Lappeenranta University of Technology
School of Business and Management
Degree Program in Computer Science

Master's Thesis

Trung Hieu Tran

DEVELOPING WEB SERVICES WITH SERVERLESS ARCHITECTURE

Examiners: Prof. Ajantha Dahanayake
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ABSTRACT

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Service-oriented architecture (SOA) and distributed systems have become popular solution to solve gaps between business needs and Information Technology services. Having widely adopted as crucial practice of SOA, web services enable communication between software components or applications over the internet. In this thesis, the author presents an innovative approach to build web services without concerns about server provision. The approach is design artefact outputted from the design science process, which consists of serverless architecture and a practice to implement into web services project. In order to prove the concept, the serverless architecture and proposed practice are employed to develop a prototype web service application. Furthermore, the thesis evaluates performance of the prototype application, in which five test scenarios are setup to examine the application's behaviors in various load conditions.

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LIST OF SYMBOLS AND ABBREVIATIONS

API(s)	Application Programming Interface(s)
AWS	Amazon Web Services
CPU	Central Processing Unit
CRUD	Create, Read, Update, Delete
FaaS	Function as a Service
HTTP	Hypertext Transfer Protocol
I/O	Input/Output
IT	Information Technology
REST	Representational State Transfer
S3	Amazon Simple Storage Service
SOA	Service-Oriented Architecture
SNS	Amazon Simple Notification Service

1 INTRODUCTION

1.1 Emergence of serverless architecture

Service-oriented architecture (SOA) has become mainstream and prime discipline to address the gap between business services and Information Technology (IT) services [1]. Over the last decades, SOA and distributed systems are developed by enterprises to serve various business domains, from letter mail, logistics to finance and banking services [2]. The fundamental of SOA is to release independent and self-describing software components which are universally available and accessible over a network via standard communication protocols [3]. As a major implementation, web services technology has adopted this concept in building modern web applications [4] [5].

For years, web applications have been developed based on a three-tier architecture that views an application as three independent layers, namely presentation, business logic, and data [6]. Basically, the architecture defines the separation of concerns among frontend (the display of data and interaction with users), data sources (the persistent storage of application's data), and backend (the mediates between frontend and data sources that handles business logic) [6] [7]. The decoupling concept allows developers to implement significant changes in a layer without influencing the other tiers, and hence of easily maintainable software. Meanwhile, from the perspective of SOA design, business logic and data layers can be implemented as web services, enabling communication via standard internet-based protocols [5]. Recently, web services publish APIs (Application Programming Interfaces) to instruct their consumers how to establish connection and exchange data [8]. The popular implementations of web services access are SOAP (Simple Object Access Protocol) [1] and REST (Representational State Transfer) [9].

A web service is deployed and served by web server, which is a software running on physical or virtual machine [10] [11]. The web server provides data transportation through HTTP (Hypertext Transfer Protocol) that listens and returns HTTP requests and responses, respectively [8]. As being hosted on a physical or virtual machine, there are requirements for configuration and maintenance works. Development team must study and decide specifications for the machine (such as processor speed, memory, and storage spaces) to obtain an adequate resource for server to run the web service. If server is built in-house, the

process would include procurement of hardware components and software licenses, as well as time and team's effort to setup. Additionally, such web server needs regular maintenance that requires human resources, for example monitoring to check errors, executing rational plans to address incidents (server is occasionally overloaded or crashed), and upgrading the system (both software and hardware components) [12]. On the other hand, web services can be deployed on computing platform, in which cloud vendors provide necessary infrastructures and computational resources to host and run applications [11] [13]. Having employed this approach, the team discards concerns about hardware components, however, the works of server and operating system configuration, monitoring and maintenance are still persistent and require human efforts [11].

Recently, cloud vendors (such as Amazon [14], Google [15], IBM [16]) have introduced serverless computing services, also known as *Function-as-a-Service* (FaaS) [17]. For instance, the computing services developed by Amazon, namely AWS (Amazon Web Services) Lambda, provides an ephemeral function's container for executing application's code [18]. The container is a fully configured environment that is compatible with running such source code. Therefore, the team can concentrate on writing back-end code for business logic and deploying to such platforms without concerning the complexity of building and maintaining infrastructure. Moreover, and more especially, function code is invoked on request, leading to remove traditional "always on" server system running behind the application [19]. This idea contributes to an emerging approach to develop web services, namely serverless architecture, in which web services are built, deployed and distributed on cloud environment with zero provisioned server [17].

To clarify, serverless architecture carries a disclaimer; despite its name, the approach does not declare the involvement of servers. In fact, there are servers that are setup and managed by cloud service vendors. The term *"serverless"* is used from the perspective of development teams, in which they do not purchase, rent, maintain either servers or virtual machines to run application's code. Instead, they are charged for actual computing resources consumed to execute the code. To put it differently, there is no cost if the code is not running. Thus, to some degree and in some circumstances, the approach of serverless architecture helps reduce operational costs in comparison with the traditional solution of constantly keeping a running server.

1.2 Research motivation

In mid-November 2014, Amazon introduced Lambda function on their Amazon Web Services (AWS) - an event-driven and computing platform [14]. The platform allows code to be executed in response to events without provision of servers or compute resources. Together with the launch of API (Application Programming Interface) Gateway, AWS Lambda has led to the concept of serverless architecture. Since last two years, serverless has become a rising topic in the world of software architectures. Yet, the community has witnessed its emergence with several open-source frameworks [20] and dedicated conferences [21].

Meanwhile, Amazon API Gateway provides a fully-managed cloud-based environment for building, releasing and maintaining APIs [18]. To be specific, it acts as entrance for applications to connect with business logics, functionalities or retrieve data from other AWS services. Code running on AWS Lambda can be certainly invoked by sending requests to API Gateway, enabling possibility to develop a complete web service. Therefore, AWS has provided adequate infrastructure to create web services without any concerns about servers (physical or virtual) configuration and monitors.

In addition to Amazon, several vendor products are introduced to support development of serverless applications. Among them, IBM and Google are big names showing their interests in this area. Similarly, Bluemix OpenWhisk has announced by IBM in the early 2016, offering an alternative for serverless computing platform [16]. On the one hand, as an answer to AWS Lambda, Google supplemented their Cloud Platform by launching Cloud Functions product [15]. As such, the serverless concept has gradually been in spotlight, in which there are diverse options for development platform offered by prestigious providers.

Moreover, in the software companies, there is a need for web services in which can be developed rapidly, highly scalable, and require insignificant maintenance effort. Since the announcement of AWS Lambda and API Gateway, the idea of employing them had been of utmost interest. However, a raising question has been how to implement efficiently and organize versioning of source code in the context of continuous integration and deployment.

In addition, having reviewed some of the literature about software architectures, specifically in web applications and services, it is worth mentioning that there is a lack of reports and research about practice of emerging serverless architecture. Yet, the author searches for research paper relating to keywords of web services architecture, cloud services, serverless architecture, and serverless application. The below table illustrates and compares the results found in different scientific databases [22], in which the number of articles concerning serverless architecture is minor. Therefore, it encourages the author to conduct a study to find a possible practice to adopt serverless architecture into developing web services.

Table 1. Search results of scientific papers based on keywords [22]

Keywords	**Science Direct**	**IEEE Explorer**	**Emerald**	**Springer**
Web services	28532 results	20750 results	17712 articles 360 case studies	28114 results
Web services architecture	13757 results	5639 results	5914 articles 52 case studies	52849 results
Cloud services	12091 results	20581 results	5066 articles 75 case studies	57098 results
Serverless architecture	35 results	8 results	2 articles	77 results
Serverless application	43 results	14 results	3 articles	118 results

1.3 Thesis structure

The thesis begins with introduction in Chapter 1, briefly telling the emergence of serverless architecture, motivation of this research, and this thesis structure. In Chapter 2, the author presents the research methodology, including research approach, research questions, objectives, as well as advantages and disadvantages of the study. Following the research design of this thesis, Chapter 3 covers the literature review part. The chapter reviews web services concept and performance testing methods for web services. Afterwards, in Chapter 4, the author provides readers with an insight into the serverless architecture and its development practice. They are also discussed in regard to the adoption of serverless architecture into building web services on a specific cloud provider - Amazon Web Services. Chapter 5 consists of discussion and explanation about detailed implementation of a

prototype web application, which is a proof-of-concept of the serverless architecture. Continuing with Chapter 6, the author conducts performance testing activities to evaluate the prototype application developed in previous chapter. They consist of different test scenarios that have distinct configurations to diversely examine the application's behaviors. Finally, Chapter 8 appears to make summary for the whole thesis. It concerns answers of the research questions arising in beginning of the research and discussion about findings. In addition, limitations of this study as well as further work possibilities are also mentioned.

2 RESEARCH METHODOLOGY

2.1 Research questions and expected outcomes

The research attempts to address problems of software company, expecting rapid development of web services with less concerns about maintaining works. As such, the research is mainly to experiment and design a possible practice to adopt the serverless architecture. The solution includes technical implementation fitting the practices of continuous development, efficient workflow, and deployment process. The newly generated solution can be applied in real-world software projects, where its efficiency and effect can be verified. There are two major research questions (RQ) that are targeted to answer:

- *RQ1: What are main components of serverless architecture?*
- *RQ2: What is the development practice of serverless architecture?*

The expected deliverables of this research are an artifact, the design of serverless architecture implementation, and a test to prove its feasibility. The build of artifact design is two-fold, which is based on working experience and background knowledge extracted from different scientific works. Such scientific works are obtained by doing literature review of relevant topics, including software architecture, web services, and available development processes, tools and techniques. The proof-of-concept of serverless implementation is delivered by a construction of rough prototype that implements the serverless architecture. Development practices in the context of continuous integration with involvement of multiple developers are put into consideration. The prototype is also benchmarked to check whether its performance is acceptable. This research will use the design science framework to validate the artifact [23].

2.2 Phases of research

March and Smith [24] indicated that outputs of design science are innovative and valuable constructs, models, methods and implementations. Those artifacts result from two basic activities of building and evaluation. Accordingly, this research targets at producing an artifact which is an implementation (a possible practice to develop application with serverless architecture). To fulfill the above, the research can consist of phases and activities which are presented in the following figure. To be noted, the time frame is estimated and subject to change.

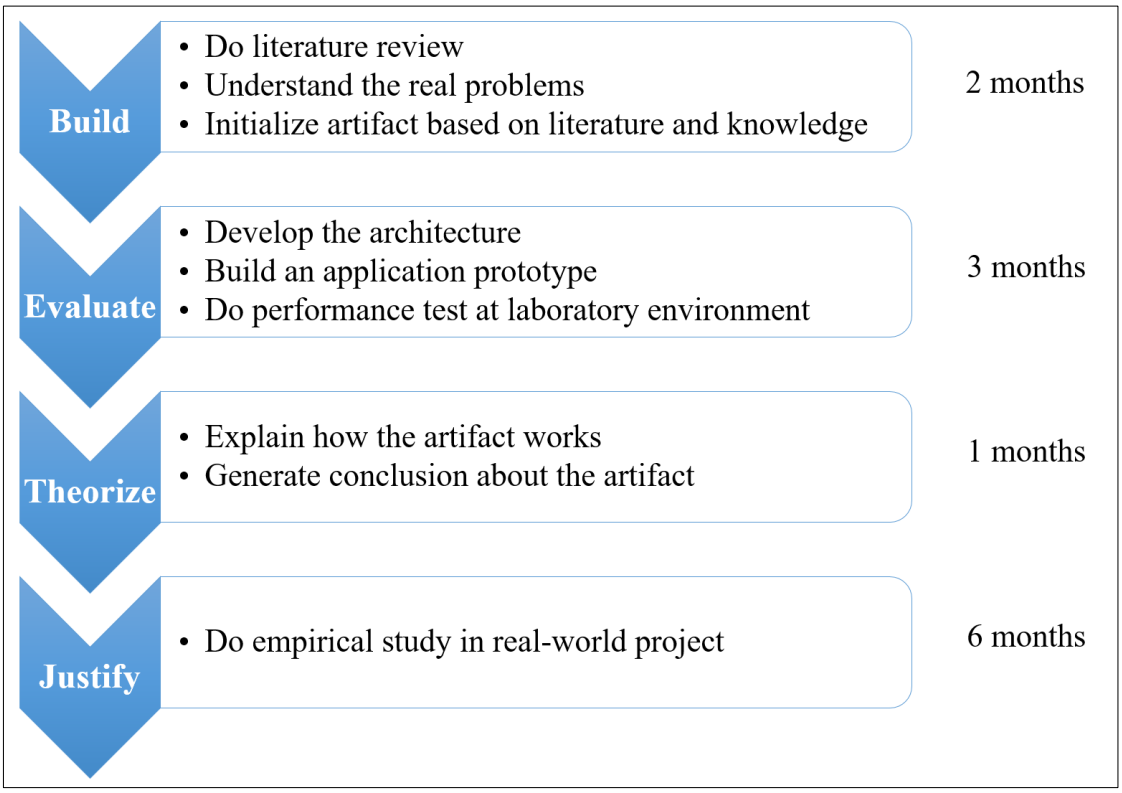

Figure 1. Phases of research and timeline

Design science's activities are twofold, consisting of two factors: build and evaluate. The build phase refers to artifact's creation to solve real problems. Within this phase, literature review is conducted to study the possibility of adopting serverless architecture. Consequently, a solution is generated and addresses the following problems:

- Components of a serverless application
- Development process and workflow
- Deployment practice in the context of continuous development

In the evaluate activity, an application prototype is developed to prove the feasibility of serverless architecture. The application is benchmarked against selected criteria to test its performance in laboratory environment. At the third phase, output of the artifact will be comprehensively discussed to theorize an approach of serverless architecture into developing web services. Finally, within the last phase of justifying, an empirical study will be conducted to examine the research output in real-world application development.

2.3 Advantages and disadvantages

The research concerns cloud computation, where majority of development activities, application deployment, and evaluation are conducted. There are several applicable cloud computing vendors on the market as listed in the introduction chapter. Among them, Amazon is the provider of choice for three main reasons. First, this research is conducted with working experience in the AWS cloud environment that helps boosting up the research progress. Second, Amazon is the pioneer of providing necessary services for building serverless applications, and hence of adequate experiences in troubleshooting and support. Finally, Amazon offers a free tier program to access AWS cloud products at reasonable cost, fitting purpose of experiment and budget.

In addition, the implementation is mainly done using Node.js and JavaScript programming language, which is applicable to the model of event-driven and non-blocking I/O. As such, the research is limited to this programming language and its relating technologies. The research does not put database design into consideration so that database technologies are not mentioned. Also, the information security is excluded from the study. As the implementation is done on the AWS, the author delegates this duty to the provider. In fact, Amazon's highest priority is to build security-sensitive data center and network architecture for customers [25]. Thus, the implementation can be conducted with confidence in a secure cloud environment.

2.4 Summary

To sum up, the advantages and limitations that this research suffers from can be listed as following:

Advantages

- Hands-on experiences in Amazon Web Services (AWS)
- Choice of the pioneering provider with rich capability of support
- Highest priority of the provider on security
- Reasonable cost that fitting the research's budget

Disadvantages

- Only AWS and their services are concerned, leading to the falsifiability of result in other providers
- Implementation language and technologies
- No database designs

3 LITERATURE REVIEW OF WEB SERVICES

3.1 Terminology and origin

Web service is widely admitted as a crucial practice of service-oriented architectures, enabling communications between software components or business applications over the internet [5] [26]. As different software or applications are implemented with different programming languages, hardware and platform, specifications of a web service are totally independent of them to provide a standard and universal method of data exchange [26]. In other words, the fundamental is that no knowledge of consumers is required to develop a web service, and vice versa. This also facilitates easy and quick integration of existing software solutions and development of distributed applications [5]. In addition, Fensel et al. [26] indicated the six basic principles that describe the common definitions and characteristics of web service, which is briefly illustrated in the following table.

Table 2. Basic principles of web service [26]

Loose coupling	Service is stateless, accessible, not tightly coupled to consumers and to its logic and implementation.
Contracted	Contract represents a service, defining its inputs, outputs, access policies, quality requirements, and error-handling procedures.
Discoverable	Service is discoverable at execution time.
Addressable	Service is uniquely identifiable in a network.
Distributed	As being separated by geographic and machine boundaries, service is capable for addressing loss of communication.
Point-to-point	A consumer uses only one producer at any point in time.

To some extent, web service can be viewed as a middleware solution, in which it defines the communication protocols and digital rules for exchanging data messages [26]. In the history of computer science, the attempts to create universal standards for development of distributed applications resulted into middleware solutions. They act as an abstraction layer, serving as interface for the actual communications and data exchanges between application's components [27]. Remote Procedure Calls (RPC), introduced and widely used in the early

1980s, was recognized as the very first middleware solution to remotely invoke procedures in a distributed system. The RPC technology acts as a layer covering implementation details from developers to provide a mechanism, which is decoupled from platform and programming language, to execute distributed procedure calls [28]. After years of advancement, different middleware techniques and architectures were introduced, such as extensions of RPC - remote method invocation or message-oriented middleware [29], and CORBA architecture [30]. Notwithstanding that, they failed to achieve the expected goal of an effective and simple communication gateway, and hence of limited use. Therefore, web service technologies were born to solve such problem, in which their emergence has solved existing problems, showing many pros over the predecessors, and being widely adopted for a long-term success [26].

To sum up, the W3C[1] agreed on a general working definition of a web service as following: *"A Web service is a software application identified by a URI[2], whose interfaces and bindings are capable of being defined, described, and discovered as XML artifacts. A Web service supports direct interactions with other software agents using XML-based messages exchanged via Internet-based protocols."* [5]

3.2 Model of web services

As discussed in the above section, basically, web services enable remote access to functions via the internet by utilizing a set of standards. The key methodology is to provide developers a mean of data communication and exchange which is free from the concerns towards programming language and operating system. Within this section, the conceptual architecture and development lifecycle of a web service will be discussed.

