Challenges in Optimizing Job Scheduling on Mesos

Alex Gaudio

Who Am I?

Who Am I?

- Data Scientist and Engineer at Sailthru
- Mesos User
- Creator of Relay.Mesos

Who Am I?

- Data Scientist and Engineer at Sailthru
  - Distributed Computation and Machine Learning
- Mesos User
  - 1 year
- Creator of Relay.Mesos
  - intelligently auto-scale Mesos tasks


Goals
1.
2.
3.

What are the goals of this talk?

1. Understand the problem of **job scheduling** using **basic principles**

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1. Understand the problem of job scheduling using basic principles

2. Learn ways to **think about, use or develop Mesos** more effectively

What are the goals of this talk?

1. Understand the problem of job scheduling using basic principles

2. Learn how to think about and use or develop Mesos more effectively

3. Have some **fun** along the way!

Contents

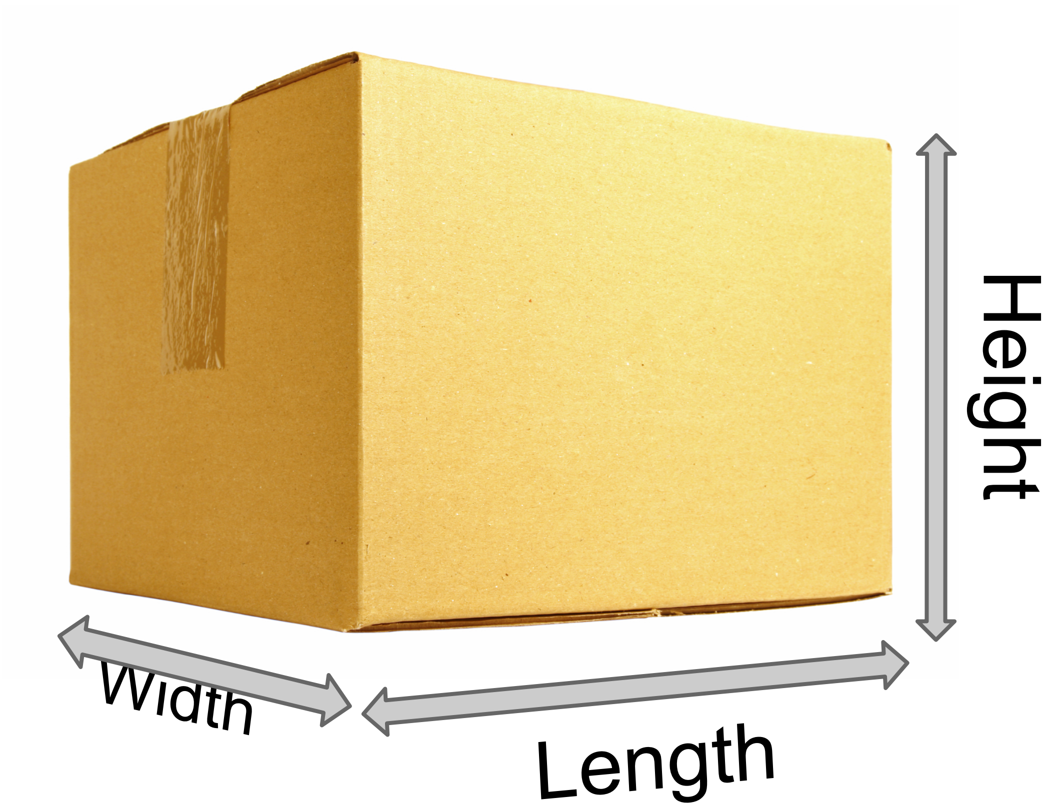
- The Problem of Utilization

- How does Mesos do (or not do) Job Scheduling?

The Problem of Utilization

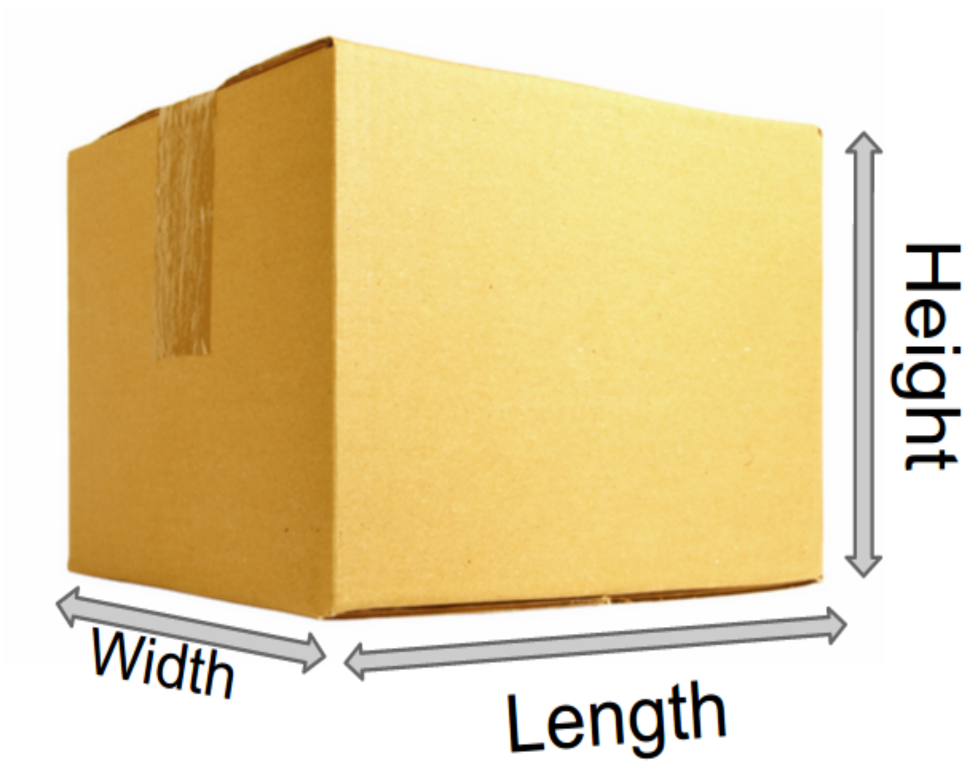
Here's a Box

The Problem of Utilization

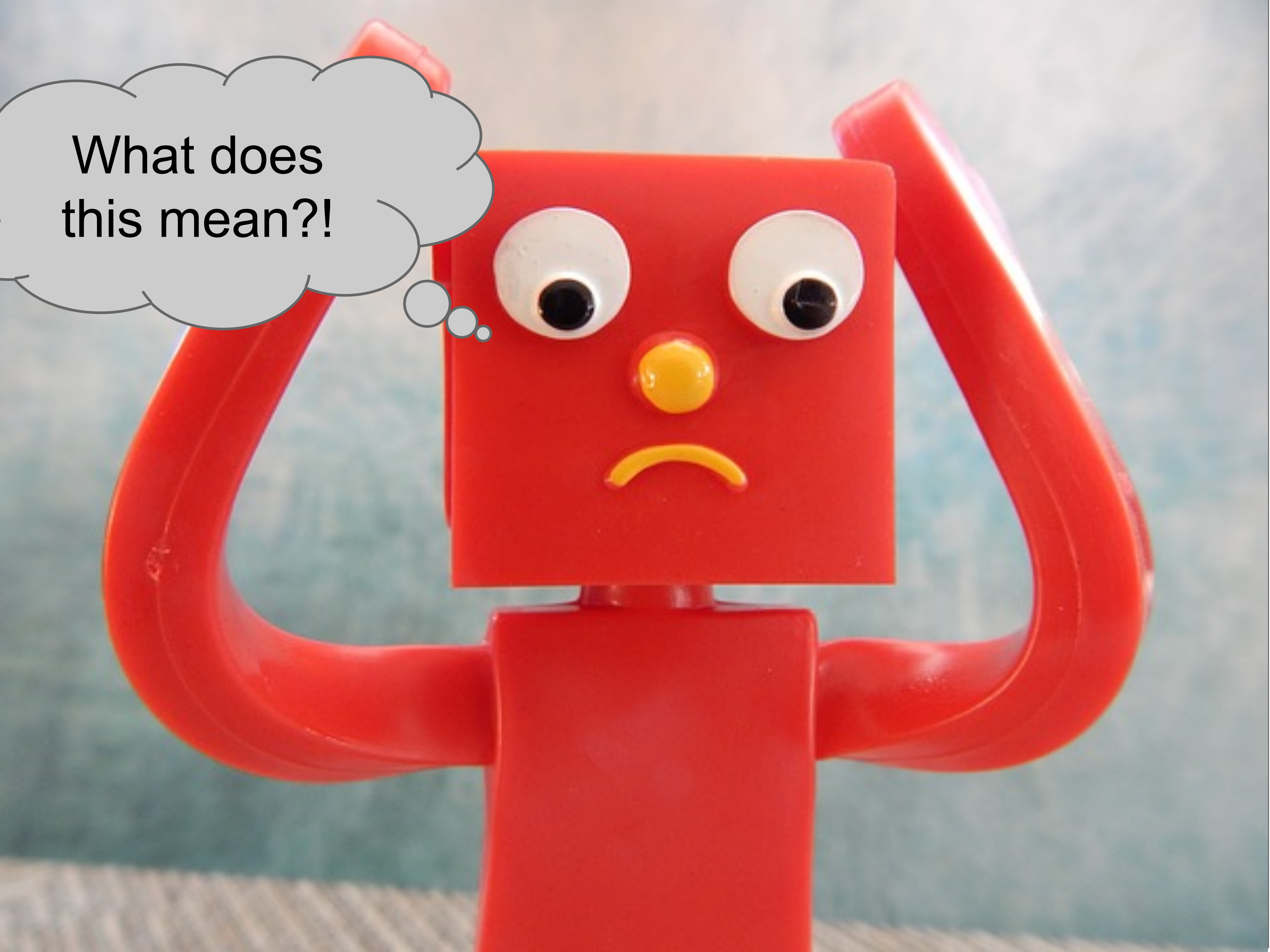


It has
3 dimensions

What can you do with a box that has 3 dimensions?



It has
3 dimensions


What does this mean?!

The Problem of Utilization

Stuff the box

The Problem of Utilization

Unpack the box

The Problem of Utilization

Box in a box

The Problem of Utilization

Carry the box

The Problem of Utilization

The Problem of Utilization

The Problem of Utilization

By Example:

Please efficiently pack these stolen boxes into my get-away car!

The Problem of Utilization

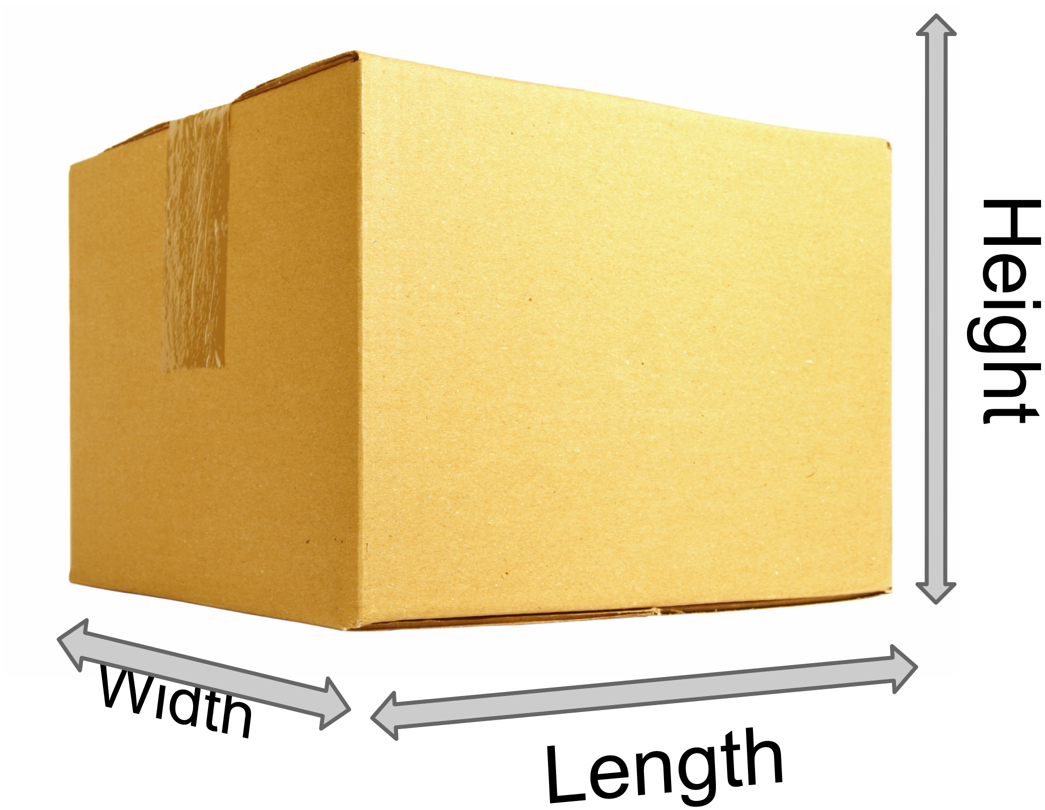
Explained By Analogy

The Problem of Utilization

Box → Computer

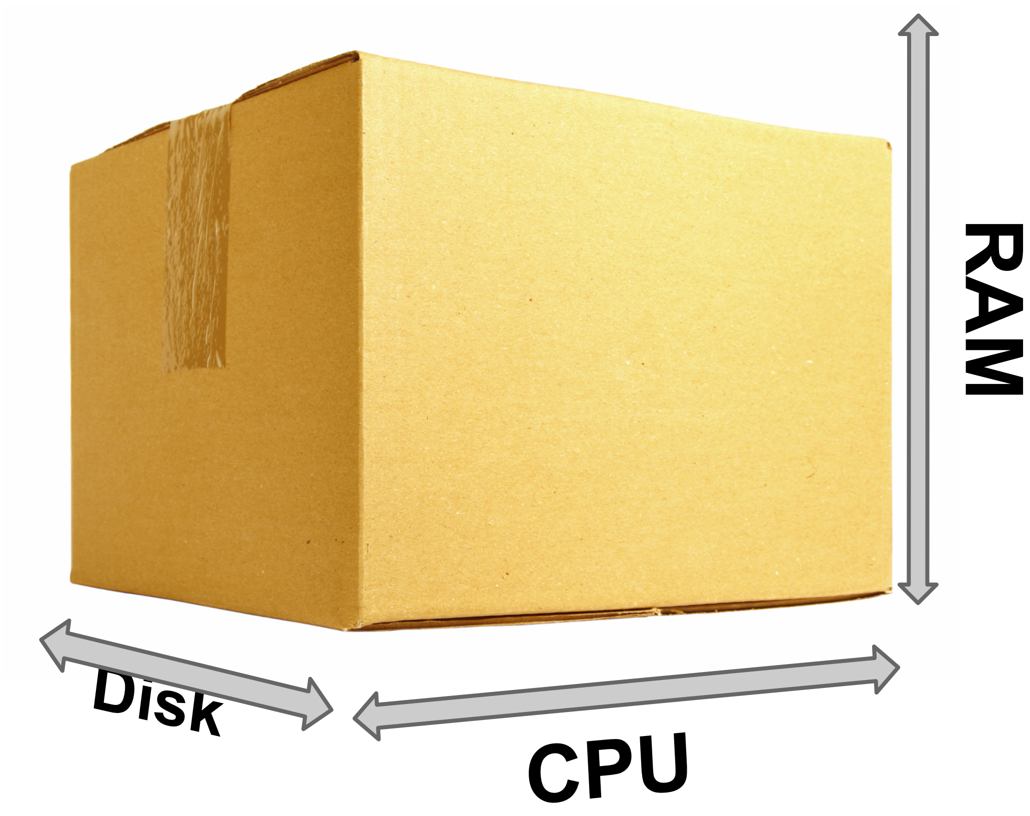
A Computer is really just a Box

The Problem of Utilization



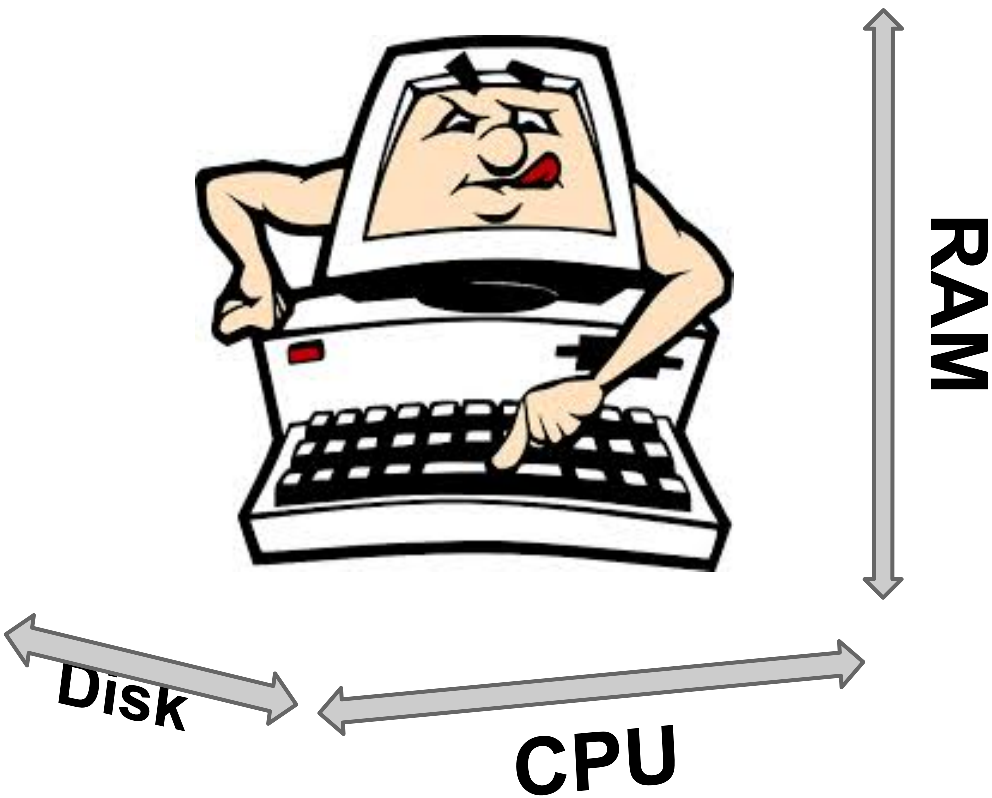
We can represent a box with 3 dimensions

