Utilising Edge Computing in a 3-Tier System between Client Devices and a Data Centre

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# Abstract

An investigation was done into the effects of utilising edge computing to provide benefits through use in different applications to both the client and the data centre. These benefits can be quantified though different metrics such as latency, computational resources required, and bandwidth utilised. Other potential benefits include deployment of applications where before it wouldn’t have been feasible because of restrictions in physical space and the cost of implementation. The reason for this investigation is because of emerging problems such as bandwidth restrictions and high CPU use of mobile devices that could be mitigated by the implementation of edge computing. These effects will be investigated in a 3-tier network by implementing a system that can utilise caching, voice recognition, and machine learning applications to provide experimental results. What was found is that edge computing provided benefits but there are trade-offs to consider in some scenarios when implementing the solution. These results are significant because of a growing strain on resources caused by the increased popularity of mobile devices.

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# Introduction and Problem Specification

Figure 1 - 3-tier network

Edge computing, sometimes called Fog computing [3], is an overarching term that refers to processing that occurs on a device at the edge of a network. The device allows for services or applications to be run in a decentralised way so the distance that the data must travel or the quantity of data being transmitted can be reduced. There can be many of these edge devices that allow for the effects of edge computing to be dispersed over a large geographical location as they tend to be greatly smaller in size than that of a data centre. A reason for the need for edge computing solutions is that there are emerging problems such as high bandwidth caused by an increase in popularity of mobile devices and high CPU on mobile devices which leads to a diminished user experience.

An edge device is physically situated on the edge of a network and is therefore closer in proximity to the client than the client is to the data centre. This allows for edge computing [2] to pre-process some data produced by or being requested by the client on an edge device. The effects of implementing different edge computing applications on a client device and a data centre will be investigated, quantified, and analysed. The effects will be measured with metrics such as latency, computational resources required and bandwidth utilised. There is an emerging problem with an increased strain being placed on the available bandwidth due to the rapid growth of Internet of Things (IoT) and mobile devices [4], and this is creating a bottleneck. Edge computing has the potential to reduce this bandwidth [3]. The bottleneck also causes a problem relating to latency of client devices which could be addressed by implementing an edge computing solution that reduces the distance that the request needs to travel. A third problem that can be addressed by the implementation of edge computing is the required computational strain being placed on client devices [5] which can be reduced by executing some of the workload remotely. This remote execution would allow for more computationally demanding tasks to be performed or for less client resources to be consumed, such as battery.

As there is currently a growing demand for edge computing [6] caused by the growth in popularity of client devices the effects of multiple users concurrently accessing resources will also be investigated. In this network, it is expected that the client will send data to the edge node that will process the request and forward it to the data centre or handle this request and return it directly to the user.

A 3-tier-network can be seen illustrated in Figure 1. In this project, the tiers will consist of a client, connected to an edge node, which in turn is connected to the data centre and the effects of the edge computing will be investigated using this setup. Client devices such as mobile phones are typically the least powerful devices as they are battery operated and need to be within the budget of the average consumer. The edge will be a device that should consider factors such as geographical and physical location [48] restrictions, cost, and processing capabilities. The data centre should be the most powerful device in the setup as there is usually one data centre to process the same number of requests that can be processed by many edge devices. The system being implemented at the edge could be required to last up to double the expected life of a server at a data centre [9] as they are not in a geographically central location, the edge devices could be dispersed widely as to allow for many users to benefit from the effects. This means that from an administrator’s perspective the system must be easily maintained, such as the ability to host multiple edge computing solutions in one environment as it allows for the easy deployment and control of the applications.

It is difficult to match state-of-the-art performance on hardware that would be feasible to implement as edge nodes. Investigation will be performed into these effects on systems such as voice recognition [7] and if their effects are justifiable with lower cost hardware. The client device will be physically closer to the edge node than it is to the data centre as this allows for reduced request latency which could lead to faster processing of requests. The edge node could be located at local content distribution servers [48] as this would allow for the effects of edge computing to be shared among many customers but still a smaller subset than what the data centre will handle.

Edge computing might not be required or useful in every scenario [5] as occasionally the stronger computational processing capabilities of the data centre could be required or the added latency of utilising edge computing might outweigh the benefits. Investigation into the effects of introducing edge computing solutions on metrics such as CPU utilisation, network utilisation and request latency is required. There are a few likely candidates for this technology, the first is caching where the edge receives a request from a client and processes and stores the request data so that it can be retrieved quickly next time the user requests it. Another candidate is voice recognition where a computationally intense task is offloaded to the edge node instead of the client or data centre. A final candidate is machine learning where the edge can be used by the data centre for assistance in producing a prediction. There are a few areas of investigation for edge computing [5] such as the effects of shorter response times from geographically closer edge servers, the benefits to user experience, and the benefits to data centres. These will be investigated by using the implemented solutions.

Edge computing is a relatively new area of study [7] and research is still being performed as to investigate its effects. Performing study and experimentation in this area is a good extension of some existing research [8]. Some aspects of edge computing are not well understood and more investigation can be performed into how edge computing can be utilised in different applications to benefit the client though reductions in request latency and computational power required and the costs associated with doing so. Another area of investigation needed is the scalability of these edge solutions and how well they can handle traffic during computationally demanding tasks. These topics will affect how useful and edge computing will be and quantify the benefits provided.

Section 2 will list requirements of the system, Section 3 will discuss design considerations and Section 4 will discuss the implementation of the design and how it was tested. Section 5 will evaluate the system and Section 6 will provide a conclusion.

# System Requirements Specification

It is realistic that the mobile device is the least powerful of the 3 tiers mentioned. The edge device would be purposefully less powerful due to economic reasons as they must be widely geographically dispersed so they are somewhere between the power of the client and the power of the data centre. The edge device may have server blades comparable to that found in a data centre however there would only be a few of them. The system developed is for research purposes so a primary goal is that the system is designed to produce results that can be recorded and analysed.

The requirements for this system;

1. An application hosted on the client device that will allow for interaction between the edge node and the data centre and display results to the user
2. The development and implementation of applications capable of performing edge computing tasks on the edge nodes
3. A data centre application capable of processing requests from the edge or from the client
4. The ability to run multiple applications on the same edge node
5. Edge node applications can be easily deployed, controlled, and updated

Requirements for the caching application;

1. A user interface that can receive user data and display result metrics to the user
2. A low latency connection between the client and edge node
3. An application developed for the edge that caches requests
4. Request data returned to the client if it exists already or retrieved, stored, and returned if it does not

Requirements for the voice recognition application;

1. A user interface that can record voice data and execute voice recognition locally or remotely and display metrics about the request to the user
2. An application developed for the edge that can process a voice request
3. Voice recognition capabilities at the data centre for handling processed and unprocessed requests
4. Can handle multiple requests concurrently on both the edge and the data centre

Requirements for the machine learning application;

1. A client user interface that can receive user input and make requests to the machine learning applications
2. An application developed for the edge that can handle machine learning requests
3. A subset of the data from the data centre available on the edge
4. A recommendation to be produced for the client on the edge

The goal of this project is to produce an edge computing infrastructure capable of producing results that can be processed and analysed to provide answers to the proposed research questions. Specifically, in each of these the interest is how edge computing affects these properties;

1. Latency for the client to obtain a response
2. The computational strain placed on the client
3. The computational strain placed on the data centre
4. Latency for the client and computational strain on the edge through the implementation of load balancing within the edge application
5. Request time through the deployment of multiple instances of an application to the edge

# Design

## Architectural Description

A high-level overview of how the client, edge and data centre will be implemented is shown in Figure 2. The communication is colour coded for clarity per application traffic between the devices in the network.

The entry point for the system will be the Electron [10] application which runs on the client Raspberry Pi 3 [11]. There will be 4 pages that the user can access from the homepage.

The edge will be comprised of 3 Raspberry Pi 3’s which will form a Docker swarm [12, 13]. The applications run in containers that can be deployed to any of the worker nodes.

There are multiple data centres depending on what application is making the request. The WebAPI [14] project will be hosted in IIS [15] and have multiple endpoints to allow for interactions from different applications

Figure 2 - System diagram

## Software System Design

The role of the client application is to run tests and get results from the edge and the data centre. It is a requirement of the system to provide an application that allows a user to interact with the edge node and data centre and to display data to the user. This will be achieved by providing an Electron [10] application that will contain separate pages for each of the applications running on the edge as to keep everything distantly separate but accessible. The client should be able to make POST requests to the data centre and proxy them through the edge node.

The role of the edge applications is to pre-process requests for the user as it is a requirement of the system to pre-process requests quickly before passing on data to the data centre or returning it to the client. Another requirement of the edge applications is the ability to run multiple applications on the same edge node to allow for extensibility. This will be achieved by running the applications in Docker Swarm [12, 13] and hosting them on unique ports which also fulfils the requirement of easily deploying, controlling, and updating the applications. Node.js [16] will be the web server that will host the code for each edge applications.

The role of the data centre as per the requirements stated is to handle a request from the client or the pre-processed request from the edge, for example if the client wants voice recognition to occur when they click a button so the fact it was pre-processed before reaching the data centre does not matter to them as long as they receive the result of the operation. The data centre will be designed and implemented utilising dependency injection, this will make maintenance, control of dependencies and code reuse easier.

### Caching Application

The purpose of the caching application is to receive requests for webpages from a client, process those requests by querying the relevant cache to check if the webpage is stored locally, and if it’s not stored it must be requested from the data centre, stored in the cache, and returned to the client. If the request has been stored it should be retrieved from the cache and returned to the client. The relevance of this in an edge computing context is to handle requests entirely at the edge to check if this will improve latency of requests and reduce the stress on the data centre as the request will travel less distance and if the cache is populated the data centre will not be queried.

Client

The caching application page required a textbox for entering an URL, and buttons for navigating home, executing the request, and clearing the cache. There should be mechanisms in place for handling navigation failures if the URL entered is incorrect or if the request fails for an unknown reason. The clear cache button should send a request to edge application and display the results of the operation to the user. The execute button should record the time taken from starting the request to the request finishing and display the webpage to the user.

Edge

The caching application should be running behind a proxy, which allows the client to request a webpage while the caching application intercepts and handles this request.

The caching application will use Redis [17] as the in-memory database to store request data for later retrieval. The mechanism that will be put in place to allow the client to clear the cache will be implemented using Redis Command Line Interface (CLI) [18]. To make deployment easier and to keep with the guidelines of Docker a caching base image will be created that will contain the Redis CLI which allows for further development to be layered upon this image.

The caching application will receive proxied requests and query the appropriate Redis cache based on this information. If the data does not exist it will make a request to obtain, store and return this information to the user. If the data already exists in the cache the information will be retrieved and returned directly from the edge application.

A Redis instance should be available on each of the edge nodes and the caching application should access each of these directly and in a fair manner. This is to utilise the available resources and not burden one entry point with requests.

### Voice Recognition Application

The purpose of the voice recognition application is to process a voice recording and receive a response consisting of written text. The execution of the request should be possible at all 3 tiers in this system so the effects on latency and computational resources of implementing edge computing can be evaluated. The relevance of this in an edge computing context is that a client should be able to offload some processing that would have occurred locally to an edge device so that less resources are utilised locally.

Client

A requirement of the voice recognition page is the ability to record your voice and use this recording during experiments. The results area should be split into two distinct sections to clearly differentiate between local processing and remote processing along with buttons to allow the user to execute these commands. The remote side should also have a checkbox to allow the user to indicate to the system if pre-processing should occur on the edge node. The local processing button should perform local voice recognition and display the results. The remote processing button should send a POST request to the data centre, account for the pre-processing checkbox, and display results to the user once completed.

