Comparative Study of Virtual Machines and Containers for DevOps Developers
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Abstract—In this work, we plan to develop a system to compare virtual machines with container technology. We would devise ways to measure the administrator effort of containers vs. Virtual Machines (VMs). Metrics that will be tested against include human efforts required, ease of migration, resource utilization and ease of use using containers and virtual machines.

Keywords: DevOps, Virtual Machines, Containers, Cloud Computing, Internet Services

I. INTRODUCTION
Virtualization is key technique driving multiple research areas in today’s world. Gone are those days when cluster of nodes in Cloud Computing environment were set up using physical servers in data center. Since the advent of virtualization, a term which goes hand-in-hand with cloud computing and is mentioned interchangeably with cloud computing, even if they are not the same, cloud infrastructure costs have gone well down. Virtualization is a technology where a virtual version of machine hardware, storage devices and network devices is created using some emulators called Hypervisors. Industry accepted virtual machines as de-facto deployment method for their production software. But, as and on cloud computing industry got matured, it was noticed that deployment of virtual machines actually caused overhead. For a few virtual machines, the overhead seems okay but when you have hundreds of virtual machines deployed in your production, the overhead adds up to a lot. This is when some companies and open source contributors came up with the idea of virtual environment instead of virtual machines. With some tweaks and additions to Linux kernel’s ‘chroot’ commands, open source contributors came up with projects like LXC (Linux Containers) and FreeBSD Jails. The concept of container is where you do not have to worry about full blown virtual machine and infrastructure costs and overhead associated with it. Rather you would just have a virtual environment and each container runs as a process [1]. This revolutionized the operations sector of software development. Fig. 1 and Fig. 2 show the final representation of system using virtual machines and containers respectively where each of these are running apache web server respectively.

In this project, we will discuss the trade-offs of using virtual machine and containers for deployment of the software in DevOps perspective. Along with the benchmarking of virtual machines and containers, we will also study the impact of
using Docker containers to deploy software to the clients. We usually read that with containers the deployment time has been reduced from days to minutes as opposed to virtual machines. Our project will try to understand the reasoning and meaning behind above statement.

II. LITERATURE SURVEY

This section provides you details about the need for isolation for running any service, and how do these modern virtualization techniques like Virtual machines and containers provide isolation during runtime.

A. Cloud Computing

Cloud computing is often confused with virtualization whereas these two technologies are similar but not exactly same. Virtualization is the technique which separates the physical architecture to create various dedicated resources, so that we are able to utilize the efficiency of our hardware completely. Cloud computing on the other hand is a service that results from the manipulation of the hardware carried out by virtualization. The world today combines these two technologies to get the best results i.e. using the virtualized environment over the cloud. Virtualization allows you to run more than one operating system and run multiple applications on the same server. So in order to incorporate these benefits, cloud computing technology saw a boom in 2012. Cloud leads to several benefits, it is setup relatively in a quick span of time plus all the servers, services, licenses are all provided. Small scale businesses are benifiting from SaaS applications available today, which allows you to pay as you use the resources. While cloud computing and virtualization both have some benifits but we consider cloud computing as an extension of virtualization.

B. Virtual Machine

A virtual machine is nothing but an application environment which imitates dedicated hardware. Using such an environment allows user to utilize the resources of its machine efficiently. A virtual machine uses a specialized software, a hypervisor which emulates the hardware resources, which enables the virtual machines to share the resources. This limits cost of additional hardware by utilizing the resources of a single machine efficiently. Reducing the number of hardware resources leads to reduce in power and as well as cooling demands, which further reduces the management efforts in managing resources. Vendors such as VMware, Oracle and Microsoft dominate the market with their products in this field.

C. Container

Containers are platforms for developing and deploying applications oblivious to the infrastructure. Container methodology enables developers to perform quick deployment and significantly reduces the delay between writing code and having it in production. Containers provide the ability to package and run an application in a loosely isolated environment, thus allowing many containers to run simultaneously in a given host. Unlike virtual machines, dockers do not have the overhead of hypervisors. Docker is one of the very well known containers. It also provides tools to manage the lifecycle of the containers.

D. DevOps:

DevOps is a product management methodology that aims at unifying application development (Dev) and operations (Ops). The main motive of this of this methodology is to support automation and monitor all steps in software construction: ranging from building, testing and
deployment. In order to achieve this, a DevOps person could have the option to either use a Virtual machine or a container. Virtual Machines give high adaptability while containers’ primarily concentrate on applications and their dependencies. Multiple containers could be deployed in a single host or virtual machine. Thus there is a good chance that if the host goes down all the containers would go down. If security and reliability is the main concern, VM should be preferred. VMs on the other hand does not provide isolation like containers. Since conatiners run on a single kernel, containers are easy to deploy and maintain.

