Stateful FaaS

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Abstract

Serverless Computing is an up and coming platform as a service offering where the cloud provider manages and allocates resources needed to keep the application running. This lets the developer focus on the application development and not on server maintenance. Alongside off loading the provisioning and maintenance of the server, Serverless computing also reduces resource waste by scaling up and down the allocation depending on the load and the configurations. The users only pay for the resources that were used by the application thereby saving huge operational cost on their infrastructure hosting.

Although Serverless might sounds like the holy grail of application hosting, the current state of art technology fall short in several places to meet the industrial requirements. Data intensive applications, streaming applications, and distributed computing are some of the fields that could be benefited heavily by implementation on Serverless platforms in terms of ease of development, efficiency and cost. But all the existing platforms offer very poor performance in these fields and works mostly via workarounds and n number of third party tools.

This thesis analyses the Serverless paradigm in depth, pointing out the reasons for this reduced adaptability. To solve these issues, we propose a lightweight extension to an existing Open Source Serverless platform, OpenFaaS, by provide flexibility, scalability and adaptability, while making sure not to violate the notion of functions. Our implementation tries to reduce the operational gap between the industrial applications and theoretical ideas produced by researches in the academia in the past few years. This thesis also offers a deep study of the full potential and limitations of Serverless thereby making it clear to the reader why more innovations are necessary in this field.

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1 Introduction

Serverless can easily be considered as the new generation of platform as a service. It can be thought of as an infrastructure where the programmer send their application as functions in a predefined format, in a supported programming language as documented by the provider. This function get hosted at a certain endpoint which can be triggered with certain events supported by the platform. In short, instead of having continuously running servers, functions operate as event handlers and when the functions execute, the equivalent CPU usage is paid for by the user. This has huge economical and architectural implications that is still waiting to be explored in its full power. While the developers worry about the logic of handling the requests/events, the infrastructure provider takes care of receiving the request, responding to them, capacity planning, task scheduling, and operational monitoring[**gotoconf**].

In the current industrial applications, data intensiveness of the applications are increasing day by day paving way to adopt several resource heavy tools to do stream processing, distributed processing etc. More than often CPU and memory loads in these machines tent to vary a lot and rather than having a dedicated server to accommodate the whole range of requirements, it makes perfect sense to convert it into a Serverless workload thereby saving up on operational cost, resource waste, and ease of development. Having said that, the current commercial offerings of Serverless do not work very great with such workloads.

This is mostly due to the sheer nature of the Serverless paradigm of being completely stateless, thereby forcing the developers to use external block storages for data store and communication. In this thesis, we try to extend Serverless to leverage its full potential by introducing an efficient form of state thereby providing flexibility, scalability and adaptibility at the same time not violating the notion of functions in these platforms. We will be extending an Open Source serverless platform called OpenFaaS considering its simplistic and expandable architecture.

Currently most of the commercial serverless offerings are closed source and vendor locked in to their respective platforms by cloud providers. But in the past couple of years the field has gotten a lot of traction in the academia and a lot of Open Source alternatives are being widely adopted. This being the case, a lot of these works hasn't been properly applied in the industry, some because of the absense of proper integrations with the industry standard tools, and some because of the operational gap between the theoretical ideas and the practicality or usability in the field. This thesis tries to reduce that gap by proposing a very secure and multi-tenant implementation of a state-ful Serverless setup which can be easily used for production quality applications. A focus on the possibility to monitor the application performance and usage provides a possibility to do fine grained billing of the resources and thereby contributing to the easy adaptability of our extension.

Using our proposed Serverless setup, we try to efficiently run a Extract-Transfer-Load(ETL) workload on streaming data. ETL basically is a pipeline that involves receiving data from source, cleaning and transforming it, and loading it to a sink. We will split the whole operation into multiple functions as per the Serverless notion and have them communicate data and state internally to complete the pipeline thereby reducing the latency and external bottlenecks.

This document describes more on Serverless paradigm, the shortcomings of it, the ones we are trying to solve, our solution and evaluation. It is split into several sections as follows:

In Section 2, we go a bit in depth to understand the history of cloud infrastructure and the technological innovations that led to Serverless paradigm. We also look in detail at the characteristics and nature of Serverless. We look at some commercial Serverless offerings and understand how in the programming world Serverless has influenced even in the way of developing. We will also see what limitations it holds at its current state of evolution and on solving which issue are we particularly interested in, in the scope of this thesis.

In Section 4, we look at the current state of research in the field of Serverless technologies and some related works.

In Section 3, We present the proposed solution for our Serverless setup going into detail about how certain unacceptable limitations can be overcome.