Edge

The voice recognition application will save the voice data it receives from the client to disk, this file will have a unique name so multiple requests can be handled concurrently. A flag in the request will be checked to see if the application needs to pre-process the request. If the request needs to be pre-processed the application should spawn a process and execute the voice recognition and forward the resulting pre-processed data to the data centre along with a flag that states the request was pre-processed. If the request does not need to be pre-processed the request should be forwarded to the data centre right away. It may not be efficient to store the voice data on disk before processing it but the way that the voice recognition library PocketSphinx [19] works is that a file path must be passed as a parameter rather than the data stream itself.

The voice recognition system should implement load balancing. It should be implemented in such a way that even if the flag for pre-processing is set, if the system CPU is currently over a threshold the request will be forwarded to the data centre anyway.

Data Centre

There should be one entry point for the voice recognition application. It will receive a POST request from the edge node and detect if the pre-processing has occurred based on a flag. If the data has been pre-processed it can be returned to the edge node and consequently back to the client. If the data is not pre-processed it must be stored and processed before being returned to the edge node. The voice recognition being performed should be the same as that being performed on the edge node.

### Machine Learning Application

The purpose of the machine learning application is to allow a user to watch a movie and produce a movie recommendations for them based on previous data. This is achieved through part processing of the request on the data centre and the edge to produce one result. There should be no user identifiable data stored at the edge, though there should be a subset of the available movies that could be used to produce a recommendation. The data centre will store user data and the full list of available movies and the client can make requests to the data centre and have the edge produce a recommendation along the way. The relevance of this in an edge computing context is that it demonstrates the flexibility of such a system to implement different applications in unique ways depending on the requirements. This can be used to reduce the strain on the data centre as it no longer needs to produce recommendations for the client.

Client

The machine learning page should only contain a home button and an area to type the user’s username and a button to log in. Once the user logs in the data centre will be queried to retrieve the users previously watched movies which will then be used to query the edge node to get a recommendation. The results of these operations will be displayed to the user. There should be a button to watch a random movie and a button to watch a recommended movie. Each of these buttons should display the movie just watched and update the users’ average results to include the newly watched movie.

Edge

Upon deployment, the machine learning application should request a subset of movies from the data centre to store locally on the edge node which will be used to produce recommendations.

The machine learning application should only ever receive post requests that contain the user ID and depending on the path that the client posted to the edge application should request a random movie to be watched or a specific one that the user requested. This could be implemented in a reusable way as the requests to the data centre will all take similar formats apart from a few variables being changed.

The main function of the machine learning application is to produce recommendations using a k-nearest neighbour evaluation based on the average of all the movies the user has watched. This user data will be received from the client as the edge application should never keep any user specific data locally that would mean it is vulnerable to attack. The application will then return a movie recommendation to the requesting client.

Data Centre

The machine learning application must be able to return a subset of the movies to the edge node based on a k-means clustering algorithm. This is to ensure that the edge device contains a broad range of available movies to recommend to the user. The data centre machine learning application must also keep a record of all the movies that the user has watched so that it can be queried by the user and eventually processed to produce a recommendation.

### Load Balancing Application

The purpose of the load balancing application is to send multiple concurrent voice recognition requests to the edge and the data centre as to measure the effects of the implemented load balancing in the voice recognition application or to measure the effects of deploying multiple instances of the application. The relevance of this in an edge computing context is to measure the effects of multiple concurrent users as to better understand the scalability of such a system and how many users the system can service.

Client

The load balancing page should contain a home button and a text box that allows a numerical value to be entered that will be used by the “Go” button to execute that number of requests and display metrics about the request in a table below. This button should account for the pre-processing checkbox when performing the operation.

## User Interface Design

Figure 3 – The homepage

The purpose of the user interface (UI) is to allow interaction with the edge nodes and data centre to perform tests and demonstrate functionality as per the requirement stated above. The homepage shown in Figure 3 shows what the user first sees when they launch the application.

The caching application page has a textbox to type URL’s, buttons to navigate to the URL, return to the homepage or clear the cache. There is a section below to display request times and the webpage.

The voice recognition application page contains a button to return home, a button to record and save the users voice and two buttons to execute the recognition locally or remotely. There is a checkbox below the remote button which indicates if the request should be pre-processed on the edge. There is also a table for displaying the results for the experiments.

When first launched the machine learning application page asks the user to enter their username. The screen is then populated with the information such as a recommendation and previous results. There are two buttons for either watching a random movie or watching the movie that was recommended to you both of which will update the UI when the operation completes.

The final link on the homepage is to the load balancing application page that contains the standard home button and a space for the user to enter the number of requests to executed. The checkbox to enable pre-processing is also present below the “Go” button that executes the requests and updates the screen with statistics such as total time and CPU use.

There is a consistent theme kept throughout the application that matches that shown in Figure 3, both in the colour scheme and the layout. It was designed to be clear and functional as to keep focus on producing results from the application.

# Implementation and Testing

## Choice of implementation languages and development environments

Client

The client needs to be a less powerful device than the device that will be used as a data centre in this system and low priced as to make it accessible, this made the Raspberry Pi 3 [11] computer a good choice [20]. Reasons for this being a good choice are that the Raspberry Pi 3 has a low price, a quad-core ARM CPU, 1GB RAM, and an ethernet port.

Electron [10] was chosen as the framework that would be used to implement the client application. Electron utilises Node.js [16] for the backend and HTML, CSS, and JavaScript for the front-end UI. The Electron framework is available on Windows, MacOS, and Linux which allows the Electron application to run cross platform and in the ARM architecture the Raspberry Pi 3 uses. As Electron is based on Node.js it allowed for more interaction with the host PC than pure JavaScript, this was necessary as to fulfil the requirement of measuring CPU use and executing the voice recognition script locally.

PocketSphinx [19] was chosen as the speech recognition engine as it is designed to work on mobile devices. It also can be built from source to work on the ARM architecture which is a requirement for the client and edge devices. It can also run on desktop machines which means it can be comparably tested with the data centre when there are more available resources.

Edge

The edge nodes are comprised of 3 Raspberry Pi 3’s, this is because they are small enough to fit in a space between the client and the data centre, they are cheap enough to be a viable option to distribute to many locations as the clients will be distributed widely and the data centre is usually in one central location and there needs to be an edge node that is physically closer to the client than the data centre is. The quad-core CPU and 1GB RAM means that the Raspberry Pi 3 is capable of processing resource intensive requests and hosting multiple applications as defined in the requirements.

It is a requirement of the system that the applications on the edge are easily maintainable, Docker [12] was used to meet this requirement. Docker is a platform that allows for applications to run in isolated containers. As there are multiple edge nodes it was specifically Docker Swarm that was used as multiple worker nodes could be added to the system and it was possible to write scripts that would build, deploy, and control different aspects of the system. For example, the caching application needed to have a Redis [17] instance on every node and Docker provides a deployment flag, ‘--mode=global’, that can be used for this purpose.

The edge node applications are written in JavaScript and run in a Node.js [16] environment. This was chosen because the client was written in JavaScript and Node.js it was a familiar language. As the client application also used Node.js is meant that there were transferable skills and there was a possibility of code reuse such as the module that was used to record an average CPU use. There was also the availability of the Node.js proxy [31] which can be used to proxy requests to the internal server. NodeRedis [41] could be utilised to communicate with the Redis servers hosted on each of the 3 edge nodes. Finally there is a Request module [42] that can be used to communicate with the data centre.

The decision to use Redis was because of the ability to use more complex data structures to store data than Memcache [49] which would make storing website data easier. Another factor in the decision was the availability of the Redis image through the Docker Hub.

Data Centre

A reality to replicate with this system is that the data centre is more powerful than the edge node, this is partly because in some scenarios, such as the voice recognition application, the data centre had to be able to process requests that the edge was not capable of processing. The data centre was written using WebAPI [14] and hosted in IIS [15] as this was readily available in a Windows development environment.

## How each component was implemented

Figure 4 – All applications deployed

Figure 5 – Unfair Redis deployment

Figure 6 – Fair Redis deployment

The client device was setup using the Raspberry Pi 3 configured with the Raspbian Jessie [21] operation system (OS) as it is designed and optimised for the Raspberry Pi. To make development of the client application easy XRDP [22] was installed which allows for a remote desktop connection from a development PC. NPM [23] was used to install the Electron framework to allow the client application to run.

The edge setup required the Raspberry Pi’s to be prepared by installing Raspbian Jessie and enabling SSH so the nodes were controllable remotely though the CLI. Docker was first installed on the first edge pi (EdgePi01) as this would become the manager node, a Docker Swarm was initialised and after Docker was installed on the other two edge nodes they were added to the swarm as worker nodes. This can be seen at the top of Figure 4 where ‘EdgePi01’ is the manager and ‘EdgePi02’ is a worker node alongside ‘EdgePi03’. After Docker was installed the commands to manage containers and images were learnt so that it was possible to administer the system correctly. For the edge to handle the hosting of multiple applications the deployment scripts for each application ensured to use different internal and external port numbers. This means that the same node can host multiple applications and Docker handles the direction of traffic to where the application is hosted within its network layer. To quickly view what containers were running on what machine Docker ARM visualizer [27] was used and can be seen with all the applications deployed in Figure 4.

By default, when an image is pulled into the Docker environment it will try to pull it from the Docker Hub [28] which is a central store of Docker images. For this system, the images should be stored locally, what this meant for setup of the development environment was the creation of a private registry. Unfortunately, the official Docker registry [29] is built to run on x86 processors and the Raspberry Pi 3 that will be hosting the private registry would be running an ARM processor. An alternative repository image was found, Docker ARM registry [30], and once it was confirmed to function as expected the applications could be tested throughout the swarm.

There are two scripts for each application, one to build the specified application using the Dockerfile provided, tag the new build with the correct name and push the build to the private registry. The reason for the private registry is to make the image available to all worker nodes in the swarm instead of just the node it was built on as all the worker nodes can query the private registry. The script then removes the old version of the service if it exists and deploys the newly created image. There is a second script that just deploys the applications without creating a new build. There is a problem with the version of Docker that is used in this system as old builds do not get cleaned up so there is another script created to do this.

The data centre setup required IIS to be configured along with the firewall so that devices could make requests to the WebAPI application. The WebAPI was deployed by creating a custom publish profile. The data centre handles requests for different applications by utilising multiple endpoints within a single API to allow for distinction. Dependency injection meant that the distinction between the two endpoints was also clear during implementation.

### Caching Application

Client

A problem that needed solved for the caching application was recording the total time that the request took. This was accomplished by attaching event handlers to the web view element that would start and stop a custom stopwatch object and display the total time for the entire request to the user. There is also an event handler attached for when requests fail altogether.

The first iteration of the caching application passed the user requested URL as a query string to the edge node which meant that the client code had to account for this to keep it hidden from the user. This was then updated when the edge application was developed further to include a proxy so that the user could make the request directly but the Electron application would proxy the request through the edge node.

Edge

The first iteration of the caching application passed the user requested URL as a query string, this was not a realistic implementation of a caching application as it should not be queried directly, so the application was altered to act as a proxy. This was solved by using the http-proxy library [31] available for Node.js. This allowed for a webpage to requested without knowledge of the caching application.

The caching application had some challenges. The application began by utilising a single Redis cache, however, every webpage request there are many small requests for each item on the page, such as images, which means that for the caching application to handle all those requests it also needs to make a separate request which would inundate the Docker Swarm manager node. A way to rectify this problem was to deploy a Redis cache to each of the worker nodes so that there were 3 instances up and running, this could be expanded if required. Setting the deployment to contain 3 instances did not guarantee that Redis would be deployed to all three nodes as shown in Figure 5. This was solved by researching Docker deployment commands and using the “--mode global” flag that guarantees that there will be an instance on every node as shown in Figure 6 which allows for the caching application to rely on the fact that each worker node has a Redis instance.

Inside the caching application a hashing function is performed on the URL of the data being requested by the client. The purpose of this was to workout which of the 3 Redis caches should be queried directly for the content, as to reduce strain on the manager node.