The Problem of Utilization



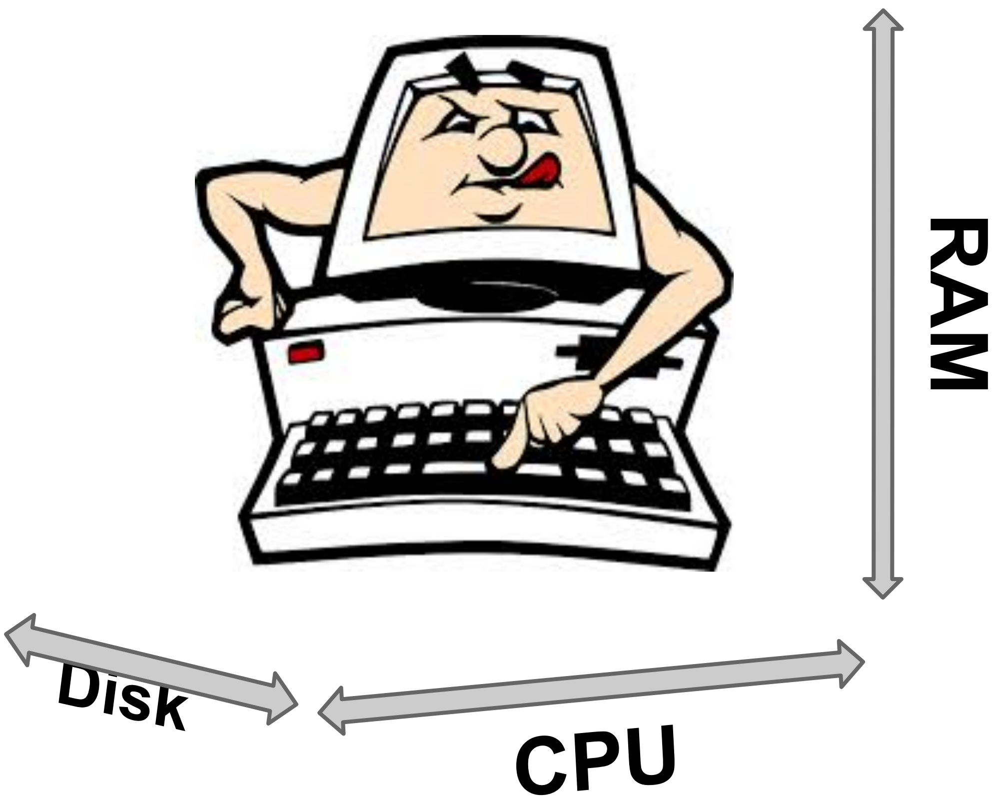
… If we relabel the dimensions

The Problem of Utilization



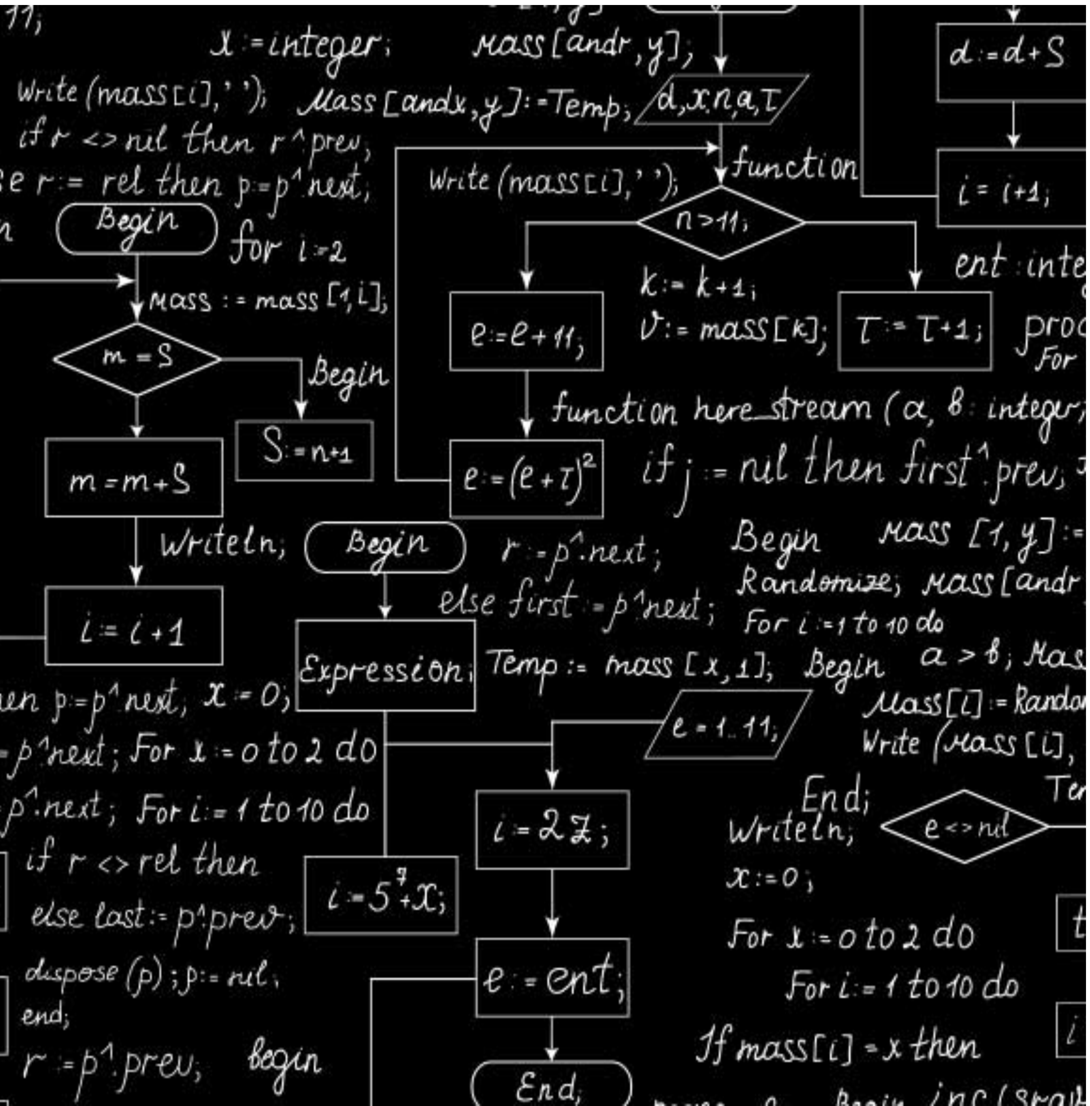
A computer,
like a box,
is a multi-
dimensional object.

The Problem of Utilization



A computer,
is just a collection of
resources

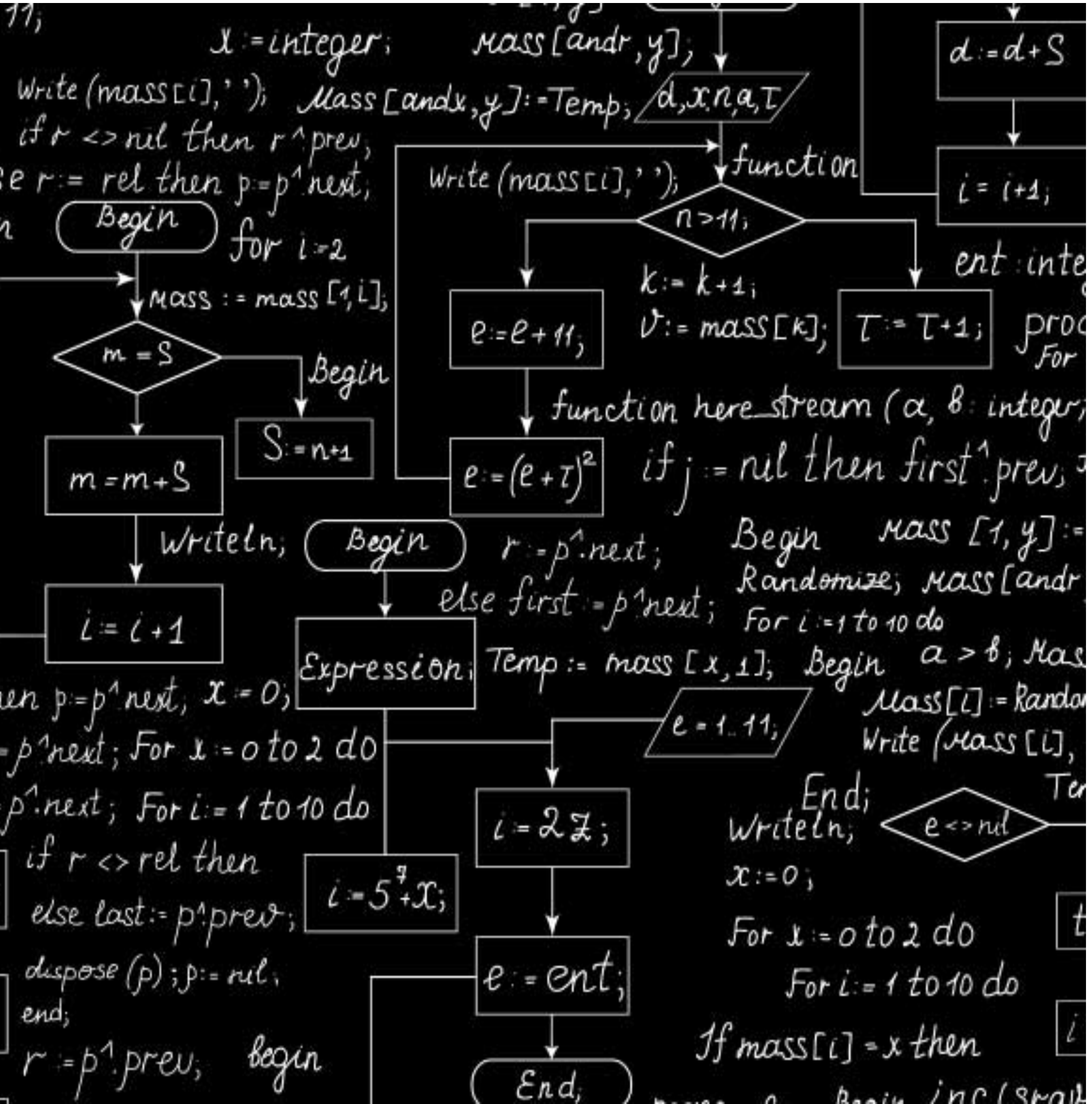
The Problem of Utilization



If we put things in boxes,

What can we put in our computer?

The Problem of Utilization



What can we put in our computer?

Processes!

$ pstree

```
init─┬─acpid
     ├─atd
     ├─collectdmon───collectd───45*[{collectd}]
     ├─consul───15*[{consul}]
     ├─cron
     ├─dbus-daemon
     ├─dhclient
     ├─docker─┬─10*[sh───env.sh───consulconf───sh───stolos─┬─sh───env.sh───con
     │        │                                            └─3*[{stolos}]]
     │        ├─11*[sh───env.sh───consulconf───sh───stolos─┬─sh───env.sh───con
     │        │                                            └─3*[{stolos}]]
     │        ├─4*[sh───env.sh───consulconf───sh───stolos─┬─sh───env.sh───cons
     │        │                                           └─3*[{stolos}]]
     │        ├─sh───env.sh───consulconf───sh───python─┬─java───89*[{java}]
     │        │                                        └─{python}
     │        └─113*[{docker}]
     ├─7*[getty]
     ├─irqbalance
     ├─mesos-slave─┬─2*[logger]
     │             ├─11*[sh───mesos-executor─┬─sh───docker───3*[{docker}]]
     │             │                         └─33*[{mesos-executor}]]
     │             ├─5*[sh───2*[docker───3*[{docker}]]]
     │             ├─10*[sh───mesos-executor─┬─sh───docker───4*[{docker}]]
     │             │                         └─33*[{mesos-executor}]]
     │             ├─6*[sh─┬─docker───3*[{docker}]]
     │             │       └─docker───4*[{docker}]]
     │             ├─sh─┬─docker───4*[{docker}]
     │             │    └─docker───5*[{docker}]
```

