

## Term Project –Cloud Application Design Analysis

Version 0.10

Project Proposal Due Date:	Friday October 27 <sup>th</sup> , 2023 @ 11:59 pm	
Project Short Presentation:	Tuesday December 12, 3:40pm – 5:40pm	(online & tentative)
Project Final Due Date:	Friday December 15 @ 11:59 pm	(tentative)

### Teams

Term Projects will typically be conducted in 4-person teams. The team should submit a single proposal.

### Objective

The goal for the term project is to implement a cloud computing application. The cloud application provides a use case that is then leveraged as a “vehicle” to perform a case study to contrast outcomes of alternate application designs. Tutorials 4, 5, and 6, prepare students to create cloud applications using the AWS Lambda serverless computing platform. A predefined serverless application project is provided as the “default” project that students can implement if they do not identify or propose another use case. For the term project, the idea is to investigate the consequences of alternate designs in terms of different evaluation criteria (i.e. performance in terms of runtime or throughput, cost, resource utilization, network latency, etc.). Groups are free to adopt the predefined project, or they are welcome to propose their own cloud application as a case study to meet the project criteria below.

Groups may propose term projects that do not build an AWS Lambda based serverless application. These projects may implement a serverless application using containers, or a cloud-based application using Infrastructure-as-a-Service cloud services. Regardless of the use case, all projects should compare and contrast design and architectural decisions for the building of a cloud software application. Alternatively, research-oriented projects that conduct original research in cloud computing are possible. Groups interested in proposing a cloud computing research project should reach out to the instructor to discuss the project idea before submitting the proposal. In addition, groups not implementing the predefined serverless application project are encouraged to consult with the instructor prior to submitting the proposal to ensure it is of appropriate scope.

Projects should implement a cloud application built using one or more cloud services. Many applications will be based on AWS Lambda, a Function-as-a-Service (FaaS) platform. The course will introduce the use of AWS Lambda, but integration of other FaaS platforms (e.g. Google Cloud Functions, Azure Functions, IBM Cloud Functions) or other compute-based hosting platforms (e.g. AWS Fargate, Amazon EC2, Google Compute Engine, Google Cloud Run, etc.) in the project is encouraged where appropriate. **The cloud application should provide a case study to enable comparing and contrasting application performance and cost implications for one or more design trade-offs.** With regards to performance, we are typically interested in quantifying metrics such as the average runtime, network latency, and data processing throughput (MB/sec) as comparisons, but other metrics are possible.

In addition to examining one-off performance, groups are encouraged to evaluate performance variation over time. We are interested in understanding the degree of performance variation over a time interval such as several hours, days, or weeks. Groups can also compare and contrast performance of cloud application deployments to alternate cloud regions, and where hardware heterogeneity (either exposed or hidden) is present in the hosting platform. Groups should report statistical performance averages, and compute standard deviation, and the coefficient of variation (CV) as a percentage. **CV=average / standard-deviation.** CV provides a way to express the difference in performance using a normalized percentage difference. CV is easy to compute and makes it easy to compare and contrast performance outcomes of systems. For example, **it is more meaningful to say your service is 3% faster than to say it is 37 ms faster.** CV removes time from the expression allowing performance comparisons when specific test cases having varying duration. Groups can also apply statistical tests to infer when performance observations are “significant”. A student t-test can be used to compare the difference of two means to have more confidence that system ‘A’ is outperforming system ‘B’.

For the term project, examples of design trade-offs for comparison include: alternate service compositions and application architectures (examples: “switchboard” architecture, full-service isolation, fully consolidated), alternative types of application flow control, use of alternative programming languages, alternate FaaS platforms, alternate cloud services, alternate cloud databases or backend data services, alternate hosting architectures (x86 vs ARM64, etc.), and alternate service abstractions, etc. etc.

### Cloud Application Use Cases:

The goal of the case study is to implement a cloud application at least two ways to enable a comparison of the performance and costs of the alternate designs. The case study will use performance experiments driven with identical input data sets as examples. The alternate designs should be tested with the same inputs to enable an “apples-to-apples” comparison.