In Section 4, the implementation of the system including the architecture and the tools used is presented.

In Section 5, we go on with the evaluation of our system as opposed to standard Serverless workloads.

We move on to Section 6 to understand the limitations of our proposed system.

In Section 7, the future work that can be done in this direction is laid out before the reader.

2 Background and Motivation

The term serverless have been vaguely thrown around the domain of cloud infrastructure in the past decade as the breakthrough resource(and hence money) saving tool that lets the developers focus on application logic rather than the deployment and server maintenance. Having said that, it is often hard to define what exactly serverless is since the service offering tend to change based on the cloud provider and the interpretations of the users. It is fair to say that serverless is a huge leap in the direction of using computational power as a resource which can be paid for as per the usage. Although the terminology is irrelevant, we will be focusing on the serverless offering called Function-as-a-Service(FaaS) where the cloud providers offer a platform to which we can upload our application code to(complying to the API rules) and get uninterrupted service of the same at an endpoint irrespective of the traffic or data load. Paying only for what resources has been used adds to the attraction of the domain. In this section, we will understand more about this technology, the popular commercial offerings the same, and its limitations and the current state of research. We will also analyze the popular data processing and streaming pipelines in the industries these days and why serverless computing fall short in being the right tool of development and deployment here.

2.1 Evolution of cloud resource management

In the past 3 decades, software deployments and infrastructure management has seen a lot of innovation and evolution. Before diving into the current industrial standards, it is important to understand the evolutions in this field to get a better grasp on the technological innovations that bought this about.

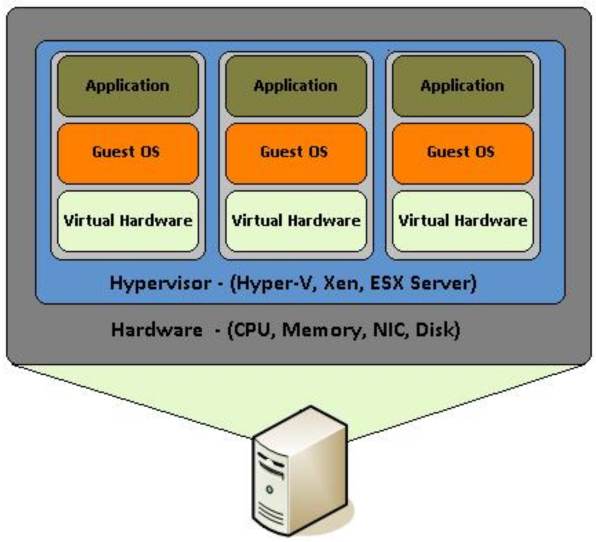
2.1.1 Dedicated servers

Even as recent as 15 years ago this was the industry standard for deployments. Dedicated servers are physical machines. The general practice was to have server racks on the premise of the company which are maintained by system administrators and all your software is hosted there. Although this method offers advanced security and high availability, it is often common that a lot of physical resources were underutilized and each resource was for single client. Not to mention the environmental impact of the reserved heavy hardware which leaves a heavy carbon footprint and e-wastes.

2.1.2 Dedicated virtual machines(BaaS)

Virtualization technology changed the face of software infrastructure by decoupling applications from the underlying hardware. Virtualized servers are not physical machines, they are a software construct. Virtual servers run on dedicated servers, the resources of which are divided between several virtual servers. To get slightly technical, virtualization usually involves installing a virtualization software(Hypervisor) on an existing operating system and then having multiple operating systems on it, sharing all the resources of the underlying operating system, yet providing great security and isolation.

Figure 1: Figure 1: Virtualization through hupervisors



Although applications in hosted on the virtual machine suffers from a heavy input/output and network overload because of the added layer of indirection, this technology reduces the resource waste to a great extend. The enterprises could share their hardware into multiple virtual machines and have different hosting and computation in each of the them. System administrators started splitting up their bare metal resources among multiple Virtual Private Servers(VPS) by the help of virtualization software. Each VPS would give you the feeling of having a real system although it is a virtualized system which is sharing the resources with other VPSs. This reduced a lot the amount of work and energy spent on maintaining server racks along with the terrible underutilization of resources.

