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EVALUATION OF SERVERLESS COMPUTING SOLUTIONS SLA MANAGEMENT



Evaluation of Serverless computing solutions
SLA Management under the aspects of ISO/IEC 19086-1:2016

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ABSTRACT

As Stephen Hawking said, we are all now connected by the Internet, like neurons in a giant brain. Since the introduction of Internet, technology improved and formed new industries by dramatically changing how people communicate, interact and access information. Since Amazon launched its Elastic Compute Cloud (EC2) service, back in 2006 the term cloud computing started to involve in commercial areas. Part of the cloud motion is the introduction of Serverless computing known as Function-as-a-Service (FaaS). Nevertheless, providing or using cloud services makes it necessary to deliver or rely on a formal framework to guarantee a certain quality of service. Especially new emerging cloud services often lack appropriate service levels or terms of service. Serverless computing is one of the latest products on the market; therefore, it is an interesting topic to assess Serverless computing solutions of major Cloud Service Providers in terms of cloud service level agreement and management. The evaluation of Serverless computing solutions in this paper will follow the criteria given by the latest version of ISO/IEC 19086-1:2016 “Cloud computing service level agreement (SLA) framework”.

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I. INTRODUCTION

Computing in a cloud can be traced back to McCarthy proposal of utility computing. Since mid-1990s, the public leveraged forms of the Internet-based computing. The official term cloud computing emerged after Amazon launched its Elastic Compute Cloud (EC2) service which enabled organizations to rent computer and processing power for running their specific applications (Erl, Mahmood, & Puttini, 2013). In general, a cloud service varies and can exist as a web-based software program with interfaces invoked by using messaging protocols, or as a remote point for administration tools or larger environments and other IT resources.

A driving factor behind cloud computing is the availability of IT resources as services.

Therefore, several models for generic types of cloud services emerged over time and are labeled with the as-a-service suffix (Erl, Mahmood, & Puttini, 2013), such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), or Software as a Service (SaaS).

Another generic type of cloud service is Function-as-a-Service (FaaS) which got introduced back in 2014 (Amazon, 2014). This type of service differs from Platform-as-a-Service from their implementation perspective. FaaS systems handle requests and the associated function within milliseconds whereas PaaS systems are using application threads to handle multiple requests for longer period. In addition, the pricing model differs as well. FaaS services are charged according to the execution time whereas PaaS service pricing is based on consumed time of a thread where the server application runs.

By using cloud services, conditions are defined and typically expressed in a service level agreement (SLA). It is a human readable part of a service contract between a cloud customer and a cloud provider. Parts of a service level agreement are features, limitations and behaviors of a cloud service, but are not limited to it. As the implementation of a service is not visible to the cloud consumer, service level agreements become a critical specification. Another important aspect of SLA's is Contract and Service Management.

Based on these findings, the following research objectives will be addressed in this document:

1. How can Serverless computing solutions be evaluated in terms of SLA Management based on ISO/IEC 19086-1:2016?
2. Which criteria are relevant to assess Serverless computing Solutions based on ISO/IEC 19086-1:2016?

The aim of this work is to discuss the research objectives under scientific aspects and to illustrate the possible fields of application based on a practical example. First, an initial literature review is conducted to provide a summary of previous related research on the research problems. Next, a catalog with defined criteria is developed to allow an assessment of Serverless computing Solutions. This catalog builds the foundation to evaluate Serverless computing solutions based on their SLA management.



The approach taken in this manuscript to answer the research problems is to do an evaluation based on defined and developed criteria to meet the requirements from a science point of view. Finally, a summary and a personal reflection are highlighting potential opportunities and create favorable conditions for future investigations around this topic.

II. RELATED WORK

In order to answer all scientific questions, it is required to gain some comprehensive knowledge foundation to define criteria, which are needed for the evaluation approach. The used information is based on secondary analysis and therefore is not newly collected.
The National Institute of Standards and Technology (NIST) formed the generally accepted definition of Cloud Computing.

Cloud Computing is often described as a stack, as a response to the broad range of services built on top of one another under the moniker “Cloud”.

NIST describes the following characteristics that are needed for a service to be considered as a Cloud. Part of these characteristics are (Kepes, 2011):

- Ability to sign up and access services without long delays that characterizes traditional IT (On-demand self-service).
- Ability to access services via common platforms i.e. desktop, laptop, mobile (Broad network access)
- Scale to cope based on demand peaks (Rapid elasticity)
- Resources are pooled across several customers (Resource pooling)
- Billing is delivered and metered as a utility service (Measured service)

The Cloud Computing stack can be separated into categories i.e. IaaS, PaaS, and SaaS. Since the introduction of FaaS, it is important to understand that this differs from Platform-as-a-Service in certain areas. Platform-as-a-Service (PaaS) includes benefits, which are well known within the Software-as-a-Service (SaaS) domain for applications over to the software development world. It can be defined as a platform that enables the creation of web applications and reduces the time to market by reducing complexity of buying and maintaining software infrastructures underneath it. Therefore, it is a platform for the creation of software, which is delivered via the World Wide Web.