Types of applications may include:

- Transform-Load-Query data processing pipeline, *variant of an Extract-Transform-Load (ETL) data processing pipeline (this is the STANDARD project...)*
- Image Processing Pipeline (apply a set of image transformations in a pipeline. These could include transformations such as rotation, crop, grey-scale, filters, etc.)
- Stream Processing Pipeline  
(Stream data to AWS Lambda for conversion, filtering, aggregation, archival storage)
- Statistics / Data Aggregation / Graph Generation
- Machine Learning inferencing or training pipelines: For example, build an application using: <https://cs.stanford.edu/people/karpathy/convnetjs/>
- Natural Language Processing (NLP) pipelines
- Map-reduce style function call chains: 1<sup>st</sup> function receives data set and splits and executes sequentially, data chunks are mapped to many concurrent/parallel instances of the 2<sup>nd</sup> function which are processed in parallel, results are then coalesced or aggregated using a 3<sup>rd</sup> function
- Image classification pipelines: one or more pretrained image classifiers would be deployed as separate functions
- Bioinformatics big data processing pipelines

## Case Study Design Trade-offs

The object for the term project is to compare and contrast alternate application design decisions to learn about their implications relative to performance, cost, cold-start latency, scalability, or any other performance level objective. Below is a list of possible design trade-offs that can be explored, but the list is not exhaustive. Groups are encouraged to be creative and to propose ambitious or unique projects to catalyze maximum learning from the experience.

**Service Composition:** Service composition refers to the decomposition of traditional applications into a service-oriented architecture consisting of independent web or micro-services. Developers must determine which functions to separate, and which functions to combine while considering the volume of data that must flow between services. For projects that investigate service composition, the application should have at least three separate services that perform a series of operations on input data. Individual Lambda functions serve to split operations into separate stages. At least one stage (service) of the computation must take a significant amount of time to compute for at least one example input (~30-seconds). Ideally, the runtime of all services combined would exceed a few minutes, though this may be difficult to achieve. It should be possible to compose the application in alternate ways:

Composition #1: Service-A Service-B Service-C  
Composition #2: Service-AB-combination Service-C  
Composition #3: Service-A Service-BC-combination  
Composition #4: Service-ABC-combination

*Note: Service-A probably can't be composed directly with Service-C because of the expected sequence of operations...Service-C would typically only operate on the output of Service-B...*

**“Switchboard” Architecture:** For a “Switchboard” architecture, all service code is combined into a single deployment package. Individual calls are made to perform function A, function B, and function C, but these calls go to the same function package. The switchboard architecture minimizes the number of service deployment packages by bundling all source code together into a single Lambda function. Control flow code at the front of the service routes incoming requests to different internal functions mapping the inputs as needed to carry out request processing using fully internal classes/methods. The “Switchboard” Architecture is in direct contrast to an architecture with full-service isolation where all functions are separated. In theory, minimizing the number of deployment packages will alter the overall cost and performance because this architecture increases instances of infrastructure reuse which should ultimately reduce the impact of the serverless infrastructure freeze/thaw cycle.

What is Serverless Infrastructure Freeze/Thaw?:

*We will talk about this later, but see this paper, section I. B. for a discussion:*

<https://tinyurl.com/y4w5ocj8>

**Application Control Flow:** A case study on application control flow will compare alternate methods to implement a sequence of service calls and their subsequent data exchange for composition #1 above.

With a laptop-client: The laptop calls all services synchronously and is responsible for moving data to and from each of them: A, then B, then C

Within Lambda: An external client makes an initial asynchronous call to Lambda Service A. Service A

then either calls Service B (1) directly, via the (2) Simple Notification Service (SNS), or using the (3) Simple Queueing Service (SQS) to trigger then next call. At the end of the calling sequence final results are stored and later retrieved by the external client using either the Simple Storage Service (S3) or an alternate service such as the Simple Queueing Service (SQS).

**Controller Function:** A FaaS function can instrument the flow control of a multi-function sequence by running synchronously and issuing various FaaS function calls. This model suffers from double billing as the controller function runs synchronously while essentially idle and waiting for other functions to respond. Ideally the synchronous controller would be deployed with a low memory size to save cost.