The caching application must be able to clear the cache across many Redis instances, this was handled by keeping a collection of all the Redis servers the application is currently connected to. This allows the clear cache request to iterate over all of them and spawn a process for remotely clearing the cache on each of the servers using the Redis CLI tools [18].

The caching application was implemented using a base image which allowed for adherence to the methodologies associated with Docker images to keep them flexible, lightweight, and reusable [33]. The base image for the caching application was used to install the Redis CLI tools required to interface with the Redis server, this means that all further images that are based of this image would can communicate with Redis servers. Another benefit of using this base layer was that it made deployment times quicker as it did not have to install the tools with every new build.

### Voice Recognition Application

Client

The first issue that needed to be solved for voice recognition to occur was for audio to be recorded on the client. Investigation into how audio was handled on Linux systems and in JavaScript applications was done. Once the microphone was setup on the client device a third-party library called Recorder.js [24] was used to capture audio using JavaScript. This recording had to be in a specific format so that PocketSphinx [19] could use it. When the user finishes recording their voice the audio file is saved to disk, this recording is then used when the user requests voice recognition to occur, whether locally or remotely.

To perform local voice recognition, the renderer thread, which can be viewed as the client thread that would normally execute JavaScript in a browser, needs to communicate with the main thread, which can be viewed as the server thread that would normally exist in a Node.js server. This happens through a communication channel called IPC [25]. The renderer thread sends a command to execute the voice recognition as it does not possess the capabilities to do so itself. Both the renderer thread and the main thread have custom event handlers attached for receiving requests and responses within this IPC channel. Once the main thread has received this request it spawns a new process, executes the voice recognition script, and waits for the response. The main thread will then send this response back to the original sender, which is the renderer thread, that then displays it to the user.

If the user decides they want remote voice recognition to occur they can select if the request should be pre-processed or not, what this does is set a custom header on the request that the edge node will receive.

Edge

The voice recognition application made use of a base image in a similar way to the caching application. The voice recognition base image has PocketSphinx [19] installed, including all the libraries required for it to work, as it was time consuming and unnecessary to install this with each new build.

To allow the voice recognition application to execute when requested a process was spawned to execute the custom bash script while taking the filename as a parameter. The file will have a custom name and will be accessed asynchronously so each request for voice recognition can be executed on multiple threads concurrently. PocketSphinx is required to be given a dictionary and language model produced from the Sphinx Knowledge Base [34]. Once the results are written to the standard output stream they are forwarded to the Data Centre.

One of the metrics that needed to be recorded for this application was the CPU use, to record this a CPU library [36] was altered and adapted into a Node.js custom module. What this means is that it can be required at the top of the server in the same fashion as the installed Node.js modules. This allowed the custom module to be reused in the client application for recording local CPU use.

This application slows down when receiving many requests concurrently as voice recognition is CPU intensive. The solution is to implement load balancing so even if the server receives many requests to pre-process the data, if the CPU use is over the threshold the request will be forwarded to the Data Centre.

Data Centre

If the data the voice recognition endpoint receives is pre-processed the data is read and returned to the user. The purpose of the data centre receiving this request is so that in the future if this application needed to be extended to do any processing on the user’s voice request all the data is available, for the purposes of this project it is enough to show that the voice request has been received and the data is valid. If the data is not pre-processed voice recognition must be performed. This was slightly more challenging on the data centre as PocketSphinx can only be built from source and it was missing dependencies that it required to build in Visual Studio 2015. There was a project available from source [38] that had a built version of the exe available so this was utilised once verified. The next challenge was how to execute a process from within WebAPI and receive the output which can then be handled in a similar way to the pre-processed data.

Some of the metrics that need to be returned from this request are network utilisation details, this is the size of the received and sent request, and CPU [39] use of the Data Centre.

### Machine Learning Application

Client

Figure 7 - First machine learning page

Figure 8 – Current machine learning page

The machine learning page went through two iterations, the first page had buttons that allowed a user to watch a movie of that genre as shown in Figure 7 however this did not show off the full capabilities of this system as well as it should have so the system was updated to perform more advanced recommendations and the UI was updated to Figure 8.

The system communicates by passing JSON [26] objects with required information such as results, averages of movies watched, and recommendations. The client will retrieve all the users previously watched movies directly from the data centre when they login.

Edge

The machine learning application on the edge went through multiple iterations in the same way as the client. The first iteration was going to produce a recommendation based on the probability of movie type they watched most frequently. The application was then updated to produce a recommendation by performing a more complex calculation discussed below.

When the edge application is first launched, it requests a subset of movies from the data centre and stores them locally to perform evaluation later. When the client requests a recommendation an average of the users previously watched movies will be sent which can then be used to find the 3 nearest neighbours. The basis for this evaluation was found online [37] and altered to produce an evaluation based on a movie object. During a request to watch a movie the edge node will make a request to the data centre as it contains the full list of movies and can store user data. The edge receives this information from the data centre and generates a recommendation after adding this new information to the existing user average and returns this information to the client.

Data Centre

To produce evaluations 1,000,000 movies needed to be created as test data. Once these were generated and stored a custom k-means [40] evaluation was performed across all of them to produce 10 clusters of movies. 10,000 movies were to be returned to the requesting edge node which means that 1000 movies were selected from each of the 10 clusters to allow for a wide range of available movies to be selected during recommendation evaluation on the edge.

There were problems when implementing the k-means evaluation as it took over 25 minutes to execute the request as it performed 474 loops of clustering over the 1,000,000 movies to produce the 10 required clusters of movies. The solution to this was to store the clustered data once it has been produced so further requests for the clustered data can return this information directly and if movies are added the k-means evaluation can be run over the updated collection of movies.

The data centre is also responsible for storing user’s view data so that it can be retrieved by clients once the user has logged in to the client application, this is so that the edge nodes never store user specific data. There are also endpoints on the data centre for returning a random movie and returning a movie with a specific ID.

### Load Balancing Application

Client

The load balancing application is used to test the voice recognition system with a multitude of requests, this is achieved by reading the value that the user has entered and creating a thread per request, in JavaScript this means executing a method in 0 milliseconds repeatedly so that they all run concurrently and ensuring that the reading of the voice data is done asynchronously as to not block any calls. The result of each request and an average of the all the requests is then displayed to the user.

## Discussion of test approach

As the client and the edge node both utilised Node.js the tests proved more difficult to write than standard JavaScript and as the nature of the code is to handle requests to different services there were few areas that could be unit tested in isolation. A unit testing library QUnit [44] was used but would throw an exception when the first Node.js keyword, ‘require’, was found. For these reasons a manual testing approach was taken and would be adequate for the system as it is for research purposes and designed to produce test results. Unit tests in WebAPI also proved difficult as a lot of the code deals with actual requests so these would be tested manually along with the rest of the system.

A lot of the tests used a happy path approach as the only interaction with the edge node and the data centre is through the client application which allows for very tight control over the data sent. However, anything that the user can do in the client application should be tested.

For the caching application, there were a total of 15 tests with a 100% pass rate. For the voice recognition application, there was a total of 29 tests. The reason for this is that there is more user interaction for this application so there are more scenarios that need to be tested. There was also a 100% pass rate for this application. For the machine learning application, there were a total of 26 tests with a 100% pass rate. The full test suite can be found in the Appendix, page 45.

# Experimentation

Figure 9 - Experimentation Network Diagram

The network setup used to run these experiments is depicted in Figure 9, the edge nodes and client are all attached to the same router and this means that there is very low latency between them as this is a requirement of the system. The router is a BT Hub 3 which is connected to a Netgear GS305-100 5 Port Gigabit Switch which has an ethernet connection into each of the Raspberry Pi 3’s using their 100 Mbps ethernet port. The Raspberry Pi’s are running Raspbian Jessie. The data centre in this setup is connected directly to the router using a Wi-Fi connection and is running Windows 10.

To run these experiments fairly the possibility of human error needs to be reduced. To accomplish this goal automated running of the experiment was implemented where possible.

## Does utilising edge computing reduce the latency of requests for the client?

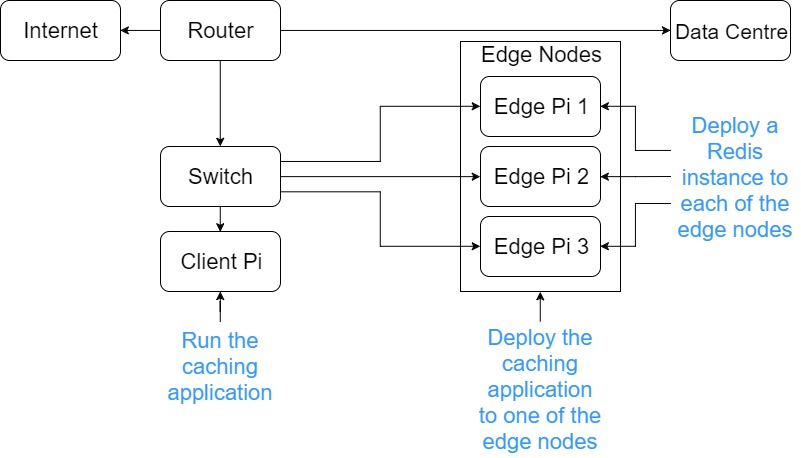
Setup

Figure 10 – Caching experimentation setup

The constants in this experiment are the interface that connects the Raspberry Pi’s to the router and the caching application being the only application deployed to the edge. There are a few variables for the experiment, the first is whether a webpage is cached or not, the second is if the caching application is being used and the last is the webpage being loaded.

Method

Measurements recorded will be the time between when the WebView element in the client application starts a request and ends a request as this is the value that will matter most to the user. Recording network use for this application without special hardware or software could present an unfair reading on the request time as this data would have to be recorded at the edge node and returned to the client device. The mechanism to perform this task that would be implemented in software would hinder the accuracy of the results and may not be feasible given the lack of control over the WebView element.

The next part has been automated per run, a single run of the experimentation can occur with no human interaction. A run consists of deploying the caching service and Redis service, executing 10 warmup requests without wiping the cache, clearing the cache once, and then performing 20 requests in a row. The reason for performing 20 requests in a row is so that there are 10 sets of 2 requests with the cache being cleared in-between each set. The first request in the set does not have a cached version to query so the cache will be populated and the second request has the cache available to read. 10 requests will be made without utilising the caching application.

There will be requests made to 3 different websites to test differences in the benefits of caching requests across different webpages. The 3 webpages will be;

1. http://www.bbc.co.uk
2. http://news.sky.com
3. http://a.singlediv.com

The reason for choosing these webpages is that the first two are sites that are static and frequently accessed so seeing how they react to caching is important. The last site is a static website that might be accessed infrequently so seeing the effects of caching on this site would be useful.

There will be 5 runs for each website and an average of the request times without using caching, using caching without a cache present and using caching with a cached version present will be taken.

Hypothesis

Webpages that are cached will be returned to the client quicker as the latency between the client and the data centre should be reduced in this setup.

Results

Figure 11 - Caching request times chart

The raw results from the 5 runs of experimentation are available in the appendix.

The difference in the “BBC” request time when comparing a cached request with a non-cached request is an improvement of 30% however the effects of adding caching means a 26% increase in request times when comparing a request with no caching to a cached request. There are similar results when comparing the caching application results for the “Sky News” request. There is a 34% improvement between a request that has not yet been cached and a request that has been cached, however by adding the caching application there is less pronounced although still detrimental effect of just 1% increase in request time. This pattern is found a third time when analysis is performed on the last request to “A Single Div”, there is an improvement of 18% when comparing the times of a non-cached request with a cached request however the difference between a request not utilising cache caching and a cached request is an increase of 20% in request time.