The term Function-as-a-Service (FaaS) is a new managed service which runs anonymous function with a snipped of source code once and triggers an event.

The benefit is that it is possible to run the code without provisioning or managing servers. Therefore, this new approach and architecture movement is known as Serverless computing. The term Compute-as-

a-service includes all required components to fulfil the promise of Service Oriented Architecture (SOA). It is even possible to provide a Serverless multi-tier architecture by physical segregation of application processing, presentation and data management functions. The Serverless model requires a complete cloud commitment because it cannot be tested locally anymore (Scarano, 2016). Another difference between Platform-as-a-Service and Function-as-a-service lies in the way how requests are handled. For Platform-as-a-service, application threads are used to handle multiple requests for a longer amount of time whereas Function-as-a-Service handles requests associated with a function in milliseconds.

The following graphic highlights the differences between FaaS and Paas as follow:

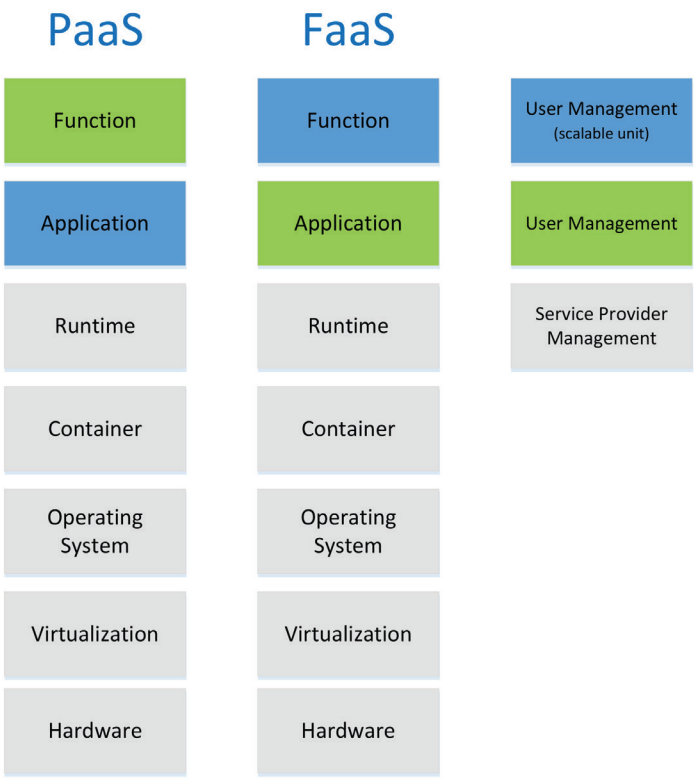


Figure 1: Difference between Faas and PaaS (in line with (Alibaba, 2016))

The key difference between FaaS and PaaS is scaling (Roberts, 2016). In a PaaS system, there is typically one single application thread which keeps running for a long period of time and handles multiple function calls. Therefore, a PaaS system allows scaling only on the level of the application but not on the level of functions. In contrast, FaaS breaks up the application into multiple individual functions (or pieces of business logic) without managing dedicated servers or server applications. As a result, FaaS allows scaling on the level of functions which makes an application more efficient.

In order to use a cloud service, a contract between the cloud provider and cloud consumer has to be established. One part of the contract is called Service Level Agreement (SLA).



A Service Level Agreement defines exactly the service and quality behavior what a cloud consumer can expect from the cloud provider.

According to ITIL (2011), a SLA is a formal, negotiated document that defines (or attempts to define) in quantitative (and perhaps qualitative) terms the service being offered to a customer. Any metrics included in a SLA should be capable of being measured on a regular basis and the SLA should record by whom. However, the integration of service level agreements is currently not regulated and can vary between cloud providers.

In 2010, a research report of Vanson Bourne demonstrated how organizations are handling services and their generalized service level agreements.

More than seventy percent of the interviewed organizations are avoiding the usage of cloud services based on their limited service level agreements.

In addition, the evaluation highlighted that companies located in Germany had financial damage due to unavailability of cloud services. As a result, the research report calculated the annual average loss caused by missing SLAs up to half million Euro per year (Federal Ministry of Education and Research, 2014).

In order to develop a standard for service level agreements, a joint ISO/IEC subcommittee of the International Organization for Standardization (ISO) has developed the ISO/IEC 19086. It is a four-part family of standards which establish a framework for cloud service level agreements (SLAs). This global standard provides guidance for organizations considering moving into the cloud and for providers offering services. In addition, the ISO/IEC 19086 provides a structure for organizations of any type of business. The first part, the ISO/IEC 19086-1:2016 (ISO, 2016), includes an overview of SLAs for cloud services, the concepts and requirements involved, and terms commonly used in cloud SLAs. The remaining parts are as follow (Microsoft, 2017):

- ISO/IEC 19086-2 - Defines metrics for properties of the standard's concepts
- ISO/IEC 19086-3 - Prescribes conformance requirements for cloud SLAs
- ISO/IEC 19086-4 - Identifies security and privacy aspects of cloud SLAs

The following figure represents an overview of the content of ISO/IEC 19086 and the relationships between the parts of ISO/IEC 19086 and other key International Standards relating to cloud computing.