III. CHOOSING BETWEEN CONTAINERS AND VIRTUAL MACHINES

Virtual machines and containers usually provide different ways to virtualize resources to run applications. In case of a virtual machine, an infrastructure layer called hypervisor partitions the server below the operating system which creates true virtual machines that share only hardware. Whereas in case of a container virtualization is done at operating system level where some middleware are shared. Virtual machines offer a higher flexibility as the application runs on a bare metal server, we can pick our own operating system and middleware but in case of a container we have to choose a common operating system as well as middleware for our application. So if you want a full platform to run multiple services Virtual machines will be a better option but if you want to deploy a scalable service on a distributed platform containers should be used [5]. We present the following factors that determine what technology should be used and when:

A. Operating System Requirements

As an DevOps, the admin can select an operating system and middleware as per his choice. This choice of the operating system could be independent of the other VMs[1] running on the same server. This is not the case with containers. The admin would have to provide a “common” operating system and middleware elements when running the applications. The is because, each container would use the core server platform and share it with other containers. Virtual Machines are thus flexible, mainly due to the fact that the applications running on the guest environment are similar to a bare-metal server.

B. Security

A virtual machine is a demarcation between the operating system and the physical hardware. An instance of Virtual Machine has its own services like BIOS, virtualized adapters for network, storage units, CPU and a replicated operating system. Therefore, the applications running over VM are oblivious to the system/hardware resources and so control to the system resources is very much restricted implying failing of one VM less likely to affect other running VMs. On the other hand, containers share kernel resources and application libraries. Thus applications running on containers are system aware. There is no hardware isolation. So, the application can take control of the system resources.

C. Scope of the application

One of the most important factors to keep in mind is the nature of the application. Containers can run in any environment regardless of the infrastructure whereas the Virtual machine partitions the server below the operating system that share the hardware. Thus, choosing VMs will be a better idea for embedded systems and infrastructural applications while containers can be used to run web applications, small databases that run on all platforms.

D. Size of the application

If there is a need to run maximum number of a particular applications on minimum number of servers, the best option is to run the applications
on the container.[2] Deploying multiple instances of a single application in multiple containers are less troublesome in comparison to the Virtual Machines. One area in which containers have gained high usage is in the field of microservices where each container runs a single service as they can be scaled quickly with the use of containers[4]. Also, the hardware requirement for deploying multiple web servers in containers would be significantly less than doing so on virtual machines. But if we have to run really huge applications or databases that require multiple machines, choosing virtual machines would be a better choice.

E. Service Model

The other factor which can be taken into account when choosing between containers and virtual machines is the service model which is used to deploy and manage environments. Virtual machines are usually deployed using tools like VMware. These tools are responsible for creating the Virtual machine and migrating it to other environments. But these are not that useful in application management with DevOps. Whereas containers on the other side provide development of the software independent of the underlying hardware which means that containers can be deployed quickly in comparison to virtual machines.

F. Requirements of the organizations

For organizations that have the requirement to run different applications on variety of software platforms, virtual machines would definitely have an edge over containers. Containers would be more difficult to use in this case because of the necessity to standardize a single hosting platform. If a software is dependent on a specific version of the operating system and there is a need to run multiple instances of the applications, containers should be preferred as the deployment would be easy and also the resource utilization would be optimum.

G. Overheads

Compared to Virtual Machines, containers have very less deployment overhead because they don’t duplicate the platform software for every instance of the application. Thus it is possible to run more components per server with container technology. Also, the deployment and redeployment of applications or components is faster with containers. In addition, each user in container environment shares the same instance of OS, kernel and memory as well as same network connection. Since, an application instance will just use an instance of user space, by mere reducing CPU usage, one can reduce the overhead of multiple OS thereby improve the performance. A new kernel is not invoked for each user session.

IV. System and Technology

- A Virtual Box or Qemu KVM as a virtual machine
- B Docker Containers
- C Kubernetes to orchestrate the containers
- D Tunneling techniques
- E Measurement tools
- F Linux Kernel programming e.g. shell scripting
- G Apache Web Server

V. Experiment

This section discusses the steps that we took to measure effectiveness of Docker containers over virtual machines to deploy a software. We measured effectiveness of Docker containers in terms of time required by each virtualization technique to start operating. In our test environment we tested a simple Apache web server that serves a website that performs heavy mathematical functions. We deploy the web server through Docker containers and virtual machine. A PostgreSQL database server serves the data to Apache web server in the backend.

