Neil Conway, Niklas Nielsen, Greg Mann & Sunil Shah

POWERING THE INTERNET WITH APACHE MESOS

MESOSPHERE

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MESOS: ORIGINS

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THE BIRTH OF MESOS

Spring 2009

CS262B

Ben Hindman, Andy Konwinski and Matei Zaharia create “Nexus” as their CS262B class project.

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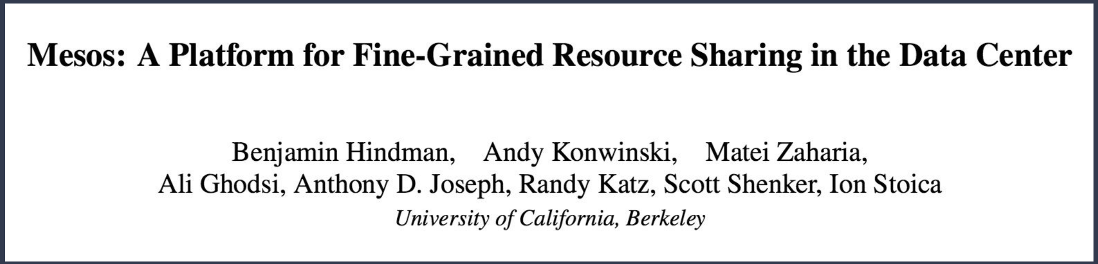
TECHNOLOGY

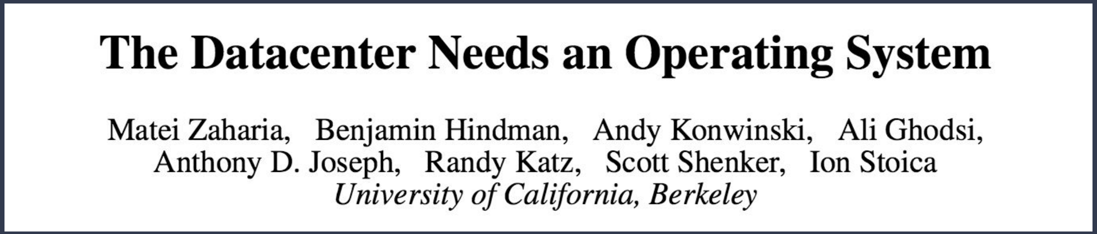

Mesos: A Platform for Fine-Grained Resource Sharing in the Data Center

Benjamin Hindman, Andy Konwinski, Matei Zaharia,
Ali Ghodsi, Anthony D. Joseph, Randy Katz, Scott Shenker, Ion Stoica
University of California, Berkeley

Sharing resources between batch processing frameworks

- Hadoop
- MPI
- Spark

VISION


The Datacenter Needs an Operating System

Matei Zaharia, Benjamin Hindman, Andy Konwinski, Ali Ghodsi,
Anthony D. Joseph, Randy Katz, Scott Shenker, Ion Stoica
University of California, Berkeley

What does an operating system provide?

- Resource management
- Programming abstractions
- Security
- Monitoring, debugging, logging

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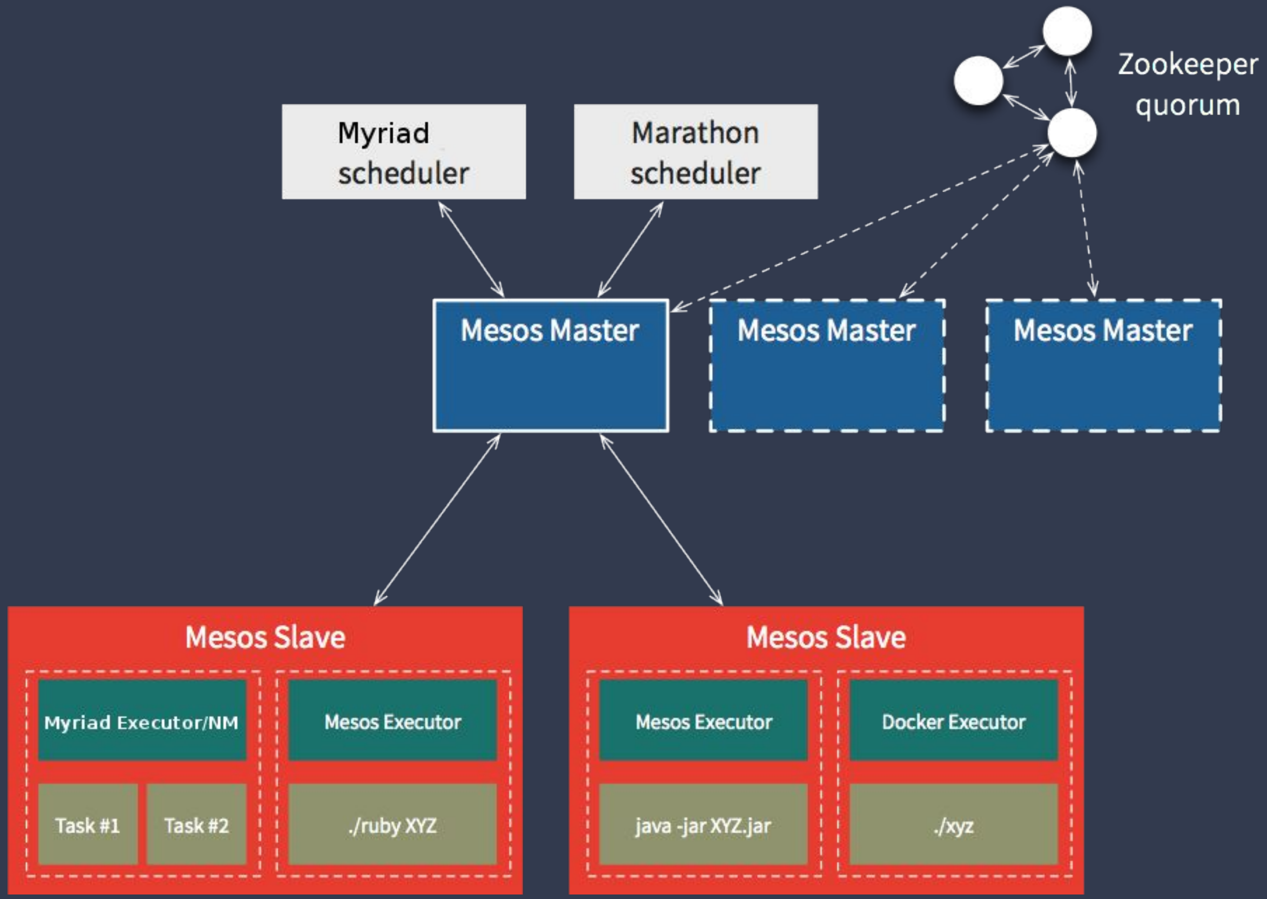
MESOS FUNDAMENTALS

ARCHITECTURE



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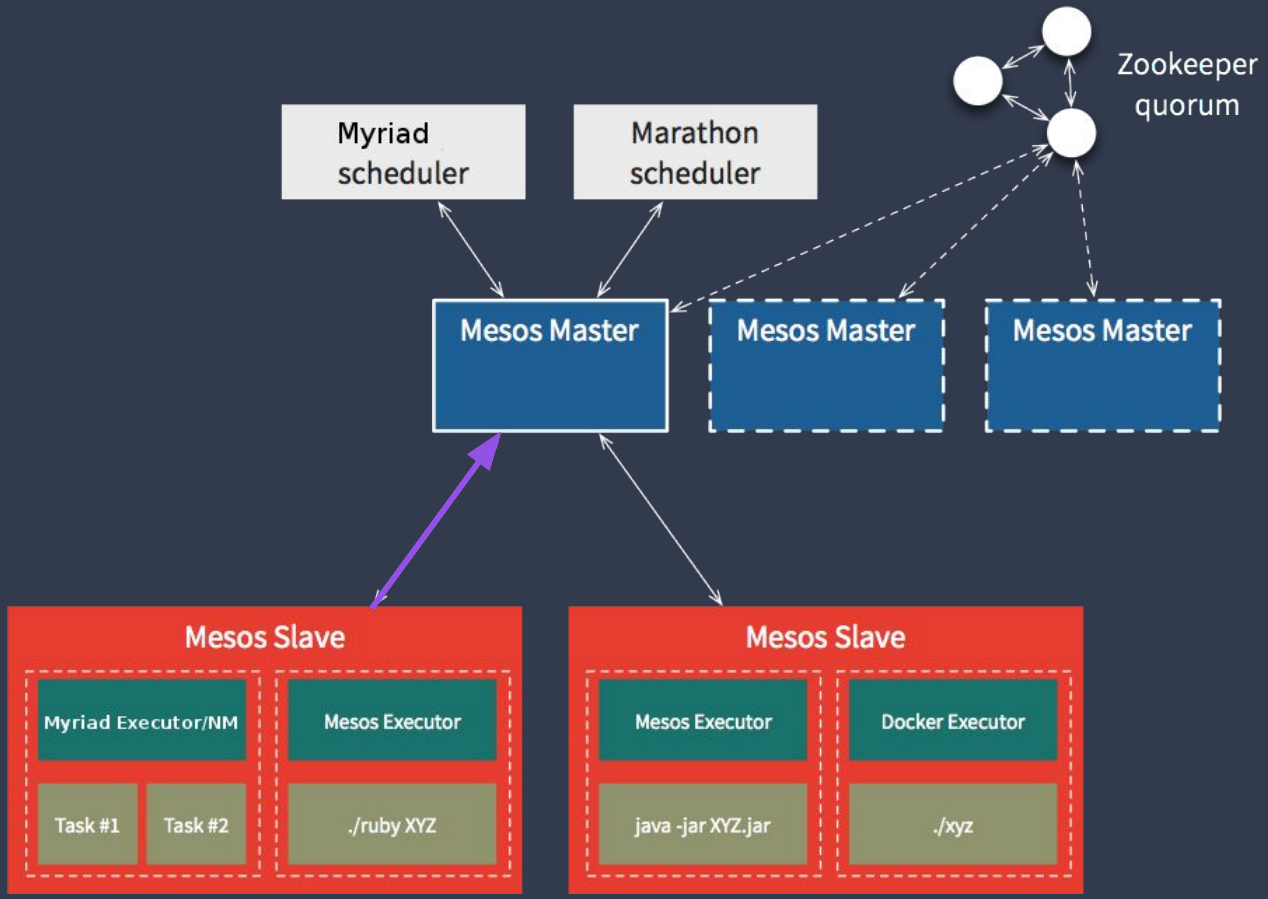
MESOS FUNDAMENTALS

ARCHITECTURE

- Agents advertise resources to Master
- Master offers resources to Framework
- Framework rejects/uses resources
- Agents report task status to Master



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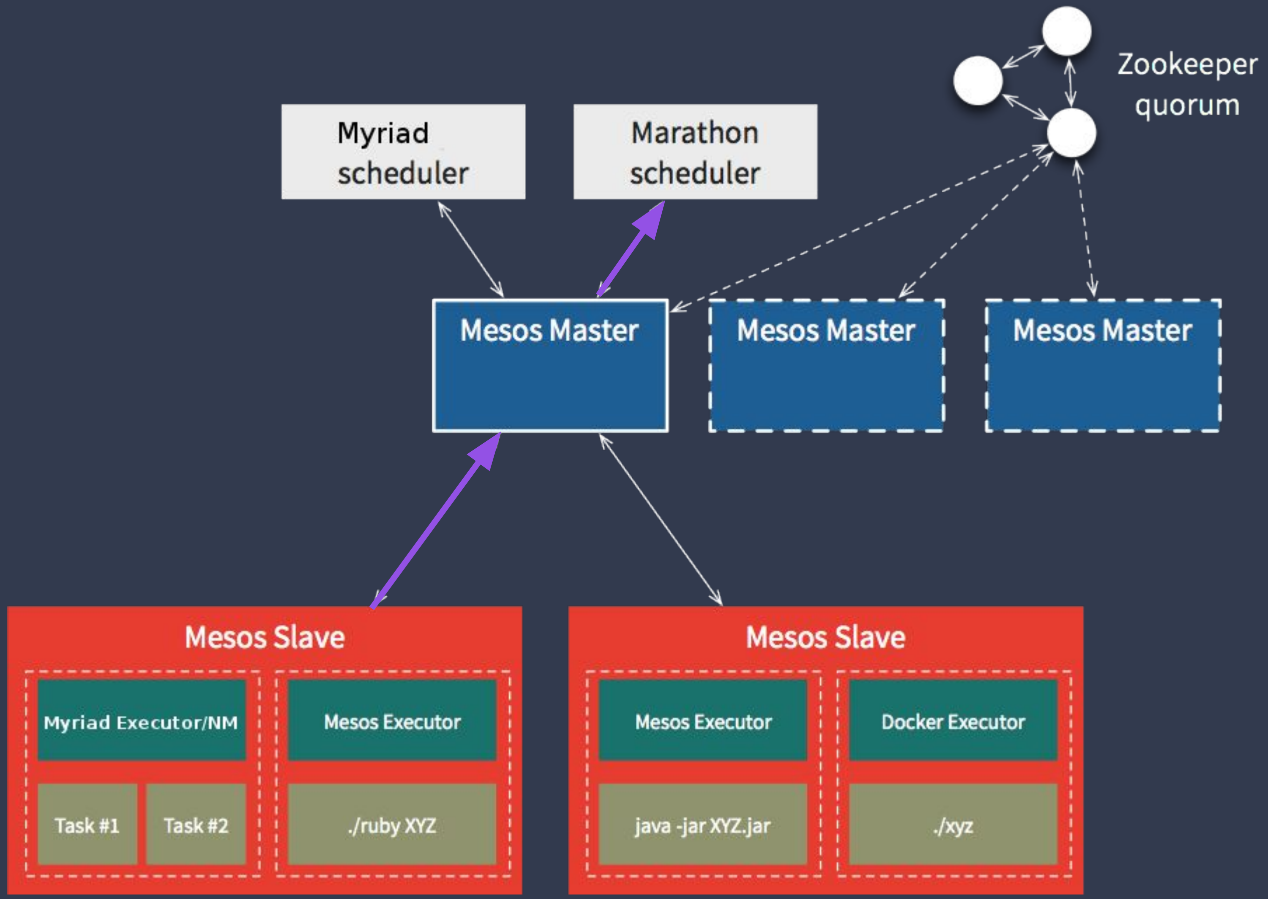

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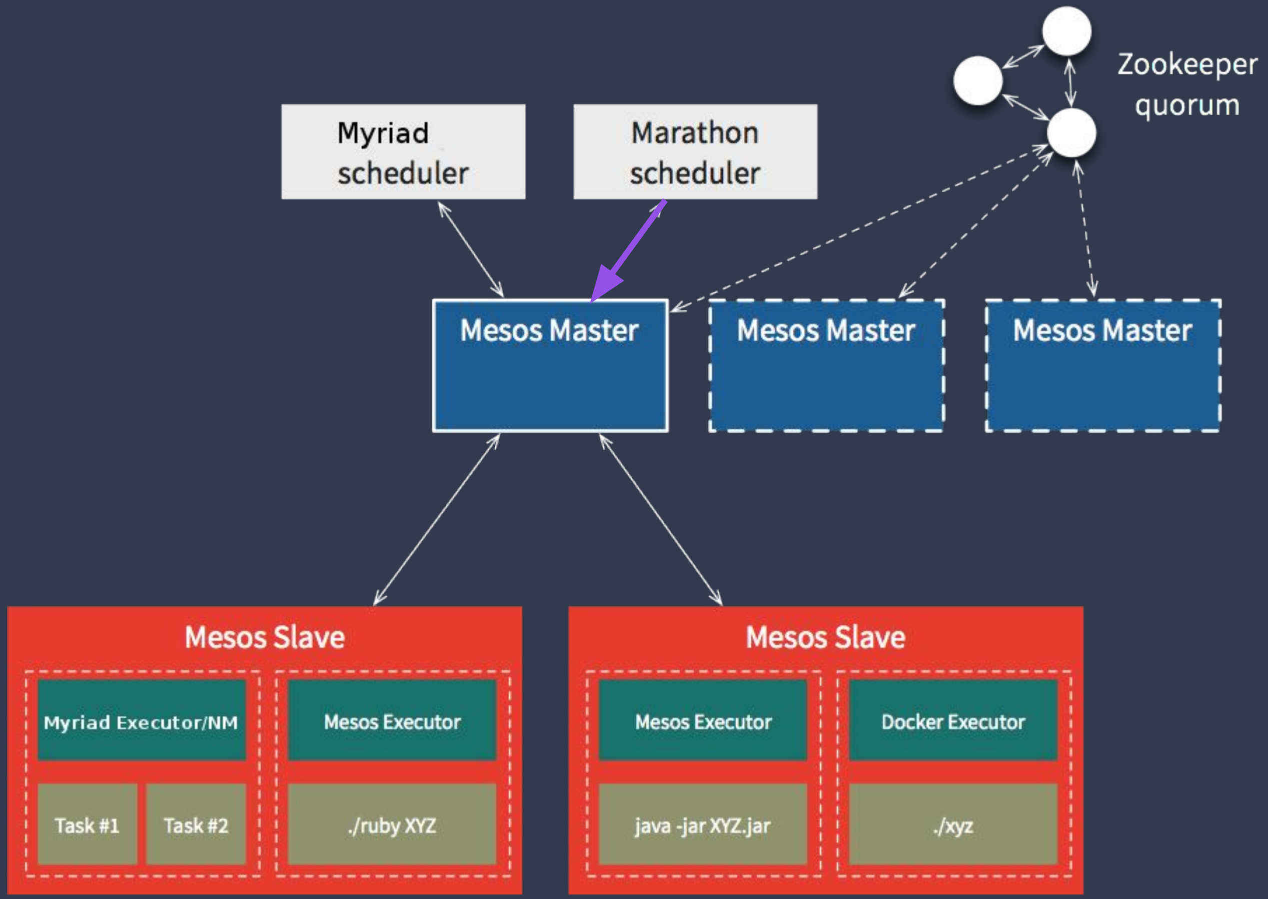

