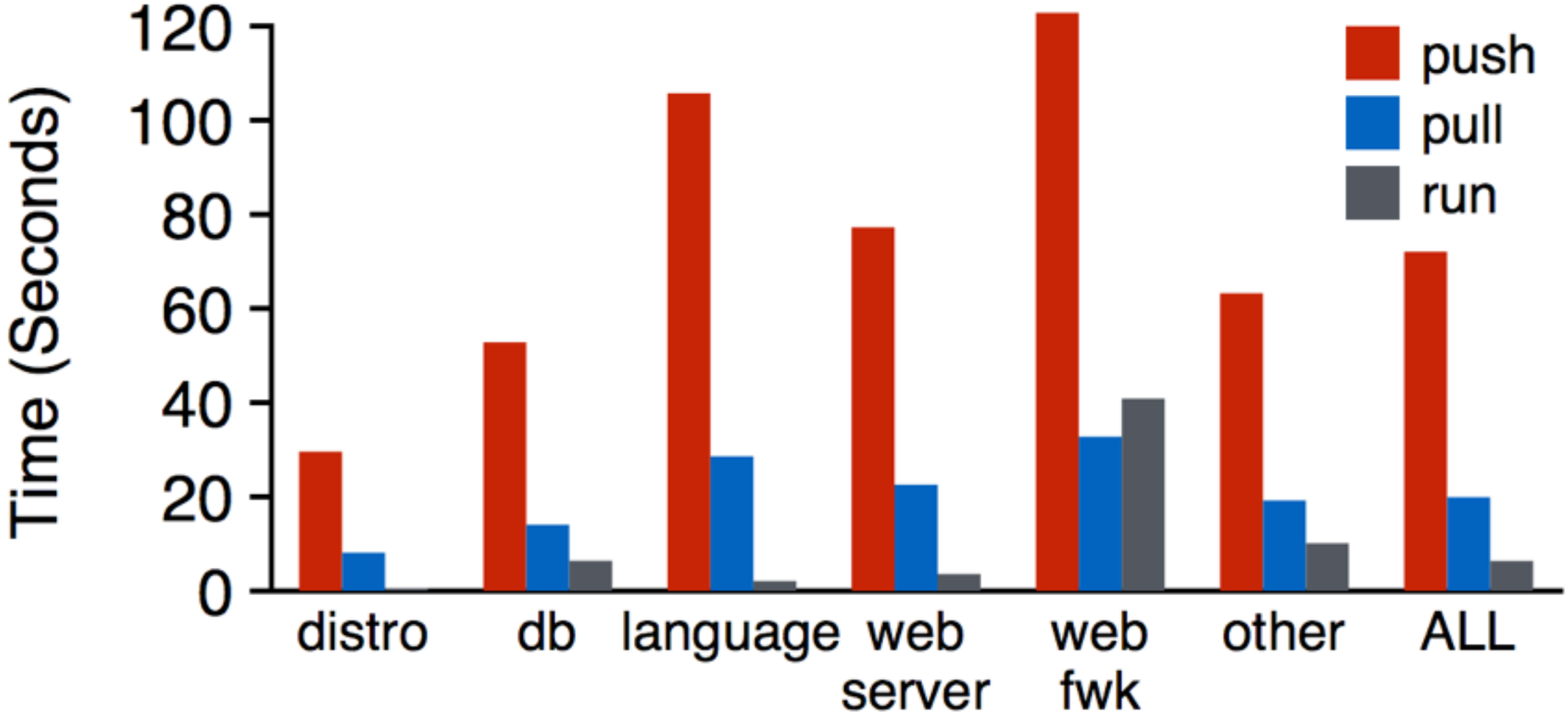


Deep data is slow

AUFS Storage Driver



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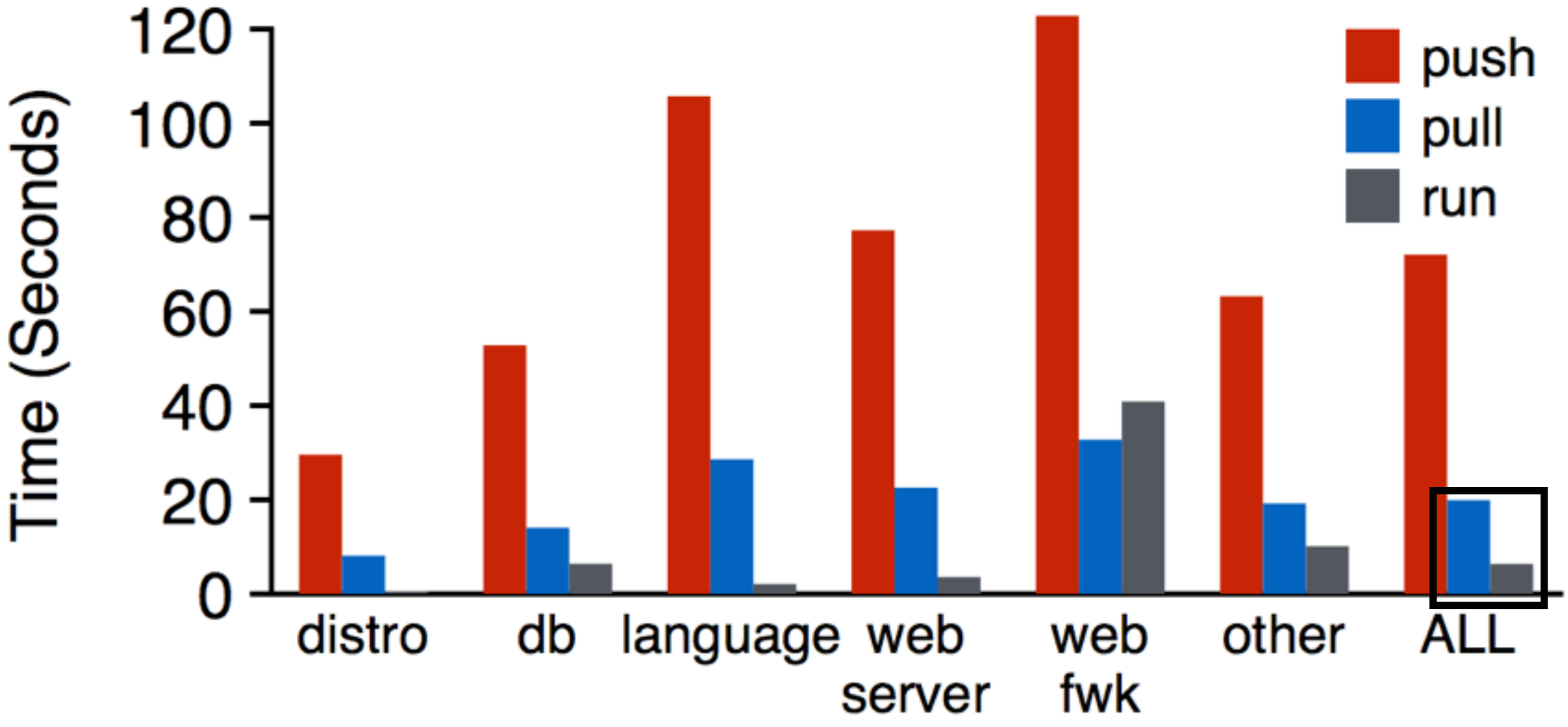

76% of deployment cycle spent on pull

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Prefetch vs. Lazy Fetch

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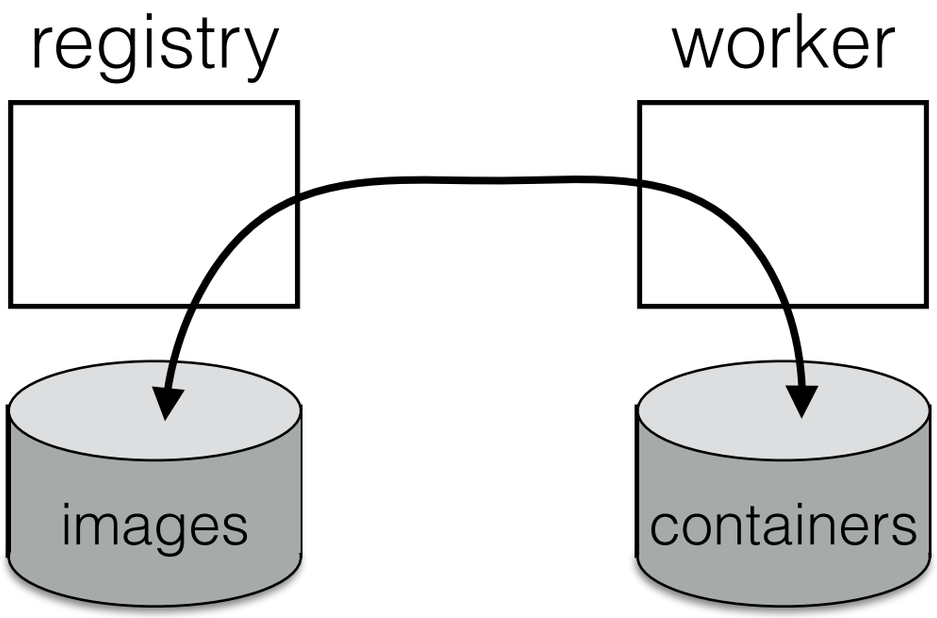

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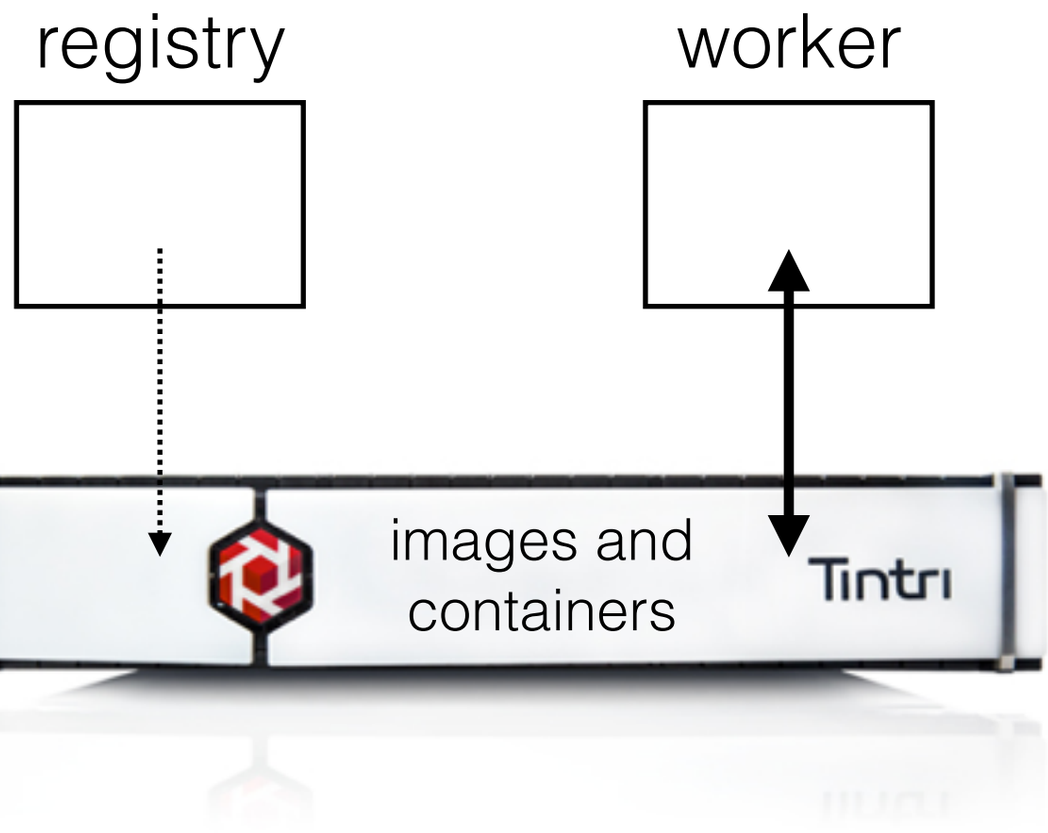

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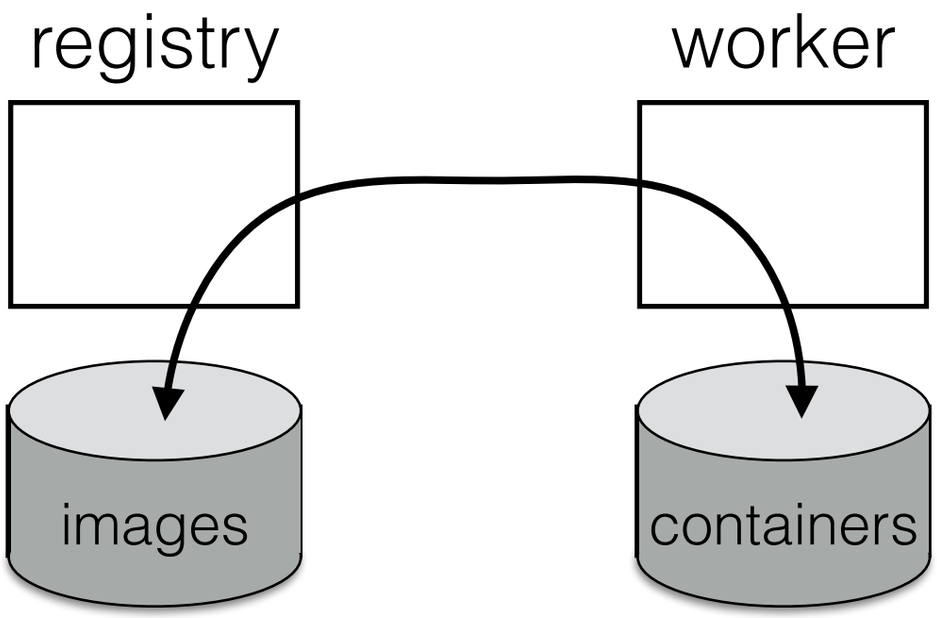
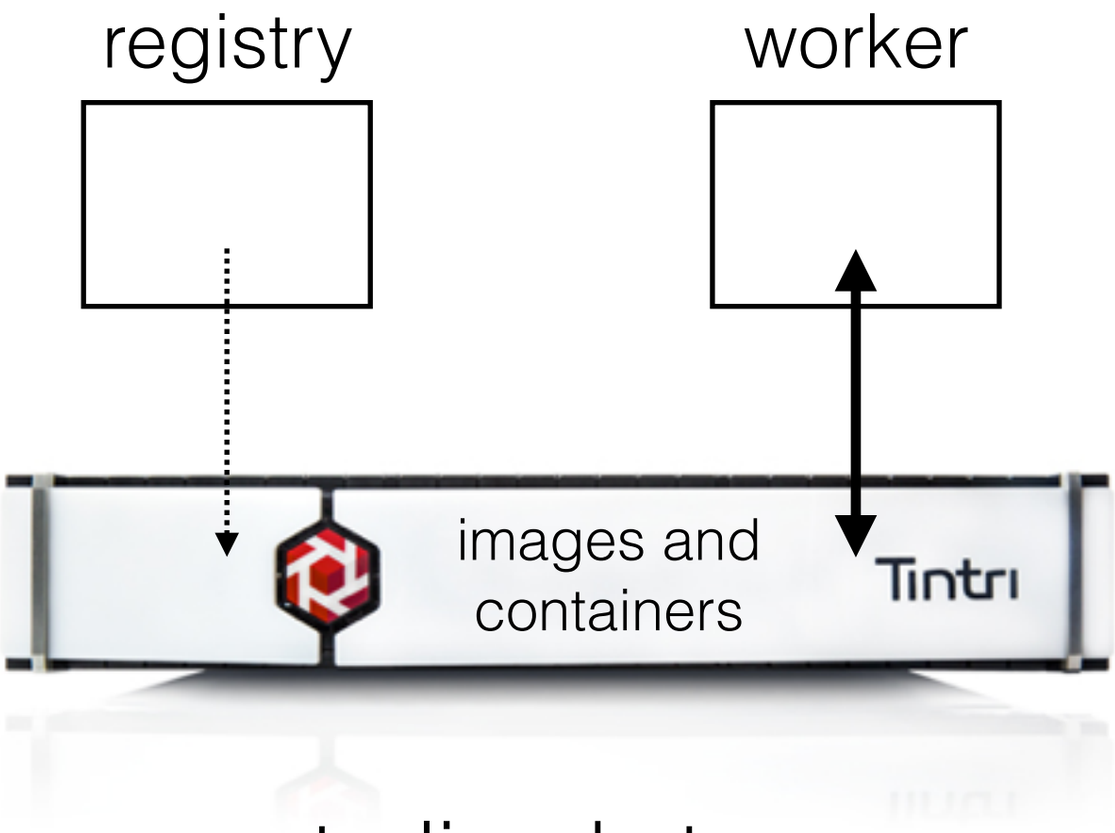


significant copying

- over network
- to/from disk

Slacker



centralized storage

- easy sharing

Prefetch vs. Lazy Fetch

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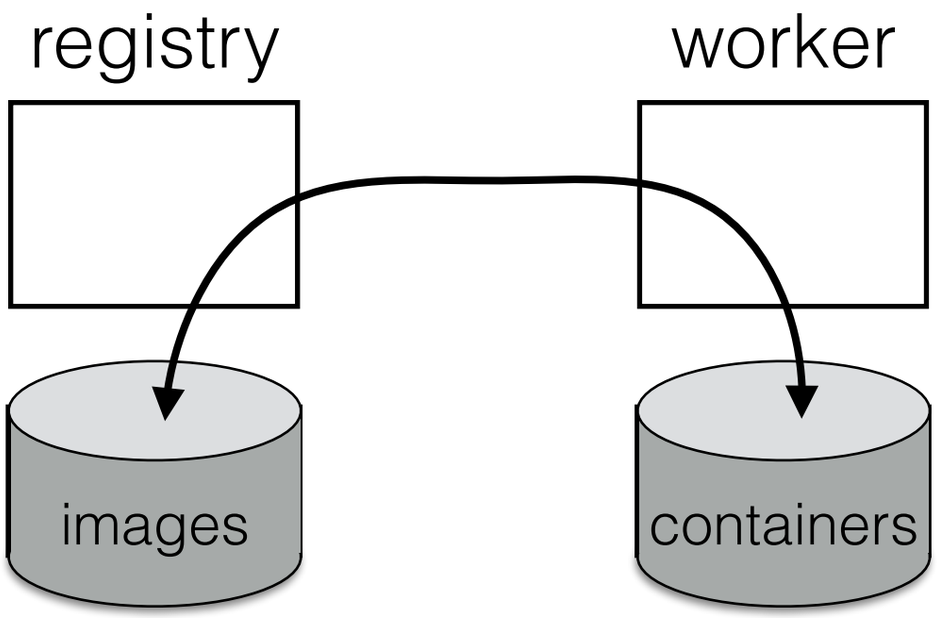