The system configuration of the machines are as follows:
A. Virtual Machine

We test our Apache based web service using virtual machine based on Ubuntu Linux distribution. Below are system specifications that we are using to study our web application through virtual machine:

- Operating System: Ubuntu 16:04
- Linux Kernel: v4.10
- Apache Web Server: Apache httpd v2.24
- Hypervisor: Oracle VM Type-2 Hypervisor

B. Containers

After deploying the web application through virtual machines, we test the same deployment through Docker containers. Below are container specifications that we are using to study our web applications:

- Docker Image: Ubuntu:latest
- Linux Kernel: v4.10
- Apache Web Server: Apache httpd v2.24
- Docker: 17.09-ce

VI. RESULTS

So far in our progress with our project, we have finished testing containers and virtual machines with respect to initial human efforts required to setup each of the virtualization solution.

A. Initial Human Efforts

When we say human efforts required to setup a virtualization solution, we mean to quantify the human effort index in various classes like cost incurred in the form of infrastructure costs, time to set up the infrastructure and time to start and stop the virtualization services.

1) Time to Start and Stop: We measured time required to start and stop the containers and virtual machines. We measured the start...
time and stopping time taken by four system administrators (they call them DevOps developers nowadays). As we already know that Docker containers are based on image creation using layered file system operations, it takes very less time around 40 ms to start and 28 ms to stop on an average to create and push a basic Docker image for a container. On the other hand, virtual machines run as standalone operating system and it takes 55 sec to start and 30 sec to stop, on an average. Therefore, we must install whole operating system from scratch to create a new virtual machine, every single time. In our comparison test, we assume that we have already installed the operating system inside a virtual machine and have Docker image readily created with Apache installed. Figures 1 to 4 describe test results in the form of time required to start and stop a virtual machine and container. Because Docker containers work as processes inside host operating system, it takes only milliseconds to launch a container to invoke a system call through Docker command line system. Whereas in case of virtual machine, it takes tens of seconds because each virtual machine must go through all generic operating system boot process like Power On Self Test (POST), loading GRUB, loading initramfs and then staring init process of a virtual machine. Therefore, we found out that as a DevOps it would be an easy choice of selecting Docker container technology instead of virtual machines as it saves a lot of human efforts in terms of time required start or stop the systems.

| Type   | Time to Start | Time to Stop |
|--------|--------------|--------------|
| Docker| 39 ms        | 27 ms        |
| VM    | 51 sec       | 29 sec       |

**TABLE I**

**ADMIN 1 EFFORTS**

Apart from human efforts required to start and stop virtual machines and containers, we must also test virtual machine and containers against other parameters that are more related to system performance as whole.

### B. Disk I/O Resource Utilization

In this section, we will try to gauge the performance of containers against virtual machines with respect to disk I/O performance. For any DevOps developer deploying an application that is I/O-heavy, it is absolutely necessary to select an appropriate choice of virtualization solution. We ran fio workload generator inside Docker containers and virtual machine which performed randread and randwrite operations on the disk. Figure 4 shows that for any I/O-heavy applications, a DevOps developer would select containers to deploy their application where containers provide lesser overhead giving the performance almost equal to bare metal machine.

![Benchmarking of Disk IOPS (higher the better)](image-url)

**Fig. 5.** Benchmarking of Disk IOPS (higher the better)
| Type    | Time to Start | Time to Stop |
|---------|---------------|--------------|
| Docker  | 43 ms         | 31 ms        |
| VM      | 49 sec        | 30 sec       |

**TABLE IV**
ADMIN 4 EFFORTS

Therefore we can infer that container provide enough disk isolation at the expense of little to no resource overhead whereas performance in virtual machine suffers badly.

**C. Network Resource Utilization**

Another important aspect of any web application is that how much network resources, we utilized network benchmark tool named netperf that performs network bandwidth benchmarking and network tuning. We ran netperf inside virtual machine and container and then compared the result with respect to bare-metal.

We can see from the Figure 5 that virtual machine performs worst when it comes to latency in networking. Containers provide bare-metal like performance. Figure 6 shows average latency measurement when it comes to containers and virtual machine. Therefore, for a DevOps developer who is trying to deploy a web application, it is a wise to select containers for deployment rather than virtual machines.

**D. CPU Resource Utilization**

We further compare containers and virtual machines in terms of Floating Point Operating Operations per Second (FLOPS) that we get. We test the CPU performance using Intel’s Linpack tool that measures CPU by performing heavy floating point operations.

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FLOPS = \text{sockets} \times \text{cores/sockets} \times \text{cycles/seconds} \times \text{FLOPS/cycle}
\]

In our tests, we found out that containers again outperform virtual machines because they make use of native system calls of host operating system. Containers also use native memory swapping for performing high value floating point operations, on the other hand, virtual machine performs poorly because of hypervisor that translates the system call to the hardware.

