CYBERINFRASTRUCTURE
INTEGRATION RESEARCH CENTER
PERVASIVE TECHNOLOGY INSTITUTE

Cluster Frameworks and Kubernetes

February 15th 2022

Suresh Marru

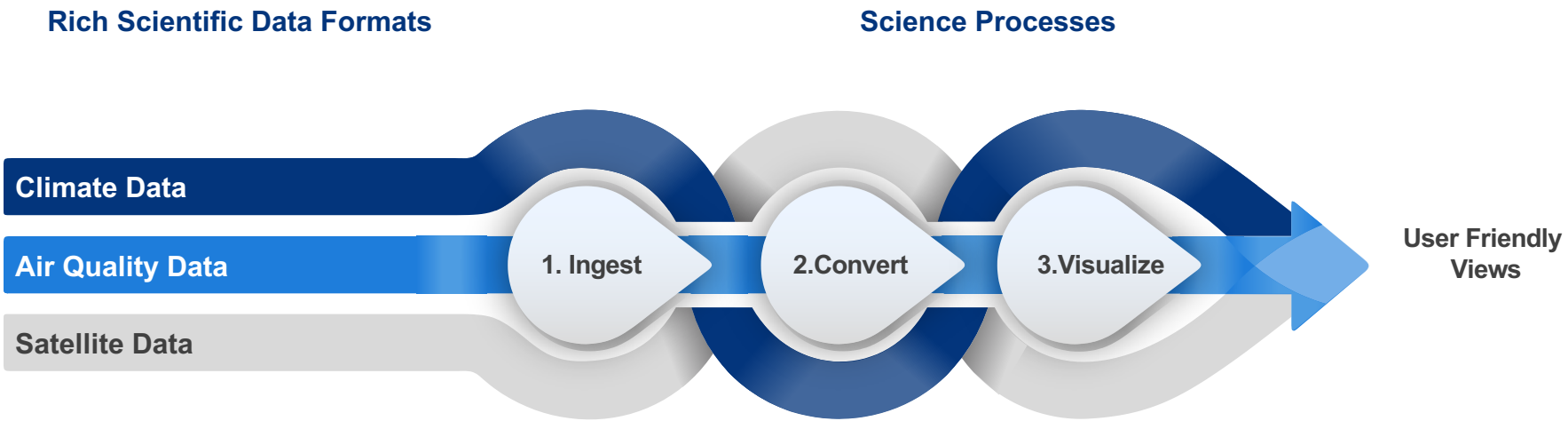
Upcoming Lectures (tentative)

- 02/17 - Consul, Kafka
- 02/22 - Service Mesh
- 02/24 - Ansible & Rancher
- 03/01 - Raft #1
- 03/03 - Jetstream
- 03/08 - Raft #2