3.2.1 Conceptual architecture

Kreger [8] indicated three roles in a web service, namely service provider, service requester and service registry. First, service provider is considered as the owner of a web service, hosting access to that web service and making it available on the internet. The provider listens for requests, processes them, and provides data to send back. On the other hand, service requester is used to identify consumers of a web service. They may be a web browser driven by an individual or other available web services. Such consumers produce different

[1] World Wide Web Consortium: an international community that works to define web standards
[2] Uniform Resource Identifier (URI): a string of characters to identify a resource

interactions with the web service based on their needs, for instance asking for data by sending requests to the provider. Third, service registry is a logically centralized storage of all service descriptions where existing services can be found and newly implemented ones are added. The following figure depicts this fundamental architecture of web services, from which three major building blocks based on these roles can be discovered.

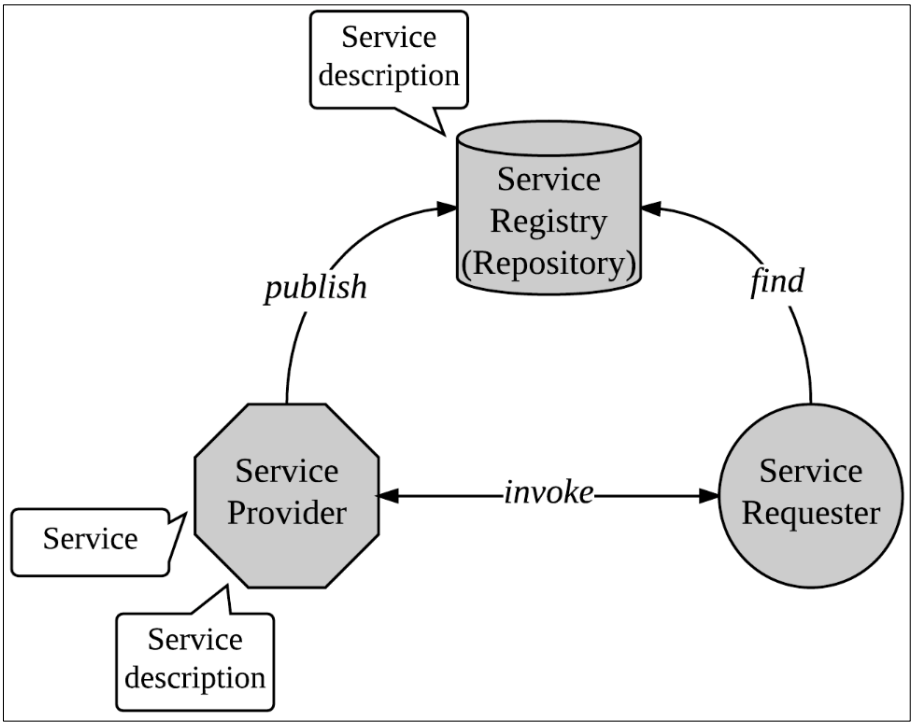

Figure 2. Web services architecture [8] [26]

Service and service description are two artifacts, in which a service is a software module deployed on platform of service provider. The module is accessible so that it can be invoked by a service requester. In many cases, a service can be implemented as a requester that interacts with other web services. Meanwhile, service description is published to service provider, service registry or both, containing comprehensive information about service's interface and implementation. The information consists of data types, operations, invocation instructions, service's location on network, and possibly necessary meta-data to facilitate utilization by its consumers. [8].

Correspondingly, there are three operations of "publish", "find" and "invoke". A service must be published together with its description so that service requester knows how to find it [26]. Depending on requirements and design, the service is published on either production

or development environment, and publishing plan is also included. The “find” operation discusses discovery of the service from service requester’s perspectives, in which details about service descriptions and how to use them are acquired. Eventually, a service needs to be invoked by the requester, and this refers to the “invoke” operation. By utilizing the “find” operations, the service requester can find the service’s location and establish interactions. [8].

3.2.2 Development lifecycle

Kreger [8] suggested a general 4-phase development lifecycle of a web service. In the lifecycle, the first phase is build, in which team organizes all development activities to build web service’s artifacts. Those activities consist of planning, analysis, design, implementation and testing. Development team works towards the goal of releasing workable and tested service to satisfy business requirements. To do so, various issues are put into consideration together with implementation and testing, such as determination of project goals, procedures and feasibility, analyzing business needs to discover requirements and expectations, as well as service specification and design. [1].

The second phase, deploy, refers to publication of the web service to make it to consumers. Deployment can be categorized into steps of service interface publishing, web service deploying, building and publishing service implementation definition [31]. Within these steps, service provider deploys run-time code and relevant metadata to enable web service and its accessibility for service requesters to use. Details of the service, including location, version and implementation’s instructions, are also provided. In addition, plan, procedure, and settings of execution environment are also put into consideration within this phase.

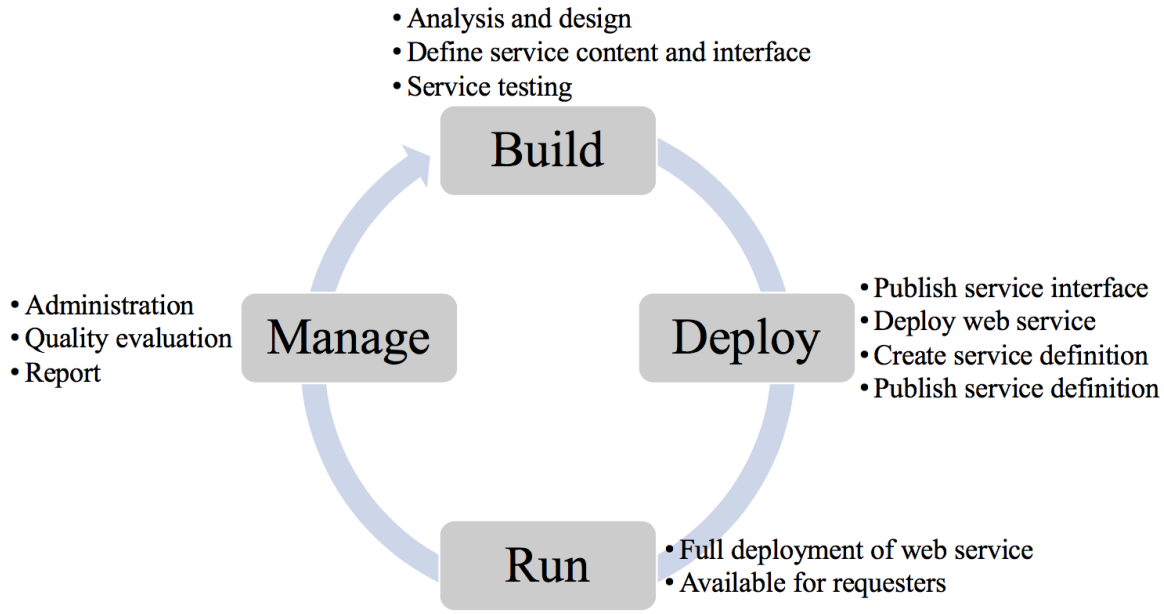

Figure 3. Development lifecycle of web services [8] [31]

Third, in the run phase, the web service is completely deployed and available over the network to use. Service requestor can perform the "find" and "invoke" operations [8]. Finally, once the service is operational, it comes to the manage phase which contains administration, maintenance and evaluation of the web service application. The purpose is to monitor its performance within the operational environment to determine whether the business processes, quality and cost are sufficiently addressed [1]. As such, measurable data are collected and different metrics are extracted from them to assess the service correspondingly to specific needs. For instance, information about service response time, up and down times or throughput can be recorded [1].

3.3 Access to web services: SOAP and REST

SOAP (Simple Object Access Protocol) and REST (Representational State Transfer) are two implementations used for accessing to web services [1]. Having developed by Microsoft since 1998, SOAP relies on XML-based mechanism to transport structured data between network applications [32]. SOAP messages consist of three elements: envelope, header, and body, and can be transported via a wide range of network protocols, such as HTTP, SMTP or FTP [8] [1]. A mandatory envelope, which is parent element of header and body, defines start and end of a message to let receiver know whether the message is completely received and can be processed. Header is an optional element describing a set of encoding rules for

additional application-defined requirements, for example, a digital signature can be included to tell receivers how to access password-protected web service. Meanwhile, body is required element that contains information about service's calls, responses, and XML data being exchanged [8].

In his doctoral dissertation published in 2000, Fielding introduced REST (Representational State Transfer) as an alternative architectural style to provide interoperability between network applications [33]. REST (or RESTful web services) was born to solve the problems of limited scalability, complexity and performance of existing protocols [34]. It targets at reducing network latency, boosting the independence and scalability of component implementations. An insight into this modern web architecture will be presented in the following sub-chapter as this thesis is mainly concerned with implementing RESTful web service.

3.4 RESTful web services

3.4.1 REST architectural style

The fundamental of REST consists of three main concepts, namely resource, representation and state [35]. A resource can be any information (for instance document, image, temporal service, or collection of other resources) which is located on a computer and represented as bit stream. To distinguish resource in an interaction between components, a resource identifier is employed. Representation contains useful metadata around a resource at any timestamp to help clients in transition within resource's states. Representation is exposed to many-to-one relationship with the resource. Meanwhile, there are two types of state in REST architectural style: resource state and application state. Basically, resource state is information about a resource and handled by server, whereas application state maintained by client refers to information about where it in interaction with server.

REST concentrates on data element, their interpretations and interactions between different application's components instead of implementation details and protocol syntax [35]. In fact, REST ignores them to lose coupling of such components. As such, a guideline set of six architectural constraints is included to promote the scalability, generality of interfaces, and independent

Table 3. Six architectural constraints of REST [33] [35]

Client - Server	Separation of concerns: data storage and interface
Stateless	Server doesn't store client context between requests
Cacheable	Response defined as non- or cacheable to prevent data reuse, increase efficiency
Uniform interface constraints	Increase visibility of interactions and reuse of resources and services • Resource-based (HTML, XML, JSON) • Manipulation of resources (how to modify resource) • Self-descriptive messages (how to process message) • Hypermedia (request and response techniques)
Layered system	Intermediary servers for • Scalability (load balancing, shared caches) • Security policies
Code on demand (optional)	Executable code (applets or scripts) to extend client's functionality

3.4.2 Applying to web services

Embarking the above six architectural constraints, web service APIs are considered as RESTful APIs which also have the following aspects:

- **Base URL**: a short string to identify a resource that associates with a protocol to obtain representation of the resource [9].
- **Media type**: exchanged data are described by media type, in which state transition of data elements are included to instruct clients to prepare requests for next available application states. For instance, a media type can be text/html, which means an HTLM document. Common media types are textual documents (text/html), structured data documents (application/json, application/xml), and images (image/png, image/jpeg). [9] [36]
- **Standard HTTP methods**: client use such methods to instruct server on what to do with data. The most popular ones are GET (retrieve data), POST (save new data), PUT (update existing data), DELETE (remove existing data) and HEAD (identical to GET but without response body) [9].

At basic scope, many RESTful web services equip client applications with CRUD interfaces (create, retrieve, update, delete) to interact with underlying databases. Notwithstanding that, deducing from the architectural style and constraints, REST is not limited to such CRUD services, but also feasible for rich state applications, such as flight and hotel reservation systems, or foreign currency exchange systems [37]. Taken a hotel reservation application as an example, a user makes a booking on the system but has not paid yet, as such the resource state is marked as active and unpaid. Once payment resource is invoked, the service is proceeded to state of processing payment, from which either confirmed or unpaid state will be next, correspondingly to successful or failed payment [38]. In the real world, many various states can be also considered, such as free or conditional cancelation of booking, later payment, and booking change.

3.5 Performance testing

Web services have been widely adopted by companies and enterprises to build web-based applications to support various aspects of social life [4] [39]. In the meantime, development community have paid more attention to the concerns over reliability and accuracy of web services [40]. Performance of web applications are therefore tested to evaluate its capacity for serving consumers. In details, performance testing is done by gathering information regarding to operations of applications, and analyzing those collected data to understand its behaviors and ability to process heavy workloads [41]. The analysis eventually comes to forecast whenever application runs out of resources to handle consumer's requests, and hence of detecting performance issues. Furthermore, the application's efficiency and optimization are also justified. Subsequently, performance testing results are utilized to figure out possible fixes to improve in subsequent releases [40] [42].

The fundamental of performance testing is to simulate end user's requests to a web application and study responses under different user loading conditions. By simulation, test generator defines virtual users, perform repeatedly user's requests to create high traffic flow to the application [41]. There are three types of web performance testing, namely stress testing, load testing, and strength testing, in which they are done by gradually increases system load to web application [40]. Stress or pressure test aims at analyzing current configuration and compatibility between hardware and software at maximum load to figure

out possible system bottlenecks. Loading test targets at determining application's capability by examining maximum load condition that the application can stand. Load test and stress test can be executed in conjunction. In contrast, strength test is performed in considerably longer duration (for hours or days) to investigate inexplicable bugs that are not easily reproduced, such as memory leaks, or database transaction [40]. In the meantime, performance testing involves various metrics and indicators to be expressed in test report as main source to measure performance and evaluate the application. The typical and major metrics are listed in following table.

Table 4. Major metrics of performance testing [40]

Metrics	Measurement units	Description
Response time	time unit (milliseconds)	Waiting time for client to receive server's response after sending a request.
Throughput	requests/second	Number of requests being handled by application in a time unit
Resource utilization	percentage	Usage of resources, such as CPU (central processing unit), memory, network bandwidth

4 INSIGHT INTO SERVERLESS ARCHITECTURE

The fundamental goal of design science research process is to solve problem by creating new knowledge [43]. Solutions are acquired through the understanding of the problem and also based on existing knowledge. They are acquired and captured in the form of viable artefacts [24]. In their published articles, Hevner et al. [23] insisted in the guidelines of design science research that outcome of the process must be purposeful artifact in the form of a construct, model, method or instantiation. In addition, the artifact is problem-specified that addresses a problem domain. Therefore, within this chapter, the author is going to present and explain about the design artefacts in this research.

4.1 Architecture components

Components of serverless architecture are serverless computing platform, API (Application Programming Interface) container, system operation monitoring tool, database and other supplement services. These components are different services provided and maintained by cloud service vendor. Among them, computing platform executes application code to handle business logic, including database access and manipulation. Meanwhile, APIs container is responsible for managing application's REST (Representational State Transfer) API in terms of publishing all API endpoints, controlling access, and monitoring traffic. Monitoring tool (or logging system) collects relevant data and information regarding to application's operation and ensures its availability. Last but not least, depending on business requirements, supplement services, such as e-mailing, location tracking, data storage and analytics, can be integrated into the application.

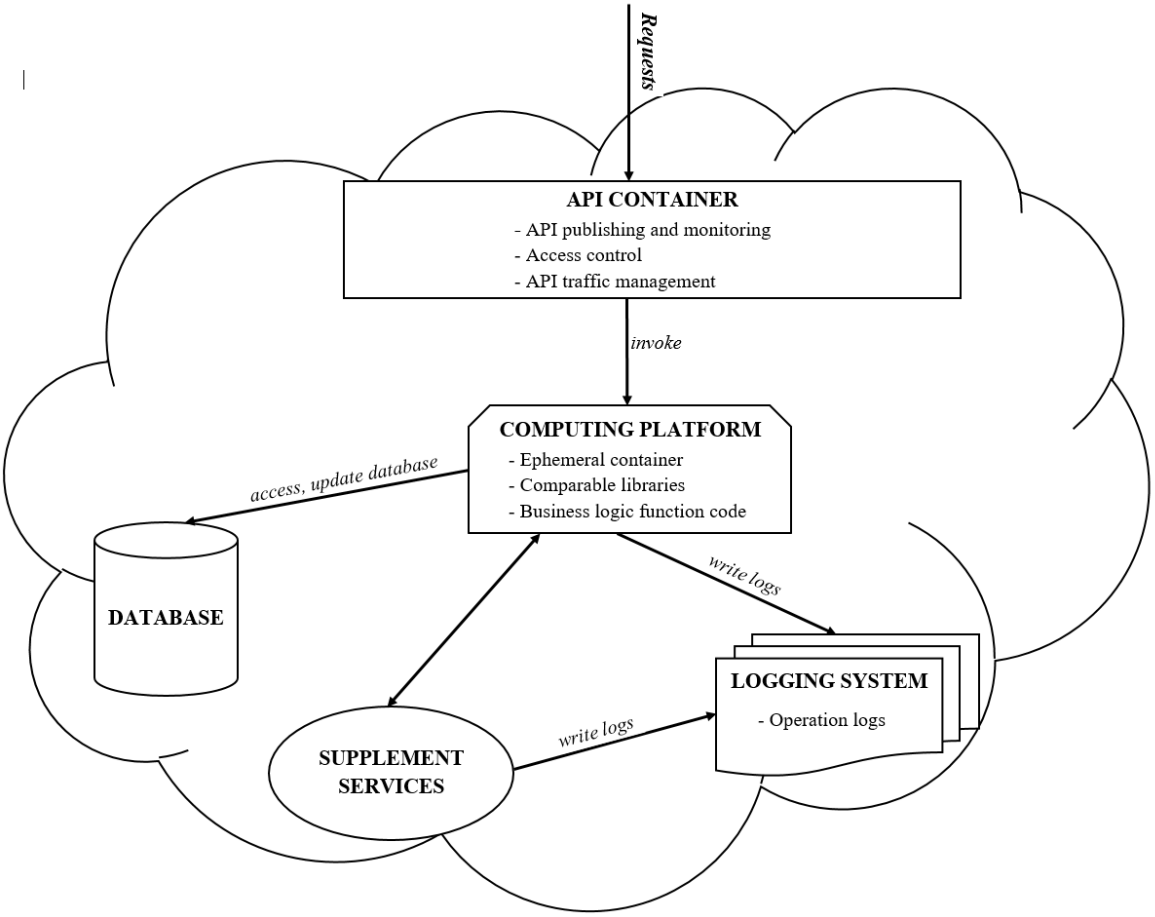

Figure 4. Major components of serverless architecture

The above figure illustrates such major components of the serverless architecture. A request to application is done through API call, which first goes to API container. The container checks whether this call is authorized, and extracts data that being sent in the body or query parameters. Subsequently, corresponding functions in computing platform are invoked to continue processing the request. The functions execute business logic with input data, establish connection with database to retrieve or manipulate data records if necessary, then prepare a response to send back to the requester. In the meantime, detailed information relating to the process are traced and logged into the operation monitoring tool. By such, they are available to be retrieved for investigation in case of incident. Furthermore, monitoring tool should be able to track and store operation data caused by any supplement services being integrated into serverless application.