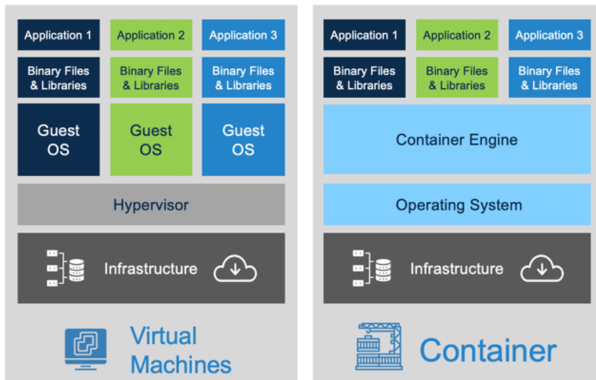
More and more companies started adapting this technology and in early 2006 Amazon Web Services(AWS) re-launched themselves as a platform that offers computing and storage space to developers and enterprises on an on-demand basis revolutionizing how companies were designing their system architecture. Soon after Google and Microsoft followed suit with their cloud infrastructure platforms offering similar services. All these providers function by maintaining huge, dedicated server farms across the globe to provide the necessary resources to the customers.

These kind of services, generally called as Infrastructure as a Service(IaaS) or Platform as a Service(PaaS), went through a series of changes during the past decade. On-demand compute instances to completely managed deployment services(eg: Google App Engine), Pay per use block storages(AWS S3) to fully managed dedicated relational databases(Google Cloud SQL, AWS RDS, etc.) a lot of really efficient and interesting services started to be available for the developers disposition. The billing scheme of these services also started to be quite flexible even allowing a per second billing plan in the past couple of years by Google.

It is also worth noting that with the advent of virtualization, the job profiles in several companies shifted from having a system administrator role to having profiles called DevOps(development and operations) who are application developers focusing on the provisioning of the virtual machines to deploy their applications. Although IaaS solved a lot of hassle around infrastructure provisioning, the systems and load of the applications still remained independent. Applications always had dedicated virtual machines even if the load/traffic to and fro the application is not constant. This meant that a lot of resources were still being wasted.

Linux Containers A game changer in the world of virtualization was containerization. Containers are yet another packaged computing environment that combine various IT components and isolate them from the rest of the system just like a virtual machine would. It was developed to solve a lot of problems with virtual machines. The purpose of the containers is to encapsulate an application and its dependencies within its own environment. This allows them to run in isolation while they are using the same system resources and the same operating system. Since the resources are not wasted on running separate operating systems tasks, containerization allows for a much quicker, lightweight deployment of applications. Each container image could be only a few megabytes in size, making it easier to share, migrate, and move. Figure 2 shows the difference in the isolation levels of containers and virtual machines. [containers]CITE Even though Linux Containers have existed for a very long time, in the past decade, containers were made a lot more approachable and adaptable as a technology by the advent of communities like Docker and rkt.

Figure 2: Figure 2: Virtual Machines Vs Containers



The light weight of the containers made it the ideal candidate for running applications. What makes container based deployments special as opposed to the ones deployed directly on the host is the consistency of the environment. The application execution environment can be recreated and ported from one system to another without affecting the functionality of the application or having to reinstall the whole binary dependencies on the new machine. Reproducability of the production environment even in the local exactly, meant that the development/testing cycle became much more efficient. The isolated package of the application, enveloped as a container image, is agnostic of the operating system it runs on opening new possibilities for the deployment. One could also limit and fine tune the resources used by a running containers giving a lot more control over the application.

Autoscaling The ease in which one can limit the resources and tweak the runtime parameters externally contributed heavily to the service offering called autoscaling which basically meant resources for an application runtime were added or removed as per the usage. All the commercial cloud providers started offering the aforementioned service in different flavors. Autoscaling on EC2 or Google Compute, AWS Fargate, etc. are some examples.

In the past two years, innovations have taken a leap in the field of isolation environments, introducing solutions like AWS Firecracker, Cloudflare workers, etc. to the community. These solutions aim at mitigating the shortcomings of Containers which we will discuss in Section 2.2.4

2.1.3 Serverless

Like mentioned earlier, in the past two years the terms Serverless and Function-as-a-Service are quite often used interchangeably. In terms of the resource reservation, Serverless can be considered as a platform as a service solution that scales. Your application will always have enough and only enough resources dedicated to it. It will scale up and down based on the load and traffic and the developer only pays for the usage. This paradigm of autoscaling has been hence applied even to database storage solutions by major cloud providers such that even the block storage is allocated based on usage and there will be a burst of reservation as soon as a certain limit is reached. The pioneers of this technology can be considered as the proprietary service Lambda by Amazon Web Services[CITE]. Several other cloud providers followed suit with similar platforms specific to their infrastructure. The nature of serverless makes it attractive for both developers and the cloud providers since in the case of former, it means paying much less and in case of the latter, it means they can easily provide shared tenant resource allocation units.

We will dive more into the properties and nature of the solution Function-as-a-Service(FaaS) in the following session.