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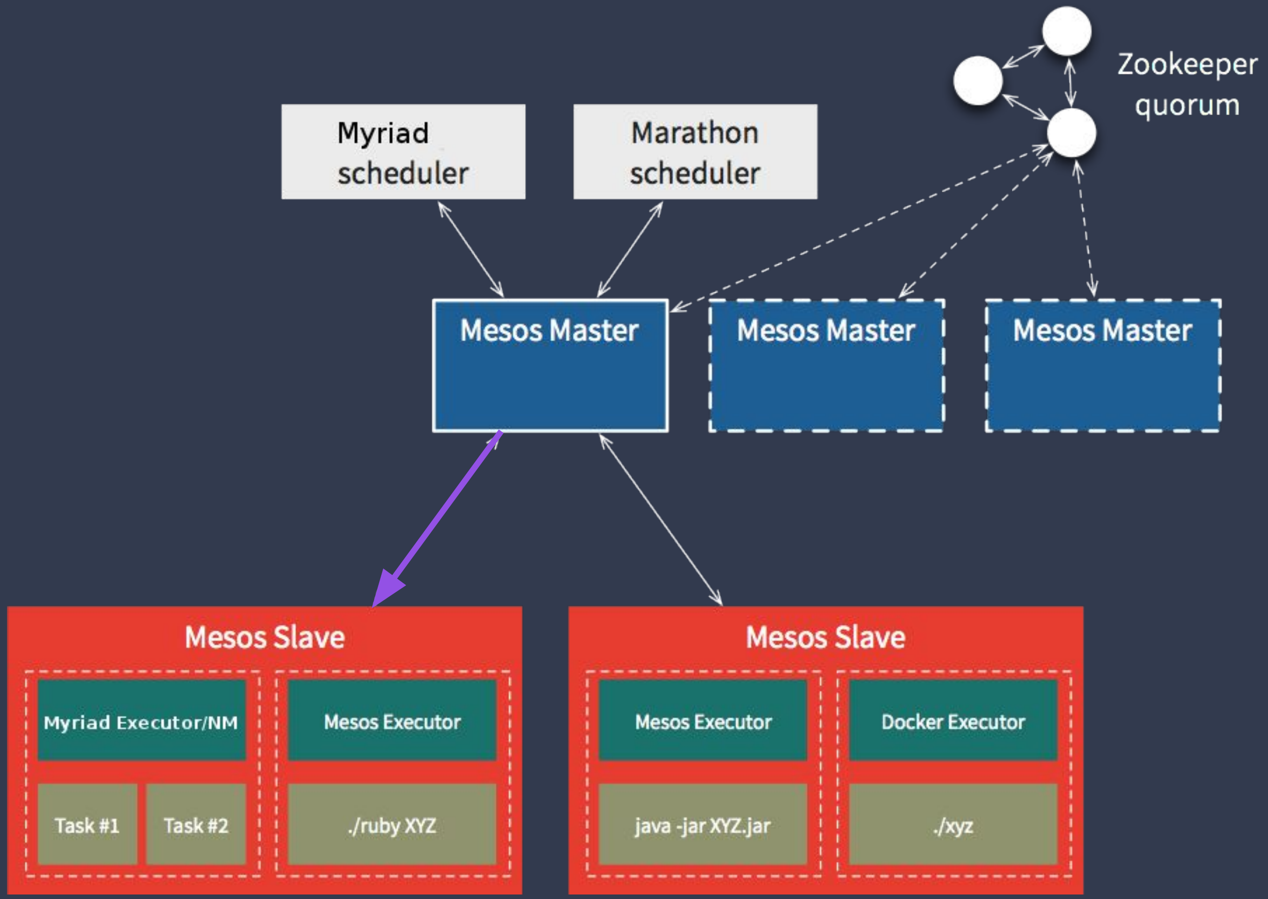

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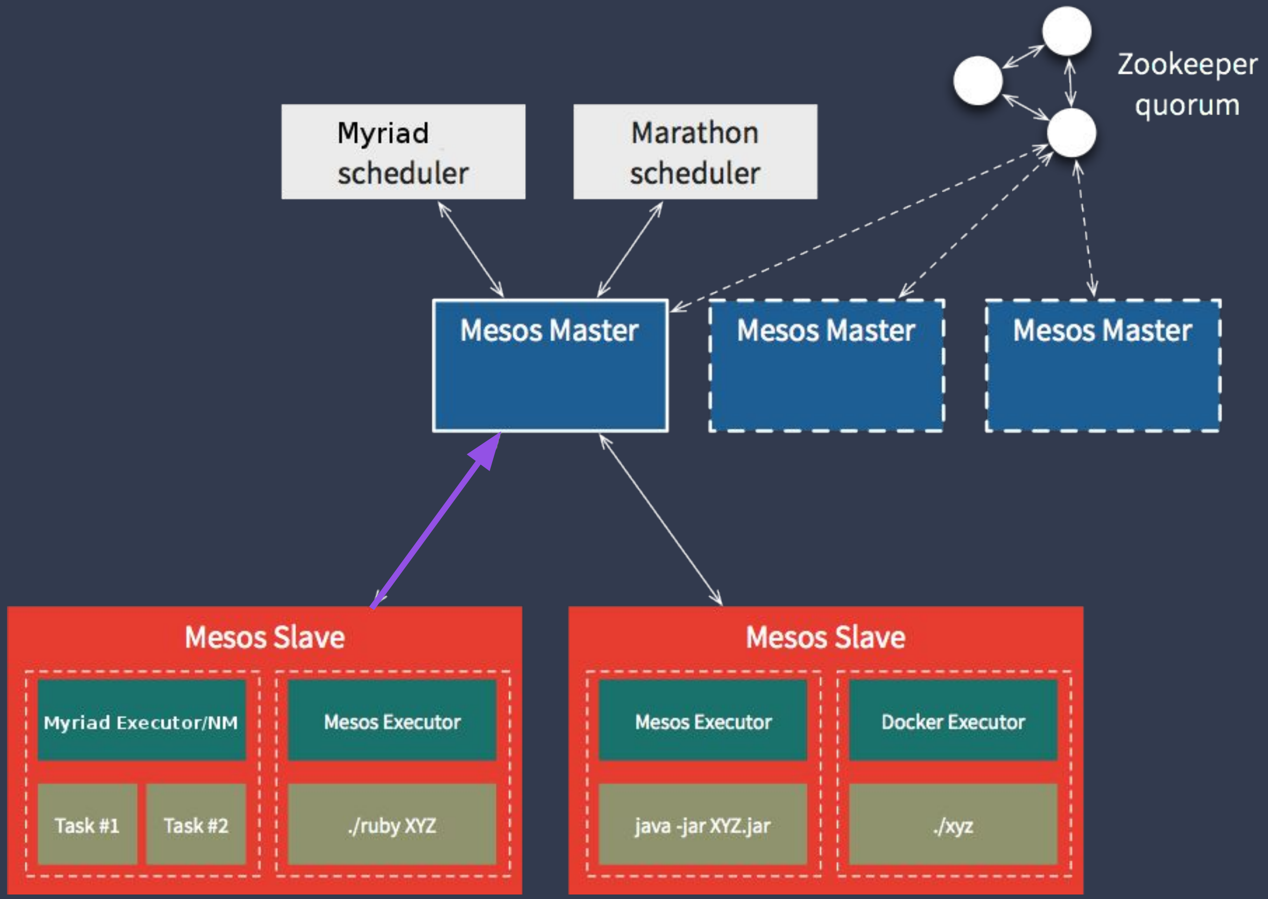

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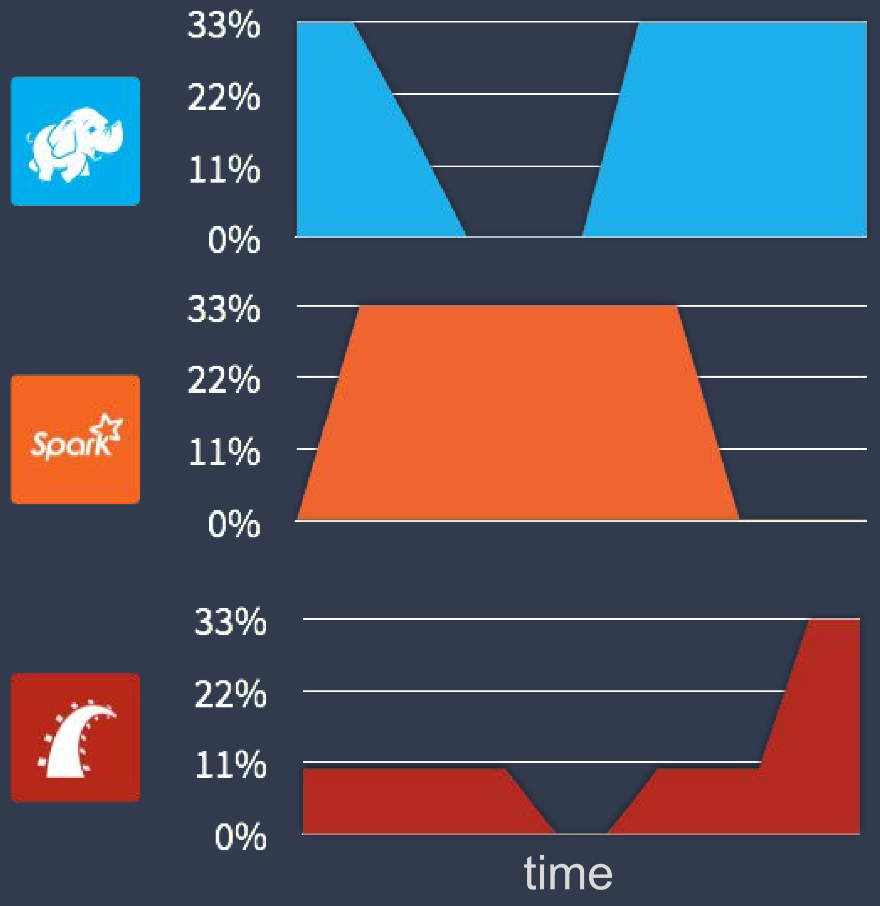
KEEP IT STATIC

A naive approach to handling varied app requirements: **static partitioning**.

This can cope with heterogeneity, but is very expensive.



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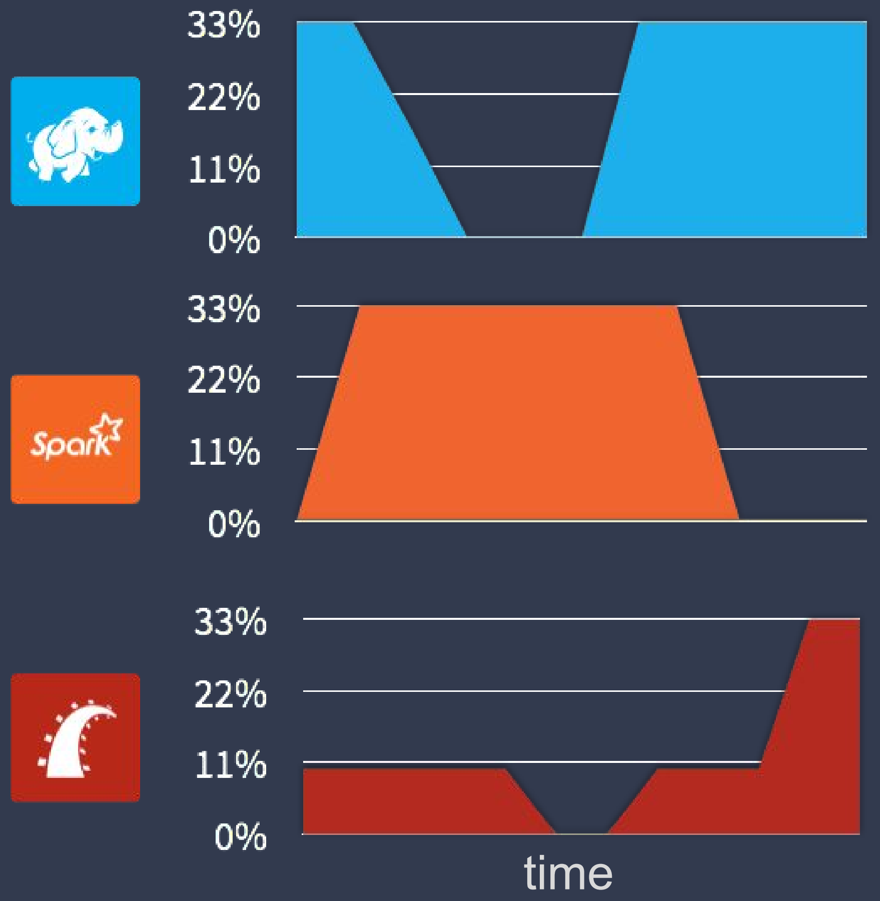
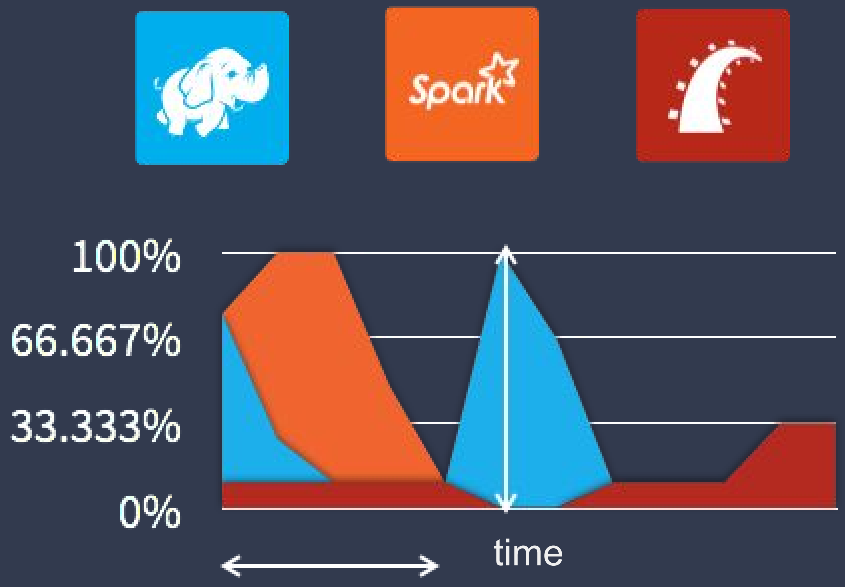
KEEP IT STATIC

Maintaining sufficient headroom to handle peak workloads on all partitions leads to **poor utilization** overall.



SHARED RESOURCES

Multiple frameworks can use the same cluster resources, with their share adjusting dynamically.