4.2 Implementation with Amazon Web Services

As mention in chapter one, Amazon is the pioneer providing compatible services as well as infrastructures for implementing serverless architecture. In their AWS cloud environment, the backbone services employed to develop serverless application are AWS Lambda functions and API Gateway. AWS Lambda is serverless computing platform, which serves as an ephemeral container with suitable software dependency to execute functional code without server provision [19]. In other words, developers need to only concentrate on writing and testing code for application's backend services while the whole computing infrastructure is managed by AWS Lambda. Meanwhile, the fully-managed Amazon API Gateway helps developer publish and maintain APIs, acting as front door to call backend service located on AWS Lambda [18]. API Gateway is bundled with management and monitoring tools to version the APIs, authorize access as well as audit the traffic. On the other hand, in terms of database engines, Amazon equips developers with different solutions for both relational (for example PostgreSQL, Oracle, Microsoft SQL Server, or MySQL) and non-relational databases (such as NoSQL) [18]. In cooperation with these backbone services and database services, there are also other AWS services to not only bring more added value to the application but also play key role in managing the its operation. The following figure visually summarizes major AWS services to support serverless architecture and their relations.

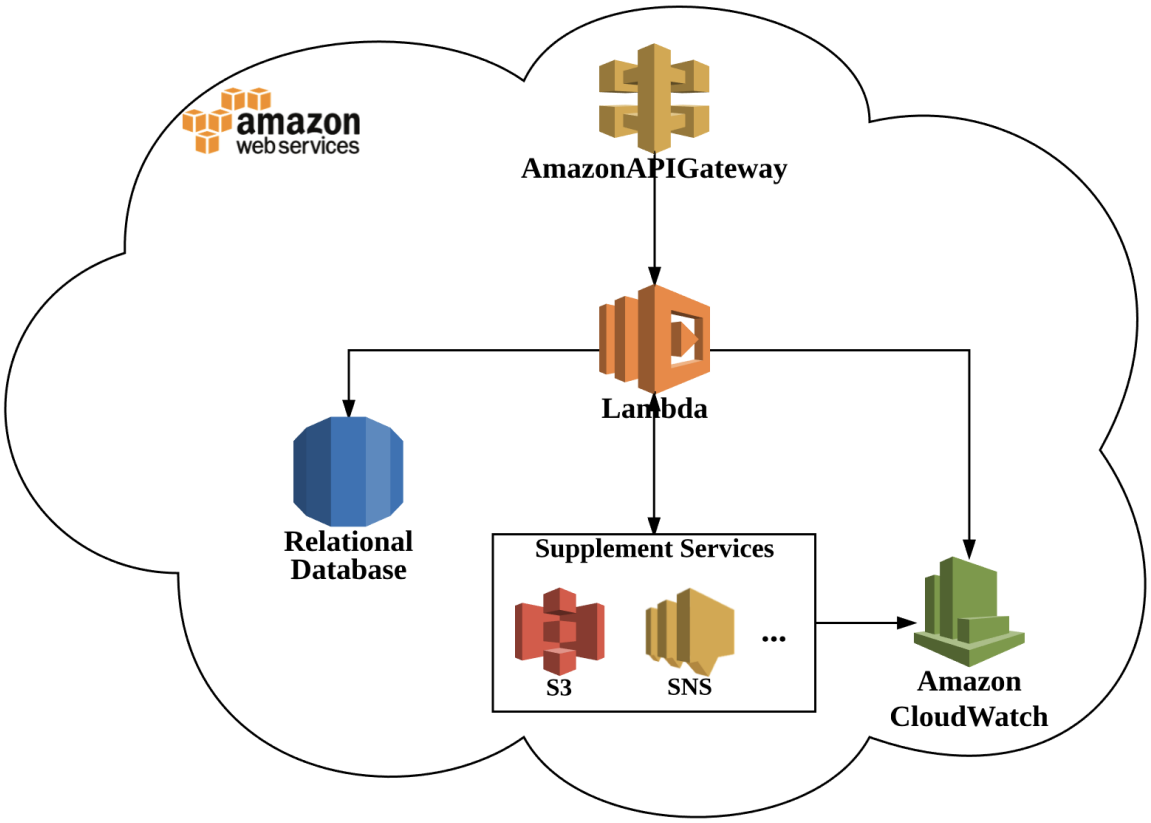

Figure 5. AWS services supporting serverless architecture

Logs and logging management system are organized with Amazon CloudWatch - a monitoring service for resources and applications running on the Amazon cloud environment [18]. CloudWatch gathers detailed information relating to operations of Lambda functions. It also provides useful metrics, configurable alarm settings to notify stakeholders whenever failing, and various filters to quickly search for correct logs [44]. Many other systems, for instance e-mailing, phone calling, or data storage, can be integrated in order to fulfill certain business needs. Fortunately, AWS offers a wide range of supplement services to fit various requirements, for example Simple Storage Service (S3) to serve as highly-scalable data object storage, Simple Notification Services (SNS) to support sending email or phone messages.

4.3 Development practices

In the world of agile software development, continuous integration and delivery is major strategy for building and releasing software. The methodology encourages developers to push new code more frequently on daily basis [45], which should be adopted into practice

of serverless architecture. To be specific, each update triggers an automated process to verify such code update by attempting to build the whole code base. In addition, the process also executes a test set, which may consist of unit tests to check small pieces of functional code and integrations test to demonstrate if individual software components work as expected. As long as the code base can be successfully built and passed certain tests, the integration process is considered completed and ready to deliver. In a word, by early verifying changes of the software, continuous integration is to increase the possibility to detect errors soon [46]. Meanwhile, the goal of continuous delivery is to ship newly-updated version more regularly to quality assurance teams to perform testing activities. As such, it helps team respond faster to requirement changes and reduce time to market of the software, hence of saving resources [47].

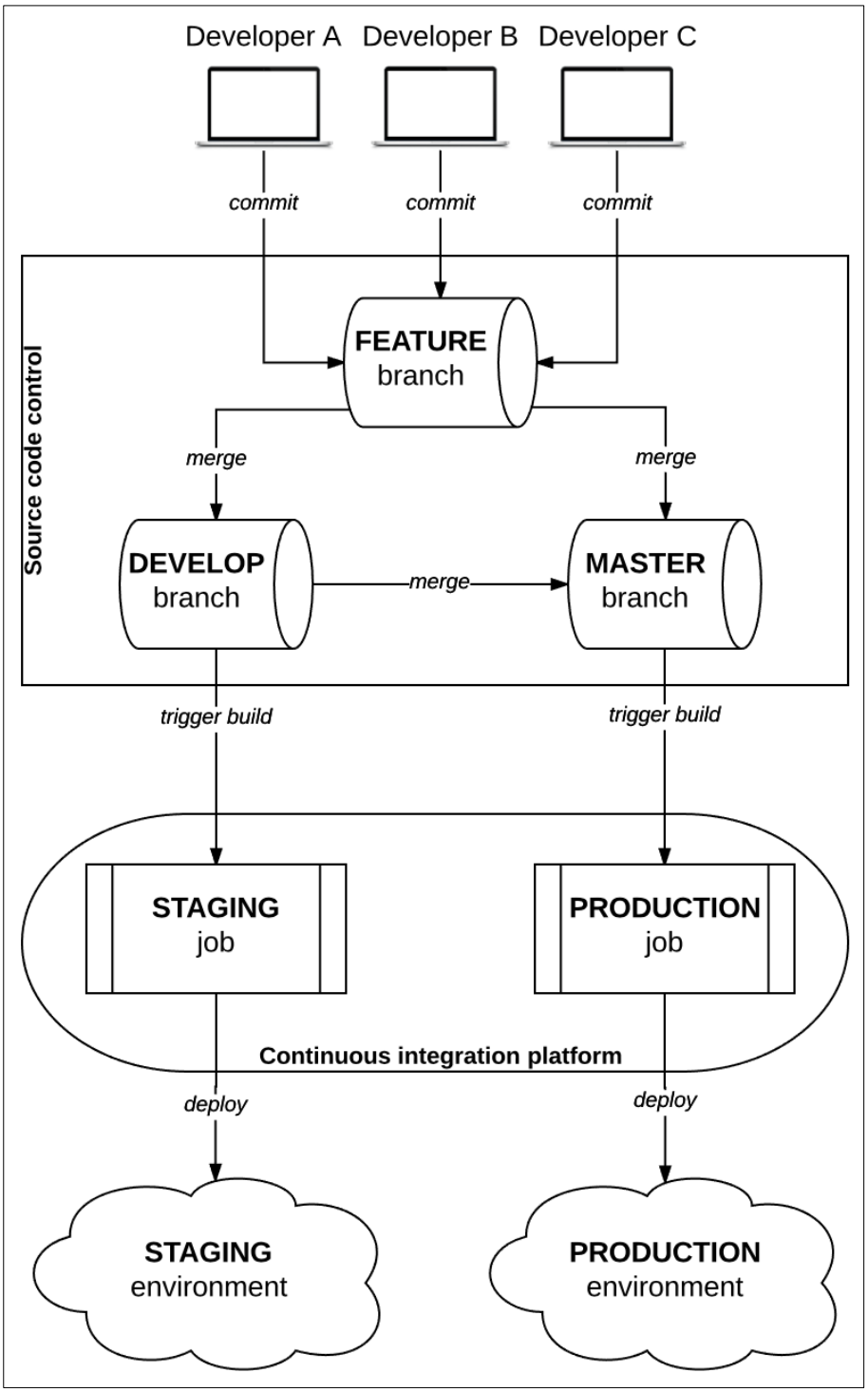

Figure 6. Continuous development workflow adopted

In software development project, there are many developers involving in the process. They write code and contribute to common repository, then continuous integration (CI) tool builds the application from such code base and tests it. Successful builds are deployed to the cloud where application is available to serve users. In order to guarantee workable release, the

author utilizes separate CI jobs to deploy application to isolated, which can be named as staging (or testing) and production. Staging is a replica of production environment so that development team can safely test the application against its business as well as performance requirements without affecting real customer's traffic.

Notwithstanding that, developers do not push code changes directly to deploy on staging environment. Main reason is to minimize possible application break that interrupts testing activities from other members, and hence of unproductivity. As a convention, developers create new function of the software and commits code to a feature branch of the code repository. The convention requires every new feature to be separately built on isolated code branch. Then, other developers must review and approve changes prior to merge into develop branch, which means to be ready for deployment to staging environment. Once application is tested and verified with updates, development team releases a version of the software for production users. It is done by merging the develop branch into master branch, subsequently triggering the build and deployment process to production environment. Furthermore, another release practice can be adapted, in which successful build version running on staging can be promoted to production environment. After that, developers proceed to merge develop into master branch to archive and finish release process. In this thesis, the author employed the first approach in developing the prototype application in the chapter 5.

4.4 Summary

Following the guidelines by Hevner et. all [23], output of a design science research is design artefact to solve a business problem. To be reflected in this thesis, the result artefact (figure 4) is delivered in the form of model with the purpose of promoting an approach to develop web services without server provision. In details, it consists of the serverless architecture (figure 4) and a practice (figure 6) to implement into web services application development project. This design artefact is a technology-oriented, equipping technical audiences with an innovative approach to develop web services application. The serverless architecture relies on a computing platform and other on-demand cloud services which allows developers to execute software function's code without infrastructure provision. The main idea is to shift concerns about backend infrastructure from in-house to cloud vendors so that development team can utilize benefits of cloud computing, and concentrate on writing application's code.

Yet, all necessary computing resources and configuration can be set and flexibly adjusted according to application's actual loading demands and scalability needs. In other words, cloud providers are responsible for doing infrastructure setup and maintenance running behind such cloud services. It does not require developers to setup physical or virtual machine, install operating system and necessary software to configure server and environment for applications. The developers are also free from mandatory maintenance works, including hardware procurement, upgrade or software patches to ensure uptime of machine and application as well.

Table 5. Reflection of guidelines

Guidelines [23]	**Thesis**
Design as an artefact *(research's outcome)*	- Serverless architecture - Development practice
Problem relevance *(solving a problem)*	- Infrastructure setup: hardware and software procurement and deployment - Infrastructure maintenance: times and efforts of team to ensure high uptime (software patches, update or hardware replacement) - Application's scalability - Concentration on writing code, testing and deploying application

A serverless application consists of the following components, which are different services provided by cloud vendor. Among listed components, the author defines API container, computing platform and logging system as the backbone components of the serverless architecture.

- API (Application Programming Interface) container: API endpoints definition and publish, access credentials for consumers, and APIs traffic management
- Computing platform: run application code to execute business logic
- Logging system: storage of application's operational logs
- Database
- Supplement services: other integrated systems or services (such as email client, data repository)

The artefact of development practice explicitly points out four main stakeholders in the work pipeline. First, it is local environment where developers write code on their own machines to create and test new application's functionalities. Second is the source code control system to share the code among developers, supports review process, and track changes to the code base. Also, it allows to revert to previous code version in the timeline in case of problems. Subsequently, the continuous integration (CI) platform comes at third place, in which build automation is handled. The CI tool executes pre-defined jobs to build and deploy the application to corresponding working environments. Additionally, different tests would be attached in order to verify that the application is up and running flawlessly. The use of CI tool simultaneously boosts development process together with the source control system, enabling developers to be less worried about manual tasks. Last but not least, the fourth stakeholder is cloud environment where application is running on. The application can be delivered in two versions with almost identical configurations. In which, one is used for testing purpose, while the other serves production users. Overall, there are four main points should be noted in the development practice as listed below:

- Each new functionality is developed in an isolated feature branch
- Code review is done prior to merge feature branch for deployment
- Branches (for example develop and master branches) are utilized to deploy application to staging (testing) and production environments
- CI jobs are created for automation process, possibly including tests to verify workable application

5 ADOPTION OF SERVERLESS ARCHITECTURE

In previous chapter, the serverless architecture is proposed and explained in regard to reflection of design science guidelines. Yet, this thesis introduces the architecture and its development practice as the output IT (information technology) artefact of the research process. According to the third guideline, which is considered as a critical step, the design artefact needs to be evaluated by utility, quality and efficacy [23]. Therefore, the author adopts the artefact into implementation of a prototype serverless application. The developed prototype is a proof-of-concept to prove the feasibility and usability of the proposed software architecture and development practice. Being a cloud vendor, Amazon Web Services (AWS) is employed together with different supporting tools and software. Within this chapter, the author provides readers an insight into the process of building, deploying and monitoring a serverless application in the AWS cloud environment. First, brief introductions about the important AWS services adopted in this project are given, namely AWS Lambda and API Gateway. In other words, they are the backbone of the serverless application. Second, due to the needs of a source code control system and CI software for build automation, the author continues to discuss about them in the following. Third, application source code will be mentioned, which concerns programming language of choice, relevant techniques as well as project configuration. Last but not least, procedure of build and deployment to cloud is also described, including application monitoring and maintenance.

5.1 AWS services as backbone of serverless application

5.1.1 AWS Lambda function

Amazon provides a web-based user interface for quick access and provision of their services, known as Amazon Web Services (AWS) management console [18]. Yet, it is simple to create new Lambda function and give settings to it from the AWS console. The major configurations shown on setting window of AWS Lambda function are illustrated in the below figure.

