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Simulation of a Kubernetes Cluster with Validation in Real Conditions

LARUE Théo

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Under the supervision of:
Michael Mercier

Defended before a jury composed of:
Head of the jury
Jury member 1
Jury member 2

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Abstract

TODO : remove the focus on HPC

The rise of containerized applications has provided web platforms with much more control over their resources than they had before with their physical servers. Soon enough, developers realized they could go even further by automating container management operations to allow for even more scalability. The Cloud Native Computing Foundation was founded in this context, and developed Kubernetes which is a piece of software capable of container orchestration, or in other words, container management. Now, as we observe a convergence between HPC (High Performance Computing) and the Big Data field where Kubernetes is already the standard for some applications such as Machine Learning, discussions about leveraging containers for HPC applications rose and interest in Kubernetes has grown in the HPC community. One of the many challenges the HPC world has to face is scheduling, which is the act of allocating tasks submitted by users on available resources. In order to properly evaluate and develop schedulers researchers have used simulators for decades to avoid running experiments in real conditions, which is costly both in time and resources. However, such simulators do not exist for Kubernetes or are not open to the public. While the default scheduler works great for most of the Cloud Native infrastructures Kubernetes was designed for, some teams of researchers would rather be able to experiment with different batch processing policies on Kubernetes as they do with traditional HPC. Our goal in this master thesis is to describe how we developed Batkube, which it is an interface between Kubernetes schedulers and Batsim, a general purpose infrastructure simulator based on the Simgrid framework and developed at the LIG.

Acknowledgement

I would like to express my sincere gratitude to .. for his invaluable assistance and comments in reviewing this report... Good luck :)

Résumé

Abstract mais en franchais

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Introduction

1.1 Studying computing infrastructures

The need for scalable infrastructure for computing has increased tremendously in the last decades. Nearly every field of computer science, from research to the service industry now needs a proper infrastructure at some point to run their models or ensure high availability of their servers to the clients. Even the public sector is now in need for efficient distrubuted infrastrcuture as the concept of "smart cities" is developing.

Organizations know what type of infrastructure will meet their needs. It can be storage facilities to store and analyze data, High Performance Computers (HPC) in order to calculate models for the industry or run large scale simulations for research, or pools of GPUs designed to compute cryptocurrency transactions and deep learning models.

However, knowing how much of these infrastructures to have and what software to run it with is a much harder problem. The most direct approach to this problem is running real life experiments with real workloads, which gives exactly what you could expect from your infrastructure. This comes with an obvious issue : it quickly becomes very costly both in time and resources as the infrastructure grows in size - To illustrate the size these computers may reach, Google calls these infrastructures wharehouse-scale computers**??**.

1.2 Contribution

Batkube, and interface between Batsim infrastructure simulator and Kubernetes

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State of the art

2.1 Infrastructure simulators

2.2 Kubernetes schedulers

kube-scheduler

Not exactly a batch scheduler, it is the default scheduler for Kubernetes made by the CNCF"" –> "hop là"

kube-batch

Poseidon

bashScheduler by rothgar

random-scheduler by Banzaicloud

k8s-custom-scheduler by IBM

scheduler by kelseyhightower

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Implementation

3.1 Batsim

3.2 Kubernetes

Kubernetes overview

In the early stages of application development, organizations used to run their services on physical servers. With this direct approach came many challenges that needed to be coped with manually like resources allocation, maintainability or scalability. In an attempt to automate this process developers started using virtual machines which enabled them to run their services regardless of physical infrasctucture while having a better control over resources allocation. This led to the concept of containers which takes the idea of encapsulated applications further.

Containers can be thought of as lightweight virtual machines. Unlike the latter, containers share the same kernel with the host machine but still allow for a very controlled environment to run applications. There are many benefits to this : separating the development from deployment, portability, easy resource allocation, breaking large services into smaller micro-services or support of continuous integration tools (containers greatly facilitate integration tests).