TWITTER & MESOS

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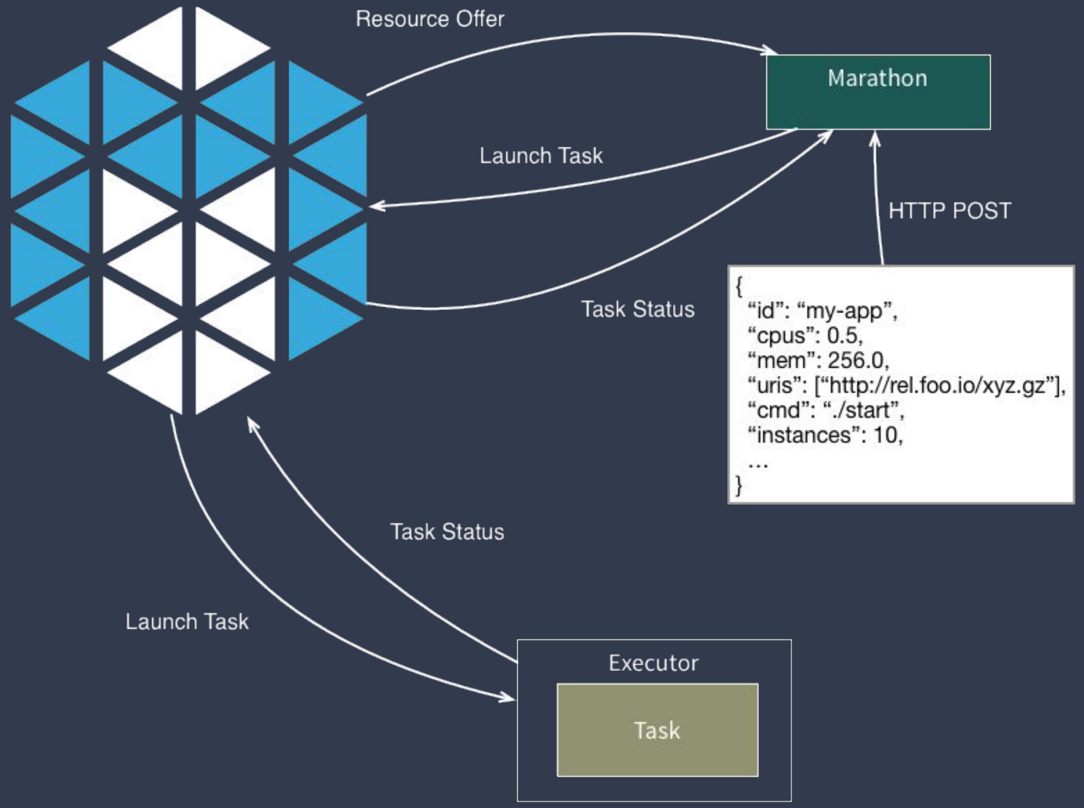
MESOS REALLY HELPS

- Former Google engineers at Twitter thought Mesos could provide the same functionality as Borg.
- Mesos actually works pretty well for long running services.



```
{
  "id": "my-app",
  "cpus": 0.5,
  "mem": 256.0,
  "uris": ["http://rel.foo.io/xyz.gz"],
  "cmd": "./start",
  "instances": 10,
  ...
}
```

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LIFE WITHOUT MESOS

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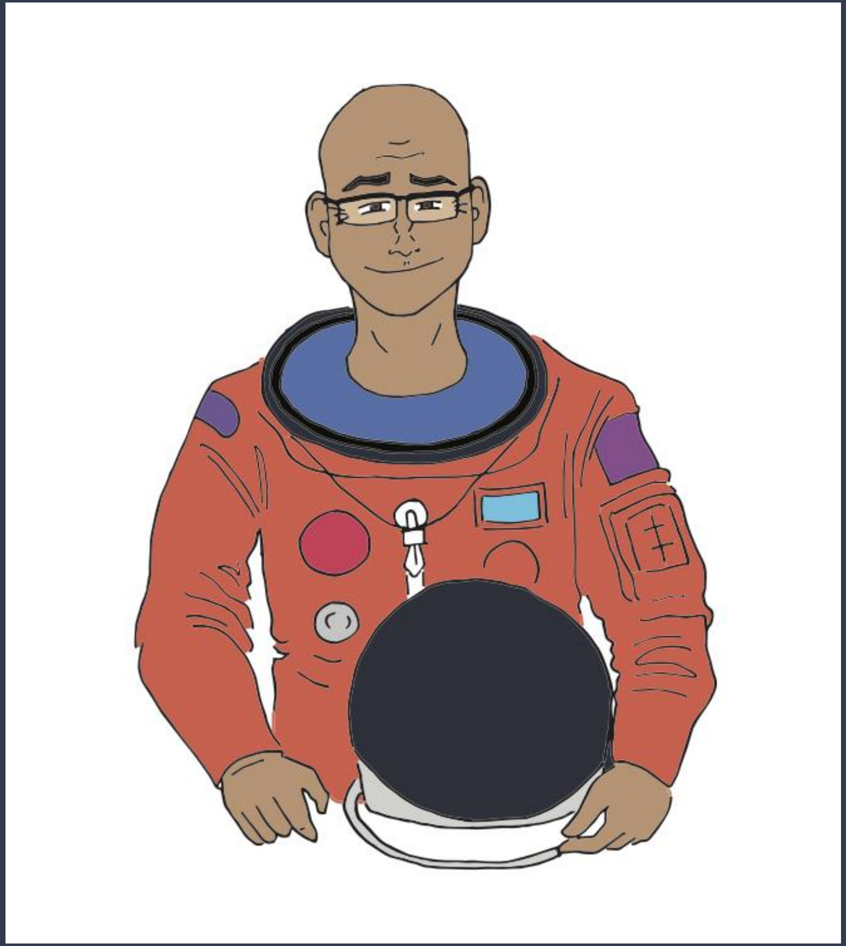
SAY HI TO DAN

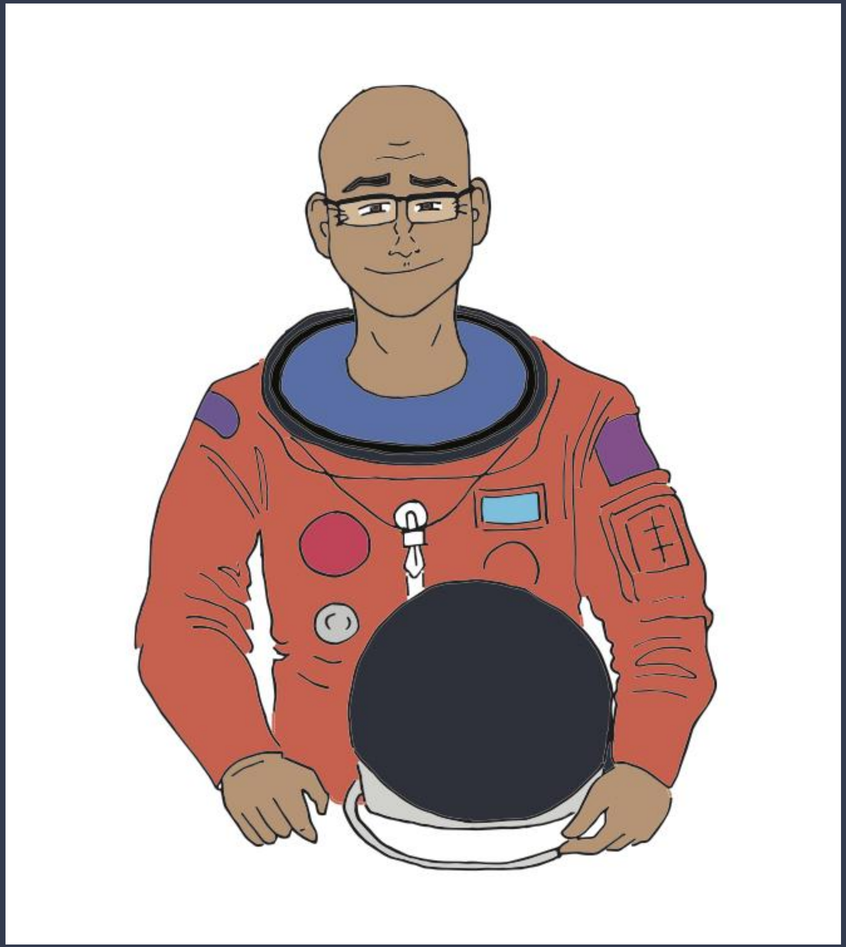
- Dan is a member of operations staff in a non-Google, non-Facebook company with large and growing users and workloads.



SO MUCH PROCESS

You’re a developer wanting to deploy a new service.

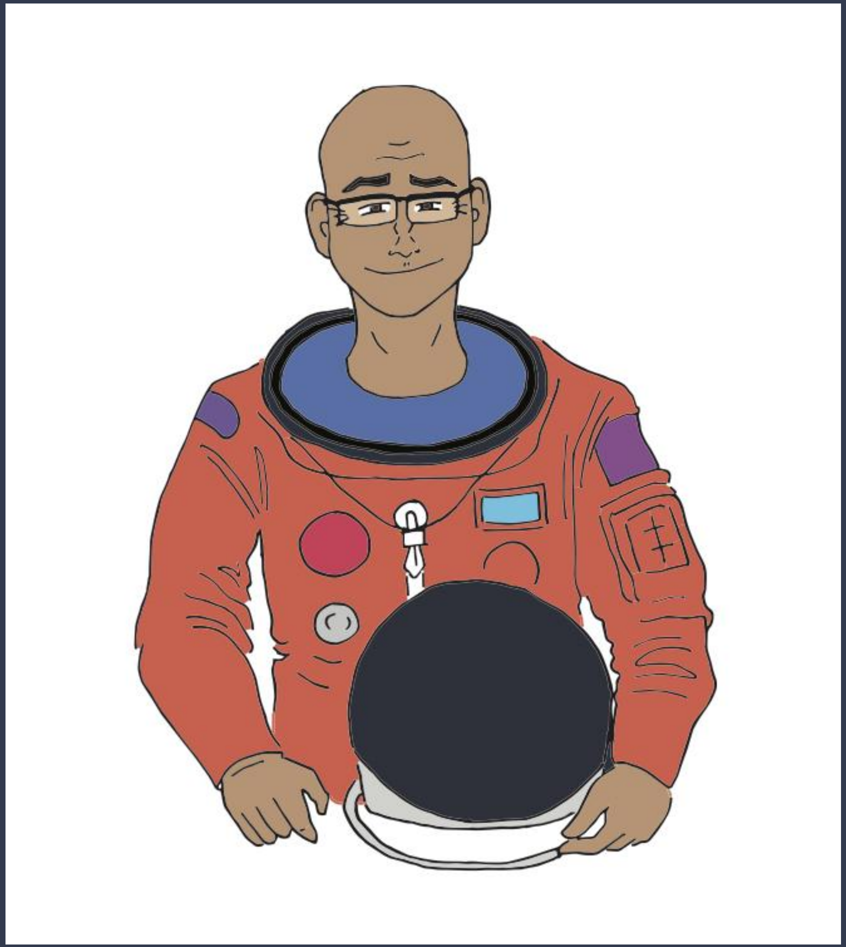
1. How many resources do you need?
   (Better overestimate, it usually takes a while to provision these.)
2. What dependencies does your application have?
3. Who monitors your applications and handles it falling over?



CHANGE IS PAINFUL

You have more users and/or you want to upgrade your application.

1. Submit another resource request.
2. Provision new machines.
3. How do we get any upgraded binaries/dependencies to existing machines?



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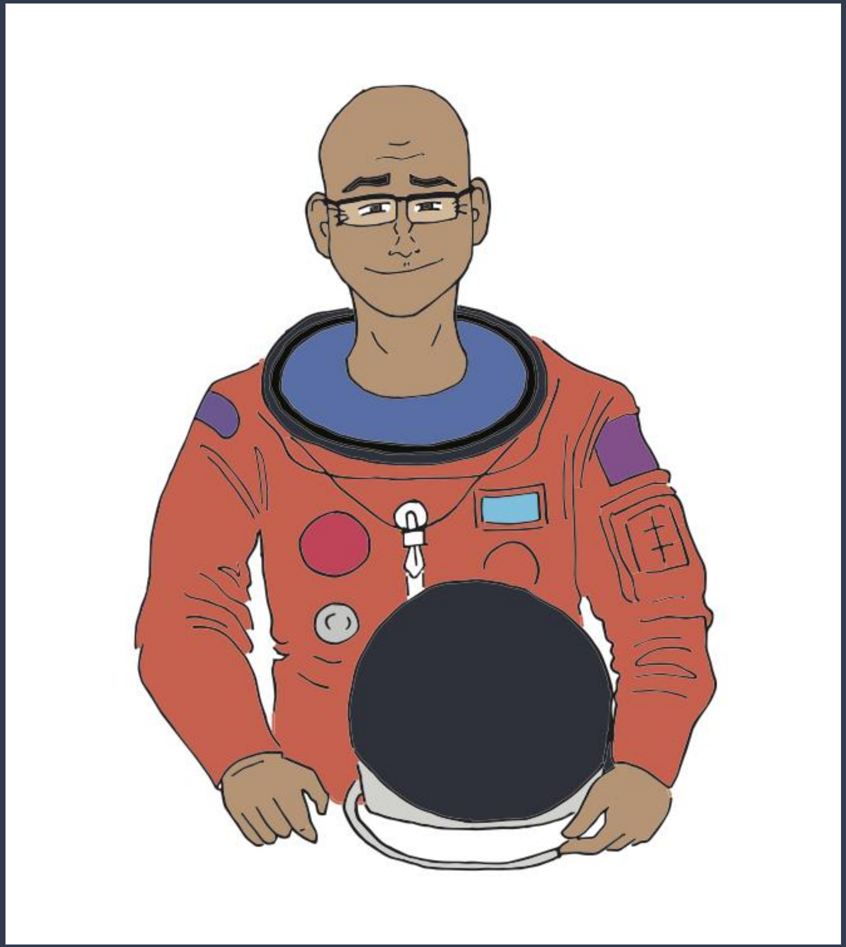
COMPLEX WORKLOADS

Dan, our operator, is forced to partition the datacenter to accommodate these demands. **Utilisation suffers**.

He must address errors and failures **manually**.

He has to deal with dependencies **on a one-off basis** for each of his developers' applications.



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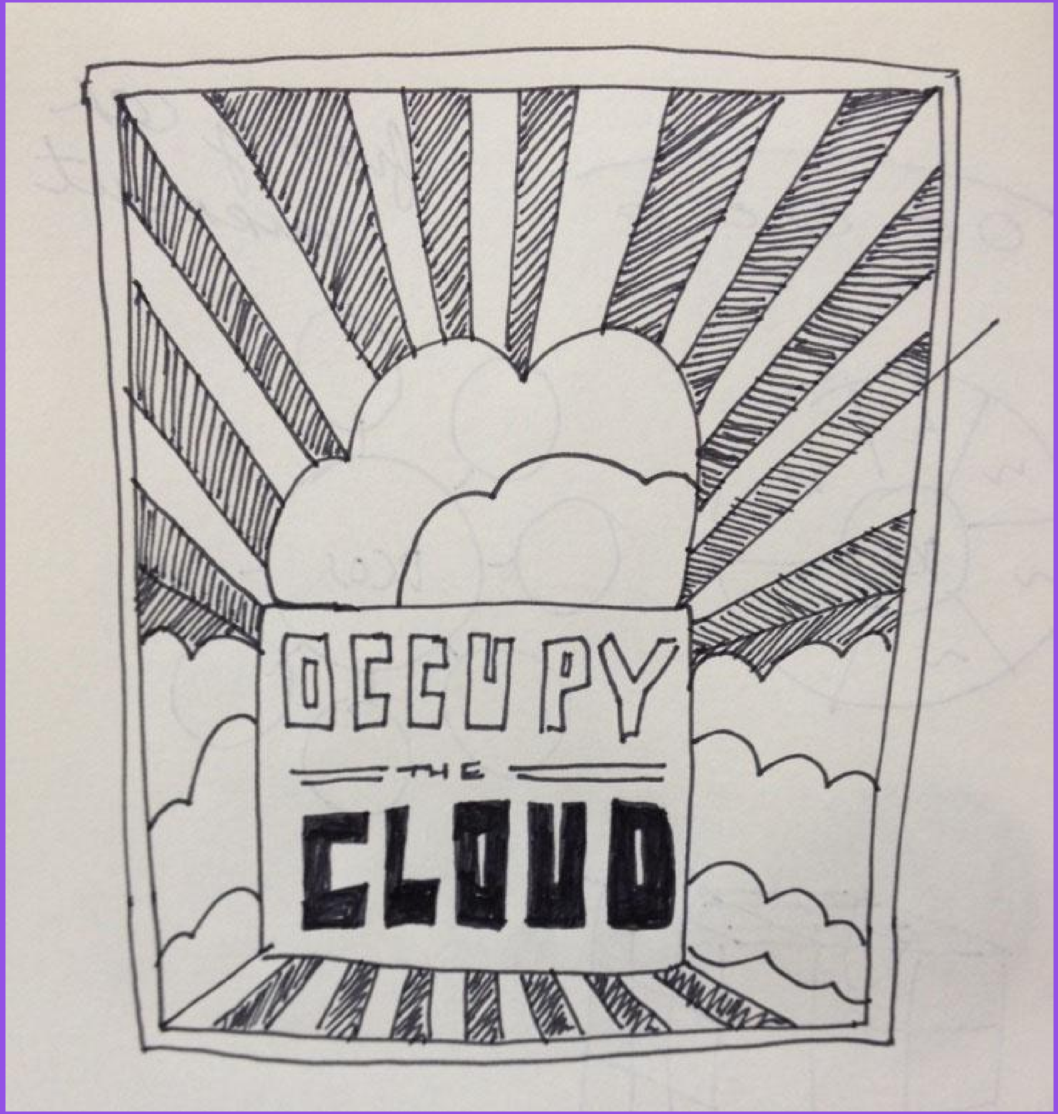

MESOSPHERE & THE DCOS

MISSION TO THE MESOSPHERE

April 2013

MESOSPHERE

Mesosphere is formed by engineers who have been using Mesos at Twitter and AirBnB.

June 2013

MESOS GRADUATES

Mesos graduates from the Apache Incubator to become a top level project.

April 2015

APPLE ANNOUNCES J.A.R.V.I.S.

Apple announces that the Siri infrastructure now runs on Mesos, atop “thousands” of nodes.

August 2015

VERIZON SCALE DEMO

Verizon demonstrates launching 50,000 containers in less than 90 seconds using Mesos and Mesosphere’s Marathon scheduler.