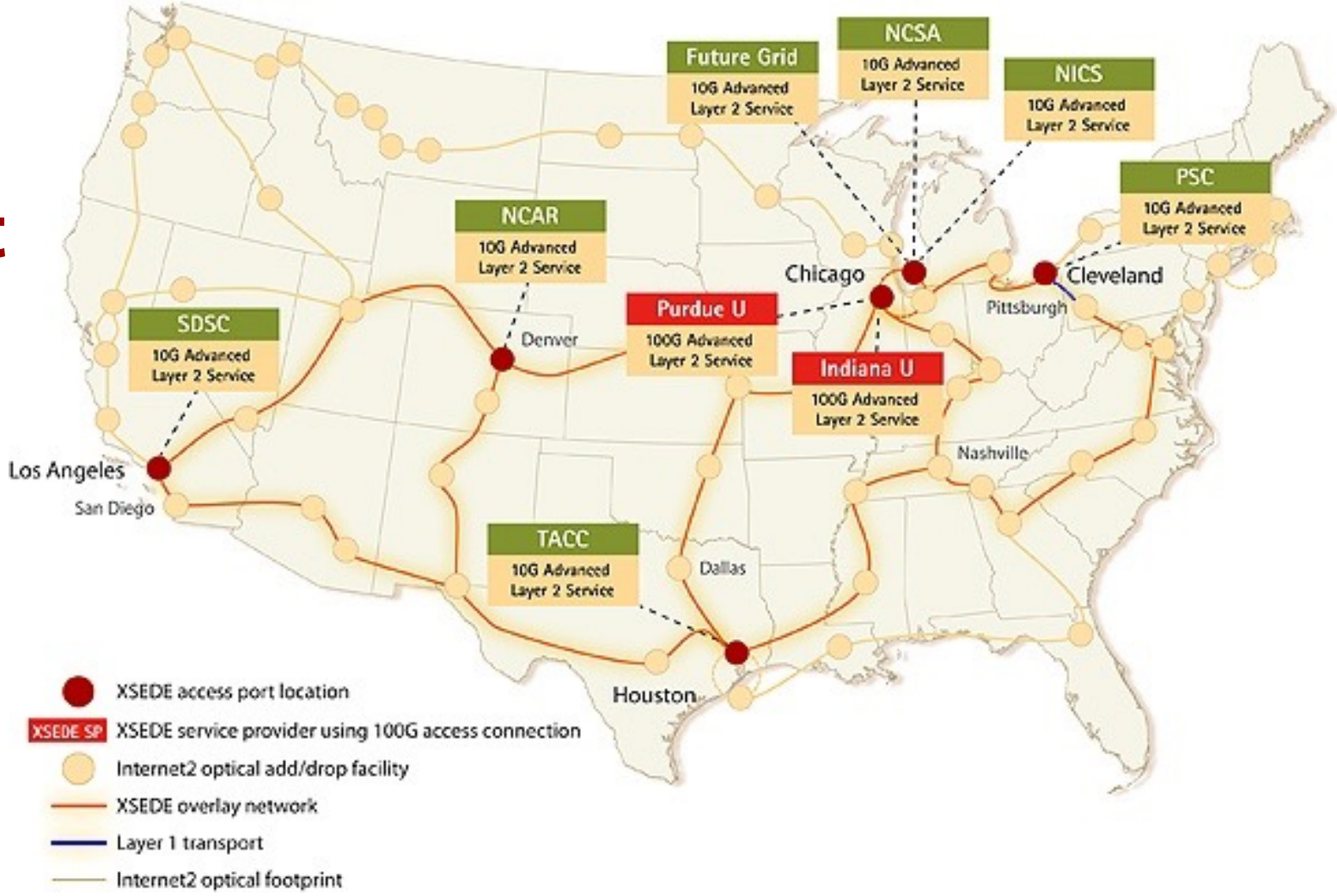
Project 2 Due March 4th

- Using a tool such as JMeter, evaluate the scaling of your system
- Using JMeter or a similar tool, measure and analyze the performance of your system's throughput under incrementally increasing loads
- Test with 1, 3, and 5 replicas (fixed) of each of your services.
- At what point does your system fail?
- What about your system failed?
- Test your system with elastic resource management (that is, system grows under load, contracts when resources are not needed).
- Inject failures and demonstrate that your system continues to function with JMeter-created or similar loads.

Project 3 onwards: NASA Earth Data - https://urs.earthdata.nasa.gov/



XSEDE Account

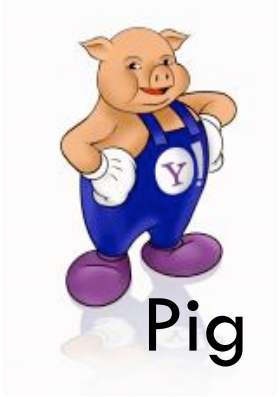


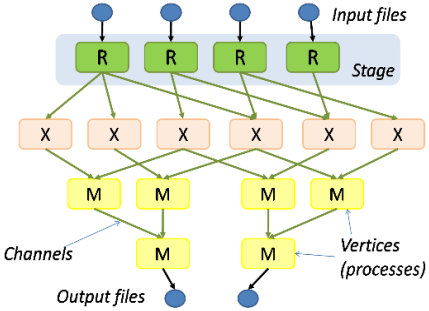
Reference Papers

- Verma, Abhishek, Luis Pedrosa, Madhukar Korupolu, David Oppenheimer, Eric Tune, and John Wilkes. "Large-scale cluster management at Google with Borg." In *Proceedings of the Tenth European Conference on Computer Systems*, pp. 1-17. 2015.
  - https://dl.acm.org/doi/pdf/10.1145/2741948.2741964
- Burns, Brendan, Brian Grant, David Oppenheimer, Eric Brewer, and John Wilkes. "Borg, omega, and kubernetes." *Queue* 14, no. 1 (2016): 70-93.
  - https://dl.acm.org/doi/pdf/10.1145/2898442.2898444
  - The lecture borrows concepts and content from this paper.

Cluster Computing Frameworks

Google
Pregel





Dryad

CIEL

S4 distributed stream computing platform

Google
Percolator

Container recap

- “Containers encapsulate the application environment, abstracting away many details of machines and operating systems from the application developer and the deployment infrastructure.”
- “Because well-designed containers and container images are scoped to a single application, managing containers means managing applications rather than machines. This shift of management APIs from machine-oriented to application oriented dramatically improves application deployment and introspection.”

The Challenge

Multiplicity of Stacks

Static website

nginx 1.5 + modsecurity + openssl + bootstrap 2

User DB

postgresql + pgv8 + v8

Queue

Redis + redis-sentinel

Analytics DB

hadoop + hive + thrift + OpenJDK

Background workers

Python 3.0 + celery + pyredis + libcurl + ffmpeg + libopencv + nodejs + phantomjs

Web frontend

Ruby + Rails + sass + Unicorn

API endpoint

Python 2.7 + Flask + pyredis + celery + psycopg + postgresql-client

Do services and apps interact appropriately?

Multiplicity of hardware environments

Development VM

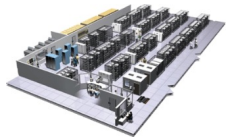
QA server

Customer Data Center

Public Cloud

Disaster recovery

Production Servers



Production Cluster

Contributor's laptop

Can I migrate smoothly and quickly?

The Matrix From Hell

	Development VM	QA Server	Single Prod Server	Onsite Cluster	Public Cloud	Contributor's laptop	Customer Servers
Static website	?	?	?	?	?	?	?
Web frontend	?	?	?	?	?	?	?
Background workers	?	?	?	?	?	?	?
User DB	?	?	?	?	?	?	?
Analytics DB	?	?	?	?	?	?	?
Queue	?	?	?	?	?	?	?