**With AWS Step Functions:** AWS provides Step functions to define a workflow of serverless functions. A state machine is defined to capture the flow of execution across a set of functions. The state machine runs on the server-side (e.g. on the cloud).

**With Function Triggers:** AWS Lambda functions can be triggered based on events spawned from other AWS services. In particular, CloudWatch can trigger functions based on events such as data arriving at a Simple Storage Bucket (S3), or based on an event timer that is triggered at a regular interval. Events can be triggered using the Simple Queueing Service (SQS) or Simple Notification Service (SNS). These function invocations can occur without the use of any dedicated cloud infrastructure (e.g. virtual machines or functions).

**Programming Languages:** Choice of programming language (e.g. interpreted vs. compiled) impacts runtime as well as initialization overhead. FaaS function executions relying on the Java Virtual Machine or .NET framework have been shown to incur additional overhead vs. running interpreted functions in Node.JS or Python. Students can perform a case study on the implications of alternative programming languages for serverless applications. For this case study, teams should implement an identical application in 2 or more languages, and then complete identical performance experiments to contrast differences. For Fall 2021, to ensure uniqueness from prior work, projects are encouraged to implement a serverless application other than the TLQ data processing pipeline. If implementing the TLQ pipeline, groups are encouraged to compare implementations using multiple versions of Java, Python, or Node.js, or investigate implementations in languages not previously tried such as C# or Ruby on AWS Lambda. Additionally, implementing this project on Google Cloud Functions, Azure Functions, or IBM Cloud Functions would be considered as entirely new.

See our paper:

<https://tinyurl.com/y46eq6np>

And a related paper:

<https://faculty.washington.edu/wlloyd/courses/tcss562/papers/Fall2019/AnInvestigationOfTheImpactOfLanguageRuntimeOnThePerformanceAndCostOfServerlessFunctions.pdf>

**Platforms:** Many commercial and private Function-as-a-Service (FaaS) platforms exist for hosting application code. One potential case study is to compare and contrast application performance for applications consisting of several FaaS functions deployed to alternate clouds. Groups should verify that alternate FaaS Platforms support identical languages so that pipelines have near-identical source code. As platforms involve different backend databases, plans should be discussed on how cross-cloud differences will be addressed in the case study to ensure equity for the comparison.

**Data Provisioning:** Data provided to FaaS functions is limited to a maximize size. On AWS Lambda the standard payload is limited to 6MB. Alternatively, data can be uploaded to external cloud services such as the Simple Storage Service (S3), Dynamo DB, Amazon Aurora, or Amazon RDS, etc. The goal of a data provisioning case study is to examine implications for data transfer (up and down) when operating with large data sizes. What is the best way (performance and cost) to move large data sets to and from the FaaS functions that require them? Network latency to access services like S3 from AWS Lambda has been noted as a potential bottleneck. Overhead on the order of 100-300ms, for example, simply to access data can significantly slow data processing times. A data provisioning case study will investigate which cloud services provide data fastest to FaaS platforms to minimize this latency to maximize the processing throughput of data processing pipelines. Use of data transfer sizes exceeding 6MB is encouraged, but not necessarily required to explore this interesting topic.

\*\* it would be interesting to measure data service performance variation – how stable is the performance of different data backends \*\*

**Containers on FaaS:** Recently, AWS Lambda has added support to access read-only Docker container images with FaaS functions. These containers can be up to 10GB in size, providing the capability to provide 10GB worth of libraries and/or data to support a broader set of use cases. One possible term project is to benchmark the performance and scalability of using containers on AWS Lambda. In particular, containers allow deploying and hosting larger applications using serverless functions.

**Alternate Cloud Services:** A case study can be performed by implementing an identical data processing pipeline with different backends. For example, for the Transform Load Query pipeline, using Amazon Aurora MySQL Serverless compared to Amazon RDS MySQL, or DynamoDB. If the two databases are not both relational database management systems (RDBMS), then the case study will need to ensure functionality equivalency of tests/experiments to the Query (Q) stage of the pipeline. In addition, alternate object storage or queue services can be compared.