After 5 rounds, the results can be shown to follow a pattern as the request time improved when reading the request from Redis rather than making an external request by an average of 27% however the cost of this caching increased the request time of even a cached request by an average of 15%. This means that the cost of caching is enough to offset the benefits gained and results in a detrimental effect to the end users. There is always a cost associated with caching as more execution time is required to query the cache however the benefits of returning a cached item should out-weigh the cost of caching the request as in an ideal system the cached data will be requested many more times than the data that is not requested. Factors that could be affecting the effectiveness of the caching is a slow processor speed as this affects the time taken to process the request. It could also be the cost of data being stored on different caches and having to make different requests to multiple Redis instances. It is also possible that there is a bottleneck somewhere in the Electron application that causes requests that are directed through a proxy to take longer than when there is no proxy present. To fix this another test could be done utilising the cache with a different application or running the caching application and Redis instances on a machine that has more computational resources in order to narrow down the source of the delay.

The average standard deviation for each round of requests was quite small apart from the first request to “BBC” and “Sky News”, the first request to the “A Single Div” site had a small standard deviation when compared to the other sites. This means that there is some variation between the time taken to make a request from the edge node and return it to the requesting client however once the request is cached it is quite consistent with the amount of time taken to retrieve and return the data.

There was a second version of the experiment run with the BBC website with the same method, the only thing that changed is that the connection to the internet was over a 3G wireless hotspot instead of a traditional wired router. This made the average request time, without caching involved, increase from 3.7 seconds to 6.2 seconds. However, the results for this slower connection were much the same as what was seen with the fibre connection. The fibre connection showed a 26% drop in request time between a request when the caching application isn’t used and a request that uses a populated cache, and the 3G connection showed a 22% drop. When using the fibre connection, there was a 30% decrease in request time when the webpage had been cached and with the 3G connection there was only a 15% improvement.

Conclusion

The hypothesis for this experiment was correct to an extent however it was unexpected that removing the caching altogether would have the lowest request time. More investigation could be done with a slower connection speed, the connection speed from the 3G hotspot was seen to decrease the negative effects from implementing the caching by 4%, however, as the connection from the router/hotspot to the Raspberry Pi’s changed from wired to wireless this could also affect the latency. It could be argued that latency from the router to the edge node in this setup should not change when the fibre connection is present regardless of the internet speed as the devices are physically close to one another, however if a website responds slowly or the internet connection is slow it could make the effects of the caching application more pronounced.

This was not the expected outcome from the experiment and an area for further research would be recording the network use during these requests to see if there are use cases where this type of caching would be worthwhile such as areas where the price of internet is high so the increase in request time would be worth the decrease in internet costs. Other options to consider is that there is a bottleneck in the system, such as the low computational power of the Raspberry Pi being unable to process the requests for each element of the webpage quickly, or the request overhead of querying the caching application and Redis that could take the form of the networking infrastructure limitations such as the 100 Mbps ethernet port on the Raspberry Pi or the efficiency of the Electron application.

## Voice recognition application experimentation

The same method will be used to answer the research questions below.

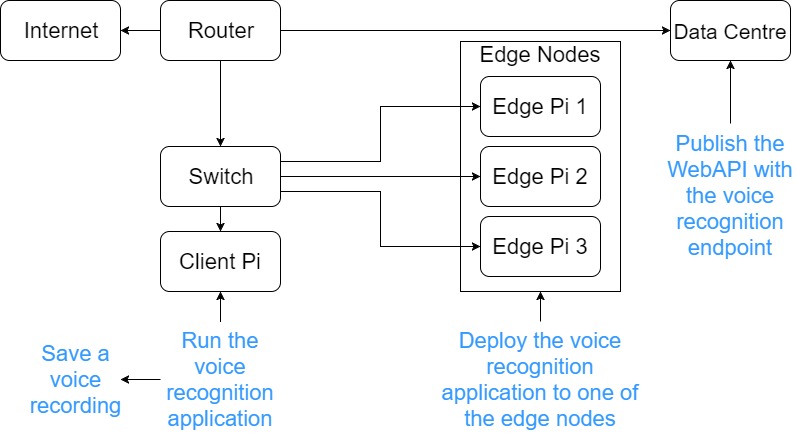
**Setup

Figure 12 – Voice recognition experimentation setup

The constants in this experiment are the voice recording used for processing at different stages, the language model and dictionary being used throughout the different stages and the voice recognition application being the only application deployed to the edge. The variable in this experiment is whether the request is processed locally on the client device, remotely pre-processed on the edge, or remotely processed at the data centre.

Method

Measurements recorded for both local and remote requests will be:

* Request time in seconds
* CPU load as a percentage of the total CPU on the client device
* RAM use of the client device in GB
* File size of recording in bytes

Additional metrics recorded for remote requests will be:

* CPU load as a percentage of the total CPU on the edge node
* CPU load as a percentage of the total CPU on the data centre
* RAM use of the edge node in GB
* RAM use of the data centre in GB
* Quantity of data received at the data centre in bytes
* Quantity of data sent from the data centre in bytes

The knowledge base that the voice recognition systems were trained with are all identical and produced using the Sphinx knowledge base tool [34]. This keeps the processing consistent across all the applications.

After the voice recognition application has been deployed, 10 warmup requests will be performed on client device, a further 10 will be performed on the edge node and a final 10 on the data centre. A run of the experiment consists of 10 requests being handled locally, 10 requests being handled without pre-processing and 10 requests being pre-processed. A single run has been automated for each of the three different request types.

The measure of time will be recorded on the client device from as soon as the request starts to when the request finishes. The same voice recording will be used across all three systems as to ensure consistency.

There will be 5 runs of the experiment in total and an average used during analysis.

### Does utilising edge computing reduce the computational load on the client?

Hypothesis

Introducing edge computing should reduce the CPU strain on the client device regardless of if the request is pre-processed on the edge device or not.

Results

Figure 13 - Client CPU use chart

The raw results from the 5 runs of experimentation are available in the appendix.

It is clear to see that the introduction of edge computing dramatically decreases the strain on the client CPU as was expected from the hypothesis. There is an 80% reduction in CPU use between local processing and a remote request that is not pre-processed and a reduction of 89% between local execution and a remote request that is pre-processed.

The standard deviation of 2.26 and 1.61 for the recorded local CPU use from the two remote requests can be explained by the first request in each being the most computationally demanding. The reason for this is because of the way the experimental automation is designed. The requests are all queued up and then executed when they were requested to, the requests are all being queued as the first request begins to execute which causes the first CPU measurement to be higher.

Accurate measurements of CPU use from within a C# application is difficult [45] as to accomplish a higher level of accuracy for this CPU reading in the WebAPI project there needs to be a second delay [45] in the request but this would skew the time that is being measured. This is the reason that an accurate comparison of the CPU in the data centre is not possible in this system and explains the high standard deviation numbers (4.96 and 16.91) for the data centre CPU, it would not be sensible to use these numbers during evaluation of the system.

Conclusion

In this experiment, the results that were obtained matched the hypothesis set out. With the introduction of edge computing the strain on the client device is lessened which could provide benefits such as improved battery life [47].

### Does utilising edge computing increase the request latency?

Hypothesis

The latency of the request should not increase much if the request is pre-processed on the edge device as both devices are Raspberry Pi 3’s however the request should be processed much quicker at the data centre as it has a faster processor although this means that the data centre is performing more work.

Results

Figure 14 - Request execution time chart

The raw results from the 5 runs of experimentation are available in the appendix.

There is a decrease in request time of 42% between local execution and a remote request without pre-processing and an increase of 19% between the local execution and a remote request with pre-processing. This increase of 0.29 seconds can be argued as a worthy trade-off when Figure 13 is evaluated to discover the 89% reduction in client CPU utilisation.

The 42% decrease (0.45 seconds) in request time caused by using the more powerful datacentre for voice recognition might not be viewed as worthwhile when there are many requests getting sent to the data centre for processing, however the data centre should be equipped to handle these requests as if it is under strain from many users more servers can be added. Though through the implementation of the voice recognition application at multiple edge computing nodes the strain placed on the data centre can be reduced and only slightly increase request time for the client.

The analysis of the data centre doing more work is difficult to quantify in this system as the CPU measurement of the WebAPI application is difficult to obtain [45] so the results for this metric can be viewed as inaccurate.

Conclusion

The first part of the hypothesis was that the request time should not increase much if the request is pre-processed on the edge device compared to the client device as both are identical machines. As shown above there is a 19% increase in request time but this only amounts to 0.29 seconds which is acceptable as the time taken to send data over the network is accounted for however this could be reduced if the edge device was more powerful than the client device. The second part of the hypothesis is that the request should be processed much quicker at the data centre which can be seen to be true as it is the fastest of the three evaluations and 42% quicker than processing the request on the client alone.

There are two trade-offs to be evaluated in this experiment the result of which will be unique to each implementation of the application. The first is the increase in request time when comparing local execution to remote execution against the decrease in CPU use on the client device. The second is the increase in latency when comparing pre-processing on the edge node to processing the request at the data centre against the increase in request time for the client.

### Does implementing edge computing reduce the network utilisation?

Hypothesis

Utilising edge computing will reduce the use of the network as less data needs to be sent to the data centre for processing, the pre-processed data is much smaller than the raw data, which in this scenario is a voice recording.

Results

The raw results from the 5 runs of experimentation are available in the appendix.

The reduction in data send to the data centre when pre-processing occurs on the edge is 99.999%. This is a reduction of 246043 bytes as the data being sent to the data centre is no longer the voice recording, it is just the 8 bytes of data that make up the text spoken. There will not be a direct correlation between size of data received and data returned, this is because two recordings that say the exact same thing could be different in size. The recording must be in a specified format with a specific bitrate so the quality of the recording will not change but the amount of silence recorded or the speed of speech could affect the length of the recording which would affect file size which in turn must be sent over the network.

There is no difference in bytes sent from the data centre so even if a larger recording that says the same thing as a smaller recording is received the bytes returned from the data centre should be identical. There is a small difference between the bytes sent from the edge and the bytes sent from the data centre, the reason for this is whitespace at the end of the text being returned from PocketSphinx that is trimmed at the data centre.

Conclusion

This is quite straightforward as it is clear the voice recording is only sent as far as the data centre and then the data required to be sent to the data centre from the edge node is dramatically decreased. This confirms the hypothesis as there is a large reduction in data sent from the edge to the data centre.

## Load balance application experimentation

The same method will be used to answer the research questions below.

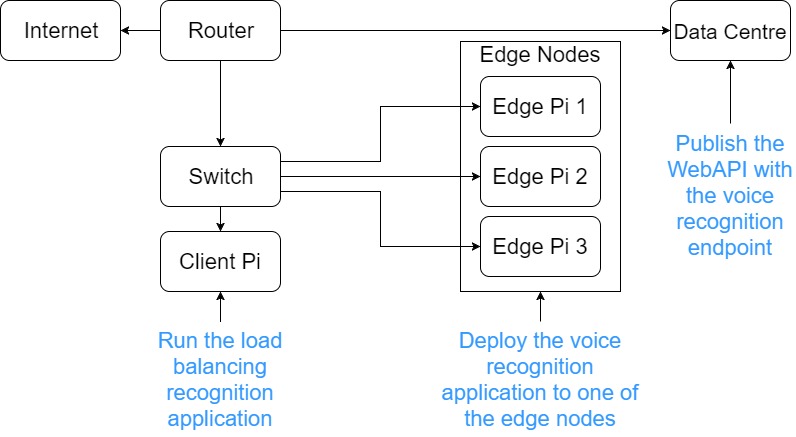
Setup

Figure 15 – Load balancing experimentation setup

The constants in this experiment are the voice recording used for processing at different stages, the language model and dictionary being used throughout the different stages and the voice recognition application being the only application deployed to the edge. The variables being evaluated are the number of concurrent requests being made, if the edge application is utilising load balancing and the number of instances of the voice recognition application.