The CNCF[1] (Cloud Native Computing Foundation) was founded in the intent of leveraging the container technology for an overall better web. In a general way, we now speak of these containerized and modular applications as cloud native computing :

“Cloud native technologies empower organizations to build and run scalable applications in modern, dynamic environments such as public, private, and hybrid clouds. Containers, service meshes, microservices, immutable infrastructure, and declarative APIs exemplify this approach.

These techniques enable loosely coupled systems that are resilient, manageable, and observable. Combined with robust automation, they allow engineers to make high-impact changes frequently and predictably with minimal toil.“[2]

Kubernetes[3] is the implementation of this general idea and was anounced at the same time as the CNCF. It aims at automating of the process of deploying, maintaining and scaling containerized applications. It is industry grade and is now the de-facto solution for container orchestration.

The basic processing unit of Kubernetes is called a **pod** which is composed of one or several containers and volumes[4]. In the cloud native context a pod most often hosts a service or micro-service.

[1]`https://www.cncf.io/`

[2]`https://github.com/cncf/toc/blob/master/DEFINITION.md`

[3]`https://kubernetes.io/`

[4]A volume is some storage space on the host machine that can be linked to containers, so they can read persistent information or store data in the long term

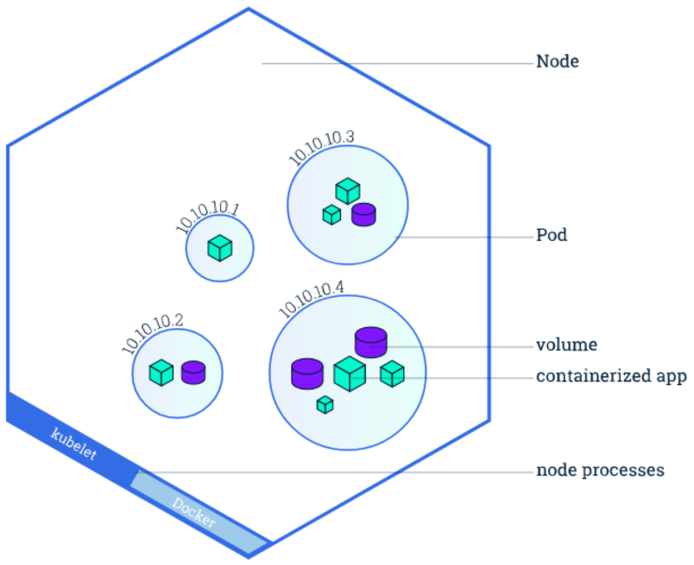


Figure 3.1: Node overview
Source: *https://kubernetes.io/docs/tutorials/kubernetes-basics/explore/explore-intro/*

Pods are bundled together in **nodes** (figure 3.1) which are either physical or virtual machines. They represent another barrier to pass through to access the outside world which can be useful to add layers of security or facilitate communication between pods. Nodes take the idea of containerisation further by encapsulating the already encapsulated services. Each node runs at least one pod and also one **kubelet** which is a process responsible for communicating with the rest of Kubernetes (or more precisely, with the master node which in turns communicates with the api server). A set of nodes is called a **cluster**. Each Kubernetes instance is responsible for running a cluster.

Kubernetes revolves its API server which is its central component (figure 3.2). The majority of operations between components go through this REST API like user interactions through kubectl or scheduling operations.