Cargo Transport Pre-1960

Multiplicity of Goods

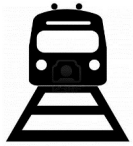


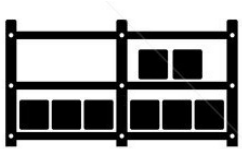



Do I worry about how goods interact (e.g. coffee beans next to spices)

Multipilicity of methods for transporting/storing

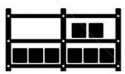





Can I transport quickly and smoothly (e.g. from boat to train to truck)

A matrix from hell

	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
							

Solution: Intermodal Shipping Container

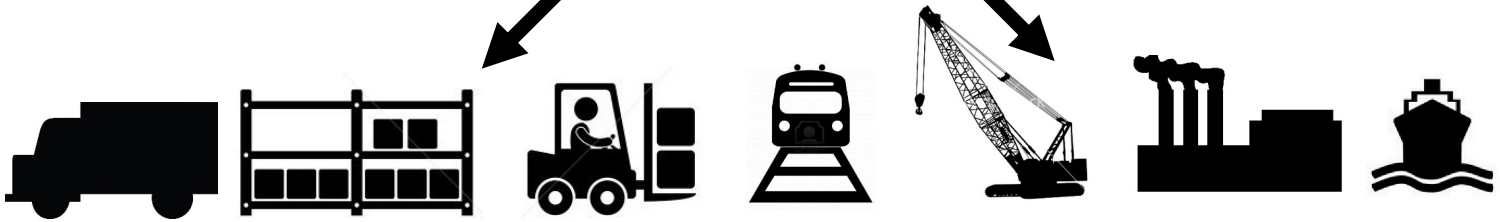
Multiplicity of Goods

Do I worry about how goods interact (e.g. coffee beans next to spices)

A standard container that is loaded with virtually any goods, and stays sealed until it reaches final delivery.

…in between, can be loaded and unloaded, stacked, transported efficiently over long distances, and transferred from one mode of transport to another

Multiplicity of methods for transporting/storing



Can I transport quickly and smoothly (e.g. from boat to train to truck)

Docker is a shipping container system for code

Multiplicity of Stacks

Static website

User DB

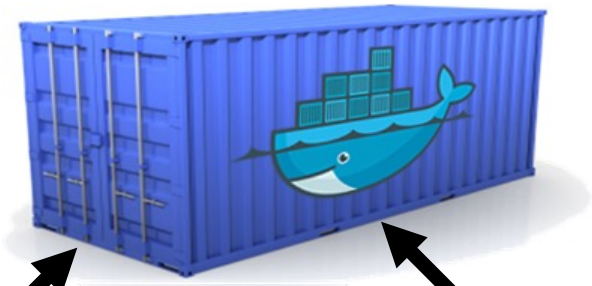
Web frontend

Queue

Analytics DB

Do services and apps interact appropriately?

An engine that enables any payload to be encapsulated as a lightweight, portable, self-sufficient container…



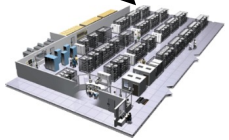
…that can be manipulated using standard operations and run consistently on virtually any hardware platform