Method

Measurements recorded will be:

* Processing time in seconds for all requests to finish
* Average request time in seconds
* Average CPU load as a percentage of the total CPU on the client device
* Average CPU load as a percentage of the total CPU on the edge node
* Average CPU load as a percentage of the total CPU on the edge node
* RAM use of the client device in GB
* RAM use of the edge node in GB
* RAM use of the data centre in GB

The same voice recording will be used throughout the experiment to allow for a fair comparison of computational load. The knowledge base that the voice recognition systems were trained with are all identical and produced using the Sphinx knowledge base tool [34]. This keeps the processing consistent across all the applications. There are 3 different types of requests in this experiment. The first is a request with no pre-processing, the second is a request with pre-processing and no load balancing, and the final is a request with pre-processing and load balancing.

The first run of the experiment will be the edge application deployed without load balancing implemented. There will be 10 sets of 10 warmup requests executed without pre-processing and 10 sets of 10 more requests with pre-processing. For a single run of the experiment, 10 sets of 10 requests will occur without pre-processing then a further 10 sets of 10 requests with pre-processing. There will be 5 runs of the experiment executed altogether and a single run has been automated. The edge application will then be deployed with load balancing enabled, and after 10 sets of 10 warmup requests a further 5 runs of 10 sets of 10 requests to pre-process the data made.

The 3 different types of request, no pre-processing, pre-processing without load balancing, and pre-processing with load balancing will be made again but with 5 runs of 10 sets of 30 requests to see the comparison of a larger number of concurrent requests.

### Does implementing load balancing improve edge computing?

Hypothesis

Adding load balancing will improve response times with large number of requests as if the edge CPU utilisation is over 70% the request will be redirected to the data centre. The strain on the edge CPU should also be lessened by introducing load balancing.

Results

Figure 16 - Request time chart

The raw results from the 5 runs of experimentation are available in the appendix.

Figure 17 - Edge node CPU use chart

There is no improvement on request time from implementing load balancing when there are just 10 concurrent requests. The request time for pre-processing without load balancing and the request time for pre-processing with load balancing stay the same to 0.006 of a second which means the edge node is capable of processing all the requests at once without the need for load balancing. However, the improvement can be seen when the number of concurrent requests is increased to 30 as there is a 61% reduction in request time when load balancing is implemented which means that the edge application has exhausted its available resources and needs to offload some execution of the voice recognition to the data centre which is also obvious to see when the edge application logs are investigated.

The edge CPU utilisation can be seen to decrease by 1% and 2% during the sets of 10 and sets of 30 requests respectively, this shows that implementing load balancing does improve performance slightly. When the CPU measurements are viewed alongside the request time measurement it is clear to see that the implementation of load balancing improves the request time and reduces the CPU utilisation of the edge device. What this means is that some strain is removed from the data centre, it is difficult to show this as per the problems with recording data centre CPU use [45] but less processing is occurring at the data centre so there should be some improvements. The computation is offloaded to the data centre if there are too many requests received at the edge so the client does not see a large delay in processing time.

It should be mentioned that when the edge application is under stress and not implementing load balancing that PocketSphinx occasionally returns empty text as the result. Implementing load balancing causes this to happen less frequently. When debugging the system, it seems that everything executed correctly and as expected apart from the voice recognition system returning no text and it only seems to happen when the processor is at max capacity.

Conclusion

**The hypothesis for this experiment was that adding load balancing would improve the response times with a larger number of requests. This is correct as when 30 requests were executed there was a** 61% decrease in response time which could not be observed when just 10 requests were executed. The second part of the hypothesis was that the strain on the CPU would be lessened by the introduction of load balancing which was observed only to a small degree of 1% and 2% which was not to the degree that was expected.

### Does deploying more than one instance of the application improve the effectiveness of edge computing?

Method

There is a slight change in method for this experiment as the application with no load balancing is deployed with 3 instances running on each node instead of 1.

Hypothesis

The response time will be closer to that of the 10 requests run as there are 3 instances of the application running across 3 different nodes. This means that there are 3 times the resources available to process the requests which should reduce the strain on each individual node.

Results

Figure 18 – Request time chart using 30 requests and no load balancing

Figure 19 – Edge CPU use using 30 requests and no load balancing

The raw results from the 5 runs of experimentation are available in the appendix.

It is clear to see that scaling this application has dramatic improvements. The voice recognition application is stateless [46], which means that it does not record information about the requesting client to alter processing during the next request. This allows for the application to be scaled by deploying more instances.

The average request time was improved by 121% when the application was scaled to 3 instances. There was also a 27% improvement in CPU use on the edge node, and as load balancing is not implemented when comparing these numbers all the requests were pre-processed on the edge. What this means is that there are dramatic improvements when the application is scaled.

The average request time for 10 requests on a single instance is 5.39s, the average request time for 30 requests on 3 instances is 6.82s which compared to the 15.06s it would take to process 30 requests on 1 instance is a vast improvement. In theory with a fair load balancer there will still be 10 requests per instance which is why the request times are close to one another.

Conclusion

The benefits of scaling the application are very clear and match what was set out in the hypothesis, however this means that a lot of the processing capabilities of that node are being used by the voice recognition application so it should be verified that other applications can perform optimally while the voice recognition application is under expected load.

## Machine learning application evaluation

Figure 20 – Recommendation after one movie

Figure 21 – Recommendation after 10 movies

The machine learning application will not be evaluated for latency or CPU use because the impact is minimal. This application is working functionally and can be evaluated as a proof of concept for an edge powered recommendation system. When the user first launches the application, they are told to enter a username. Currently the username does not already have to exist though registration could be added. If the user is new to the system the only option they have is to watch a random movie however if this was to be productised they could have a selection of popular movies or a selection of movies from each of the clusters produced from the data centre as to display a large range of available types of movies. If the user has already watched movies when they login they are presented with an average of the movies they watched that were retrieved from the data centre and a recommendation generated from the edge node based on this average.

Upon deployment, the edge node requests a subset of movies from the data centre. This subset is generated using K-Means clustering. The data is split into 10 clusters and as 10,000 movies are returned to the edge node, 1000 movies from each cluster are selected to be returned. K-Means was chosen as this would split the movies into distinct groups that would allow for a wide range of movies to be available on the edge for when a recommendation is required.

As shown in Figure 20 this system can produce a recommendation that has a Euclidean distance of 0.523 which means the recommended movie metrics are close to the metrics of what the user has watched. This is also the case if the user has watched multiple movies (Figure 21) by taking an average of the user’s movies and using that to generate the recommendation which has a Euclidean distance of 0.497. The maximum Euclidean distance possible with a movie recommendation is 2.822 so in both cases the recommended movie is close to what the user has watched.

This type of system adds value to the end user by allowing them to receive recommendations as to what one of the million movies available would suit their tastes. There is value added to the owner of the system by removing the need for a powerful central data centre. If the data centre is powerful enough to record results and query the available movies the recommendation algorithm can be executed on the edge nodes, and as there are a number of available nodes each of these devices is required to be less powerful than the central data centre.

The concept of implementing machine learning in a 3-tier network whilst utilising edge computing to produce recommendations can be further explored by continuing development of the system and producing a quantifiable analysis of the accuracy of the predictions by performing experimentation with real users. It is possible to quantify this with fake data or by applying Euclidean distance as seen previously however the results are less relevant than real data from real users. There could be a feedback mechanism implemented so if a user watched a movie and disliked it or disliked the recommendation provided this could be accounted for when a new recommendation is produced, or if the user knows they like certain types of movies this could be fed to the system to find movies that match certain criteria. The number of clusters produced at the data centre and the number of movies returned to the data centre could be altered to evaluate the accuracy of the prediction.

There was some experimentation needed to see what the optimum number of movies to store on the edge node is. To produce these numbers the edge application was deployed and the data centre was configured to return a different number of movies per round of the experiment. A user who had watched 10 movies then logged in to the client application 10 times to produce 10 recommendations. The results of these operations were recorded can be viewed in the appendix below.

Figure 22 – Recommendation request time graph

When a user requested a recommendation when there were 1,000 movies the average request time was 0.24 seconds, when the number of movies increased to 10,000 the average request time increased to 1.13 seconds and when movies increased to 100,000 the request time was 10.03 seconds. The request didn’t finish when using 1,000,000 movies as the Node.js server ran out of memory however this is irrelevant as a request time of 10 seconds is too long for a user to wait after logging in or watching a movie to receive the recommendation.

Figure 23 – Recommendation Euclidean distance graph

When the user requested a recommendation with 1,000 movies on the edge the Euclidian distance was 0.542, this decreased to 0.391 when there were 10,000 movies and decreased again to 0.278 when there were 100,000 movies.

The results show a trend as the more movies you have available for providing a recommendation the smaller the Euclidian distance. There is a 374% increase in request time between 1,000 movies and 10,000 movies on the edge node. This increase in request time causes a 39% decrease in Euclidean distance which means that the recommendation produced is more accurate. There is a further 789% increase in request time between 10,000 movies and 100,000 movies which relates to a further 40% increase in recommendation accuracy. This puts 10,000 movies on the edge node as being a good trade-off between request speed (1.13 seconds) and recommendation accuracy (0.391 Euclidean distance) however the real-life accuracy of the recommendation would need to be tested with real movie data and real users to understand if the user likes the movie that is recommended to them.

If 100,000 movies are stored at the edge it produces a better prediction but the computational power required to parse through all available movies causes the request to take too long and if there are only 1,000 movies available the processing is very quick but the accuracy of the prediction is diminished as a result. 10,000 movies being parsed and evaluated is a good compromise between speed and accuracy.

# Conclusion

The 3-tier network was implemented as discussed in the introduction and problem specification and shown in Figure 1. There is a client, edge, and data centre where the edge pre-processes or handles requests to ease the computational strain on the other tiers. The system is easily administered and maintainable and the benefits of adding edge computing to different applications has been quantified and analysed, such as the effect on response times and computational load. The 3 applications developed for the system are caching, voice recognition and machine learning as per the candidates proposed.

As there are multiple research questions proposed and results obtained to answer these questions so it is useful to discuss the significance of them individually. The first is if utilising edge computing reduces latency of requests for the client, the purpose of this is to discover if the implementation of edge computing could be used to benefit the client and ultimately the end users experience. What was found was that the implementation of the caching application increased the request time even with a cached request which means that the cost of querying the cache outweighs the time benefits gained by utilising the cache. An experiment performed with a technology called Edge Accelerated Browsing (EAB) [5] found that with some requests the render time would increase however their results show that in most cases implementing EAB decreases render time. These results can be compared as they are both experimenting with web browsing while implementing edge computing solutions however it should be noted that EAB performs processing such as rendering and optimised transmissions whereas the application developed for this system performs caching across multiple instances so they are different approaches to the same objective.

The second research question proposed was if utilising edge computing would reduce the computational load for a client, this is useful to understand as battery life on client devices is becoming more of an issue [47] and by performing less tasks locally that require a large amount of CPU time the battery life should improve. What was found is that there are drastic improvements to computational load on client devices by offloading resource intensive tasks to edge computing solutions.

After revealing the benefits on client CPU use it was useful to discuss the effects of implementing this solution, so the third research question proposed was if edge computing increased the latency of request for the client device. This would compare the execution time of remote processing vs local processing. The latency of requests for processing occurring remotely has been discussed before [48] however the on-demand gaming platform that was being used to investigate these effects requires much more emphasis on latency as per the nature of multiplayer gaming. What was found in that study is that the latency decreased with the implementation of edge solutions that are closer in geographical proximity to the clients. With the solution implemented here for voice recognition what was found is that a small increase in latency could be justified by the large benefits in CPU use on the client device and can be attributed to the extra steps needed to perform the remote execution.

As remote processing was found to be beneficial to the client, the effects of this remote processing on network utilisation was investigated. Data must be sent further if the request is to be processed on the data centre which has a negative effect on bandwidth [7] compared to if the request is pre-processed on the edge node which is geographically closer to the client. There was a drastic decrease in data being sent to the data centre when edge computing was introduced. Decreasing the bandwidth used provides benefits such as reduced costs [4] and there is no effect on the result the user receives.