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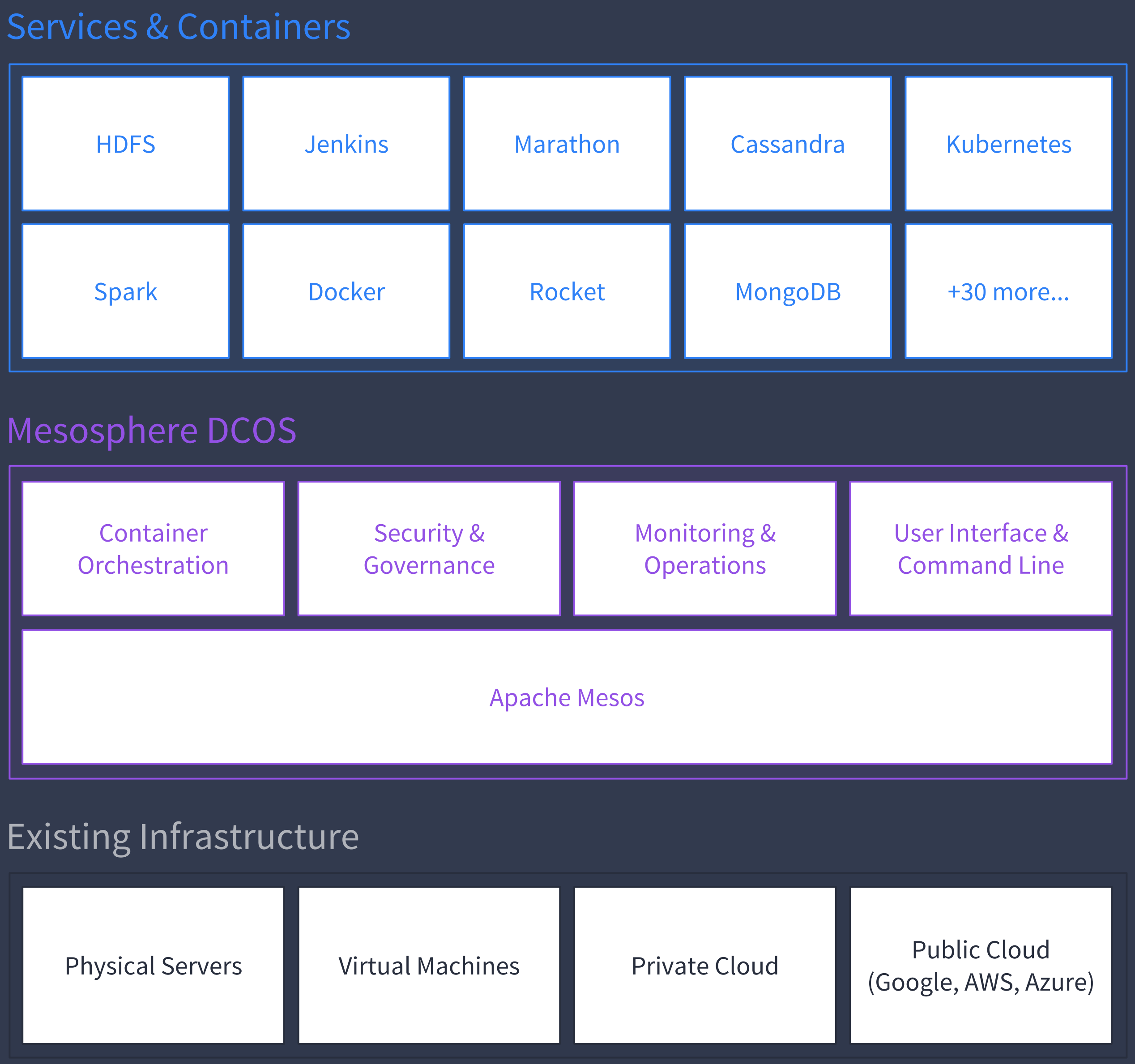
The Vision

MESOSPHERE DCOS



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THE DATACENTER OPERATING SYSTEM

DCOS aims to make developing & deploying distributed apps easier.

Short-term:

- Software installation/removal
- Seamless upgrades
- Automatic failure detection, reconciliation

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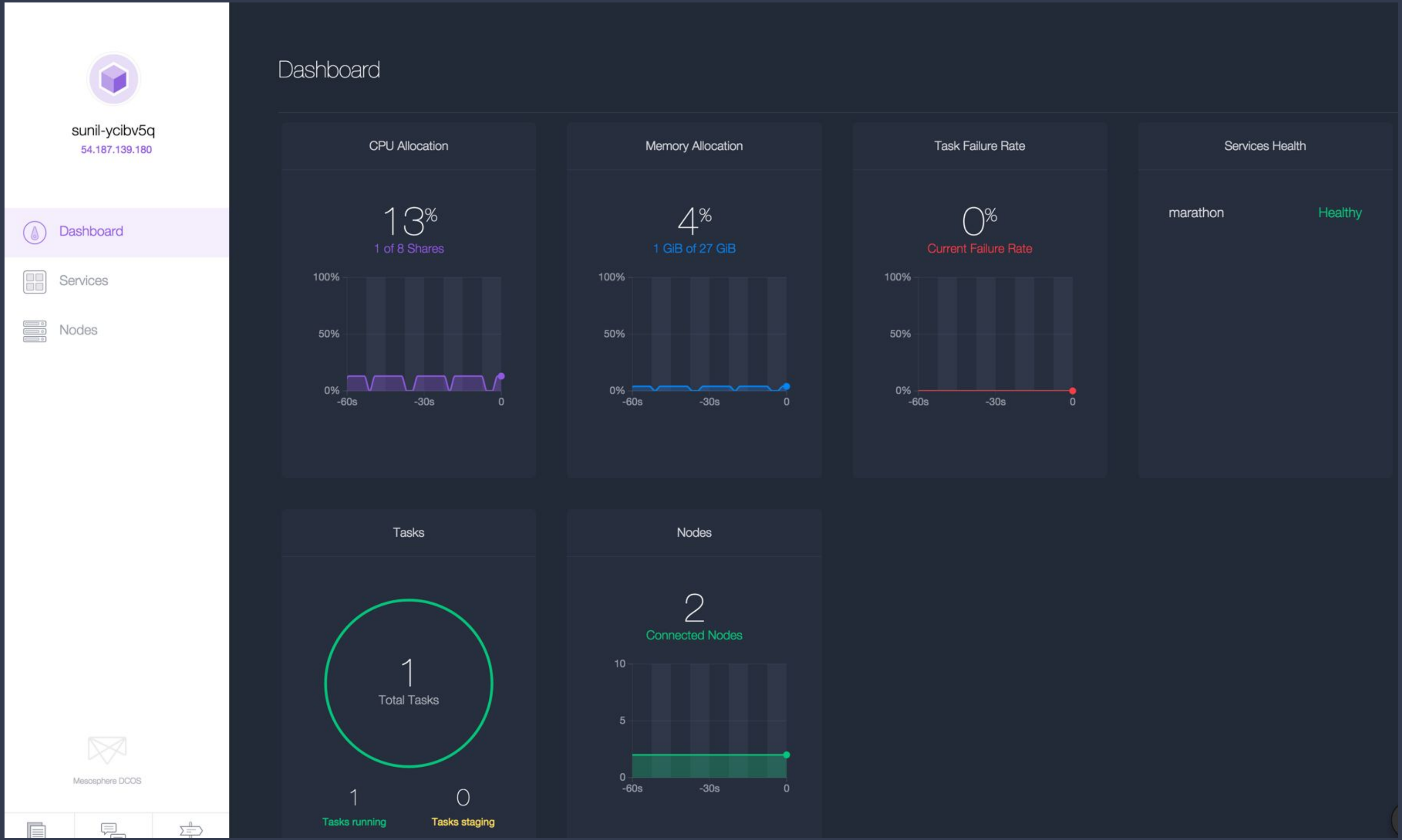
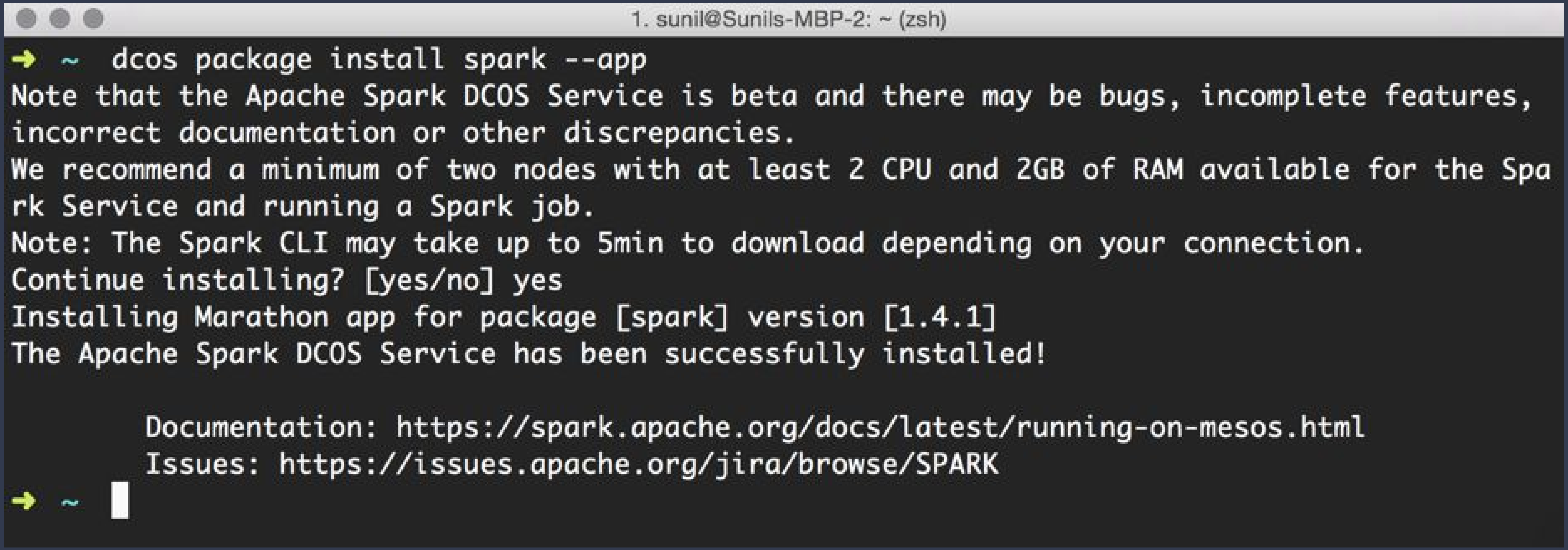
A UNIFIED INTERFACE TO THE DATACENTER



THE COMMAND LINE TO THE DATACENTER


1. sunil@Sunils-MBP-2: ~ (zsh)

```
➜  ~  dcos package install spark --app
Note that the Apache Spark DCOS Service is beta and there may be bugs, incomplete features,
incorrect documentation or other discrepancies.
We recommend a minimum of two nodes with at least 2 CPU and 2GB of RAM available for the Spa
rk Service and running a Spark job.
Note: The Spark CLI may take up to 5min to download depending on your connection.
Continue installing? [yes/no] yes
Installing Marathon app for package [spark] version [1.4.1]
The Apache Spark DCOS Service has been successfully installed!

        Documentation: https://spark.apache.org/docs/latest/running-on-mesos.html
        Issues: https://issues.apache.org/jira/browse/SPARK
➜  ~ █
```

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PRODUCTION CUSTOMERS AND MESOS USERS

Bloomberg

verizon

NETFLIX

2σ TWO SIGMA

PayPal

ebay

airbnb

HubSpot

Government Agencies

yelp

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WHAT WILL IT TAKE TO MAKE DAN HAPPY?

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CONTAINERS EVERYWHERE

Many Mesos tasks run in **containers**:

- Mesos containerizer
- Docker
- Universal containerizer (in progress)

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CONTAINERS EVERYWHERE

Many Mesos tasks run in **containers**:

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- Universal containerizer (in progress)

Containers use standard linux features to create an isolated execution environment:

- kernel namespaces
  - process isolation
- control groups (cgroups)
  - resource isolation
- chroot
  - filesystem isolation
- seccomp
  - restricted kernel access

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CONTAINERS EVERYWHERE

Containers also help Dan solve his dependency problem by giving tasks everything they need to run.

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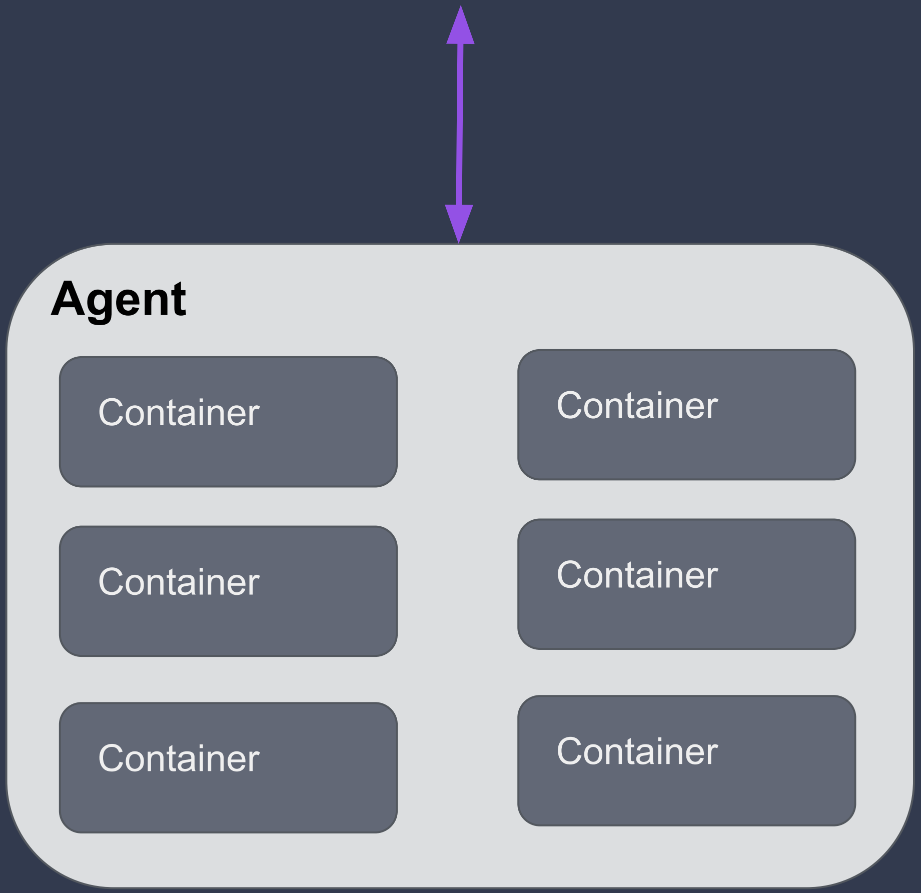
CONTAINER NETWORKING

Containers isolate tasks on the agent, but what about their communication?

The status quo in a Mesos cluster: one IP per agent.

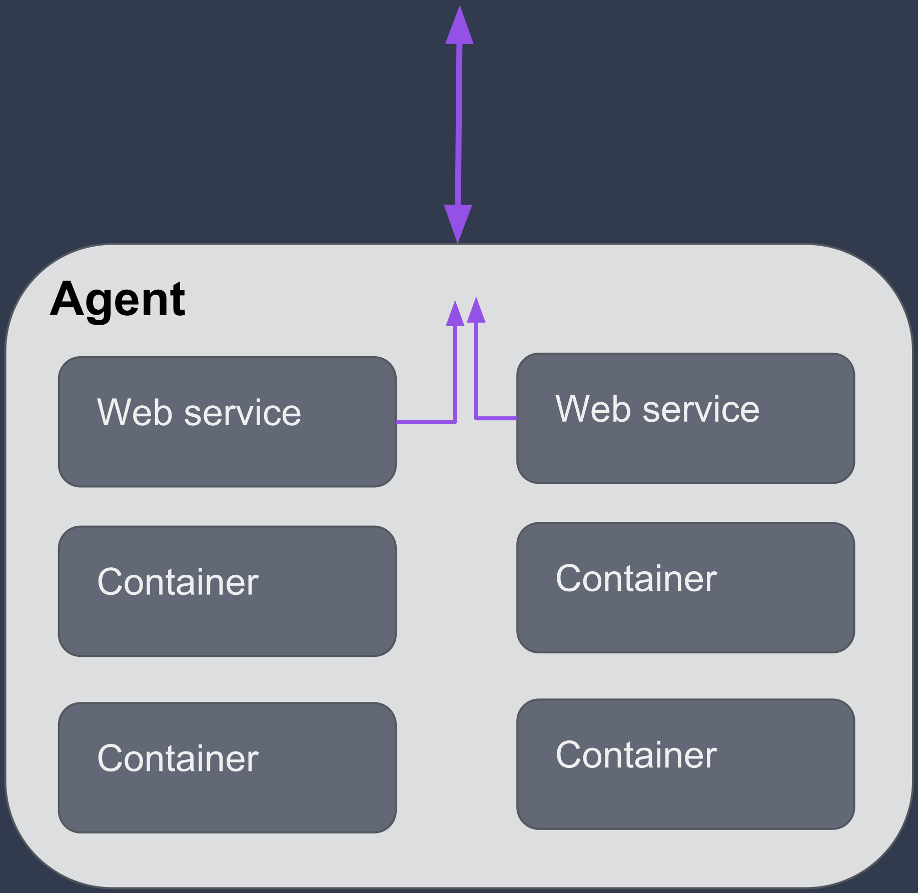
Many containers per agent: they must share a single IP.



