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Beyond Containers: Orchestrating Microservices with Minikube, Kubernetes, Docker, and Compose for Seamless Deployment and Scalability

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***Abstract*— In this paper, we explore the orchestration of microservices using Minikube, Kubernetes, Docker, and Docker Compose. We discuss how these technologies enable seamless deployment and scalability of microservices architectures. Through practical examples and insights, we demonstrate the benefits of utilizing these tools in modern software development. By leveraging Minikube for local Kubernetes environments and Docker for containerization, developers can streamline their development workflow and enhance the efficiency of their deployments. Additionally, Docker Compose facilitates the management of multi-container applications, further simplifying the orchestration process. Our exploration showcases the power of these tools in enabling flexible, scalable, and resilient microservices architectures.**

Keywords*— *Microservices, Kubernetes, Minikube, Docker, Docker Compose, Docker Hub

I. INTRODUCTION

In recent years, containerization technologies such as Docker have gained significant traction in the software development industry. Containers provide a lightweight and portable way to package applications and their dependencies, ensuring consistency across different environments. Alongside containerization, container orchestration platforms like Kubernetes have become essential tools for managing and scaling containerized applications in production environments. In this paper, we delve into the orchestration of microservices using a combination of Minikube, Kubernetes, Docker, and Docker Compose. Minikube provides a local Kubernetes environment, allowing developers to experiment with Kubernetes features without the need for a full-scale cluster. Kubernetes, on the other hand, offers powerful features for deploying, managing, and scaling containerized applications across clusters of machines. A monolithic program can be divided into tiny, autonomous components, each of which provides a single, clearly defined functionality, thanks to microservices. The majority of IT firms, including Uber, Netflix, Spotify, and Amazon, are converting to microservices to improve the scalability and performance of their applications in a distributed cloud environment [1]. Microservices are ideally suited for the world of software containers, which offer to make run-time administration and deployment easier. Provisioning, management, communication, and fault tolerance for containers may all be automated with a container orchestration platform. It can be quite helpful for managing and deploying intricate microservice-based systems at every stage of their development. While there are a number of orchestration solutions available [2], Kubernetes is the most widely used option in both academic and industry settings. We also explore Docker and Docker Compose, which complement Kubernetes by providing tools for building and managing container images, as well as defining multi-container applications. Together, these technologies form a robust ecosystem for orchestrating microservices, enabling seamless deployment, scaling, and management of modern software architectures.

II. LITERATURE REVIEW

The author addressed the management of elasticity in microservice-based cloud systems, delving into existing rules and architectures [3]. Recognizing the limited research on directly tackling the elasticity challenges of complex microservice applications, we also delve into methods for scaling individual containers. Managing individual containers presents challenges [4]. While a small team can effectively handle a few containers for development purposes, managing hundreds of containers can be overwhelming, even for a large team of experienced developers. Kubernetes emerges as a crucial tool for deployment in containerized environments. It facilitates scheduling, deployment, and the mass creation and deletion of containers. Additionally, Kubernetes streamlines the rollout of updates, eliminating the need for manual intervention and abilities on a large scale that would otherwise prove extremely tedious to do. Imagine that you updated a Docker image, which now needs to propagate to a dozen containers [5]. While you could destroy and then re-create these containers, you can also run a short one-line command to have Kubernetes make all those updates for you. Of course, this is just a simple example. Kubernetes has a lot more to offer [6]. Microservices promote agility by enabling teams to develop, deploy, and scale services independently. Kubernetes facilitates this agility by providing a declarative approach to managing infrastructure, allowing developers to define desired states for their applications and letting Kubernetes handle the implementation details [7]. Microservices rely on containerization technology as their primary enabler. From an organizational perspective, the integration of containerization and microservices strengthens the microservice architecture style, enabling the advancement of an organization's organizational stack and technology in line with its architectural frameworks [8]. Within our work, we concentrate on Kubernetes for container orchestration and Docker as a tool for containerization [9].

III. SYSTEM ARCHITECTURE

A. Overview of Minikube

Minikube is a tool that enables developers to run Kubernetes clusters locally. It is designed to be a lightweight

and easy-to-use solution for testing and developing Kubernetes applications. Minikube runs a single-node Kubernetes cluster inside a virtual machine (VM) on your local machine, providing an environment that closely mirrors a production Kubernetes cluster. Install and set up Minikube by following a few straightforward steps.

