CSC7071 TECHNICAL REPORT

Kubernetes

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1.0 Background:

1.1 What is Kubernetes?

Kubernetes, also commonly referred to as k8s, is a container orchestration platform that specialises in automating the deployment, management, and scaling of containerised applications [1]. The name Kubernetes comes from the traditional Greek word for “helmsman”, which is someone who steers a ship, such as a container ship. Kubernetes main design goal is to make it easy for organisations to deploy and manage complex distributions, while benefiting from improved utilisation that containers enable [2].

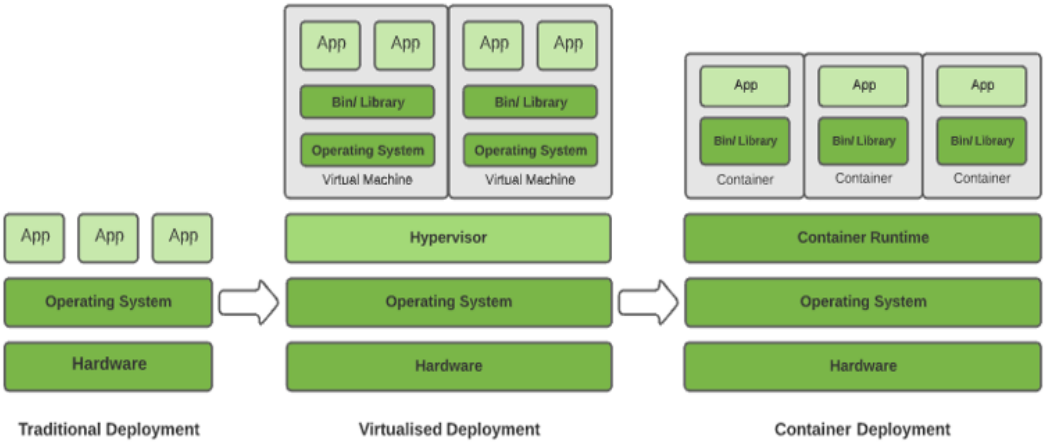
1.2 History..

1.2.1 Creation

Kubernetes was the third container management system developed by Google, after Borg and Omega, and is written in the ‘Go’ programming language. It was developed at a time when external developers where becoming involved with Linux containers, and Google had established a rising business selling public-cloud infrastructure [1]. Unlike Borg and Omega, which are internal Google systems, Kubernetes was open sourced in 2014, and is managed by Cloud Native Computing Foundation.

1.2.2 Application Deployment & Earlier Technologies

Figure 1. The evolution of application deployment



Traditionally, organisations used physical servers for running applications, which causes resource distribution problems as multiple applications running on one physical server can result in one application consuming the majority of resources, affecting the performance of other applications. The solution of running each application on different physical servers leads to underutilised resources, and expensive costs in running multiple physical servers.

Virtualization was introduced as a solution to the problems of using physical servers, through enabling multiple operating systems to run on a single physical system, whilst sharing hardware resources [3]. Virtualization uses software to create an abstraction layer over a computers hardware, enabling these elements to be divided into virtual machines that each run their own operating system and behave as

an independent computer [4]. The advantage with virtualisation is that, the physical servers resources are better utilised, the costs associated with hardware are reduced, and applications can be added and updated with ease, enabling better scalability.

A container is an executable unit of software that contains all the components needed to run an application, including code, libraries and dependencies. Unlike virtual machines, containers don't require a guest operating system for every instance, which means they are fast, portable and lightweight, while offering significantly less overheads than the physical server or virtualisation approaches. As a result of the benefits to organisations using containers, they have now become the de facto compute units of modern cloud-native applications [5].

1.2.3 Container Orchestration

As many organisations began embracing containers, container orchestration was introduced to addresses the challenges of managing hundreds and thousands of containers across systems. Container orchestration is an automated process of managing the lifecycle of containers, through scheduling, deployment, scaling, load balancing, health monitoring, resources allocating, and redundancy handling [6].