2.2 FaaS

So far, we have covered the infrastructure management style of FaaS or Serverless in general. Let us get a bit in detail into the specifics of the hosting platform that provides the FaaS functionality.

Most FaaS platforms being closed source, provides the client API for developers to supply a package including their code and dependencies to. Most platforms supports a limited set of programming language runtime although it is usually possible to do workarounds to deploy custom runtime. Behind the screen, the platform containerizes the application and deploy it so as to get triggered via pre-defined hooks specified by the developer. The infrastructure also provides endpoints or interfaces to specify the maximum and minimum CPU and memory allocated for the application, the maximum timeout for the application(although there is a hard bound on this imposed by the infrastructure provider usually). To understand the flow of FaaS workloads, it is important to be aware of the following properties of the platform.

2.2.1 Properties of FaaS

Statelessness Statelessness in deployments is a conscious decision that was taken during the conception of the Serverless infrastructure model to make the management of the platform straight forward and less cumbersome. Statelessness simply means that the applications that are to be deployed on the said platform exists as independent functions that are pure in nature. As in, the same data input given to the function always produces the same output at any point in time. This can be considered as the side-effect less programming. The data source and sink of the function can be any supported platform or tool as per the requirement, but there won't be any intermediate state or cache for the function. This means that the function at any execution will have no information about the previous execution unless explicitly specified.

The main advantage with this method for the infrastructure manager is pretty obvious. The fact that there are no volumes necessary to store any internal state means that the function can be scaled up and down independently and the whole infrastructure can stay elastic. Along with this, the provider can schedule the function in any node in the cluster that they use to host the application, move it around as per the usage burst, have multi-tenant deployments in a single machine ensuring the proper isolation for maximum profitability, and the list goes on.

In short, the notion of function is of prime importance in a Function-as-a-Service workload like the name suggests.

Triggers The functions that are hosted on a FaaS solution need to get triggered on a timely basis or based on an event. Usually most cloud providers provide more than a few ways to trigger the functions which the developer can choose from. Some of the most common triggers for FaaS applications are

- HTTP requests: An endpoint will be provided by the platform for the function that was deployed.

This endpoint can be called as an REST API endpoint and the event handler of the function will get the payload from the call.

- Data arrival in a storage or data broker system

This is the most popular and heavily used triggering mechanism in FaaS. The idea is that the function gets triggered as soon as a new data arrives in whatever format at a particular storage setup. This can be arrival of a file object in the S3 block storage, arrival of streamed data in Kafka message broker system, etc. This method is the most suited for big data and streaming data applications since the function can be activated as soon as the new data is detected in the source. Usually the FaaS infrastructure provide supports more than a bunch of source storage to be used as the sources for the trigger.

Cron Another very common way to trigger function is based on a schedule. The programmer can choose how often the function should be triggered on what days of the week, month, year, etc.

Parallelism

Developer friendliness

Dependency management

Debugging and testing

Deployment

Logging and monitoring

Billing

2.2.2 How programming models are getting affected by this

Faas + Microservices In Software Systems Design, a very heavily discussed topic is if to design the application in a monolithic fashion or a microservices fashion. Monolith is the kind of design pattern where you have one big application doing multiple functions and maintained as one solid stack.

On the contrary, when one designs their app in a microservices pattern, they will have split up their application into multiple smaller parts which can be independently built and deployed, and yet working together with inter app communications. Both of these methods has its advantages and challenges. When monoliths are easier to develop and maintain, it can be very hard to test and manage due to the size, and usually if one part is buggy, it tends to break the whole system. On the other hand, microservices, since they work as independent units don't usually affect each others working and can be very easily tested and maintained. It is although often a very tedious task developing a system that fragmented and maintaining it that way.

With the advent of FaaS, a very interesting pattern has been adapted in the industry. The pattern pushed microservices one step further. The idea is that instead of having microservices that are available and on at all time, the huge applications are split up into functions that can be deployed to a FaaS infrastructure and triggered with the help of HTTP endpoints to act as a part of web application setup. This method is very effective resource usage wise and much easier to deploy and manage compared to vanilla microservices which has to be built and deployed independently.

Statelessness a.k.a Functional programming model Like mentioned earlier, the notion of function is very important for the serverless platforms. It is intrinsically linked with functional programming. It is very interesting to note that Amazon named their FaaS solution Lambda which is a very basic concept of functional programming. Stateless clean functions that produce no side effect was objectively the perfect choice for an infrastructure solution of this scale.