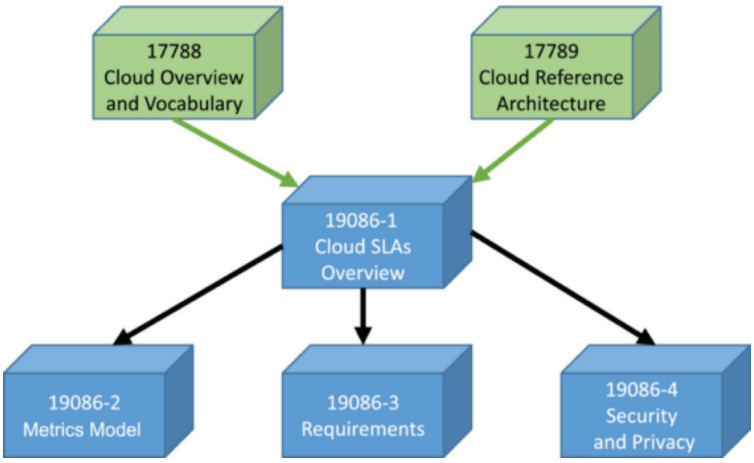


Figure 2: Relationship of parts of ISO/IEC 19086 and other cloud computing standards

III. USE CASE

As described in the previous chapters, Serverless computing is also known as Function-as-a-Services (FaaS) which provides the flexibility of code execution by using computing capacity of a specific cloud provider. As mentioned by Craig (2016), the following properties are named as a Serverless computing / Function-as-a-service:

- No Server Visibility
- Small-Size Payloads
- Ad Hoc Payload Format
- Event-Triggered Invocation
- Short Life Spans
- Cost-Efficient
- Variable Performance
- Limited Polyglot Support
- Cloud Provider Lock-In
- Inefficient Code Sharing

By now, there is no scientific or standardized definition that specifies all capabilities of this newly emerged cloud service. Global players in the cloud business like Amazon, Google, IBM and Microsoft offer their Serverless products on public clouds, and various companies like Netflix are heavy consumers of such solutions (Forbes, 2017). Additionally, the open source community also announced several Serverless computing projects (Forbes, 2017).

By reflecting service architectures like Netflix or comparable other services which rely strongly on the availability of these kinds of services, it is interesting how the different solutions of the leading cloud



providers differ from another in terms of the assured service level agreements. Terms like warranty, utility, availability and reliability must be implemented well to keep up the service quality. In order to compare and evaluate the services in a standardized way, elements of the ISO IEC 19086-1:2016 (ISO, 2016) will be used to define and measure the criteria by using the following FaaS Use Case:

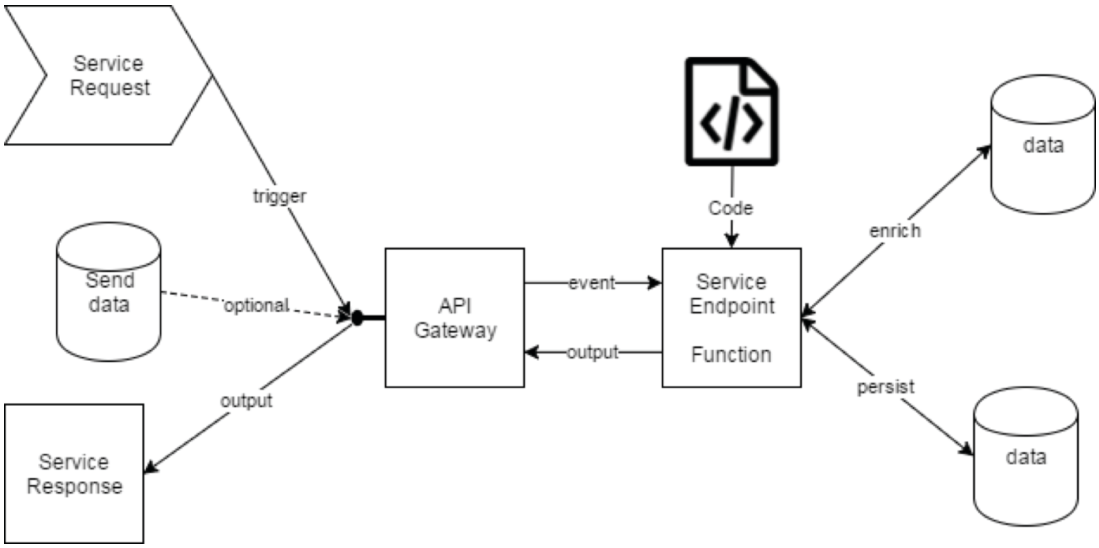


Figure 3: Simple example for a FaaS Use Case

Furthermore, the evaluation objects for this FaaS Use Case are:

- Amazon AWS Lambda
- IBM Bluemix OpenWhisk
- Google Cloud Functions
- Microsoft Azure Functions

IV. EVALUATION

Serverless applications are applications that promise high cost-efficiency by relying on third-party cloud infrastructure services. Cloud Service Providers solely provision cloud infrastructure services on-demand for the execution time of an application request. Typically, this request is executed in a composition of multiple cloud infrastructure service functions that are coordinated by an orchestration engine.

Given to the global nature of cloud computing, it is necessary to be able to rely on common definitions, vocabulary, terms, concepts, and architectures.

In this context, the ISO/IEC 19086-1:2016 (ISO, 2016) was established to mutually benefit Cloud Service Customers (CSC) and Cloud Service Providers (CSPs) by creating a framework that would enable consumers

and providers to more easily compare various cloud computing service offerings.

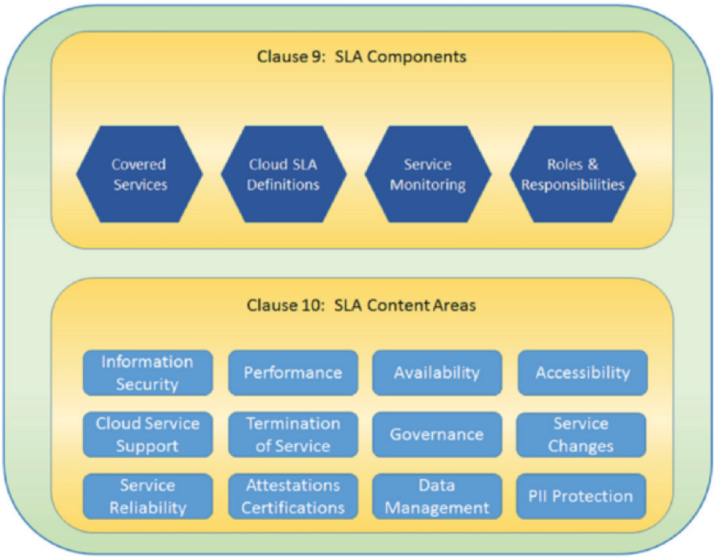


Figure 4: SLA components and SLA content areas (ISO, 2016)

As a result, the ISO/IEC 19086-1:2016 (ISO, 2016) contains details in 12 content areas which provide a much-needed standardized information for those who are involved in the cloud-computing assessment and contracting process.

The purpose of the following evaluation is to examine the existence, scope and implementation of service level agreements based on ISO/IEC 19086-1:2016 (ISO, 2016) for Serverless applications provided by four (4) CSPs (Amazon, IBM, Google, and Microsoft). The evaluation will take place in three steps. First, it is verified what kind of service level agreement exists. Second, the relevant SLA will be validated with the evaluation criteria of the ISO/IEC 19086-1:2016 (ISO, 2016). Finally, the criteria determinate wither it is applicable or not.

Due to the fact, that most Cloud service agreements are specially tailored to their needs, we have also included corresponding base agreements of the relevant Cloud service level agreements in the evaluation as topics like contract, privacy; support, warranty, etc. have already separate terms and agreements. The following terms and agreements are used in this section:

- Amazon AWS Lambda FAQs (Amazon, 2017)
- Amazon AWS Service Terms (Amazon, 2017)
- Amazon Customer Terms (Amazon, 2017)
- Amazon EC2 (Amazon, 2017)
- IBM Bluemix Service Description (IBM, 2017)
- IBM Cloud Service Agreement (IBM, 2017)



- Google Compute Engine (Google, 2016)
- Google Cloud Platform Terms (Google, 2017)
- Google Privacy Policy (Google, 2014)
- Microsoft SLA for functions (Microsoft, 2016)
- Microsoft Online Service Terms (Microsoft, 2017)

For ease of handling the evaluation criteria are bundled in four sections: Performance, service, data management, and governance. This approach considerably simplifies the interpretation of the results. The detailed evaluation sheet can be found in the Appendices section.

A. PERFORMANCE

This section includes accessibility standards to be met, availability guarantees, capacity, and elasticity specifications.

The components in detail:

- Accessibility: A description of assistive technologies (for people with disabilities) the CSP implements as part of the service.
- Availability: The amount of percentage of time in each period that the cloud service is accessible and usable.
- Capacity: Service properties related to the capacity of the service that can be included in the Cloud SLA.
- Elasticity: A description of the ability of a cloud service to dynamically adjust the amount of resources.