1.2.4 Docker

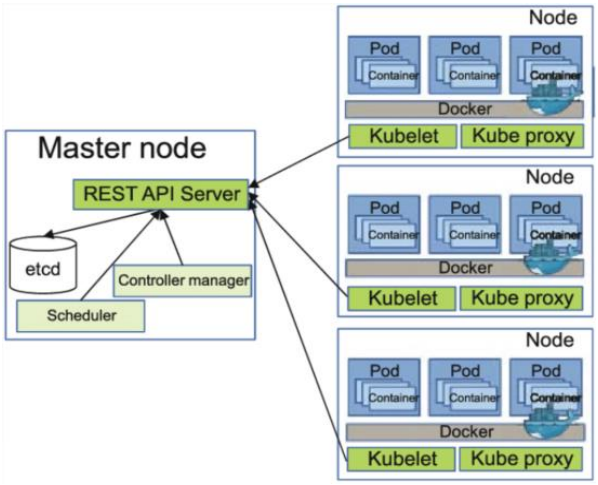
Kubernetes and Docker are seen as complementary products, with many organisations combining the technologies to get the best out of both. Docker was released in 2013 and specialises in the configuration, building and distributing of containers, while Kubernetes specialises in automated scheduling and management of application containers. Therefore, Kubernetes is the orchestrator, and Docker is the container run time engine for many organisations. Prior to the release of Docker Swarm, which is a container orchestrator, Docker actually recommended Kubernetes as a container management solution in production [7].

2.0 Current Situation:

Kubernetes is viewed today as the de facto standard for container orchestration. Since its release in 2014, it has quickly grown to dominate the container environment in terms of application development and infrastructure management [8].

2.1 How does Kubernetes work?

Figure 2. The Kubernetes cluster



Source: ResearchGate

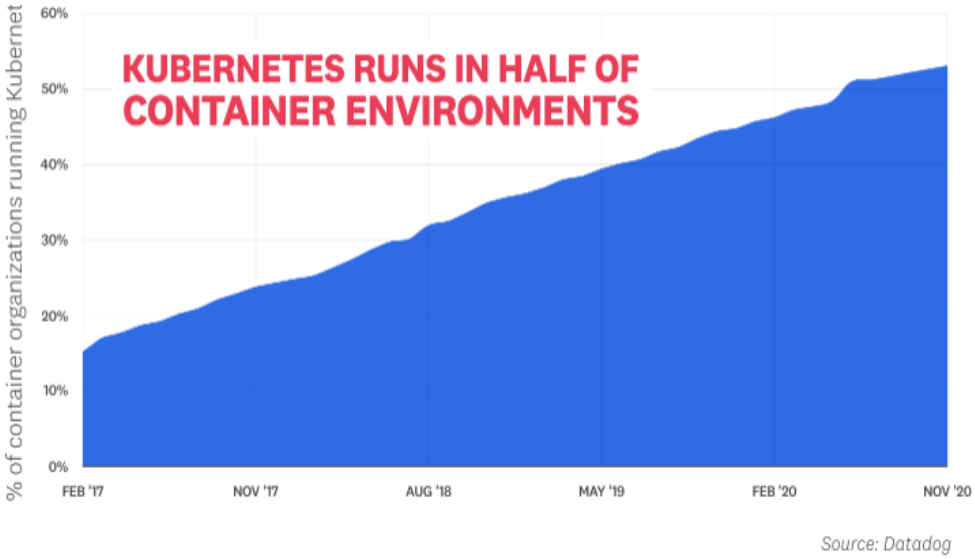
The building blocks of Kubernetes are clusters, which are made up of nodes that represent virtual or physical machines that host applications in the form of containers. The master node in the Kubernetes cluster is the control plane, which orchestrates the applications running on nodes, monitoring them constantly to ensure they match the desired state declared by the programmer [9]. The worker nodes are responsible for the deployment, running and management of containerised applications.

Worker nodes are made up of pods, which are a group of one or more containers, which share the same IP address, hosts name and resources. Containers are able to move around a cluster easily, as pods abstract network and storage from the underlying container. Each worker node includes the tools necessary to manage containers, such as Docker, along with a Kubelet, which is a software agent that receives and carries out orders from the master node. Kubectl, which is a command line interface, is used by developers to manage clusters via communication with the Kubernetes API.