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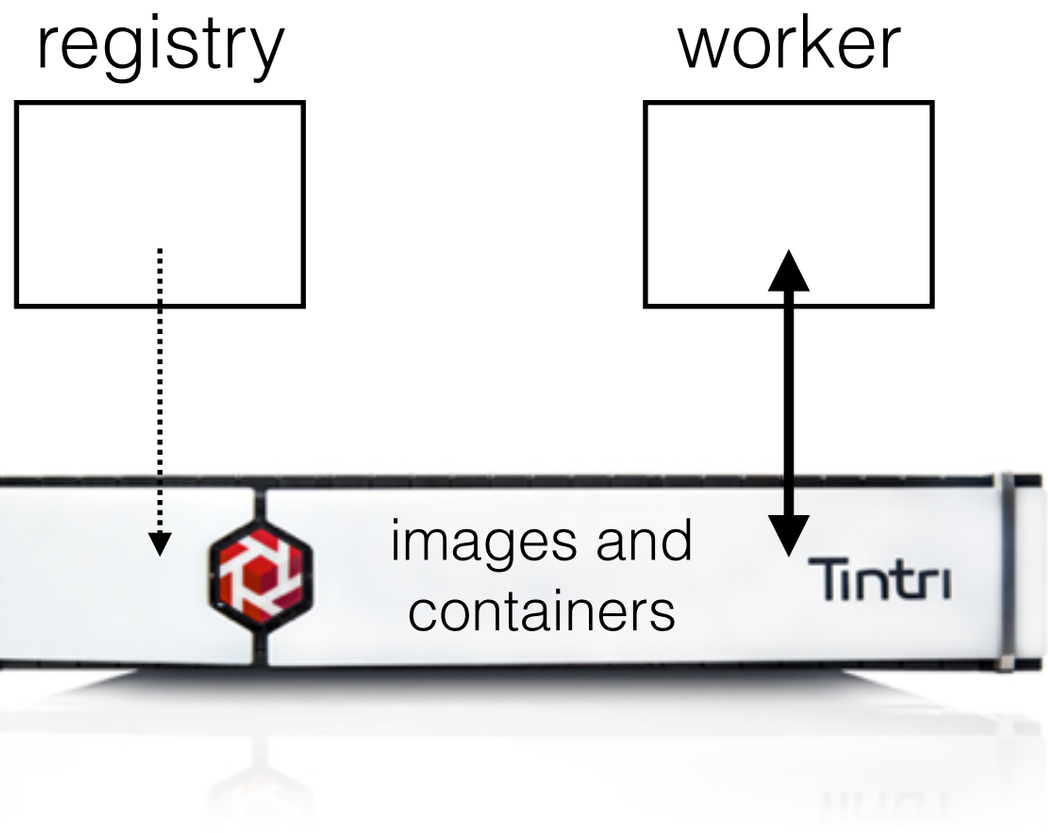

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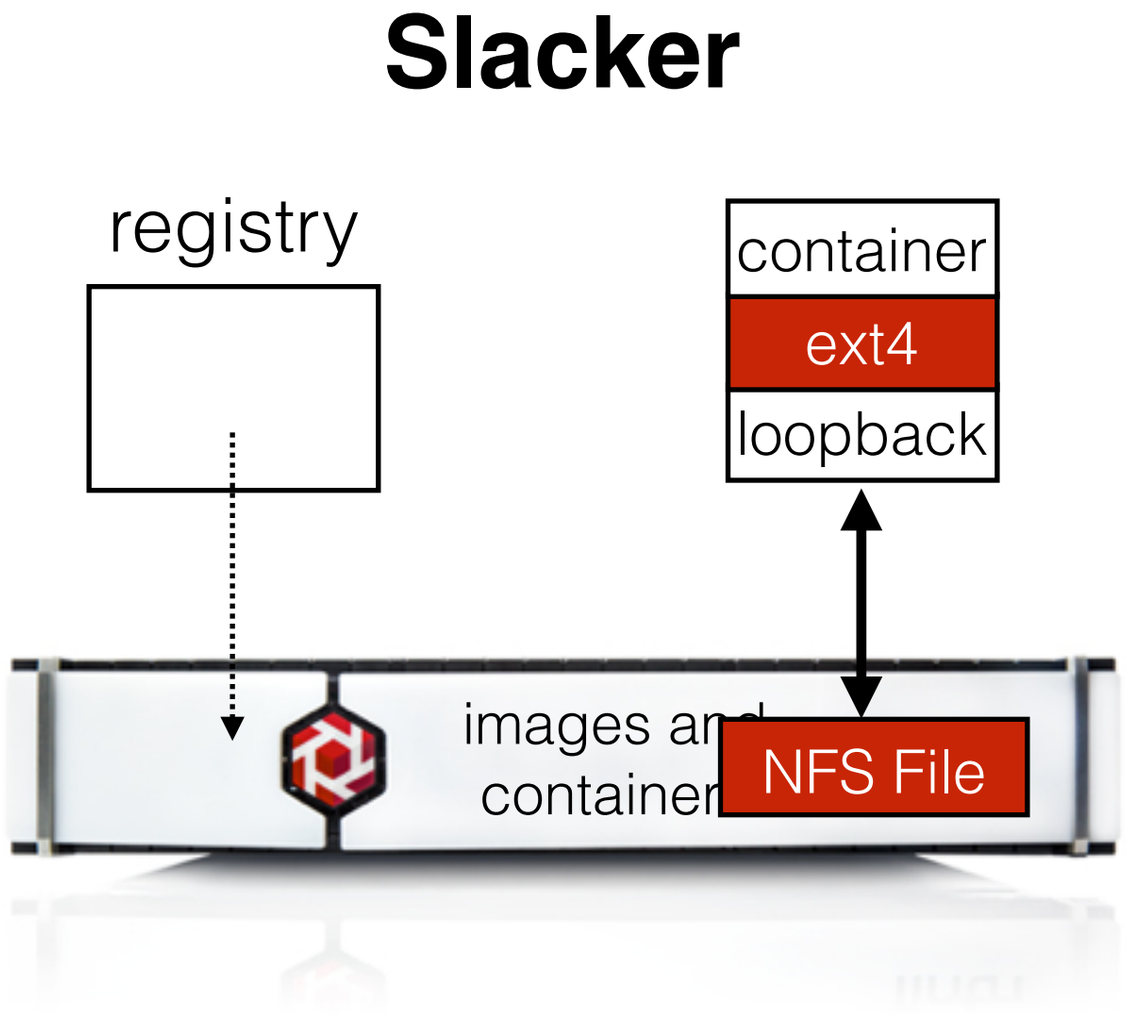

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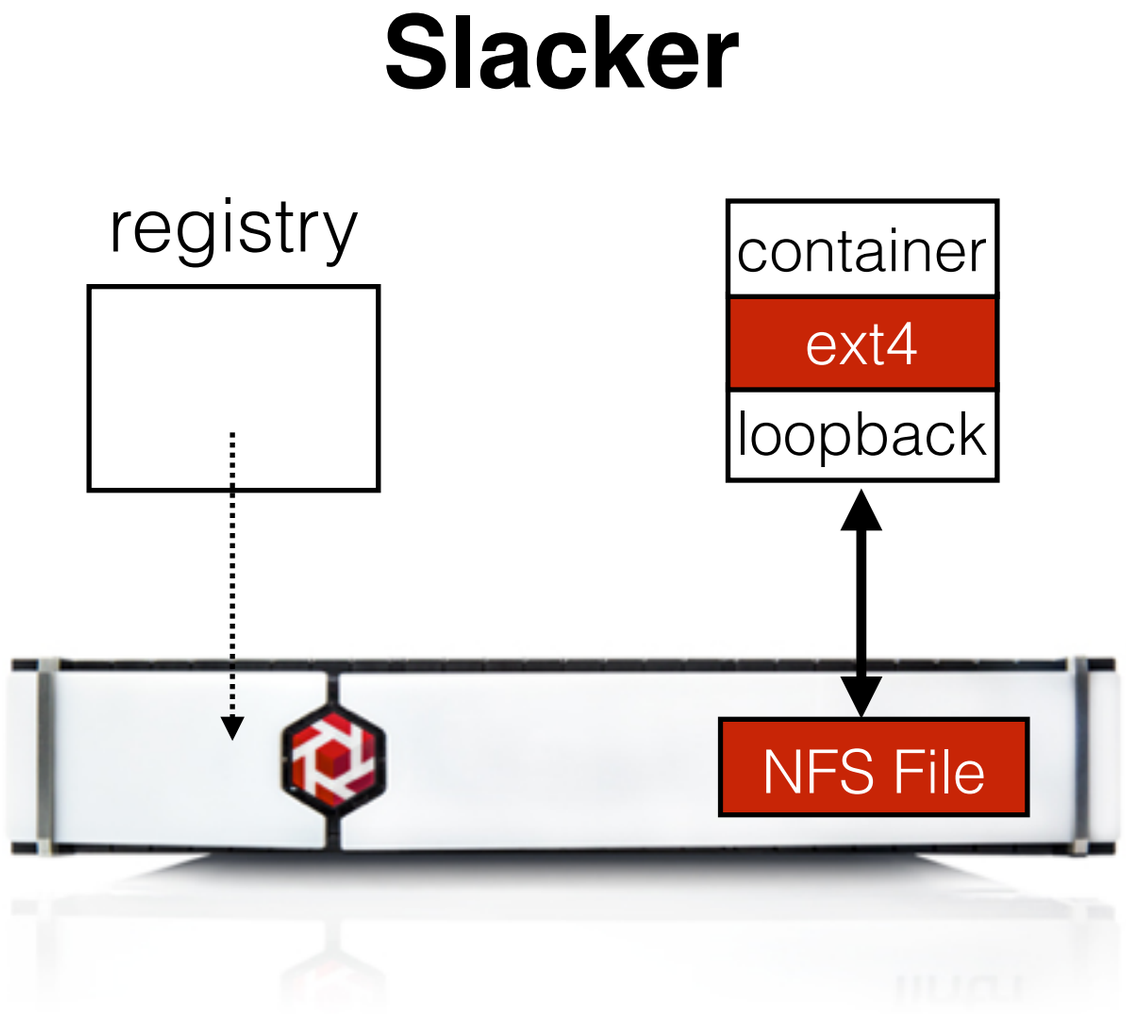

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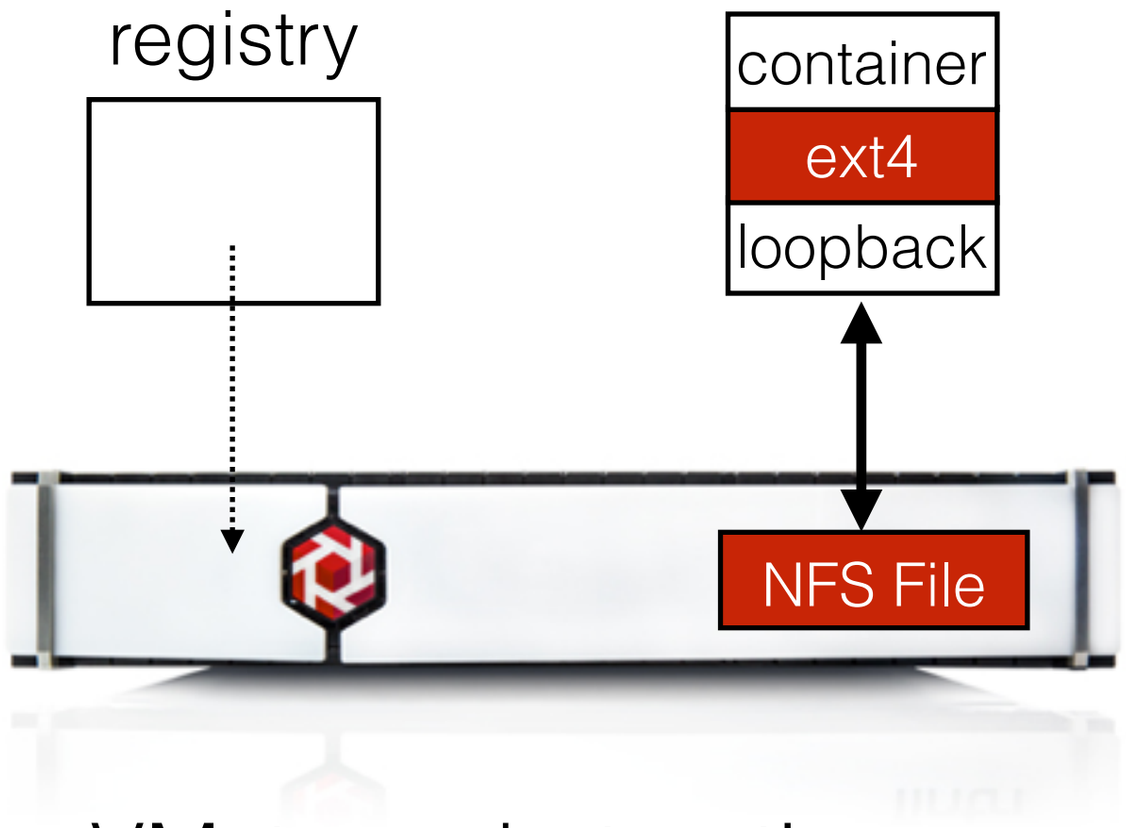


VMstore abstractions…

VMstore Abstractions

Copy-on-Write

- VMstore provides **`snapshot()`** and **`clone()`**
- block granularity avoids AUFS's problems with file granularity