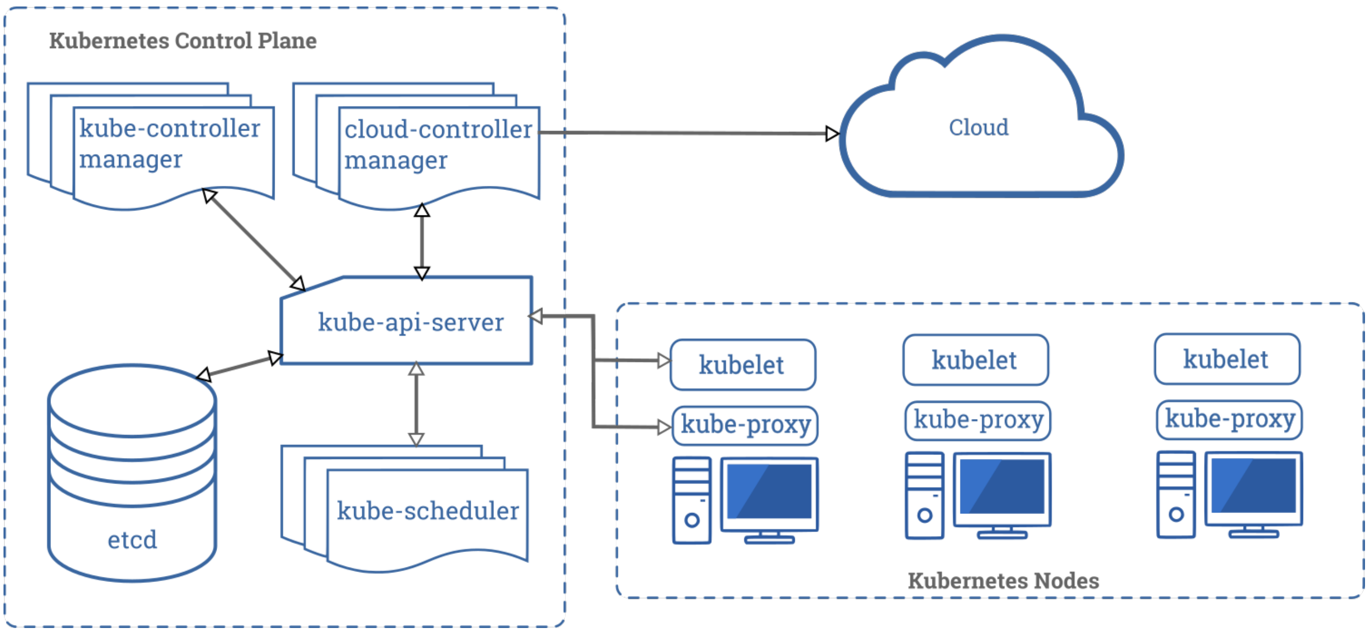


Figure 3.2: Components of Kubernetes
Source: *https://kubernetes.io/docs/concepts/overview/components/*

HPC and Kubernetes

The difference between HPC and Cloud Native computing lies in the workloads they are intended to tackle. Kubernetes was designed for Cloud Native applications. Services or micro services are run in containers and are expected to be available at all times : they are replicated as many times as the user desires and restarted whenever a failure occurs. High availability is at the core of Kubernetes container management. On the other hand, depending on scheduling policies, HPC is focused on user wait time, maximizing resource usage, optimizing energy costs... For instance, in case of failure, it is sometimes not sufficient to restart the single job that failed : the entire submission must be re-run if it is part of several jobs computed in parallel.

Kubernetes is now the standard for AI and Machine Learning as shown by the many efforts at making this coupling an efficient environment[2][4][3], which brought an increasing interest for container driven HPC aswell and Kubernetes for HPC in particular. Batch schedulers such as kube-batch[5] have been implemented for kube, and numerous HPC applications like slurm[6] now support containers as well.