What this change bought about is a thriving interest in functional programming languages. A lot of the functional programming languages belonging to the LISP family and some purely functional ones have seen a very increasing adaptation in the past few years in Serverless platforms. Since these languages are perfectly suited for stateless program it is only natural that they can be efficiently used to code for this environment.

2.2.3 Popular commercial offerings

AWS Lambda

Google cloud functions

Azure functions

2.2.4 Where Serverless computing fall short

Although serverless computing might sound like the silver bullet of the deployment solutions, it is a field that is still being rapidly grown and researched on. There are several staggering shortcomings for this technology that makes it unsuitable for certain applications. The current offering have the following noticeable limitations.

Lack of state As mentioned earlier, statelessness is a primary nature for serverless workloads making it easy to deploy and port agnostic of the environment and server. Hence serverless/auto-scaling paradigm generally push for a development style involving no state to make the infrastructure simple, encouraging a functional style of development. Although this can contribute to easily scalable and parallelisable applications, it often limits the technology from being adapted in applications that are data intensive and/or requires faster response times. The fact that serverless functions don't store any intermediate state requires the application developers to use a block storage to store the data and state after the execution. This basically means communication via slow storage and adds a lot to the latency. This discourages the use of serverless in distributed computing which is actually a domain that needs very fine grained communication between the functions and usually a lot of resources are wastefully dedicated to ensure high availability.

A function during execution has no clue of the previous executions and its results. Which is something that is usually very basic for data analysis operations. The developers in this case are forced to send the data after each execution to a block store and retrieve the data from the block store before the next execution. Other than the input output overhead and the network latency this adds, it is a violation of the elastic nature of the Serverless paradigm.

I/O Latency Like was mentioned earlier, FaaS have had a lot of influences in the system architecture and programming paradigms like would with any new infrastructure management system. It is quite unfortunate though that, even with a paradigm with such huge potential, FaaS is very conventional when it comes to its data engineering architecture. Functions are run in isolated units separate from the data or data store. This is actually a very huge system design anti-pattern because Input/Output have and will remain to be a bottle neck even with heavy memory and huge number of dedicated cores to a function. The pattern where the data is taken to code as opposed to code to data adds to the latency, cost, and inconvenience. For the clarity of the reader, an example of a code shipping architecture is procedures that you run in databases. The code is moved to the data than the other way around in this.

Coordination issues among functions As we saw in the previous sections, FaaS workloads are usually containerized by the cloud provider to deploy it easily in their node pool or cluster. By nature, docker containers are indiscoverable units that need to be opened up explicitly to the network of the host machine. Meaning that, we cannot explicitly address the docker container directly using an IP address or an endpoint. Cloud providers do not open up the container to the network consider the potential security issues this can cause and the necessity of state in this case. They provide handles to communicate with the function or trigger-able entry points, but no direct network addressability.

What this implies is that, if the developer has multiple functions that has to be composed together to form a pipeline, rather than triggering each other internally and directly, the developer will have to hack around by either triggering it via an HTTP endpoint if the provider allows that, or like was mentioned in the previous point via an external block storage, or other external queueing systems they provide, etc. In either of these scenarios, it is hard to avoid added latencies.

This makes FaaS particularly inefficient for applications like distributed computing when it depends on very fine grained communication between the functions. With FaaS we can only ensure very weak consistency across function storages making it a pretty bad candidate. What this also means is that there is no way we can actually have efficient parallelism even if we have many powerful cores installed over the current state of FaaS since the block storage will always be a bottleneck.

It goes without saying that most big data applications that need ephermeral storages between function executions suffers from the very similar kind of latencies as well. This includes function compositions like ETL on streaming and batch data alike.

CITE[onestepforward]

Vendor lock-in It is no secret that the most widely used FaaS/serverless offerings are the ones by proprietary cloud providers where they hand twist the developers into complying to their programming environment and runtime thereby forcing devs to use their technologies. What such practices contribute to is limited innovations and development around the paradigm of Function as a service itself and people re-inventing the wheel by creating custom made code and hack to fit each of these provider runtime.

In a system like FaaS, where you are basically out-sourcing the whole setup of your application to a vendor, the fact that the whole ecosystem is closed source and uses the tools developed by the vendor only means that the user has near to zero control over the infrastructure and the pipeline is not transparent at all for any kind of performance optimization or fine tuning.