Output of a computer's Process Tree

$ pstree

```
init─┬─acpid
     ├─atd
     ├─collectdmon───collectd───45*[{collectd}]
     ├─consul───15*[{consul}]
     ├─cron
     ├─dbus-daemon
     ├─dhclient
     ├─docker─┬─10*[sh───env.sh───consulconf───sh───stolos─┬─sh───env.sh───con
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     │        │                                            └─3*[{stolos}]]
     │        ├─4*[sh───env.sh───consulconf───sh───stolos─┬─sh───env.sh───cons
     │        │                                           └─3*[{stolos}]]
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```

This is an interesting slide!

Why is the pstree slide interesting?

1. It introduces the concept of a **process**.

A process is an instance of code that accesses resources over time.

Why is the pstree slide interesting?

1. It introduces the concept of a process.

A process may **use**, **share**, **steal**, **lock** or **release** resources

Why is the pstree slide interesting?

2. It shows a computer with **multiple processes** running on it.

Why is the pstree slide interesting?

2. It shows a computer with **multiple processes** running on it.

- The processes access the same pool of resources.

Why is the pstree slide interesting?

2. It shows a computer with **multiple processes** running on it.

- Shared access to same pool of resources.
- Processes are categorized into a hierarchical structure.

At this point, we can ask a couple great questions!

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- Why don't computers just have 1 process per box?

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- Is it inefficient to have so many processes on one box?

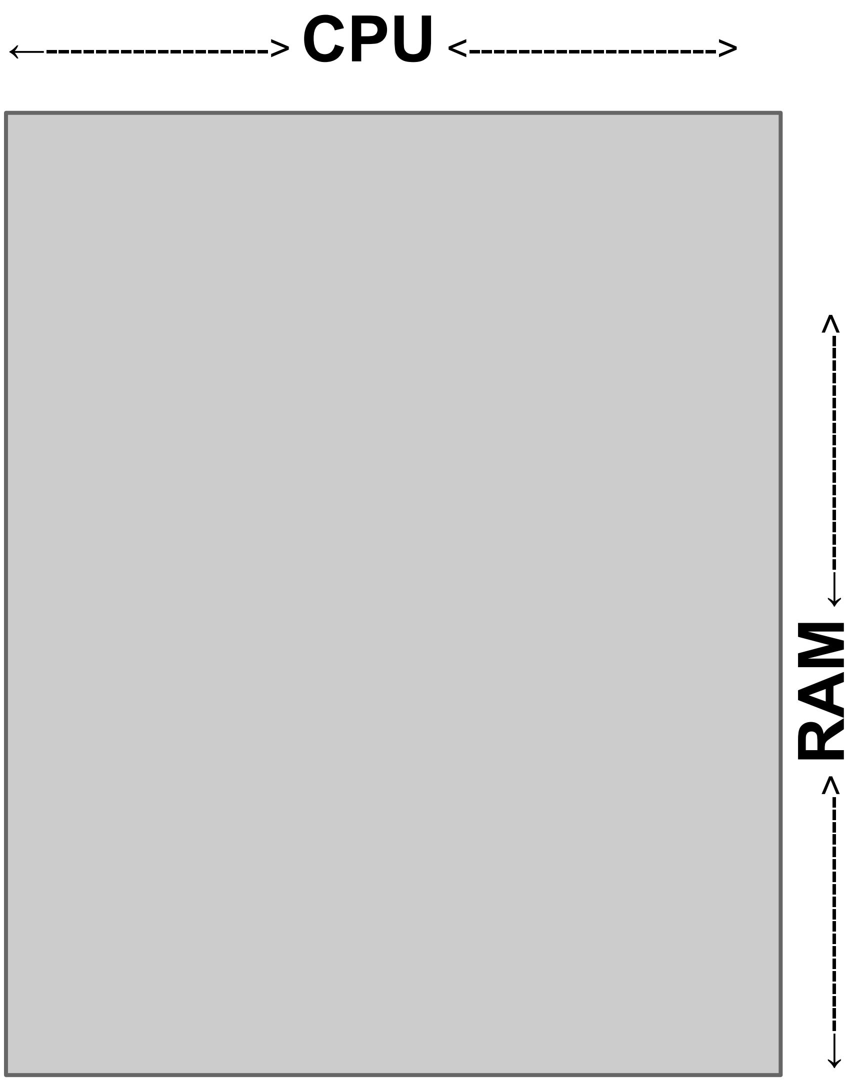
At this point, we can ask a couple great questions!

- Why don't computers just have 1 process per box?
- Is it inefficient to have so many processes on one box?
- Aren’t processes just another kind of box?

The Problem of Utilization

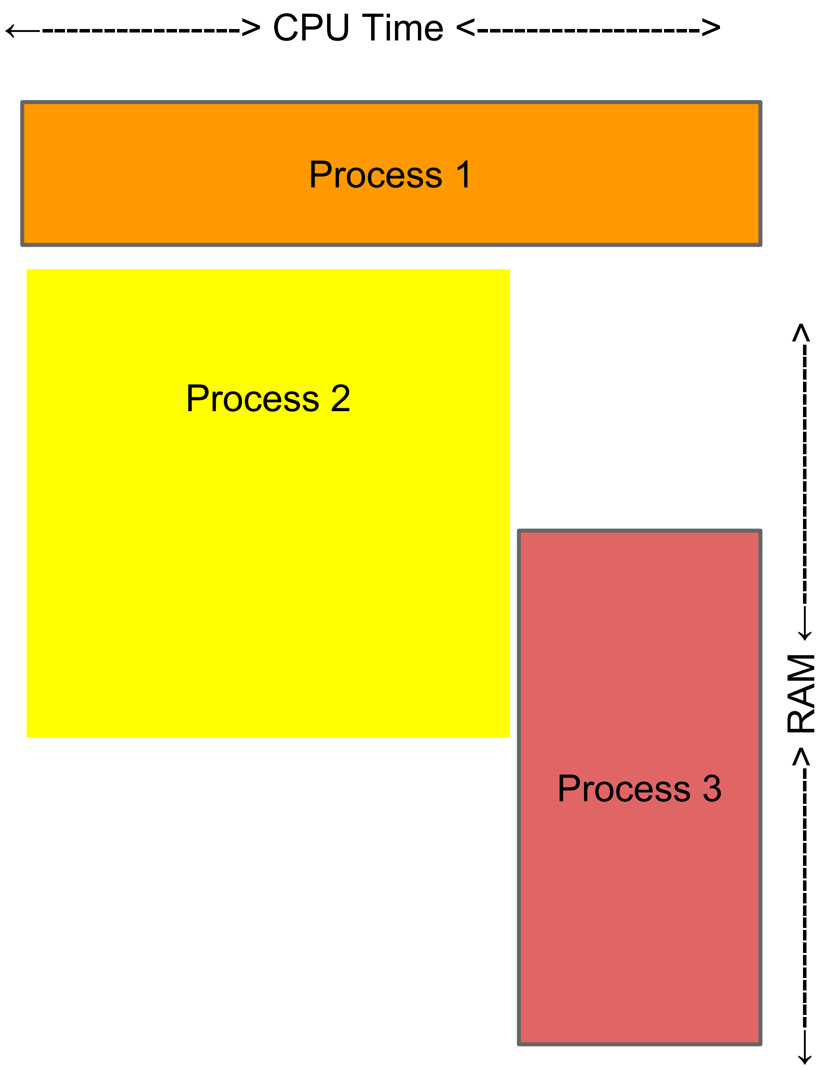
Let’s try to answer these questions!

The Problem of Utilization



Imagine a computer with only 2 resources.

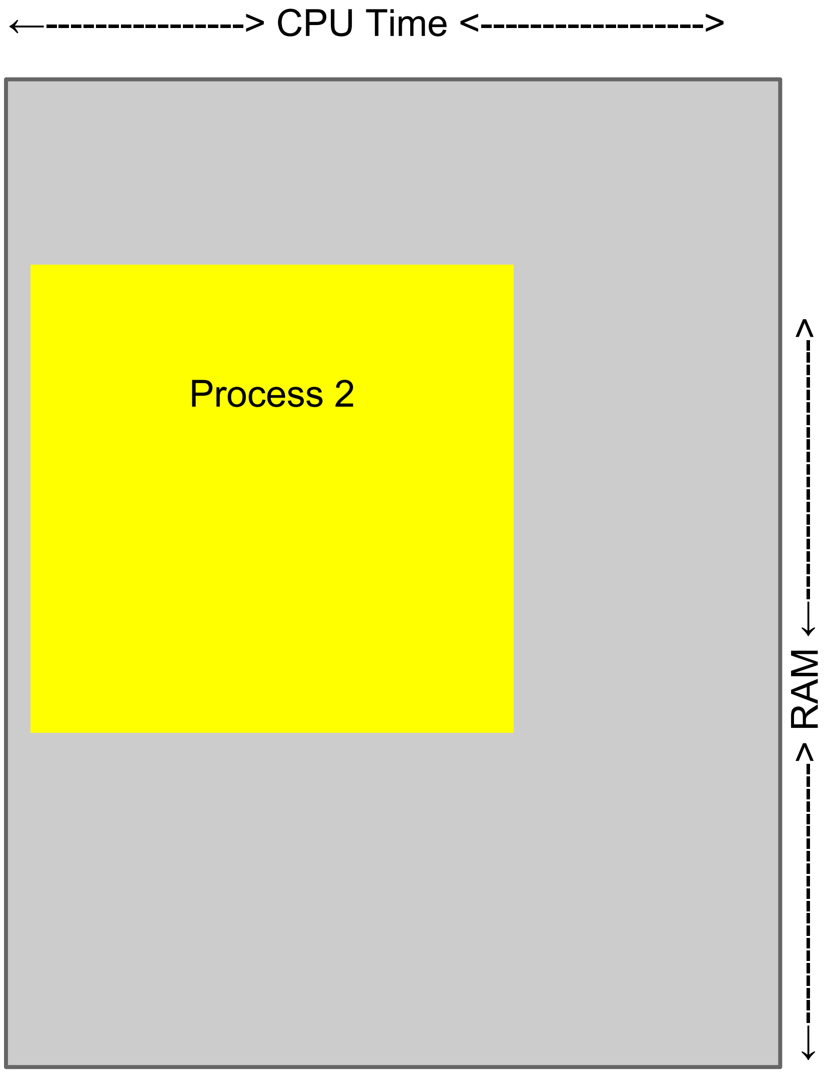
The Problem of Utilization



Imagine a computer
with only 2 resources.

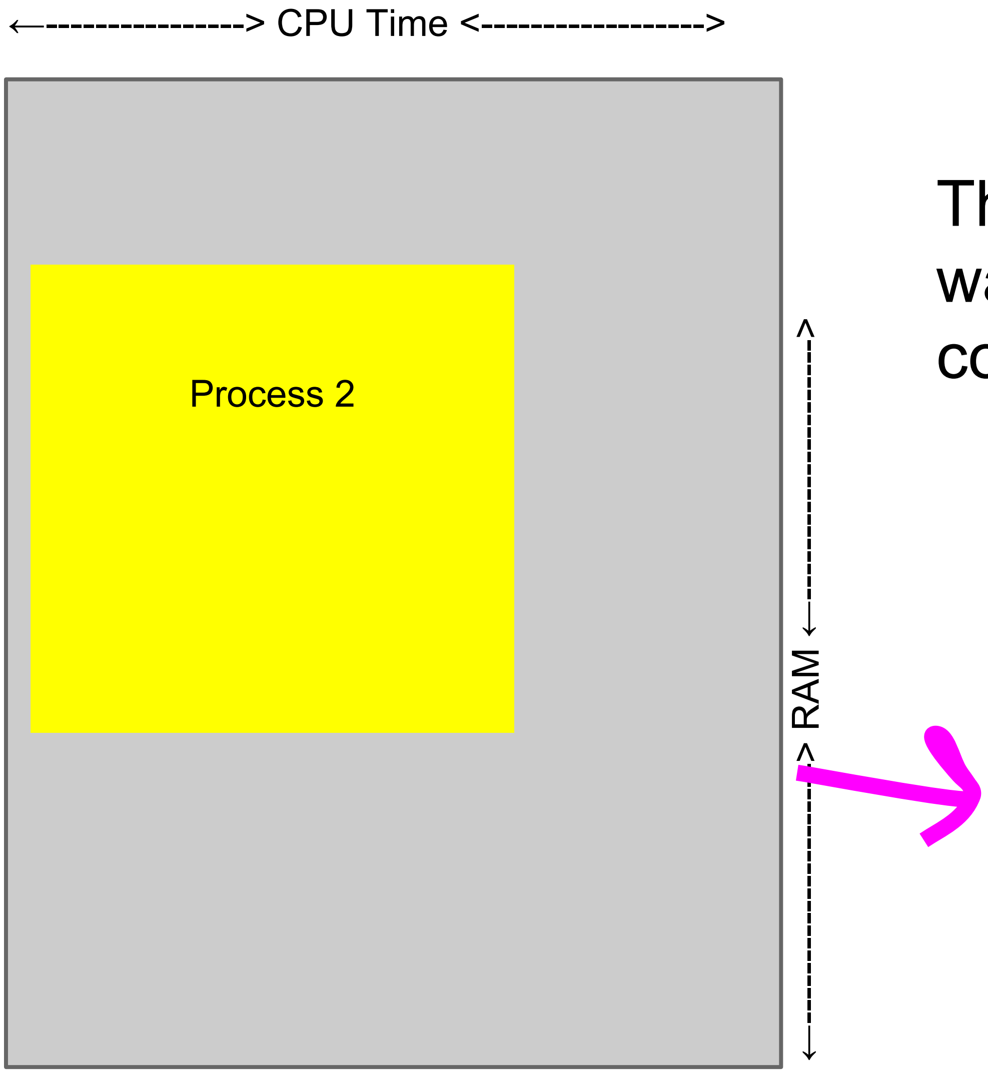
Only 3 distinct process
types run on this computer

The Problem of Utilization



There is a fixed number of ways we can use up the computer's resources.

The Problem of Utilization

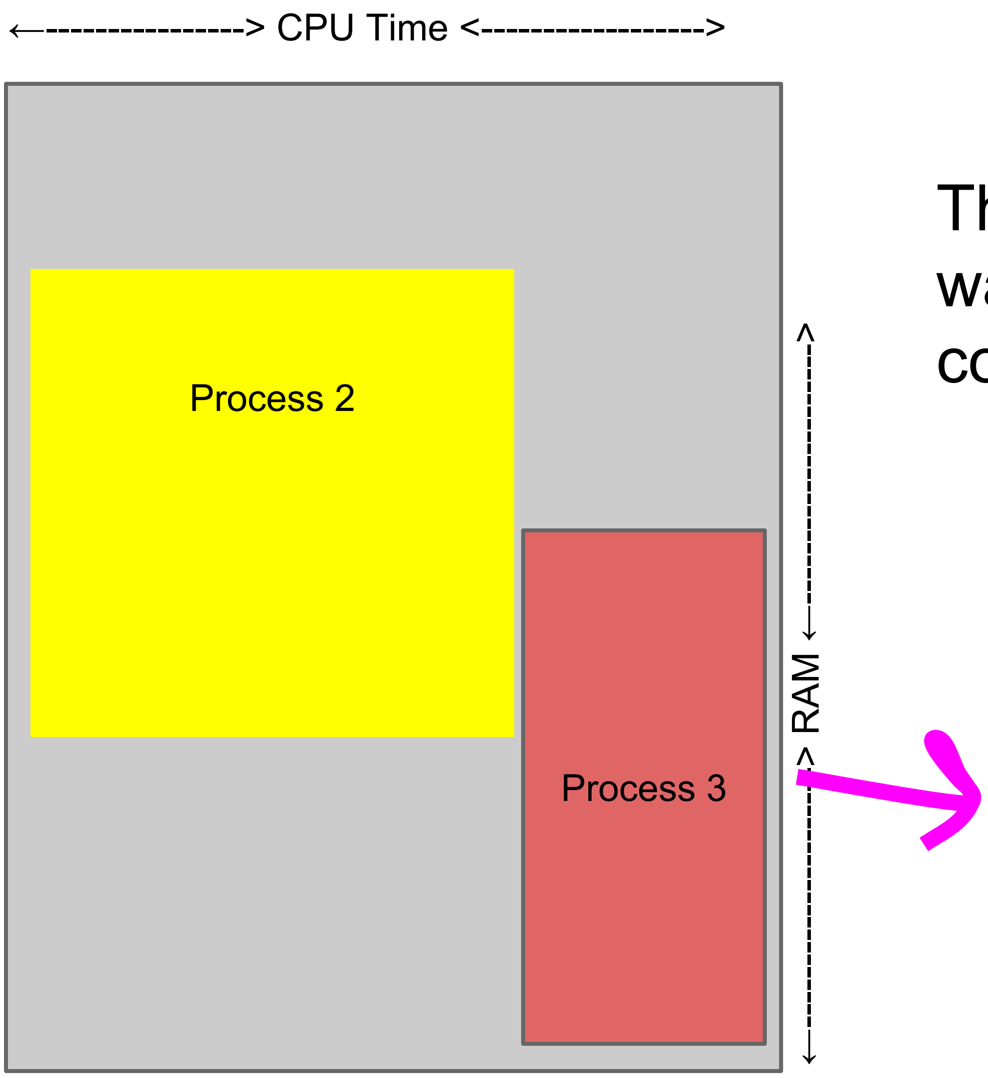


There is a fixed number of ways we can use up the computer's resources.