- Install a Hypervisor: Minikube uses a hypervisor to create a VM for running the Kubernetes cluster. Popular choices include VirtualBox, HyperKit, and KVM [10].
- Install kubectl: Kubectl is the command-line tool used to interact with Kubernetes clusters. Install it to manage and deploy applications on your Minikube cluster [11].
- Install Minikube: Download and install the Minikube binary suitable for your operating system. Minikube provides a single executable that simplifies the setup process [12].
- Start Minikube Cluster: Use the minikube start command to launch a local Kubernetes cluster. Minikube will handle the creation of the VM, installation of Kubernetes components, and configuration of kubectl [11].

B. *Kubernetes Essentials*

Kubernetes, often abbreviated as K8s, is an open-source container orchestration platform designed to automate the deployment, scaling, and management of containerized applications [13]. It was originally developed by Google and is now maintained by the Cloud Native Computing Foundation (CNCF). Kubernetes provides a robust and extensible platform for managing containerized workloads and services, facilitating both declarative configuration and automation. The primary purpose of Kubernetes is to address the complexities of deploying and managing applications in a distributed, containerized environment. With support for various container runtimes, including Docker and containers, Kubernetes abstracts away the underlying infrastructure, allowing developers to focus on designing scalable and resilient applications. Kubernetes cluster architecture refers to the structure and components of a Kubernetes cluster, which is a set of nodes that host containerized applications. It typically consists of master nodes and worker nodes. The master nodes manage the cluster and its components, while the worker nodes run the applications [14]. Figure (1), illustrates the Kubernetes cluster architecture:

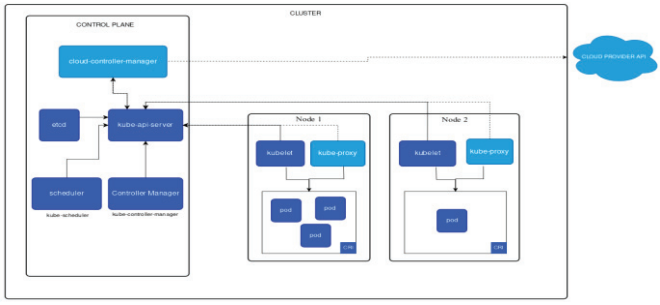

Fig. 1. Kubernetes cluster architecture

1) *Master Node (Control Plane):* - The master node, often referred to as the control plane, is responsible for managing the overall state of the cluster. Key components of the master node include:
   - **API Server**: Serves as the front-end for the Kubernetes control plane, handling communication with the cluster.
   - **Controller Manager**: - Ensures that the cluster is in the desired state by controlling various controller processes.
   - **Scheduler**: Assigns workloads to worker nodes based on resource requirements and constraints.
   - **Etcd:** - Consistent and highly-available key-value store used as Kubernetes' backing store for all cluster data.
2) *Node (Minion*): - Nodes, also known as minions, are the worker machines responsible for running containers. Each node runs a container runtime (e.g., Docker), and the following components:
   - **Kubelet**: - Ensures that containers are running in a Pod.
   - **Kube-Proxy**: - Maintains network rules to allow communication between Pods.
   - **Container Runtime**: - The software is responsible for running containers, with Docker being a commonly used runtime.
3) *Pod:* - is the smallest deployable unit in Kubernetes and represents a single instance of a running process in a cluster. Pods are the basic building blocks that hold containers and shared resources, providing an isolated environment for the application [15].
4) *Service:* - Services define a set of Pods and a policy to access them. They enable network communication between different sets of Pods, providing a stable endpoint for accessing applications [16].

C. *Benefits of Kubernetes in Microservices Architecture*

Microservices architecture, characterized by its modular and loosely coupled design, has gained popularity due to its ability to enhance applications' scalability, resilience, and portability. Kubernetes, an open-source container orchestration platform, plays a pivotal role in enabling these benefits. Kubernetes facilitates scalability by automatically managing the deployment, scaling, and operation of application containers across clusters of hosts. This ensures that microservices can dynamically scale in response to changing workloads, maintaining optimal performance [17].

Additionally, Kubernetes enhances resilience by providing features such as automated health checks, self-healing capabilities, and rolling updates. These mechanisms help minimize downtime and ensure the high availability of microservices, even in the face of failures or disruptions. Moreover, Kubernetes promotes portability by abstracting away the underlying infrastructure complexities. Microservices can be deployed consistently across diverse environments, including on-premises data centres, public clouds, or hybrid setups, without necessitating significant modifications [18].