CONTAINER NETWORKING

This causes headaches:

- Port conflicts
- Security compromises
- Performance
- Service discovery



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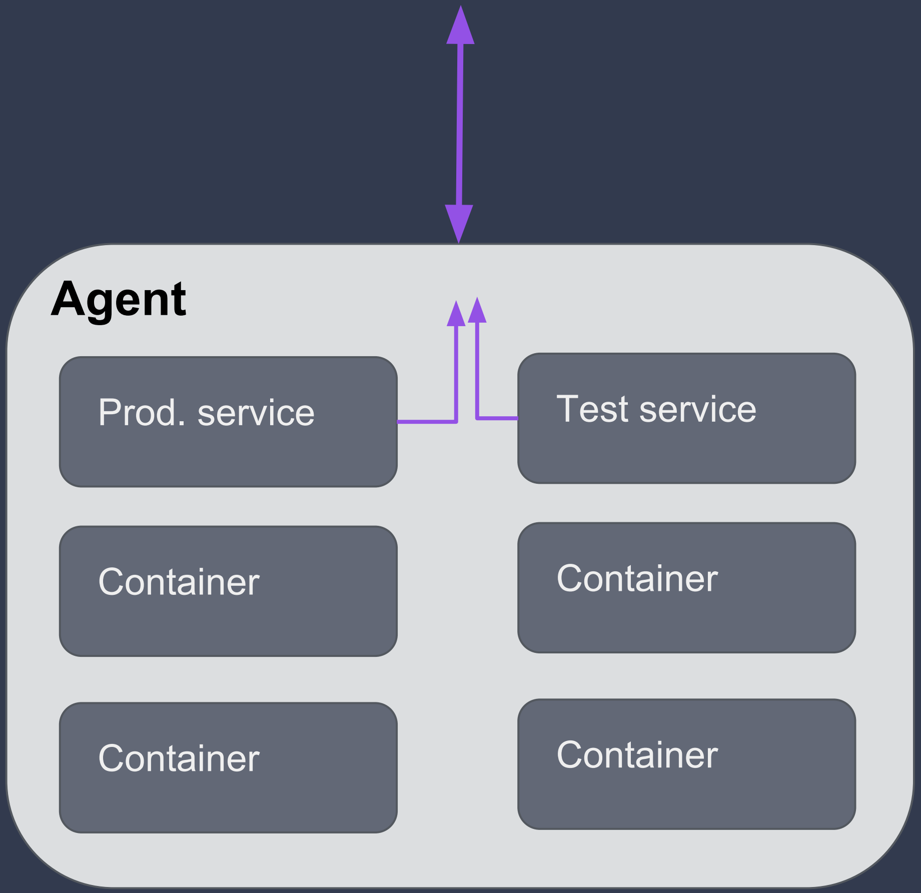

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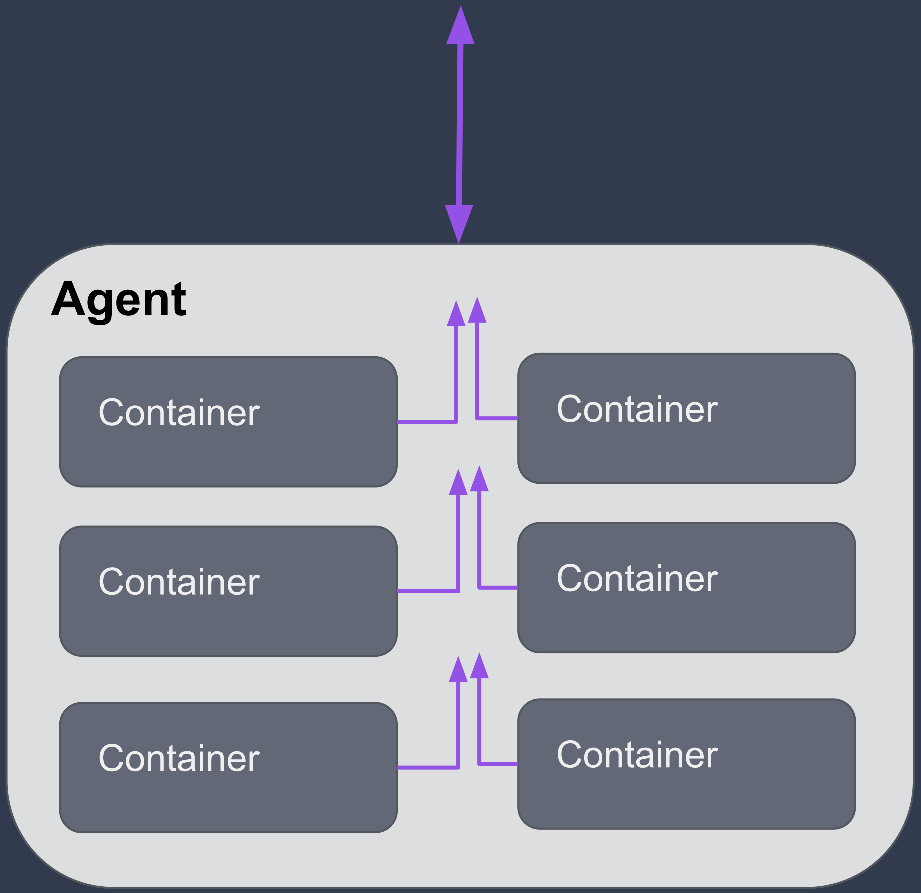

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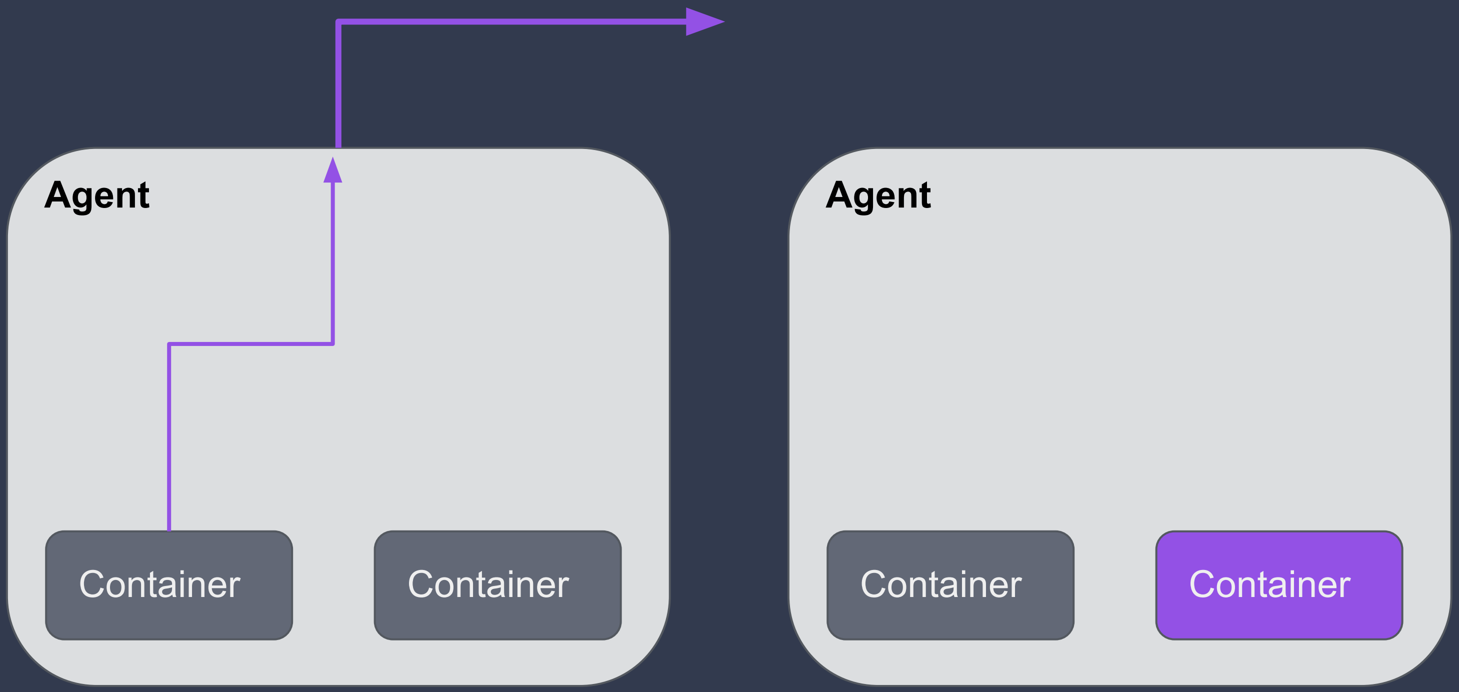

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NETWORK ISOLATION

Segregating containers’ network traffic can solve these problems in an elegant, maintainable way.

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NETWORK ISOLATION

Segregating containers’ network traffic can solve these problems in an elegant, maintainable way.

Implemented as Mesos modules:

- Project Calico
- Port-mapping isolation
- …

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CALICO NETWORK ISOLATION

Calico Network Virtualizer & IP Address Manager:

- Pure Layer-3 solution
- Uses linux features to route container traffic
- Provides security policies
- Advertises routes to local containers via BGP
- Can assign IP-per-container

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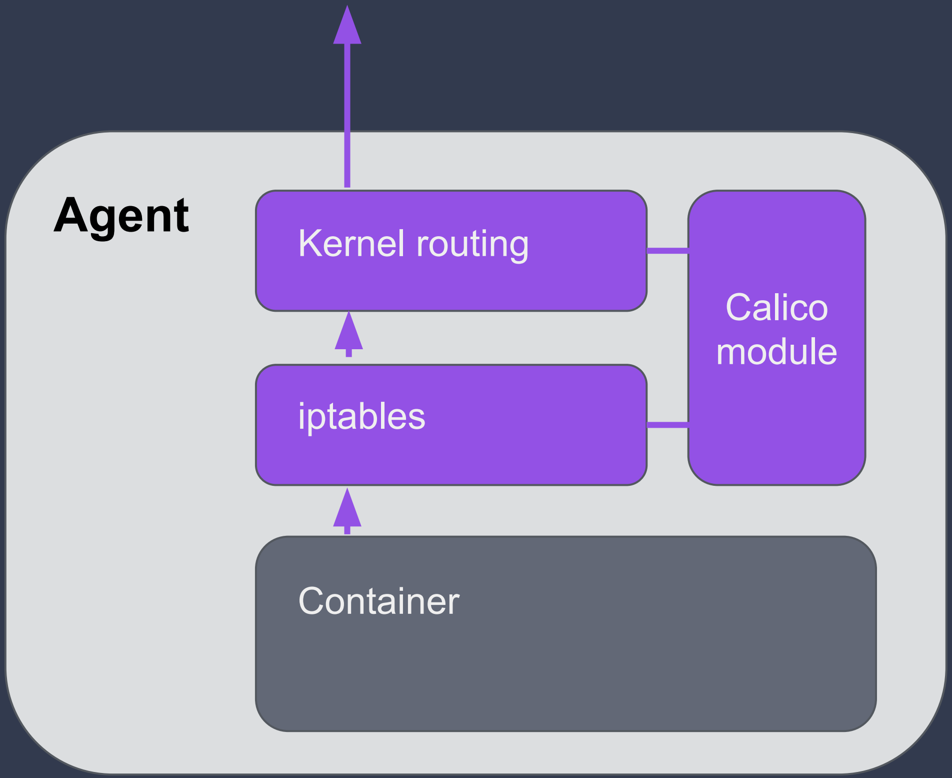
CALICO NETWORK ISOLATION



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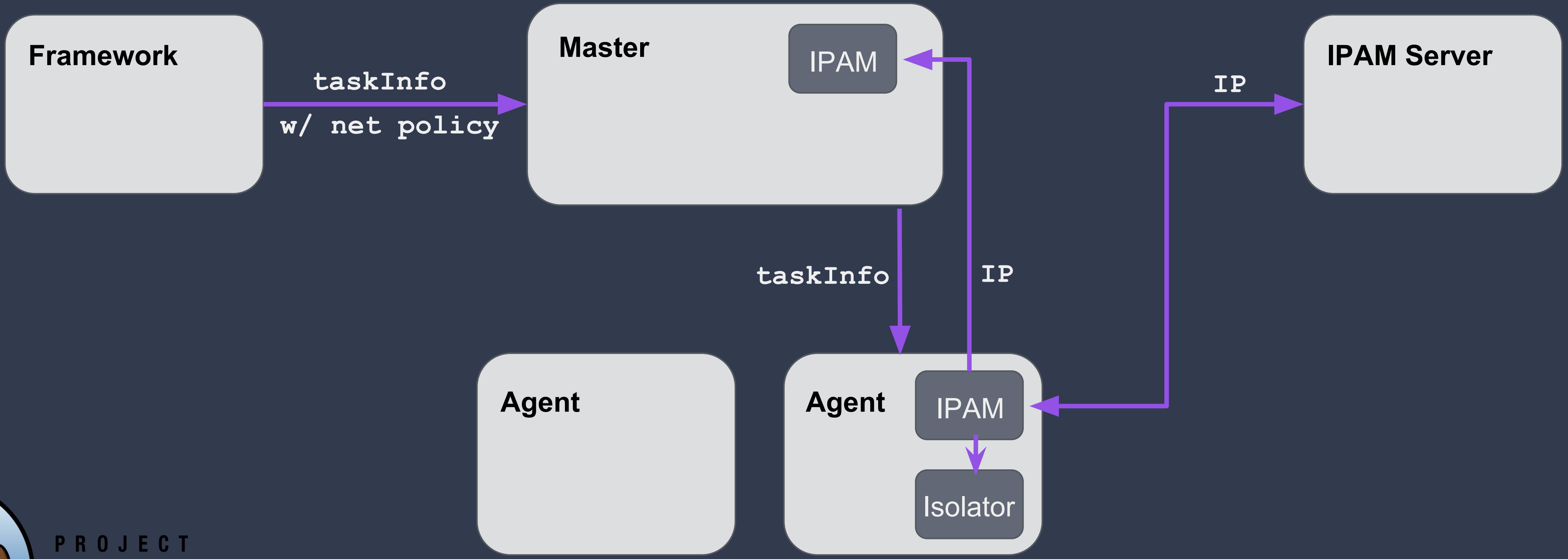

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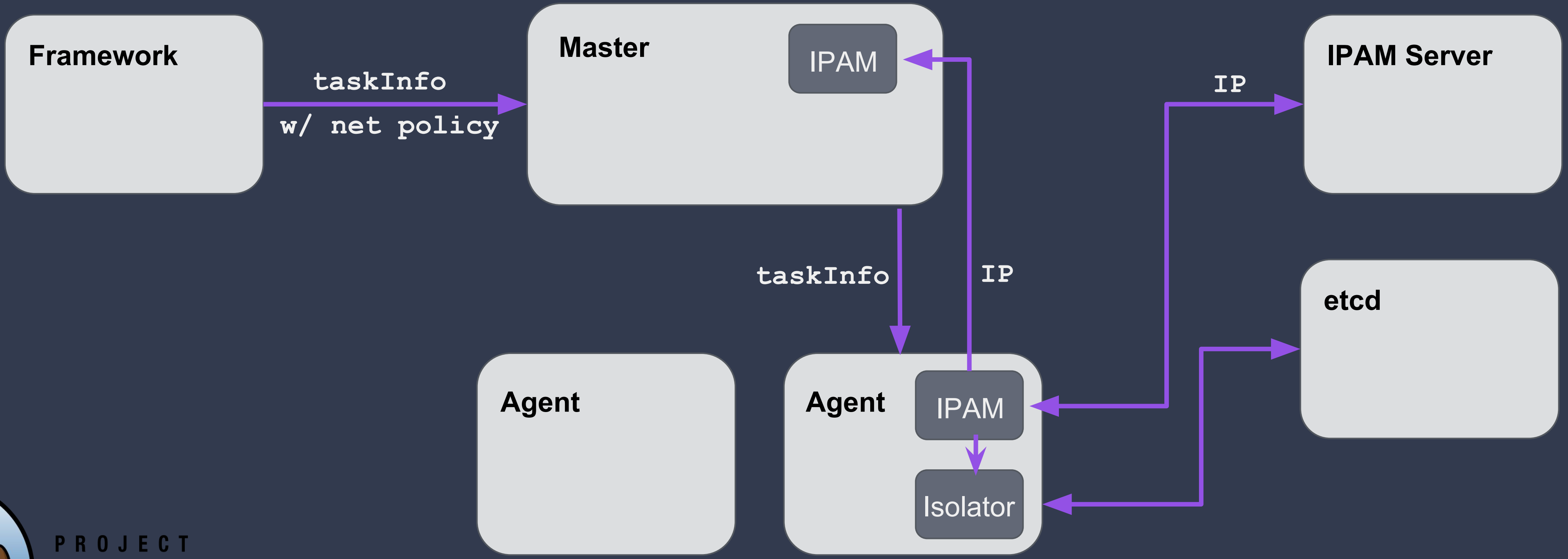

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NETWORK ISOLATION

What if I don’t have enough IPs to go around?