**Performance Variability:** The group can use their application case study to examine cloud performance variability across hours, days, weeks, availability zones, and regions. The idea is to see if there are reproducible patterns. Can good performance during certain time windows be leveraged to improve performance and reduce costs for data processing?

**Service Abstraction:** Apache Libcloud and Apache jclouds provide middleware which abstracts vendor specific details for using cloud services. Currently support is only for object storage services. One idea is to leverage an abstraction library (i.e. jClouds) as a means to make source code cross-cloud (e.g. vendor agnostic). The group could implement their own abstraction layer for a relational database to implement an entirely generic serverless application that is not locked into a specific FaaS platform.

**Alternate CPU Architectures:** Recently AWS Lambda added support for executing code on Graviton2 ARM64-based processors. These are RISC based server processors more similar to the CPUs found in mobile devices and smart phones than traditional CISC based Intel processors. These processors offer some advantages over Intel. One is price. Amazon discounts the use of the Graviton2 processors by approximately ~20% compared to Intel. These processors also eliminate hyperthreading, which appears to result in overall more consistent performance. Developing a serverless application and then comparing performance of Intel vs. ARM CPUs would be an excellent case study topic.

See our paper on the topic here:

[http://faculty.washington.edu/wlloyd/papers/hotcloudperf\\_lambda\\_variability\\_final.pdf](http://faculty.washington.edu/wlloyd/papers/hotcloudperf_lambda_variability_final.pdf)

**Multiple Topics:** Some groups may want to explore multiple case studies. The advantage of having multiple goals is in the end, groups may discover that one goal produced better and more interesting results than another. This strategy can help the project grade, and may even lead to a publication!

**Predefined Project(s)**  
**AWS Lambda TLQ (Transform, Load, Query) Data Pipeline**

The predefined project is to implement a multi-stage TLQ pipeline as a set of independent AWS Lambda services. If implementing the predefined project, it is only necessary to specify the design trade-offs that will be studied, because the application use case is already defined. This will save groups time.

Examples of design-tradeoffs that can be studied: Service Composition/Architecture, “Switchboard” Architecture, Application Flow Control, or Data Provisioning. The TLQ pipeline is similar to an Extract-Transform-Load (ETL) pipeline. The Transform phase (Service #1) performs data extraction and transformation as a single service because data is only from one source. Service #1 performs E(xtract) and T(ransform), service #2 performs data L(oad), and Service #3 performs data Q(ueying). The E(xtract) is combined with T(ransform) because input data is provided in a single easy-to-use format.

**Sales Database**

Sales Data is provided in CSV format. As sample input dataset consists of up to 1.5 million rows and 179 MB of data uncompressed. Data columns include:

Region	text
Country	text
Item Type	text
Sales Channel	text
Order Priority	text
Order Date	date
Order ID	integer
Ship Date	data
Units Sold	integer
Unit Price	float
Unit Cost	float
Total Revenue	float
Total Cost	float
Total Profit	float

Data files are available at:

[http://faculty.washington.edu/wlloyd/courses/tcss562/project/tlq/sales\\_data/](http://faculty.washington.edu/wlloyd/courses/tcss562/project/tlq/sales_data/)

An alternative larger dataset (approx. 6 GB) consisting of medical records data is also available at:

[http://faculty.washington.edu/wlloyd/courses/tcss562/project/tlq/medical\\_records\\_data/](http://faculty.washington.edu/wlloyd/courses/tcss562/project/tlq/medical_records_data/)

In addition, it should be possible to write a program to further grow these datasets by randomizing their content.

### **Service #1 (Extract and Transform):**

Service #1 either receives the CSV data directly as an input parameter in the data payload (e.g. see REST multipart), or accesses data using a pointer to a CSV file in S3, or other cloud data service.