- **Scalability**: - Kubernetes allows for easy scaling of applications by adjusting the number of replicas running in the cluster.

- **Resilience**: - With features like self-healing and automated rollouts and rollbacks, Kubernetes ensures that applications remain available and stable.
- **Portability**: Containers encapsulate applications and their dependencies, making it easy to move applications between different environments seamlessly.
- **Resource Efficiency**: Kubernetes optimizes resource utilization by scheduling containers based on resource requirements and constraints.

IV. DOCKER

A. Graphical User Interfaces (GUIs)

Docker provides a user-friendly graphical user interface (GUI) through Docker Desktop, catering to developers who prefer visual representations of their containers and images. The Docker Desktop interface simplifies container management, image creation, and resource allocation [19].

1) Key Features:

- ***Container and Image Management***: Easily view, start, stop, and remove containers and images through an intuitive interface.
- ***Resource Allocation***: Allocate resources like CPU and memory using sliders for each container.
- ***Network Configuration***: Visualize and manage container networks through the GUI.

2) Ease of Use Considerations:

- The GUI offers an accessible entry point for developers unfamiliar with command-line interfaces.
- The visual representation aids in understanding container relationships and resource utilization.

B. Integration and Interoperability

Docker seamlessly integrates with various development tools, continuous integration platforms, and cloud services. Its versatility allows developers to incorporate Docker into their existing workflows with minimal friction.

1) Integration Examples:

- IDE Integration: Plugins and extensions for popular Integrated Development Environments (IDEs) like Visual Studio Code simplify Docker file creation and container management.
- Continuous Integration: Docker can be easily integrated into CI/CD pipelines using tools like Jenkins, GitLab CI, or GitHub Actions.
- Orchestration Platforms: Docker images can be seamlessly deployed to Kubernetes clusters, ensuring compatibility with modern orchestration solutions.

2) Ease of Use Considerations:

- Extensive support for industry-standard integrations simplifies adoption for development teams.
- *Compatibility with popular CI/CD tools facilitates streamlined automation.*

V. DOCKER COMPOSE

A. Graphical User Interfaces (GUIs)

Docker Compose primarily relies on a declarative YAML file for configuration and deployment. While there isn't a dedicated GUI for Docker Compose, tools like Portainer and Kitematic offer visual interfaces for managing Docker Compose applications [19].

1) Key Features:

- Portainer:- Provides a web-based interface for managing Docker containers and Compose applications. Users can deploy and monitor services with ease.
- Kitematic:- Offers a simple GUI for managing Docker containers and Compose applications, suitable for users who prefer visual interaction.

2) Ease of Use Considerations

- GUIs enhance Docker Compose's accessibility, especially for users who prefer visual representation.
- Simplifies the management of complex multi-container applications.

B. Integration and Interoperability

Docker Compose integrates seamlessly with Docker, extending its ease of use to multi-container applications. It aligns well with various orchestration platforms, making it a valuable tool for local development and testing examples of integration are below: -

- Docker Swarm: Docker Compose files can be used to define multi-container applications in Docker Swarm, simplifying the transition to production environments.
- Kubernetes: While Docker Compose is not native to Kubernetes, tools like Kompose facilitate the translation of Compose files to Kubernetes manifests.

VI. DOCKER HUB

Docker Hub is a central repository for Docker images, playing a crucial role in the containerized application development lifecycle. Its ease of use significantly influences the collaborative development process, offering a centralized hub for image management and distribution [17]. Docker Hub provides an intuitive web interface for users to explore, search, and manage Docker images. The design emphasizes simplicity, allowing users to navigate repositories, view tags, and access documentation effortlessly. The characters of Docker Hub as below: -

- Search Functionality: Enables users to find images quickly based on keywords and tags.
- Repository Organization: Intuitive organization of repositories and tags, facilitating easy navigation.
- Automated Builds: Simplifies the process of automating image builds from source code repositories.
- Clean and user-friendly web interface caters to users of all experience levels.

- Features like automated builds enhance efficiency, automating repetitive tasks

Additionally, Docker Hub integrates seamlessly with popular CI/CD platforms, allowing for automated image builds and deployments. This integration streamlines the development workflow and ensures that the latest, tested images are readily available. Examples of integration as below:

- GitHub Actions: Docker Hub integrates with GitHub Actions to automate image builds triggered by code commits.
- Jenkins: Plugins and integrations with Jenkins facilitate the incorporation of Docker Hub into CI/CD pipelines.