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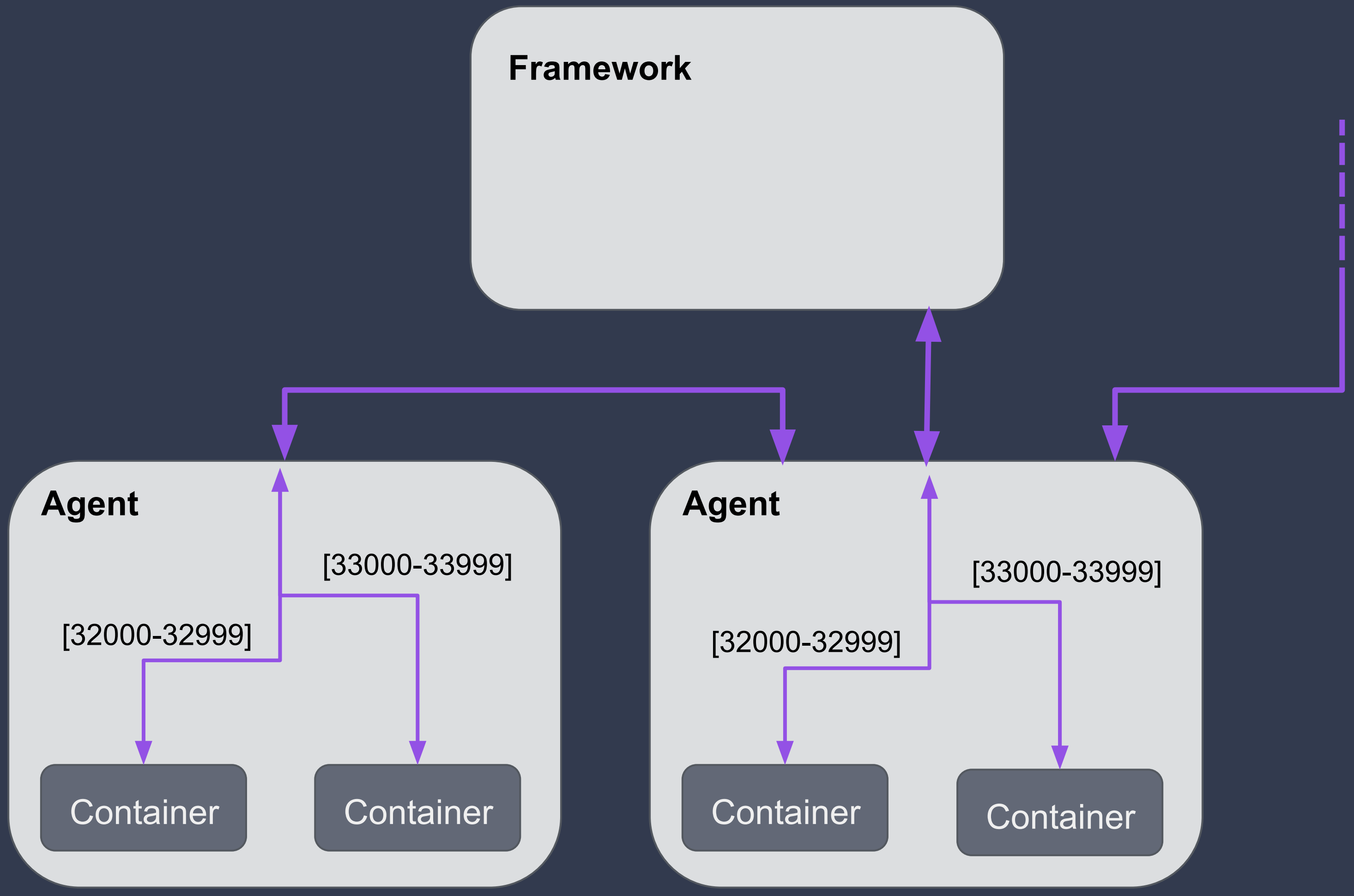
PORT-MAPPING ISOLATOR

- Ports distributed amongst containers on each agent
- Network traffic routed by port using TC rules
- Implemented with `libnl` (via netlink messages)
- Ports assigned and tracked via scheduler (ex: Aurora)



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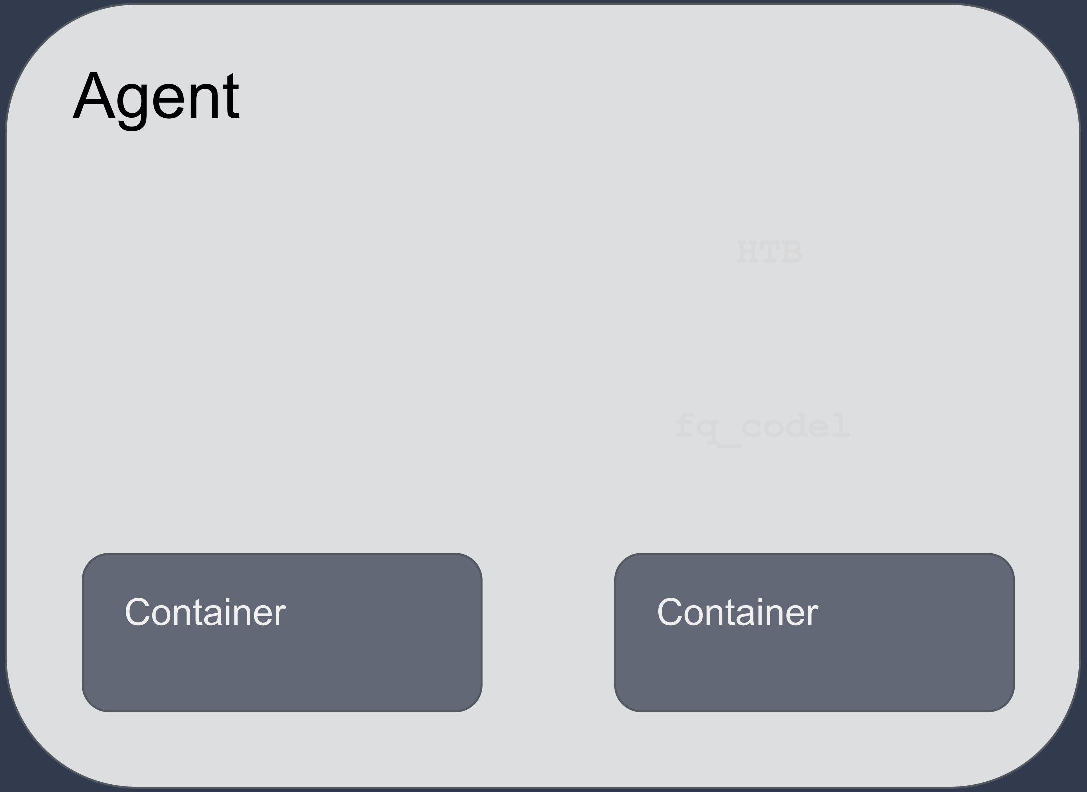
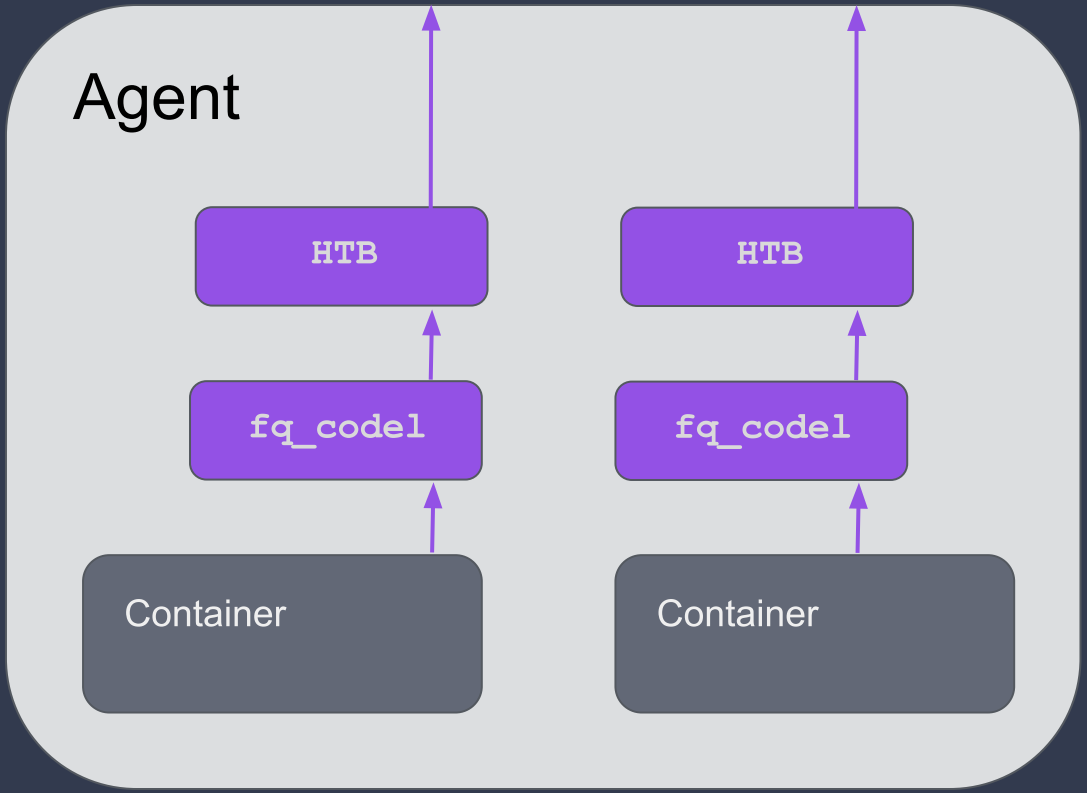
PORT-MAPPING ISOLATOR

What about performance?



PORT-MAPPING ISOLATOR

- `fq_codel` defines discrete network flows for containers
- Separate flows prevent buffer bloat
- Hierarchical token bucket (HTB) employed to limit bandwidth



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WORKLOADS CHANGED SINCE 2009

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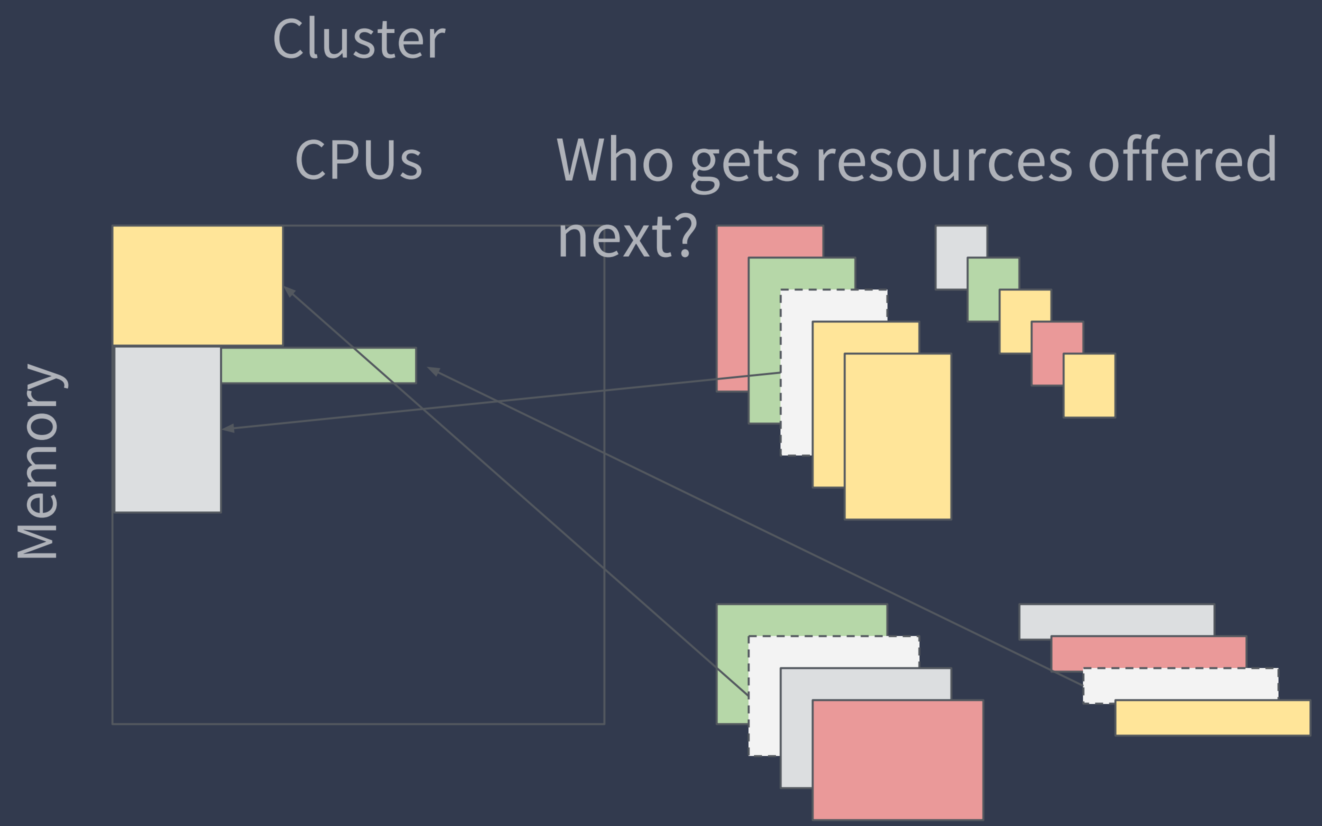
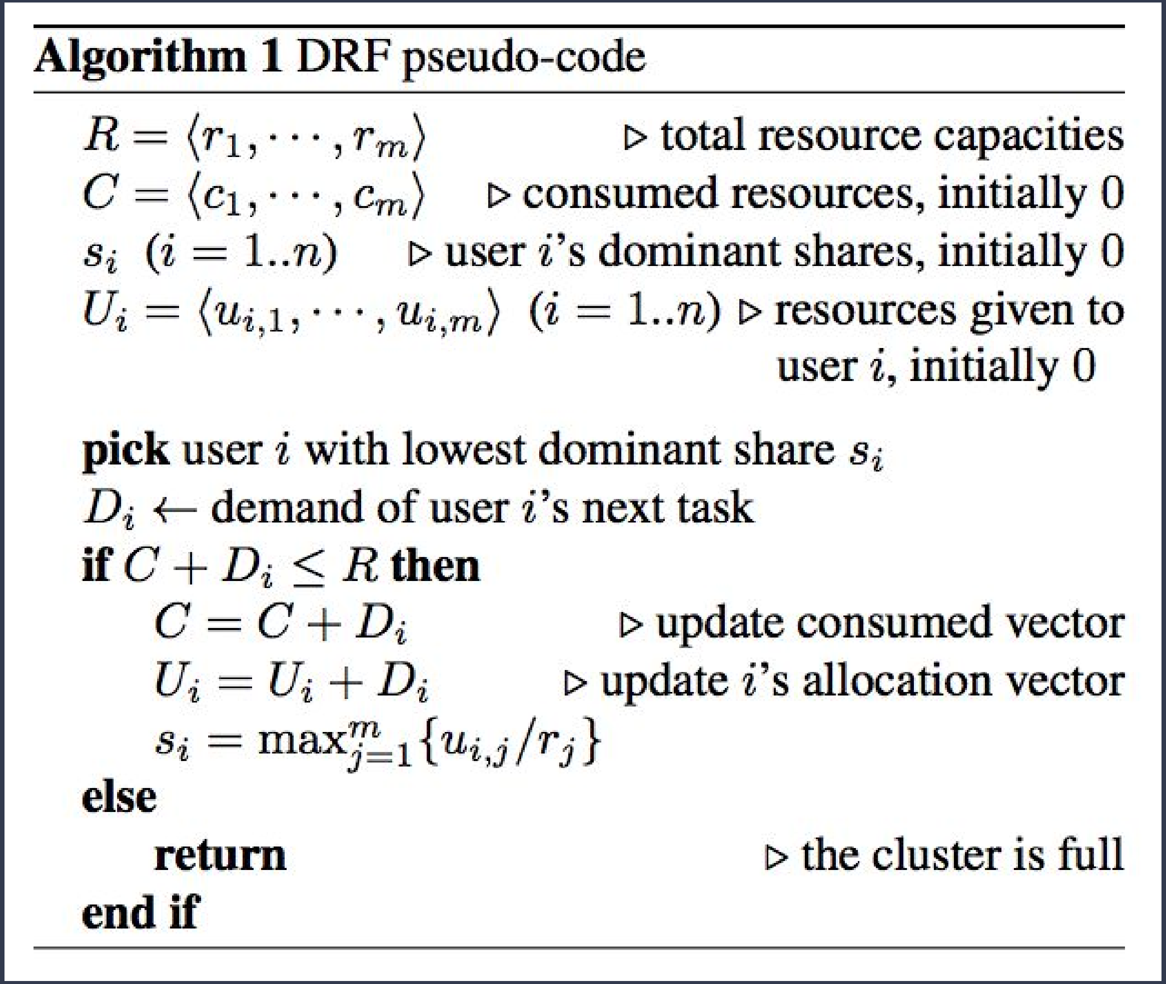
FAIRNESS FOR MULTI-DIMENSIONAL RESOURCES?



Who gets resources offered next?

While we can do fitting, how do we express fairness over different units and dimensions?

DOMINANT RESOURCE FAIRNESS



Algorithm 1 DRF pseudo-code

```
$R = \langle r_1, \cdots, r_m \rangle$    ▷ total resource capacities
$C = \langle c_1, \cdots, c_m \rangle$    ▷ consumed resources, initially 0
$s_i \ (i = 1..n)$    ▷ user $i$'s dominant shares, initially 0
$U_i = \langle u_{i,1}, \cdots, u_{i,m} \rangle \ (i = 1..n)$    ▷ resources given to user $i$, initially 0

pick user $i$ with lowest dominant share $s_i$
$D_i \leftarrow$ demand of user $i$'s next task
if $C + D_i \leq R$ then
    $C = C + D_i$    ▷ update consumed vector
    $U_i = U_i + D_i$    ▷ update $i$'s allocation vector
    $s_i = \max_{j=1}^{m}\{u_{i,j}/r_j\}$
else
    return    ▷ the cluster is full
end if
```

TIME DIMENSIONALITY HAS CHANGED!

Multitenancy now expands domains of multiple batch schedulers with a mix of:

- Long lived services
- Storage services
- Short lived analytics tasks

Is extreme fairness what you really want?