`snapshot(nfs_path)`

- create read-only copy of NFS file
- return snapshot ID

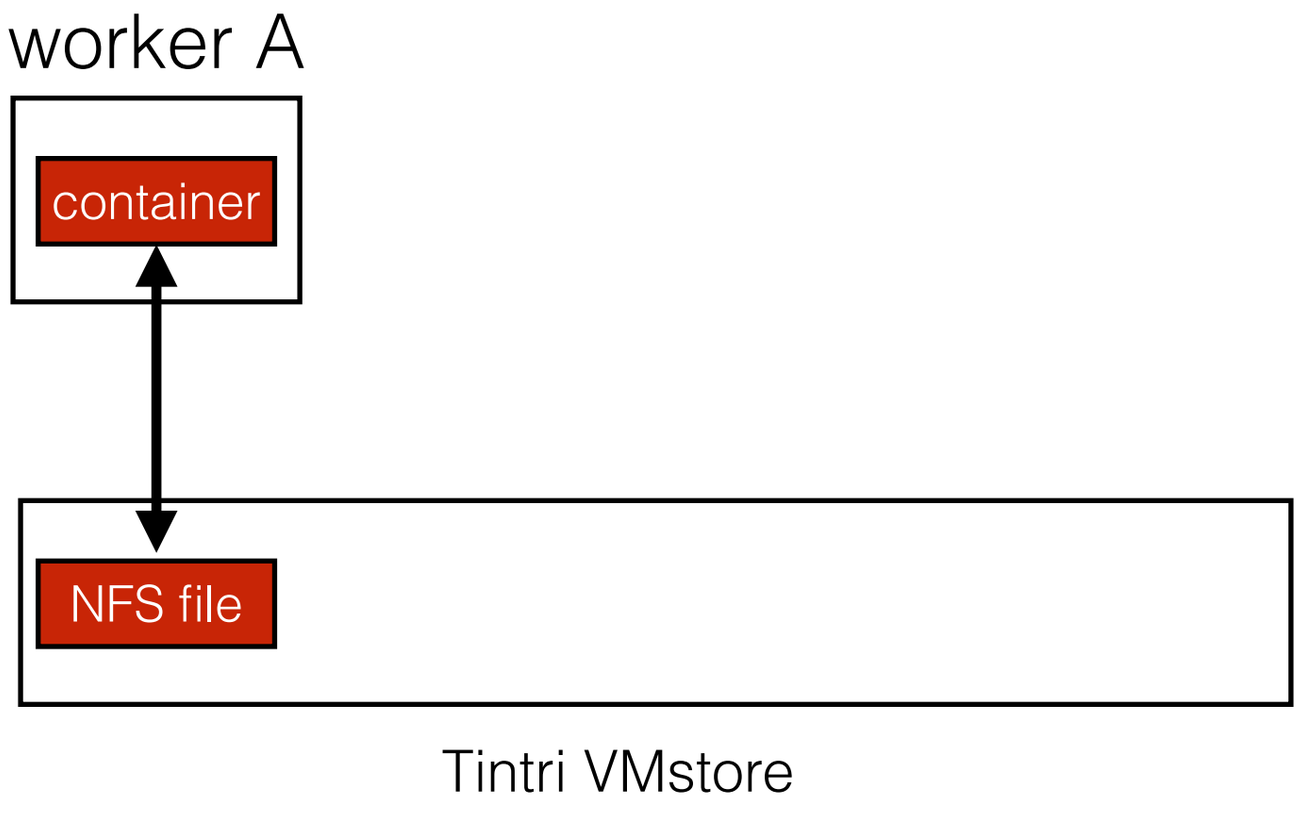
`clone(snapshot_id)`

- create r/w NFS file from snapshot

Slacker Usage

- NFS files ⇒ container storage
- snapshots ⇒ image storage
- `clone()` ⇒ provision container from image
- `snapshot()` ⇒ create image from container

Snapshot and Clone



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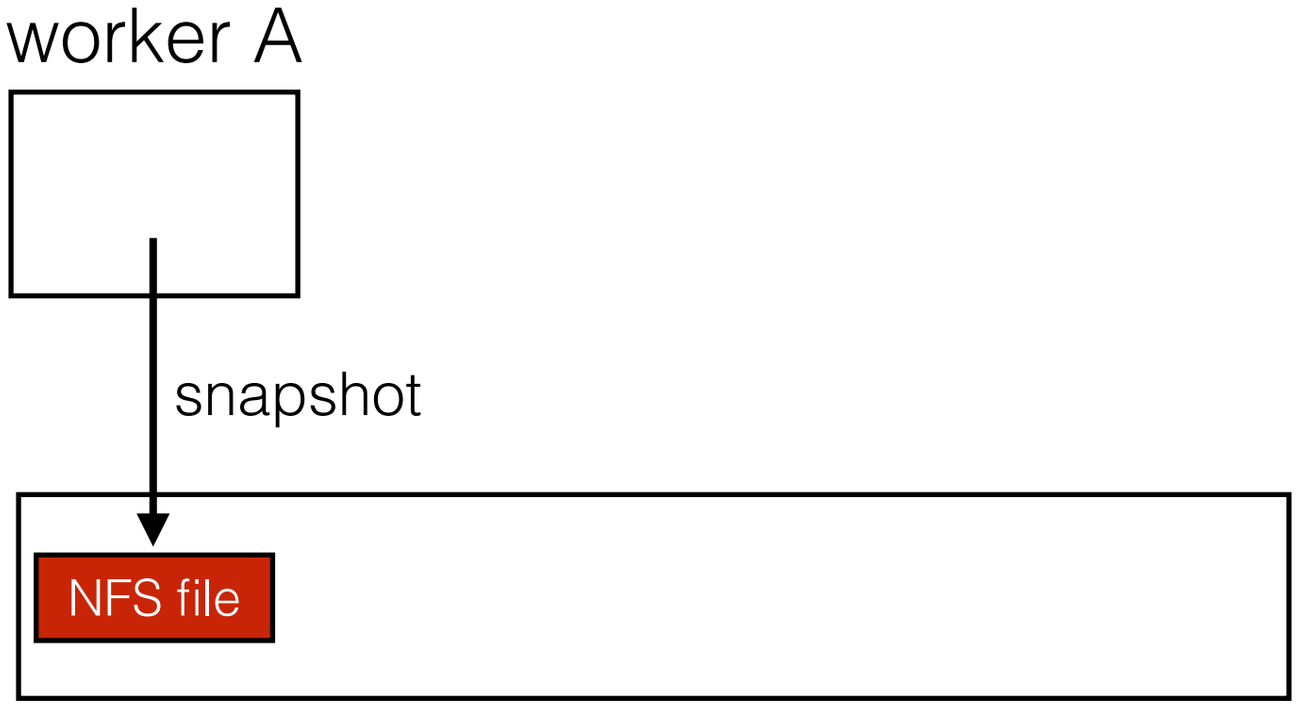

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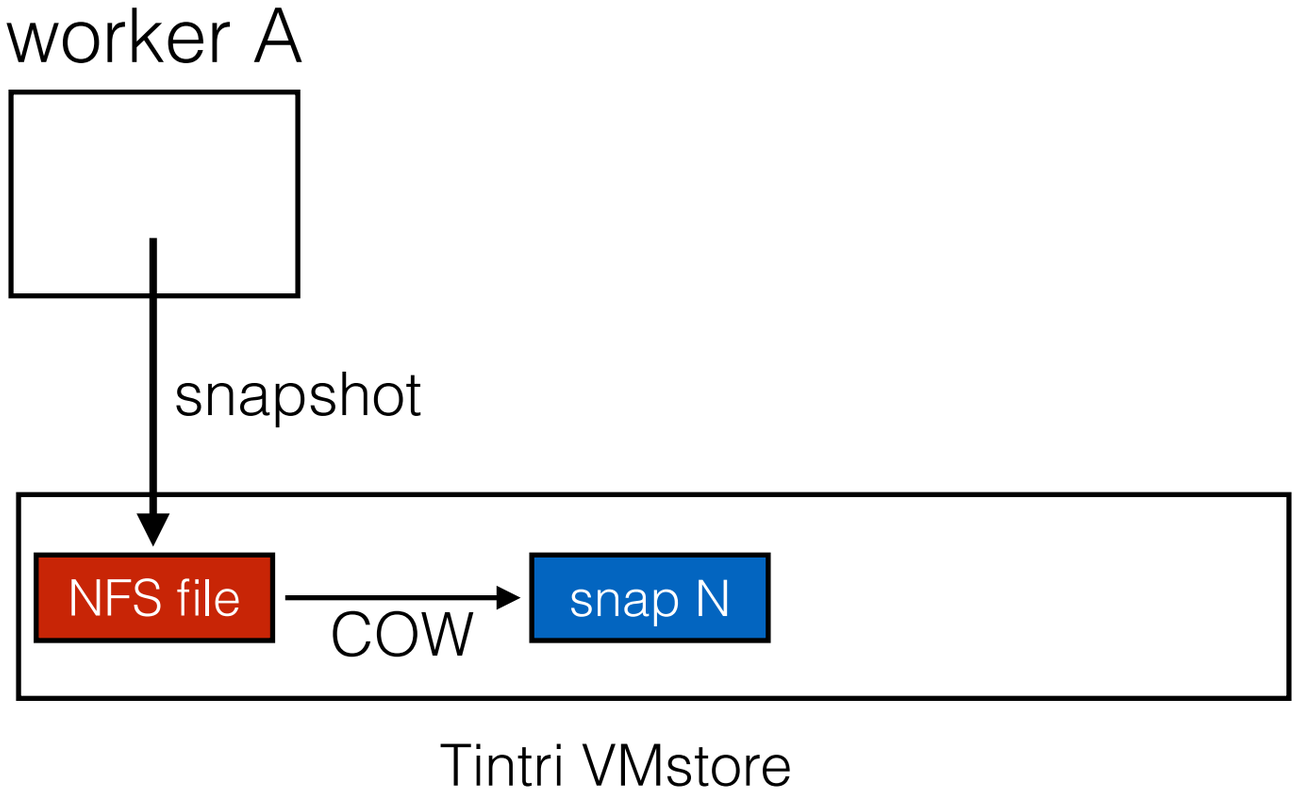

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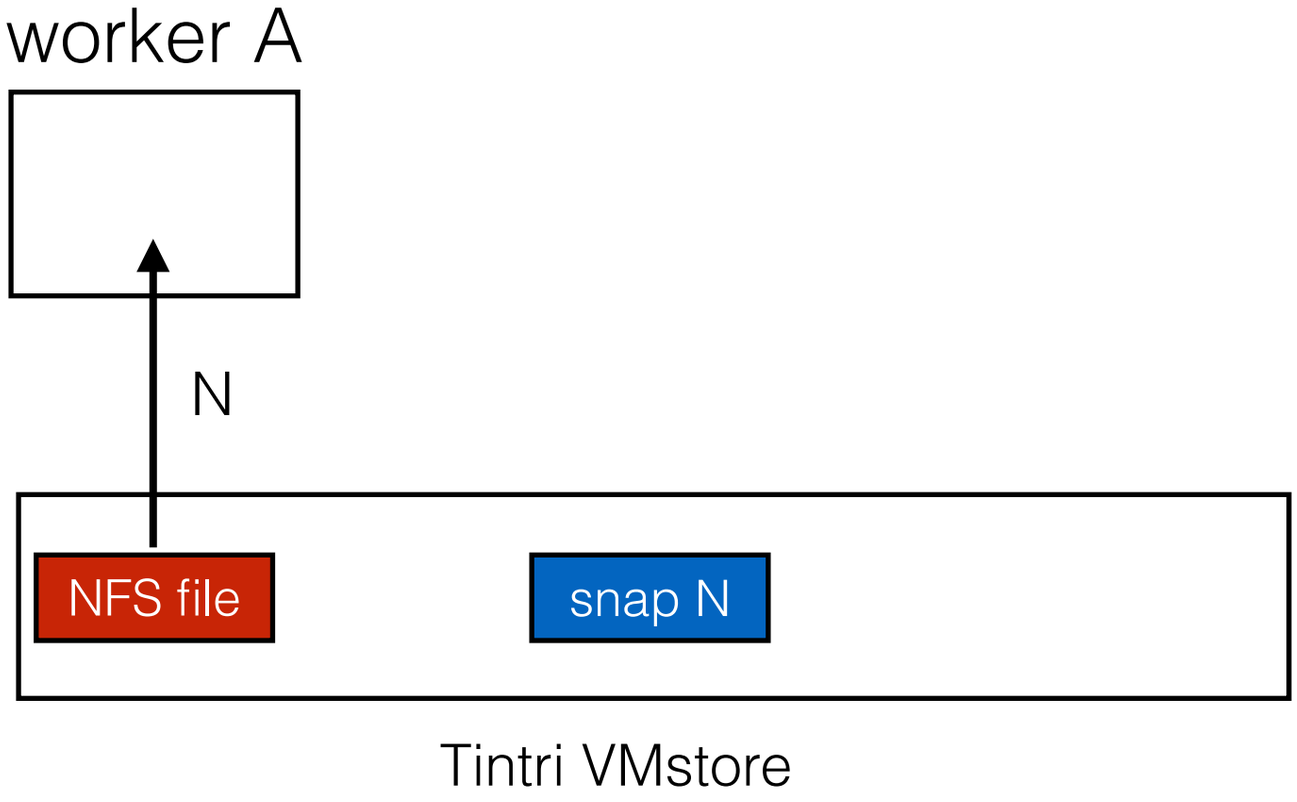

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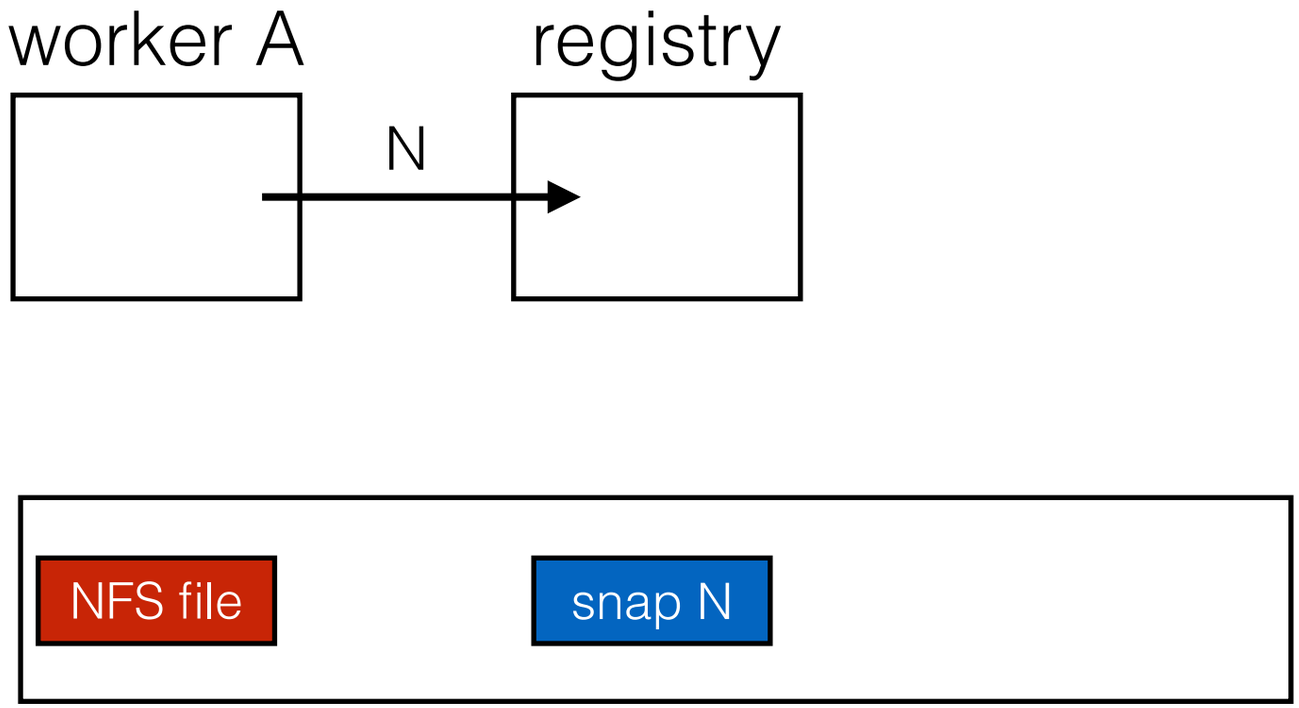