Multiplicity of hardware environments

Development VM

QA server

Customer Data Center



Public Cloud

Production Cluster

Contributor's laptop

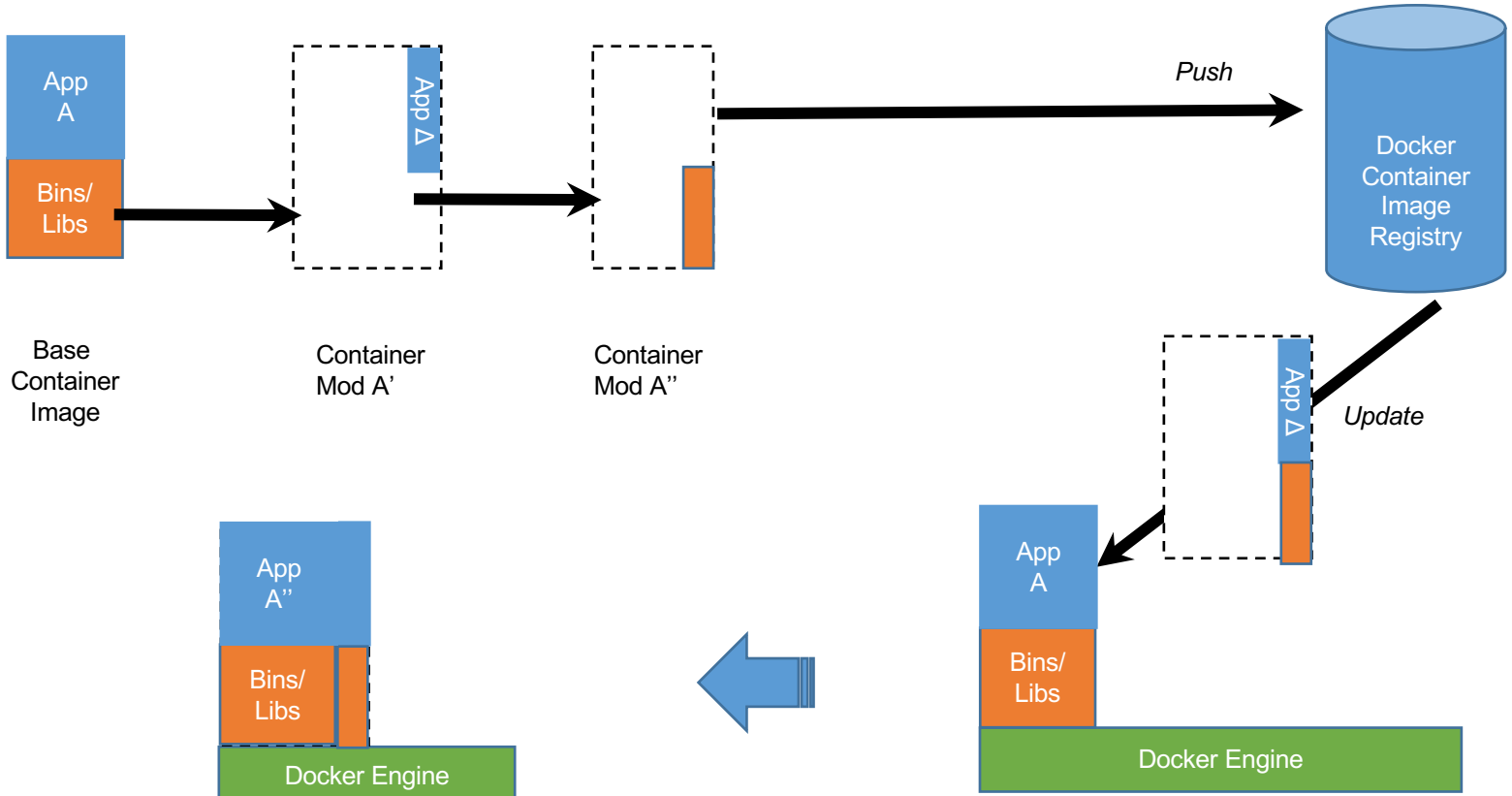
Can I migrate smoothly and quickly

Docker: Infrastructure as Code

- In short, Docker lets you define in script files everything about each of your microservices.
- Combine this with CI/CD systems to deploy EACH microservice.
  - Your development to test to production environments should be identical and reproducible.
  - Testing and production deployments for each service should be infinitely clone-able.
- This is not elasticity, but it is a prerequisite.
- Docker and other containers have much less overhead