1 process at a time.

Could be great if all processes were the size of the computer

The Problem of Utilization



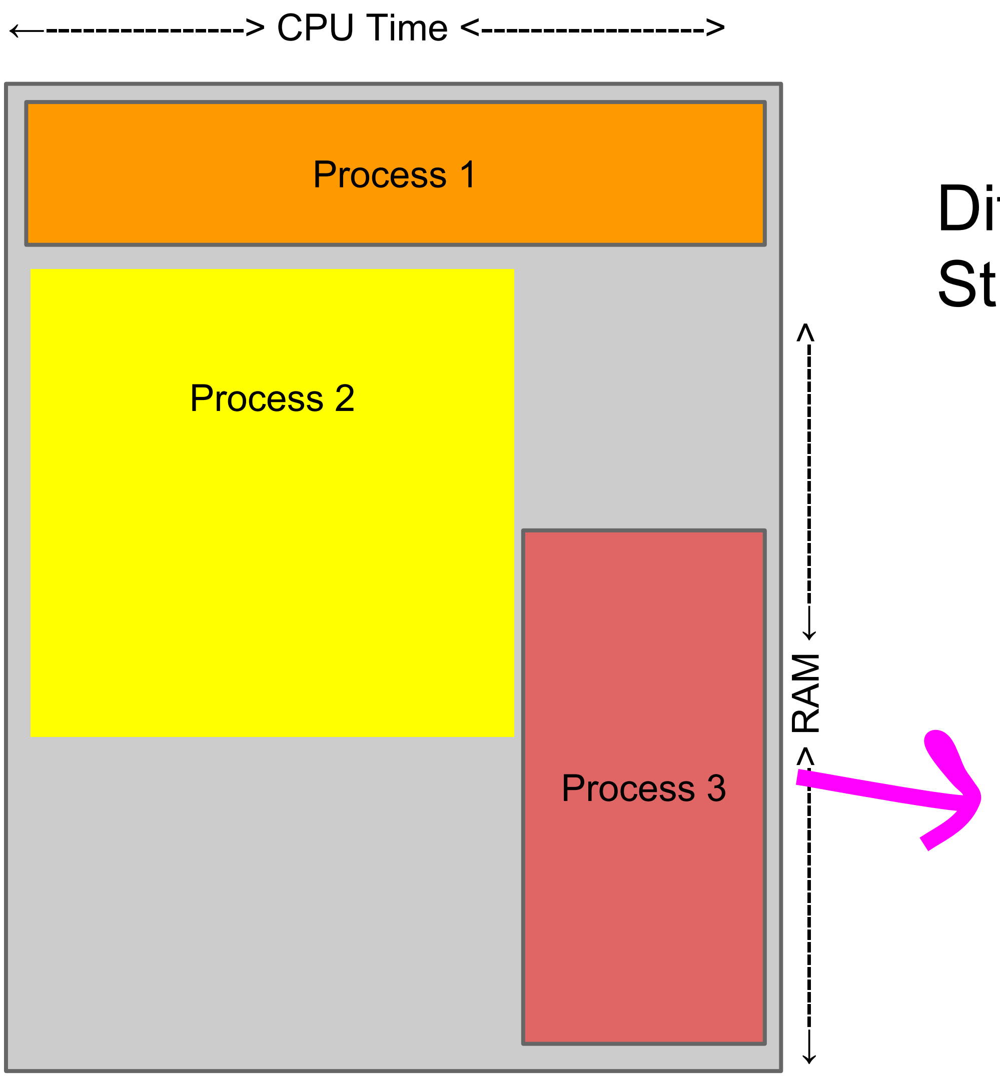
There is a fixed number of ways we can use up the computer's resources.

2+ processes

Sharing resources

New Concept: **Shared State**

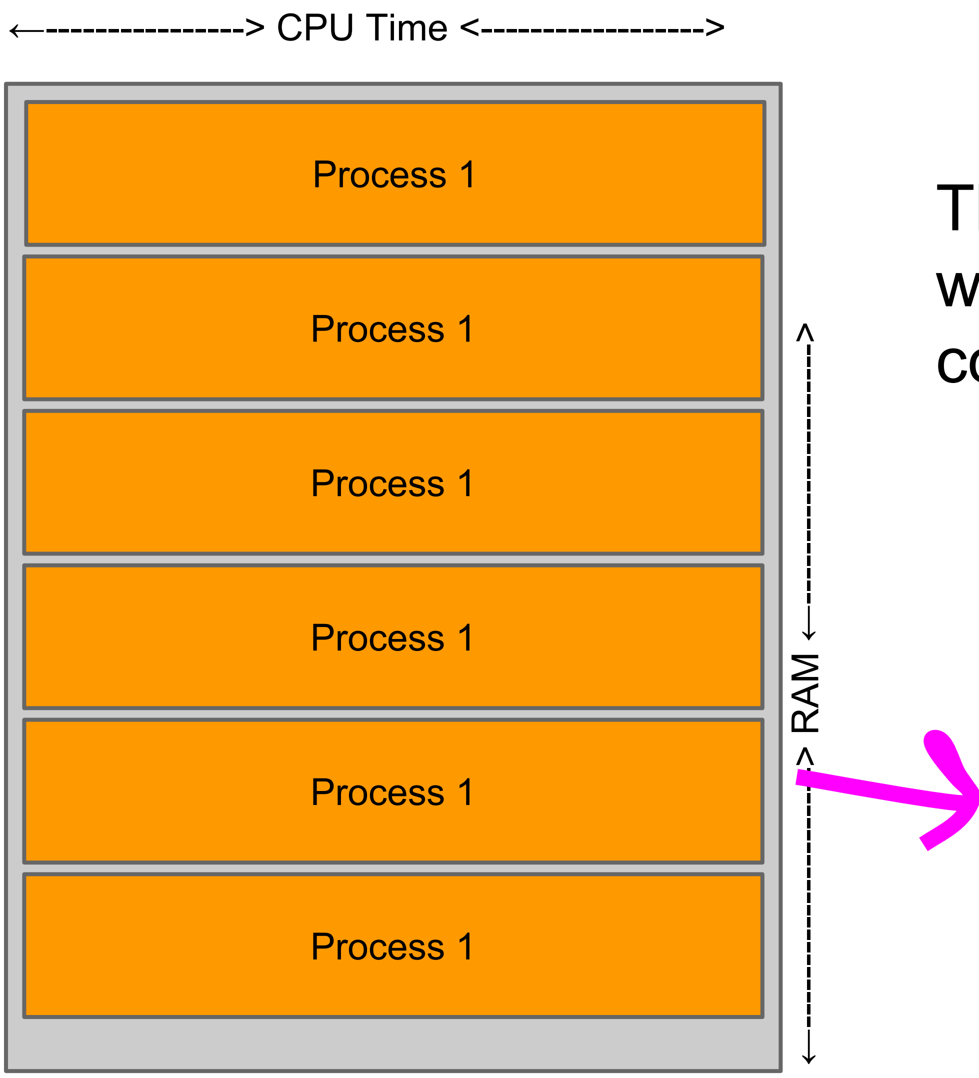
The Problem of Utilization



Different Utilization Strategies

Maximum Variation Under-utilized

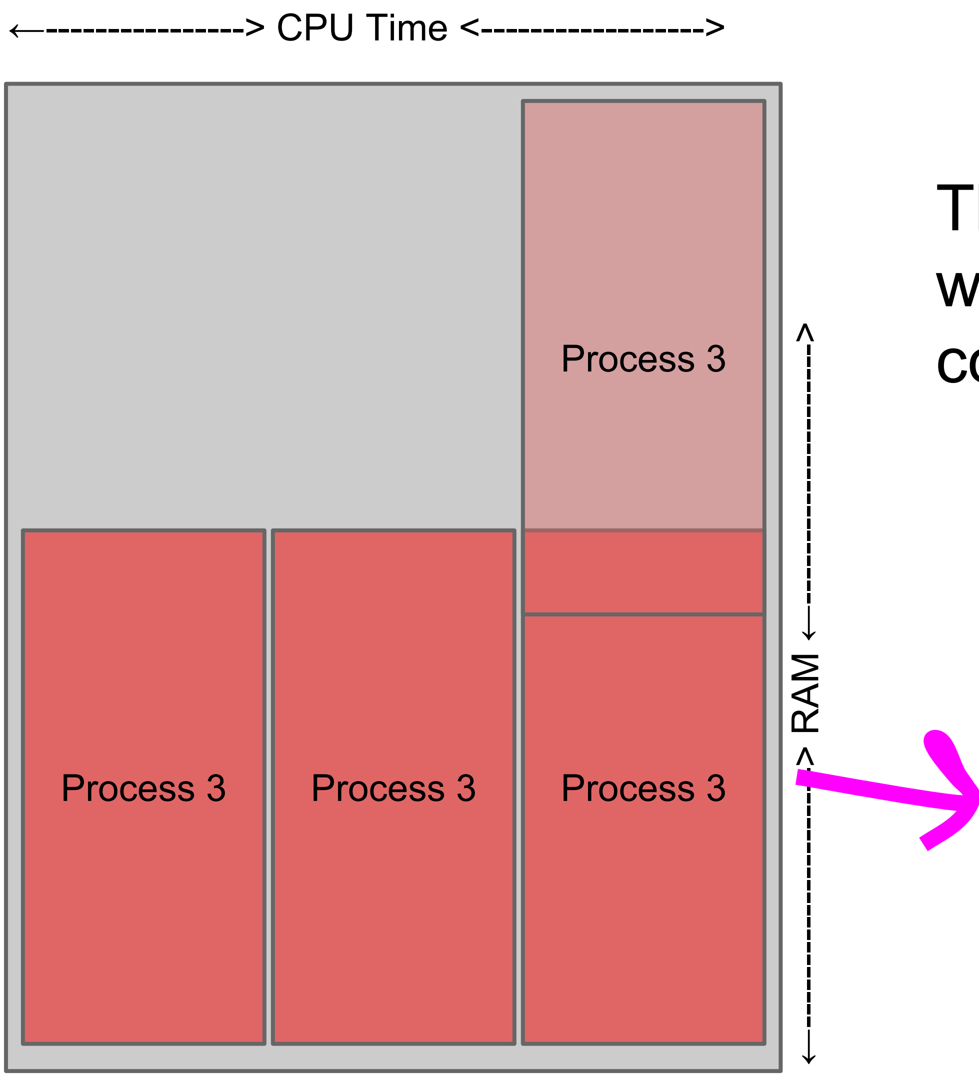
The Problem of Utilization



There is a fixed number of ways we can use up the computer's resources.

Maximum Utilization
No Variation

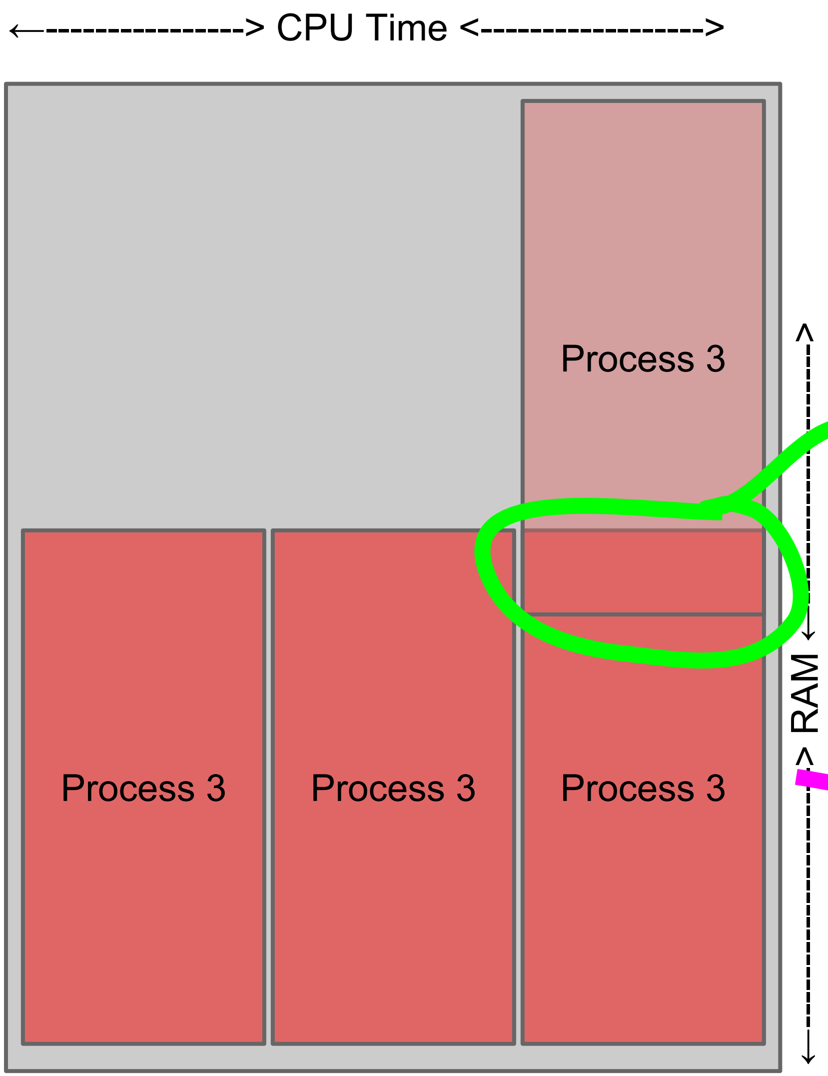
The Problem of Utilization



There is a fixed number of ways we can use up the computer's resources.

Over-provisioned and Under-utilized

The Problem of Utilization



Competing for shared resources. Unclear consequences.

Over-provisioned and Under-utilized

The Problem of Utilization

A multi-dimensional problem!

And

very complicated!

Take-Aways

Many ways we can use a computer’s resources.

Many different factors inform how we choose to utilize a set of resources.

Benefits of Shared State

- increased utilization
- flexibility to do different things simultaneously
- exposes a lot of interesting problems to solve

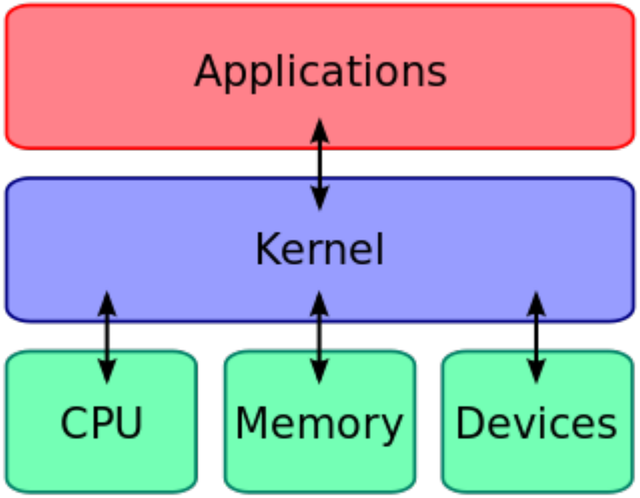
Drawbacks of Shared State

- resource competition
  - network and io congestion
  - context switching
  - out of memory errors

- less predictable
  - constantly changing dynamic systems
  - non-deterministic waiting
  - feedback loops

One machine, a host of problems

- Operating systems are complicated!
- Your laptop’s kernel solves these scheduling problems well.




STOP
WAIT A MINUTE
HOLD UP BOO BOO
memegenerator.net
Wait!

The Problem of Utilization

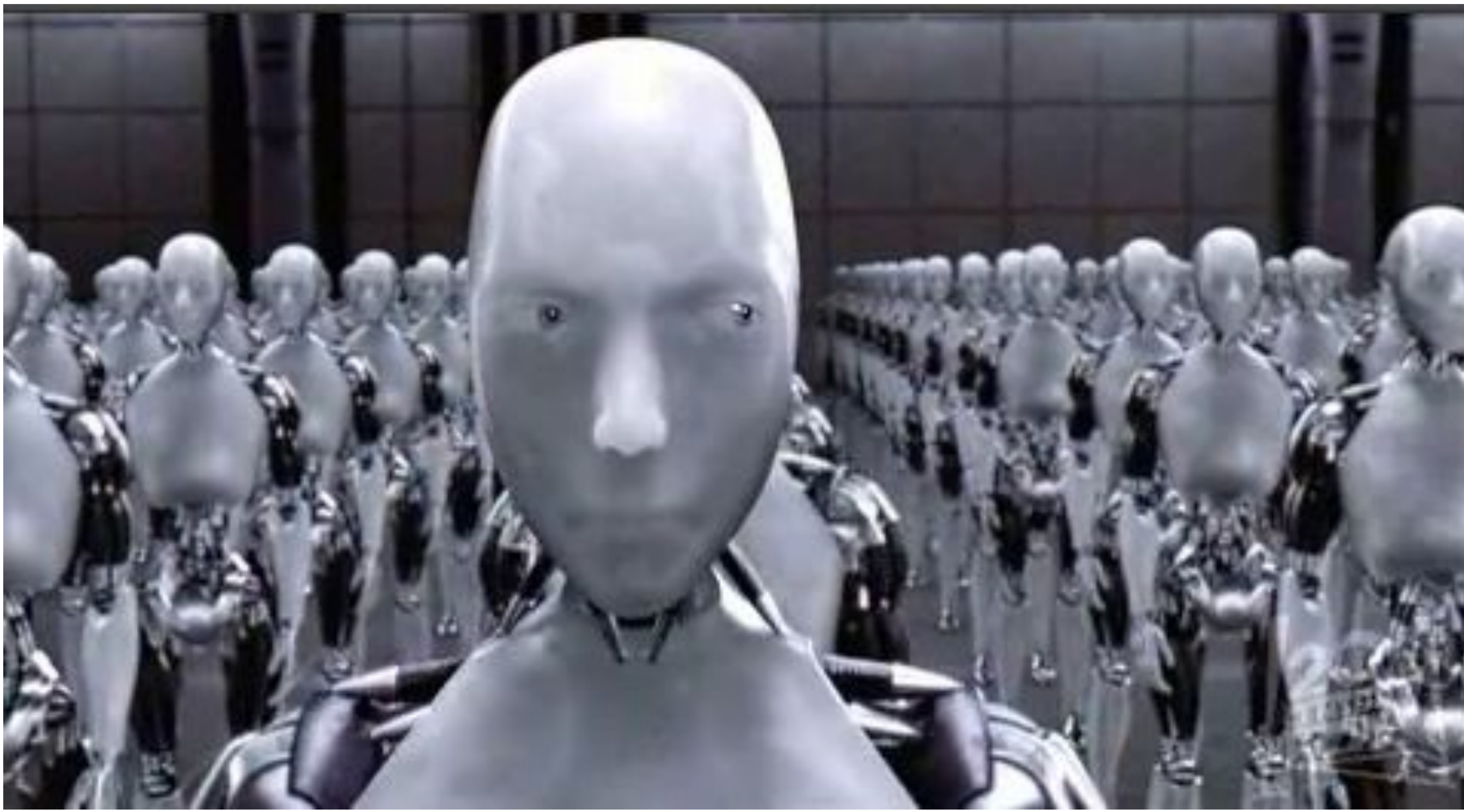
- Thus far, we've discussed resource utilization on 1 machine.
- Is 1 machine enough?
- And what about Mesos?

Obviously, 1 machine isn't enough

- Problems of scale:
    - Too much data
    - Not enough compute power
    - Everything can't connect to 1 node

- Problems of reliability and availability:
    - 1 machine is a Single Point of Failure
    - No redundancy

Many machines, then?



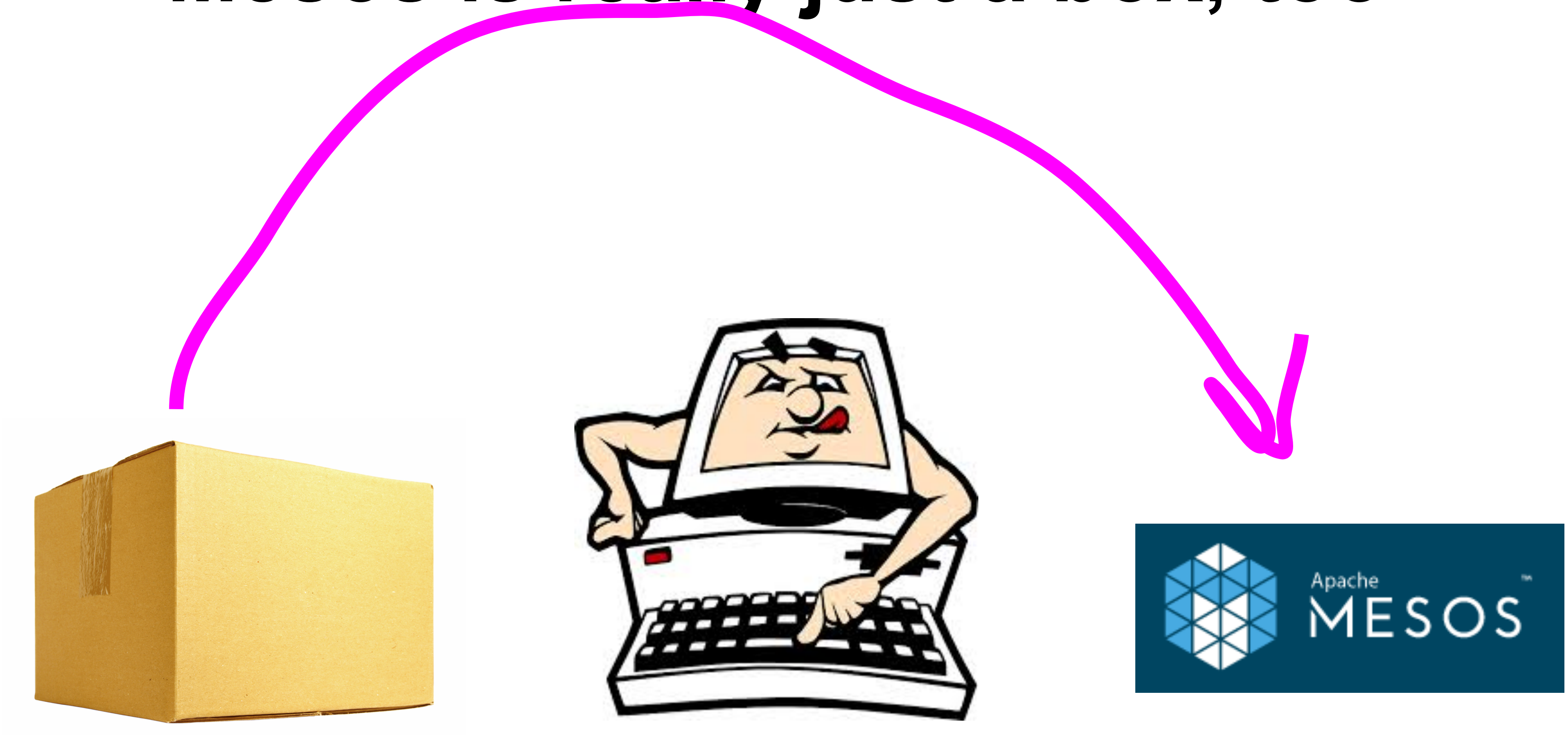
Mesos!

Recall the Box...

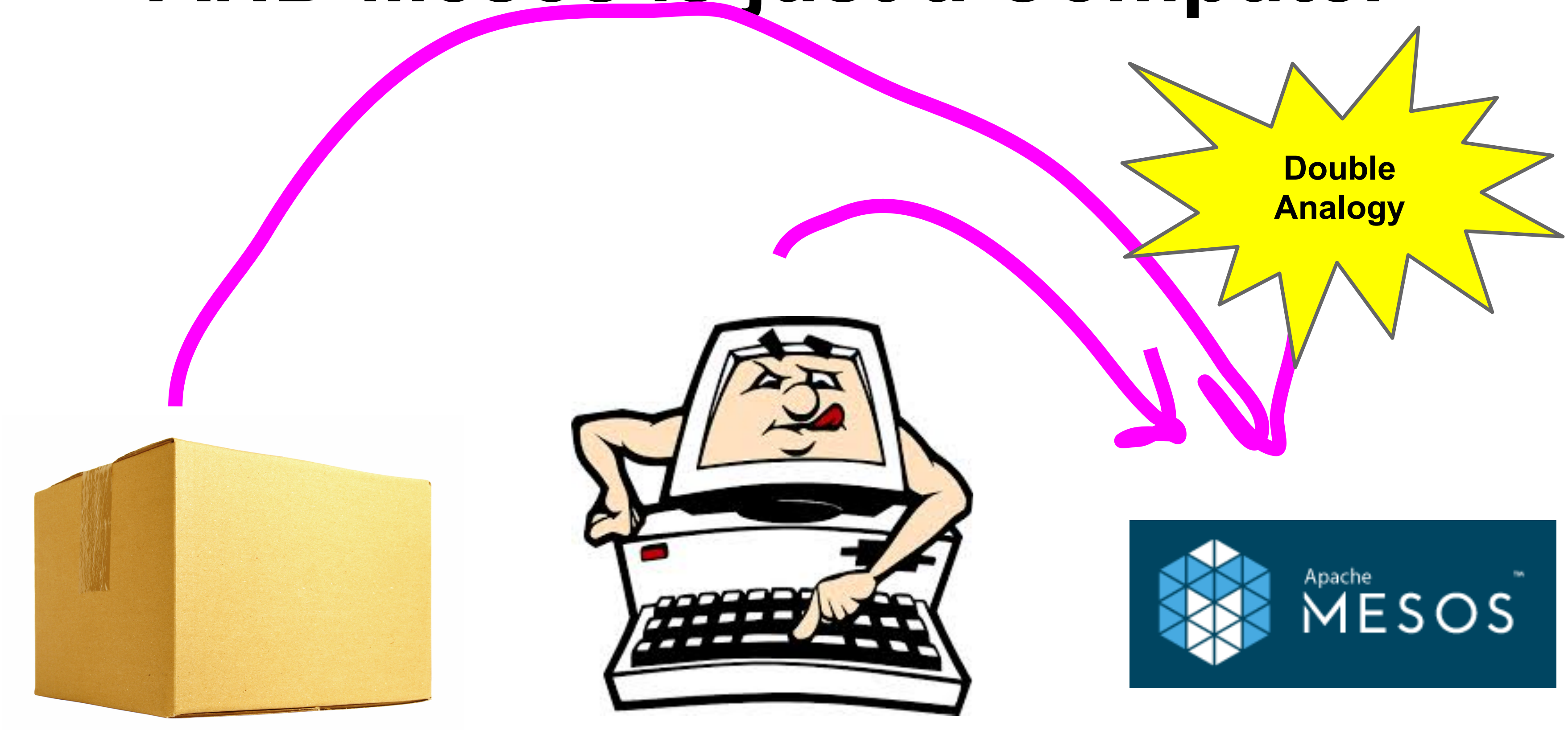
Box → Computer

A Computer is really just a Box

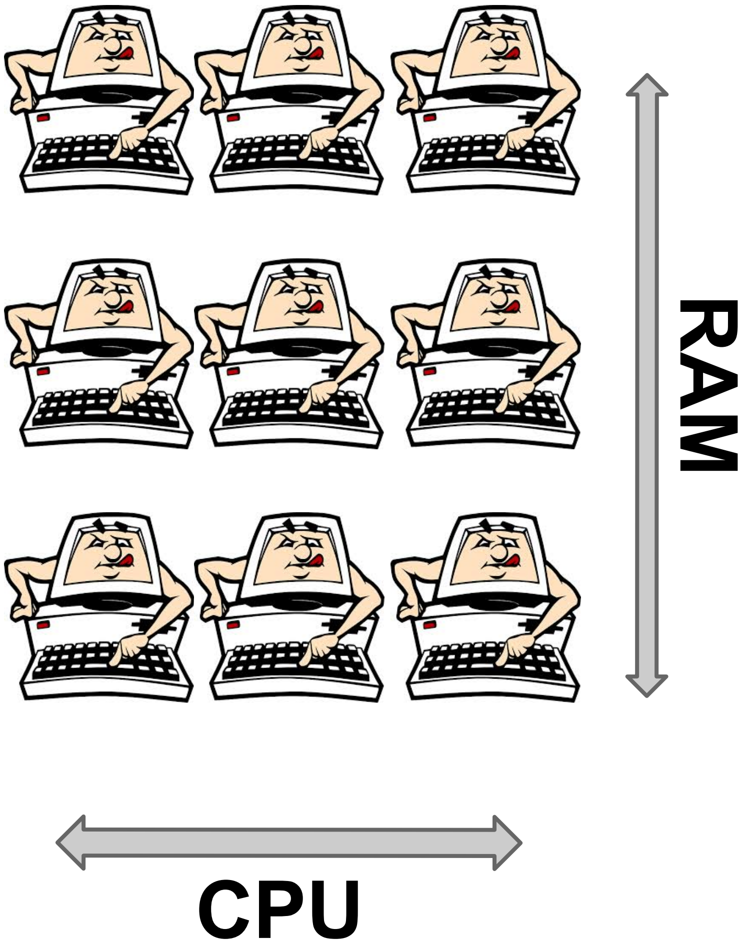
Mesos is really just a box, too



AND Mesos is just a Computer



Mesos is a Distributed Computer