Our CPU benchmark performance on Intel Core i7 Skylake CPU show that containers again outperform virtual machine. Therefore, containers provide enough CPU isolation with little to no overhead as compared to virtual machine.
E. Checkpoint, Restore and Migration

After our research on checkpointing and restore mechanisms in virtual machines and containers, we found out that virtual machine managers like VirtualBox, VMWare and KVM Qemu have better solutions built-in them that provide easy checkpointing and restore on virtual machines. On the other hand, we found out that checkpointing and restore mechanism is difficult to implement and there are not really many robust tools that achieve the same. We found out that Docker's native support for checkpoint restore and some third-party tools like CRIU (Checkpoint Restore in User-space) do not have enough documentation and community support to allow a DevOps developer easily migrate their containers let alone supporting live migration of containers.

VII. LIMITATION OF CONTAINERS

While containers are beneficial for their lesser resource requirements, there are a few limitations when using containers:

A. Security Issues in Containers

While there may be numerous benefits for a DevOps developer to deploy their application inside a container, there are a few scenarios where it would be wise to use virtual machines instead of containers.

1) Shared Kernel: As containers are based on a single Linux kernel, if an attacker attacks underlying Linux kernel and if the kernel is brought down then all the containers that are running on top of that kernel come under risk. Thus, even if containers require less resources to provide just enough isolation, it should not be taken for granted especially if an application requires strong isolation and security. If a DevOps developer must use containers for their benefits but also requires strong isolation and security then they may try to run containers inside virtual machines for added isolation and security. Unlike virtual machines, the shared kernel in containers impacts the security. The whole host might shut down if a container does something nasty [7].

2) Unrestricted Network Access: Various containers on a host operating system share same hardware. Therefore, in most deployments, containers are left with unrestricted access through network interfaces. This may cause a security concern that is often overlooked. An attacker that has gotten into a container may take down other containers in the cluster by exploiting unrestricted network access.

3) Running Containers with Privilege Mode: As containers are run as daemon processes, it is very risky to run containers with root user privilege. An attacker can exploit the privilege level with which the container is running to take down whole host operating system along with all other containers running on the host operating system.

B. Securing the Containers

Below are a few ways where we can secure the containers [8]:

- App Armor - Administrators can assign security profile to each program running in the system.
- BlackDuck Security - It is mainly used in containers inventory and mapping known security vulnerabilities to image indexes
- REMnux - It is an open source Linux toolkit. It assists the DevOps in analysing malwares and to reverse engineer infected application.
- Cilium - It acts as a medium of network security between container applications.
- Dockscan - It analyses the installation process and monitors the running containers.

C. Live Migration

We tried to test checkpoint and restore mechanism inside containers using Checkpoint and Restore in Userspace (CRIU), but it did not work well inside Docker. We communicated with
CRIU community and Docker community to carry out checkpoint restore inside containers. However, as we discussed above, owing to limited documentation and support we could not perform migration efficiently. This might be another area where containers might not be beneficial to use as various virtual machine vendors already provide robust tools and support for live migration of virtual machines.

Containers provide weak isolation as compared to virtual machines. Therefore, if a DevOps developer wants to deploy an application that requires higher levels of security then it is better to use virtual machines.

VIII. CONTRIBUTIONS

All members of our group contributed equally. All the tasks including infrastructure setup, microbenchmarking the infrastructure and authoring the documentation of the project were divided and completed by all the team members with equal efforts.

IX. ACKNOWLEDGEMENT

We would like to thank Prof. Richard Martin for his suggestions and support throughout the project.

X. CONCLUSION

Our project studies the concept of virtualization using virtual machines and containers. Our work demonstrates the benefits of containers when compared to virtual machines for a DevOps developer who is looking to deploy their application. As showcased in section V and VI, we can see that containers exhibit lower overhead while providing same services for application deployments as in virtual machine. Containers are shown to use lesser system and human resources to operate compared to virtual machines and provide just enough isolation and better performance improvement for an application deployed inside then as opposed to virtual machines. On the other hand, we also discussed a possibility of deploying highly secured and isolated applications. In such scenarios, as we discussed, it is much wiser to use virtual machine for deployment rather than containers owing to their stronger isolation and security mechanisms as compared to containers. Therefore, we conclude that it really depends on a DevOps developer and the application they want to integrate, deploy or migrate on what virtualization technique should be used. If the application requires just enough isolation with lesser resource utilization, we definitely recommend using containers as opposed to virtual machines.

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