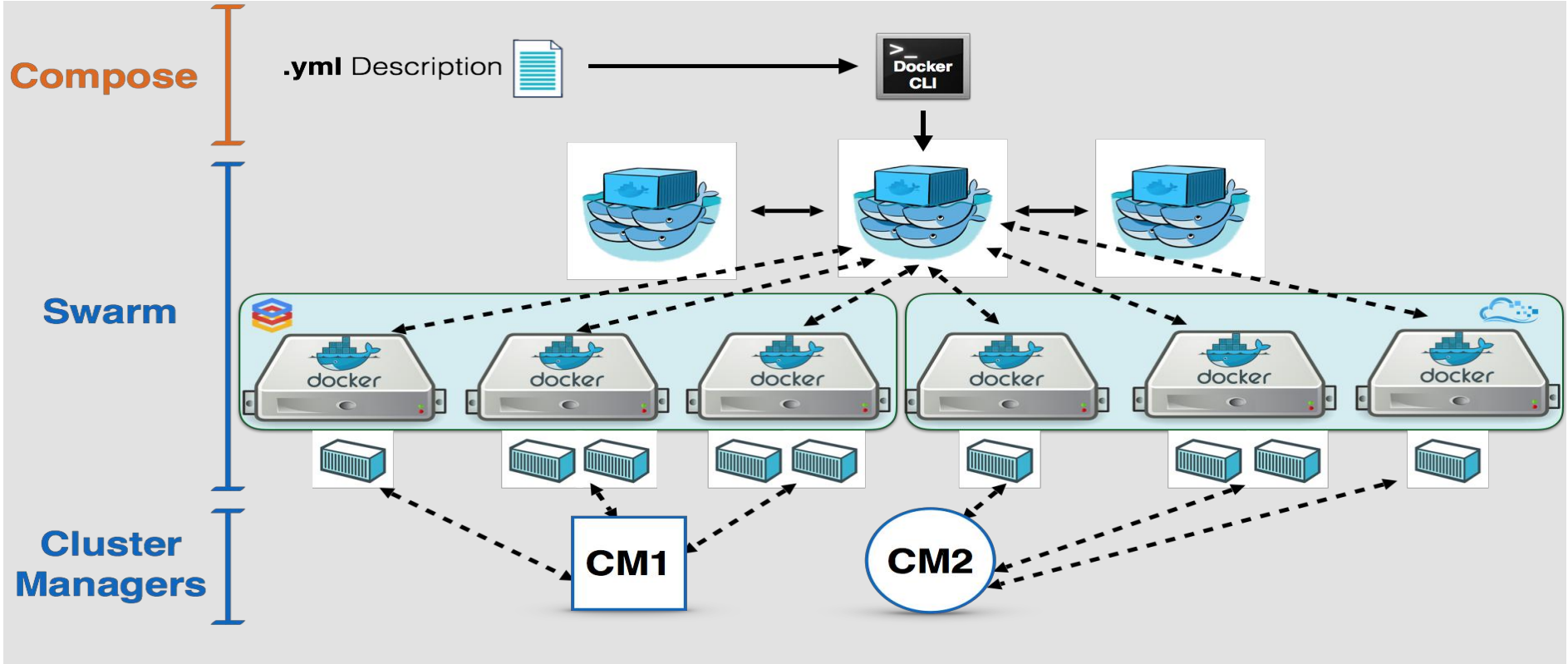
Changes and Updates

https://docs.docker.com/storage/storagedriver/



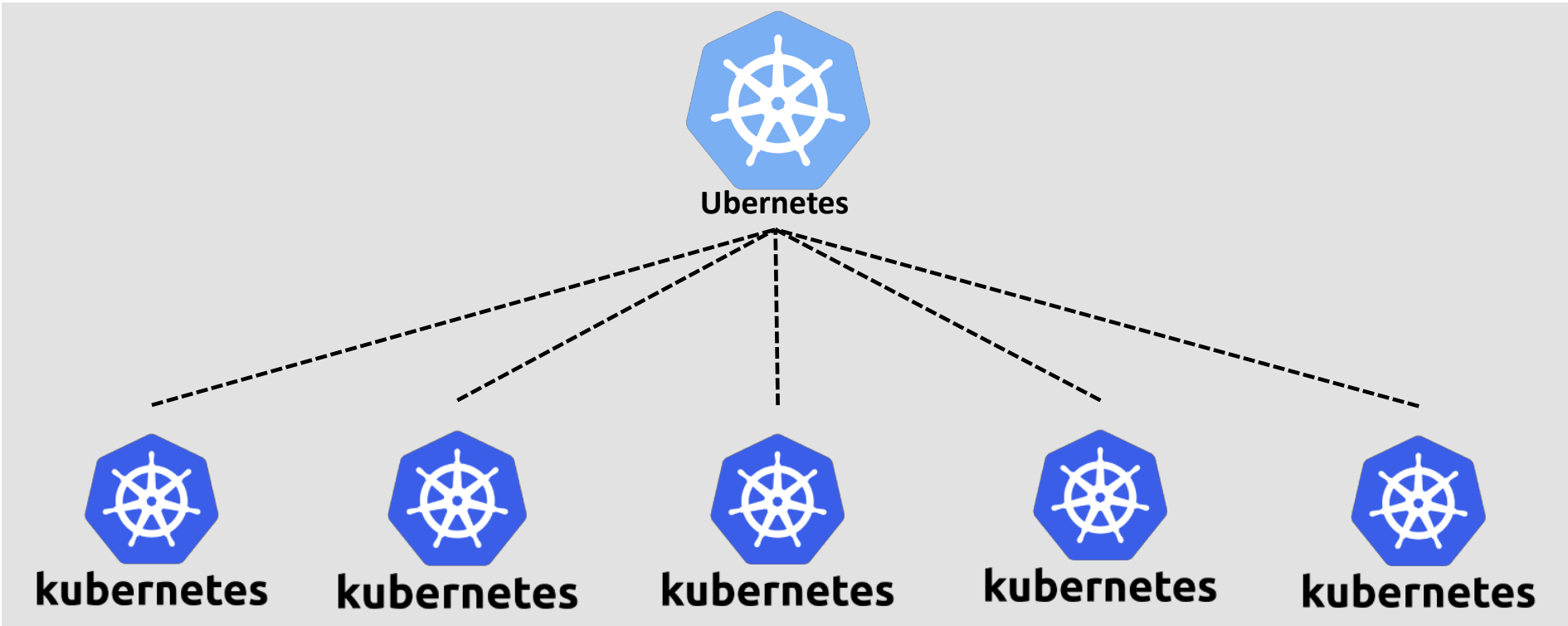
Cloud Federation

Docker Swarm (Cluster Federation)



Cloud Federation

Ubernetes (Google)



Google Borg

- Borg: An OS of Cluster (Datacenter)

- Motivation
  - Hide the details (programmer focus on App)
  - Provide resource sharing
  - Provide high reliability and availability for Cluster

The User Perspective

```
job hello_world = {
   runtime = { cell = 'ic' }                // What cluster should we run in?
   binary = '.../hello_world_webserver'     // What program are we to run?
   args = { port = '%port%' }               // Command line parameters
   requirements = {      // Resource requirements
     ram = 100M
     disk = 100M
     cpu = 0.1
   }
   replicas = 10000   // Number of tasks
}
```

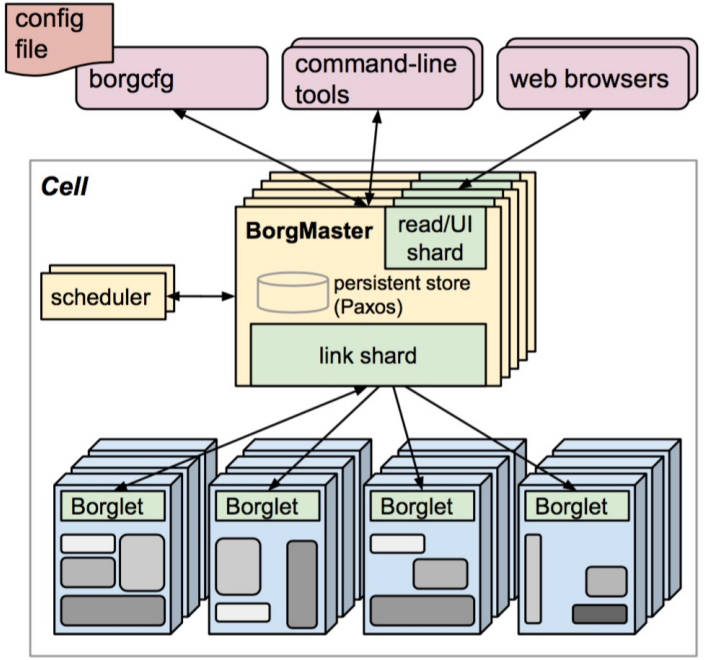
> borgcfg .../hello_world_webserver.borg up

The User Perspective

- Allocs
  - Reserved set of resources
- Priority, Quota, and Admission Control
  - Job has a priority (preempting)
  - Quota is used to decide which jobs to admit for scheduling
- Naming and Monitoring
  - 50.jfoo.ubar.cc.borg.google.com
  - Monitoring health of the task and thousands of performance metrics