VII. Difference between Docker Compose and Kubernetes

Docker Compose and Kubernetes are both widely used tools in the realm of container orchestration, each with its strengths and purposes. While Docker Compose is more suited for defining and running multi-container Docker applications in local development environments, Kubernetes excels in managing large-scale containerized applications in production environments. The key differences lie in their scalability, complexity, and target use cases. Figure (2) illustrates the contrasting features and use cases of Docker Compose and Kubernetes:

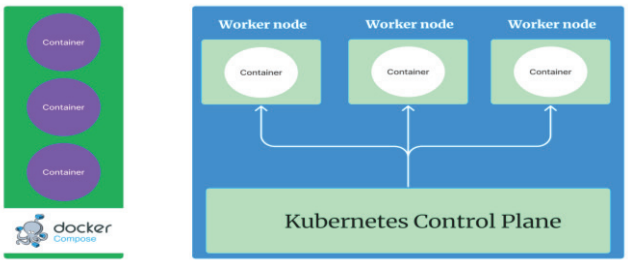

Fig. 2. Difference between Docker Compose and Kubernetes

A. Microservices in Kubernetes

1) ***Service Registry:*** **-** A central element in microservices architecture is the service registry, and in Kubernetes, Etcd, a distributed key-value store, plays a pivotal role. Etcd stores information about the various microservices deployed in the cluster, enabling dynamic service discovery. Each microservice registers its location and details with Etcd, ensuring a real-time, centralized repository for service metadata.

2) ***API Gateway:*** **-** To manage external access to microservices, Kubernetes employs the Ingress Controller as an API Gateway. Acting as an entry point, the Ingress Controller handles external traffic routing based on predefined rules. This ensures a controlled and secure pathway for requests entering the Kubernetes cluster, streamlining the interaction between external users and microservices.

3) ***Microservices Pods:*** **-** At the heart of microservices deployment in Kubernetes are the Microservices Pods. Each microservice is encapsulated within its own Pod, representing an independent, deployable unit. This encapsulation promotes isolation, allowing developers to focus on specific microservices without impacting the entire application. Kubernetes manages the lifecycle, scaling, and distribution of these Pods.

4) ***Service Discovery:*** **-** Microservices communicate dynamically in a decentralized manner through service discovery. Each microservice registers with the service registry (Etcd) during deployment. This dynamic registration allows other microservices to discover and communicate with each other based on their real-time locations and status. The decentralized nature ensures flexibility and adaptability in the rapidly changing microservices landscape.

5) ***External Communication:*** For external communication Kubernetes relies on Ingress routing. External requests entering the cluster are directed through the Ingress Controller, which acts as an intelligent entry point. The Ingress Controller utilizes predefined rules to route traffic to the appropriate microservices. This mechanism simplifies external access and provides a unified interface for communication with microservices.

6) ***Internal Communication:*** **-** Microservices interact internally through Kubernetes Services, forming the backbone of communication within the cluster. Services abstract the underlying complexity of microservices' network architecture. This abstraction allows microservices to communicate seamlessly, promoting loose coupling and facilitating the orchestration of complex, interconnected systems.

7) ***Deployment*****: -** In Kubernetes, the Deployment resource plays a crucial role in defining the desired state for a set of identical microservice Pods. Developers specify the number of replicas, container specifications, and update strategies. This configuration ensures that the desired number of microservice instances is running and aligns with the application's overall deployment strategy.

8) ***Service:*** **-** The Service resource in Kubernetes exposes microservices internally, allowing them to communicate with each other within the cluster. By defining a Service, developers create a stable endpoint for other microservices to discover and interact with. This abstraction promotes a decoupled architecture, where each microservice focuses on its functionality without the need to understand the underlying network details.

9) ***Ingress:*** **-** To facilitate external access to microservices, Kubernetes employs the Ingress resource. Ingress defines how external HTTP/S traffic should be routed to microservices based on rules. These rules include paths, backend services, and TLS settings. The Ingress resource simplifies the management of external access points, ensuring a coherent and controlled entry for incoming requests.

VIII. Facilitating Communication Between Microservices and Exposing Applications Globally

Figure (3) illustrates the communication flow between the microservices in the Kubernetes cluster. The React application communicates with both the FastAPI and Node.js microservices to fulfill user requests. External access to the

React application can be facilitated through Node Port or Load Balancer, depending on your deployment preferences.