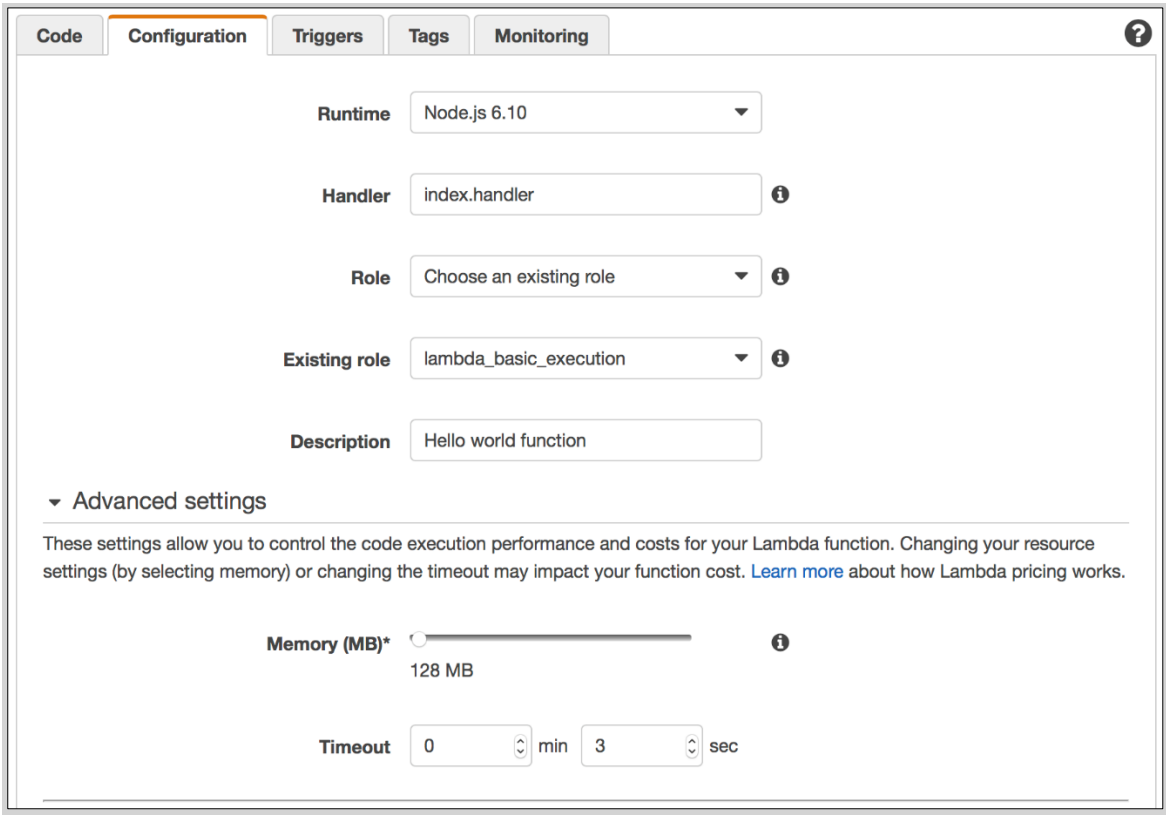

Figure 7. Major configurations of Lambda function

The most crucial setting is runtime - execution environment of function code. The runtime is picked depending on choice of development team for programming language and framework. In this research, the author decided to code serverless application in Node.js, therefore the runtime should be Node.js 6.10. In addition to Node.js, AWS Lambda also supports Python, Java and C# languages. Another crucial configuration, handler, is a method dedicated for each Lambda function, which is the beginning point whenever the function is called. On the one hand, memory is desired computation resources allocated for a Lambda function, meaning that higher memory is more powerful. Timeout defines maximum execution time of a function to prevent infinite run. In other words, whenever reaching timeout AWS Lambda stops a running function.

While configuring Lambda function, developers can place code directly on the AWS console. A sample *"Hello World"* function and its handler are also given to demonstrate the programming model of AWS Lambda. The sample code outputs a simple JSON response, consisting of HTTP (Hypertext Transfer Protocol) success code 200 and a response message. To ease development, Amazon established documents to explicitly explain the programming

model for developers to properly write code of Lambda function. Through the AWS console, the Lambda function can be invoked for testing purpose and the result is presented in the following figure.

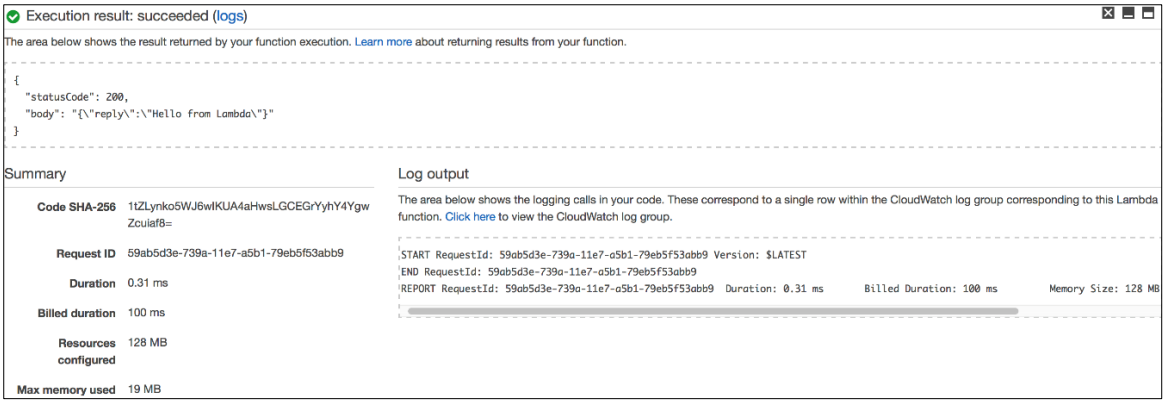

Figure 8. Test invocation of Lambda function

From the above summary, it can be seen that the maximum memory used as computation resources for this request was 19 MB. The result is far lower than the configured memory size (128 MB), meaning that current setting is capable for standing higher load. The summary also revealed that a time of 0.31 milliseconds was taken to complete execution and return a result.

5.1.2 API Gateway

In previous section, a sample Lambda function is created to return a simple JSON message in each invocation. In a web service, to call this function, a dedicated API endpoint is defined together with a corresponding HTTP method. Moreover, the endpoint has own resource identifier (basically an URL), and possibly accepts data sent by requester through query string or request body. In AWS cloud environment, API Gateway is adopted to publish and manage such endpoint. The following figure presents the user interface of API Gateway on the management console.

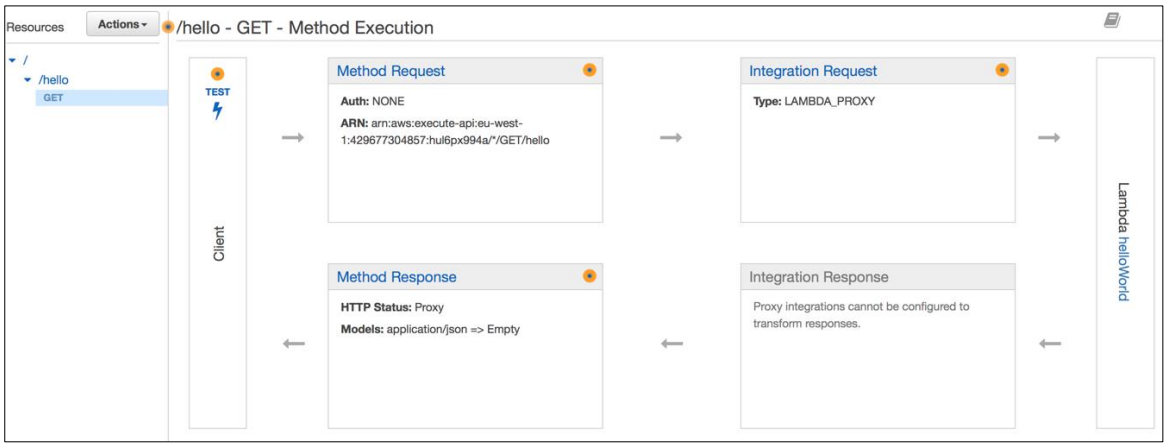

Figure 9. Sample endpoint in API Gateway on AWS management console

The *hello* endpoint is created to listen for GET requests to call the sample Lambda function *"Hello World"* by linking to its Amazon Resource Name (ARN). It is noted that each resource on AWS cloud environment has a unique identifier (defined by AWS as ARN), and hence of Lambda function. It is also possible to directly test the endpoint on AWS console to check whether published API is working, and result is visually shown as below. Other than that, AWS console shows trace log of any request with helpful information for developers to debug.

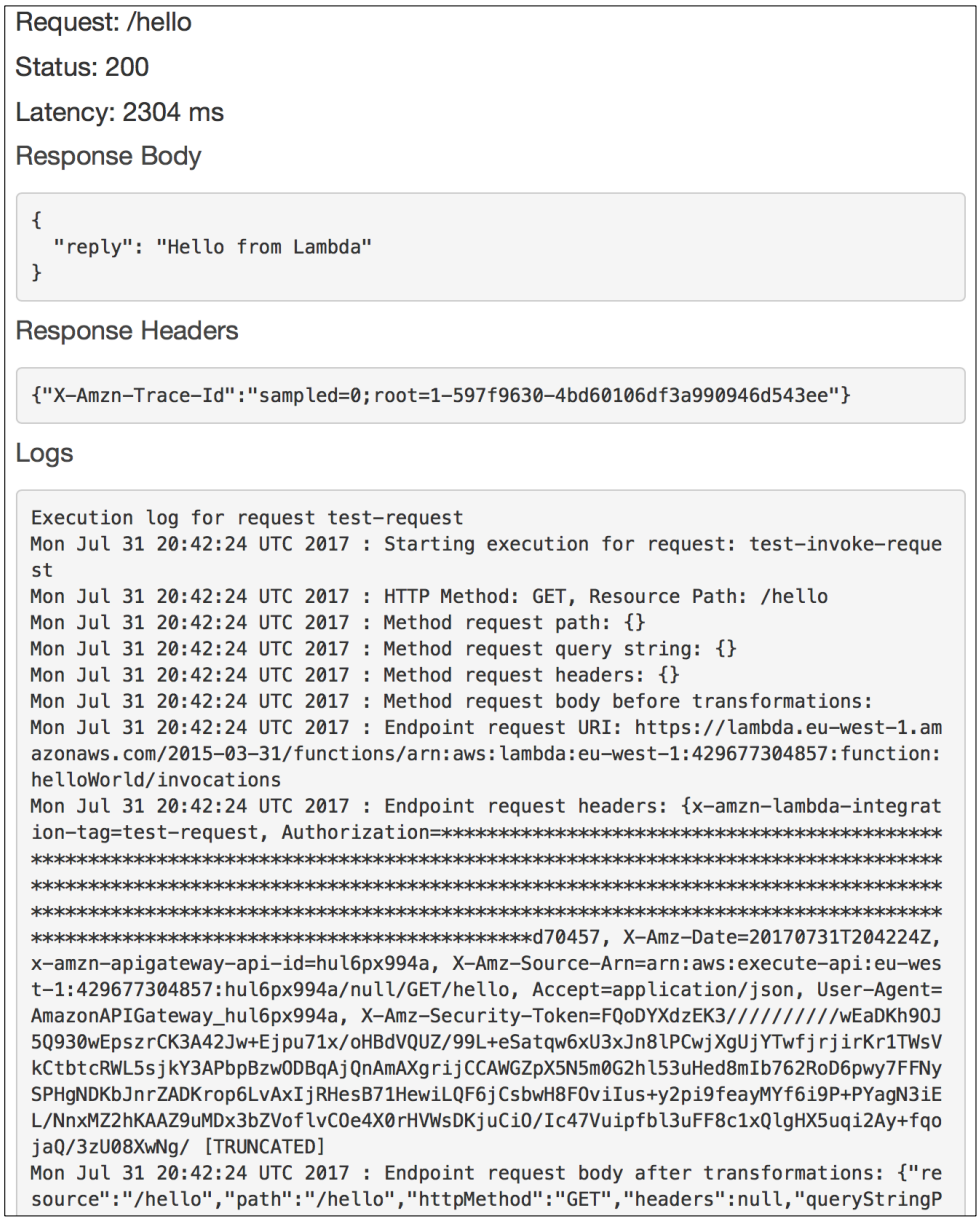

Figure 10. Test API call on AWS console

The sample API is publicly accessible for all users to send requests and retrieve data. However, in many cases, security requirements ask for access restriction so that only permitted requesters are able to use the API. Thus, requesters must include into every call a sort of credential authorized by the API publisher, in order to be identified. Fortunately, API Gateway equips developers with built-in API keys for an instant implementation of protection. Once being enabled, the API expects *"x-api-key"* header to consider valid requests to accept, otherwise to reject them. Value of this header is set to the API key which is generated and provisioned by API Gateway. The below figure demonstrates two requests to this secured API, among them, the first request did not include *"x-api-key"* header but the

other did. The result reveals that the first attempt was forbidden with HTTP status code 403 returned to caller, whereas the second was successful. It got successful HTTP status code 200 and could retrieve returning data as a JSON string.

```
~ $ curl -i -X GET "https://hul6px994a.execute-api.eu-west-1.amazonaws.com/example/hello"

HTTP/1.1 403 Forbidden
Content-Type: application/json
Content-Length: 23
Connection: keep-alive
Date: Thu, 03 Aug 2017 19:54:50 GMT
x-amzn-RequestId: 9c4572f8-7885-11e7-ab7a-779254395ae4
x-amzn-ErrorType: ForbiddenException
X-Cache: Error from cloudfront
Via: 1.1 8b1633b834f6beaa5a2d7797c38cf775.cloudfront.net (CloudFront)
X-Amz-Cf-Id: Y_osBwYjfSMBk_fsx_z2nlZwLaZ5m9U7dJYMYDt-a5_j57m7DEG30g==

{"message":"Forbidden"}~ $
~ $
~ $
~ $
~ $
~ $
~ $ curl -i -X GET "https://hul6px994a.execute-api.eu-west-1.amazonaws.com/example/hello" \
> -H "x-api-key:sU5KXrC70H1wRw1ybznYz3YaEbODYhFr5PUA6v1y"

HTTP/1.1 200 OK
Content-Type: application/json
Content-Length: 29
Connection: keep-alive
Date: Thu, 03 Aug 2017 19:55:36 GMT
x-amzn-RequestId: b751202f-7885-11e7-a556-6d4009c3a74b
X-Amzn-Trace-Id: sampled=0;root=1-59837fb7-6624531fde31baedf7e2a8f7
X-Cache: Miss from cloudfront
Via: 1.1 9e6a829fab539aea0c15afd27fd9d1ad.cloudfront.net (CloudFront)
X-Amz-Cf-Id: UuFBcg3eero70GoMy3GUyOITdb2hFjSM0_dbuTld3uCDKWlpz_zfTQ==

{"reply":"Hello from Lambda"}~ $
```

Figure 11. API requests demonstration

5.2 Source code control and other tools

In previous sub-chapter, a demonstration on AWS management console to create a sample API resource of a web service is given. However, it is unpractical to track changes made by navigating around the console, and hence of unmaintainable application, especially there are many people involving in the project. Yet, it becomes more difficult to learn whoever performs any code update or adjust few configurations of a AWS resource. As such, in order to tackle the issue, it is crucial to adopt a versioning system to manage project's code base instead of direct update on the AWS management console. The version control software also

aims at tracking all relating AWS infrastructure employed to build the serverless application. In other words, all changes should be recorded for revision, which can be traced easily and probably reverted to previous settings in case of problems.

In this thesis, the author adopts Bitbucket [48] as the code management platform to control source code of the serverless prototype application. The platform is developed by Atlassian [49], equipping the author convenient solution to version the source code. A basic CI tool is also integrated which will be used to build and deploy the project. Furthermore, Atlassian offers reasonable subscription pricing for small team using their platform, and it is suitable for this study's budget.

5.3 Coding prototype application

5.3.1 Database

In this thesis, the developed prototype application is a RESTful web service with basic CRUD operations (create, read, update, delete). It provides API for consumers to retrieve or manipulate data records from a database by sending requests to appropriate HTTP endpoints. Having noticed earlier, database design and its implementation are not included in the project's scope. By such, a sample database is adopted from the community of PostgreSQL database engine [50]. A Linux virtual machine is also configured to serve as database server for this purpose. Details about all database tables and their entities can be seen in the entity relationship diagram placed in appendix of this thesis. It should be noted that not all entities have been taken into development of the prototype application due to the research's scope and limitation.

5.3.2 Project structure

The below figure presents a look at the organization of the application where various components as well as configuration files can be seen. At root directory, *models* directory gathers all classes representing the database's entities, for example actor, address, city and country. Each model class defines properties for individual entity, serializes and maps it to relevant table in the database. The *functions* directory contains all AWS Lambda functions, being divided correspondingly to API resources of the prototype application. For instance, sub-directory *actor* contains all functions to handle incoming requests from consumers and

executes relating business logics. Moreover, the author also includes several test data, saved in JSON files, to simulate execution of those functions on local machine. Last but not least, all shell scripts are centralized in the *bashscripts* directory. These scripts are used for testing, validating code, building and deploying the application to AWS cloud environment.

Figure 12. Components and project structure

There are a number of configuration files in the project, namely *"package.json"*, *"serverless.yml"*, *"bitbucket-pipelines.yml"*. Firstly, the JSON file contains list of required software dependencies, and defines commands to run the shell script files in the *bashscripts* directory. The file also stores description about the application, such as name, version tagging, contributor and license. Meanwhile, *"serverless.yml"* is used to configure all

components and infrastructure of the serverless application to be deployed on AWS cloud environment. To be specific, this YAML file organized settings for AWS Lambda functions, including HTTP endpoints dedicated to them. In addition, computing memory, function timeout, API key to protect application are also attached. In the meantime, *"bitbucket-pipelines.yml"* applies configuration for the Bitbucket's built-in CI tool to build and deploy the application.

5.3.3 Dependencies management and installation

The project needs external software libraries, also known as dependencies, which are pre-written code of functions, classes or scripts available for developers to reuse or integrate into an application [51]. Those libraries help developers to reduce coding efforts and boost the development process. Furthermore, many libraries (or dependencies) have been released and supported by prestigious organizations or community of qualified developers, and hence of less bugs or errors. In this project, the author adopts several software libraries, requiring to be installed prior to any development work with AWS services. As being mentioned previously, they are listed in the configuration file *"package.json"*. The below table provides brief information about the most important dependencies used to support the prototype application. In addition, the subsequent figure gives an instruction to install software dependencies in Node.js application development project by shell command.