The scalability of edge computing had to be investigated to verify that the solution implemented is scalable to handle multiple requests concurrently. The resource intensive task of voice recognition had a large decrease in request time when load balancing was implemented however this means that the data centre is handling some of the requests which removes the benefits gained from edge computing such as network utilisation. A solution to this was to scale the application to have multiple instances running concurrently on multiple edge nodes. Both these approaches to load balancing produced positive results which is what was expected.

Raspberry Pi is a cost-effective way to learn about the importance of performance as it is a low powered device when compared to the data centre. Docker ran on the ARM processor of the Raspberry Pi without issues and the reason that the benefits of edge computing were only apparent in some cases could be for reasons discussed in a paper about the performance of a low power Raspberry Pi cloud [20]. There are limitations because of the network interface speed of 100Mbps on the Raspberry Pi as discussed in the paper [20] which could be a contributing factor as to why the caching application was not as effective as expected however they found a solution to the problem by replicating data on each of the worker nodes. The caching application only stores data on one instance of Redis at a time which meant a web request still had to be performed to obtain data stored on a different node. The system provided enough power to run multiple instances of Node.js servers in parallel. There were a few networking challenges with this system but once the system is setup it is easy to administer and control.

The conclusions met for the research questions proposed are significant as they show that there is potential for edge computing applications to benefit the client and the data centre that can be deployed to a geographically wide area on hardware that is affordable and easily maintainable.

Development of this system was continuous throughout the year, there were short term goals that were met so that the larger goals, such as completing one of the applications in its entirety, were achieved. The system was easy to break into smaller components because of its nature, there are a distinct section for the client, edge, and data centre for each of the 3 applications developed. One of the main learning points for project management was to clearly define what the application should be and ensure that all members involved are clear before starting development, though this can also be difficult to achieve because of changing requirements as the system under development takes shape. An example of this is the machine learning application as once development was nearing completion it was clear that the system was not showing its full potential so it was adapted and redesigned so that the resulting application was better than what was laid out at the start.

It would be useful to see experimental results relating to the quality of the recommendation produced by the machine learning application to see quantifiably what benefits it provides however to do this would require finding a subset of users to provide their opinion and developing the system to work with real movie data rather than test data which is out of the scope of this project. There was some experimentation that could be quantified with the current machine learning setup relating to the quantity of movies stored on the edge device. What was found is that there are obvious improvements in recommendation accuracy when more movies are stored on the edge node but this leads to an increase in request time as the computation power required to parse the movies increases. The application is useful to show the different ways that edge computing can be implemented. The first way shown is a request being handled entirely at the edge with the caching application without the data centre having to be queried. The second way is having the option of doing the processing/pre-processing at any of the 3 tiers in the network with the voice recognition application. The final way shown is the tiers working in conjunction with one another to produce a result with the machine learning application. It shows the flexibility of such a system depending on what the requirements are.

This project has great potential to be taken further, the machine learning application has some very interesting concepts that could be expanded upon for further research such as more complex problems being solved by utilising multiple edges. The caching and voice recognition applications quantifiably show the benefits of edge computing and could be developed further into real world robust systems to be analysed.

Overall the results show that it is not always beneficial to use edge computing depending on the individual use cases. In some cases where this system was found to not meet the hypothesis, such as the caching application, there exists a common practice for which it is proven to be worthwhile, such as Twitter [50], which means that there are other factors in this system diminishing the potential returns. However, there are benefits that can be obtained with the implemented applications if it is utilised correctly and the trade-offs evaluated.

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# Appendices

## Caching System Tests

Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can reach Caching Application page | Click on the caching application button on the home page | The Caching Application page is now launched | True |
| Home button | Click home button | Should be returned to the home page | True |
| URL bar is present | On the caching page ensure there is a URL bar | The URL bar is present | True |
| Can type into URL bar | Click into the URL bar and type an address | The address typed will show up in the URL bar | True |
| Go button without URL typed | Click the Go button when there is no URL typed out | Nothing, there will be no error | True |
| Go button with an invalid URL typed | Click the Go button when an invalid URL is typed into the URL bar | A message will appear warning the user that the request failed | True |
| Go button with a valid URL typed | Click the Go button when a valid URL is typed | The requested webpage will be fetched and displayed to the user | True |
| The timer | Click the go button with a valid URL | The timer will start and when the round is finished it will record the total time to complete the request | True |
| Clear cache button | Click the clear cache button | Information will appear to indicate that the cache on the edge node was cleared successfully | True |
| Can connect to the proxy | Make a web request | Ensure that the proxy is utilised | True |

Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can connect to all the Redis instances | Deploy the web server and check the logs | The server will automatically connect to all the Redis servers | True |
| Can make request to Caching Web Server | Make a curl request to the Edge Node using the host name and port number | Receive Data back | True |
| Clear cache request | Call the Edge Node with a ClearCache request | The clear cache command is executed using the redis-cli and the cache is cleared from all Redis instances. This information is then returned to the user | True |
| Receive new request | Call the Edge Node with a new URL | The content is retrieved, stored in the correct Redis instance, and returned to the client | True |
| Receive a request for the second time | Call the Edge Node with a URL that has already been requested | The content is retrieved from the correct Redis instance and returned to the user | True |

## Voice Recognition System Tests

Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can reach the Voice Recognition page | Click on the Voice Recognition button on the home page | The Voice Recognition Application page is now launched | True |
| Home button | Click home button | Should be returned to the home page | True |
| Recording status after page launch | Launch the Voice Recognition application | The recording status should be “Not Recording” | True |
| Recording status after clicking record | Click the record button | The recording status should change to “Recording” | True |
| Recording status after stopping recording | Click the stop recording button after starting a recording | The recording status should change to “Finished recording” | True |
| Recording button when not recording | Stop a recording or don’t start a recording | The recording button should read to “Start Recording” | True |
| Recording button when recording | Start a recording or don’t stop a recording | The recording button should read “Stop Recording” | True |
| Execute local recognition button without recording | Press the Execute Local Recognition button without recording a phrase | The results should say you said nothing | True |
| Execute local recognition button after recording | Press the Execute Local Recognition button after recording a phrase | The execution of the recording should be performed locally | True |
| Execute remote recognition button with no recording | Press the Execute Remote Recognition button without recording a phrase | Error should be shown to user | True |
| Execute remote recognition button after recording without edge processing | Press the Execute Remote Recognition button after recording a phrase and don’t tick the pre-process checkbox | The Execution of the recording should be performed remotely on the Data Centre | True |
| Execute remote recognition button after recording with edge processing | Press the Execute Remote Recognition button after recording a phrase and tick the pre-process checkbox | The Execution of the recording should be performed remotely on the Edge Node and the results sent to the Data Centre | True |
| Local Results section when no local evaluation has occurred | Launch the Voice Recognition Application and don’t perform local evaluation | The results section is empty | True |
| Local Results section when the local evaluation has occurred | Perform local evaluation | The local results section should show statistics | True |
| Remote Results section when no remote evaluation has occurred | Launch the Voice Recognition Application and don’t perform remote evaluation | The results section is empty | True |
| Remote Results section when no remote evaluation has occurred | Perform remote evaluation | The remote results section should show statistics | True |

Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can make request to Voice Recognition Web Server | Make a curl request to the Edge Node using the hostname and port number | Receive Data back | True |
| Receive Get Request | Make a get request to the Edge Node | Message about only allowing POST requests | True |
| Receive Put Request | Make a put request to the Edge Node | Message about only allowing POST requests | True |
| Receive post request with invalid data | Make a post request with an invalid audio file or incorrect data | No error and gracefully handled | True |
| Receive post request with valid recording | Make a request with a valid voice recording | A JSON object is returned with information about the request and the audio spoken | True |
| Receive valid request with the pre-process header | Make request with the pre-process request header set | The processing of the voice file happens on the Edge Node | True |
| Receive valid request without the pre-process header | Make request without the pre-process request header set | The voice recording is sent to the data centre for processing and the results returned to the user | True |
| Request information from the Data Centre when the WebAPI is not published | Remove the WebAPI and make a request | The service should record an error | True |
| Request information from the Data Centre when the WebAPI is published | Publish the WebAPI and make a request | The information should be returned correctly | True |
| Measure CPU use | Make a regular request | The CPU use on the edge node should be returned as part of the request | True |
| Measure Time of request | Make a regular request | The Time taken to process the request should be recorded | True |

Data Centre Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Receive valid request to process voice | Make a valid POST request with invalid voice data | The voice is processed correctly and a valid response is produced | True |
| Receive valid request to record information | Make a valid POST request with textual data from a pre-processed request | The request should be handled gracefully and a response sent | True |

## Machine Learning System Tests

Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can reach the Machine Learning page | Click on the Machine Learning button on the home page | The Machine Learning Application page is now launched | True |
| Home button | Click home button | Should be returned to the home page | True |
| Username box is present | On the Machine Learning page ensure the username box is visible | The Username box is visible | True |
| Can type into the username box | Click into the username box and type a username | The username typed will show up in the username box | True |
| Login button without username typed | Click the Login button when there is no username typed out | User will not be shown a logged in page and an error will appear | True |
| Login button with a valid username typed | Click the Login button when a valid username is typed | The username box and login button will be replaced with the machine learning application page | True |
| Login as a user who has never watched a movie | Type a username that does not exist in stored user data in the data centre | The previous results section and recommendation section will not be populated | True |
| Login as a user who has previously watched a movie | Type a username that does exist in the stored user data in the data centre | The previous results will contain an average and count of all previously watched movies and a recommendation will be presented | True |
| Watch a random movie | Click the button to watch a random movie | The movie that you just watched will be shown. There will also be an updated recommendation. The average results will also be updated | True |
| Watch a recommended movie when there is no movie recommendation | Click the button to watch the recommended movie when there is no movie recommendation | A warning will be displayed to watch a movie | True |
| Watch a recommended movie when there is a valid recommendation | Click the button to watch the recommended movie when a movie recommendation is available | The movie you have been recommended will be watched and you will receive an updated recommendation | True |

Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can make request to Voice Recognition Web Server | Make a curl request to the Edge Node using the hostname and port number | Receive Data back | True |
| Receive Get Request | Make a get request to the Edge Node | No error and message returned | True |
| Receive Put Request | Make a put request to the Edge Node | No error and message returned | True |
| Receive post request with invalid data | Make a post request with incorrect JSON | Error message is returned | True |
| Get movies on launch | Deploy the application | A request is performed to download movies from the Data Centre | True |
| Write received movies to disk | Deploy the application | The received movies from the Data Centre are stored on disk | True |
| Get Recommendations | Make a request to get recommendations | A movie is returned to the client as a recommendation | True |
| Watch Random Movie | Make a request to watch a random movie | The request is forwarded to the Data Centre and a recommendation is produced then all the data is returned to the Client | True |
| Watch Movie | Make a request to watch a specific movie | The request is forwarded to the Data Centre and a recommendation is produced then all the data is returned to the Client | True |
| Produce recommendation | Make a request that will return a recommendation | A recommendation is produced by performing Nearest Neighbour evaluation | True |

Data Centre Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Receive request to GetMovies | Make a GET request for “GetMovies” | The data returned is a subset of the movies available at the data centre | True |
| Receive request to GetPreviousMovies with a UserID that doesn’t exist | Make a POST request for “GetPreviousMovies” with a UserID that does not exist | The system should handle the fact that the user has not watched any movies yet and return nothing | True |
| Receive request to GetPreviousMovies with a UserID that exists | Make a POST request for “GetPreviousMovies” with a UserID that exists | The system should return a collection of the movies the user previously watched | True |
| Receive request to WatchRandomMovie | Make a POST request for “WatchRandomMovie” with a user ID | Watches a movie at random and records the fact the user watched the movie and return this data | True |
| Receive request to WatchMovie | Make a POST request for “WatchMovie” with a user ID and movie ID | Store the fact the user watched this movie and return the movie data. | True |