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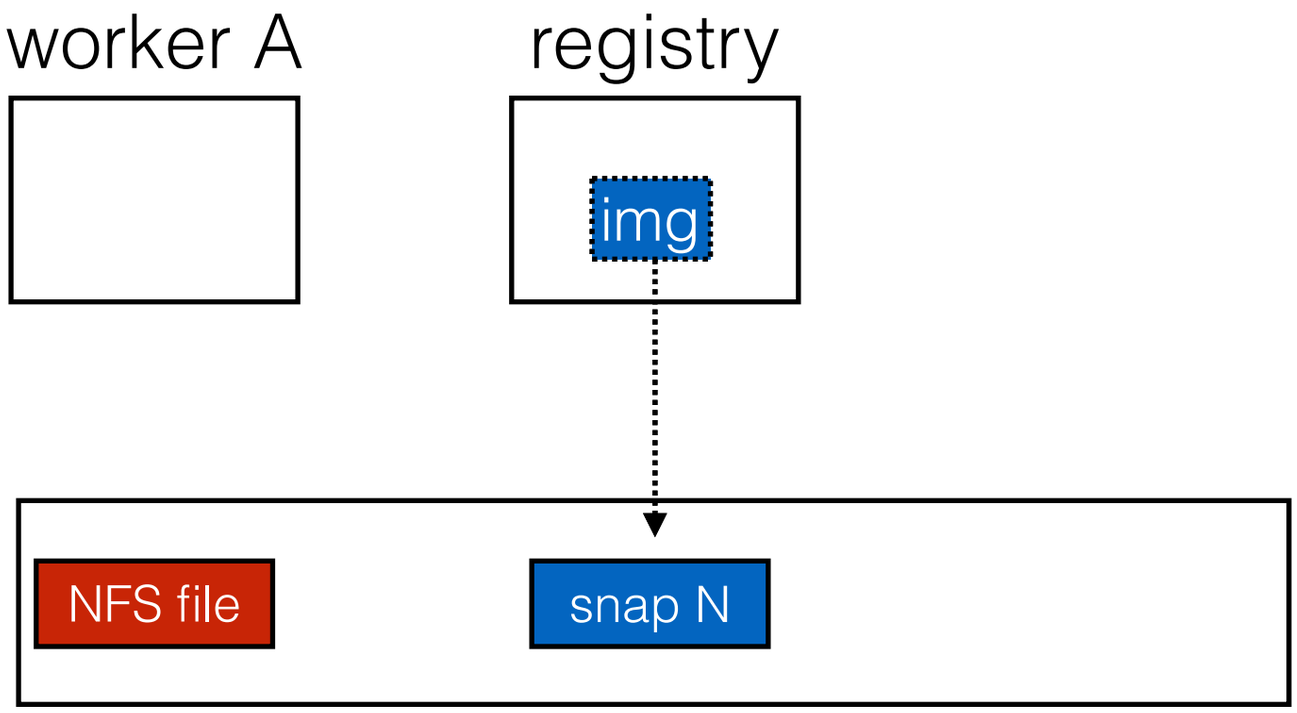

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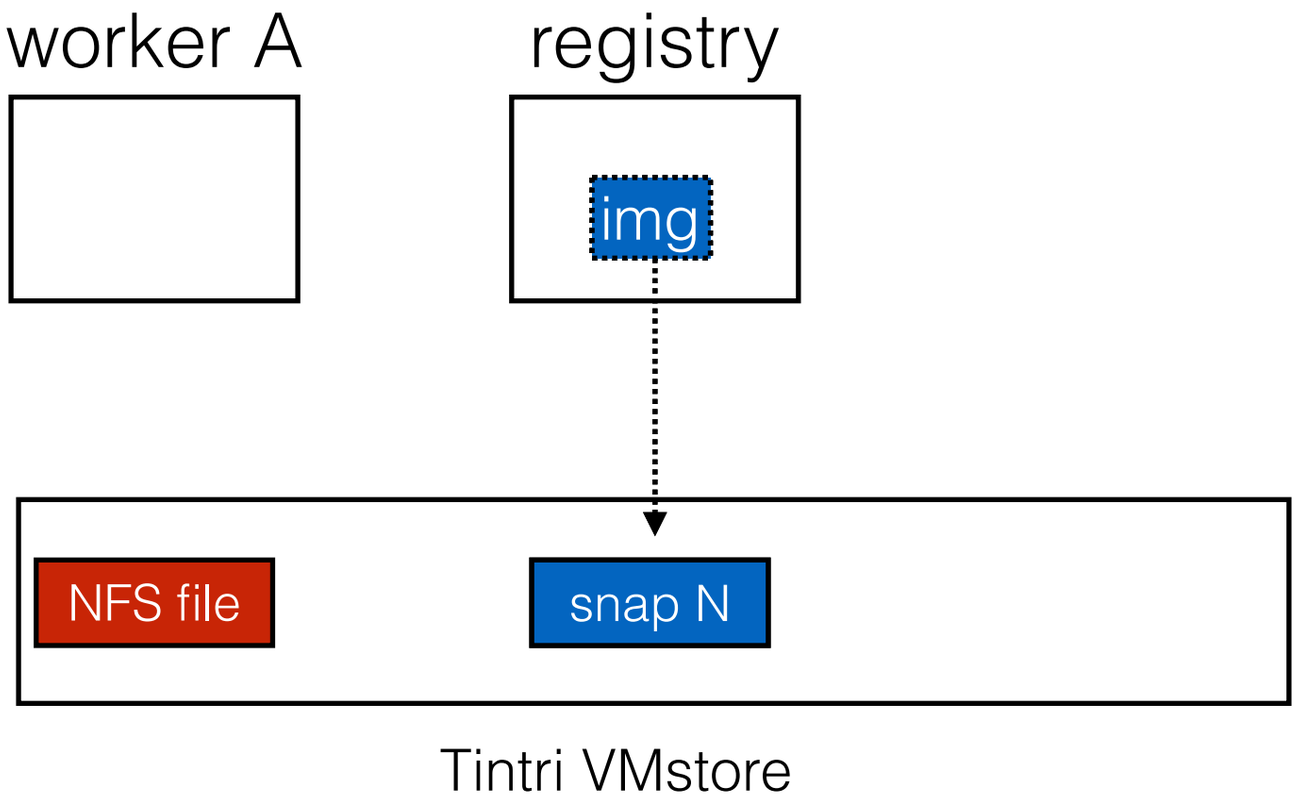
Note: registry is only a name server.
Maps layer metadata ⇒ snapshot ID



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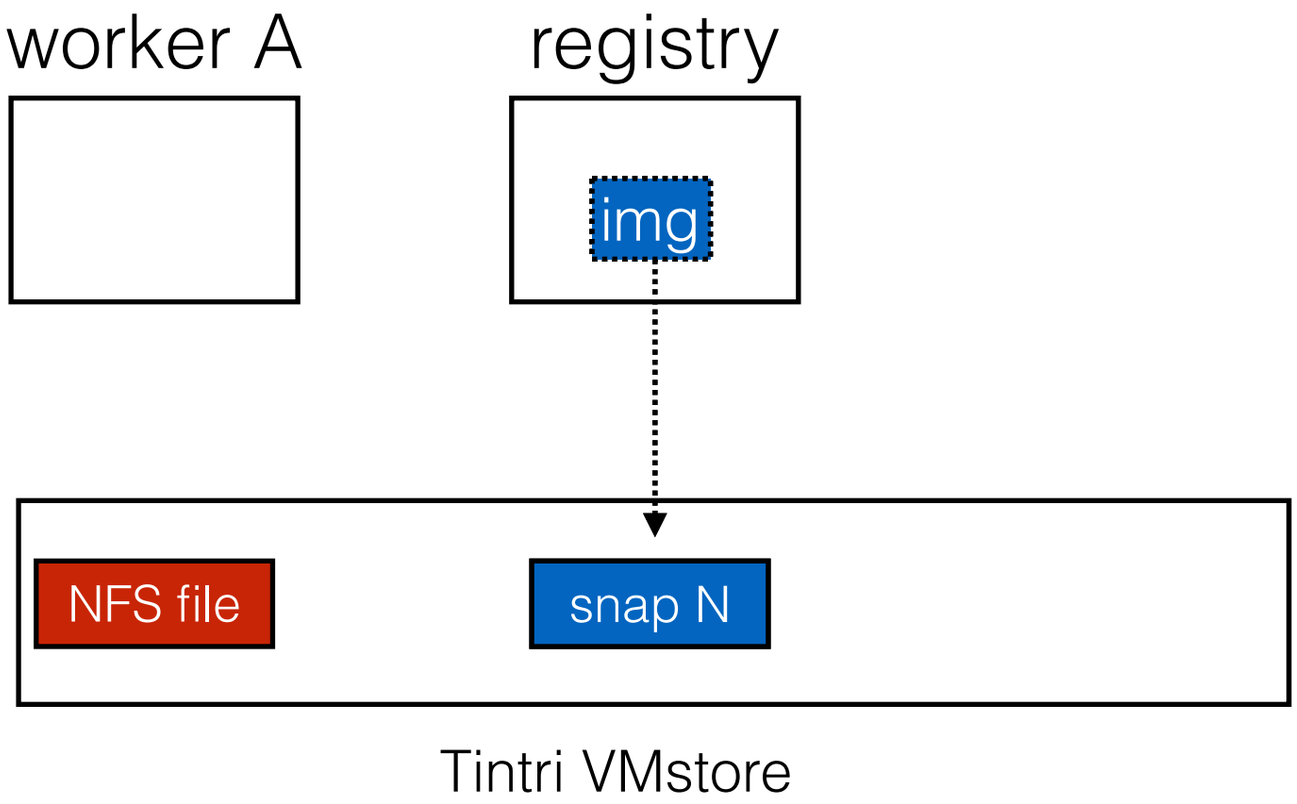

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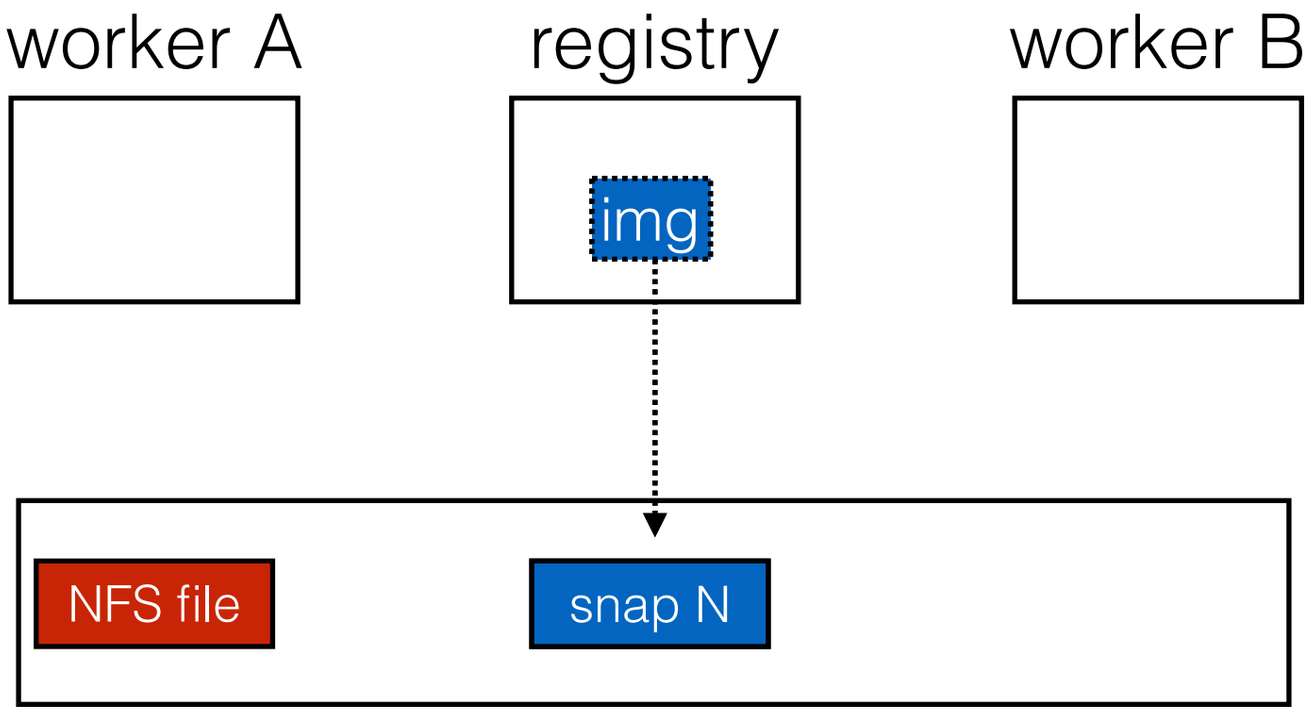

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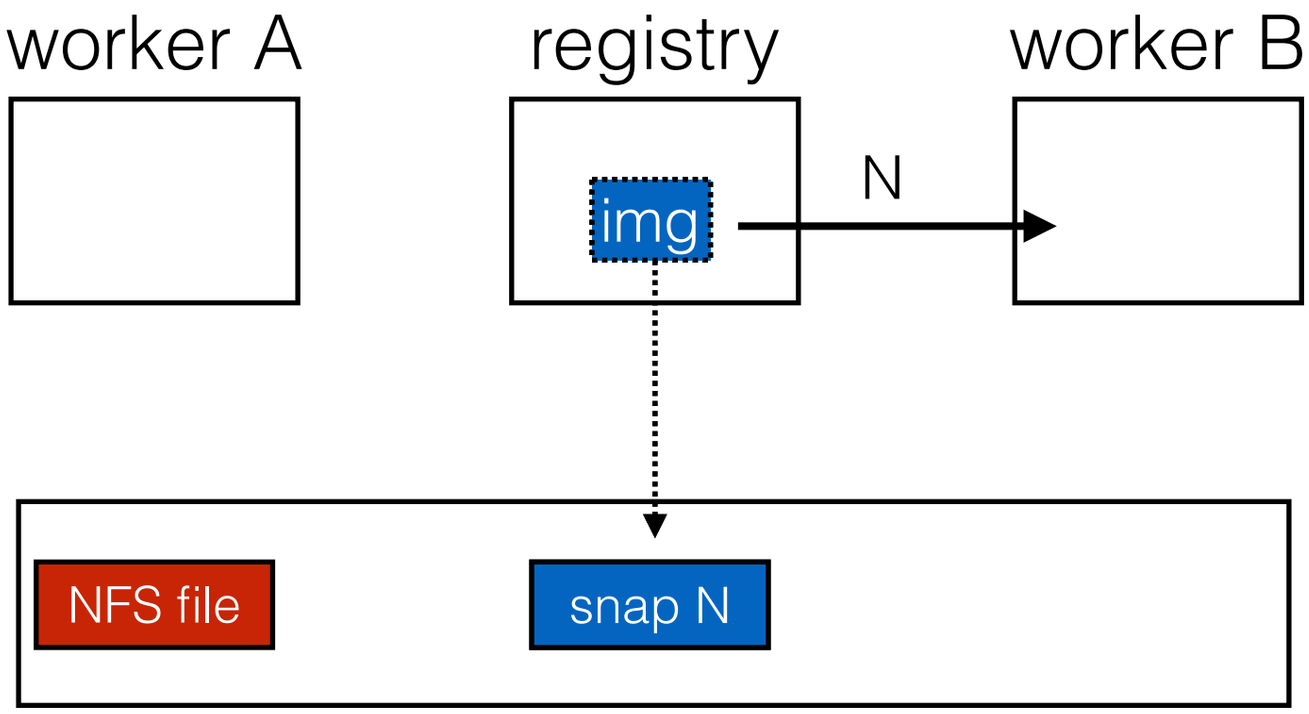