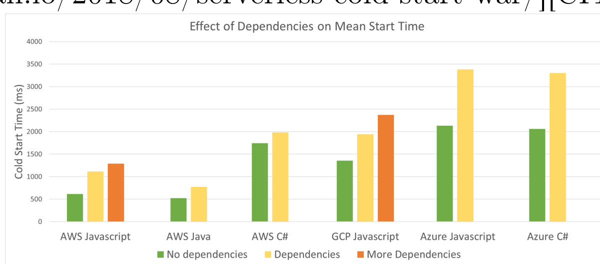
Fixed timeouts This is the one of the other bigger reasons that hinder the usage of FaaS in big data applications. In applications that involve heavy number crunching algorithms, there are chances that often the function needs to run for a longer period of time. Current commercial FaaS offerings has a fixed timeout, exceeding which the function execution is automatically terminated irrespective of the stage of the execution. The fact that the platform offer little to no control over this discourages the developers to use the tool.

Currently the maximum timeout for function execution in AWS and GCP platforms for the FaaS setups are 15 minutes and for Azure functions it is 10 minutes. These are all extremely bounding as conditions especially for functions that are composed and a function should wait for the other functions to finish executing.

Cold Start Cold start it the delay that the function incurs after the invocation or triggering of the function till the execution of the function. In the background, FaaS uses containers to encapsulate and execute the functions. When an user invokes a function, FaaS keeps the container running for a certain time period after the execution of the function (warm) and if another request comes in before the shutdown, the request is served instantaneously. Cold start is about the time it takes to bring up a new container instance when there are no warm containers available for the request CITE{Blog}. In most platforms serverless latency on average is measure to as 1-3 second CITE{BLOG}, which can have very dramatic impacts when it comes to certain workloads. According a 2018 survey, this is the third biggest concern developers have regarding the serverless platform CITE{BLog}.

The cold start time in-fact is overblown by several factors in the infrastructure. All the popular commercial FaaS offerings suffer from a cold start time. It can referred that irrespective of the language runtime used, the start time tend to be almost the same on a platform. The main deciding factor is the dependencies that were packaged for the application which obviously makes the container slower to start because of the heaviness. Figure 3 shows the cold start time differences across different commercial cloud providers under different runtime and different dependencies.

Figure 3: Figure 3: Cold start across cloud providers [[https://mikhail.io/2018/08/serverless-cold-start-war/][CITE]]



A solution for this problem, other than keeping the dependencies small, is to have a warm function up at all times so it can handle the request right away for time sensitive applications. The problem here though is that most commercial offerings do not offer this option. Instead the developers are forced to keep pinging the function to keep it warm for the next trigger. This is a very hacky solution and reduces the whole efficiency of the platform in general. Most of the cloud providers are although aware of this problem and are trying to be innovative and introduce lighter alternatives to Linux containers in the FaaS platform these days.

Security issues in a multi-tenant environment Like was previously mentioned, the whole FaaS infrastructure offering is economical for the cloud provider because they get to share their node pool among all their standard customers making the resource cost for them very low. The problem with this practice though is that this introduces safety issues for the data that is executed in the machines. Linux containers are not particularly secure as an isolation mechanism since they share a Kernel with the host operating system. This means that any bug or back door introduced to the Kernel get affected to all the containers as well exposing the customer data at a very high risk. This is an issue that is actively being worked on by companies. Till a while ago, the solution for this was to encapsulate the containers in a light weight VM which unfortunately contributed to the heavy cold start time. But recently the innovative new alternatives for Linux containers are also aimed at to fix these issues.

Function caches Along with the above mentioned issue with multi-tenancy across customers, a similar issue can occur under the same customer who runs an application across multiple of their client. The problem is that each function has an inaccessible cache that get cleaned up at an arbitrary time hidden from the user. There is a chance that somehow cache from the previous execution of the function somehow lingered and the data from one client got leaked on to another or got corrupted by the other. If the developers are not cautious enough while coding and usage of variables, there is a high chance for data corruption and leakage on the platform.

2.3 Stream Processing/ETLs

2.4 Problem statement

From the above set of evaluations, there is no doubt that Serverless is the way of the future infrastructure maintenance and deployment. Even with the current state of art FaaS offerings, 21% of the entire workload is Data processing applications that include heavy batch and streaming Extract, Transform and Load operations CITE{SURVEY}. Having said that, the implementation usually involves numerous hacks in this setup, even after which the latency of the I/O, network and the platform itself slows from leveraging the full potential of the idea. All the existing commercial offerings being closed source and vendor locked in, implies that the limitations are set for you by the cloud provider and is often very difficult to fiddle with it or to extend the system so as to support an extra runtime, increase the running time, etc. Along with this, the way current FaaS offerings deal with function compositions and parallelism are extremely clumsy and almost always explicit. While this lets the providers have a very generic way of dealing with the platform and holds to the one way to code them all paradigm, the gateways often tend to be a bottleneck. Also the data transfer between functions always depend on a storage based off of Block IO which contribute to the latency immensely.