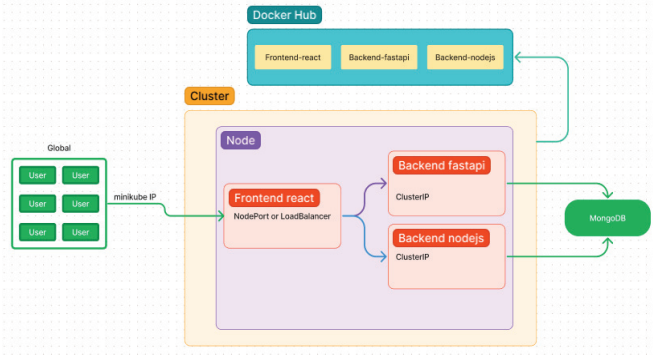

Fig. 3. Microservices Communication

This architecture promotes modularity, scalability, and maintainability by leveraging microservices with specific functionalities. Each microservice operates independently, facilitating easier development, deployment, and maintenance.

IX. Frontend and Backend Application

The front end of our application is developed using React, a popular JavaScript library for building user interfaces. The React application is designed to interact with the backend services to fetch data and provide a seamless user experience. For external access to the React application, Kubernetes offers two primary Service types:

- NodePort: Exposes the React application on a static port on each node in the cluster. External traffic is directed to one of these nodes. Developers can access the application via the node's IP address and the assigned NodePort.
- LoadBalancer: Provides a fully managed, external load balancer to distribute traffic across multiple nodes. This is especially useful in cloud environments where an external load balancer can handle incoming requests and distribute them to nodes running the React application.

The backend of our application includes a FastAPI microservice, which is a modern, fast web framework for building APIs with Python 3.7+. FastAPI is known for its automatic OpenAPI and JSON Schema generation, making API development straightforward. The FastAPI microservice is configured with a Kubernetes Service of type ClusterIP. This type exposes the service only within the cluster, making it accessible to other microservices but not directly reachable from outside the cluster. This enhances the security and isolation of the FastAPI microservice. This microservice is connected with MongoDB for efficient data storage and retrieval. Another component of our backend is a Node.js microservice, which provides specific functionalities required by the React application. Node.js is a lightweight and efficient JavaScript runtime commonly used for building scalable network applications. Similar to the FastAPI microservice, the Node.js microservice is configured with a Kubernetes Service of type ClusterIP. This allows communication between microservices within the cluster, ensuring a controlled and secure interaction. This microservice also is connected with MongoDB for efficient data storage and retrieval. It is important to mention that each microservice can have different databases, such as PostgreSQL, MongoDB, or HarperDB. However, in this case, all microservices are connected to a single MongoDB database.

X. Performance Evaluation

Table (1) show a comparative analysis of Docker-compose, Minikube, and Kubernetes (K8s) across various performance metrics. When evaluating the performance of Docker-compose, Minikube, and Kubernetes, it becomes evident that Kubernetes outperforms both Docker-compose and Minikube in various aspects. Kubernetes excels in scalability, container orchestration, multi-node support, load balancing, resource management, auto-scaling, fault tolerance, networking, persistent storage, rolling updates, declarative configuration, service discovery, security, and ecosystem support. It boasts advanced features and extensive community support, although it comes with a relatively steep learning curve. On the other hand, Docker-compose offers basic functionalities with limited scalability and orchestration capabilities. Minikube provides a middle ground between Docker-compose and Kubernetes, offering moderate features and support. Overall, the choice between Docker-compose, Minikube, and Kubernetes depends on the specific requirements of the application, the level of expertise of the team, and the desired performance outcomes.

TABLE I. A comparative analysis of Docker-compose, Minikube, and Kubernetes (K8s) across various performance metrics.

Feature	Docker-compose	Minikube	Kubernetes (K8s)
Scalability	x	?	Yes
Container Orchestration	Basic	Limited	Advanced
Multi-Node Support	No	Limited	Yes
Load Balancing	No	Limited	Yes
Resource Management	Basic	Limited	Advanced
Auto-scaling	No	Limited	Yes
Fault Tolerance	No	Limited	Yes
Networking	Limited	Limited	Advanced
Persistent Storage	Limited	Limited	Yes
Rolling Updates	No	Limited	Yes
Declarative Configuration	No	Limited	Yes
Service Discovery	No	Limited	Yes
Security	Basic	Limited	Advanced
Community Support	Widespread	Moderate	Extensive
Learning Curve	Low	Moderate	High
Ecosystem	Limited	Limited	Extensive
Monitoring	No	Basic	Advanced
Logging	No	Basic	Advanced
GUI	No	Limited	Yes