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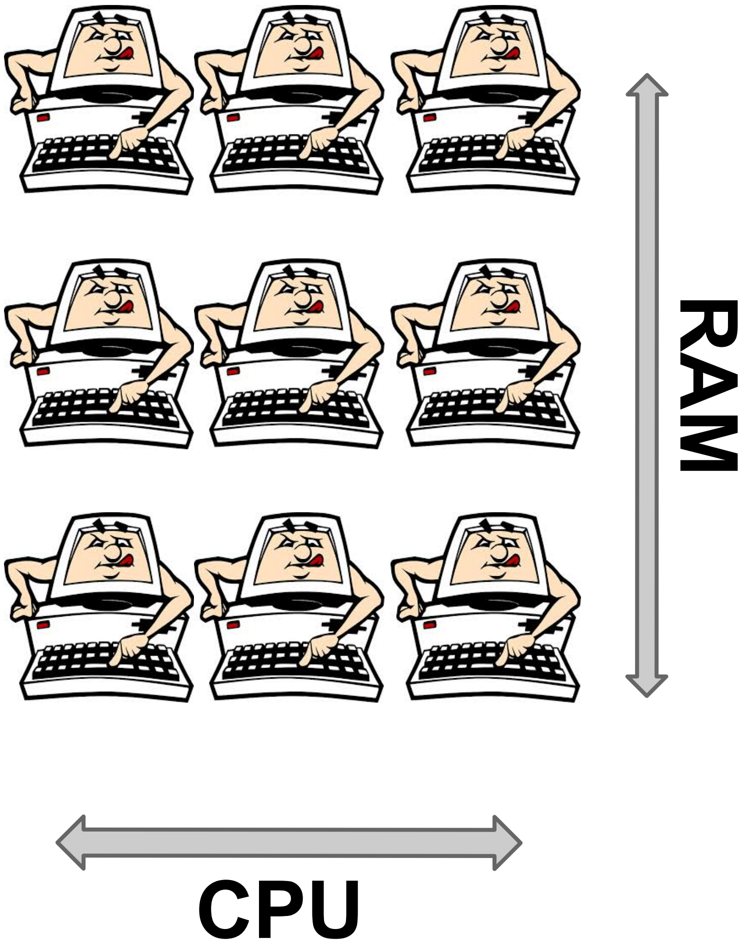
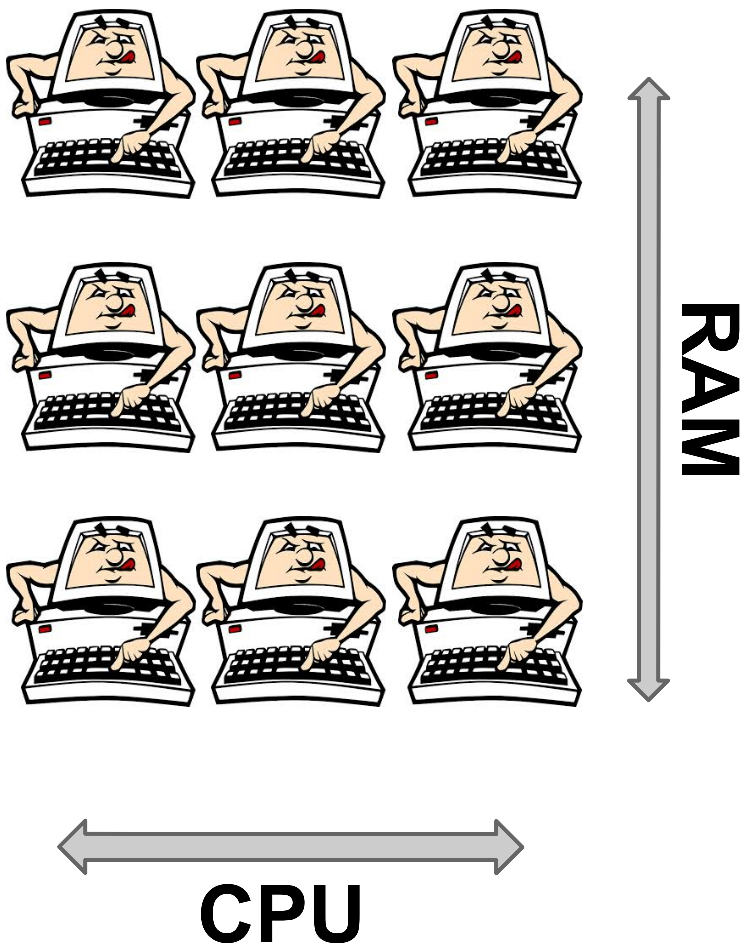


- a lot of machines
- all solving the similar problems

Mesos is a Distributed Computer

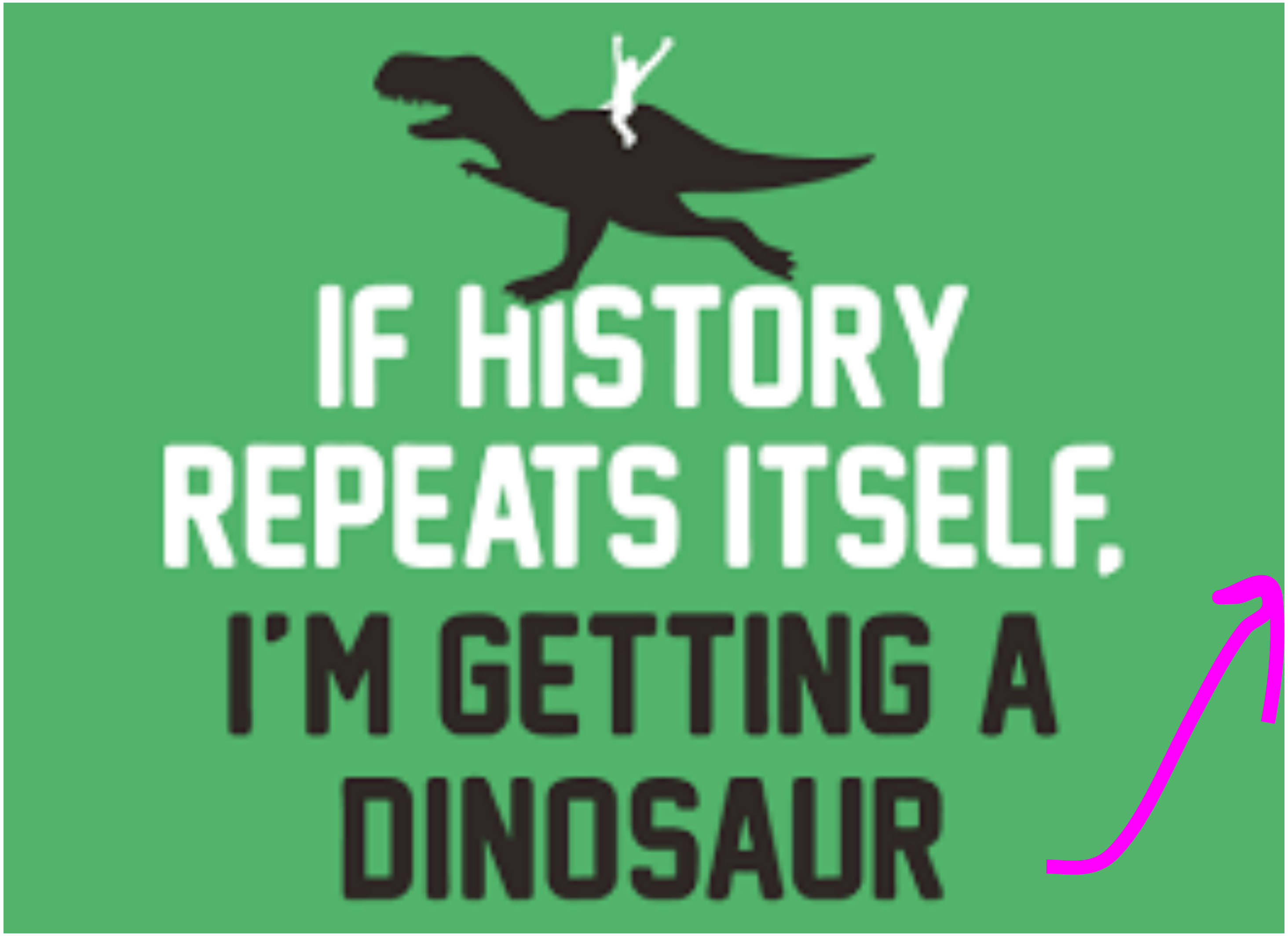


- a lot of machines
- all solving the similar problems

- We need ways to tell each machine what to do.

Must rebuild all elements of an operating system in context of a distributed system!

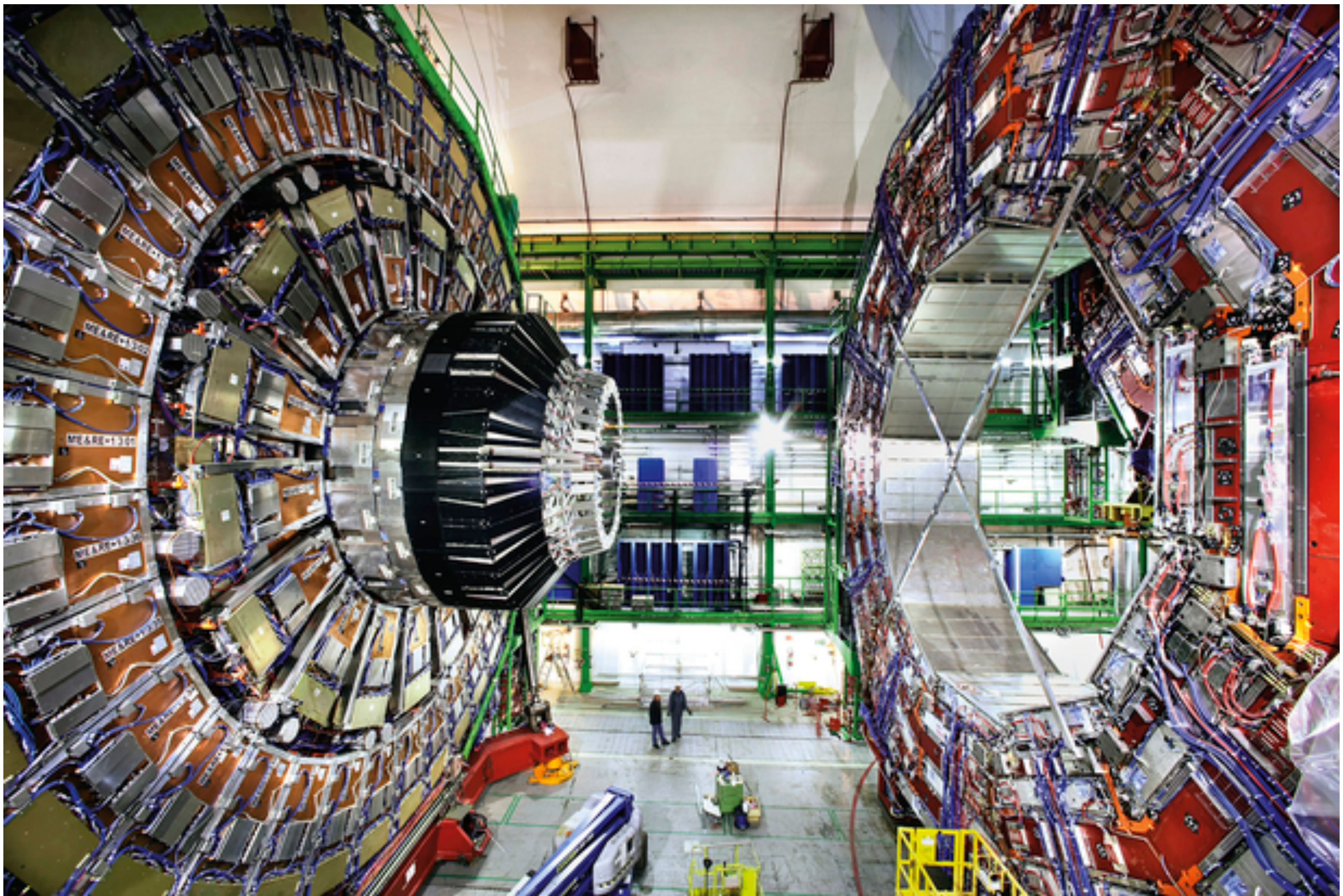
Must rebuild all elements of an operating system in context of a distributed system!



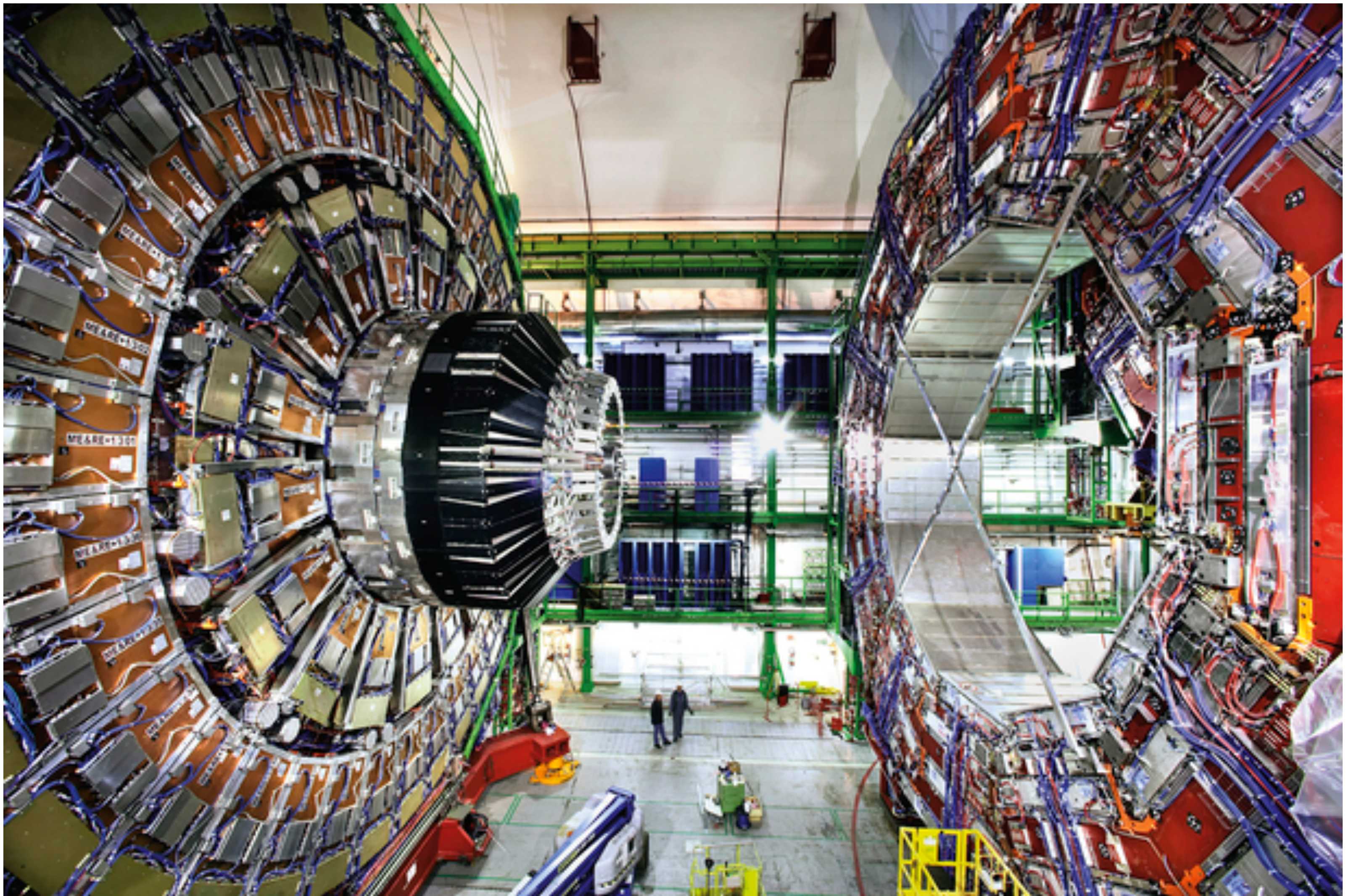
Same old problems

Awesome new technology

Part 2:



Part 2:
How does Mesos do Job Scheduling?

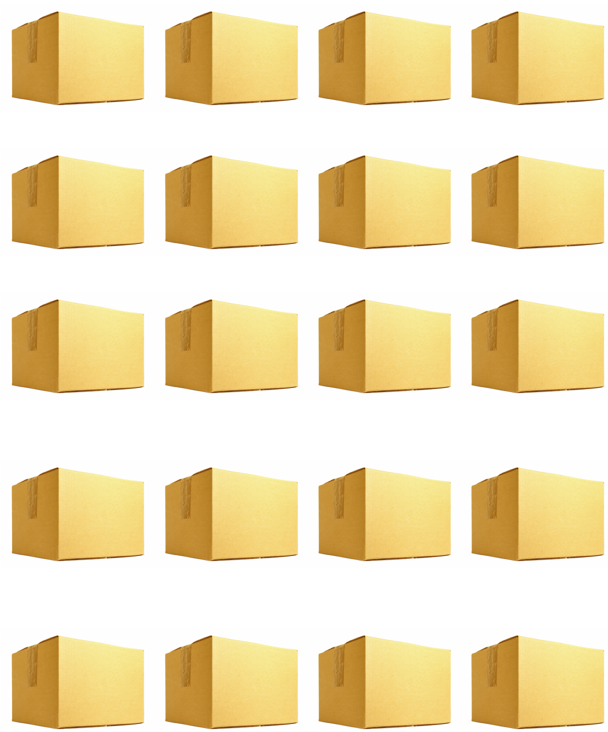


How Mesos does Job Scheduling

A very big box

Let’s call it “**Grid**”

How Mesos does Job Scheduling

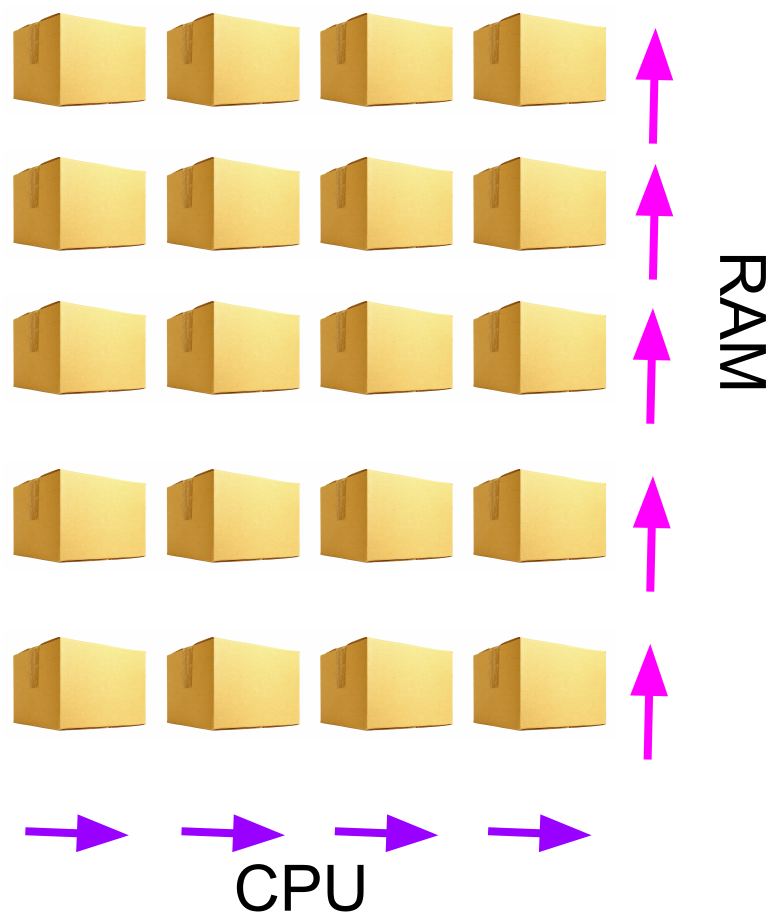


Mesos Slaves
(aka computers or boxes)

The “Grid” holds a lot of smaller boxes.

The little boxes are “**Slaves**”

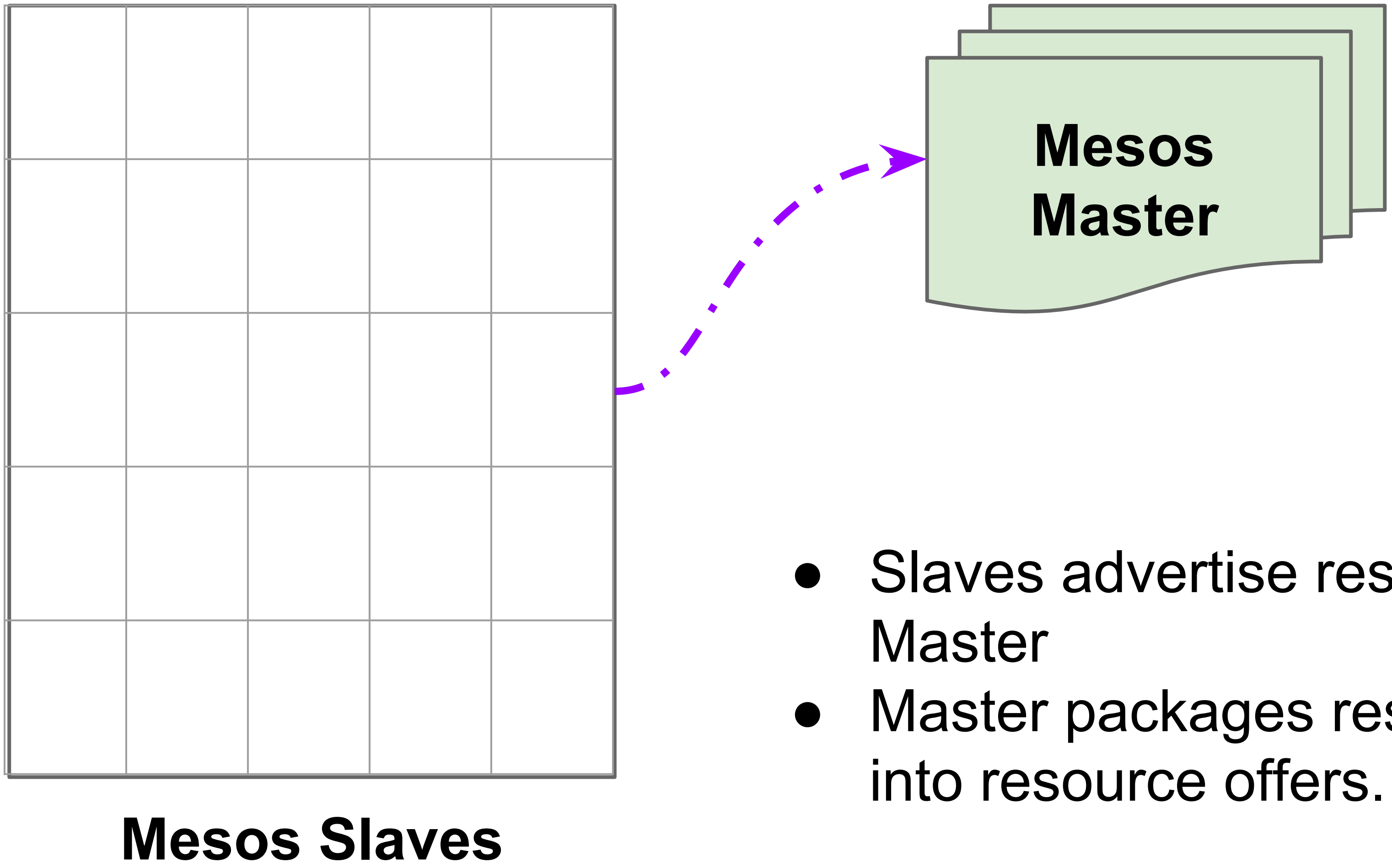
How Mesos does Job Scheduling



Mesos Slaves

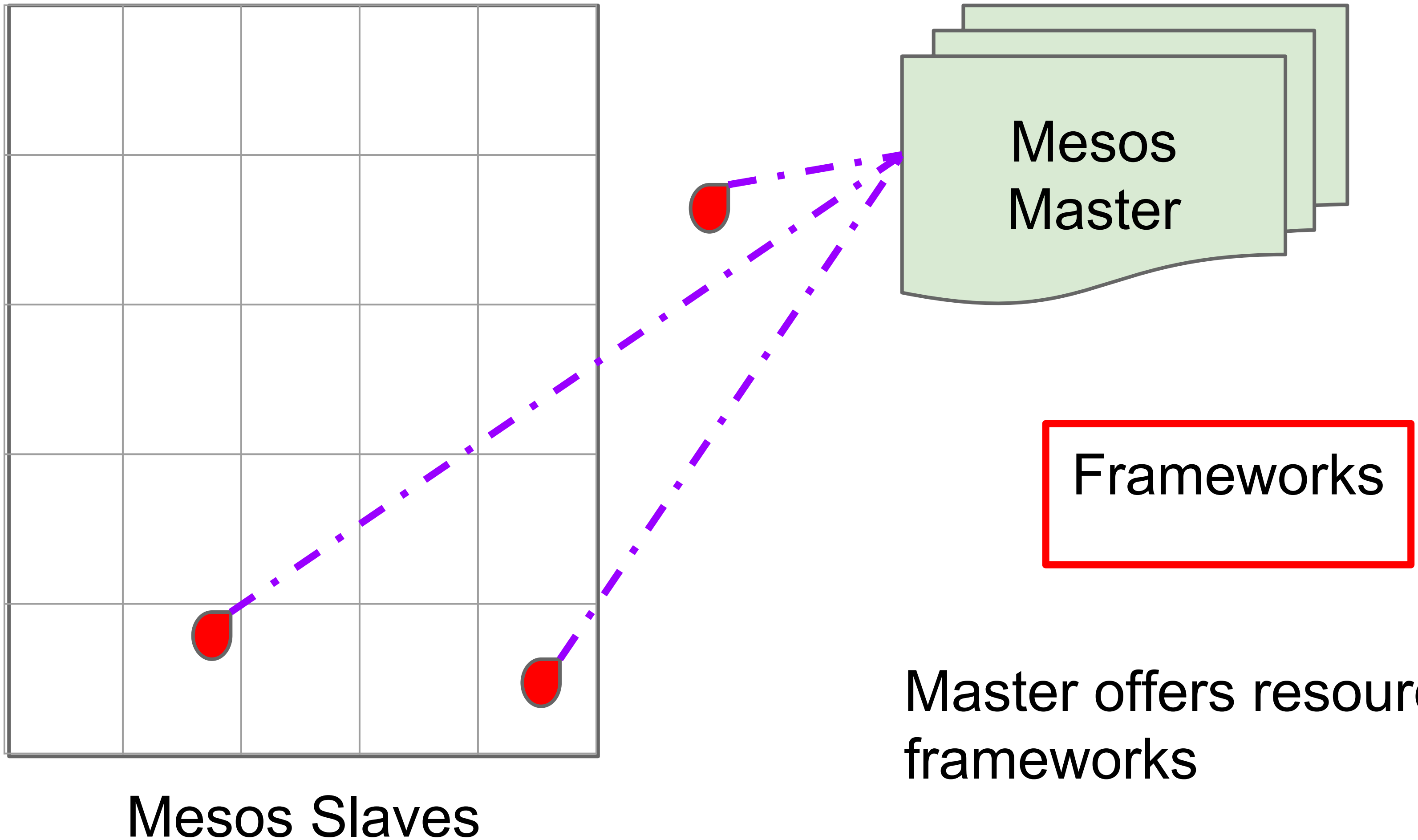
Each slave is a partitioned pool of resources

How Mesos does Job Scheduling



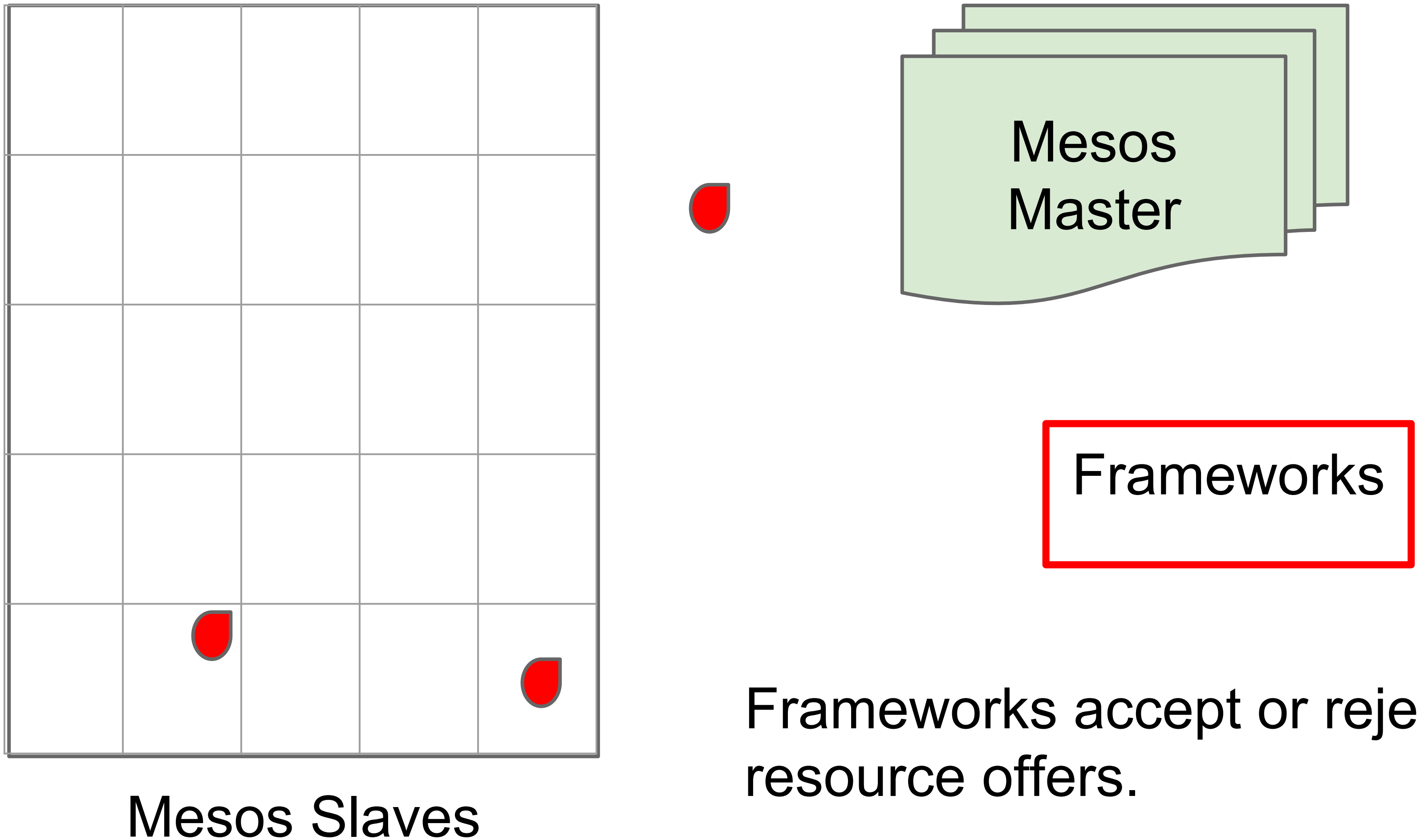
- Slaves advertise resources to Master
- Master packages resources into resource offers.

How Mesos does Job Scheduling



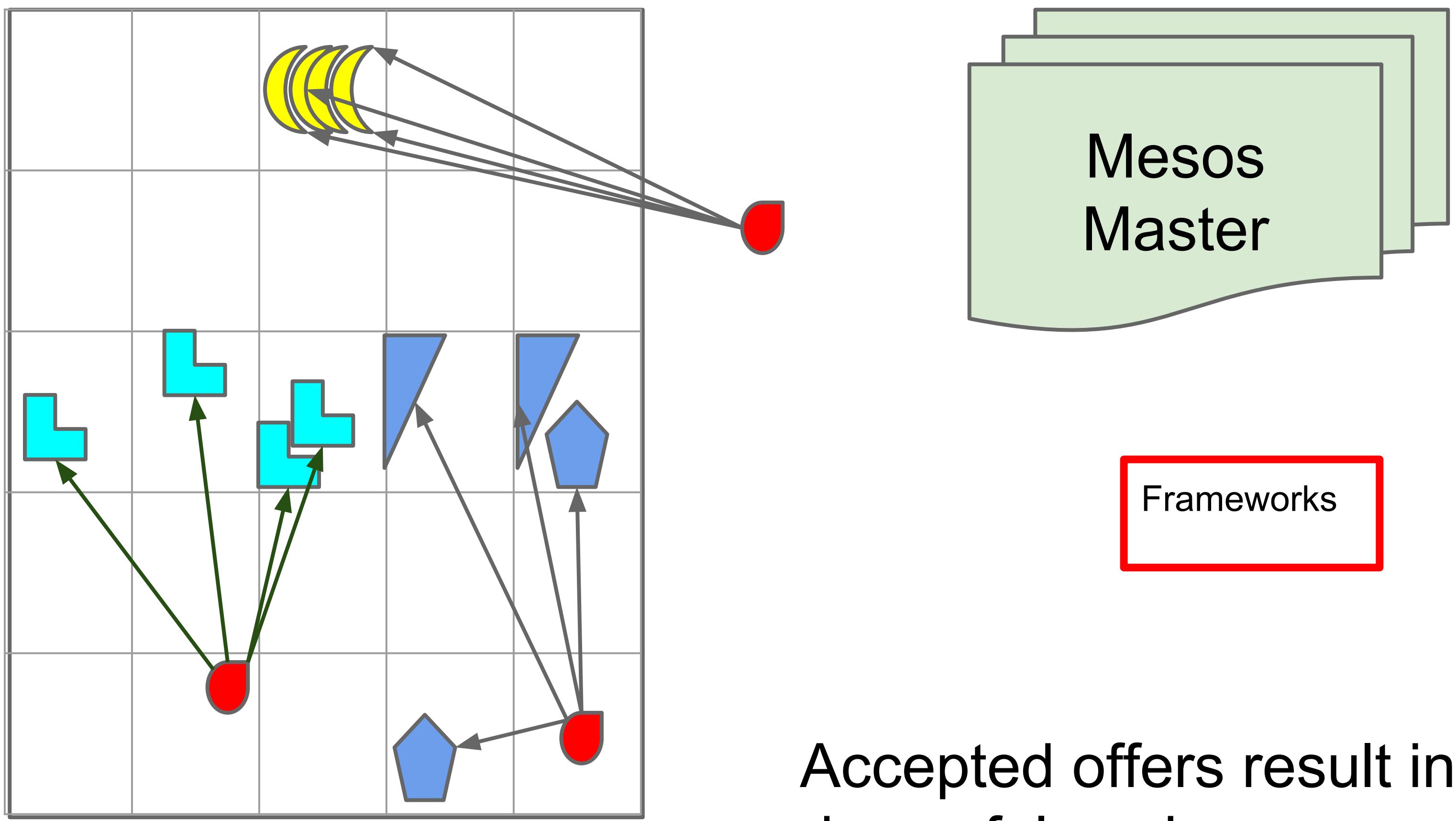
Master offers resources to frameworks

How Mesos does Job Scheduling



Frameworks accept or reject resource offers.

How Mesos does Job Scheduling



Mesos Slaves

Accepted offers result in tasks that do useful work.

3 Types of Scheduling Architectures

(aka 3 Types of Distributed Kernels)

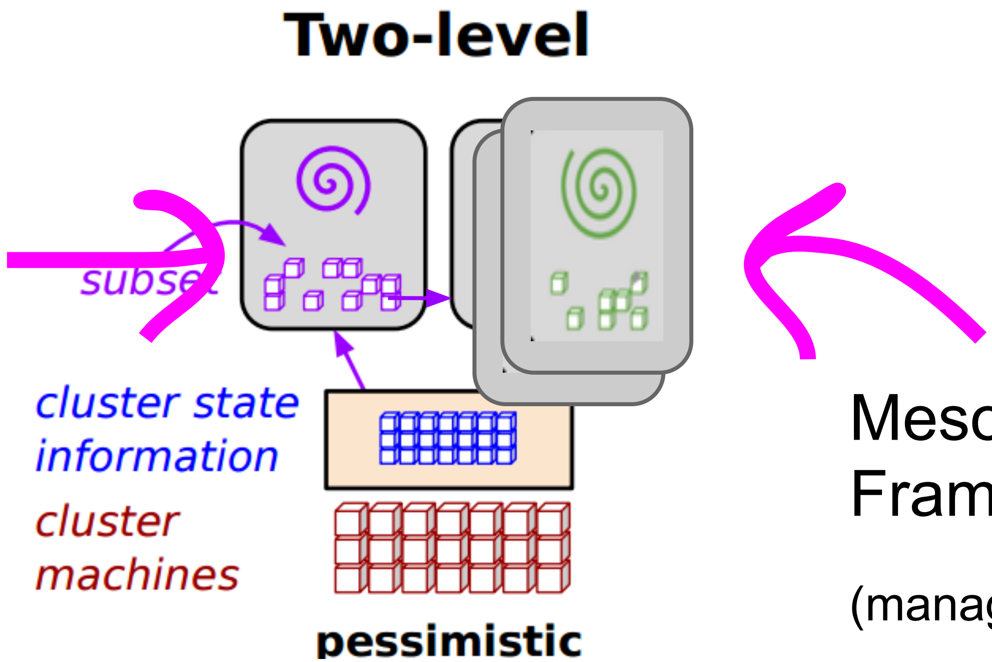
Monolithic **Two-level** **Shared state**

Mesos has a two-level architecture.

3 Types of Scheduling Architectures

Mesos Master

(manage resource and framework state)

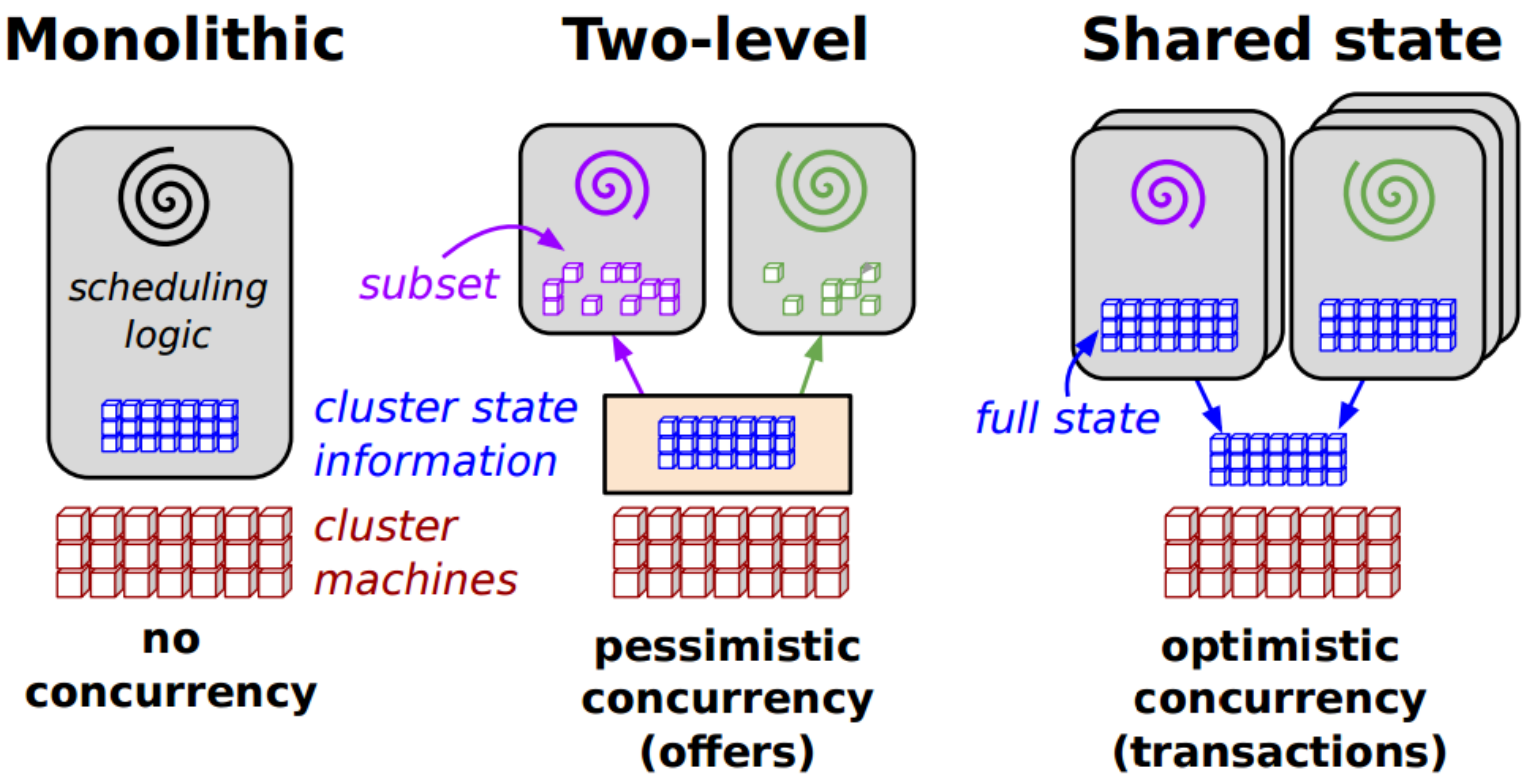


Mesos Frameworks

(manage task state)

from the Google Omega Whitepaper

3 Types of Scheduling Architectures



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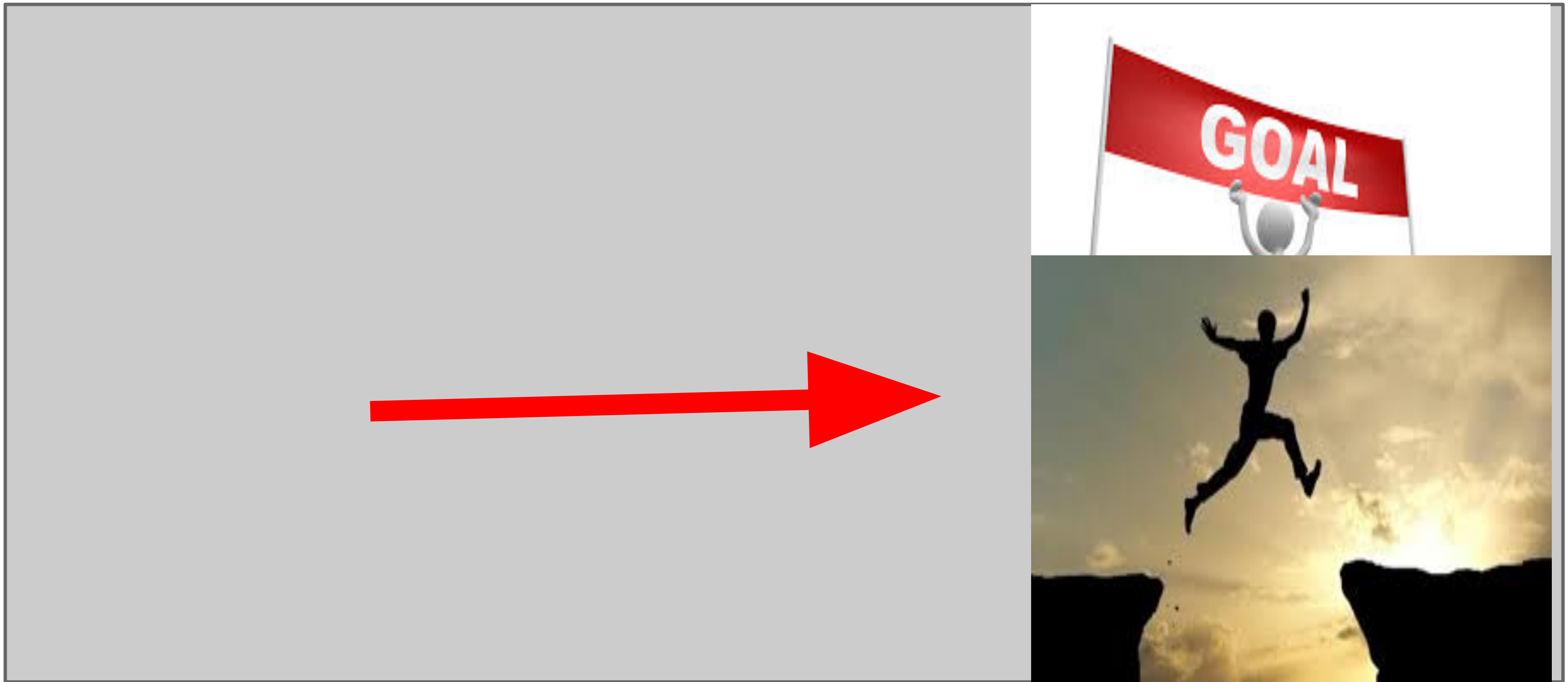
Monolithic **Two-level** **Shared state**



3 Types of Scheduling Architectures

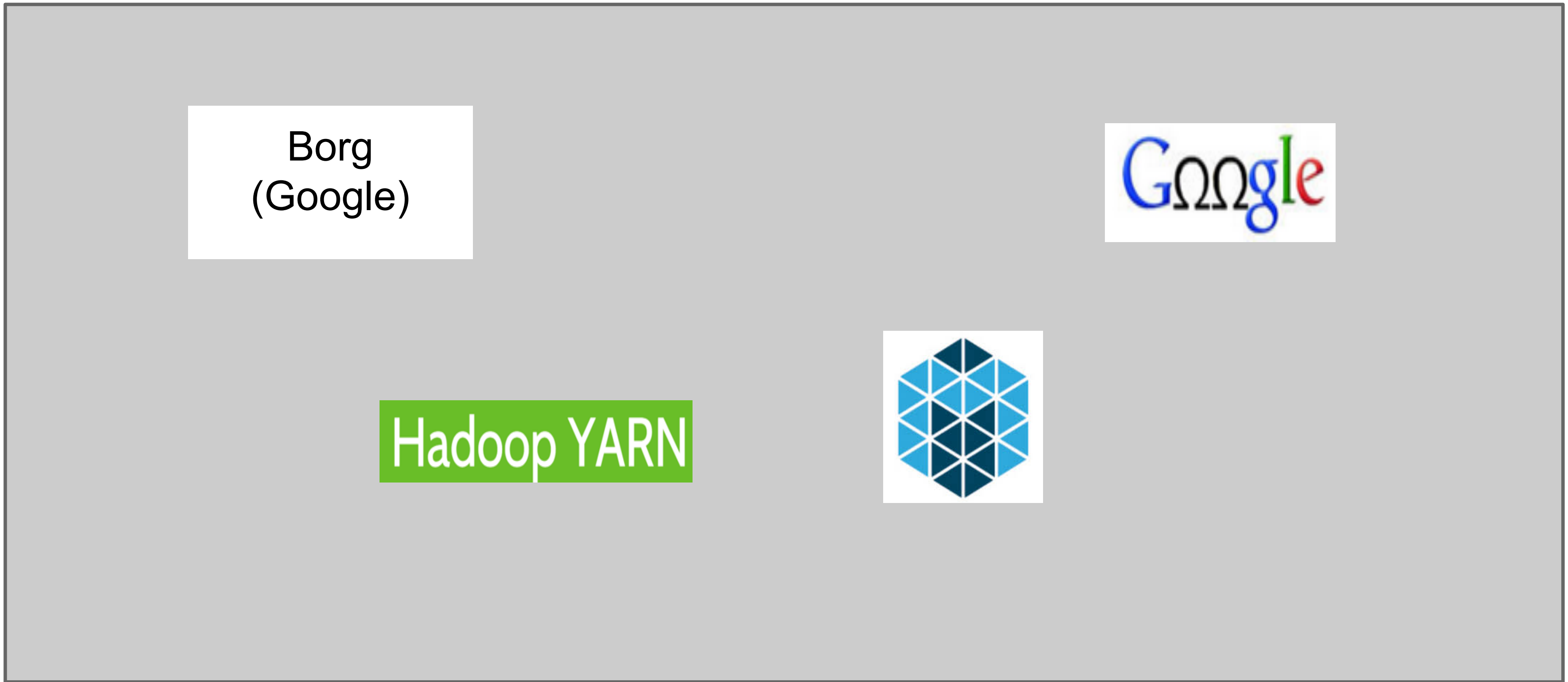
(aka 3 Types of Distributed Kernels)

Monolithic **Two-level** **Shared state**

3 Types of Scheduling Architectures

(aka 3 Types of Distributed Kernels)

Monolithic | **Two-level** | **Shared state**



Remainder of this talk...