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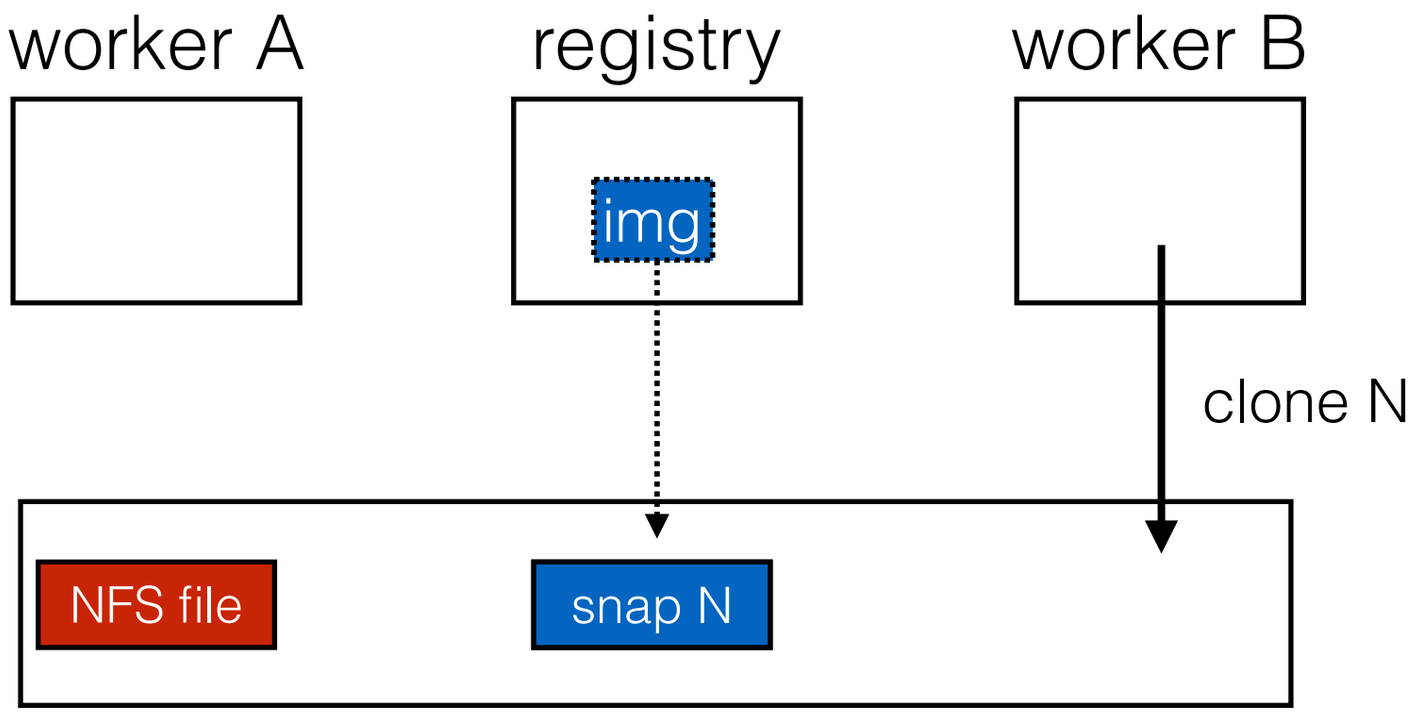

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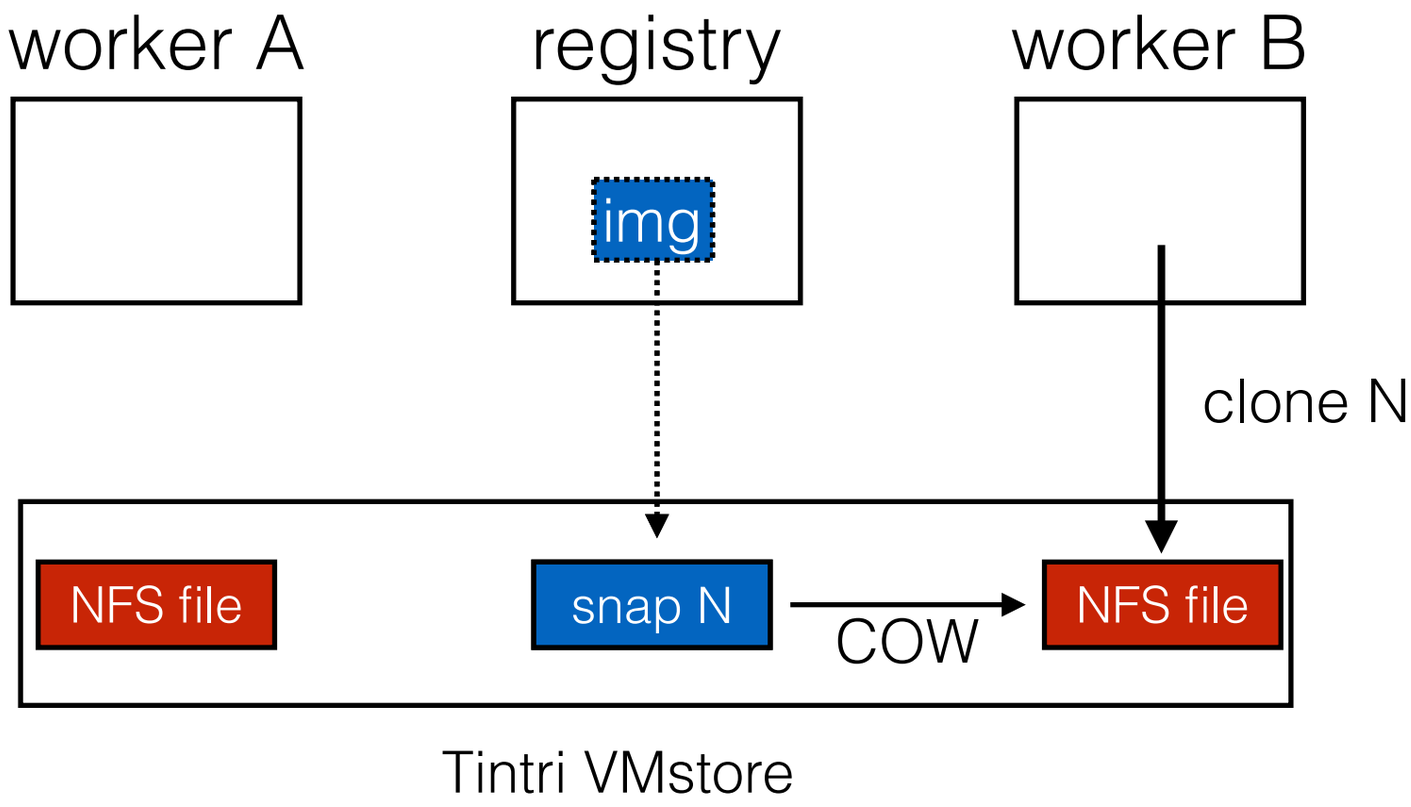

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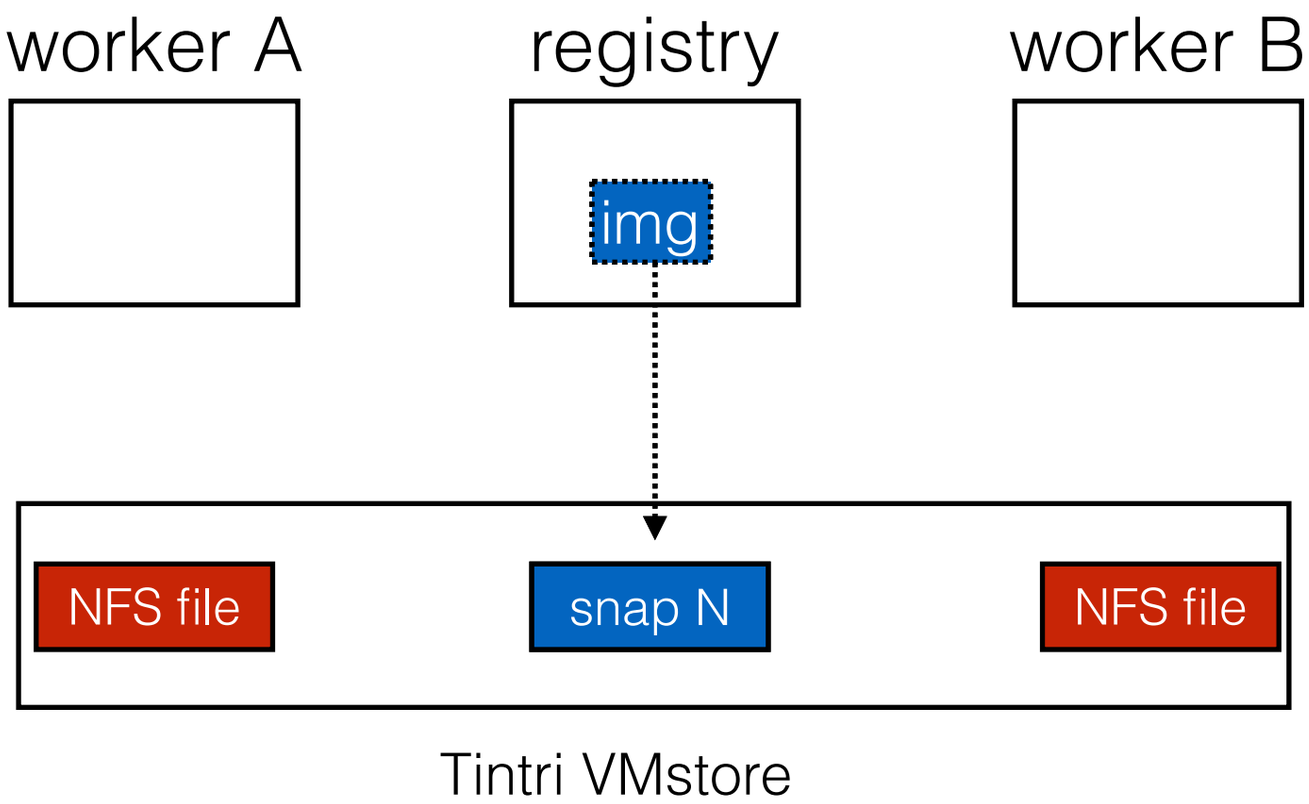

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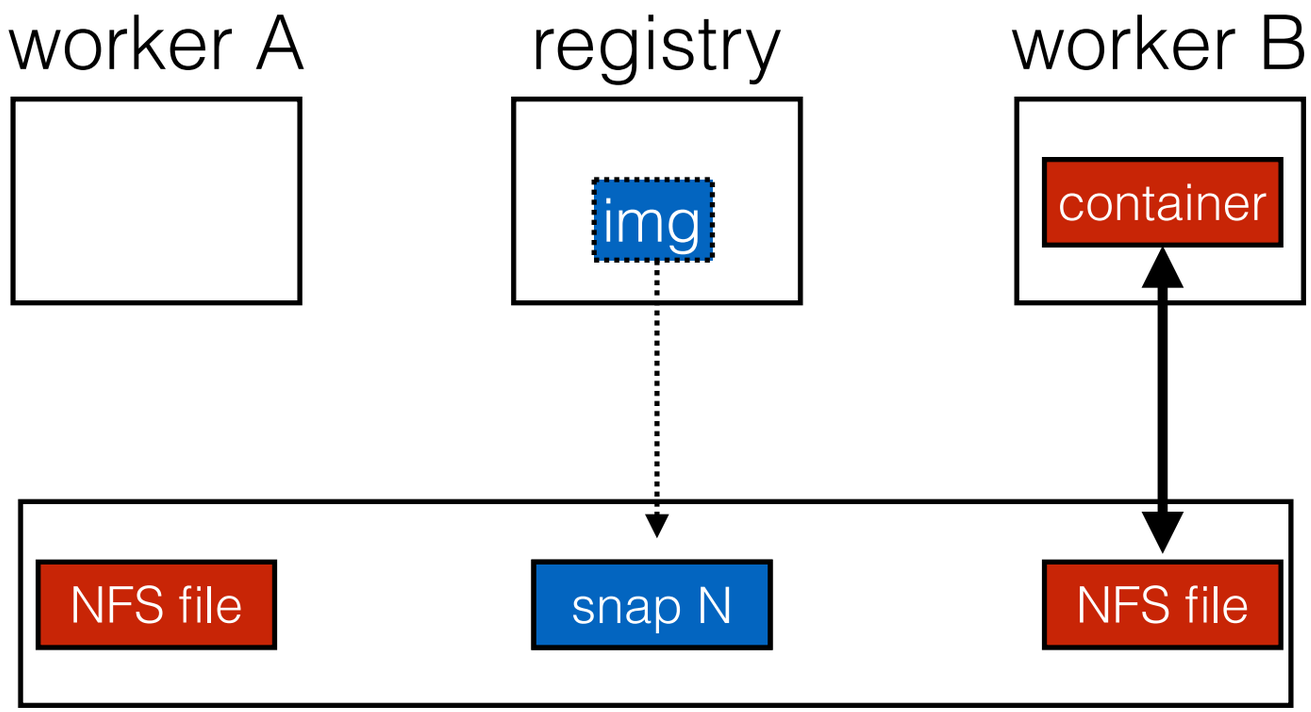

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Block Level

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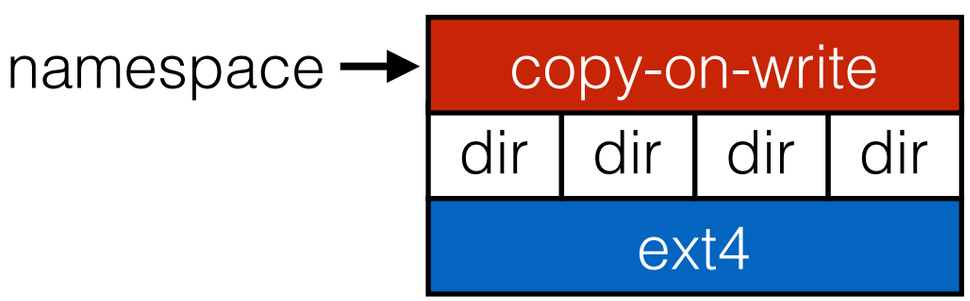
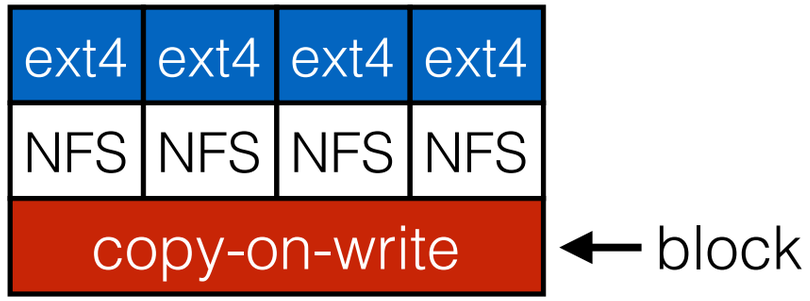


AUFS



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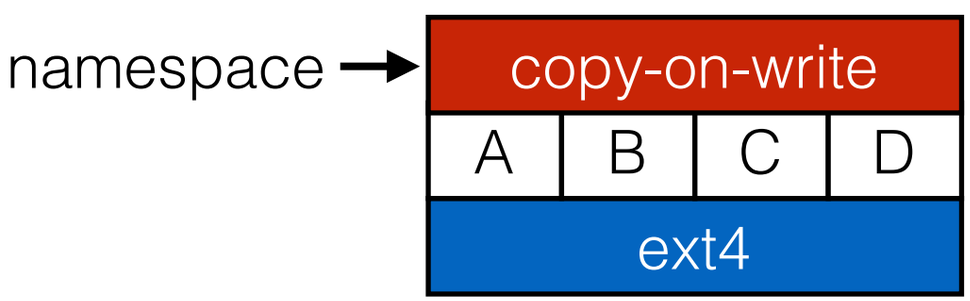
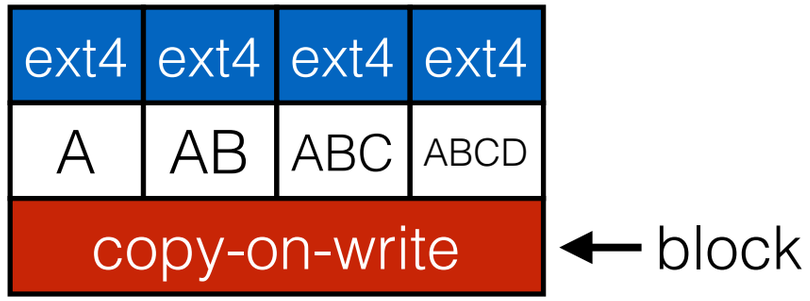