Borg Architecture

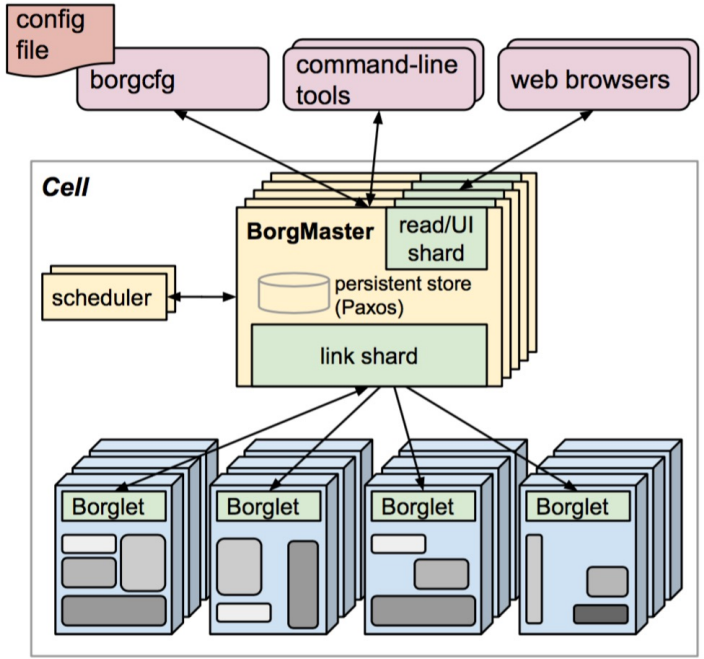
- Borgmaster
  - Main Borgmaster process & Scheduler
  - Five replicas
- Borglet
  - Manage and monitor tasks and resource
  - Borgmaster polls Borglet every few seconds



The high-level architecture of Borg(A Cell)

Borg Architecture

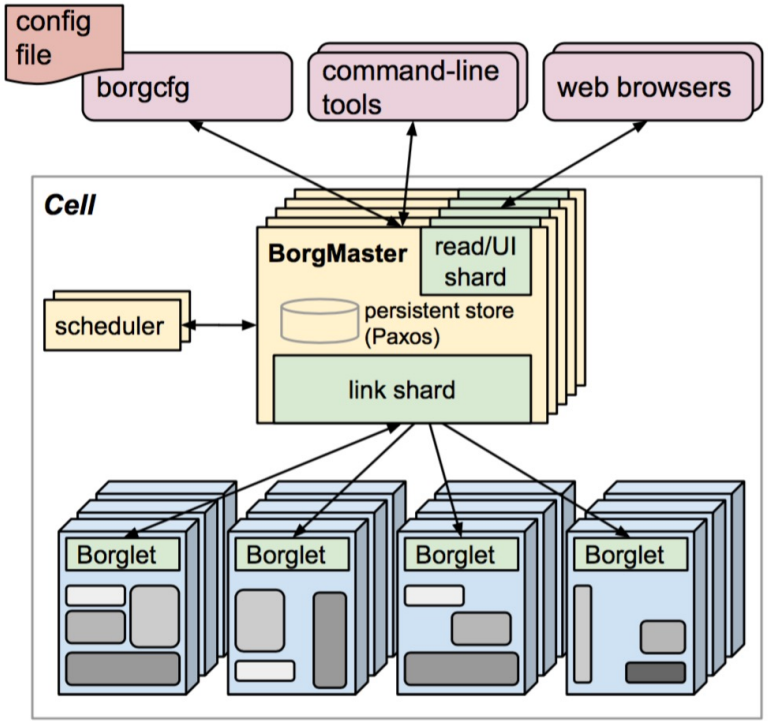
- Scheduling
  - feasibility checking: find machines
  - Scoring: pick one machines
    - User preferences & build-in criteria
    - E-PVM VS best-fit
    - Tradeoff



The high-level architecture of Borg(A Cell)

Scalability

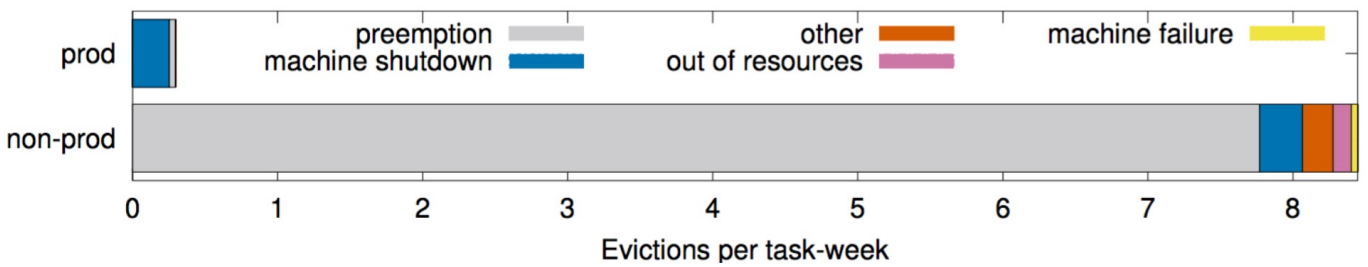
- Separate scheduler
- Separate threads to poll the Borglets
- Partition functions across the five replicas
- Score caching
- Equivalence classes
- Relaxed randomization

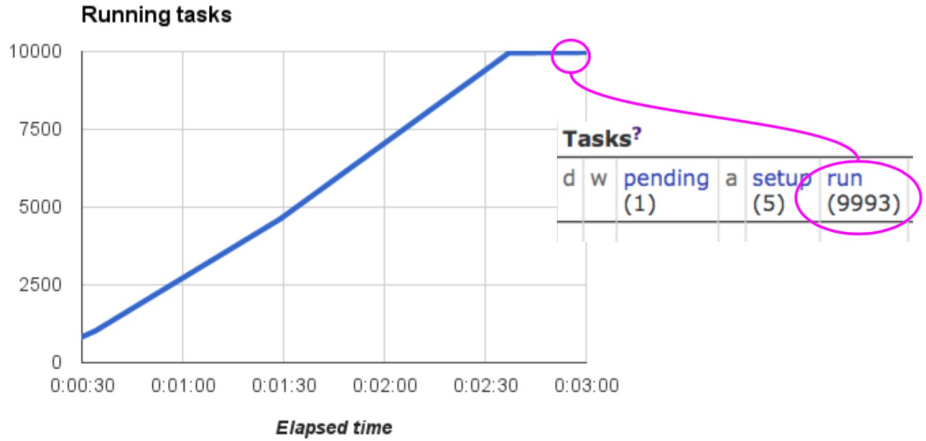


The high-level architecture of Borg(A Cell)