Point out weaknesses with Mesos that

1. Prevent it from being a shared state kernel.

2. Can make Mesos challenging to use.

Remainder of this talk...

1. Optimistic Vs Pessimistic Offers

2. DRF Algorithm and Framework Sorters

3. Missing APIs / Enhancements

Optimistic Vs Pessimistic Offers

We Trust Everyone!

Optimistic Vs Pessimistic Offers

Optimistic Vs Pessimistic Offers

Optimistic Vs Pessimistic Offers

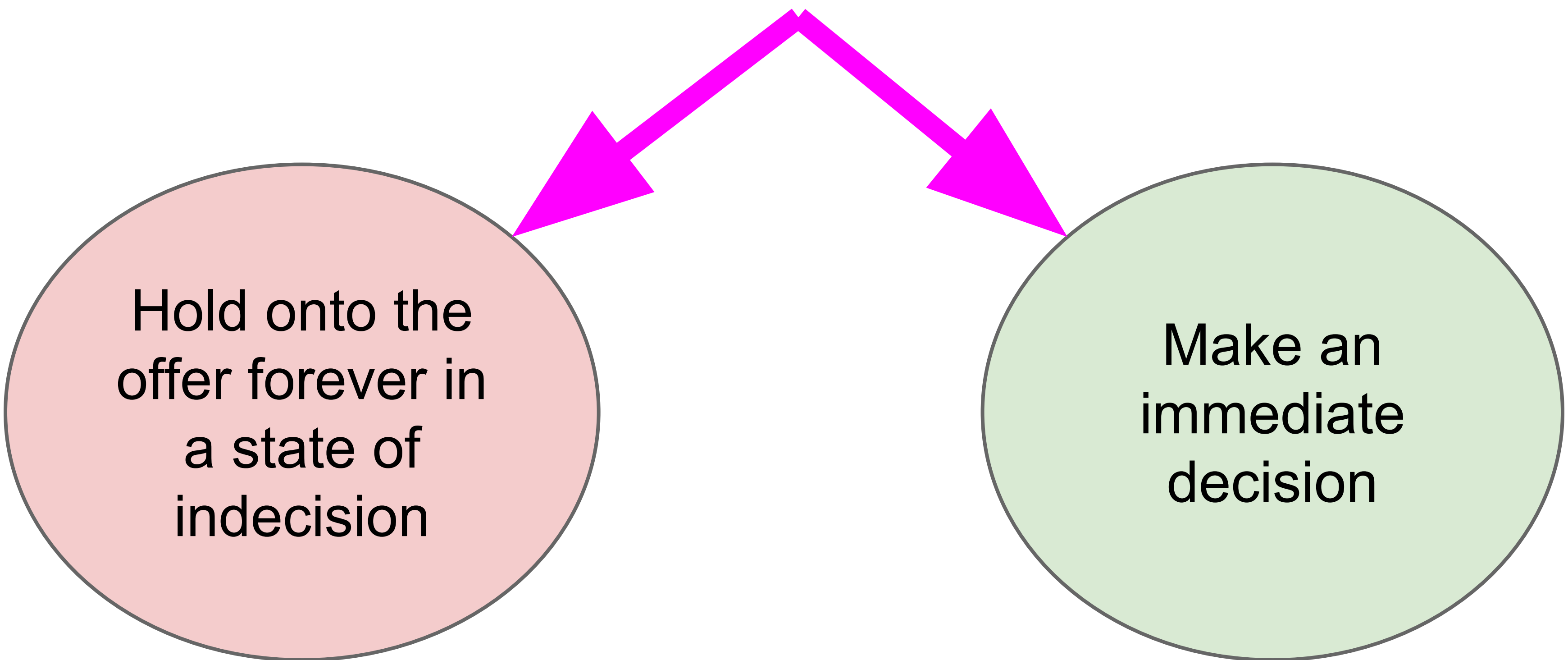
- 2 frameworks sharing the same resources is not safe

Optimistic Vs Pessimistic Offers

- 2 frameworks sharing the same resources is not safe
- A chunk of resources is only offered to a single framework scheduler at a time.

Why is this a problem?

When a Framework receives resource offers, it has 2 options:



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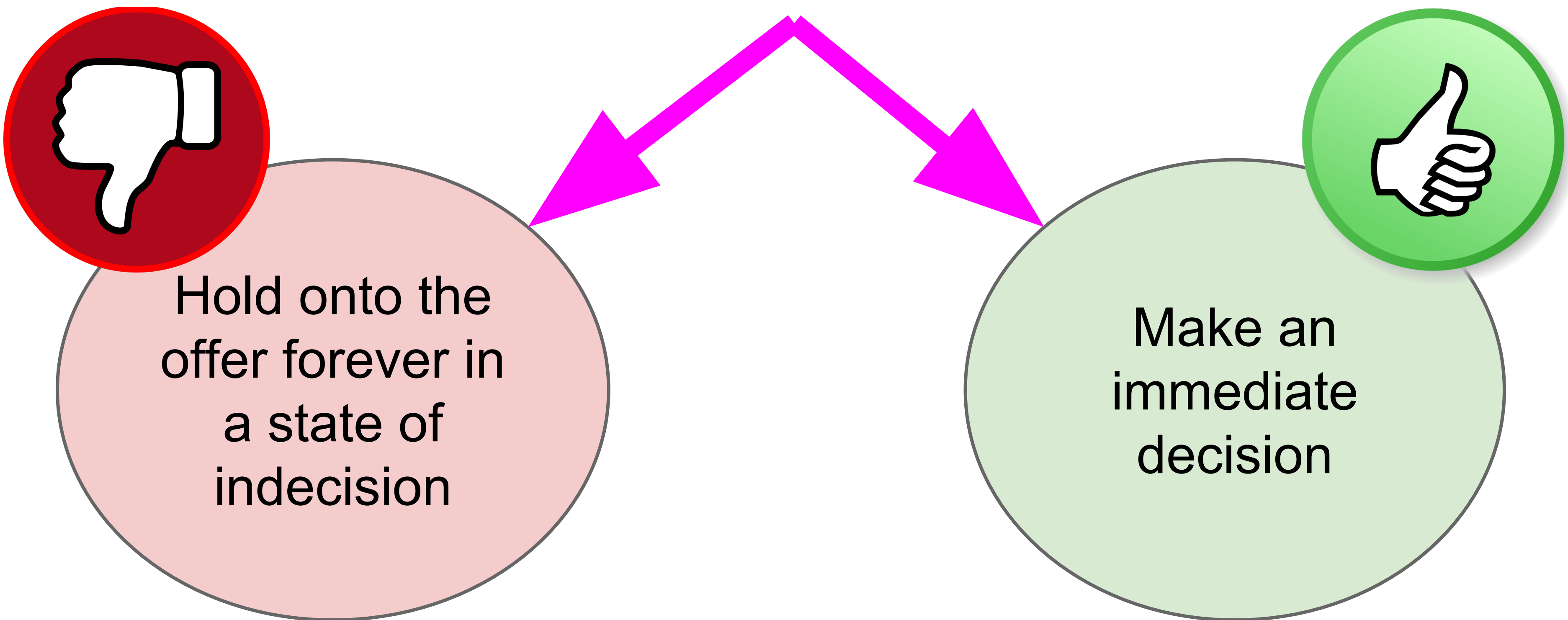


Why is this a problem?

Under-utilization

If the framework holds the offer forever, those resources can't be used.

… or eaten!

Why is this a problem?

Under-utilization

Can be hard to schedule large tasks

Why is this a problem?

Gaming the System

If it's hard to schedule large tasks, frameworks might hold onto tons of offers until it can schedule its huge task.

Why is this a problem?

Gaming the System:

One could create many instances of a framework to trick Mesos to let it hoard more offers!

Workarounds / Solutions

- --offer_timeout Set short timeouts to penalize slow frameworks

- **MESOS-1607**: Wait for optimistic offers!
    - Submit one offer to multiple frameworks, but rescind the offer when necessary.
    - Encourages more sophisticated allocation algorithms

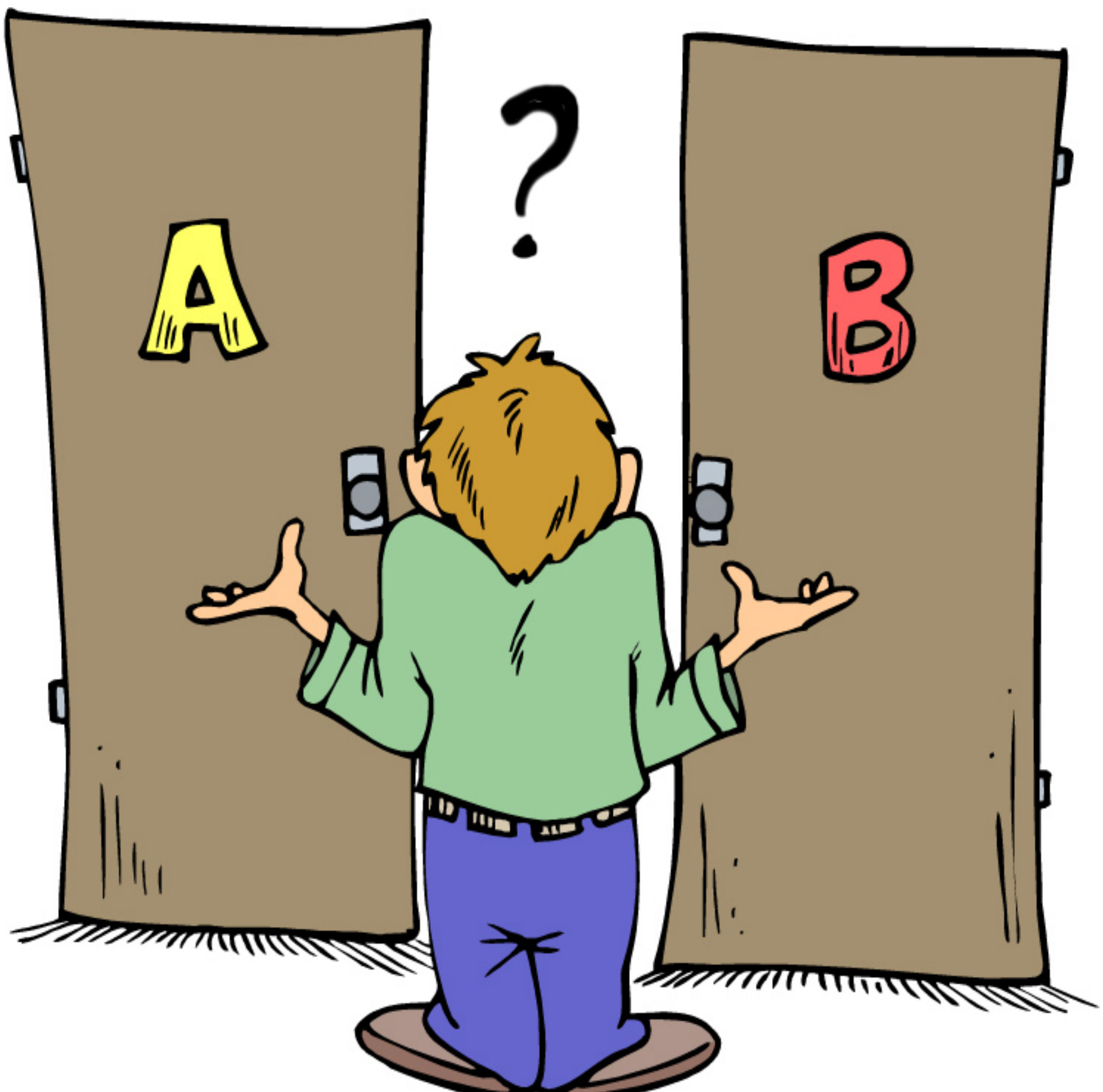
Remainder of this talk...

1. ~~Optimistic Vs Pessimistic Offers~~

2. **DRF Algorithm and Framework Sorter**

3. Missing APIs / Enhancements

DRF and Framework Sorter



DRF and Framework Sorter

Mesos Master must choose which Frameworks to give offers to first.

DRF and Framework Sorter

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In a pessimistic system, this is very important!

What is DRF?

“Dominant Resource Fairness” Algorithm

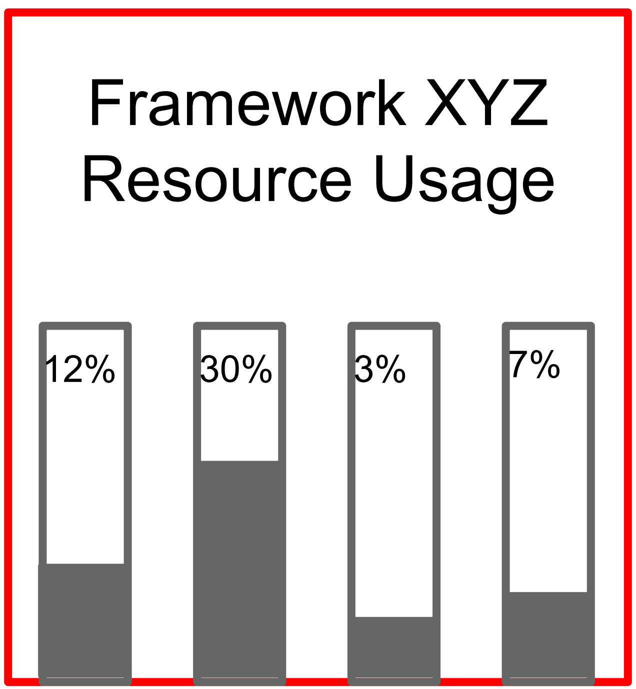
What is DRF?

“Dominant Resource Fairness” Algorithm

- A method for prioritizing which frameworks to give a resource offer to first.

What is DRF?

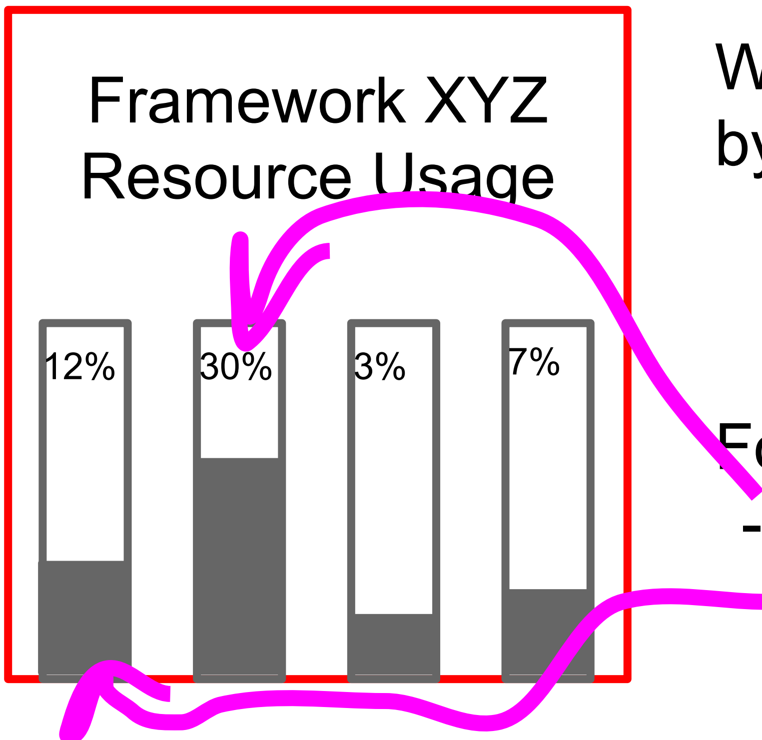
"**Dominant Resource** Fairness" Algorithm



We can represent a framework by how many resources it uses.

What is DRF?

“Dominant Resource Fairness” Algorithm



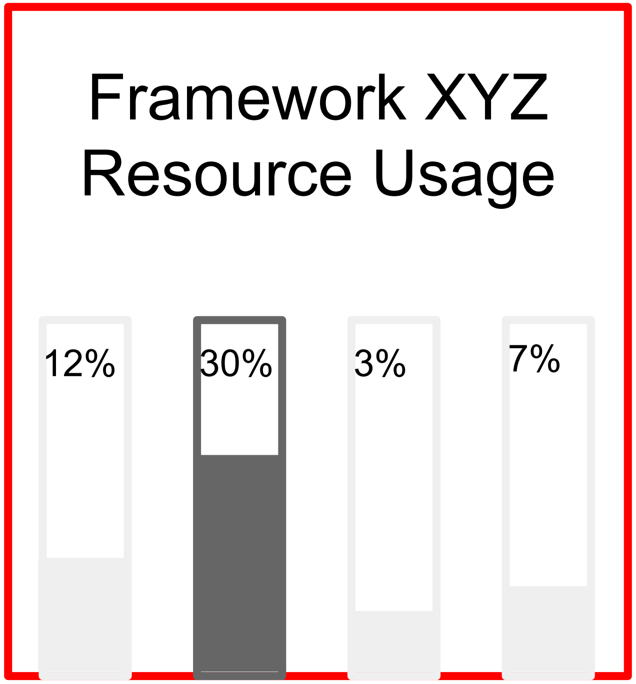