Example Service #1 transformations (can implement others):

1. Add column **[Order Processing Time]** column that stores an integer value representing the number of days between the [Order Date] and [Ship Date]
2. Transform [Order Priority] column:  
L to "Low"  
M to "Medium"  
H to "High"  
C to "Critical"
3. Add a **[Gross Margin]** column. The Gross Margin Column is a percentage calculated using the formula: [Total Profit] / [Total Revenue]. It is stored as a floating point value (e.g 0.25 for 25% profit).
4. Remove duplicate data identified by [Order ID]. Any record having an a duplicate [Order ID] that has already been processed will be ignored.

Non-Switchboard Architecture: Transformed data should be written out in CSV format and stored in Amazon S3 or other cloud data service for retrieval by Service #2.

"Switchboard" Architecture: Transformed data should be: (1) persisted locally as a CSV file under /tmp, (2) stored in memory, and/or (3) persisted to Amazon S3. These alternate data transfer mechanisms between steps of the TLQ data processing having a "Switchboard" Architecture represent alternate designs which can be studied. With the "Switchboard" Architecture all services share the same infrastructure. When Service #2 is called, it may find the cached data in memory or under /tmp leftover from Service #1. If the data is unavailable, it is requested from Amazon S3. See article regarding data caching on AWS Lambda: <https://medium.com/@tjholowaychuk/aws-lambda-lifecycle-and-in-memory-caching-c9cd0844e072>

Scaling Scenario: If there is just one call to Service #1 to transform the data, but 10 calls to Service #2 to load the data, using the "Switchboard" Architecture, one call would find the data locally, and 9 calls will need to request the data from Amazon S3.

### **Service #2 (Load):**

Service #2 requests include a pointer to the transformed CSV data in S3.

Service #2 loads the data from the CSV file into a single table relational database. The table is keyed by the [Order ID] field which must be unique. Duplicate rows should have been already filtered out by Service #1.

Database:

There are several options for a "data" tier for a serverless application.

Amazon Aurora is Amazon's serverless database service. Both a MySQL and PostgreSQL versions are supported. Our ETL pipeline will perform an initial data transformation (S1), create a relational representation (S2), and then allow multiple read-only queries to be performed (S3). Since queries in S3 are read-only, using an external data service is not required.

Use of the locally hosted database SQLite is also a possibility. The advantage is elimination of a dependency for an external data service for read-only queries. This will keep everyone's costs down. The disadvantage is that there are many unsynchronized copies of the database spread across Lambda functions. Groups may SQLite as a comparison to a serverless backend database (Amazon RDS, etc.) Synchronization of individual SQLite databases deployed across Lambda functions is not required, as this would be non-trivial, but could be a good research project.

SQLite:

<https://www.sqlite.org/index.html>

Groups can propose and adopt alternate backend database approaches and technologies for data storage and query processing as part of their proposed case study. Design of a serverless application's data tier is likely to have a significant impact on overall performance and hosting costs.

For using a local file-based database with the "Switchboard" Architecture, once Service #2 loads data into a database, such as SQLite, the file can be (1) persisted locally under /tmp in the serverless container for later use by Service #3. For non-switchboard architectures, Service #2, exports the SQLite DB file to Amazon S3 for retrieval and replication by Service #3. Groups can devise clever ways to persist SQLite databases to S3 and pull them down locally when queries run on cold infrastructure.

For simplicity, it is okay to assume that queries will be read only, and that data is only modified during the load phase of the pipeline. Groups wishing to perform "update" queries in the "Q" phase will run into the problem of how to synchronize data across Lambda functions.

### **Service #3 (Query):**

Service #3 performs filtering and aggregation of data queries on data loaded into a relational database by Service #3. Service requests will be in JSON format.

Service #3 is backed by the same SQLite DB (or Amazon Aurora/RDS) to perform meaningful queries to produce output in JSON array format. Each row will be represented as a single JSON object in an array.

Filtering and aggregation is supported by generating SQL queries.

Each call to Service #3 will specify 1 or more columns to aggregate data on (GROUP BY), and 0 to many filters which involve including a WHERE clause to an SQL query to specify column matching requests. Aggregation involves adding a GROUP BY clause to an SQL query and using a function such as SUM(), AVG(), MIN(), MAX(), and COUNT().