Table 6. Project dependencies summary

Name	Purpose	Item in package.json
Serverless framework	Backbone library in this project that provides support in building, deploying, managing Lambda functions, API Gateway and other AWS resources	`"serverless": ">=1.11.0"`

PostgreSQL database client	Providing connection gateway between application and PostgreSQL database	`"pg": "^6.1.5",`
		`"pg-hstore": "^2.3.2",`
		`"pg-pool": "^1.7.1"`

Serialization library	The Object-relational Mapping (ORM) library allows application to interact with data from a database via the Object-oriented paradigm	`"sequelize": "^3.30.4",` `"sequelize-cli": "^2.7.0"`

Code convention check	Verifying new code against a universal convention to maintain a standard way of coding within development team	"eslint": "^3.19.0", "eslint-config-airbnb-base": "^11.1.3", "eslint-plugin-import": "^2.2.0"

```
prototype-app $ cat package.json
{
  "name": "prototype-app",
  "version": "0.0.3",
  "description": "Prototype-app",
  "main": "index.js",
  "dependencies": {
    "dotenv": "^4.0.0",
    "eslint": "^3.19.0",
    "eslint-config-airbnb-base": "^11.1.3",
    "eslint-plugin-import": "^2.2.0",
    "moment": "^2.18.1",
    "pg": "^6.1.5",
    "pg-hstore": "^2.3.2",
    "pg-pool": "^1.7.1",
    "sequelize": "^3.30.4",
    "sequelize-cli": "^2.7.0",
    "serverless": ">=1.11.0",
    "url": "^0.11.0"
  },
  "scripts": {
    "test": "echo \"Error: no test specified\" && exit 1",
    "style": "sh ./bashscripts/checkstyle.sh",
    "deploy": "sh ./bashscripts/deploy.sh"
  },
  "repository": {
    "type": "git",
    "url": ""
  },
  "license": "ISC"
}
prototype-app $ npm install
npm WARN deprecated minimatch@2.0.10: Please update to minimatch 3.0.2 or higher to avoi
npm WARN deprecated minimatch@0.2.14: Please update to minimatch 3.0.2 or higher to avoi
npm WARN deprecated graceful-fs@1.2.3: graceful-fs v3.0.0 and before will fail on node r
' to find it in the tree.
(                    ) ⠹ extract:argparse: sill gunzTarPerm extractEntry lib/blacklist.js
```

Figure 13. Installation of software dependencies

5.3.4 API resources

The author utilizes configuration file *"serverless.yml"* in order to define all AWS Lambda functions and APIs on API Gateway. All settings for these AWS resources are transformed to code so that version control software could easily manage. At the top of *"serverless.yml"*, the author defines necessary information for the application, such as stage (marking application's environment as staging or production for deployment), resources allocated to Lambda functions (computing memory, timeout). Among them, application's stage is parameterized, therefore it can be flexibly deployed to different environments on AWS.

Runtime and memory of AWS Lambda are Node.js and 128 Megabytes, respectively. Timeout is set to 6 seconds, meaning that AWS terminates execution of Lambda function after this maximum duration in order to avoid infinite run. The mechanism also helps to prevent meaningless cost, and hence of saving budget.

```
prototype-app $ cat serverless.yml
service: prototype-app

frameworkVersion: ">=1.11.0"

provider:
  name: aws
  profile: awsdev
  region: eu-west-1
  stage: ${opt:stage}
  runtime: nodejs6.10
  memorySize: 128
  timeout: 6
  apiKeys:
    - ${opt:stage}-devkey

custom:
  apiversion: v1

functions:
  probeGetHealth:
    handler: functions/probe/probehandler.getHealth
    description: Check health status
    events:
      - http:
          method: get
          path: ${self:custom.apiversion}/probe/health
          private: false
```

Figure 14. Configuration of first API

First endpoint of the prototype application is implemented for consumers to check health status of the web service. It accepts requests made with HTTP method GET over the network. Staying behind the endpoint, the AWS Lambda function is named as *probeGetHealth* with brief description. The code file for this Lambda function is stated as value of *handler*, which must be an absolute path within the project's structure. The author decides to allow public access to this API resource, meaning no credential or API key required in HTTP requests. As such, value of the key *private* must be assigned to *false*.

On the other hand, the below API resources allows consumers to interact with database of the prototype application, which requires a stricter access right. Those endpoints include various HTTP methods, GET, POST and PUT, to retrieve, create and manipulate records of actor table in the database. The below figure illustrates configurations of these endpoints in the application's *"serverless.yml"* configuration file. Due to the nature of database security, it must be noted that these endpoints were private, which only accept traffics from identified consumers. In other words, they must include a sort of assigned credential in every request so as to bypass API's firewall protection. Therefore, being differently than the health check, the value of *private* is set to *true* for these endpoints.

```
actorGetById:
  handler: functions/actor/actorhandler.getActorById
  description: Get an actor by id
  events:
    - http:
        method: get
        path: ${self:custom.apiversion}/actor/{id}
        private: true
actorCreateNew:
  handler: functions/actor/actorhandler.createNewActor
  description: Create new actor and save to database
  events:
    - http:
        method: post
        path: ${self:custom.apiversion}/actor
        private: true
actorUpdate:
  handler: functions/actor/actorhandler.updateActor
  description: Update information of an actor
  events:
    - http:
        method: put
        path: ${self:custom.apiversion}/actor/{id}
        private: true
```

Figure 15. Configuration of actor endpoints

From the above figure, the first GET endpoint, *actorGetById* searches for an individual actor from the database by its ID (which is the identifier of the record on database). The actor's ID is attached to query string on the API's Uniform Resource Identifier (URI) that can be seen in sample request's demo. Second, *actorCreateNew* is implemented to add new actor to the database via POST requests. Detailed information about new actor must be sent in request's body. Meanwhile, in order to update details of a particular actor, consumers make a PUT request to *actorUpdate* endpoint with data included in the body. Similar to retrieve

information of an actor, the URI of this API contains the ID of the actor. The below demo gives examples of valid requests to these particular endpoints.

```
~ $ curl -i -H "x-api-key:sU5KXrC70H1wRw1ybznYz3YaEbODYhFr5PUA6v1y" \
> -X GET "https://v0a8typ6v0.execute-api.eu-west-1.amazonaws.com/staging/v1/actor/99"
~ $
~ $ curl -i -H "x-api-key:sU5KXrC70H1wRw1ybznYz3YaEbODYhFr5PUA6v1y" \
> -X POST "https://v0a8typ6v0.execute-api.eu-west-1.amazonaws.com/staging/v1/actor" \
> --data '{"first_name": "John","last_name": "Doe"}'
~ $
~ $ curl -i -H "x-api-key:sU5KXrC70H1wRw1ybznYz3YaEbODYhFr5PUA6v1y" \
> -X PUT "https://v0a8typ6v0.execute-api.eu-west-1.amazonaws.com/staging/v1/actor/99" \
> --data '{"first_name": "Bacon","last_name": "Tuna"}'
```

Figure 16. Sample requests with different HTTP methods

5.3.5 Business logic code

Amazon Web Services (AWS) Lambda function's handlers store code of the application's business logic. Coding the handlers must follow a defined programming model documented by AWS [52] to ensure compatibility with the AWS Lambda environment. Basically, the handler is a function code to be invoked firstly whenever a function is executed. Handler's syntax contains three parameters, namely *event*, *callback* and *context*. Developers utilize the *event* parameter to extract data being passed to Lambda functions, including request data sent by API (Application Programming Interface) consumers. Depending on request method, such data could be passed as query string or attached to request's body. The Lambda function follows defined business to process the data, then prepares result as response for API callers by passing it through the *callback* parameter. Last but not least, the *context* parameter represents an object which stores all runtime information of Lambda function, for example different settings of the function, memory limit or execution time.

```
prototype-app $ cat functions/probe/probehandler.js
const pckg = require('../../package.json');

module.exports.getHealth = (event, context, callback) => {
  const response = {
    statusCode: 200,
    body: JSON.stringify({
      probe: pckg.version,
      description: pckg.description,
      status: 'ok'
    })
  };

  callback(null, response);
};
```

Figure 17. Function probeGetHealth handler

The above code defines response of *probeGetHealth* endpoint to report availability status of the application. The author implements simple logic for this health check function, in which it sends message together with status code 200 (standard response for a successful HTTP (Hypertext Transfer Protocol) request) back to callers. In addition, the response also tells brief information about the service, such as current version and description.

In the prototype application developed in this study, many API calls work with data which are exchanged between requesters and the API. Having previously mentioned, the *event* parameter stores all input data for AWS Lambda function regardless being sent in body or as query string. To be specific, the function handler named *getActorById* of the endpoint *actorGetById*, actor's identifier (ID) is passed in the Uniform Resource Identifier (URI) of GET request. On the other hand, in POST or PUT requests, such as in function handlers named *createNewActor* and *updateActor*, the convention is to store information as key-value pair and transport them as part of request's body. Although all cases save those data in the *event* parameter of AWS Lambda function, extracting them from the body or from the URI requires different implementations. The below code provides details about the solution.

```
// Handler to serve GET request
module.exports.getActorById = (event, context, callback) => {
  const actor_id = ${event.pathParameters.id} //retrieve data from resource URI
  /***
    ... more code ...
  ***/
};

// Handler to serve POST request
module.exports.createNewActor = (event, context, callback) => {
  const body = JSON.parse(event.body);  //retrieve data from request body
  /***
    ... more code ...
  ***/
};

// Handler to serve PUT request
module.exports.updateActor = (event, context, callback) => {
  const body = JSON.parse(event.body);  //retrieve data from request body
  const first_name = body.first_name;   //retrieve data from request body
  const last_name = body.last_name;     //retrieve data from request body
  /***
    ... more code ...
  ***/
};
```

Figure 18. Code to retrieve data from requests

5.4 Application build and deployment

A continuous integration (CI) software is adopted to build and deploy the prototype application. Whenever changes occurring in the project's code base, the CI software runs pre-configured job to release new application version to the Amazon Web Services (AWS) environment. The process will be triggered automatically or manually. In this project, the author employs Bitbucket platform [48] as version control system to host the code. Atlassian [49] also integrates a simple CI software into Bitbucket to assist build automation. This built-in CI tool is adequate and fulfills requirements of the prototype development. Apparently, different projects may demand more advanced CI software with the ability to tweak, such as Jenkins [53] or Atlassian Bamboo [54], to fit their works and project's scopes.

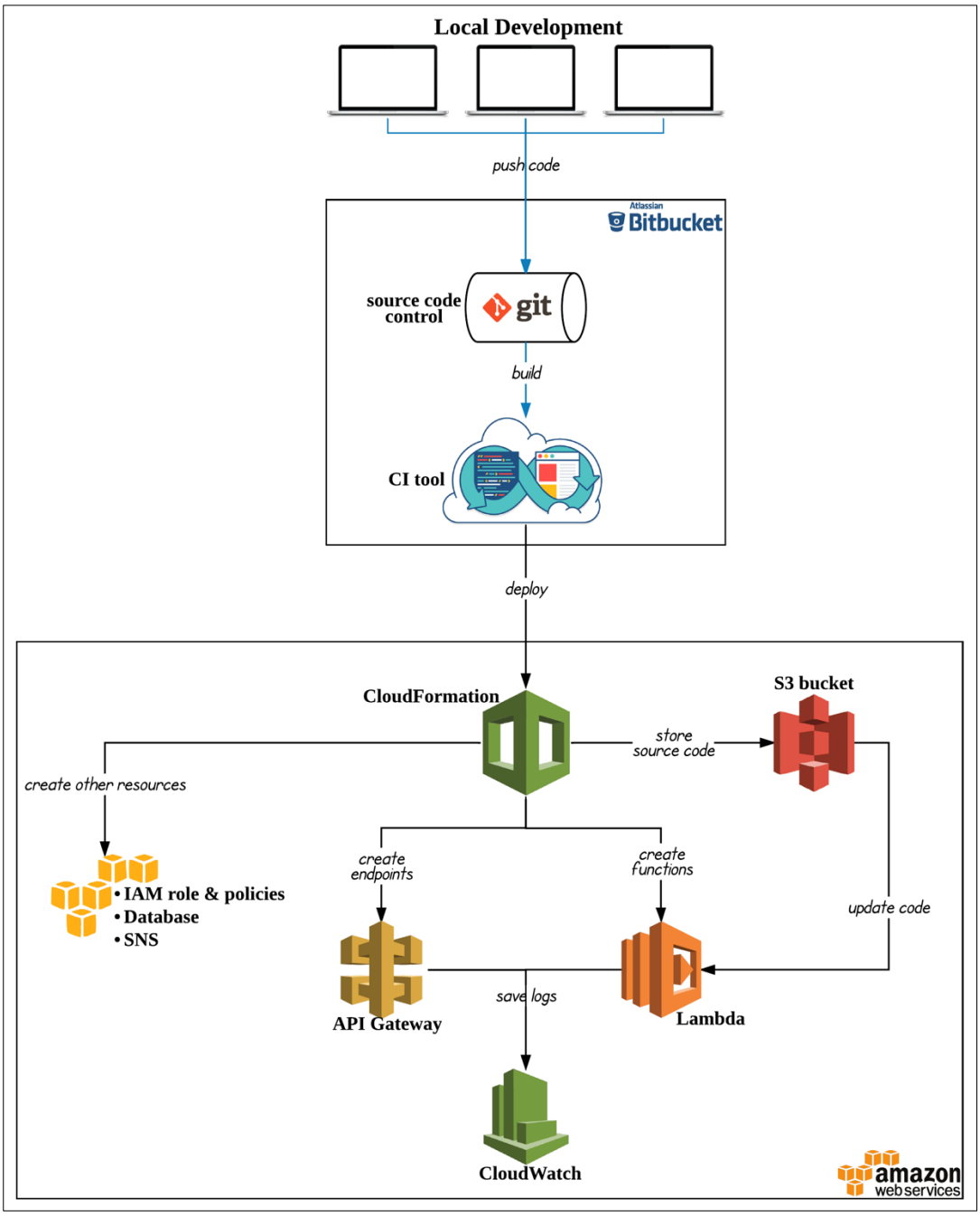

Figure 19. Insight into build and deployment pipeline

The author defines different tasks for CI job in the configuration "*bitbucket-pipelines.yml*" and shell scripts. The configuration file follows convention documented by Atlassian to obtain compatibility with the Bitbucket CI software. In other words, the CI tool firstly read settings from this file to know about tasks to execute. Furthermore, the configuration lists all deployment jobs for both staging and production environment, which are triggered by changes in develop and master branches, respectively. Meanwhile, the shell script

"*pipeline.sh",* placed in directory *bashscripts,* consists of various tasks to perform in the deployment pipeline according to application's environment. In general, following tasks are defined:

- Installing required software dependencies for the project
- Validating convention of the code
- Updating structure of database table (if necessary)
- Executing scripts to update new code for Lambda functions and other AWS resources
- Checking application health by calling the health check endpoint

At lower view of the deployment pipeline, the CI tool performs updates for AWS resources which serve as components of the prototype application. Infrastructure changes are detected from the *"serverless.yml"* file to inform AWS CloudFormation to update corresponding resources. In other words, AWS CloudFormation is a service to easily create and maintain collections of related resources that assemble a software and contribute to its development [18]. Basically, in the AWS environment, all settings for the application's components and its necessary resources are centralized and wrapped into a CloudFormation stack. Running any update on this stack results into migrating changes in all resources under its management.

To be specific, CloudFormation manages provision of the backbone services of the serverless prototype application. Taken inputs from the *"serverless.yml"* configuration, CloudFormation set all definitions and configurations for Lambda functions and API Gateway. Application code is kept in a S3 bucket prior to apply to Lambda functions for latest changes. Last but not least, other relevant and necessary AWS services are also updated by CloudFormation in order to ensure application's availability, for instance IAM roles and policies to manage access and operation permission to all resources within the AWS environment [18].

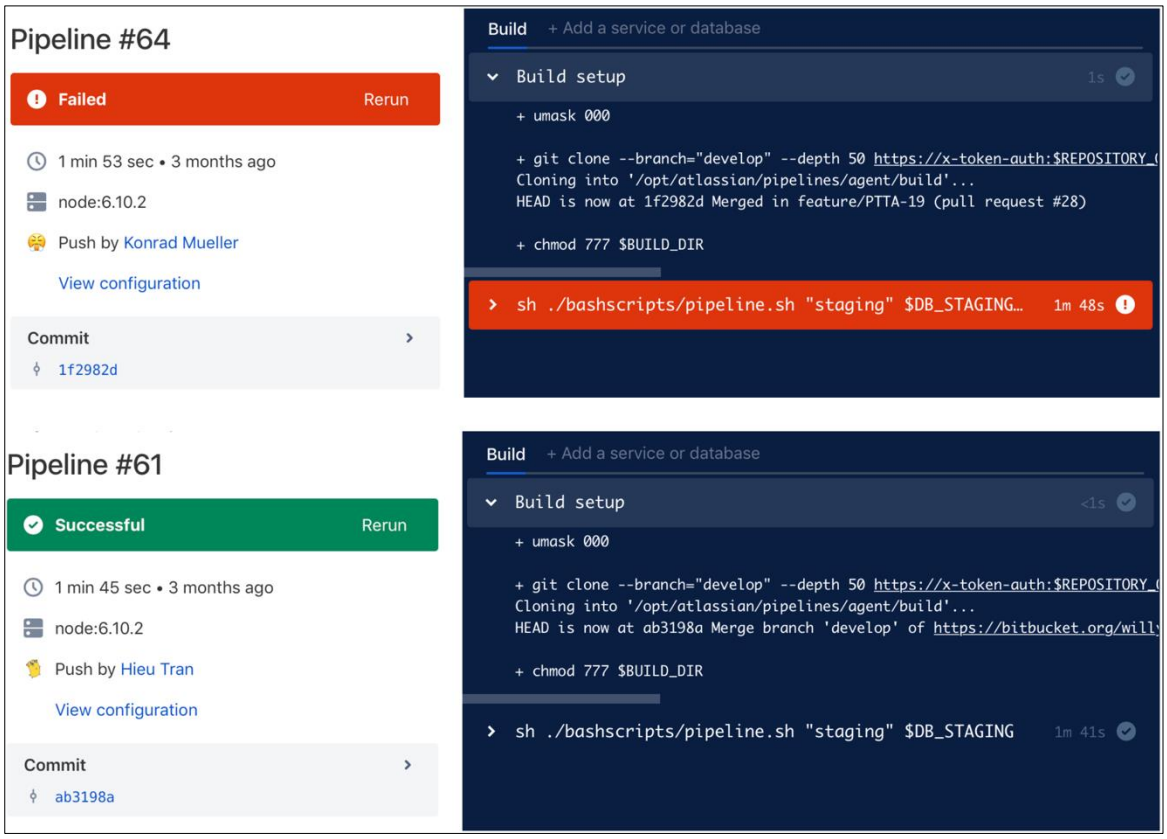

Figure 20. Failure versus success in deployment pipeline

The above figure illustrates two contrary scenarios of the deployment pipeline revealed in the CI tool's console. Once all deployment tasks being successfully executed, deployment pipeline is marked as success, meaning a healthy service was ready to serve. In contrast, whenever being considered failure due to any unsuccessful task, the pipeline rejects new code deployment and reverts to latest stable version. This rollback mechanism is useful to avoid unhealthy application state, and possibly service break. In other words, rollback also helps to ensure no malfunction or misleading behaviors of the application.