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SEVERAL POs AT CUSTOMER SITES

“My framework is starved! Why isn’t my framework receiving any resources?”

- Some frameworks has a lot of work to do, others less. All gets a fair share by default.
- Configuration is hard with weights, static reservations, etc

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EASY TO MAKE MISTAKES IN SCHEDULER IMPLEMENTATIONS

```
resourceOffers(offers) {
  ...
  if (is_ok(offer)) {
    launchTasks(offer);
  }
}
```

```
resourceOffers(offers) {
  ...
  if (is_ok(offer)) {
    launchTasks(offer);
  } else {
    declineOffer(offer);
  }
}
```

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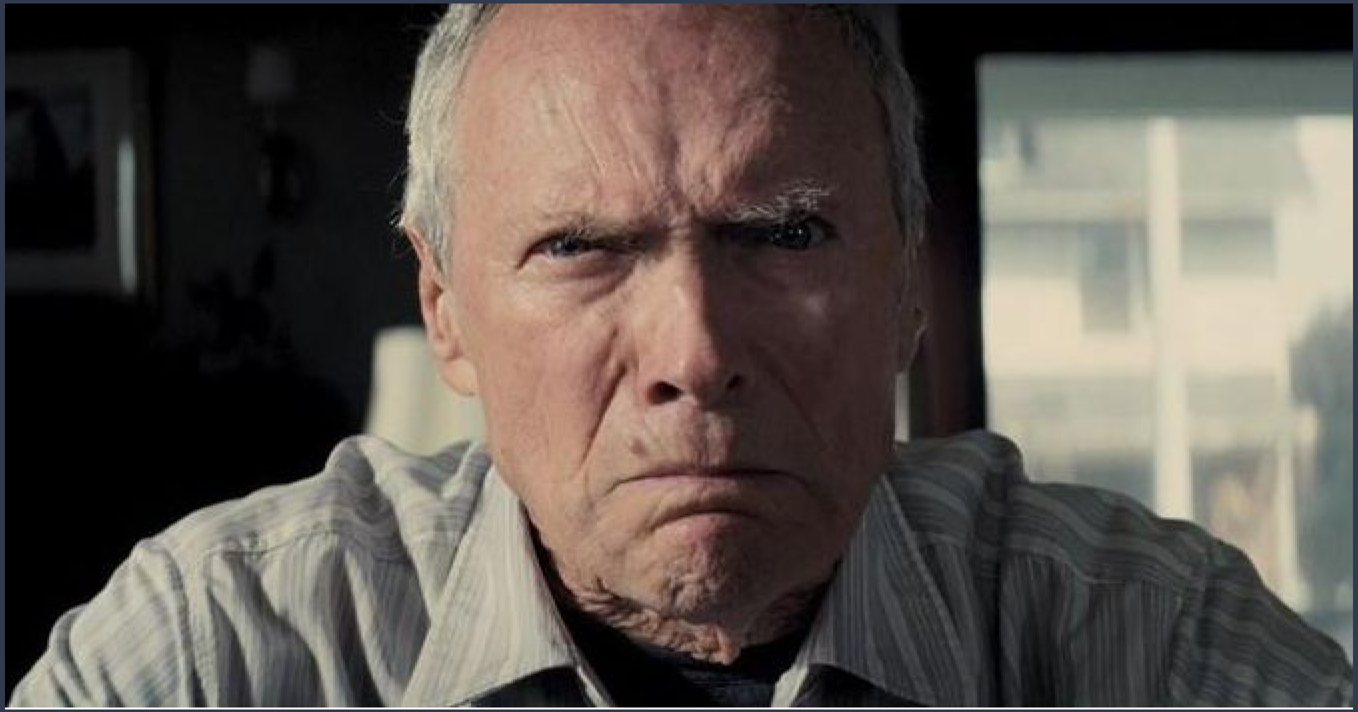
POs MAKE DAN UNHAPPY



WHAT DID TWITTER DO?

- Uses Apache Aurora for most of its operations
- It implemented preemption assuming it was the only scheduler available

MULTI-TENANCY BECOMES TOO RISKY FOR CRITICAL SYSTEMS

- Companies partition Mesos cluster into many smaller Mesos clusters
- Run multiple copies of the same framework on top of Mesos
- Avoid running multiple frameworks all together
- That was surely not the intent

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IN THE WORKS

- Quotas ensure minimum set of resources for frameworks
- Optimistic offers enables resource parallelism
- Cooperative preemption through Inverse offers

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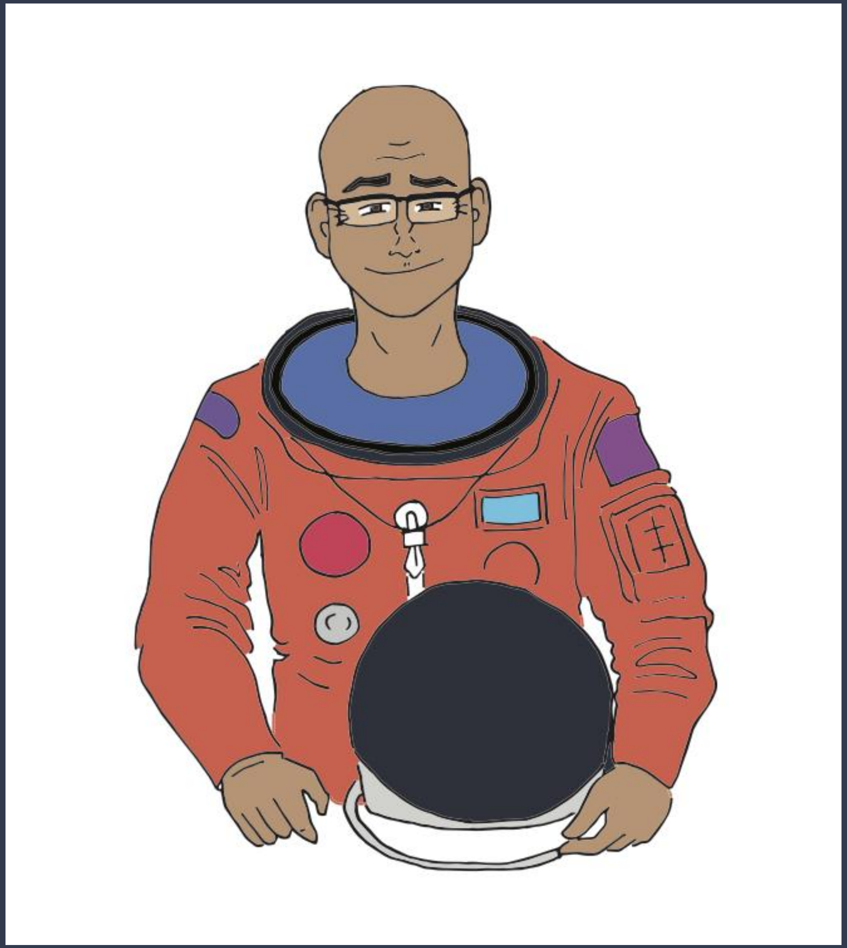
LET’S ASSUME DAN IS HAPPY WITH HIS CLUSTER



THAT MAKES HIS BOSS HAPPY

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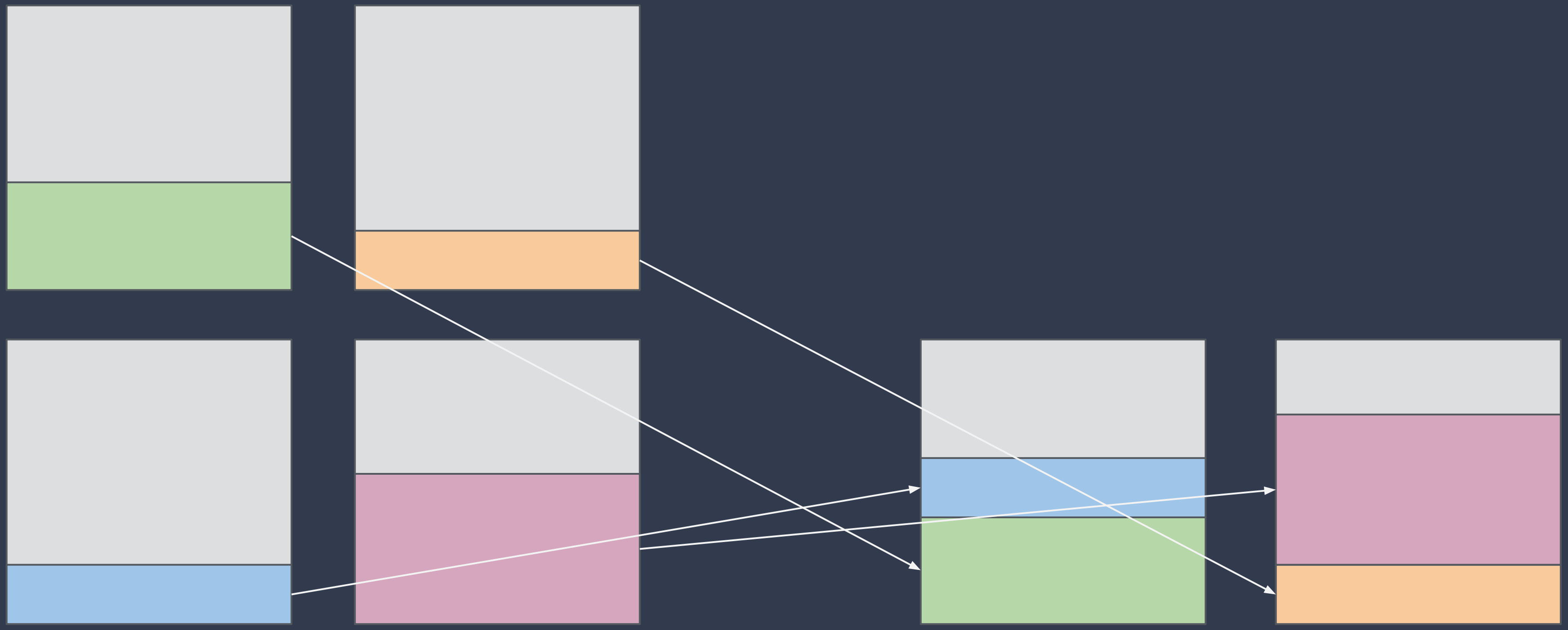
AND THEIR CFO IS HAPPY TOO

MESOS HELPS REDUCE WASTED RESOURCES



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ESTIMATING RESOURCES IS HARD

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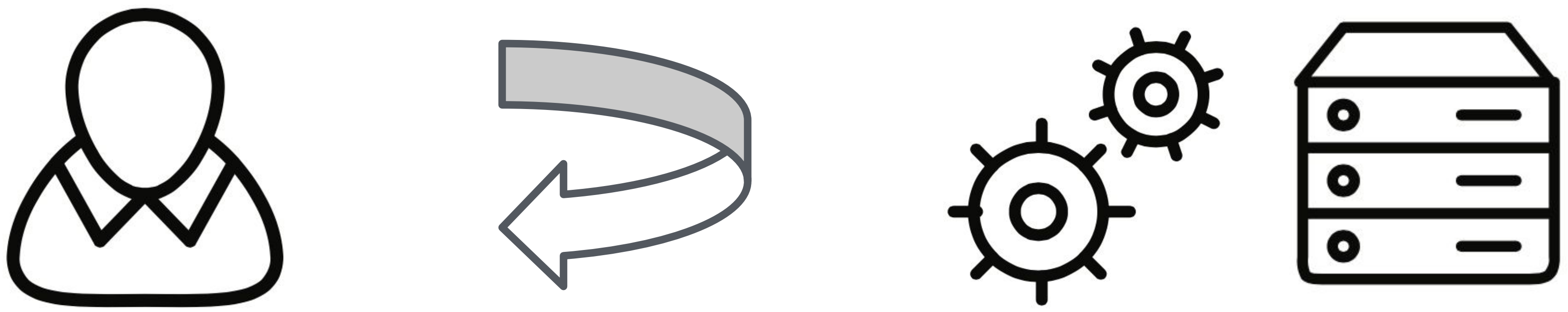
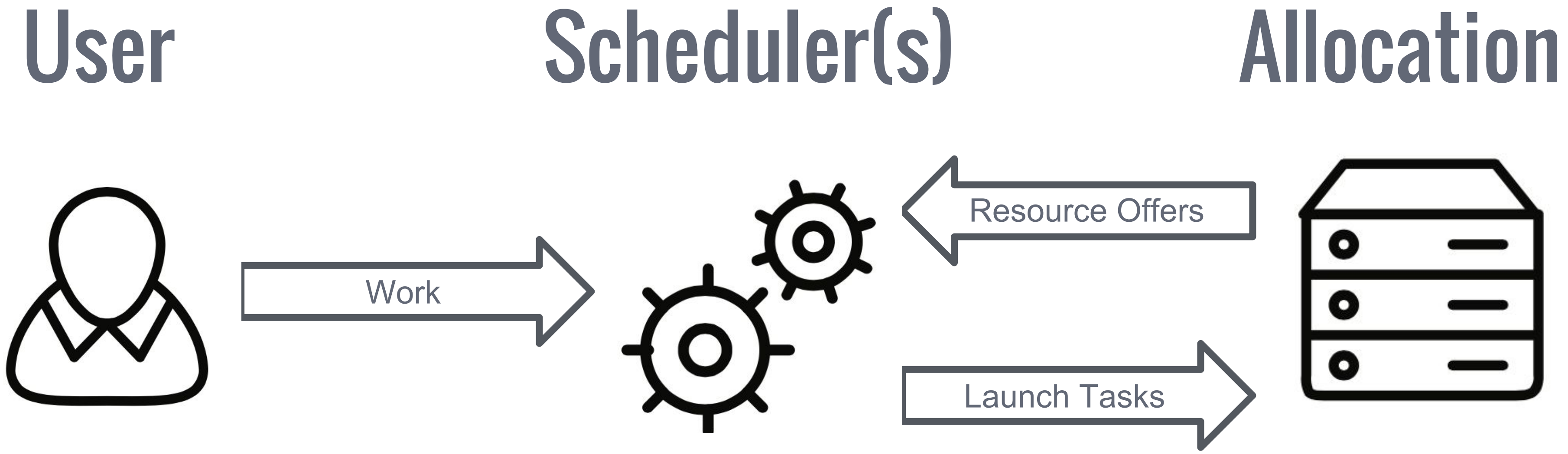
MESOS ENABLES MULTIPLE SCHEDULER ALGORITHMS



“Please run container X on Y resources”

MESOS ENABLES MULTIPLE SCHEDULER ALGORITHMS



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RESOURCES REPRESENT ALLOCATION

Resources represent allocation

How are users supposed to know how many resources their workload requires?

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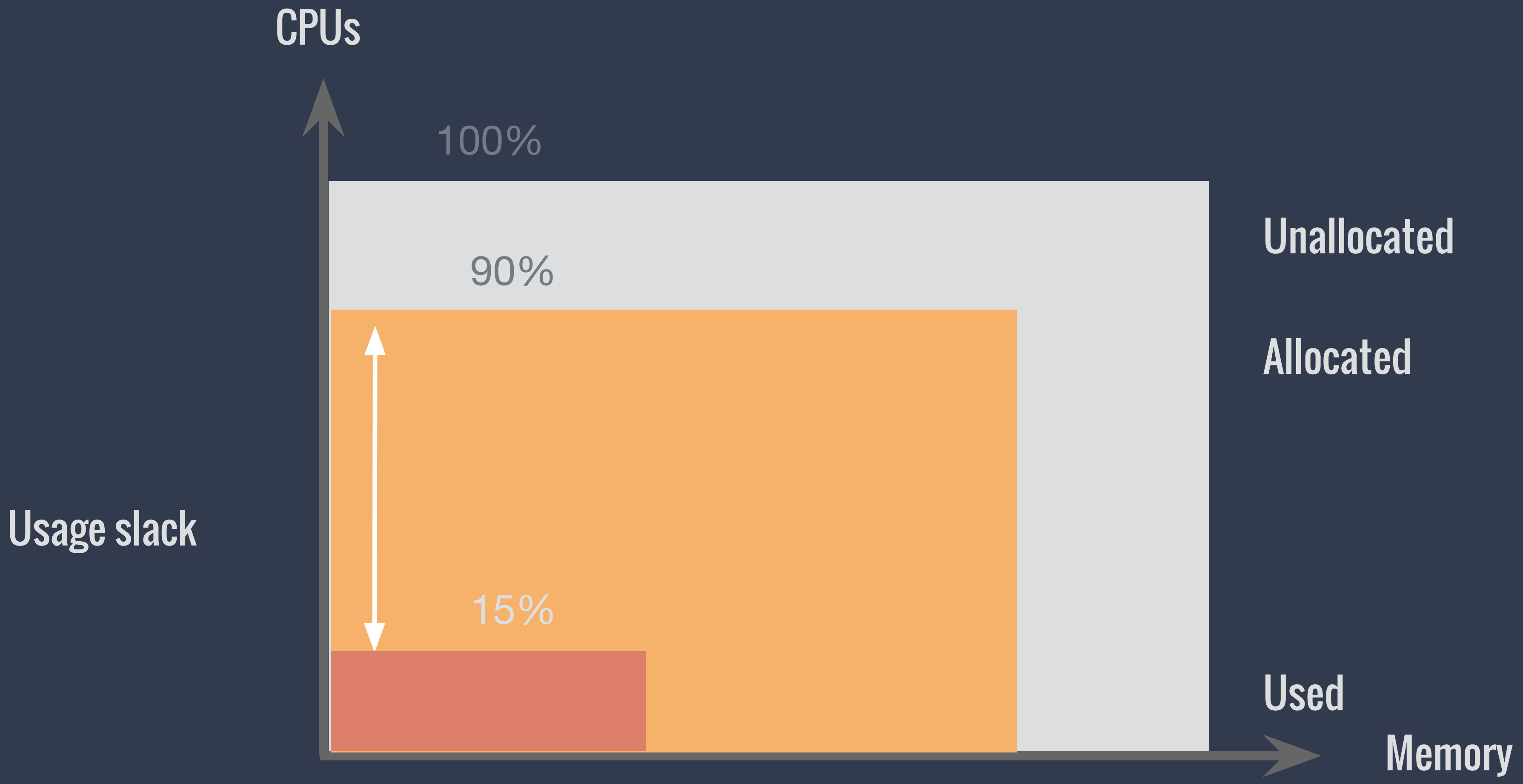
RESOURCES REPRESENT ALLOCATION