## Load Balancing System Tests

Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can reach the Load Balance page | Click on the Load Balance button on the home page | The Load Balance Application page is now launched | True |
| Home button | Click home button | Should be returned to the home page | True |
| Number of Requests box is present | On the Load Balance page ensure the number of requests box is visible | The number of request box is visible | True |
| The checkbox for pre-processing requests can be selected | There is a checkbox for enabling pre-processing of requests and it can be ticked | The checkbox is visible and can be ticked | True |
| The go button is visible | Check the button for executing the requests is visible | The button for executing the requests is visible | True |
| Press go when nothing is entered into the Number of requests box | Don’t type anything in the “Number of requests” box and press “Go” | An error should appear | True |
| Press go when text is entered | Type a value that is not numerical | An error should appear | True |
| Press go when numbers are entered | Type a value that is numerical, non-negative and less than 50 | The number of requests entered should start executing and display in the results section | True |
| Press go when a number greater than 50 is entered | Type a value that is greater than 50 | An error message should appear warning you to enter a valid number | True |

## Experiment Results

### Caching Results

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Run 1 |  |  |  |  |  |  |  |  |  |
| Iteration |  | BBC | |  | Sky News | |  | A Single Div | |
|  | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request |
| 1 | 3.46 | 4.4 | 4.71 | 3.77 | 4.79 | 3.46 | 1.59 | 2.65 | 1.84 |
| 2 | 3.93 | 8.49 | 4.65 | 3.72 | 6.21 | 3.55 | 1.58 | 2.34 | 1.86 |
| 3 | 3.62 | 8.24 | 4.5 | 3.93 | 3.93 | 3.64 | 1.62 | 2.24 | 1.86 |
| 4 | 3.34 | 4.93 | 4.64 | 3.75 | 4.87 | 3.44 | 1.66 | 2.21 | 1.88 |
| 5 | 6.66 | 4.9 | 4.94 | 3.56 | 9.73 | 3.45 | 1.61 | 2.19 | 1.86 |
| 6 | 3.44 | 8.08 | 4.66 | 3.73 | 3.93 | 4.05 | 1.68 | 2.21 | 1.87 |
| 7 | 4.04 | 4.25 | 4.93 | 3.57 | 4.34 | 3.5 | 1.58 | 2.59 | 1.88 |
| 8 | 3.57 | 8.88 | 4.95 | 3.68 | 9.8 | 3.9 | 1.62 | 2.25 | 1.87 |
| 9 | 3.53 | 8.32 | 4.89 | 3.65 | 3.87 | 3.58 | 1.58 | 2.37 | 1.86 |
| 10 | 3.94 | 4.35 | 4.54 | 3.54 | 4.64 | 3.46 | 1.66 | 3.15 | 1.92 |
| Avg | 3.953 | 6.484 | 4.741 | 3.69 | 5.611 | 3.603 | 1.618 | 2.42 | 1.87 |
| Standard Deviation | 0.980623951 | 2.043369766 | 0.171817086 | 0.118133634 | 2.293388807 | 0.20928715 | 0.037357135 | 0.302948474 | 0.021081851 |
| Run 2 |  |  |  |  |  |  |  |  |  |
| Iteration |  | BBC | |  | Sky News | |  | A Single Div | |
|  | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request |
| 1 | 3.63 | 4.67 | 4.57 | 3.84 | 4.22 | 3.5 | 1.63 | 2.51 | 2 |
| 2 | 3.48 | 5.08 | 4.74 | 3.7 | 6.27 | 3.8 | 1.63 | 2.24 | 2.17 |
| 3 | 3.56 | 9 | 4.48 | 3.56 | 4.9 | 4.24 | 1.58 | 2.14 | 2.32 |
| 4 | 3.43 | 4.67 | 5.01 | 3.63 | 4.25 | 3.82 | 1.6 | 2.13 | 2.12 |
| 5 | 3.73 | 9.23 | 4.21 | 3.69 | 4.74 | 3.83 | 1.61 | 2.31 | 2.16 |
| 6 | 3.76 | 4.26 | 4.46 | 3.7 | 8.53 | 3.72 | 1.61 | 1.89 | 2.36 |
| 7 | 3.84 | 4.71 | 4.58 | 3.7 | 3.97 | 3.5 | 1.59 | 2.15 | 2.11 |
| 8 | 3.53 | 9.59 | 4.57 | 3.76 | 12.35 | 3.9 | 1.63 | 2.18 | 2.18 |
| 9 | 3.54 | 4.62 | 4.51 | 3.68 | 4.62 | 3.82 | 1.62 | 3.46 | 2.33 |
| 10 | 3.57 | 4.6 | 4.71 | 3.76 | 4.26 | 3.59 | 1.63 | 2.6 | 2.13 |
| Avg | 3.607 | 6.043 | 4.584 | 3.702 | 5.811 | 3.772 | 1.613 | 2.361 | 2.188 |
| Standard Deviation | 0.131153006 | 2.242092525 | 0.209135788 | 0.075836081 | 2.677488251 | 0.218062173 | 0.018287822 | 0.435340225 | 0.114387256 |
| Run 3 |  |  |  |  |  |  |  |  |  |
| Iteration |  | BBC | |  | Sky News | |  | A Single Div | |
|  | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request |
| 1 | 3.54 | 7.88 | 4.59 | 3.79 | 4.21 | 3.8 | 1.62 | 2.3 | 1.88 |
| 2 | 3.87 | 4.54 | 4.39 | 3.78 | 4.49 | 4.03 | 1.66 | 2.18 | 1.76 |
| 3 | 3.84 | 8.35 | 4.72 | 3.76 | 9.87 | 3.88 | 1.59 | 1.96 | 1.74 |
| 4 | 3.61 | 4.5 | 4.79 | 3.64 | 4.66 | 3.54 | 1.6 | 2.18 | 1.76 |
| 5 | 4.14 | 4.67 | 4.53 | 3.72 | 4.64 | 4.86 | 1.59 | 2.16 | 1.78 |
| 6 | 3.64 | 7.88 | 4.61 | 3.86 | 4.73 | 3.58 | 1.55 | 1.87 | 2.45 |
| 7 | 3.41 | 4.06 | 4.13 | 3.89 | 4.45 | 3.74 | 1.58 | 2.99 | 2.21 |
| 8 | 4.07 | 4.75 | 4.58 | 3.75 | 8.39 | 3.56 | 1.59 | 3.33 | 1.8 |
| 9 | 4.12 | 9.53 | 4.68 | 3.75 | 4.46 | 3.71 | 1.61 | 1.92 | 1.81 |
| 10 | 3.61 | 8.45 | 4.48 | 4.25 | 3.91 | 3.64 | 1.6 | 2.2 | 2.02 |
| Avg | 3.785 | 6.461 | 4.55 | 3.819 | 5.381 | 3.834 | 1.599 | 2.309 | 1.921 |
| Standard Deviation | 0.260906539 | 2.118859494 | 0.18761663 | 0.166563301 | 2.020502963 | 0.391895678 | 0.028460499 | 0.476035713 | 0.237180194 |
| Run 4 |  |  |  |  |  |  |  |  |  |
| Iteration |  | BBC | |  | Sky News | |  | A Single Div | |
|  | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request |
| 1 | 3.46 | 3.86 | 4.5 | 3.84 | 5.07 | 3.88 | 1.6 | 2.31 | 1.81 |
| 2 | 3.35 | 4.11 | 4.78 | 3.8 | 4.39 | 3.85 | 1.58 | 2.09 | 2.15 |
| 3 | 3.63 | 5.34 | 4.38 | 3.73 | 3.68 | 4.08 | 1.64 | 1.97 | 1.84 |
| 4 | 3.85 | 4.88 | 4.94 | 3.43 | 4.19 | 3.7 | 1.59 | 2.1 | 1.85 |
| 5 | 4.04 | 4.07 | [8 - Obvious Error] | 3.65 | 4.42 | 3.56 | 1.6 | 2.6 | 1.82 |
| 6 | 3.43 | 9.54 | 4.58 | 3.75 | 3.9 | 4.05 | 1.57 | 2.67 | 1.87 |
| 7 | 3.76 | 4.82 | 4.65 | 3.85 | 4.63 | 3.67 | 1.58 | 2.13 | 1.75 |
| 8 | 3.46 | 8.11 | 4.32 | 3.49 | 4.53 | 3.53 | 1.59 | 2.07 | 1.83 |
| 9 | 3.56 | 4.16 | 4.57 | 3.85 | 3.75 | 3.68 | 1.59 | 2.04 | 1.8 |
| 10 | 3.34 | 8.44 | 4.77 | 3.71 | 4.75 | 3.66 | 1.59 | 2.37 | 1.84 |
| Avg | 3.588 | 5.733 | 4.61 | 3.71 | 4.331 | 3.766 | 1.593 | 2.235 | 1.856 |
| Standard Deviation | 0.231170932 | 2.123126887 | 0.198934663 | 0.147798662 | 0.450812846 | 0.191380946 | 0.018885621 | 0.243139192 | 0.108341025 |
| Run 5 |  |  |  |  |  |  |  |  |  |
| Iteration |  | BBC | |  | Sky News | |  | A Single Div | |
|  | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request | No Cache Request | First Request | Second Request |
| 1 | 3.59 | 4.95 | 4.96 | 3.83 | 3.46 | 3.61 | 1.58 | 1.8 | 1.76 |
| 2 | 3.66 | 4.35 | 4.7 | 3.72 | 4.86 | 3.62 | 1.61 | 1.8 | 2.08 |
| 3 | 3.33 | 8.34 | 4.74 | 3.76 | 3.64 | 4.06 | 1.61 | 2.8 | 1.86 |
| 4 | 3.63 | 4.84 | 4.57 | 3.88 | 4.14 | 3.62 | 1.65 | 1.75 | 1.73 |
| 5 | 3.42 | 4.68 | 4.8 | 3.7 | 4.67 | 4.01 | 1.63 | 2.29 | 1.74 |
| 6 | 3.64 | 4.07 | 4.84 | 3.76 | 3.91 | 4 | 1.6 | 2.48 | 1.77 |
| 7 | 3.55 | 4.33 | 4.64 | 3.68 | 4.13 | 3.8 | 1.57 | 1.75 | 1.79 |
| 8 | 3.47 | 4.73 | 4.75 | 3.7 | 5.14 | 3.59 | 1.6 | 1.78 | 1.82 |
| 9 | 3.63 | 8.46 | 4.6 | 3.76 | 3.88 | 4.36 | 1.6 | 2.11 | 1.75 |
| 10 | 3.65 | 4.71 | 4.7 | 3.75 | 3.87 | 3.74 | 1.64 | 1.78 | 1.73 |
| Avg | 3.557 | 5.346 | 4.73 | 3.754 | 4.17 | 3.841 | 1.609 | 2.034 | 1.803 |
| Standard Deviation | 0.113436228 | 1.631422011 | 0.116809436 | 0.061680179 | 0.547336987 | 0.257571996 | 0.02514403 | 0.373696252 | 0.105835302 |