2.2 How widely used is Kubernetes?

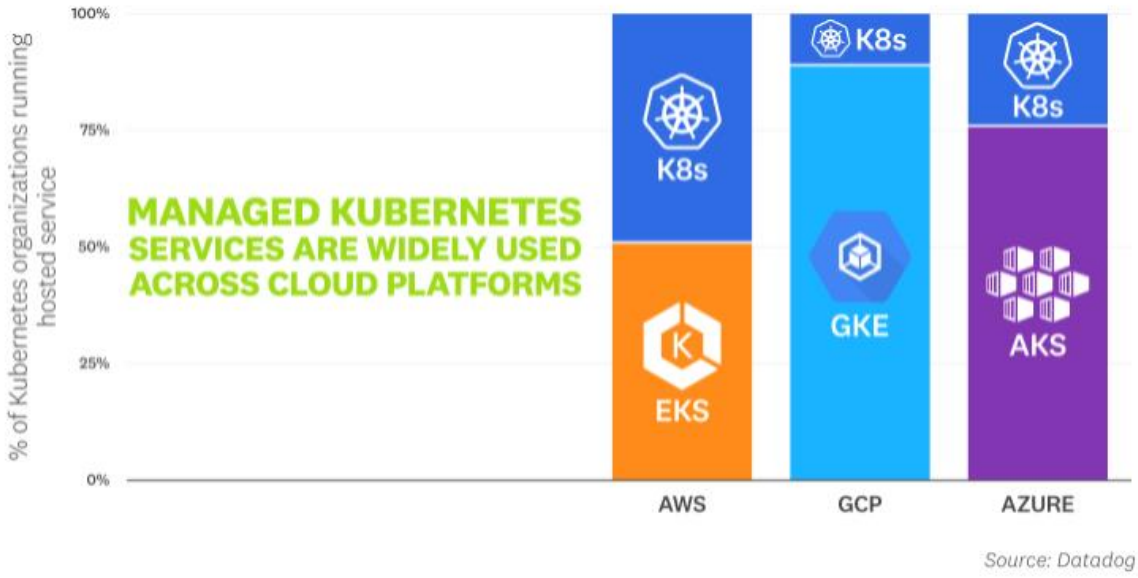
Currently, half of organisations that run containers use Kubernetes, through cloud provider services, or in self-managed clusters. The platforms use has more than doubled since 2017, and continues to grow progressively without signs of slowing down [10].

Figure 3. Kubernetes use today



Many well-known cloud providers are using Kubernetes as an integral part of their hybrid cloud approaches, with customers increasingly using Kubernetes services, such as Google Kubernetes Engine (GKE), Azure Kubernetes Service (AKS), and Amazon Elastic Kubernetes Service (EKS) [11]. On Google cloud, GKE dominates as approximately 90% of organisations running Kubernetes on Google cloud, rely on GKE to manage their environments. AKS is used by organisations to handle deployment, scaling and management of Docker containers and applications, and continues to grow in popularity on Microsoft Azure, being used by over two thirds of users. (EKS) enables organisations to implement, execute and scale Kubernetes applications in the AWS Cloud or on-premises and continues to rise in popularity. [10].

Figure 4. Use of managed Kubernetes services



According to stackshare, many of the well-known companies that use Kubernetes in their tech stacks include Shopify, Udemy, Robinhood and The New York Times [12]. Enlyft has collected data on 24,477 companies that use Kubernetes, with their research showing that Kubernetes has 24.53% of the market share across 12,500 technology products, 32% of companies using Kubernetes specialise in computer software, while 14% specialise in Information Technology [13]. Kubernetes updates are released every quarter, providing new features and enhancements. However the majority of organisations continue to run older, more established version of Kubernetes [10].

The 2020 Kubernetes Adoption Report gathered the following data from respondents:

- 84% confirmed their organisation used a Kubernetes environment to either test or develop AI models and applications.
- 89% expect Kubernetes to play a larger role in infrastructure management of their organisation in the near future.
- 73% see the faster application deployment as the biggest benefit to using Kubernetes.
- 40% confirmed that 41-60% of their organisations new applications run containers.
- 23% confirmed 61-80% of their organisations application run containers.
- 46% increased their use of Kubernetes in the preceding year to reduce IT costs. [11]

The Annual Cloud Native Computing Foundation survey of 2020 reported:

- Use of containers in production has increased to 92%, up from 84% in 2019, and 23% in 2016.
- Kubernetes use in production increased to 83%, up from 78% in 2019. [14]

2.3 Current Issues..

2.3.1 Ethical

Worldwide annual data traffic is predicted to increase by 60% by 2025, with cloud computing applications driving the majority of that growth, increasing the environmental footprint of the online world. Data centres used in cloud computing contain computer equipment that generates a lot of heat, and therefore requires constant wide scale cooling, which accounts for 40% of total energy consumption, and up to 80% in cases where the data centre is located in a warmer region. Moving

data centres to countries with cooler climates is a difficult process due to concerns with data security and encryption, as many countries and trade areas, have passed laws that require the data of their citizens to be stored on servers within national borders. In addition to high volume of electronic waste produced by the industry, the disposal of toxic batteries and chemical coolants used by data centres have the potential to negatively impact the local environment [15].