If using a local DB, Service #3 begins by checking if there is a local SQLite DB file saved. If no file exists, the master copy produced by Service #2 can be downloaded from Amazon S3 and cached to support Service #3 requests.



Service #3 will accept requests to filter the full data set by column, for example:

- [Region]="Australia and Oceania"
- [Item Type]="Office Supplies"
- [Sales Channel]="Offline"
- [Order Priority]="Medium"
- [Country]="Fiji"

Service #3 will support the following data aggregations by column.

- Average [Order Processing Time] in days
- Average [Gross Margin] in percent
- Average [Units Sold]
- Max [Units Sold]
- Min [Units Sold]
- Total [Units Sold]
- Total [Total Revenue]
- Total [Total Profit]
- Number of Orders

Service #3 outputs each row of output from a relational database query as a separate JSON object in a JSON array. The JSON objects include the data aggregation(s) based on specified filters.

### **Alternate Projects**

#### **Parallel Client – TLQ Pipeline**

As an alternative to developing a TLQ pipeline that will be invoked sequentially to process one record at a time, groups can implement a parallel client which will divide a large dataset into chunks for parallel processing. The serverless pipeline would then transform data in parallel for the "T" service, and load data records in parallel for the "L" service to a backend database. The objective would be to minimize the time to load the entire dataset by using multiple concurrent serverless function instances to process data in parallel.

#### **Streaming TLQ Pipeline**

As an alternative to the standard project, groups may implement the Transform Load Query as a streaming application, where instead of providing large CSV files to S3 for batch processing, the group implements a client which streams individual records to the pipeline for processing at varying time-intervals, for example once every second, or fraction of a second. The pipeline would then need to collect data sent from hundreds or thousands of service requests as opposed to having all data immediately available in a large CSV file (e.g. blob). The group could integrate the use of Amazon Kinesis in this project. Clients invoking the TLQ pipeline can consider use of a Poisson distribution to randomize when data is delivered for processing.

#### **Image Processing Pipeline**

As an alternative to the standard project, groups can implement a multi-stage image processing pipeline that applies filters and transformations to graphics images. Stages may include operations such as

“grey-scale”, “resize”, “rotate”, “sepia”, etc. Processing will generally involve applying a fixed set of filters and transformation in sequence, repeatedly. Various sequences can be tested.

### **Stream Processing Pipeline**

As an alternative to the standard project, groups can implement a multi-stage stream processing pipeline that implements data conversion, filtering, aggregation, and archival storage over data streams that are provided at a varying degree of throughput rates (records/sec). The group could integrate the use of Amazon Kinesis in this project and compare throughput with Amazon Kinesis, and without Amazon Kinesis (e.g. pure AWS Lambda implementation) to examine performance and cost of data streaming using Kinesis and Lambda.

For other ideas or feedback on project ideas, please consult the instructor.

### **Project Proposal Submission Requirements**

**[7% of project grade]**

The following are key requirements of the project proposal:

Each team will submit a 1 to 2 page short project proposal description. *The proposal length will typically be longer if NOT implementing the predefined project as the cloud application.*

The proposal must identify:

1. The **member names** of the project group.  
*(group size should be 4 – instructor permission required for different sizes)*
2. The name of the group project **contact person**. The group project contact person will serve as the group’s contact for email queries. The group contact person may also lead scheduling and arranging group meetings and work sessions, creating agendas for project check-ins, ensuring that tasks are assigned to group members, and submitting deliverables on Canvas. Alternatively, these role assignments can be determined differently by discretion of the group members.
3. A **description of the proposed cloud application**. If conducting the predefined project, this can simply be: “Our team will complete the predefined project.”. If an alternate cloud application is to be developed, a project description should be included which defines the application. For a serverless application this includes a description of the serverless functions, and a description for how the functions work together in a pipeline or architecture. Alternate projects should generally consist of a minimum of 3 serverless functions, services, or stages. If not a service-based application, applications should possess complexity that is comparable or greater than the predefined project. If this is doubt, the project proposal should describe why the group believes the alternate system is technically interesting enough to serve as a viable use case for the TCSS 462/562 term project.
4. The project description should identify the **design-tradeoffs** that will be investigated using the cloud application use case the group develops, for example: Service Composition/Architecture,

CPU Architecture, Application Flow Control, Programming Languages Comparison, FaaS Platform comparison, or alternate data service backends.