Availabili

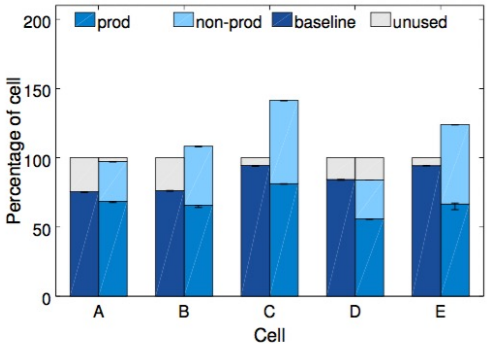
- System
  - Borgmaster:
  - Borglet: Borgmaster
  - Take checkpoint
- Job
  - Reschedules evicted tasks
  - Spreading tasks across failure domia
  - ...



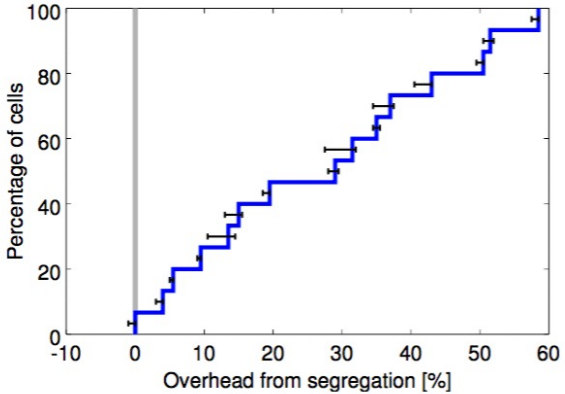


Utilization

- Cell Sharing
  - Segregating prod and non-prod work into different cells would need more machines



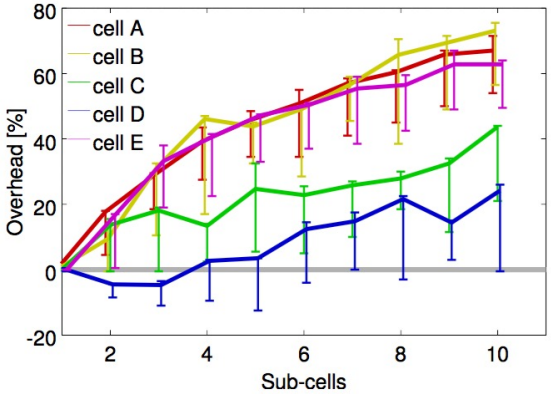
(a) *The left column for each cell shows the original size and the combined workload; the right one shows the segregated case.*



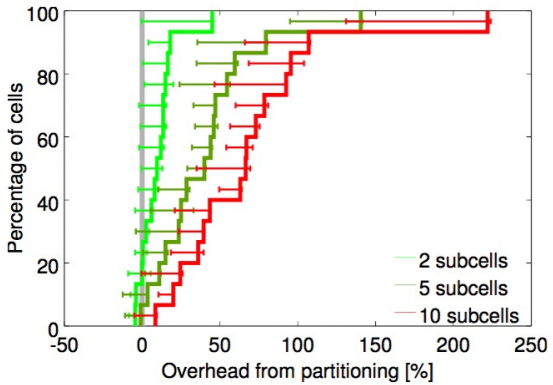
(b) *CDF of additional machines that would be needed if we segregated the workload of 15 representative cells.*

Utilization

- Cell Size
  - Subdividing cells into smaller ones would require more machines



(a) *Additional machines that would be needed as a function of the number of smaller cells for five different original cells.*

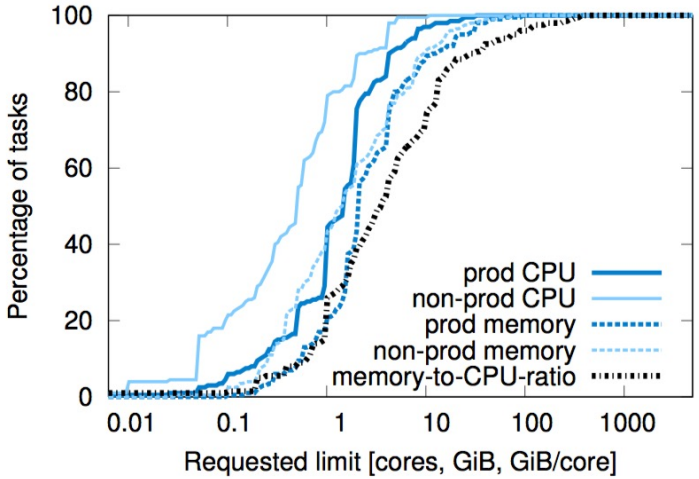


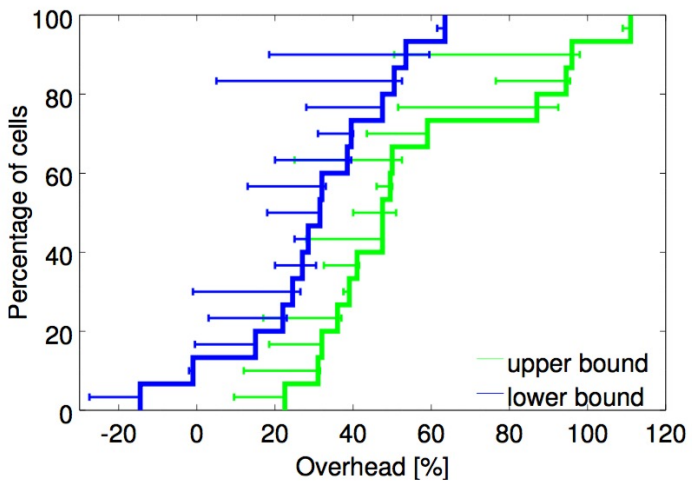
(b) *A CDF of additional machines that would be needed to divide each of 15 different cells into 2, 5 or 10 cells.*