5.5 Monitoring and maintenance

The operational monitoring of serverless application is done through CloudWatch, a monitoring service to automatically collects operation information of resources and running application on the cloud [18]. Yet, CloudWatch streams activities and events concerning the prototype application to different log streams containing their time and details. To be specific, API (Application Programming Interface) Gateway traces all consumer's calls to each endpoint and records them into different metrics, such as number of requests, duration

as well as error counts. To be added, CloudWatch also distinguishes them by environments (staging or production). Taken as an example, the below figure presented a graph of metrics concerning API calls in staging environment of this prototype application.

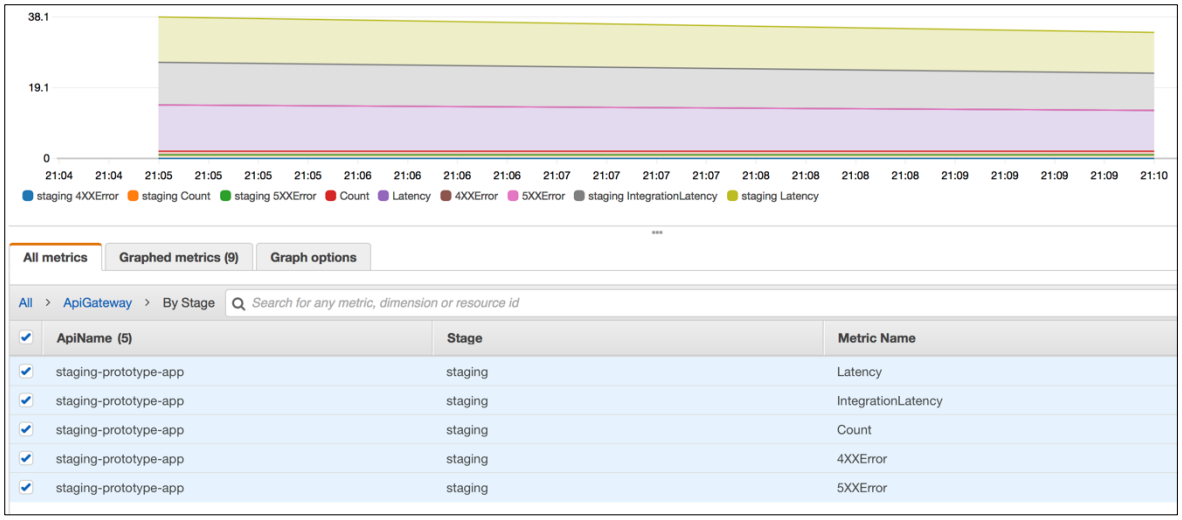

Figure 21. Graphed metrics of API requests

Meanwhile, CloudWatch collects logs of Amazon Web Services (AWS) Lambda functions and categorizes them into separate groups corresponding to each individual function. Inside a log group, log messages are split into various streams with a reasonable number of items to facilitate lookup. AWS also equips CloudWatch with filter box to assist developers to search for wanted log items based on names. Therefore, in the development of this prototype application, the author adopts a naming convention for Lambda functions. The purpose is to distinguish those functions from serving environment, and hence of easily locating correct application logs.

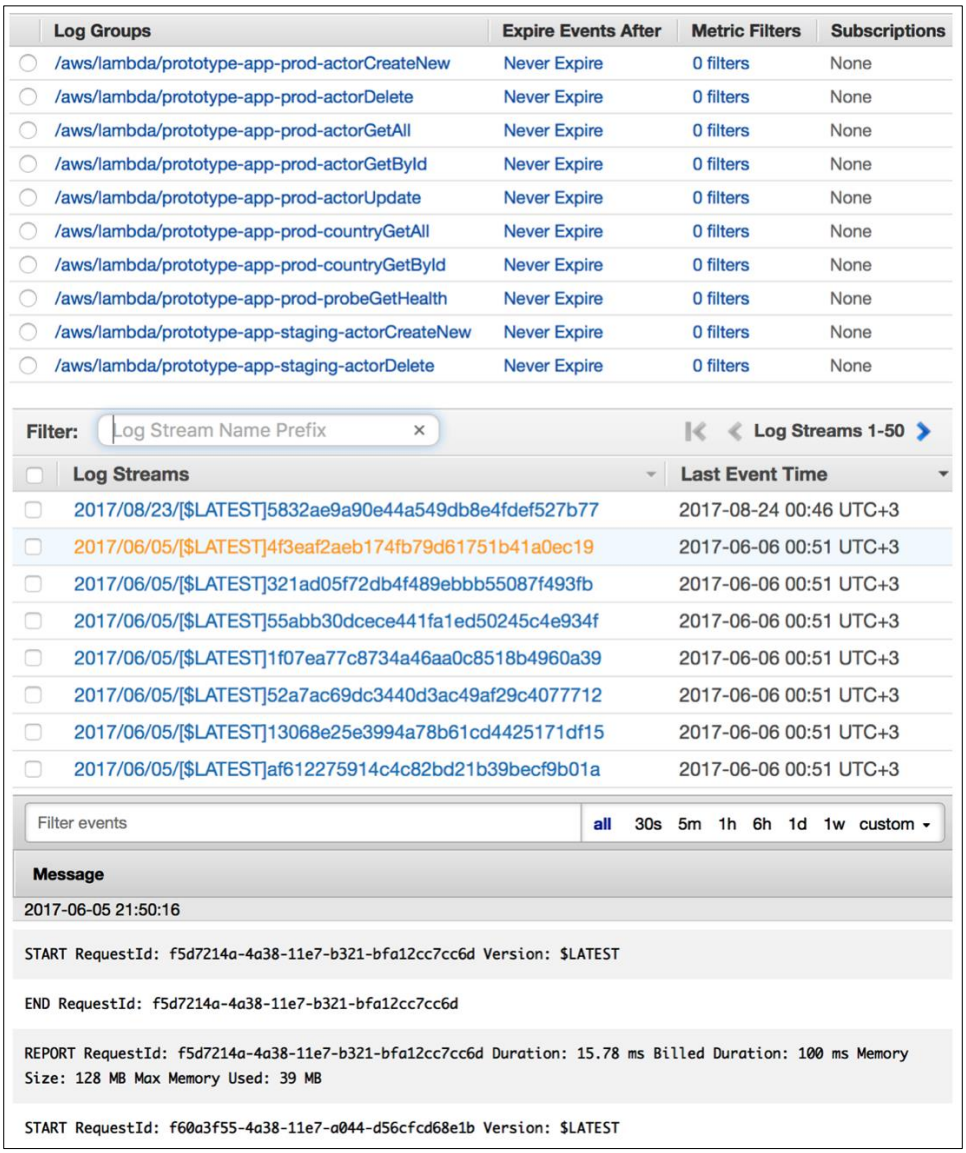

Figure 22. Logs of Lambda functions on CloudWatch

Taking a deeper look, a log stream contains many events, in which a single event represents an invocation time of AWS Lambda function. As can be seen from above example, each event has information about execution time and computing memory consumed. In addition to default log messages, developers can implement custom logging mechanism to store more useful operation information of the application. Yet, custom logs possibly include some sorts of explanation about requesters who call the API and details of the call. Such information is meaningful to application debug whenever errors or incidents occur. Depending on nature of chosen programming language, logging messages are outputted in diverse ways, but they will be automatically saved in a log stream on CloudWatch.

5.6 Summary

In this Chapter 5, implementation of a serverless prototype application is comprehensively discussed with the aim of proving the concept of serverless architecture. First, the author equips readers with a brief introduction about backbone services of the serverless architecture used from Amazon Web Services (AWS). The introduction also give instruction about creating and using those services directly from the AWS management console. However, solely using this approach to maintain resources is unpractical because it is hard to track application's changes and do automation deployment. Thus, it should include necessary software and tools to support the development process, which are given subsequently in below table. Third, detailed discussion about the technical implementation, project structure, and coding techniques are mentioned. It also explains about software dependencies and library needed for the prototype application. Their usage purposes, functionalities as well as installation are reviewed. Subsequently, the fourth issue is the use of continuous integration (CI) platform to automatically build and deploy the application to AWS. Last but not least, briefing about operation monitoring and application maintenance is also covered.

Evaluation of the design artefact introduced in this thesis is conducted by confirming the reliability and usability of the serverless architecture in developing web service application. There are several techniques and methods to use in design evaluation [23], among which the experimental method is employed. The design artefact is studied in laboratory environment, in which elements affecting to the artefact's operation and behaviors are controlled based on pre-defined conditions [55]. Yet, the author simulates a software project to apply the serverless architecture and its development practice. The software requirements are not created from actual analysis of any business need. Furthermore, a small team of three virtual developers are also formed. They participate in the project and simultaneously commit changes to the code base. All in all, the simulated project aims at creating a web service, deploy it to AWS cloud environment, maintain and monitor its operation. Meanwhile, the team follows the suggested development practice, containing different conventions for source code management, code review, as well as project build and deployment. The author reveals the result that the design artefact is successfully adopted into creating a workable web application. The prototype dedicates to run on AWS and utilizes its services to serve as components of the architecture.

The prototype application provides consumers different APIs (Application Programming Interfaces) to interact with the backend and execute corresponding business logics. It can be achieved by sending requests to suitable API endpoint with appropriate data through Hypertext Transfer Protocol (HTTP) calls. API's consumers set methods in each request to perform appropriate CRUD (Create – Read – Update - Delete) operations. The application decides which operation to use and what to execute according to the HTTP verb and data it receives. In a RESTful web service, HTTP method GET is used to retrieve data, whereas POST, PUT and DELETE methods to manipulate records in database, which are to add new record, adjust and remove existing one, respectively [33]. As a conclusion, the following table gives a summary of cloud services to serve as components of the serverless architecture. Moreover, employed tools and software to support the development of prototype application are also listed.

Table 7. Summary of prototype application

	Software or services	**Note**
Amazon Web Services	API Gateway	API container
	AWS Lambda	Serverless computing platform
	CloudWatch	Logging system
	CloudFormation	Deploying AWS resources
	S3 bucket	Lambda function code storage
Source code management	Git	Version control software
	Atlassian Bitbucket	Code repository
Continuous integration software	Bitbucket Pipeline	Being integrated into Bitbucket

6 TESTING SERVERLESS PROTOTYPE APPLICATION

Performance of the prototype application is studied to understand feasibility to adopt the serverless architecture into building production web services. The author employs load testing [40] to watch application's operation in different scenarios and configurations. Main purpose is to examine application's behaviors under various load conditions. To fulfill the goal, the author utilizes a cloud-based testing software to execute tests. Within this section, the tests' setup and results are summarized together with comprehensive discussions about such results.

6.1 Mutual testing configuration

In this study, mutual settings used in test scenarios are virtual user, loading iterations, and test duration, being listed in below table. Other configurations of ramp-up and delay times are distinguishing to generate distinct levels of stress on the application in each scenario. These elements will be discussed explicitly in each scenario. It should be noted about the restrictions on allocating resources for the load testing. Due to tight budget of this research, the author must choose a very basic load test option, which prevents to have higher loads to the application. The budget subscription allows to bring up maximum of 50 concurrent users in a test.

Table 8. Configuration elements [56]

Setting	Explanation	Applied number
Virtual users	Number of concurrent users to simulate heavy usage of many people.	50
Iterations	Number of time a test will be run until completed. Infinite iterations setting is equivalent to unlimited execution.	infinite
Duration	Maximum load time of a test before it is terminated.	6 minutes
Delay time *(milliseconds)*	Delay time between HTTP requests.	*Depending on test*
Ramp-up *(seconds)*	The time required to bring all virtual users online.	*Depending on test*

A total of five test scenarios are executed, being categorized into two groups. The group A consists of requests to four API endpoints of the prototype, in which third quarter of them

queries the database to ask for data. The scenario 1 and 2 belong to this group. On the other hand, all six endpoints of the second group (B) have interactions with the database. Half of them retrieves data records, meanwhile the other execute manipulating queries to the database by either adding, editing or deleting a row. Main purpose of these groups settings is to diversify load tests by simulating different application's use cases. Other than that, the following table gives brief explanation for different stats that will be mentioned in analysis and discussion about test results.

Table 9. Stats in load test's report [57]

Total requests	Overall number of requests sent to the application. Each request expects to have one response returned from the application.
Samples	Similarly, a sample is one request to the application.
Hits per Second	Number of samples initiated every second.
Average throughput (hits/seconds)	It is average of data rates delivered to the application, which is measured by hits per second. For example, the average throughput of 50 hits/seconds means that there are 50 requests every second.
Average response time (milliseconds)	Response time is amount of time required to process a request, being measured by elapsed time between first byte of data to leave a user and last byte of data received by that user. Average response time is the mean of such times from all requests. In other meaning, this stat reveals how long average user get response.
90% response time (milliseconds)	It is the 90^{th} percentile of response time, experienced by majority of users.
Error rate (%)	The error percentage of all requests.

Last but not least, it should be noted about some of 90% response time stats missing in group B's reports. They will be marked as not applicable (n/a). It is because of a limitation of the adopted loading test tool, which only returns list of top five slowest endpoints regarding this stat. Therefore, it is not possible to retrieve data for all six tested endpoints. Notwithstanding that, due to this nature, it is confidently confirmed that the missing endpoints show better performance than the rest in such test scenario. To equip readers with an insight into test report, executive summary of Scenario 3 (group B) is attached to this thesis as Appendix 4.

6.2 Group A - Scenario 1

In the first configuration, the application is tested by continuously receiving number of requests to different GET endpoints. Ramp-up and delay periods are set to 120 seconds and 500 milliseconds, respectively. This setup results in 27486 requests over a period of 6 minutes. In other words, the application prototype is stressed at average throughput of 76.6 hits per second.

Table 10. Scenario 1 - Test configuration and summary

Test configuration	**Ramp-up**	120 seconds
	Delay time	500 milliseconds
Executive results *(all endpoints)*	**Total requests**	27486 samples
	Average throughput	76.6 hits/second
	Average response time	53 milliseconds
	90% response time	66 milliseconds
	Error rate	0%

Apparently, it is witnessed that the prototype application easily handles all requests without any error. Specifically, average response times of all endpoints are 53 milliseconds (ms), and being stable at 66 milliseconds (with a rate of 90% all requests). The following table presents more details about explicit outcomes of each endpoint.

Table 11. Scenario 1 - All endpoint's results

Name	Endpoints	Samples	Hits/s	Average time (ms)	90% time (ms)
Health check *(service information)*	GET /probe/health	6888	19.19	66.92	70
Get an actor *(retrieve an actor from its id)*	GET /actor/13	6855	19.53	50.32	59

Get all countries *(list all countries)*	GET /country	6866	19.45	49.68	64
Get a country *(retrieve a country from its id)*	GET /country/100	6877	19.32	43.58	55

In addition, the below figure illustrates application's behavior during load period. As can be clearly seen, average response time mostly stabilizes, even when number of users increases (leading to higher total hits per second). It is also noted that there are spikes in response time at beginning and ending of the test, which lower overall performance.

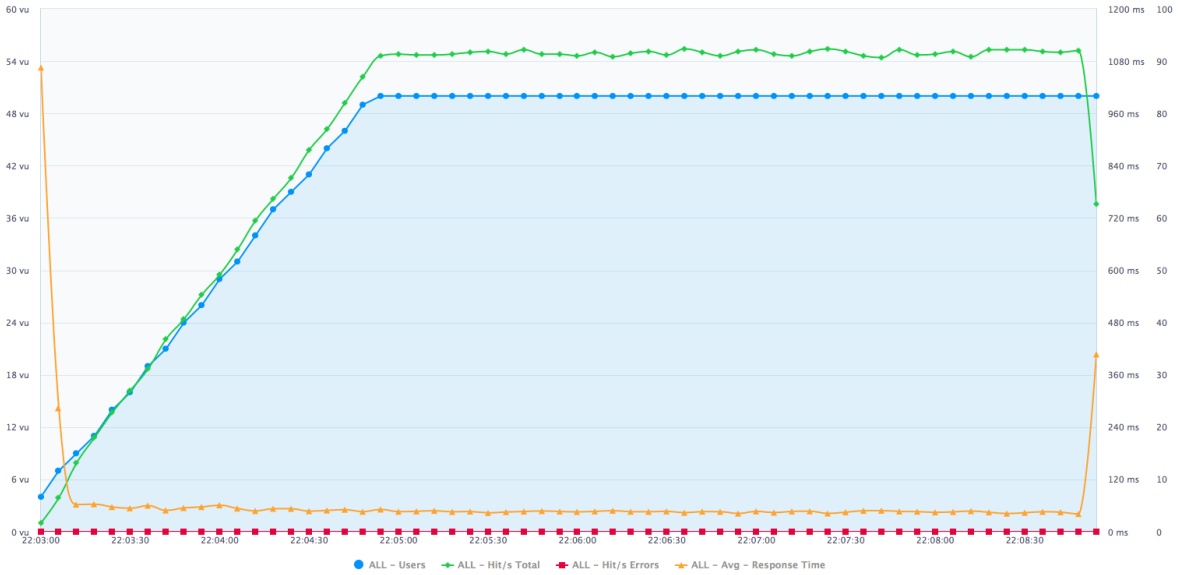

Figure 23. Scenario 1 - Timeline report

6.3 Group A - Scenario 2

Second stress targets at same endpoints with the first scenario, but few different settings are applied in order to generate higher load. The author set ramp-up to 50 seconds while delay was reduced to 100 milliseconds. Consequently, in comparison with the first scenario, this setup bombards the application with quadruple number of requests within the identical testing time of 6 minutes. To be specific, the author witnesses an aggregate 112174 hits, meaning that in every second the application must handle an average of 311.6 requests.