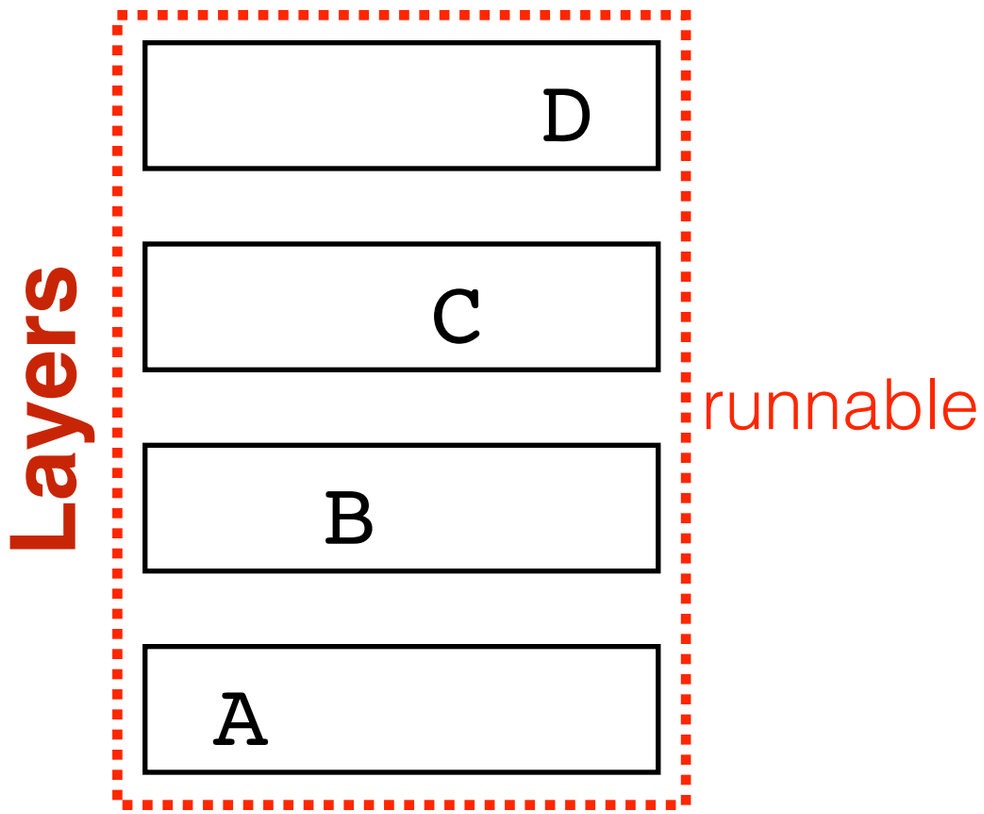
AUFS



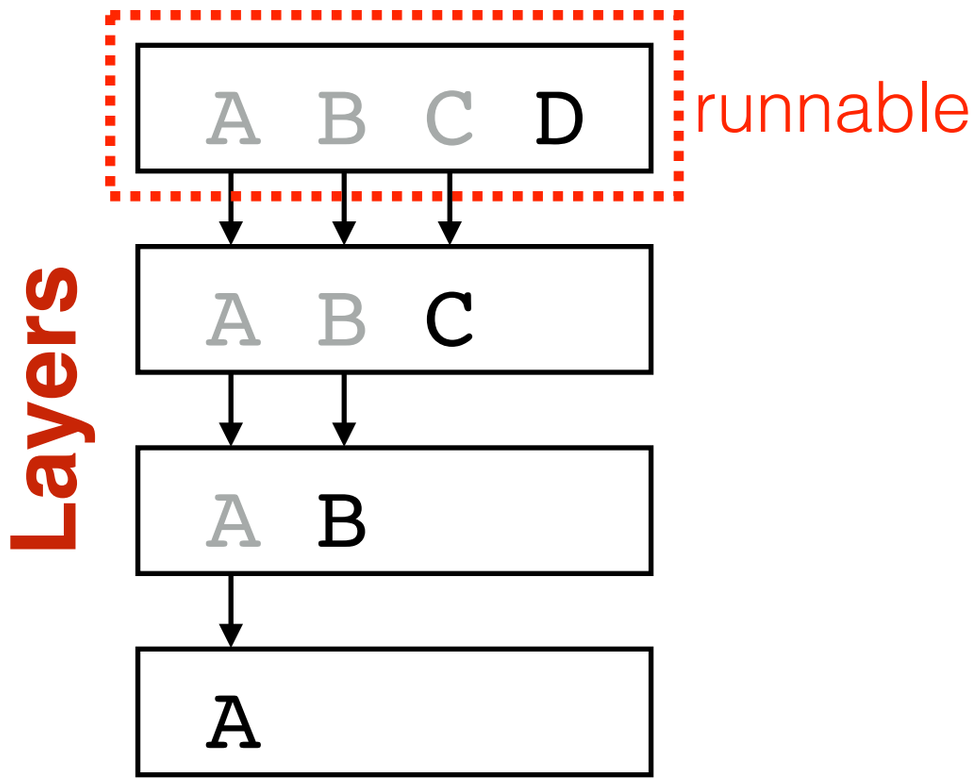
Slacker

Challenge: Framework Assumptions

Assumed Layout



Actual Layout



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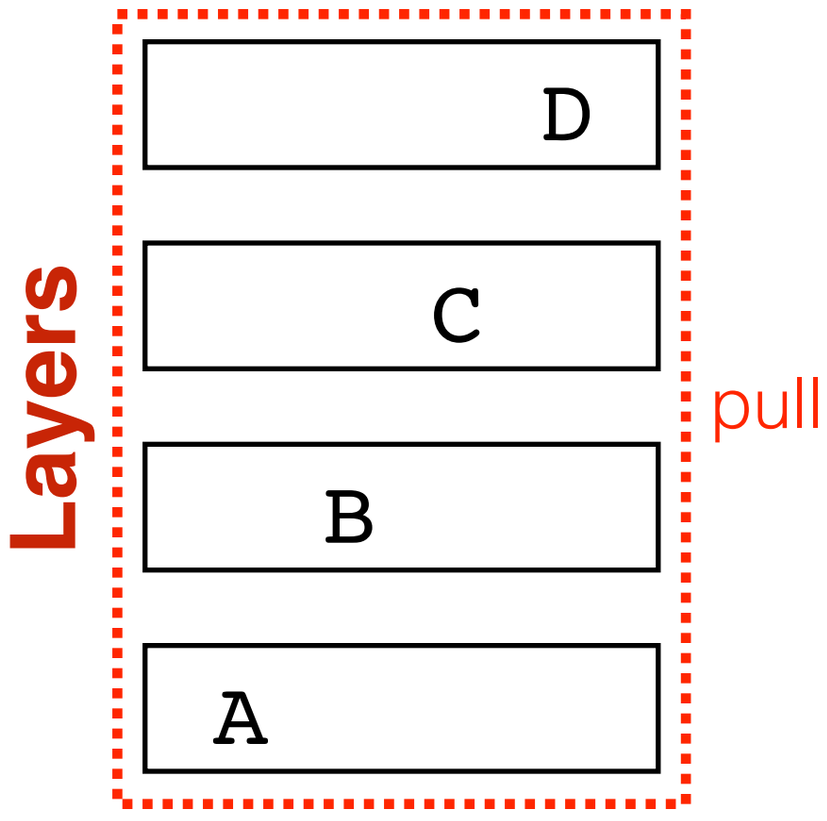
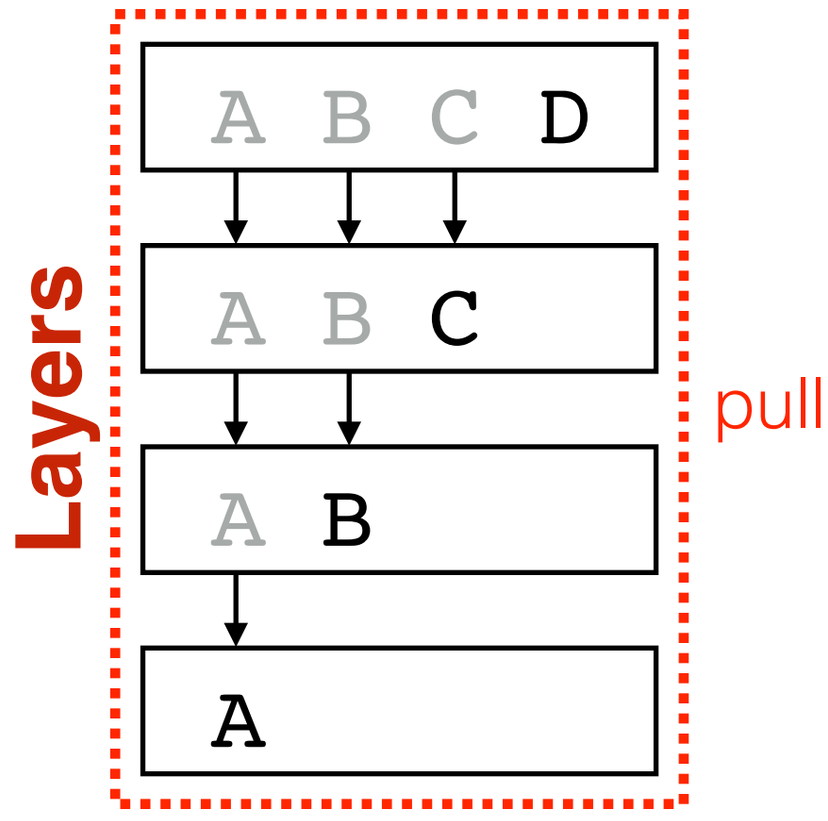
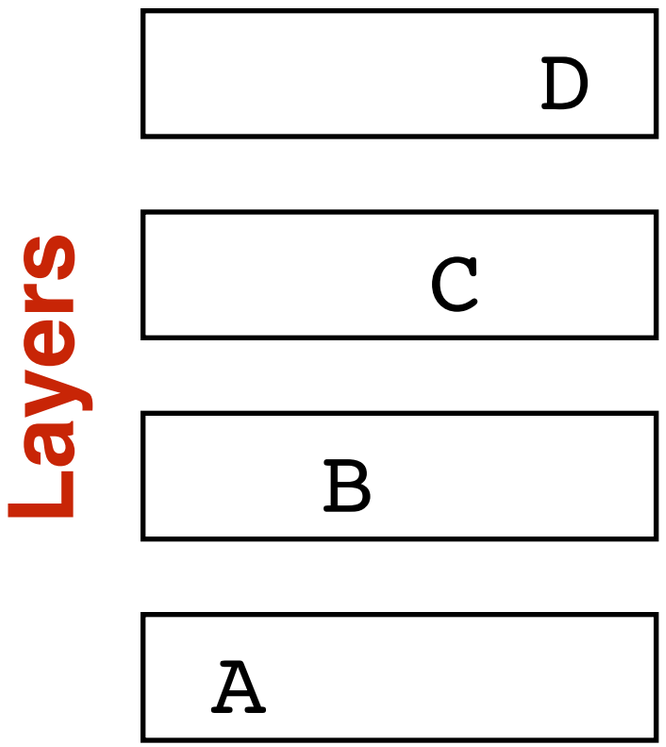




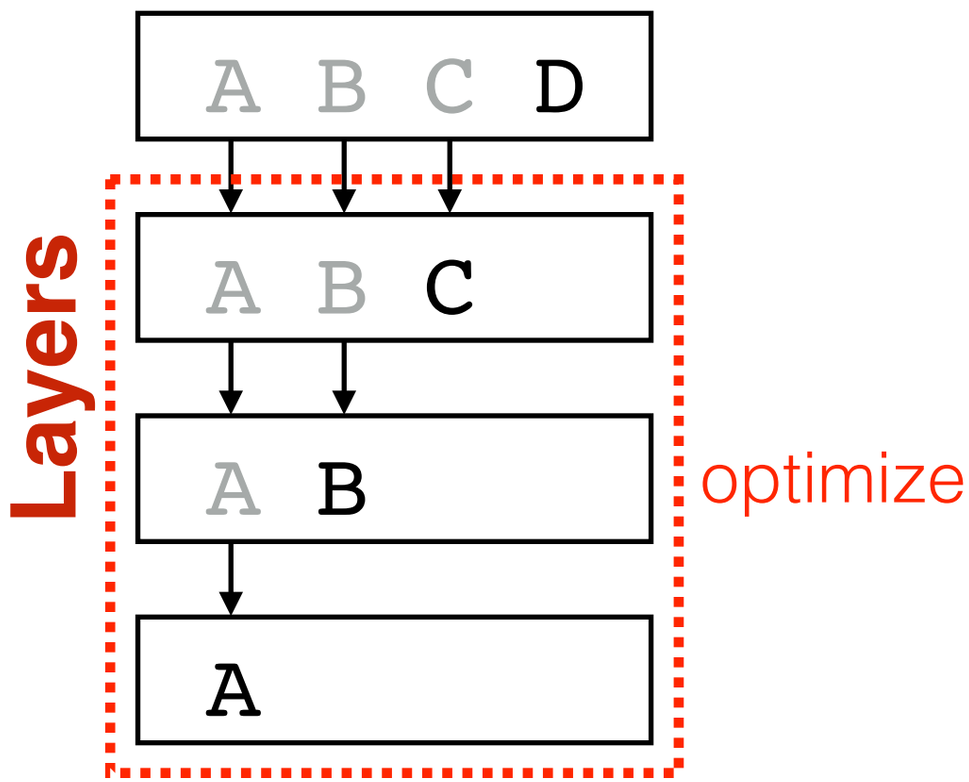
Challenge: Framework Assumptions

Strategy: **lazy cloning**. Don't clone non-top layers until Docker tries to mount them.

Assumed Layout



Actual Layout



Slacker Driver

Goals

- make push+pull very fast
- utilize powerful primitives of a modern storage server (Tintri VMstore)
- create drop-in replacement; don't change Docker framework itself

Design

- lazy pull
- layer flattening
- cache sharing

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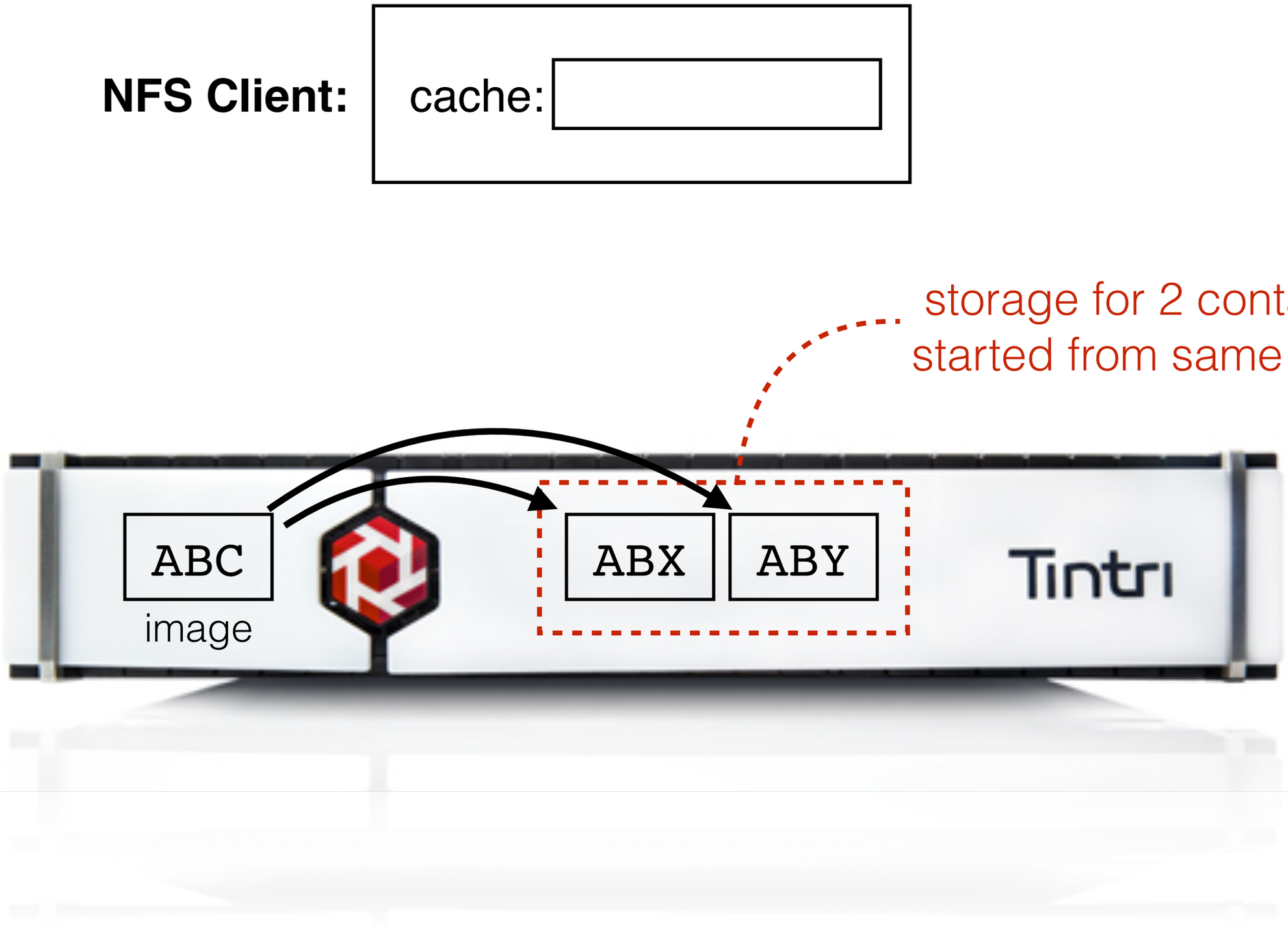
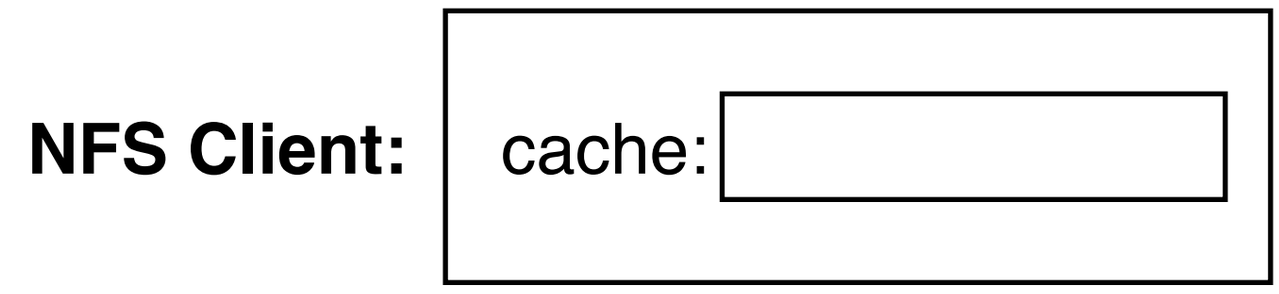
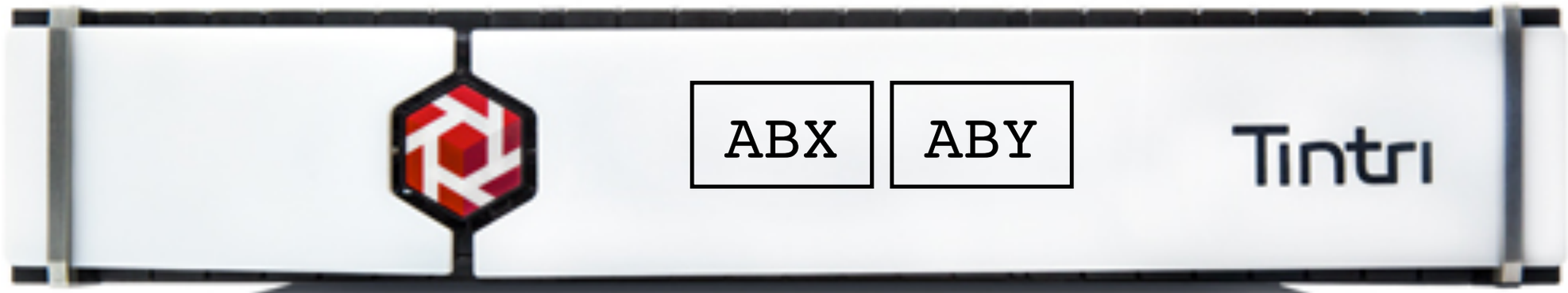