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Performance	Assesibility	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Availability	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	Yes	Yes
	Capacity	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	No	No
	Elasticity	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No

Figure 5: Performance evaluation

B. SERVICE

This section describes the basics for what service the CSP will offer most notably monitoring, response time, and resilience/fault tolerance. It also takes a deeper look at disaster recovery, backup/recovery, and support plan pricing and specs. The components are:

- Service monitoring: A description of parameters that are monitored by the CSP and the data provided to the CSC.
- Response time: The response time between a stimulus (trigger) to the cloud and the response of the service to the stimulus.
- Service resilience: A description of the methods employed by the CSP which afford resilience and Fault Tolerance for the cloud service(s). It also describes methods available to the CSC to afford resilience and fault tolerance for their own workload.
- Disaster recovery: A plan that includes a documented set of procedures adopted by the CSP for restoring the cloud service as well as the CSC's applications and data.
- Backup and restore data: A list of CSC data backup methods available to the CSC or employed by the CSP.
- Cloud service support: This component covers operational aspects such as point of contact, escalation procedures, as well as technical aspects.

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Service	Service monitoring	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Response Time	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Service resilience, fault tolerance	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Disaster recovery	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Backup and restore data	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Cloud Service Support	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No

Figure 6: Service evaluation



C. DATA MANAGEMENT

This section provides the building blocks and basics of data ownership, intellectual property, data portability, location, and more. The components in detail are:

- Cloud service provider data: This component defines and describes the cloud service provider data.
- Cloud service customer data: This statement defines and describes the cloud service customer data.
- Intellectual property rights: This component describes the ownership of the data.
- Account data: A description of the data elements for account data.
- Derived data: A description of data, which are the result of interaction with the cloud service by the CSC.
- Data portability: A description of methods, formats and protocols by the covered service(s) for data portability.
- Data deletion: A description of methods for the removal of access to data through the user and administrator capabilities of the cloud service.
- Data location: Data may be subject to requirements for the physical location.
- Data examination: CSPs may electronically examine incoming data before being passed to the cloud service to prevent materials prohibited by the terms of service from being processed or stored in their system.

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Data Management	Cloud service provider data	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Cloud service customer data	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Intellectual property rights	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Accout data	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Derived data	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Data portability	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Data deletion	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Data location	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Data examination	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No

Figure 7: Data management evaluation

D. GOVERNANCE

Finally, this section defines the roles and responsibilities of both parties, including information security, termination of service, changes, law enforcement access, and applicable certifications/audits/attestation.

- Roles and responsibilities: A description of roles and responsibilities for both the CSP and the CSC.
- Personally identifiable information: All information, which can be, used the identity to which the information relates or might be directly or indirectly linked to.
- Information security: References to ISO/IEC 27017 (ISO, 2015) and ISO/IEC 27018 (ISO, 2014) which addresses Information Security for Cloud services and Data protection. These standards are in turn based on the sets of security objectives and controls contained in ISO/IEC 27002 (ISO, 2013).
- Termination of service: A description of processes for notifying a CSC that the cloud service agreements are being terminated.
- Changes of features and functionality: A description of methods by which the CSP will notify CSC of changes to the features and functionality of the covered service(s).
- Law enforcement access: A statement of CSPs for notifying CSCs of any law enforcement request for customer data or account data.
- Attestation, certification, and audits: A list of standards, policies, and regulations where the CSP's compliance has been verified by an accredited certifying body.

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Governance	Roles and responsibilities	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Personal identifiable information (PII)	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	No	No
	Information security	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Termination of service	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Changes to features and functionality	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	Universal	Universal	Universal	Individual
		Applicable	FAQ	No	No	No
	Law enforcement access	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
	Attestation, certification, and audits	Name	AWS Lambda FAQ	IBM Bluemix	Google Compute Engine	SLA for Functions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No

Figure 8: Governance evaluation



V. RESULTS

This section presents a summary of the evaluation within the thematic criteria indicated. We use a Fibonacci-sequence-based valuation technique for estimating with a slight modification (only one, three, and eight whereas one means "Not existing", three stands for "Existing but vague", and eight for "Existing and/or fulfilling"). This approach ensures that single results do not influence each other mutually as they grow at about the same rate at which humans can perceive meaningful changes in magnitude.

Since data is expressed in absolute values, no weighting is used in this assessment. Therefore, all evaluation categories and criteria are equivalent for two reasons. First, we want to conduct an objective examination of the evaluation criteria based on ISO/IEC 19086-1:2016 (ISO, 2016). This approach ensures that this assessment is neutral without any bias. Second, any appropriate weighting depends on the intent use of the respective Cloud service criteria such as availability, information security, etc. Therefore, weighting have be determined on a case-by-case basis. It depends on the individual use case, local conditions, specifications and customer requirements which criteria might have a higher weighting than others.

Again, the detailed evaluation sheet (inclusive scoring) can be found in the Appendices section.