We can represent a framework by how many resources it uses.

For example:

- 30% of total RAM
  12% of total CPU

What is DRF?

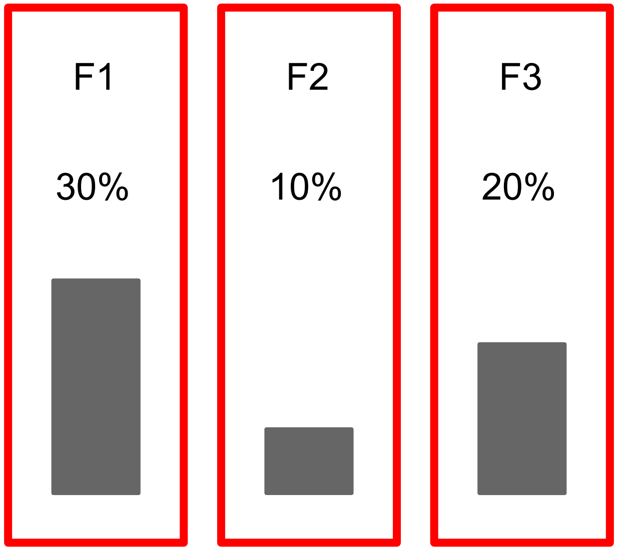
“**Dominant Resource** Fairness” Algorithm



Framework XYZ’s Dominant Resource is the 30% RAM

How does DRF work?

"Dominant Resource Fairness" Algorithm



Identify all frameworks by their dominant resource

How does DRF work?

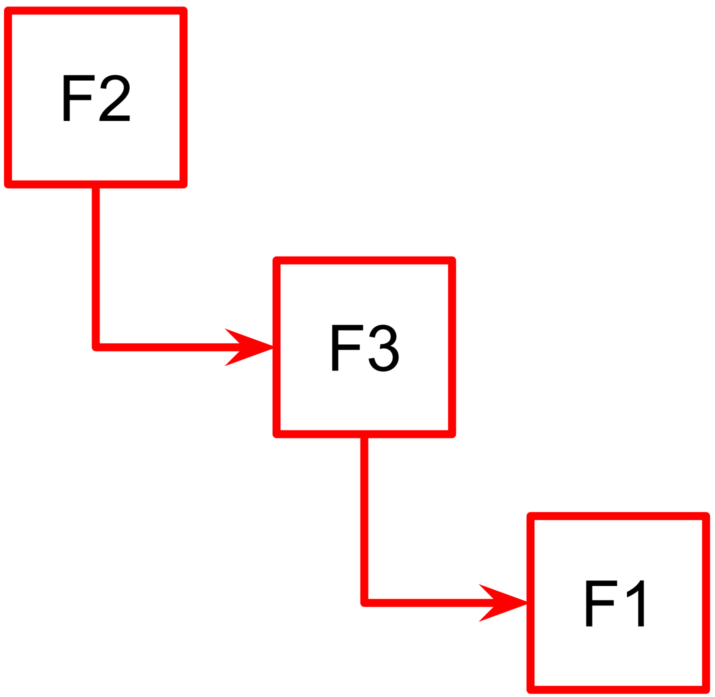
“Dominant Resource Fairness” Algorithm

Out of all frameworks (F1, F2 and F3),

F2 has the minimum dominant share of resources.

How does DRF work?

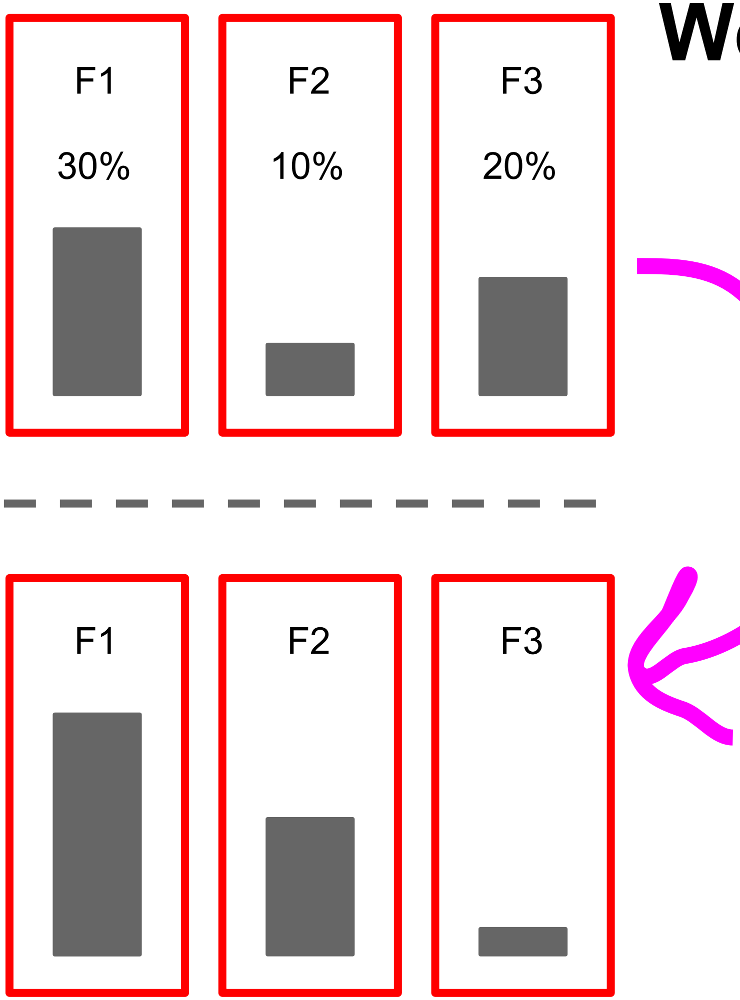
“Dominant Resource Fairness” Algorithm



DRF says that as long as resources are available,

Mesos should offer resources to F2 first, F3 second, and F1 last.

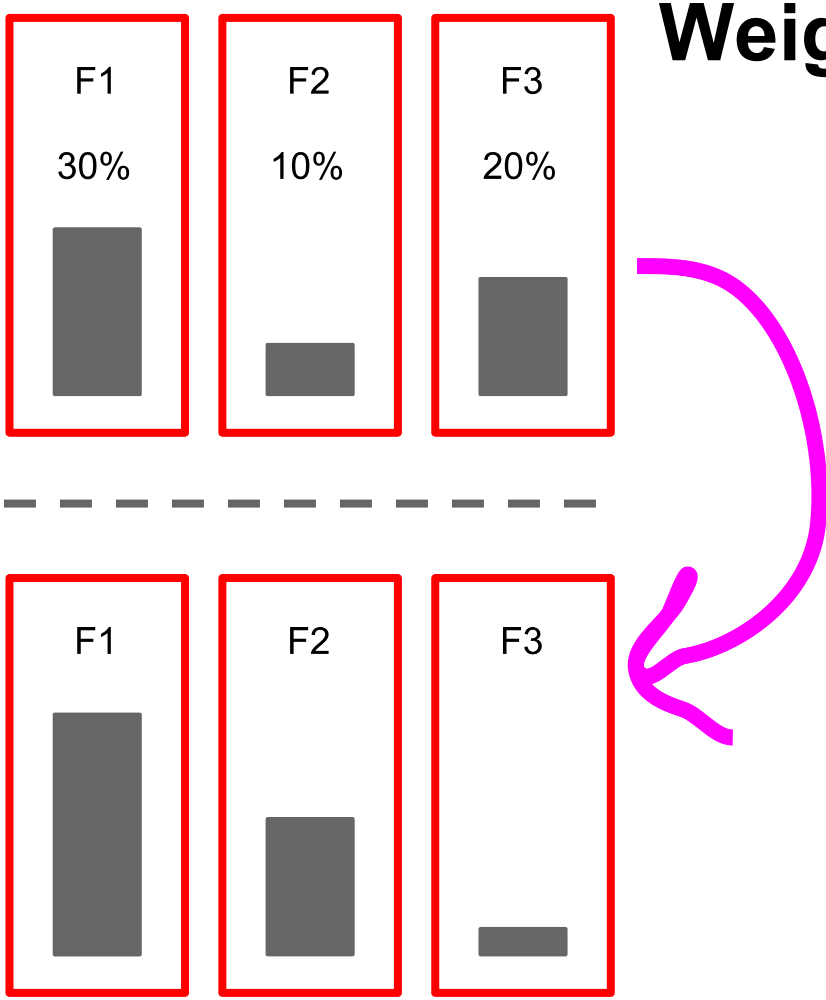
How does DRF work?



Weighted DRF

Per-framework weights, if defined, adjust the dominant share for each framework.

How does DRF work?



Weighted DRF

Per-framework weights, if defined, adjust the dominant share for each framework.

Weighting informs Mesos that it should generally prefer some Frameworks over others.

DRF is great if...

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- All frameworks have work to do

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- A framework's "hunger" for more resources does not change over its lifetime

DRF is great if...

- All frameworks have work to do
- A framework's "hunger" for more resources does not change over its lifetime
- You know apriori that specific frameworks to use more or less resources

DRF is bad if...

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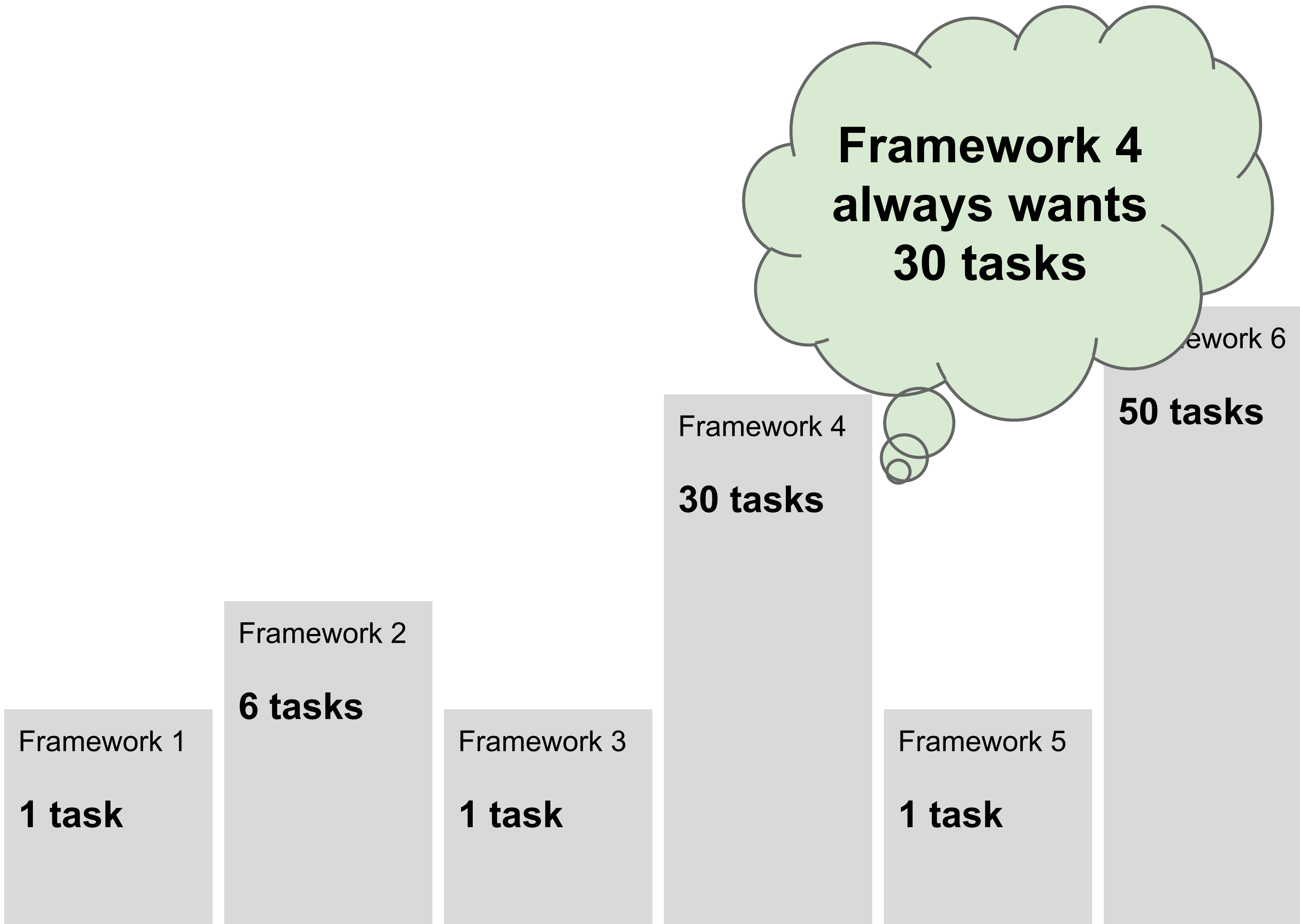
- Some frameworks don't want any more tasks, while others do.

DRF is bad if...

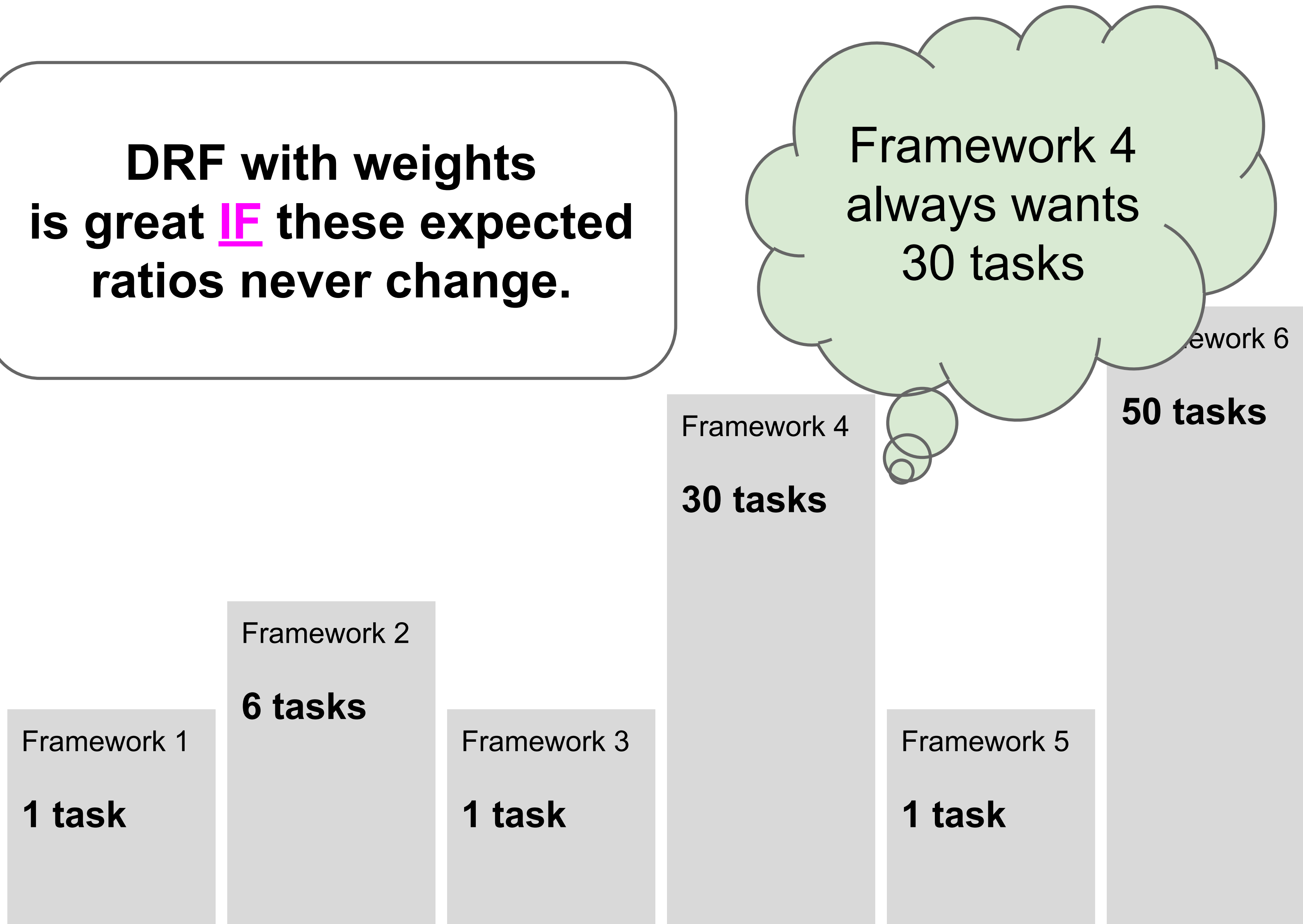
- Some frameworks don't want any more tasks, while others do.
- The framework's "hunger" for resources changes over its lifetime (perhaps based on queue size or pending web requests)

DRF Examples

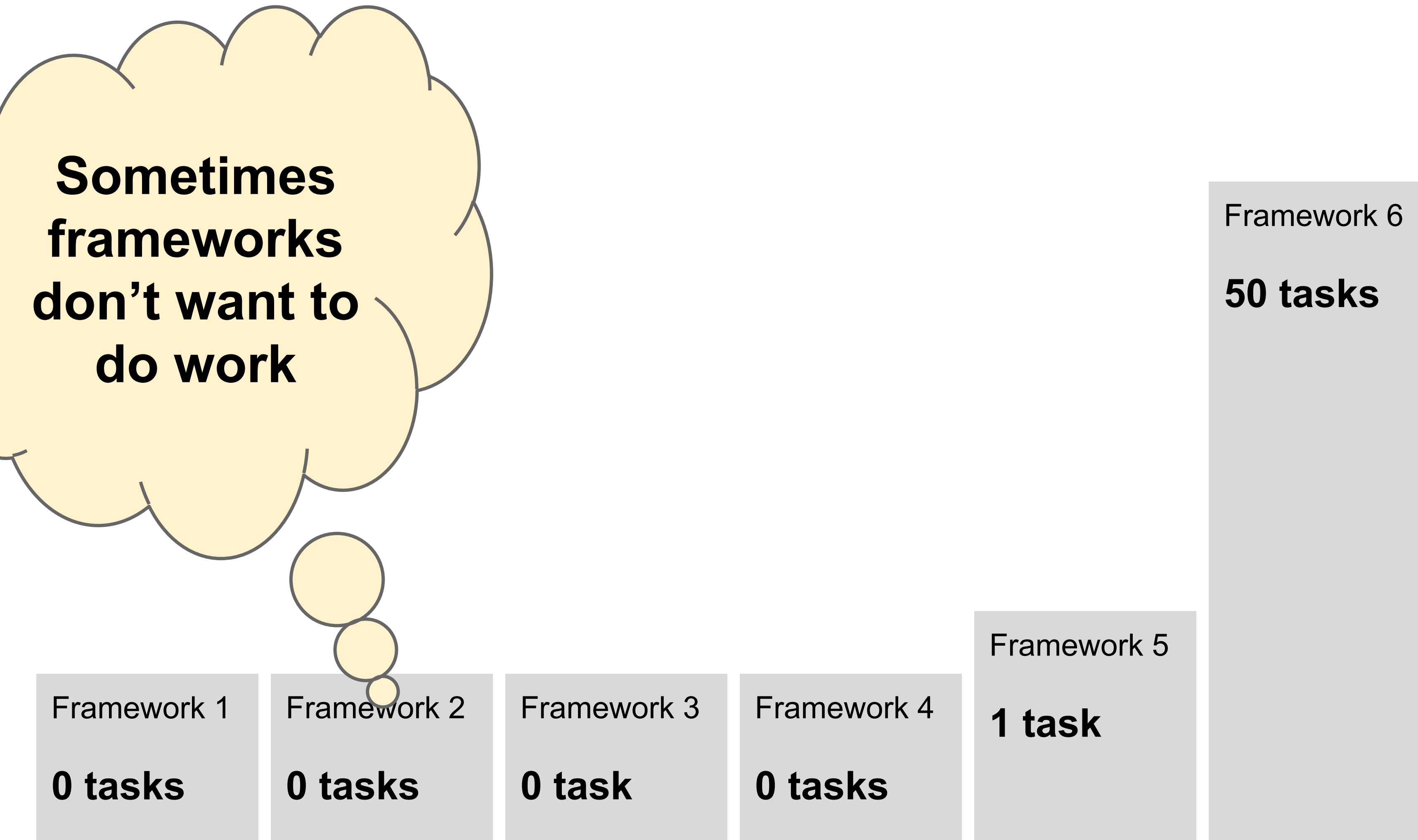


DRF Examples

DRF with weights is great IF these expected ratios never change.



DRF Examples



DRF Examples

Sometimes frameworks don't want to do work

- DRF gives preference to the "0 tasks" frameworks.
- Framework 6 gets starved for resources!

Framework 1	Framework 2	Framework 3	Framework 4	Framework 5	Framework 6
0 tasks	**0 tasks**	**0 task**	**0 tasks**	**1 task**	**50 tasks**

DRF Examples

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Real-world Examples of Bad DRF