5. **Proposed evaluation metrics.** Most groups will consider one-off performance (runtime, network latency, throughput) Units can be identified, for example, seconds or MB/sec. Where the comparison of design trade-offs may be weak, groups are encouraged to enhance their project performance evaluation to evaluate performance variation/variability over several hours, days, weeks, or across alternate cloud regions or platforms. Groups can also report on the performance impacts of heterogeneous hardware in the cloud. Groups can also report and compare hosting costs of their application designs. Cost is typically strongly correlated with performance, so this can actually be fairly easy to provide.

A minimum of 2-3 criteria must be identified and evaluated. Groups are free to propose criteria not included below:

- average round trip time for individual service or serverless function calls
- average workflow round trip time (seconds) for the complete pipeline of functions:  $a \rightarrow b \rightarrow c$
- (\*) hosting cost of processing a batch of requests for individual functions
- (\*) hosting cost of processing a batch of requests for the complete pipeline/workflow of functions:  $a \rightarrow b \rightarrow c$
- scalability: average function or pipeline runtime with an increasing number of concurrent function invocations e.g. from  $\sim 1$  to 100
- cold function/pipeline performance: performance of function(s) on initial call after more than 5 minutes of inactivity (groups should plan to try different hibernation intervals)
- warm function/pipeline performance: performance of service(s) that have been actively used within the last 5-minutes
- function/pipeline network latency – time spent transferring data from client(s) to the cloud(s) hosting the serverless functions
- data processing throughput of functions or pipeline measured in rows of data processed per second

*(\*) To make it easier to interpret costs, it is suggested to measure the cost of individual function calls, but present results using hypothetical workloads of  $\sim 1,000,000$  function calls.*

For performance evaluation, test cases need to be considered. Will the group perform sets of 10 repeated tests using identical input data? Will there be 100 tests? 1000? When will varying input data be used?

6. **Work plan.** The proposal should then include a brief description of how the work will be done. This description can be short, but can include information regarding how team members will work together (i.e. in-person vs. remote) as well as what tools will be used to support the effort.

If available, at the end of your proposal include any references to websites or research papers that were used to support your project proposal.

Research paper searches can be supported using <https://scholar.google.com>.

Projects will ultimately be evaluated by the overall quantity and quality of work performed. This includes how well groups convey the results of their case study through written and oral presentation forms. Groups should plan to perform a thorough evaluation and analysis that results in the generation of eye-catching graphs and tables. Groups should not simply present large unanalyzed raw data sets with no conclusions if wanting an optimal project grade.

## 2 Future Deliverables

The final project will involve a short group project presentation (1 slide) live or recorded for inclusion during the final class session on Tuesday December 12<sup>th</sup> from 3:40 to 5:40pm. The tentative plan is this session will be held online via Zoom. Requirements of the final project presentation will be provided later on.

The final project will also involve a written report in the IEEE or ACM conference format or a 10 to 15 minute recorded video presentation. Both the project report and video presentation formats will require the same content. The results of the overall project will be described and the alternate designs explained. The report will then describe test results for the evaluation criteria and provide a cost / performance comparison. Project reports will also include a background and related work discussion to describe cloud technology used, and any relevant comparison studies. Additional details and requirements for the final project report will be provided later on.

## 3 Project Check-ins (10% of the course grade)

There will be one or two “written” project check-ins throughout the quarter. The project-checkins are grouped in the same category as activities and quizzes. Groups are encouraged to meet with the instructor before/after class, during office hours, or by scheduling an appointment to seek clarification and for assistance.

## 4 Submission Deadline

Project proposals should be submitted in PDF format on Canvas no later than 11:59pm on Friday October 27<sup>th</sup>.

## Change History

Version	Date	Change
0.1	10/10/2023	Original Version