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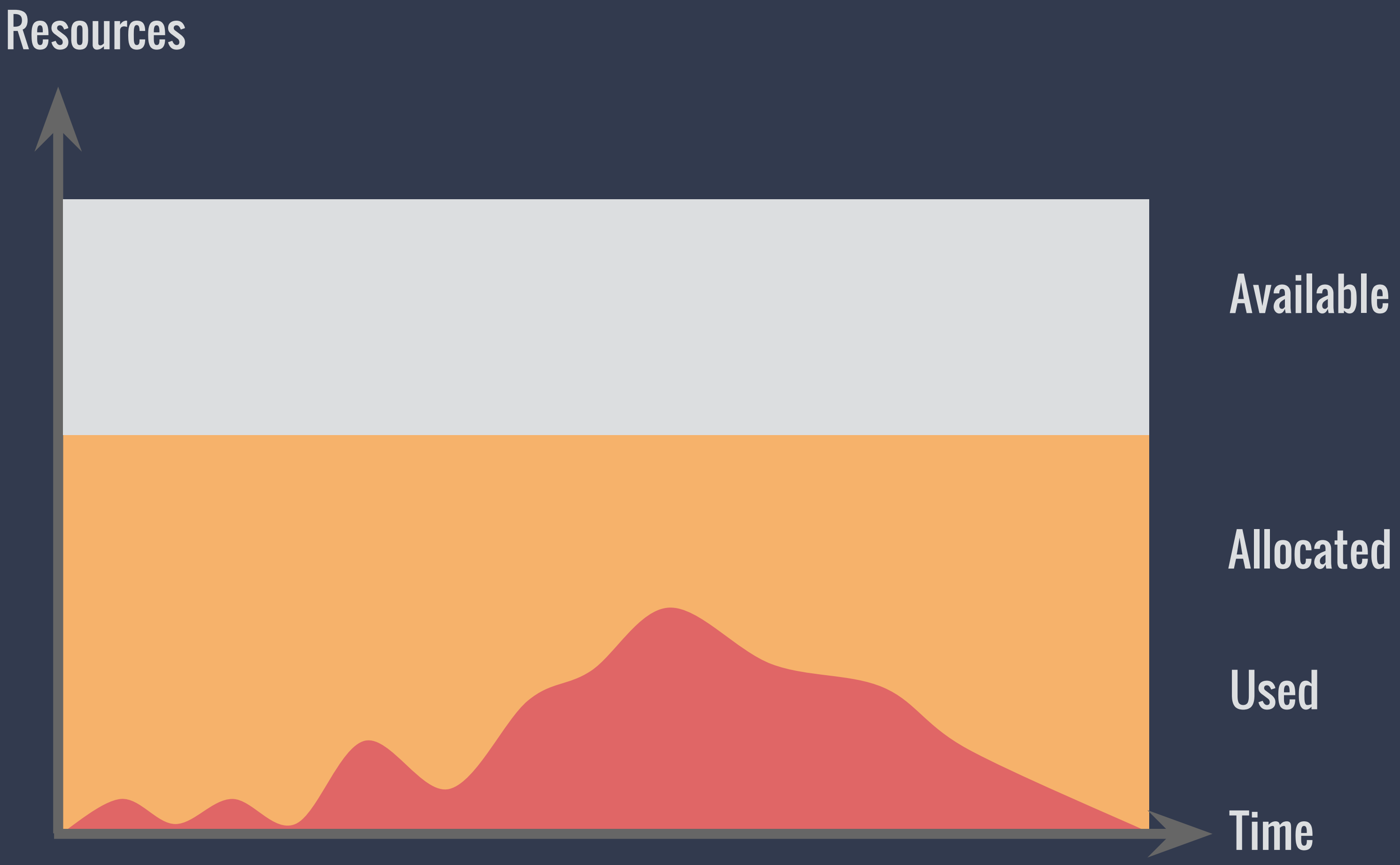
USAGE SLACK HURTS UTILISATION



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FIRST STEPS TOWARDS IMPROVED UTILISATION

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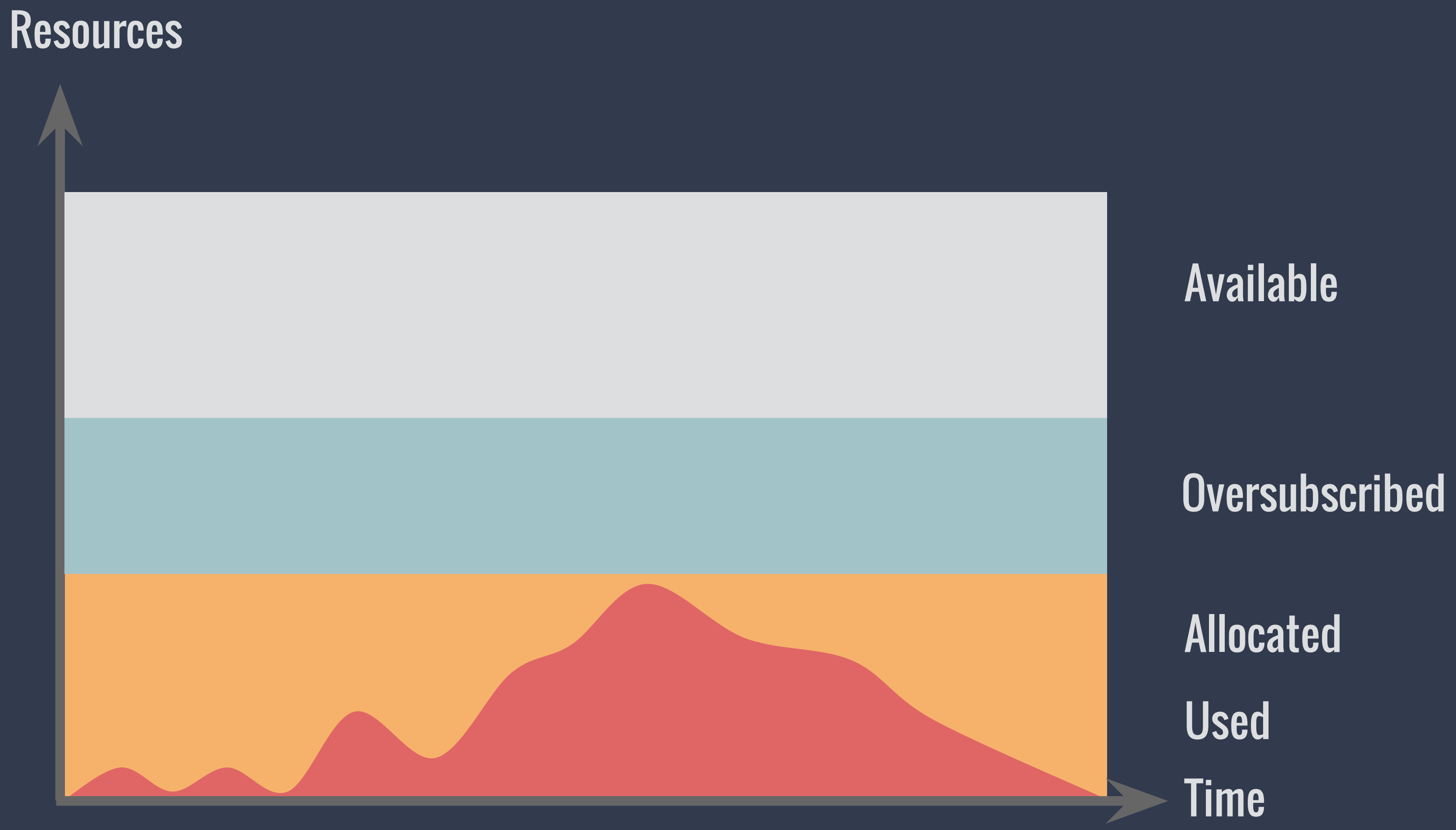
OVERSUBSCRIPTION ENABLES TASKS TO RUN ON SLACK



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TWO COMPONENTS ENABLE OVERSUBSCRIPTION

Resource Estimator

Quality of Service Controller

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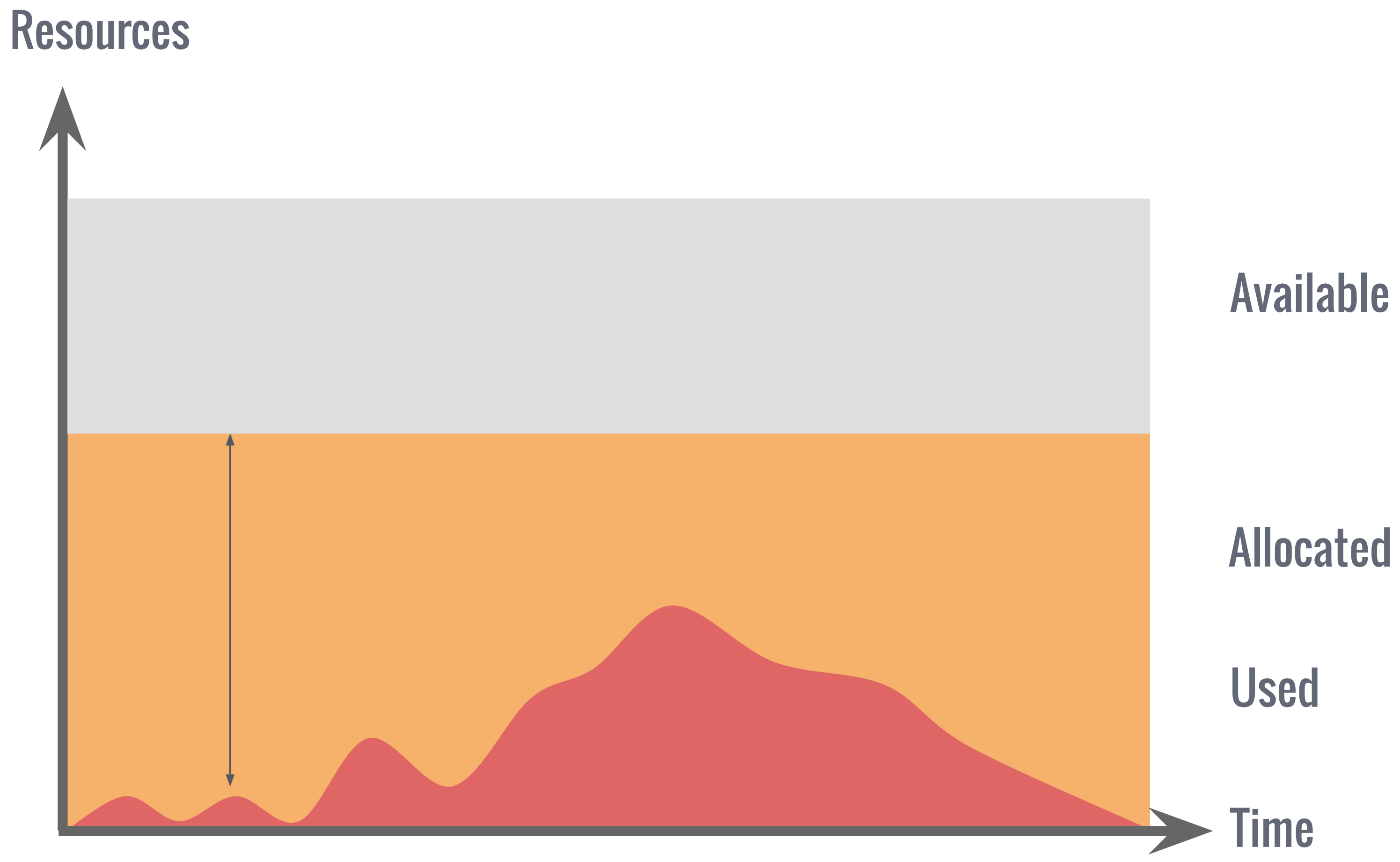
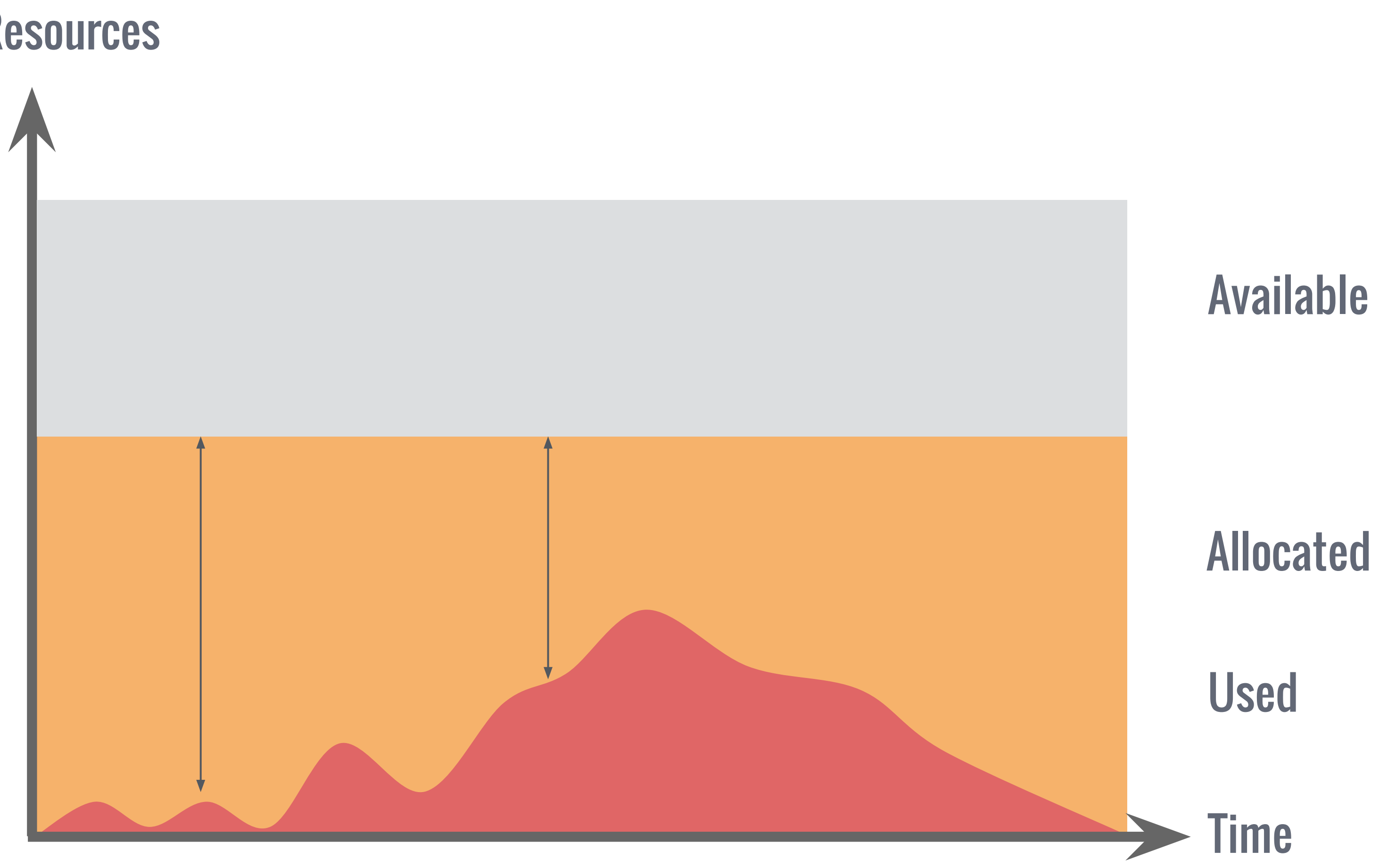
ESTIMATING OVERSUBSCRIBABLE RESOURCES

How many resources should be oversubscribed?



WHAT DO WE DO ABOUT MISPREDICTIONS?

Now, what happens when things change?



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THE QoS CONTROLLER

- Can shut down best effort containers
- In the future, it will be able to correct by
  - Freezing
  - Throttling
  - Resizing
  - Cooperating with the framework

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MANY RESOURCES CANNOT BE ISOLATED

- Logical units on the chip
- Last level caches
- Memory bandwidth
- I/O
- Chip power supply

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OVERSUBSCRIPTION WITH INTEL: SERENITY

https://goo.gl/jWtu7V

WRAPPING UP

- Mesos is being used in production at huge scale
- It forms the core of an operating system for the datacenter
- Lots of exciting work yet to do!

Slides at http://mesosphere.github.io/presentations

(P.S., we’re currently hiring interns!)

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