Challenge: Cache Sharing





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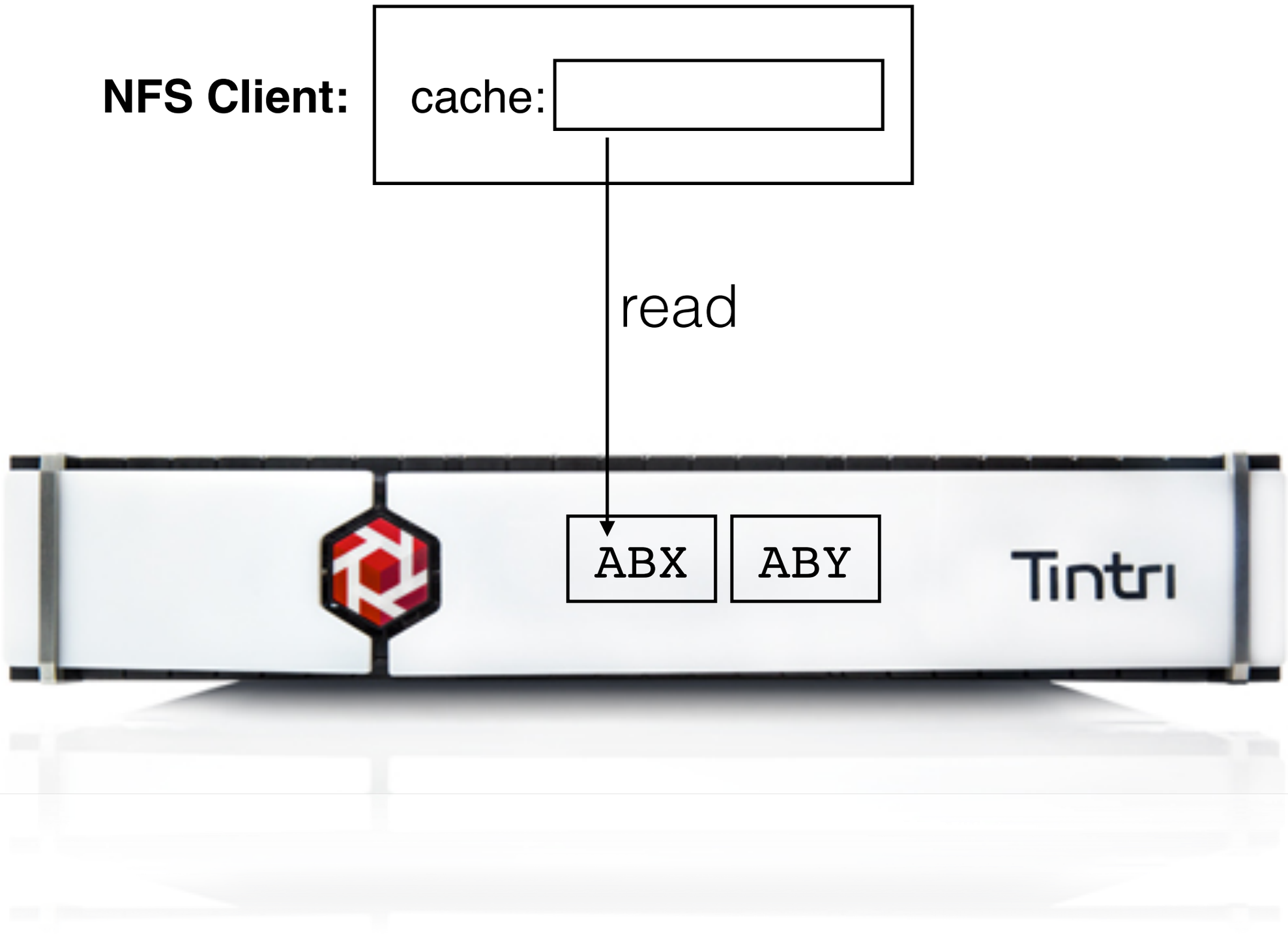
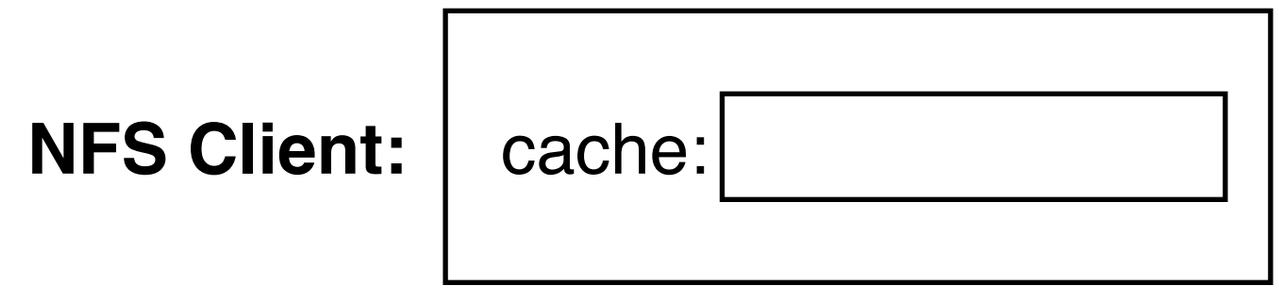
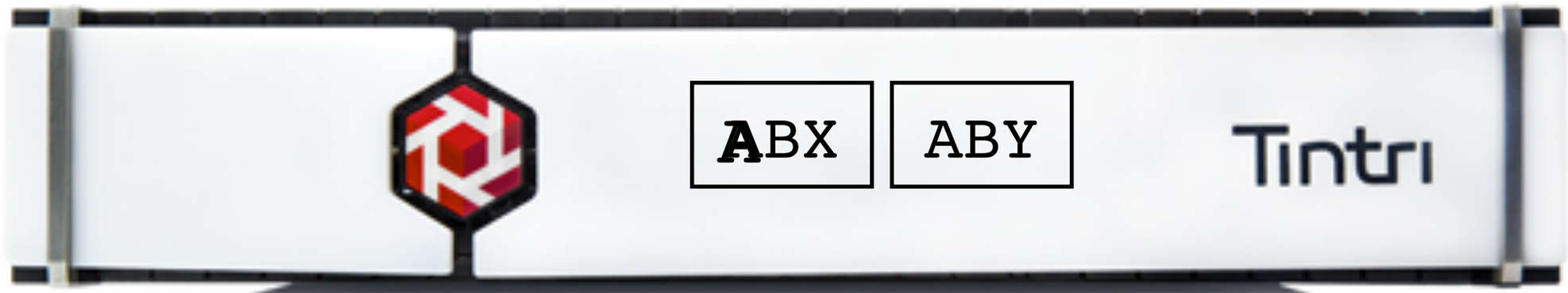


Challenge: Cache Sharing





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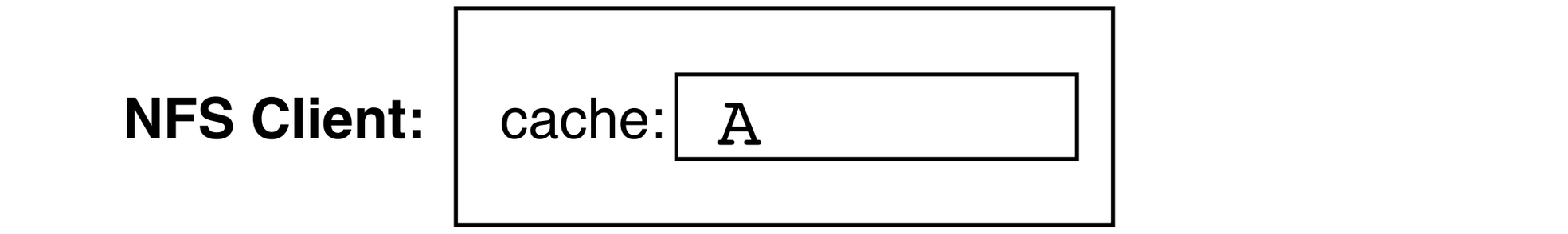

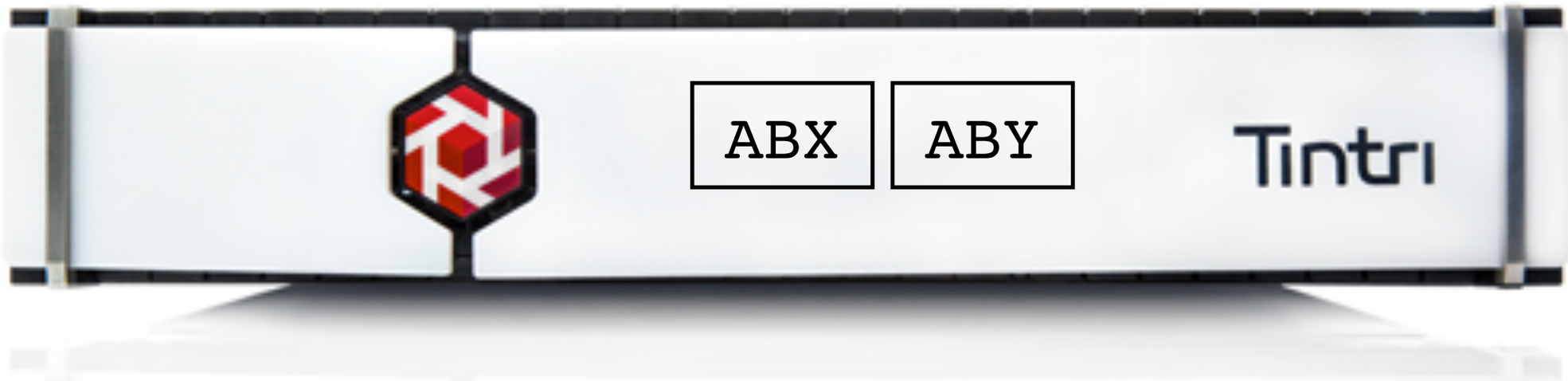

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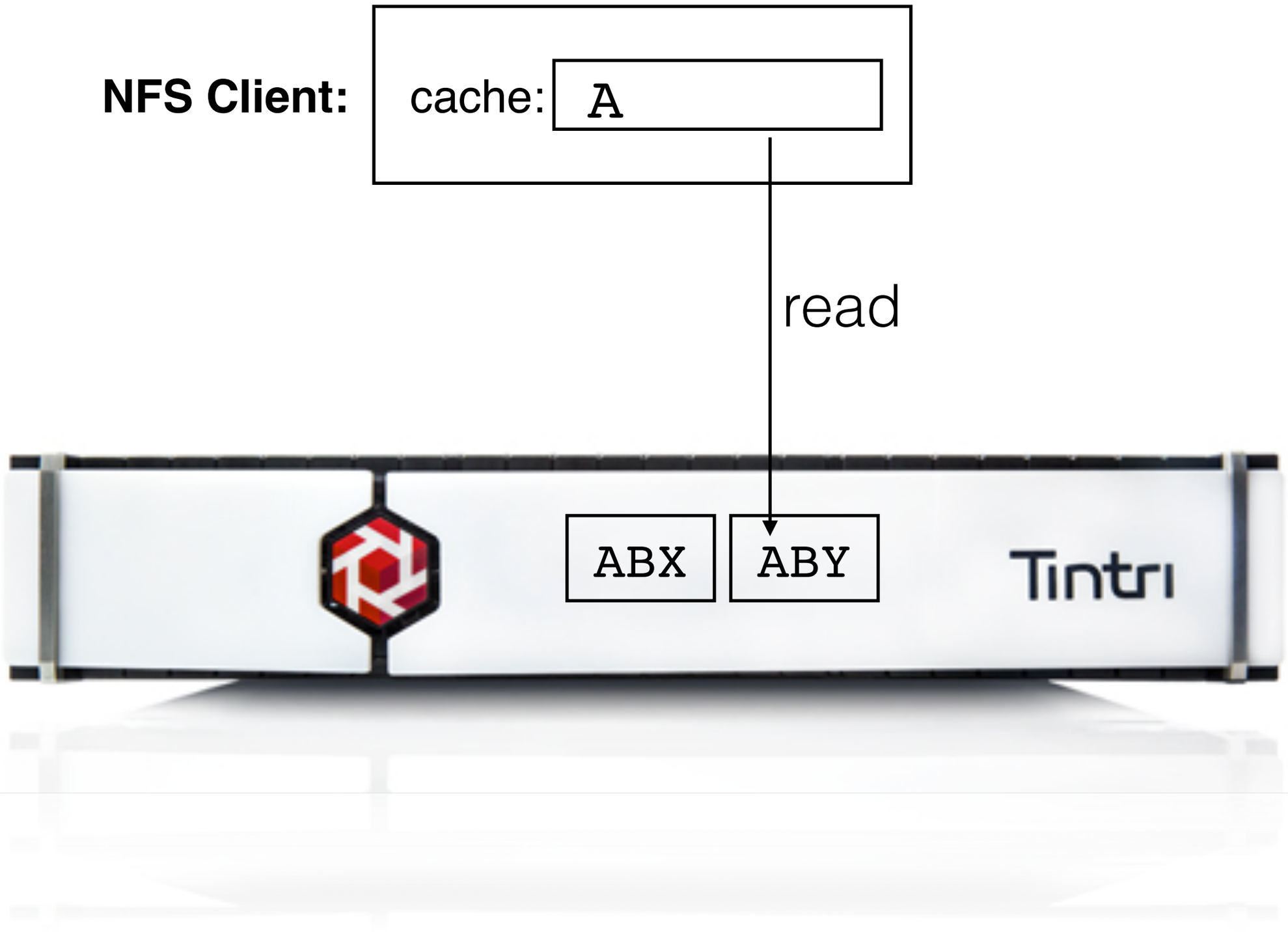