Utilization

- Fine-grained resource requests

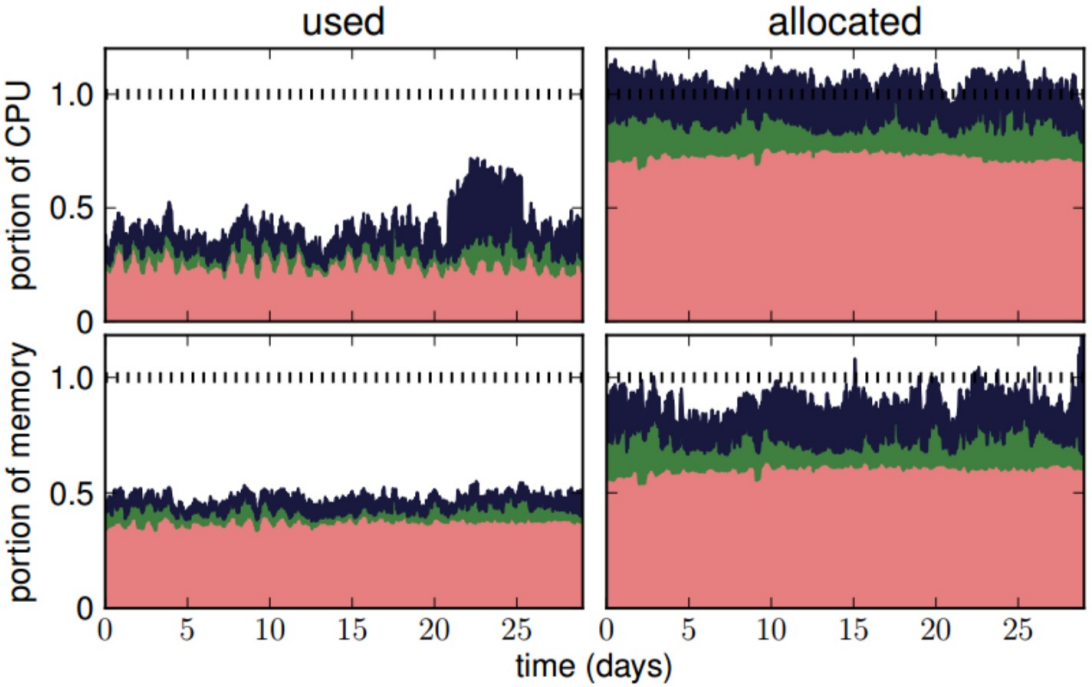
No bucket sizes fit most of the tasks well Bucketing resource would need more mach





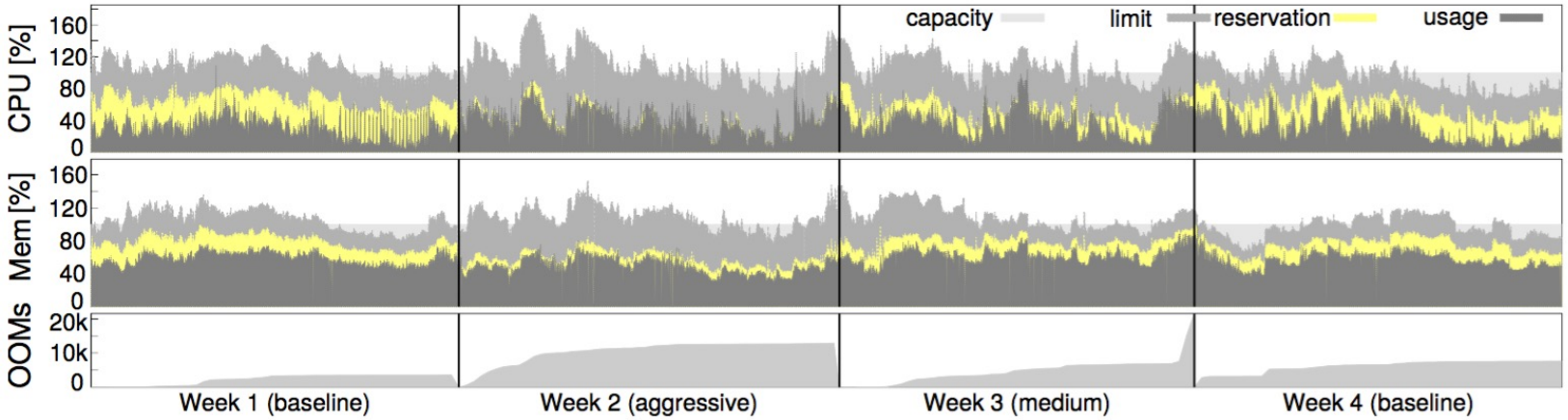
Utilization

- Resource reclamation
  - estimate how many resources a task will use and reclaim the rest for work
  - Kill non-prod if not available



Utilization

- Resource reclamation
  - Choose medium



Isolation

- Security isolation
  - chroot jail as the primary security isolation mechanism
- Performance isolation
  - High-priority LV task(prod) get best treatment
  - compressible resources: reclaimed
  - non-compressible resources: kill or remove task

Kubernetes

- Evolved from Borg
- An open-source system for automating deployment, operations, and scaling of containerized applications
- Pods: groups of containers
- Labels
- Replica controller
- Services