The focus of the thesis is mostly to propose a solution for the aforementioned issues. We are proposing a Open Source infrastructure, infrastructure that can be maintained by the companies which can offer a multi-tenant and completely elastic platform to deploy their data intensive and high throughput applications on. By nature, these data intensive applications can be a composition of multiple functions, that would pass along data between them. The setup would user ephemeral in memory storage to keep intermediate data. This infrastructure would comply perfectly with the notion of Serverless in the sense that, each element in the system would be independently elastic and scalable. Function composition based on conditionals and branching should be supported by the system along with independent scaling of the functions based on the load, so there wouldn't be any bottlenecks. An easily adaptable programmable API is required for defining this composition.

According to the aforementioned survey, the developer community is concerned about the monitoring and debugging of the functions during the development stage due to the lack of reproducability of the runtime. Our system should give a lot more flexibility and traceability when it comes to the development process. Along with that, we should aim at building a system that is easily adaptable and stable enough for production workloads, and easily integratable with the common development tools like Github, CI/CD pipelines etc.

3 Related work

Serverless has gained a lot of attention and traction from the scientific community in the past few years because of its massive implications in resource conservation and innovative programming when one doesn't have to worry about compute management anymore. The issues that were discussed in sessions above are being studied by various studies and the most significant ones are worth noting.

In a very recent Literature review CITE{PAPER}, 112 different academic papers and grey journals in and around the paradigm of FaaS were analyzed. The researchers found a staggering lack in the practicability of the work that were proposed by the scientific community. Along with the lack of reusability and reproducability, it was found that 88% of these proposals were worked in and around AWS lambda, which is not very universal as FaaS solution especially considering its vendor locked in and closed source attributes. The study also mentions how most of these works being done focus on unrealistic workloads that are not very common in the production setups in the industry. The paper also says how the current research lacks methods to chain and branch functions in a meaningful way.

In CITE{PAPER}, the authors interestingly look at the issues that the state of art isolation mechanisms in FaaS infrastructure bring forward as was mentioned earlier. These include the lack of security and the heavy cold start time. It introduces faaslets, an alternate isolation policy to be used instead of containers. With this, faaslets can share data across instances there by reducing data transfer costs. In a contemporary study CITE{PAPER}, an orchestration mechanism called TriggerFlow is introduced. It is a really interesting tool to manage the lifecycle of a cloud function. In this smart triggering system, function composition is allowed using Distributed Acyclic Graphs(DAG) to define control flow and data flow in the pipeline. This has huge potential as an idea, although currently the usability of the platform is terrible and it can be quite bloated as a entry point to a FaaS system especially since it is not a very elastic platform.

Serverless in the wild: characterizing and optimising the serverless workload at a large cloud provider Published date: 6 Jun 2020

Here a way to reduce the cost of warm starts(practice of just keeping the resources idle to avoid cold start time) We depend on a learned histogram that charts the idle time of each application. For better results we can switch to ARIMA model. Use cases on both azure & openwhisk

FaaSdom: A Benchmark Suite For Serverless Computing Published date: 5 Jun 2020

It is a docker based platform that implements wrk2 This would be a really great tool to benchmark cross platform. Code

Towards Fine-Grained Billing For Cloud Networking Published: 24 Mar 2020

This is suggesting methods for the cloud provider to offer a fine grained billing by better usage of vswitched, network colocation, etc. This is an interesting read but beyond the scope of my research.

Firecracker: lightweight virtualization for serverless applications Published date: 25 Feb 2020

This is the isolation solution used by AWS based on KVM Although from the security pov firecracker is great, from the performance pov it is comparable to containers.

INFINICACHE: Exploiting Ephemeral Serverless Functionsto Build a Cost-Effective Memory Cache Published date: 20 Feb 2020

This is an in memory object cache. Super interesting. It uses erasure coding and data backup to ensure high availability. They implement it with AWS lambda. Lambda runtime is connected to a priority based queue. Could be useful to think of something like this for streaming data.

Cloudburst: stateful functions-as-a-service Published date: 14 Jan 2020

bring data to caches next to function runtimes a highly-scalable key-value store for persistent state, local caches co-located with function execution environments, and cache-consistency protocols to preserve developer sanity while data is moved in and out of those caches. It uses a DAGs for chaining functions. This is not yet wire speed though. The isolation is very weak, and it has a long way to come to be applied in production.

Serverless Computing: A Survey Of Opportunities, Challenges and Applications Published date: 23 Dec 2019

Doesn't introduce anything new. Issues like, function invocation latency, storage, state, security, are all mentioned. They suggest the use of a distributed queue for function composition. I could use inifinicache this way.