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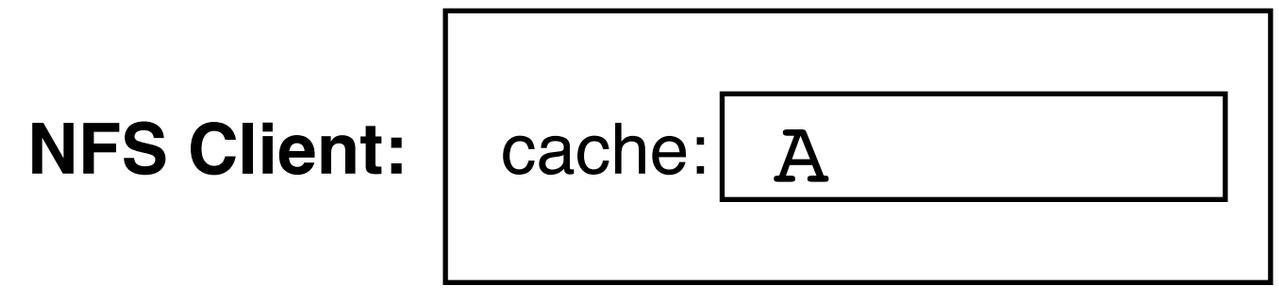

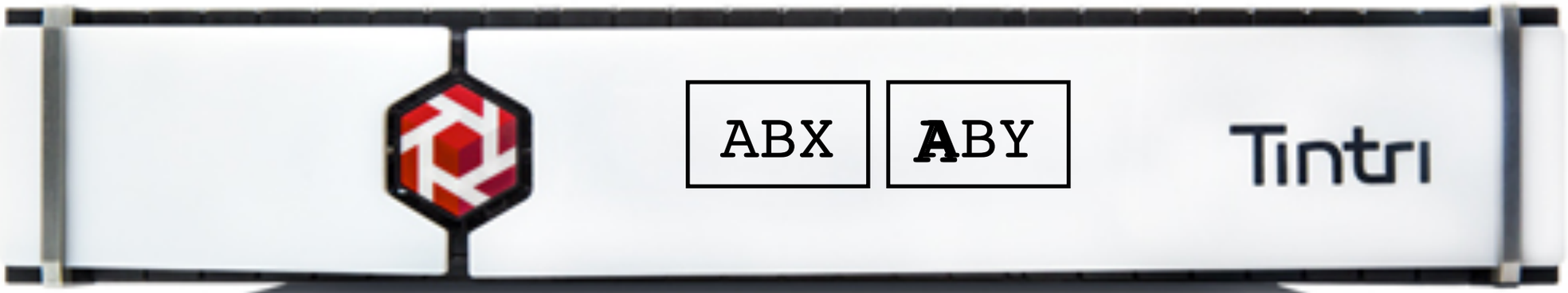

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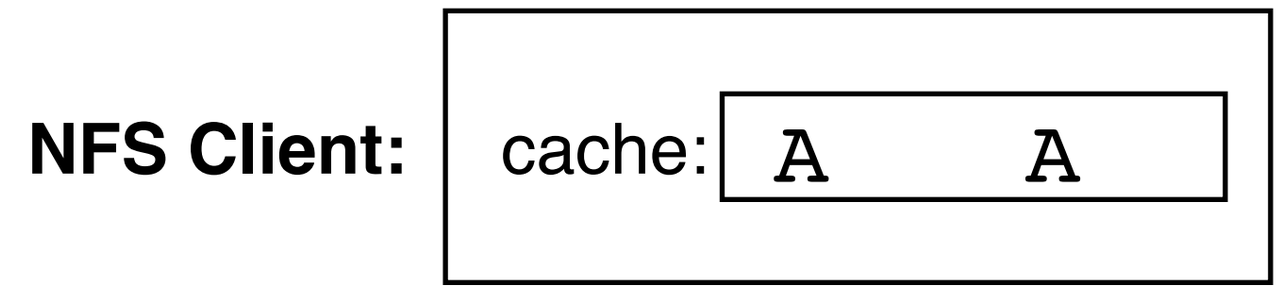

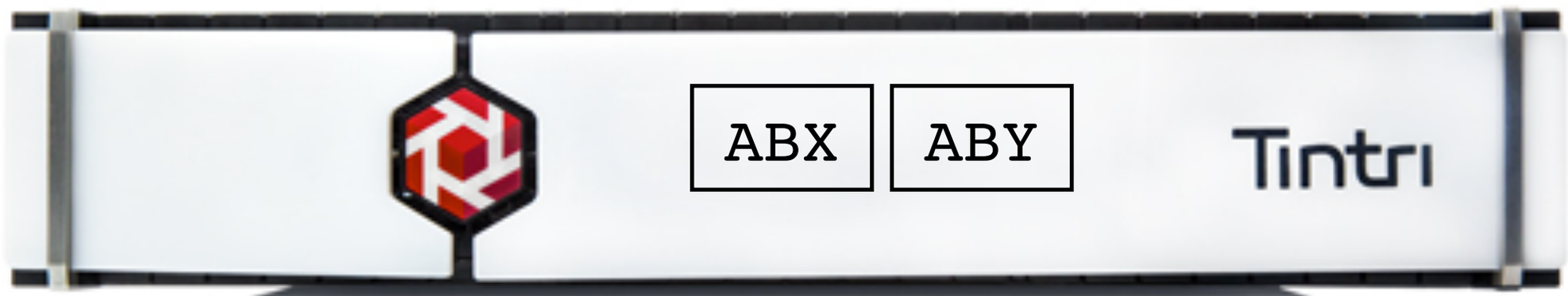

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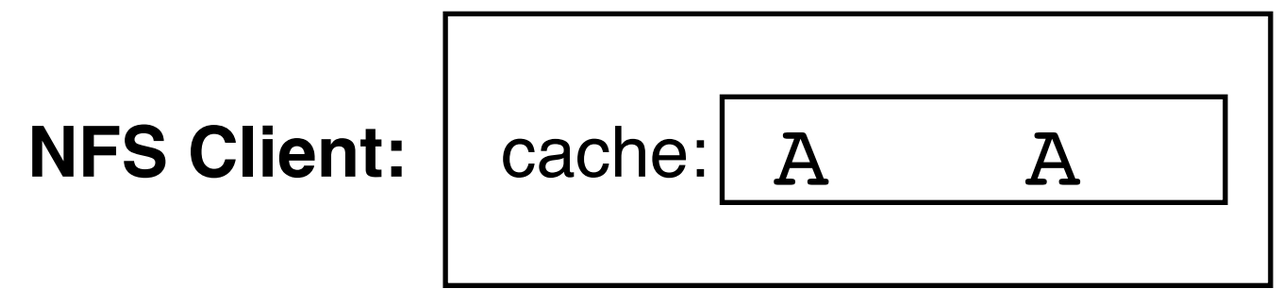
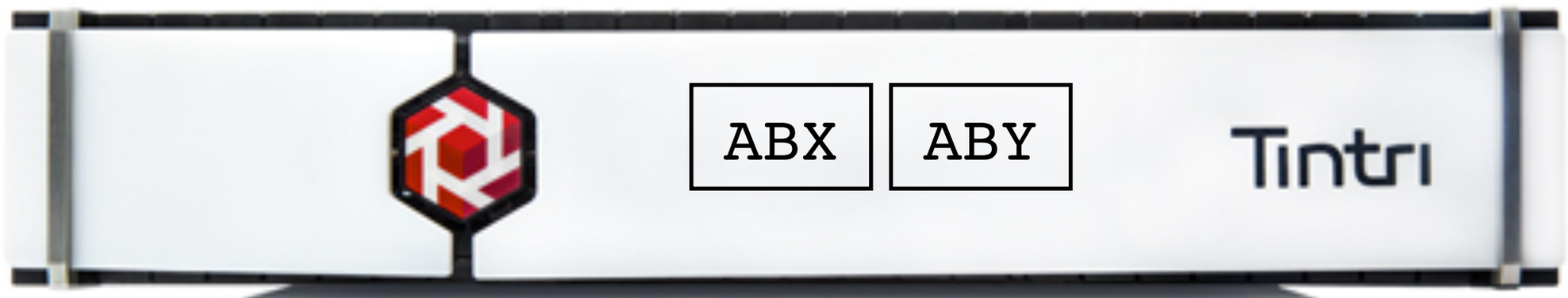


Challenge: how to avoid space and I/O waste?



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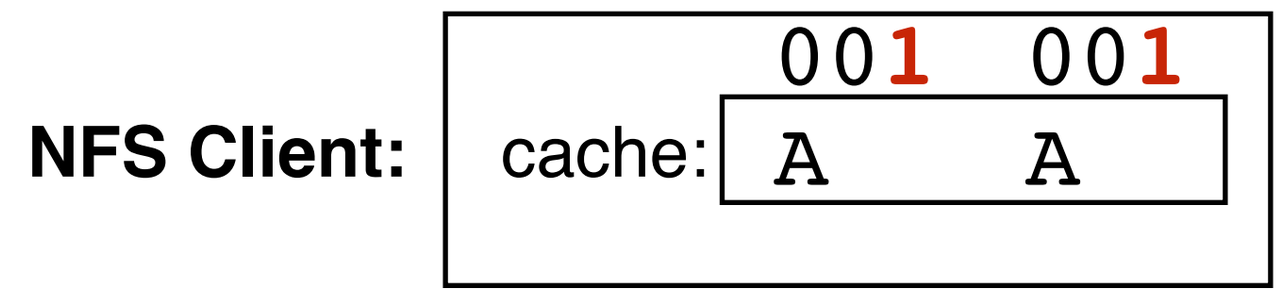
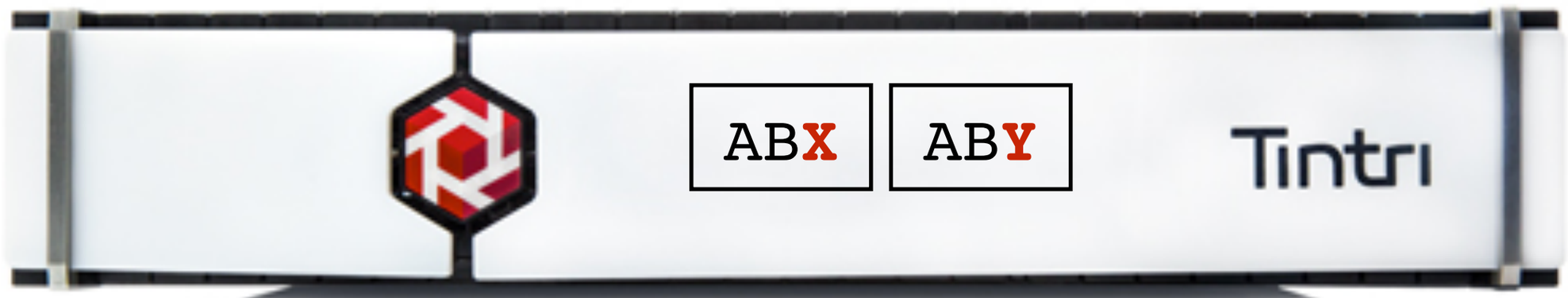


Strategy: track differences and deduplicate I/O (more in paper)



Slacker Outline

Background

Container Workloads

Default Driver: AUFS

Our Driver: Slacker

Evaluation

Conclusion

Questions

What are deployment and development speedups?

How is long-term performance?

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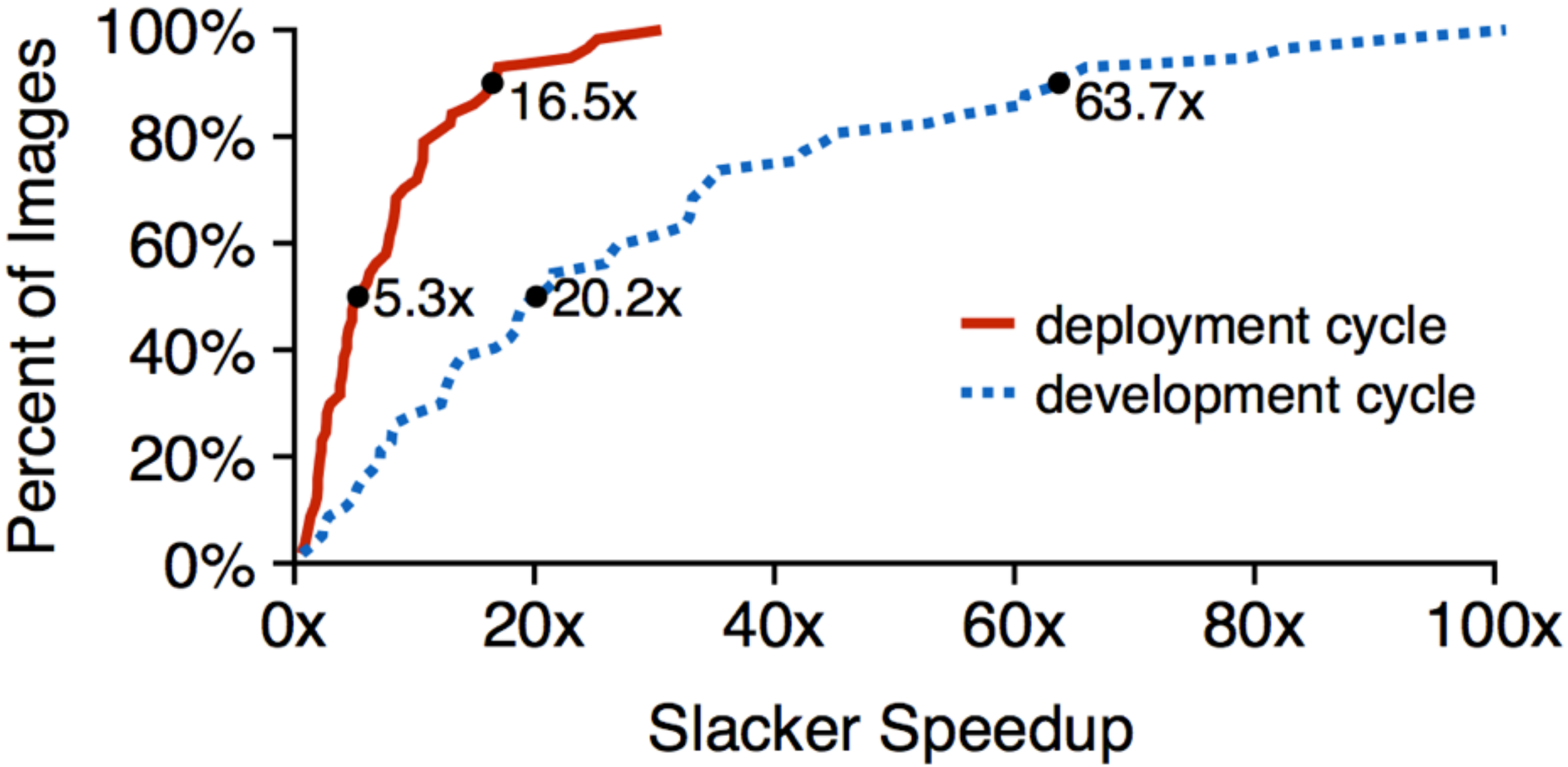
How is long-term performance?

HelloBench Performance



deployment: pull+run
development: push+pull+run

Questions

What are deployment and development speedups?

- 5x and 20x faster respectively (median speedup)

How is long-term performance?

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Server Benchmarks

Databases and Web Servers

- PostgreSQL
- Redis
- Apache web server (static)
- io.js Javascript server (dynamic)

Experiment

- measure throughput (after startup)
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Experiment

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Result: Slacker is always at least as fast as AUFS

Questions

What are deployment and development speedups?

- 5x and 20x faster respectively (median speedup)

How is long-term performance?

- there is no long-term penalty for being lazy

Slacker Outline

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Container Workloads

Default Driver: AUFS

Our Driver: Slacker

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Conclusion

Containers are inherently lightweight

- but existing frameworks are not

COW between workers is necessary for fast startup

- use shared storage
- utilize VMstore snapshot and clone

Slacker driver

- **5x** deployment speedup
- **20x** development speedup

HelloBench: https://github.com/Tintri/hello-bench

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