A. INDIVIDUAL ASSESSMENT

1) PERFORMANCE

The analysis of the performance section gives a homogenous picture. All CSPs make a clear statement regarding the cloud service availability and they describe availability as a percentage of time that the service is available and usable. On the other hand, all CSPs do not make any clear statement about elasticity and capacity. Only IBM makes a vague statement that the capacity in practice for any configuration of the Cloud service may change slightly than the configured capacity. In summary, all CSPs are at similar level in this section.

	Amazon	IBM	Google	Microsoft
Accessability	1	1	1	1
Availability	8	8	8	8
Capacity	1	3	1	1
Elasticity	1	1	1	1
Total	11	13	11	11

2) SERVICE

The assessment of the service section gives a mixed result. All CSPs offers a Cloud service support that covers operational aspects such as point of contact, escalation procedures, or technical aspects. On the other hand, not all providers also provide any information about service monitoring or even responsiveness, which may play a critical role in designing micro services-based applications. Poorly designed platforms will introduce startup latency and delay the invocation process, which would become obvious to customers.

When it comes to the criteria service resilience, disaster recovery, and backup/restore, the differences between the CSPs become very clear. Both, Google and Microsoft, make a very straightforward statement here. In contrast, Amazon officially shifts the responsibility for data integrity to the customers, whereas IBM makes no statement here at all.

As a result, IBM ranks at the very bottom while Google and Microsoft earn the most points in this section.

	Amazon	IBM	Google	Microsoft
Service Monitoring	1	1	1	1
Response time	1	1	1	1
Service resilience	3	1	8	8
Disaster recovery	1	1	8	8
Backup / Restore	8	1	1	1
Cloud service support	8	8	8	8
Total	22	13	27	27

3) DATA MANAGEMENT

The analysis of the data management section gives a split picture. All Cloud Service Providers offer a range of services with similar benefits, performance and efficiency incl. Cloud Service Provider and Customer data, intellectual property rights, account data, and derived data provide. In contrast, not all providers offer any description or statement regarding data portability. This shows clearly the lack of common technical standards to facilitate the transfer from one provider to another. Finally, data location and data examination are handled differently which needs to be addressed in the analysis as well.

As a result, Amazon and Google earn the most points in this section.

	Amazon	IBM	Google	Microsoft
Cloud service provider data	8	1	8	8
Cloud service customer data	8	8	8	8
intellectual property rights	8	8	8	8
Account data	8	8	8	8
Derived data	8	8	8	8
Data portability	1	1	1	1
Data deletion	8	8	8	8
Data location	8	1	8	1
Data examination	8	8	1	1
Total	65	51	58	51



4) GOVERNANCE

The final assessment of the governance section gives a unified picture as well. All CSPs offer a range of services with similar performance capabilities incl. roles and responsibilities, termination of service, and law enforcement access. There are only slight differences in Personal Identifiable Information and Data examination. However, it is remarkable that Google lacks in PII, Data examination and Information Security, which ranks Google at the very bottom while Amazon earns the highest result in this section.

	Amazon	IBM	Google	Microsoft
Roles and responsibilities	8	8	8	8
Personal dentifiable information (PII)	8	8	1	1
Information security	8	8	3	8
Termination of service	8	8	8	8
Changes to features and functionality	8	8	8	8
Law enforcement access	8	8	8	8
Attestation, certification and audits	8	8	8	1
Data examination	8	1	1	8
Total	64	57	45	50

B. SUMMARY OF THE EVALUATION

The overall assessment of the evaluation is obtained by adding up the points given for each single criterion.

	Amazon	IBM	Google	Microsoft
Performance	11	13	11	11
Service	22	13	27	27
Data management	65	51	58	51
Governance	64	57	45	50
Total	162	134	141	139

From an overall evaluation viewpoint, Amazon earns the highest results, followed by Google, Microsoft, and IBM. Again, we want to point out that the results of this evaluation do not interpret the quality of a specific cloud service but evaluate the quality of the service level agreement. At the one end of the spectrum, Amazon' Cloud SLA framework is very strong in the areas Data management and Governance but it has still room for improvement in the areas Performance and Service. Google and Microsoft, which run virtually neck-and-neck, do have their strength in the field of services but lack in Performance and Governance. Finally, IBM has a very strong governance but has some problems in the other disciplines.

In order to answer the second part of the research objectives, a framework with a set of methods has been developed and deployed which can be used not only for Serverless computing services but also for any

cloud service. The framework consists of four criteria which have been aggregated from 12 SLA content areas. This approach considerably simplifies the evaluation and the interpretation of the results.