XI. Conclusions

Our exploration of "Beyond Containers: Orchestrating Microservices with Minikube, Kubernetes, Docker, and Compose" highlights the vital role these tools play in modern software architecture. Minikube, Kubernetes, Docker, and Docker Compose are essential for efficient and scalable microservices deployment. Minikube provides a local Kubernetes environment for seamless testing and iteration of applications. Kubernetes simplifies the management, scaling, and deployment of microservices, ensuring optimal resource utilization. Docker and Docker Compose are crucial for

packaging applications and orchestrating multi-container environments. Docker's simplicity and portability enhance the development and deployment lifecycle, while Docker Compose simplifies complex orchestration processes. This synergy between Minikube, Kubernetes, Docker, and Compose enables streamlined development workflows and addresses scalability and resilience challenges in distributed systems. In the era of "Beyond Containers," characterized by paramount agility and scalability, embracing these tools empowers developers and DevOps teams to navigate microservices orchestration successfully, ensuring adaptable systems in the evolving digital landscape.

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REFERENCES

[1] I. Nadareishvili, R. Mitra, M. McLarty, and M. Amundsen, Microservice Architecture: Aligning Principles, Practices, and Culture. O'Reilly, 2016.

[2] E. Casalicchio, "Container orchestration: A survey," in Systems Modeling: Methodologies and Tools. Cham: Springer, 2019, pp. 221–235.

[3] C. Barna, H. Khazaei, M. Fokaefs, and M. Litoiu, "Delivering elastic containerized cloud applications to enable DevOps," in Proc. of SEAMS

[4] Ali, F.I., Ali, T.E. and Al-dahan, Z.T., 2023. Private Backend Server Software-Based Telehealthcare Tracking and Monitoring System. International Journal of Online & Biomedical Engineering, 19(1).

[5] Li, Z., Kihl, M., Lu, Q. & Andersson, J. Performance overhead comparison between hypervisor and container-based virtualization. In Proceedings Of The 2017 IEEE 31st International Conference On Advanced Information Networking And Applications (AINA).

[6] Ali, F.I., Ali, T.E. and Hamad, A.H., 2022, October. Telemedicine Framework in COVID-19 Pandemic. In 2022 International Conference on Engineering and Emerging Technologies (ICEET) (pp. 1-8). IEEE.

[7] Germar, S., Paul, P., Matthias, F., Dirk, R., Feryel, Z., and Jerker, D.,"Micro Service based Sensor Integration Efficiency and Feasibility in the Semiconductor Industry", Infocommunications Journal, Vol. XIV, No 3

[8] Stubbs J, Moreira W, Dooley R. Distributed Systems of Microservices Using Docker and Serfnode. 2015 7th International Workshop on Science Gateways. 2015 June;p. 34–39.

[9] Ali, T.E., Morad, A.H. and Abdala, M.A., 2021, June. Efficient Private Cloud Resources Platform. In 2021 International Conference on Electrical, Communication, and Computer Engineering (ICECCE) (pp. 1-6). IEEE.

[10] The Kubernetes Authors. Kubectl Drivers. minikube.sigs.k8s.io/docs/drivers/

[11] The Kubernetes Authors. Kubectl Install. kubernetes.io/docs/tasks/tools/install-kubectl/

[12] Official Minikube Documentation. minikube.sigs.k8s.io/docs/start

[13] Official Minikube Documentation and Commands. minikube.sigs.k8s.io/docs/commands

[14] The Official Kubernetes documentation. kubernetes.io/docs/home

[15] The Official Kubernetes documentation and architecture. kubernetes.io/docs/concepts/architecture

[16] The Official Docker documentation. docs.docker.com

[17] The Official Docker hub documentation. hub.docker.com

[18] R. S. Kannan, L. Subramanian, A. Raju, J. Ahn et al., "GrandSLAm: Guaranteeing SLAs for jobs in microservices execution frameworks," in Proc. of EuroSys '19. ACM, 2019.

[19] A. Bauer, V. Lesch, L. Versluis, A. Ilyushkin, N. Herbst, and S. Kounev, "Chamulteon: Coordinated auto-scaling of micro-services," in Proc. Of IEEE ICDCS '19, 2019, pp. 2015–2025