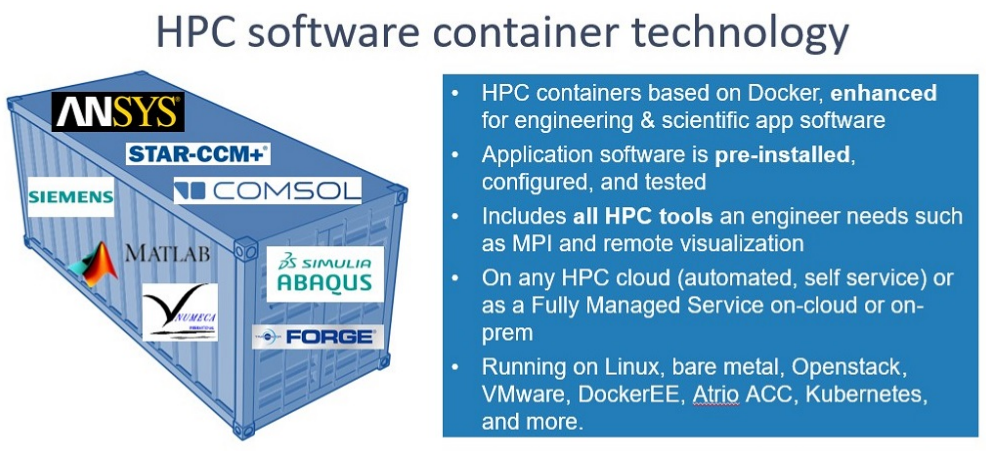
Indeed, containers have many advantages that HPC users can benefit from. Here are some notable ones:

- First off, research has shown that Kuberenetes offer similar performance to more standard bare metal HPC[1].

- Users will get the same environment everywhere making up for a uniform and standardized workplace.

- Portability : users could seamlessly hop from one infrastructure to another based on their needs and criteria like price, performance, and capabilities rather than compatibility.

- Encapsulation : HPC applications often rely on complex dependencies that can be easily concealed into containers.



HPC software container technology

- HPC containers based on Docker, **enhanced** for engineering & scientific app software
- Application software is **pre-installed**, configured, and tested
- Includes **all HPC tools** an engineer needs such as MPI and remote visualization
- On any HPC cloud (automated, self service) or as a Fully Managed Service on-cloud or on-prem
- Running on Linux, bare metal, Openstack, VMware, DockerEE, Atrio ACC, Kubernetes, and more.

Figure 3.3: The container technology for HPC
Source: *https://www.hpcwire.com/2019/09/19/kubernetes-containers-and-hpc/*

Despite all those advantages, Kubernetes is not ready yet to be used in proper HPC environment because it lacks vital components like a proper batch job queuing system, and support for MPI applications. It cannot yet compete against the very well established HPC ecosystem, but that time may come soon as containers are becoming more and more integrated in modern infrastructures.

[5]https://github.com/kubernetes-sigs/kube-batch
[6]https://slurm.schedmd.com/containers.html

3.3 Objectives

The goal of this project is to design and implement Batkube, which will be an interface between Batsim and Kubernetes schedulers. With this interface, we want to compare Batsim results gainst data from a real Kubernetes cluster, given HPC workloads.

3.4 Technical challenges

3.4.1 Translation

3.4.2 Time hijack

TODO

Algorithm 1: Requester loop

```
Input: req: request channel, res: result channel map
1  while Batkube is not ready do
2      wait
3  requests = []request
4  while req is not empty do
5      m = <- req /* Non blocking receive */
6      requests = append(requests, m)
7  sendToBatkube(requests) /* Only requests with duration > 0 are actually sent.
       Batkube will always anwser. */
8  now = responseFromBatkube()
9  for m in range requests do
10     res[m.id] <-now /* The caller continues execution upon reception */
```

Algorithm 2: Time request (time.now())

```
Result: Current simulation time
Input: d: timer duration, req: request channel, res: response channel map
Output: now : simulation time
1  if requester loop is not running then
2      go runRequesterLoop() /* There can on ly be one loop runing at a time */
3  id = newUUID()
4  m = newRequestMessage(d, id) /* Requests are identified using uuids */
5  resChannel = newChannel()
6  res[id] = resChannel /* A channel is associated with each request */
7  req <- m /* The code blocks here until request is handled */
8  now = <-resChannel /* The code blocks here until response is sent by the
       requester loop */
9  return now
```

3.4.3 Re-building the API

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Evaluation

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Conclusion

Bibliography

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