C. SERVERLESS COMPUTING

The evaluation shows clearly that Serverless computing is a new technology. The ideas and concepts of Serverless computing have been around for a while but the implementation of Serverless computing has started few years ago. Therefore, the service levels agreements for Serverless computing and their corresponding cloud services are rudimentary and mainly focused on availability metrics only. For example, Amazon was one of the first major cloud provider to offer a Serverless computing solution called Lambda but the company is still providing a FAQ (Amazon, 2017) instead of a service level agreement. Another example is Google functions which is still in Beta state (Google, 2017) with resulting consequences. IBM (2017) provides a cloud service agreement which is very generic for all IBM's cloud based services but no SLA in specific to Openwhisk. Only Microsoft (2016) published a specific Service level agreement for Azure Functions but the content covers only few criteria of the ISO/IEC 19086-1:2016 (ISO, 2016). All Cloud Service Providers make no warranties regarding response time, elasticity, service resilience, and more. Instead, the responsibility, the risk of data loss or falsification remain with the customer.

D. ISO/IEC 19086-1:2016

As stated by the Cloud Standards Customer Council (2015), cloud service agreements are a set of documents or agreements that contains the terms governing the relationship between the cloud customer and the cloud service provider. However, as the cloud computing market is still developing, Cloud Service Customers should be aware that there may be a mismatch between their expectations and the cloud providers' actual service terms. At worst, SLAs often are inconsistent, strongly fragmented and lacking in governance.

In the context of the evaluation, the ISO/IEC 19086-1:2016 (ISO, 2016) made it easy to compare a set of service level agreements of several Cloud Service Providers by using common definitions, vocabulary, and terms. It provides an overview of the cloud-computing agreement environment, along with foundational concepts, and the terms and definitions that are generally recommended to be included in an executed cloud-computing service-level agreement. As a result, this standard helped us to identify the key criteria regarding performance, service, data management, and governance objectives despite multiple types of cloud-computing models and deployment methods.

As a result, by taking the ISO/IEC 19086-1:2016 (ISO, 2016) into account, the evaluation clearly identified the gaps and weaknesses of existing service level agreements. It also provided a list of possible measures and solutions in order to have an equivalent level of effective service levels. By using this standard, organizations will be able to define and communicate their goals and needs to providers, allowing both parties to form a better cloud service level agreement.



VI. CONCLUSION

This chapter presents the conclusion of the research work carried out in this paper. We summary the contributions of this essay and their implication to the Serverless computing Solutions SLA Management under the aspect of ISO/IEC 19086-1:2016 (ISO, 2016). We present in subsection A the summary of the essay contributions. In subsection B, we discuss the issues not covered by our proposed solutions.

A. SUMMARY

In this paper, the most recent Cloud SLA provided by today's leading Cloud Service Providers (Amazon, IBM, Google, Microsoft) have been subject to an assessment in reply to the research question how Serverless computing Solutions be evaluated in terms of SLA Management based on ISO/IEC 19086-1:2016 (ISO, 2016). This standard normally addresses the content of any Cloud SLA in 4 SLA Components and 12 SLA content areas but for this work, the structure and the setup of the content areas as been completely restructured and is now laid out more clearly in four criteria (Performance, Service, Data Management, and Governance). In a further step, all relevant Cloud SLAs for Serverless computing have been compared with the thematic criteria indicated and scored by using a Planning-Poker valuation technique. Finally, the overall assessment of the evaluation was obtained by adding up the points given for each single criterion. Serverless computing is a very new and fast-growing solution. The results of the assessment demonstrate that the related service level agreements do not have reached a same degree of maturity as traditional cloud service products (IaaS, PaaS, and SaaS). Furthermore, it should be considered that the results do not include the remaining parts of the ISO/IEC 19086:2016, in particular the metric model, the core service level objective requirements, and conformance requirements in the area of Security and Privacy.

B. CONSTRAINTS ON ESSAY CONTRIBUTIONS

We have restricted our evaluation intentionally on this topic and the ISO/IEC 19086-1:2016 (ISO, 2016) although there are other interesting projects norms, and standards, which have a similar approach in applying these important subjects. In this context, we refer here to Star Audit (2017) and the project SLALOM (2017). The purpose of the Star Audit (2017) scheme is to provide an accountable quality assessment of cloud services through a transparent and reliable certification process. In contrast, the SLALOM initiative (2017) provides a framework and templates for legal clauses and technical specifications by using the advances of ISO standards.

VII. FUTURE WORK

Current Cloud SLAs are not mature enough to manage Serverless computing services. Therefore, we are still faced with challenges, which might be interesting for further studies.

A. ISO/IEC 19086:2016

ISO/IEC 19086:2016 (ISO, 2016) is for the benefit and use of both Cloud Service Providers and Cloud Service Customers. The purpose of part 1 is to avoid confusion and to create a common understanding between CSP and CSC. However, parts 2, 3, and 4 of the family go into the metrics model, service level objective requirements, as well as security and privacy measures that need to be discussed under scientific aspects and demonstrated in a practical example.

B. MACHINE-READABLE SLAS

As stated by Ahronovitz, et al. (2010), machine-readable SLAs will allow Cloud Service Providers of online services and cloud service costumers to specify the services and service levels they require, to confirm that SLAs are being met, and automatically deal with possible SLA violations.