Understanding Open Source Serverless Platforms:Design Considerations and Performance Published Date: 13 Dec 2019

This compares openfaas kubeless knative The CPU usage is almost comparable in all the platform OpenFaas is said to have the most flexible architecture

Formalizing Event-Driven Behavior of ServerlessApplications Published on: 8 Dec 2019

Provides a detailed operational semantics for FaaS. It includes, object stores, key values etc. Could be useful to conceptualize control flows.

Narrowing the Gap Between Serverless and its State withStorage Functions Published date: 20 Nov 2019

Shredder is super interesting because it implements the function shipping approach. It uses v8 isolates to implement the sandboxes

Formal foundations of serverless computing Published date: 20 Nov 2019

Problems with misusing states in serverless a persistent store with transaction support necessary to manage shared state Introduces an operational semantics lambda SPL, a serverless composition language Function composition is being well done by this.

Caching Techniques to Improve Latency inServerless Architectures (Published date: 17-Nov-2019

Vaguely mentions an in memory cache for aws lambda

In Search of a Fast and Efficient Serverless DAG Engine Published date: 14 Oct 2019

They introduce a system to do scheduling of jobs specified as DAGs. I think the memory footprint of this implementation is quite heavy. Trigger flow is an improvement.

SERVERMIX: TRADEOFFS AND CHALLENGES OF SERVERLESS DATA ANALYTICS Published date: 26 Jul 2019

A big date serverless piece. A lot of it sounded like mission statements.

Fog Function: Serverless Fog Computing for DataIntensive IoT Services Date: 18 Jul 2019

Out of scope. For edge devices.

Cloud Programming Simplified: A Berkeley View onServerless Computing Date: 10 Feb 2019

Mentions a lot of issues like need for ephemeral storage, coordination, security, hardware heterogeneity, etc.

A framework and a performance assessment for serverless MapReduce on AWS Lambda Date: 02 Feb 2019

This is a very practical paper. I used this to implement my first version of mapreduce on OpenFaaS. Code is on my github

Serverless Computing: One Step Forward, Two Steps Back Date: Jan 2019

A great read, I got the idea of function composition from this. Shows weak parallelism and hence distributed computing is terrible. Recommends a function shipping architecture.

Serverless architecture efficiency: an exploratory study Published date: 13 Jan 2019

Doesn't offer much. Weakly implements a serverless version of spark. Concludes that the lambda implementation is suboptimal after benchmarking. Costless: Optimizing Cost of Serverless Computing through Function Fusion and Placement (23 Nov 2018)

Pocket: Elastic Ephemeral Storage for Serverless Analytics Date: Oct 2018

This is a key value based storage specifically designed for serverless application. Implements dynamic block allocation based on kubernetes hueritics Project is not super active but I could deploy it and try it out

Anna: A KVS For Any Scale Published date: 8 Sep 2018

Another brilliant key value store that scales as well. It is distributed in nature and has local caches for better data locality. It is the basis for cloudburst

SAND: Towards High-Performance Serverless Computing Published Date: 11 July 2018

This is a similar idea to cloudburst and Faasm. A different sandboxing, function composition internally using a hierarchical message bus

First International Workshop on Serverless Computing(WoSC) 2017 Report from workshop and panel on the Status of Serverless Computing and Function-as-a-Service(FaaS) in Industry and Research Published in 2017

It is a bit outdated but defined a lot about what is serverless and if it is good for longer running processes, is state okay, etc.

Serverless Computing: Current Trends and Open Problems Published Date: 10 Jun 2017

This is a more practical approach on serverless and its issues. Talks about problems with deployment and the devops tools. It is yet again a bit outdated.

Consistency analysis in Bloom: a CALM and collected approach Published Date: 9 Jan 2011

This is a distributed programming model with interesting state sharing ideas. This was mentioned in a paper as a potential alternative to the programming model for serverless since the traditional methods or way of thinking might not work for FaaS.

4 Proposed Solution

4.1 Introducing autoscaling ephermeral storage to ETLs.

4.1.1 Describe pocket and the way it works.

4.2 Function composition to pass and retrieve the data in the middle stages

4.2.1 DAGs, branching and jumping

4.3 Multitenancy support by namespaces

4.4 Tracking the usage fine grained and billing data accordingly

5 Implementation

5.1 Architecture

5.2 Tools

5.2.1 OpenFaaS

5.2.2 Pocket

5.2.3 Kubernetes

5.2.4 FaaS-flow

5.2.5 Prometheus

6 Evaluation

7 Future work

8 Conclusion

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