2.3.2 Technical

As there are many Kubernetes distributions, with different associated tools, it can be challenging for users moving from one distribution to another. Cloud based Kubernetes services such as GKE and EKS, have a very different suite of management tools and user experience, which creates challenges when moving from one to service to another [16].

Kubernetes consist of many different components, which means each component needs to be handled separately when running installation or updates. Most Kubernetes distributions current lack well-automated solutions for this issue, and would benefit from more streamlined, centralised management in this area. [16].

For small organisations that want more manual control over how workloads within their cluster are structured, this can be a difficult process when using Kubernetes as it was created for web-scale deployments [9].

3.0 Opportunities & Risks

3.1 Opportunities

Through replacing old versions of applications with new versions using rolling deployments, Kubernetes offers zero down time. The use of pods, which are responsible for running the applications containers, enables Kubernetes to increase the applications overall up time across its lifecycle. When development teams update the code and container image for an application, Kubernetes creates new pods with the updated container image, and guarantees these new pods are healthy and running before destroying the old pods [17]. If a deployment is not stable for example if the containers fail, Kubernetes offers rollbacks for deployments to make sure there is limited downtime.

Through implementing Kubernetes into an organisations tech stack, application developers are encouraged to write code as micro services. The micro services architecture approach to application development enables faster, and easier software changes compared to the monolithic approach, through dividing the applications code up into independent parts called services, making it modular and reusable, resulting in more efficient testing and high speed deployment [18]. The Kubernetes Adoption Survey of 2021 found that 73% of respondents said the top benefit from adopting Kubernetes was the ability to deploy new apps more quickly [10].

Kubernetes assigns worker nodes to run on containers within a cluster based on available resources, which enables better utilisation of compute resources across a cluster, enabling an organisation to get more work out the same number of machines and in turn cut costs [2]. An organisation may also identify opportunities to cut further costs, by reducing the number of unnecessary cloud instances or servers they operate.

Monitoring containers and rescheduling those that fail or terminate prematurely is another task Kubernetes automates. Developers can setup health checks, which enables Kubernetes to automatically detect when a container that hasn't yet crashed is faulty, before restarting that specific container [7]. The self-healing of failed containers ensures clusters always function at the optimal

state, and reduces downtime while mitigating any issues with the upkeep process of an application [19]. As Kubernetes is a declarative system, organisations can still have control over where specific containers get scheduled, where necessary.

Automatically scaling up a container, in instances where a containerized service experiences more demand than it can handle, is another key feature of Kubernetes. The process of auto scaling involves creating replicas of a container to help service the high request load [19]. Therefore, an organisation no longer requires a team of engineers to spend time manually deploying and configuring container replicas to scale up an application to meet demand. Organisations using Kubernetes can therefore scale and deploy faster than they ever have in the past, as teams can now deploy multiple times a day instead of one deployment a month [20].

Organisations who decide to use Kubernetes can be confident that it will be feasible to do so for many years. All major cloud vendors are supporting Kubernetes while alternative container orchestration platforms are far behind in terms of ecosystem and cloud vendor support. The Kubernetes eco system is growing fast as new products are released regularly, that support different needs on top of Kubernetes [8]. As many software engineers want to work for companies that use modern, and highly rated technologies, a Kubernetes and cloud native stack attracts talent to organisations workforces. The 2021 Stack Overflow developer survey reported Kubernetes as the 3rd most loved, and 3rd most sought after platforms [20].

Kubernetes also offers portability and flexibility, in that it can function in any type of infrastructure, whether public or private cloud, or an on premises server, as long as the OS is Linux or a post 2016 Windows version. Most other container orchestrator platforms lack this portability, as they are restricted to particular infrastructures [22].

3.2 Risks

It is widely accepted that Kubernetes has a steep learning curve. There is a long journey with learning Kubernetes, which starts with basic container, and container orchestration concepts, to gaining efficient experience in deployment and operations. Therefore the process of training staff can be time consuming and expensive.

As Kubernetes consists of many moving parts, which are configured and installed separately, the task of provisioning storage, ensuring security, maintaining availability and monitoring can be intimidating for newcomers to container orchestration, with 40% of organisations stating they were experiencing a Kubernetes-related skills shortage [14]. As not all organisations have the facilities to train in house experts, many are required to employ experienced talent within the domain, which can be expensive, with the average UK salary for Kubernetes developers currently at £70,000.