A machine-readable SLA will allow customers an automated, dynamic selection of Cloud Service Providers. This type of automation makes it possible to find the cheapest possible provider for some tasks but also the most secure provider for business-critical functions. This approach is also predestined for the use in multi-cloud environments.



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APPENDIX

A. EVALUATION SHEET

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Performance	Assesibility	Name	AWSLambda FAQ	IBMBluemix	Google Compute En	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	Amazon EC2	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	1	1	1
	Availability	Name	AWSLambda FAQ	IBMBluemix	Google Compute En	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	Yes	Yes
		Details	N/A	99.95% availability	Uptime 99.00% - < 99.95%	Uptime 99.00% - < 99.95%
		Framework	Amazon EC2	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	No	Yes
		Details	Uptime >= 99.0%, but less than 99.9%	N/A	N/A	N/A
		Score	8	8	8	8
	Capacity	Name	AWSLambda FAQ	IBMBluemix	Google Compute En	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	No	No
		Details	N/A	Vague description	N/A	N/A
		Framework	Amazon EC2	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	3	1	1
	Elasticity	Name	AWSLambda FAQ	IBMBluemix	Google Compute En	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	Amazon EC2	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	1	1	1

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Service	Service monitoring	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	Amazon EC2	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	1	1	1
	Response Time	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	1	1	1
	Service resilience, fault tolerance	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	Yes	Yes
		Details	Customers responsibility	N/A	Section "Data processing & Security Terms"	Section BCM
		Score	3	1	8	8
	Disaster recovery	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	Yes	Yes
		Details	N/A	N/A	Section "Data processing & Security Terms"	Data Recovery Procedures
		Score	1	1	8	8
	Backup and restore data	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	No	No
		Details	Customers responsibility	N/A	N/A	N/A
		Score	8	1	1	1
	Cloud Service Support	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Only when separate agreement	Vague description	Support Service Guidelines	Vague description
		Score	8	8	8	8



			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Data Management	Cloud service provider data	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	Yes	Yes
		Details	Customers responsibility	N/A	Section "Data processing & Security Terms"	Microsoft Azure Core Service
		Score	8	1	8	8
	Cloud service customer data	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Privacy poli	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Customers responsibility	Customers responsibility	Customers responsibility	Customers responsibility
		Score	8	8	8	8
	Intellectual property rights	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Customers responsibility	Customers responsibility	Customers responsibility	Customers responsibility
		Score	8	8	8	8
	Accout data	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Privacy poli	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Valid email address and a valid form of payment	Valid email address and a valid form of payment	Valid email address and a valid form of payment	Valid email address and a valid form of payment
		Score	8	8	8	8
	Derived data	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Privacy poli	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Maintenance or providing Service Offerings	Maintenance or providing Service Offerings	Maintenance or providing Service Offerings	Maintenance or providing Service Offerings
		Score	8	8	8	8
	Data portability	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Score	1	1	1	1
	Data deletion	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Available	Section 2	Section "Data Processing & Security Terms"	Available
		Score	8	8	8	8
	Data location	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	Yes	No
		Details	Customers responsibility	N/A	Section 1	N/A
		Score	8	1	8	1
	Data examination	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	No	No
		Details	Customers responsibility	Customers responsibility	N/A	N/A
		Score	8	8	1	1

			Amazon Lambda	IBM OpenWisk	Google Cloud Functions	Microsoft Azure Functions
Governance	Roles and responsibilities	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Available	Available	Available	Available
		Score	8	8	8	8
	Personal identifiable information (PII)	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	Yes	No	No
		Details	N/A	Customers responsibility	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Privacy poli	Microsoft Online Se
		Applicable	Yes	Yes	Yes	No
		Details	AWS IAM	Customers responsibility	Available	N/A
		Score	8	8	1	1
	Information security	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Customers responsibility	Customers responsibility	Section 1, but vague	Section "Online Service Information Security Policy"
		Score	8	8	3	8
	Termination of service	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Section 7	Section 7	Section 9	Section "Privacy"
		Score	8	8	8	8
	Changes to features and functionality	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	Universal	Universal	Universal	Individual
		Applicable	FAQ	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	Yes
		Details	Section 2	Section3	Section 1	Section "General Terms"
		Score	8	8	8	8
	Law enforcement access	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Customer Agr	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	Yes	Yes	No
		Details	Section4	Section 8	Section3	N/A
		Score	8	8	8	1
	Attestation, certification, and audits	Name	AWSLambda FAQ	IBMBluemix	Google Compute Er	SLA forFunctions
		Type of SLA	FAQ	Universal	Universal	Individual
		Applicable	No	No	No	No
		Details	N/A	N/A	N/A	N/A
		Framework	AWS Service Terms	IBM Cloud Service A	Google Cloud Platfo	Microsoft Online Se
		Applicable	Yes	No	No	Yes
		Details	List	N/A	N/A	Section "Online Service Information Security Policy"
		Score	8	1	1	8



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