Table 12. Scenario 2 - Test configuration and summary

Test configuration	**Ramp-up**	50 seconds
	Delay time	100 milliseconds
Executive results *(all endpoints)*	**Total requests**	112174 samples
	Average throughput	311.6 hits/second
	Average response time	49 milliseconds
	90% response time	68 milliseconds
	Error rate	0.01% (7 samples)

Despite few errors, it is confident to confirm capability of the prototype application for managing this level of stressing. Yet, the author considers error rate of 0.01% to be insignificant in this case, in which there are only 7 error samples in such huge sample size. In the meantime, interestingly, average response of this test scenario is slightly faster than the first one (49 versus 53 milliseconds) although much higher demand for throughput occurred. Taking further look at each endpoint, most of them have better performances than in the first test scenario. Especially, *"Get an actor"* endpoint shows nearly 22% faster, meaning a big gap from the author's perspective.

Table 13. Scenario 2 - All endpoint's results

Name	Endpoints	Samples	Hits/s	Average time (ms)	90% time (ms)
Health check *(service information)*	GET /probe/health	28063	77.95	67.35	78
Get an actor *(retrieve an actor from its id)*	GET /actor/13	28024	78.28	39.26	54
Get all countries *(list all countries)*	GET /country	28037	78.10	46.03	62
Get a country *(retrieve a country from its id)*	GET /country/100	28050	78.13	41.36	56

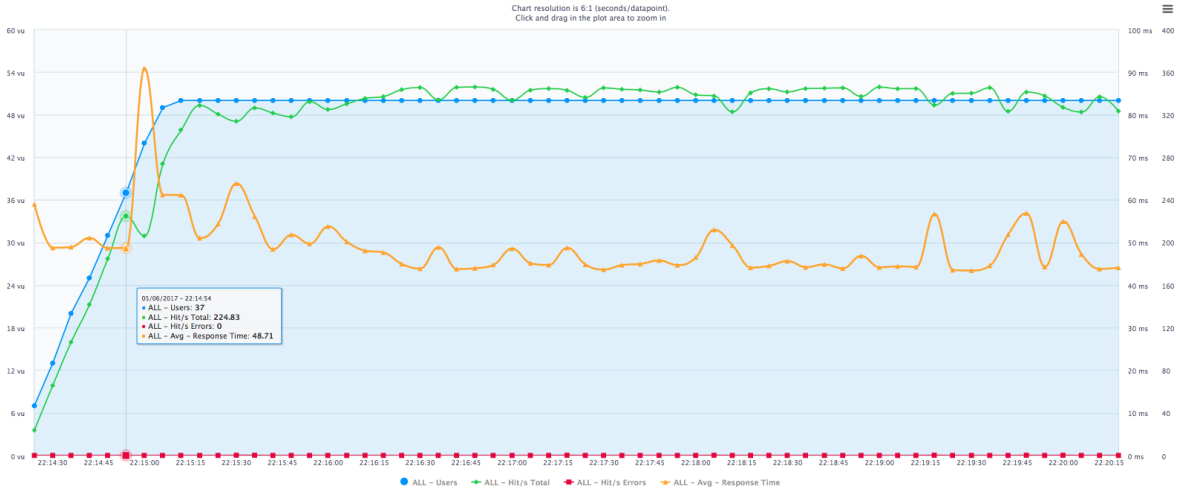

Figure 24. Scenario 2 - Timeline report

Comparing to the previous scenario regarding loading timeline, the author recognizes no peak of average response time at the start and end time. However, there are several spikes over the testing time, among which the most critical one is a 100% increase while the others raise only 20-25%. Furthermore, the highest response in Scenario 2 is around 90 milliseconds, whereas it is about 1000 milliseconds in Scenario 1. Therefore, in general, the author considers better performance in the second test. Such result is fairly surprising because the first plan generates a lower stress level.

6.4 Group B - Scenario 3

Table 14. Scenario 3 - Test configuration and summary

Test configuration	**Ramp-up**	120 seconds
	Delay time	500 milliseconds
Executive results *(all endpoints)*	**Total requests**	27098 samples
	Average throughput	75.3 hits/second
	Average response time	57 milliseconds
	90% response time	87 milliseconds
	Error rate	0%

The above table reveals configurations applied in this test - 120 seconds for ramp-up and 500 milliseconds delay time. Briefly, these settings result in 27098 requests to the application

(relatively similar to the first scenario), being tantamount to 75.3 per every second. In addition, the result also reveals that the application successfully passes this third load test without any error. Average performance is comparatively similar to the first and second tests, which all stay below 60 milliseconds to return a response. In contrast, Scenario 3 indicates a less positive number regarding the rate of 90% response time. This stat stabilizes at averagely 87 milliseconds to each request for the majority of users. More specifically, the application shows lower performance in comparison with the previous test scenarios, which are 66 and 68 milliseconds, respectively.

In the explicit analysis of each endpoint, all of them have very much alike stats, ranging from 40 to under 50 milliseconds of average response time. Meanwhile, the average response times of *"Create new actor"* and *"Get a country"* double, being at 86.36 and 81.87 milliseconds. The reason for slower response time probably causes from complicated settings of this test plan, which contains both reading and writing operations to database. Notwithstanding that, the author would like to consider an acceptable performance in this Scenario 3, especially when the application flawlessly handles all requests.

Table 15. Scenario 3 - All endpoint's results

Name	**Endpoints**	**Samples**	**Hits/s**	**Average time (ms)**	**90% time (ms)**
Create new actor *(add new actor to database)*	POST /actor	4538	12.61	86.36	102
Get all countries *(list all countries)*	GET /country	4532	12.62	49.64	64
Edit an actor *(update information of an actor)*	PUT /actor/4999	4518	12.62	40.06	*n/a*
Get an actor *(retrieve an actor from its id)*	GET /actor/3999	4513	12.64	44.26	57
Delete an actor *(remove actor from database by its id)*	DELETE /actor/699	4497	12.63	41.39	56

Get a country *(retrieve a country from its id)*	GET /country/50	4500	12.64	81.87	98

** n/a: not applicable*

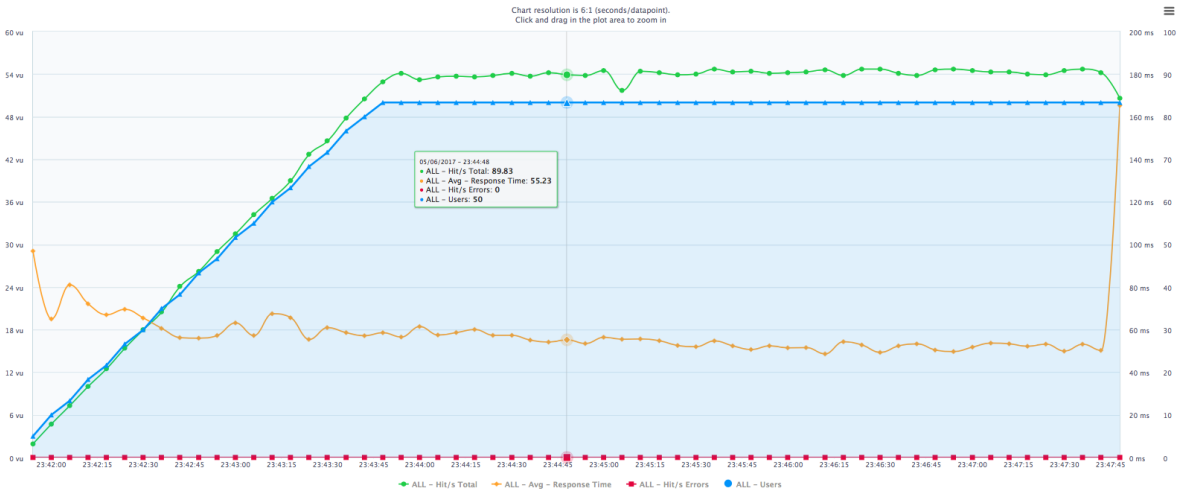

Figure 25. Scenario 3 - Timeline report

As can be seen, the average response time is quite stable over most of loading time. Furthermore, the graph illustrates a downward trend from above to below point of 60 milliseconds. There is a huge spike at the end in the timeline when the response time almost triples. It also shows spikes at the beginning, being much similar to the previous test plans. However, it is positive to witness a significantly lower peak time, staying at slightly above 160 milliseconds in comparison with around 1000 milliseconds in the Scenario 1.

6.5 Group B - Scenario 4

Having suffered from slower response in Scenario 3, this test configuration is not set to possible maximum numbers yet so as to gently increase stress level. Ramp-up duration reduces to 50 seconds, meanwhile 200-millisecond delay time is adopted - a decrease of 60%. As a consequence, a total number of 58628 requests is generated, being equivalent to 163.3 hits per second logged. On the other side, for all endpoints, it takes averagely 86 milliseconds (or 104 milliseconds in 90th percentile) to return a response to user. Comparing to other test scenarios, the executive report reveals a lower performance in general. However, this test's result is still good because error rate stays at 0% and around 100 milliseconds in response time is still positive number from the author's viewpoint.

Table 16. Scenario 4 - Test configuration and summary

Test configuration	**Ramp-up**	50 seconds
	Delay time	200 milliseconds
Executive results *(all endpoints)*	**Total requests**	58628 samples
	Average throughput	163.3 hits/second
	Average response time	86 milliseconds
	90% response time	104 milliseconds
	Error rate	0%

Table 17. Scenario 4 - All endpoint's results

Name	Endpoints	Samples	Hits/s	Average time (ms)	90% time (ms)
Create new actor *(add new actor to database)*	POST /actor	9801	27.30	258.89	160
Get all countries *(list all countries)*	GET /country	9795	27.36	59.13	88
Edit an actor *(update information of an actor)*	PUT /actor/4999	9777	27.31	60.08	85
Get an actor *(retrieve an actor from its id)*	GET /actor/3999	9753	27.32	49.29	70
Delete an actor *(remove actor from database by its id)*	DELETE /actor/699	9751	27.31	44.13	62
Get a country *(retrieve a country from its id)*	GET /country/50	9751	27.39	43.05	*n/a*

** n/a: not applicable*

To understand the reason, the author examines each API endpoint separately and explores a three times lower performance of *"Create new actor"*. Average response time for POST requests to this endpoint is 258.89 milliseconds, but the 90% of users experience faster time

at 160 milliseconds. In other words, it seems that a minor number of requests gets exceptional behavior of 1.5 times slower feedbacks. Regardless this endpoint, all of the others show much similar performance like in other scenarios, in terms of both average and 90% response time.

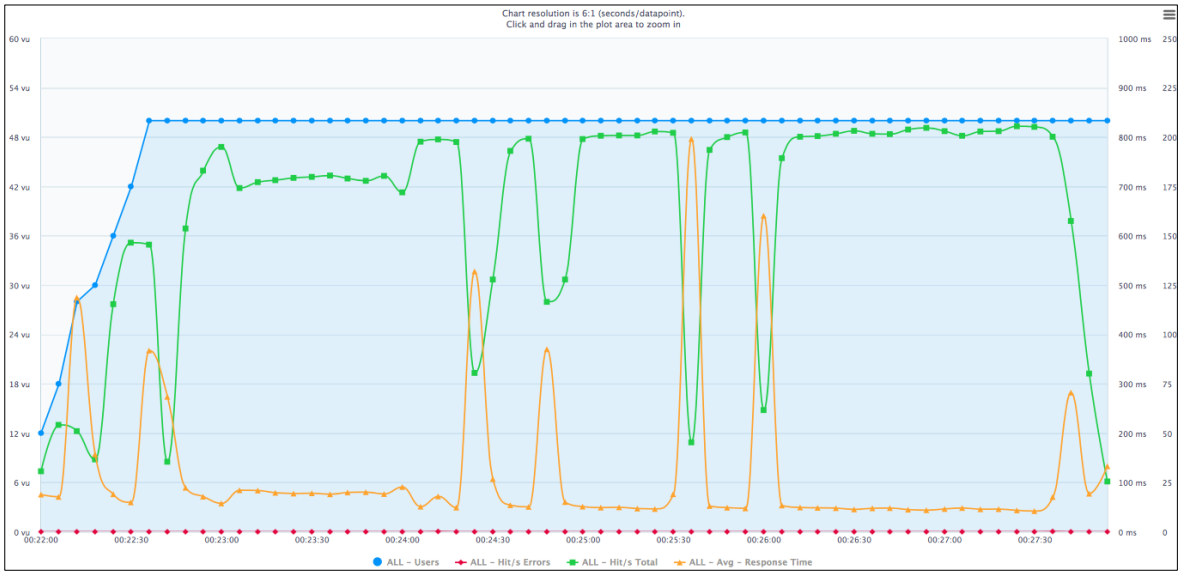

Figure 26. Scenario 4 - Timeline report

The timeline chart reveals relatively unstable response time during the load test, being dissimilar experience from the other tests. The graph shows huge spikes, in which response time skyrockets from under 100 milliseconds per request to 400, 500 or even 600 milliseconds. In addition, hits per second fluctuates greatly, meanwhile in other test scenarios such number stabilizes at a constant rate. The author recognizes that throughput hits drops correspondingly to whenever spikes occurred. As such, load level temporarily declines, making the application handle all requests more easily at that moment. In a word, considerable spikes and decreases in interim throughput contribute to the relative lower performance, indicating a weaker ability of the prototype application to handler massive requests.

6.6 Group B - Scenario 5

Despite slower response in Scenario 4, the application does not fail any request. Therefore, it is worth trying a higher stress level in this fifth test plan. As such, the ramp-up and delay

time are set to their possible maximum of the load test subscription. Such settings are identical to them in the Scenario 2 of group A. Consequently, the application has to handle a total number of 111706 requests, in corresponding to approximately 18600 samples for each endpoint. The total average throughput is 311.2 hits per second, being divided to around 51.92 hits reaching an individual resource each second.

Table 18. Scenario 5 - Test configuration and summary

Test configuration	**Ramp-up**	50 seconds
	Delay time	100 milliseconds
Executive results *(all endpoints)*	**Total requests**	111706 samples
	Average throughput	311.2 hits/second
	Average response time	49 milliseconds
	90% response time	84 milliseconds
	Error rate	0%

Result reveals that the application successfully manages the load with error-free. Surprisingly, it can be seen that response time of all endpoints is better than previous tests in group B. Most endpoints also have more positive performance at around 39 to 46 milliseconds in response time, excepting *"Create new actor"*. This individual POST endpoint is slower than the others, requiring averagely 90 milliseconds to reply a request. Notwithstanding that, despite much higher load, it should be admitted that the application showed a favorable performance. Yet, in this case, the stress level of Scenario 5 doubles and quadruples in comparison with Scenario 4 and Scenario 3, respectively.

Table 19. Scenario 4 - All endpoint's results

Name	Endpoints	Samples	Hits/s	Average time (ms)	90% time (ms)
Create new actor *(add new actor to database)*	POST /actor	18638	51.92	90.43	110
Get all countries *(list all countries)*	GET /country	18626	52.03	46.65	63

Edit an actor *(update information of an actor)*	PUT /actor/1999	18623	52.02	38.74	*n/a*
Get an actor *(retrieve an actor from its id)*	GET /actor/99	18618	52.01	40.38	55
Delete an actor *(remove actor from database by its id)*	DELETE /actor/199	18606	52.12	40.72	54
Get a country *(retrieve a country from its id)*	GET /country/105	18595	52.09	39.53	54

** n/a: not applicable*

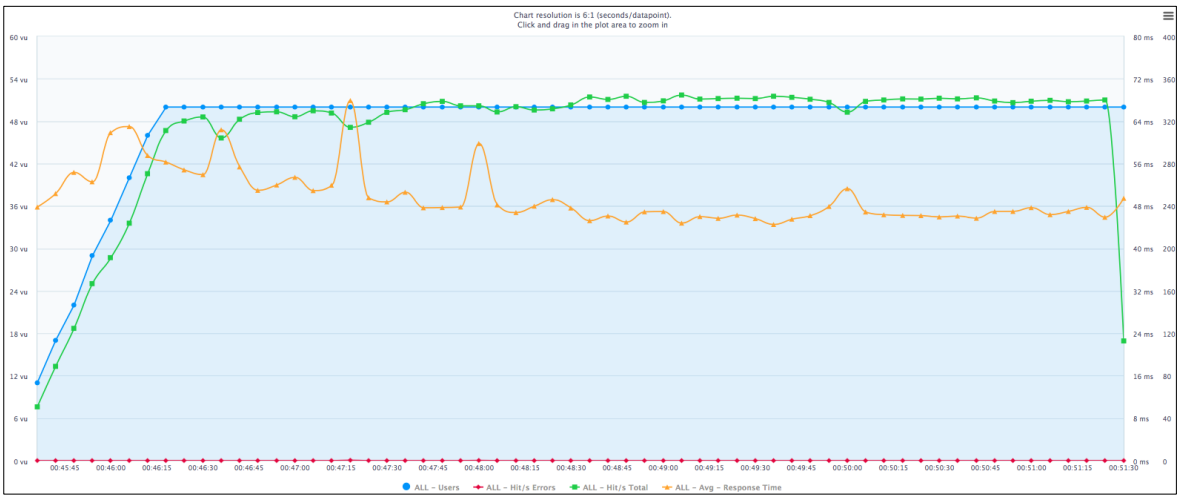

Figure 27. Scenario 5 - Timeline report

In contrast to previous tests, from the timeline chart, average response time indicates no considerable number at the start and end time. In spite of several spikes, it is positive to experience inconsiderably high peaks in average response, being around 20 milliseconds more than the average response of 50 milliseconds. To consider against Scenario 4, this result surprises the author because it bombards the application with twice more number of requests, and hence of a satisfactory performance.