The complexity of Kubernetes is not suited for small-scale applications as discussed in section 2.3.2. Being able to develop applications that can scale up and down to meet requirements is better suited for larger scale applications [20]. Therefore, the benefits of running an application on Kubernetes for small-scale applications may be outweighed by the cost of resources and time spent on setup.

The State of Container and Kubernetes Security 2020 survey, carried out by StackRox, reported that 90% of respondents have experienced a security incident in their container and Kubernetes environment within the past 12 months, while 44% of respondents said they delayed application deployment due to security concerns . The majority of security incidents (69%), were caused by misconfiguration, which shows that the significant configuration required for Kubernetes can easily lead to human error [23].

As the adoption of Kubernetes has accelerated, the number of security threats has increased, including data theft, denial of service attacks and computational power theft. Cryptojacking is a common attack type, where attackers carry out cryptocurrency mining operations on a victims cluster through harnessing the networks underlying infrastructure, causing underperformance, reduced productivity, and increased costs for organisations [24].

4.0 Future of Kubernetes

The Cloud Native Computing Foundations survey of 2020 provided an insight for the future of Kubernetes with results showing a steady increase in organisations using containers in production, from 23% in 2016, to 92% in 2020. The results show that organisations using more than 5,000 containers accounted for 23% which is an increase from 11% in 2016, while 61% of organisations use more than 250 containers, which is an increase from 57% in 2019 [14]. The increase in the number of containers that organisations are using in production, inevitably leads to an increase in Kubernetes users, as organisations require a container orchestrator platform to manage the high volume of containers.

The use of Kubernetes has continued to increase, with 91% of respondents reported using the platform, with 83% using Kubernetes in production. There has been a steady increase in the number of organisations using Kubernetes, with 58% in 2018, and 78% in 2019 [14]. The eco system surrounding Kubernetes continues to grow alongside its use, with 383 companies, and over 2,400 individuals contributing to Kubernetes during the release cycle of its version 1.19 update (25). The Kubernetes contributor community website 'kubernets.dev' has since been launched which is a hub for all things Kubernetes. The results show that the popularity of Kubernetes continues to rise each year, and this is expected to continue in the future, with 95% of respondents stating they would recommend CNCF technologies [14].

The 2021 Kubernetes Adoption Survey reported that 84% of respondents have used Kubernetes to develop and test AI models, which shows the role of Kubernetes within organisations is expanding. As Kubernetes offers an infrastructure that enables data science teams to experiment with different models, in different environments at a high speed, the use of Kubernetes to develop and test AI models is expected to continue to rise [11].

Results also show that 89% of respondents expect Kubernetes to expand its role in infrastructure management in the future [11]. This is unsurprising, as a number of Kubernetes extensions such as the Container Network Interface, Container Runtime Interface, and the Container Storage Interface, are enabling more organisations to use Kubernetes to automate their storage, network and compute infrastructure.

The Kubernetes service provider named Civo, recently launched a learning programme to tackle the complexity issues of using Kubernetes, providing depth tutorials [26]. The introduction of training programs such as Civo's will lead to an increase of more knowledgeable Kubernetes users in the future, resulting in less security challenges as a result of misconfigurations.

The increase in vulnerabilities and cyberattacks continue to rise with the popularity of microservices, and use of hybrid cloud technologies. The global container and Kubernetes security market is expected to reach a value of $8.24 billion by 2030. With these projections, security challenges are expected to increase, but mitigation of these threats will become more efficient [16].

5.0 Summary

Kubernetes is the most popular container orchestration platform used today, helping organisations manage containerised applications in various types of physical, virtual, and cloud environments.

Kubernetes features:

- Automated scheduling
- Self-Healing
- Automated rollouts & rollbacks
- Service discovery & load balancing
- Auto-scaling

Kubernetes benefits and opportunities:

- Limited down time
- Faster deployments
- Better utilisation of resources
- Multi-cloud capabilities
- Portability & flexibility
- Market leading platform with vast eco system
- More productive workforce

Kubernetes drawbacks & risks:

- Steep learning curve
- Complexity not suited to small scale applications
- Security issues can arise through misconfigurations
- Environmental impact of cloud computing

The future looks promising for Kubernetes, with a steady increase in container orchestration use expected to continue, alongside the platforms continual expansion into infrastructure management and AI within organisations.

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