Any Framework that declines usable offers suggests DRF isn't working well

- Consumer Framework that consumes an occasionally empty queue
- Web Server Framework that sometimes doesn't get a lot of requests
- Database Framework that doesn't have a lot to do sometimes

Workarounds / Solutions

- Ensure all your frameworks always want more tasks
  - Can be very hard, perhaps impossible, to do.
  - ie. What if a framework just maintains N services?
  - Might encourage sloppy or inefficient frameworks.

Workarounds / Solutions

- Write your own allocation algorithm!
  - See Li Jin’s 11:50 talk, "Preemptive Task Scheduling in Mesos Framework"
  - Maybe other talks?

Workarounds / Solutions

- wait for optimistic offers to make this less of an issue
- allow frameworks to periodically restart themselves and define a different DRF weighting every time they restart

DRF Speculation

- A really good dynamic weighting algorithm would benefit by knowledge of the current distribution of weights by other frameworks across the system.
    - Frameworks could compete with each other based on this information
    - Makes Mesos more like a shared-state scheduler

Remainder of this talk...

1. ~~Optimistic Vs Pessimistic Offers~~
2. ~~DRF Algorithm and Framework Sorter~~
3. **Missing APIs / Enhancements**

THE DISCLAIMER

These are my opinions

Not sure whether others will agree

If you have opinions too, let’s get beers tonight!

Missing APIs / Enhancements

- In my opinion, different framework sorter algorithms and even optimistic offers, will only take us so far.

Missing APIs / Enhancements

- Frameworks should more actively leverage statistics about resource utilization to inform mesos master about how it should be allocated.

Missing APIs / Enhancements

- Frameworks should more actively leverage statistics about resource utilization to inform mesos master about how it should be allocated.
  - Frameworks know their resource needs better than the Master.
  - Some frameworks can make simple decisions
  - Others can be smart in how they wish to populate the grid

Missing APIs / Enhancements

- Frameworks should be able to tell mesos what they will want in the future (and how badly they want it)
    - Let the framework developer community play the game to “optimize this scheduling problem”

- The DRF algorithm, or hierarchical allocator in general, should leverage historical data.

For more about our story,
check out this talk at 4:50!

Building A Machine Learning Platform to Predict User Behavior on Mesos -
- Jeremy Stanley,