6.7 Summary

Load test is employed to examine the prototype application to understand its performance and behaviors in a simulating operation environment. The author defines five testing scenarios to diversify the load condition and stress levels applied to the application. They are categorized into two groups, in which the first group contains 2 test scenarios performing only GET HTTP (Hypertext Transfer Protocol) requests. Meanwhile, the tests in the second group demand more from the application, consisting of various HTTP request's types (GET, POST, PUT, DELETE) of a RESTful (Representational State Transfer) web service. In an overview, the application operates well in all testing scenarios to handle all requests with significantly minor percentage of errors. The below table provides a review about rate of errors.

Table 20. Number of requests and errors in all tests

	Number of requests	**Number of errors**	**Error rate**
Scenario 1	27 486	0	0%
Scenario 2	112 174	7	0.01%
Scenario 3	27 098	0	0%
Scenario 5	58 628	0	0%
Scenario 5	111 706	0	0%
Overall	337 092	7	0.0021%

Times of average and 90% response indicate positive numbers in all test cases, ranging from 49 milliseconds to around 100 milliseconds. From the timeline graphs, the prototype illustrates relatively stable in terms of response times over testing period in most of all tests. The author witnesses a spike at the beginning of tests where response time stays at its peak. It would be caused by a warm-up time to wake up the prototype application after being inactive for a period of no request. Yet, Amazon provides AWS (Amazon Web Service) Lambda as container with necessary runtime environment settings. Whenever a function is invoked by API (Application Programming Interface) Gateway to respond an API request, AWS Lambda spends a certain time to launch a suitable container to execute code. The container can be reused in subsequent invocations, however after being idle for a while, AWS Lambda drops that container [19]. Therefore, it leads to an obligated latency to create

a new container. Differently than others, Scenario 4 reveals fluctuating response times over the 6-minute stressing period with several huge spikes. This exceptional performance is surprising as loading level is still twice lower than Scenario 5, in which the stat stabilizes. Taking closer look at tested API's endpoints, they have showed likely similar figures in the both stats, meaning that the application has same performance in different load conditions. Among them, it is seen that HTTP requests manipulating data records in database (POST, PUT and DELETE) require longer time to be completed.

7 CONCLUSION

7.1 Findings and discussion

In this thesis, design science approach is employed to conduct the research. The output of the research process is a design artefact, which consists of the serverless architecture and its development practice. The serverless architecture is an approach to build web services, while the development practice equips development team with a way to adopt it. As such, the author answers two main research questions (RQ) introduced in the chapter 2.

RQ1: What are main components of serverless architecture?

Main components of the serverless architecture are a serverless computing platform, API (Application Programming Interface) container and an operation monitoring tool. They are different cloud services provided by a cloud vendor. Among them, the computing platform is an ephemeral container with necessary software dependency installed to execute application's code without any server provisioning activities. API container helps publish, control access and maintain different APIs for consumer's usages to call backend service. Meanwhile, the monitoring tool tracks and stores operating logs of the application, which are useful to debug in case of incidents. Furthermore, database and supplement services (such as e-mail, phone or data storage) can be integrated into a serverless application in order to fulfill certain business requirements.

RQ2: What is the development practice of serverless architecture?

Various tools and software are employed in development of a serverless web application or web services. First, a version control software is used to maintain a common repository to provision changes of code base. The source code not only includes business logic but also all infrastructure configurations to serve the serverless application. Second, a continuous integration (CI) tool equips development team with the ability to build and deploy application to cloud environment. In addition, CI tool manages this process in an automated manner to increase working efficiency as well as time-saving. By using version control software, two development branches (develop and master) are dedicated for staging and production versions of the application, which are corresponding to the testing (staging) and production environments of the application. Developers create an isolated branch to write code for new feature. After being reviewed by others, this feature branch can be merged into

develop branch for deploying to test environment. Once new feature is verified and passes all tests, it is merged into master branch for production release. Changes pushed to develop or master branch will trigger build and deployment process, which are defined by relevant jobs in the CI platform.

The design artefact introduced in this thesis contains the serverless architecture and development practice to adopt the serverless architecture into building web services. It aims at solving business problem of a need for approach to develop and maintain web services without any worries about server provision. The presented artefact is delivered in the form of a model, containing the serverless architecture (illustrated in figure 4 in chapter 4.1) and a practice to adopt into development (illustrated in figure 6 in chapter 4.3. Specifically, the approach asks for less mandatory maintenance works relating to the application, such as procurement, installation and upgrade for both hardware and software. It helps reduce time and efforts of development team as the concerns are shifted to other party. Yet, cloud vendors are responsible for infrastructure, computing platform as well as necessary services at its highest availability and uptime. In other words, developers can focus on writing code, testing and deploying application at high scalability.

Following the guidelines of design science process, the author evaluates the outcome design artefact in terms of its utility, quality and efficacy. Thus, in controlled laboratory settings, a prototype application is developed with the adoption of the serverless architecture and introduced development practice. The prototype is powered by Amazon Web Service (AWS) cloud environment, being a proof-of-concept to confirm the feasibility and usability of the design artefact. A small team of three virtual developers is simulated to join the project, continuously write code for application's functionality, and push to the code base for build and deployment. Load testing is employed to check and evaluate the performance of the prototype application. Different scenarios and test cases are configured to watch the application's behaviors in various stressing level. The loading test reveals promising results as the application is capable for handling all tests with a very minor error in comparison with a considerable number of requests. As such, from the study, the author can confirm the feasibility of the design artefact of the serverless architecture and the development practice.

7.2 Research limitation and further research suggestion

There are limitations in this research to be discussed within this section. First, the research is not executed with full steps of design science process as it skips justification and communication of findings with the community (both technology and management oriented people). This limitation can be resolved by empirical studies of commercial projects in which the serverless architecture and practice are adopted. Researchers observe the development process, and collect evidence to conduct analysis of the adopted approach. Through the study, utility, quality and efficacy of the design artefact can be evaluated with real-world validation. Second, the development of serverless prototype application is limited to the Amazon Web Services (AWS) environment. AWS Lambda, API (Application Programming Interface) Gateway, AWS CloudWatch and others are concerning services in the design as well as implementation. As a result, it probably leads to the falsifiability of this study's findings when implementing with other cloud vendors available in the market. Third, technical implementation of the prototype application is counted as one limitation. Database design is excluded from the scope of this research. The design is an open-source sample from the PostgreSQL community. The database server is not powered by any cloud services but running on regular virtual machine. Moreover, the author picks JavaScript and Nodejs as the sole programming language and technology of choice. As such, it would falsify the research's results when developing with other technologies, or design and implementation of database are included.

Based on the limitations pointed above, the author would like to give suggestions on further research regarding the serverless architecture. First, adoption of the design artefact into commercial project can be examined. It helps to validate and justify the serverless architecture in real-world environment rather than in controlled laboratory configuration in this thesis. Second, the implementation of serverless architecture on cloud environment provided by other vendors can be studied. Those cloud providers can be Google Cloud and Microsoft Azure. Such studies will diversify the findings of this thesis in which the author only concentrate on Amazon Web Services.

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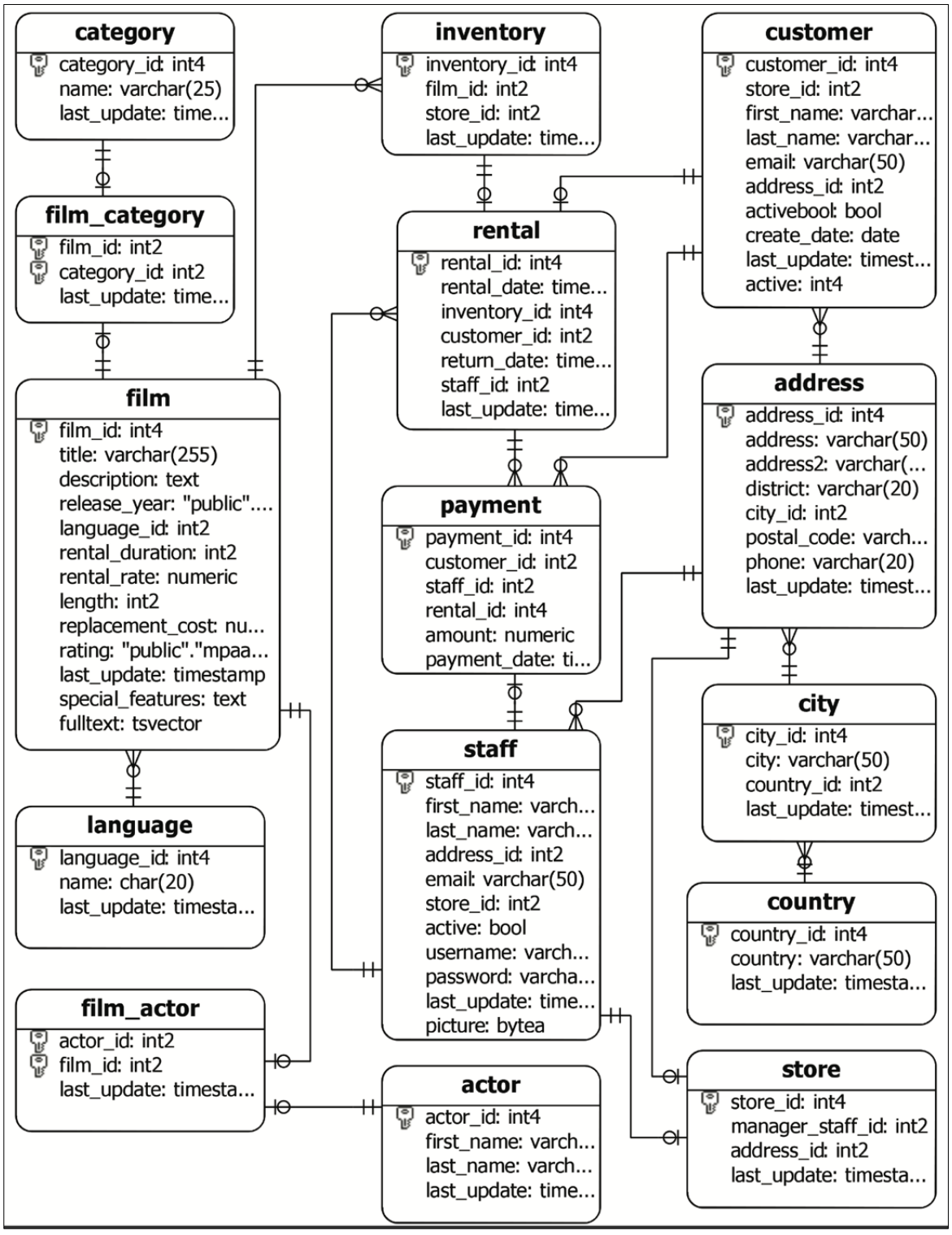
APPENDIX

Appendix 1 - Entity relationship diagram of sample database [50]



Appendix 2 - Executive summary of Scenario 3 (group B)

BlazeMeter

LOAD TEST REPORT

Staging - 3 GETs POST PUT DELETE - 120/500

Report created by Hieu Tran.
Date of Run: Mon, 06/05/2017 - 23:41
8 minutes test master

DESCRIPTIVE SUMMARY / CONCLUSIONS

Average Throughput	Avg. Response Time	90% Response Time	Error Rate
75.3	57	87	0
Hits/s	Milliseconds	Milliseconds	%

TOP 5 SLOW RESPONSES

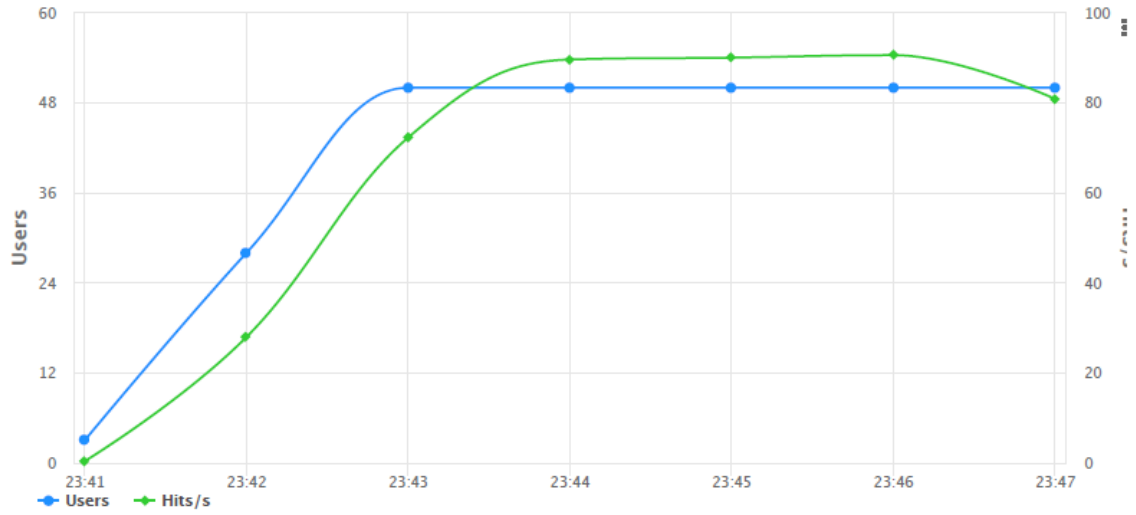
Request	% of executions	Avg Time	90% Time	Max Time
Create new actor	16.75%	86.356 ms	102 ms	2887 ms
Get a country	16.61%	81.867 ms	98 ms	1068 ms
Get all countries	16.72%	49.642 ms	64 ms	3046 ms
Get an actor	16.65%	44.256 ms	57 ms	2904 ms
Delete an actor	16.60%	41.388 ms	56 ms	2867 ms

TOP 5 ERRORS

THERE WERE NO ERRORS DURING THE TEST

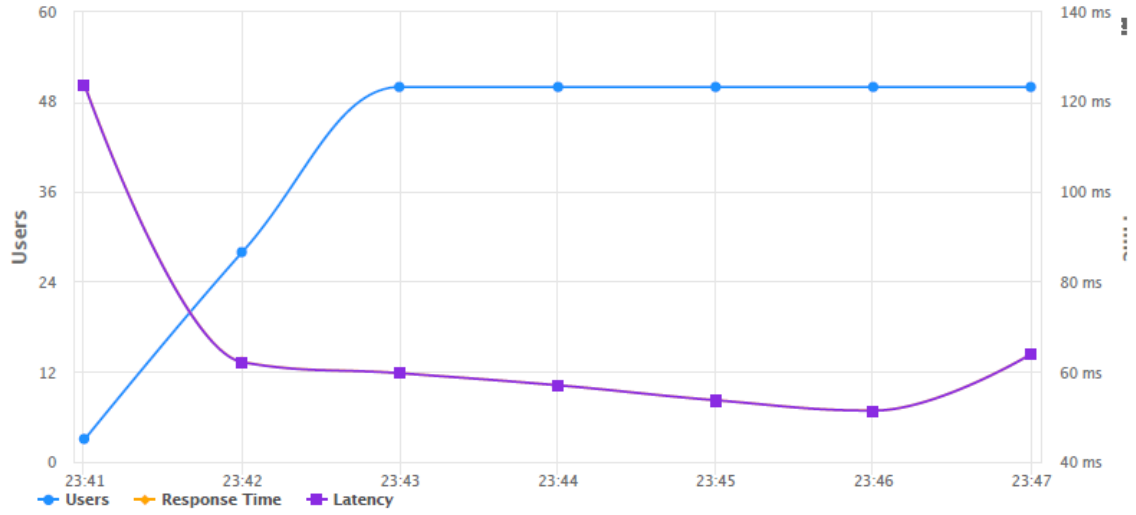
TIMELINE GRAPHS

Concurrent Users and Hits/s



TIMELINE GRAPHS

Concurrent Users and Response Time



AGGREGATE REPORT

Label	#Samples	Average	90% Line	99% Line	Error %	Hits/s
Get an actor	4513	44.256 ms	57 ms	184 ms	0%	12.64
Get all countries	4532	49.642 ms	64 ms	187 ms	0%	12.62
Get a country	4500	81.867 ms	98 ms	201 ms	0%	12.64
Edit an actor	4518	40.060 ms	55 ms	176 ms	0%	12.62
Delete an actor	4497	41.388 ms	56 ms	174 ms	0%	12.63
Create new actor	4538	86.356 ms	102 ms	216 ms	0%	12.61

ERROR REPORT

THERE WERE NO ERRORS DURING THE TEST

GLOSSARY

Virtual User
The entity used by load generation tool to simulate real users accessing the system under test.

Throughput
Number of requests completed in a time interval.

Response Time
The time that passed to perform the request and receive full response.

Bandwidth Usage
Amount of the network traffic that goes through network infrastructure.