|  |  |  |  |
| --- | --- | --- | --- |
| Run 1 |  |  |  |
| Iteration |  | BBC (3G) | |
|  | No Cache Request | First Request | Second Request |
| 1 | 4.22 | 9.09 | 5.23 |
| 2 | 8.81 | 8.53 | 7.5 |
| 3 | 6.61 | 6.54 | 7.41 |
| 4 | 6.44 | 7.35 | 5.3 |
| 5 | 5.77 | 8.05 | 7.41 |
| 6 | 6.95 | 5.32 | 7.37 |
| 7 | 4.36 | 9.43 | 7.82 |
| 8 | 6.33 | 9.49 | 7.58 |
| 9 | 5.69 | 10.23 | 7.47 |
| 10 | 4.28 | 8 | 6.64 |
| Avg | 5.946 | 8.203 | 6.973 |
| Standard Deviation | 1.430207444 | 1.491971477 | 0.948566755 |
| Run 2 |  |  |  |
| Iteration |  | BBC (3G) | |
|  | No Cache Request | First Request | Second Request |
| 1 | 4.21 | 10.83 | 9.26 |
| 2 | 6.63 | 7.52 | 10.98 |
| 3 | 5.68 | 11.66 | 8.05 |
| 4 | 6.69 | 11.04 | 5.81 |
| 5 | 6.76 | 10.3 | 5.7 |
| 6 | 5.49 | 16.29 | 8.99 |
| 7 | 5.84 | 11.75 | 8.83 |
| 8 | 6.74 | 9.2 | 8.8 |
| 9 | 3.86 | 6.28 | 5.79 |
| 10 | 6.6 | 10.64 | 7.17 |
| Avg | 5.85 | 10.551 | 7.938 |
| Standard Deviation | 1.070046728 | 2.692481095 | 1.77639335 |
| Run 3 |  |  |  |
| Iteration |  | BBC (3G) | |
|  | No Cache Request | First Request | Second Request |
| 1 | 6.87 | 7.13 | 7.91 |
| 2 | 10.31 | 9.53 | 7.67 |
| 3 | 5.05 | 8.18 | 7.71 |
| 4 | 7.23 | 6.83 | 8.75 |
| 5 | 5.44 | 8.77 | 5.98 |
| 6 | 7 | 9.36 | 7.82 |
| 7 | 4.41 | 7.69 | 5.68 |
| 8 | 5.07 | 8.43 | 5.47 |
| 9 | 6.02 | 6.91 | 8.69 |
| 10 | 4.16 | 10.32 | 7.06 |
| Avg | 6.156 | 8.315 | 7.274 |
| Standard Deviation | 1.813457104 | 1.192609184 | 1.19017459 |
| Run 4 |  |  |  |
| Iteration |  | BBC (3G) | |
|  | No Cache Request | First Request | Second Request |
| 1 | 10.33 | 7.39 | 8.62 |
| 2 | 7.57 | 6.93 | 7.96 |
| 3 | 6.15 | 7.46 | 8.73 |
| 4 | 8 | 7.14 | 8.35 |
| 5 | 9.28 | 11.23 | 9.09 |
| 6 | 7.33 | 11.39 | 8.68 |
| 7 | 5.83 | 6.39 | 8.41 |
| 8 | 4.76 | 9.47 | 5.73 |
| 9 | 5.2 | 8.86 | 8.86 |
| 10 | 6.21 | 6.67 | 4.67 |
| Avg | 7.066 | 8.293 | 7.91 |
| Standard Deviation | 1.784209753 | 1.852212191 | 1.481755715 |
| Run 5 |  |  |  |
| Iteration |  | BBC (3G) | |
|  | No Cache Request | First Request | Second Request |
| 1 | 5.68 | 11.59 | 8.17 |
| 2 | 7.7 | 9.47 | 7.83 |
| 3 | 5.07 | 7.65 | 8.52 |
| 4 | 7.46 | 8.43 | 8.78 |
| 5 | 4.5 | 6.41 | 7.93 |
| 6 | 6.45 | 7.78 | 8.01 |
| 7 | 5.7 | 10.36 | 7.83 |
| 8 | 6.81 | 8.62 | 7.59 |
| 9 | 6.21 | 7.15 | 7.83 |
| 10 | 5.76 | 7.7 | 7.79 |
| Avg | 6.134 | 8.516 | 8.028 |
| Standard Deviation | 1.006072672 | 1.564780425 | 0.36571999 |

### Voice Recognition Results

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Run 1 |  | | | |  | | |  | | |  | |
| Iteration | Local Execution | | | | | | | | | | | |
|  | Local CPU | | | | Local RAM | | | Execution Time | | | File Size | |
| 1 | 28.5 | | | | 0.15 | | | 1.62 | | | 245804 | |
| 2 | 28.23 | | | | 0.15 | | | 1.565 | | | 245804 | |
| 3 | 27.18 | | | | 0.15 | | | 1.556 | | | 245804 | |
| 4 | 28.41 | | | | 0.15 | | | 1.566 | | | 245804 | |
| 5 | 27.21 | | | | 0.15 | | | 1.547 | | | 245804 | |
| 6 | 27.76 | | | | 0.15 | | | 1.545 | | | 245804 | |
| 7 | 26.97 | | | | 0.15 | | | 1.591 | | | 245804 | |
| 8 | 28.01 | | | | 0.15 | | | 1.596 | | | 245804 | |
| 9 | 27.09 | | | | 0.15 | | | 1.535 | | | 245804 | |
| 10 | 27.29 | | | | 0.15 | | | 1.577 | | | 245804 | |
| Avg | 27.665 | | | | 0.15 | | | 1.5698 | | | 245804 | |
| SD | 0.58652 | | | | 0 | | | 0.026418848 | | | 0 | |
| Run 2 |  | | | |  | | |  | | |  | |
| Iteration | Local Execution | | | | | | | | | | | |
|  | Local CPU | | | | Local RAM | | | Execution Time | | | File Size | |
| 1 | 29.11 | | | | 0.14 | | | 1.591 | | | 245804 | |
| 2 | 27.64 | | | | 0.14 | | | 1.547 | | | 245804 | |
| 3 | 27.57 | | | | 0.14 | | | 1.544 | | | 245804 | |
| 4 | 28.94 | | | | 0.14 | | | 0.1547 | | | 245804 | |
| 5 | 27.49 | | | | 0.14 | | | 1.566 | | | 245804 | |
| 6 | 27.72 | | | | 0.14 | | | 1.588 | | | 245804 | |
| 7 | 27.47 | | | | 0.14 | | | 1.588 | | | 245804 | |
| 8 | 27.38 | | | | 0.14 | | | 1.542 | | | 245804 | |
| 9 | 28.06 | | | | 0.14 | | | 1.551 | | | 245804 | |
| 10 | 27.9 | | | | 0.14 | | | 1.613 | | | 245804 | |
| Avg | 27.928 | | | | 0.14 | | | 1.42847 | | | 245804 | |
| SD | 0.614253 | | | | 0 | | | 0.448215063 | | | 0 | |
| Run 3 |  | | | |  | | |  | | |  | |
| Iteration | Local Execution | | | | | | | | | | | |
|  | Local CPU | | | | Local RAM | | | Execution Time | | | File Size | |
| 1 | 28.66 | | | | 0.15 | | | 1.632 | | | 245804 | |
| 2 | 27.83 | | | | 0.15 | | | 1.545 | | | 245804 | |
| 3 | 26.33 | | | | 0.15 | | | 1.567 | | | 245804 | |
| 4 | 27.42 | | | | 0.15 | | | 1.532 | | | 245804 | |
| 5 | 26.83 | | | | 0.15 | | | 1.518 | | | 245804 |
| 6 | 27.48 | | | | 0.15 | | | 1.52 | | | 245804 | |
| 7 | 27.41 | | | | 0.15 | | | 1.543 | | | 245804 | |
| 8 | 27.6 | | | | 0.15 | | | 1.518 | | | 245804 | |
| 9 | 28.01 | | | | 0.15 | | | 1.533 | | | 245804 | |
| 10 | 27.11 | | | | 0.15 | | | 1.529 | | | 245804 | |
| Avg | 27.468 | | | | 0.15 | | | 1.5437 | | | 245804 | |
| SD | 0.641107 | | | | 0 | | | 0.034467537 | | | 0 | |
| Run 4 |  | | | |  | | |  | | |  | |
| Iteration | Local Execution | | | | | | | | | | | |
|  | Local CPU | | | | Local RAM | | | Execution Time | | | File Size | |
| 1 | 27.79 | | | | 0.15 | | | 1.619 | | | 245804 | |
| 2 | 28.1 | | | | 0.15 | | | 1.542 | | | 245804 | |
| 3 | 27.2 | | | | 0.15 | | | 1.564 | | | 245804 | |
| 4 | 27.96 | | | | 0.15 | | | 1.569 | | | 245804 | |
| 5 | 26.92 | | | | 0.15 | | | 1.548 | | | 245804 | |
| 6 | 26.9 | | | | 0.15 | | | 1.527 | | | 245804 | |
| 7 | 27 | | | | 0.15 | | | 1.535 | | | 245804 | |
| 8 | 28.01 | | | | 0.15 | | | 1.54 | | | 245804 | |
| 9 | 27.29 | | | | 0.15 | | | 1.538 | | | 245804 | |
| 10 | 27.9 | | | | 0.15 | | | 1.539 | | | 245804 | |
| Avg | 27.507 | | | | 0.15 | | | 1.5521 | | | 245804 | |
| SD | 0.489423 | | | | 0 | | | 0.026793241 | | | 0 | |
| Run 5 |  | | | |  | | |  | | |  | |
| Iteration | Local Execution | | | | | | | | | | | |
|  | Local CPU | | | | Local RAM | | | Execution Time | | | File Size | |
| 1 | 28.42 | | | | 0.15 | | | 1.622 | | | 245804 | |
| 2 | 27.72 | | | | 0.15 | | | 1.565 | | | 245804 | |
| 3 | 28.11 | | | | 0.15 | | | 1.55 | | | 245804 | |
| 4 | 28.04 | | | | 0.15 | | | 1.561 | | | 245804 | |
| 5 | 28.41 | | | | 0.15 | | | 1.543 | | | 245804 | |
| 6 | 26.64 | | | | 0.15 | | | 1.537 | | | 245804 | |
| 7 | 27.42 | | | | 0.15 | | | 1.553 | | | 245804 | |
| 8 | 28.02 | | | | 0.15 | | | 1.559 | | | 245804 | |
| 9 | 28.18 | | | | 0.15 | | | 1.553 | | | 245804 | |
| 10 | 27.8 | | | | 0.15 | | | 1.55 | | | 245804 | |
| Avg | 27.876 | | | | 0.15 | | | 1.5593 | | | 245804 | |
| SD | 0.531417 | | | | 0 | | | 0.023527998 | | | 0 | |
| Remote request without pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | Local CPU | | | | Edge CPU | | | Data Centre CPU | Local RAM | | | Edge RAM | | | Data Centre RAM | Data Received At DC | | Data Sent From DC | | | File Size |
| 0.904 | | 10.28 | | | | 1.74 | | | 33.42 | 0.15 | | | 0.54 | | | 6.22 | 246051 | | 7 | | | 245804 |
| 0.793 | | 4.72 | | | | 6.03 | | | 34.05 | 0.15 | | | 0.54 | | | 6.38 | 246051 | | 7 | | | 245804 |
| 0.854 | | 4.12 | | | | 0.95 | | | 31.17 | 0.15 | | | 0.54 | | | 6.41 | 246051 | | 7 | | | 245804 |
| 0.847 | | 2.41 | | | | 0.95 | | | 28.24 | 0.15 | | | 0.54 | | | 6.41 | 246051 | | 7 | | | 245804 |
| 0.838 | | 3.92 | | | | 2.88 | | | 29.45 | 0.15 | | | 0.54 | | | 6.36 | 246051 | | 7 | | | 245804 |
| 0.903 | | 3.92 | | | | 2.4 | | | 22.6 | 0.15 | | | 0.54 | | | 6.35 | 246051 | | 7 | | | 245804 |
| 0.913 | | 4.97 | | | | 2.59 | | | 37.27 | 0.15 | | | 0.54 | | | 6.35 | 246051 | | 7 | | | 245804 |
| 0.892 | | 5.31 | | | | 2.1 | | | 35.95 | 0.15 | | | 0.54 | | | 6.36 | 246051 | | 7 | | | 245804 |
| 0.828 | | 4.55 | | | | 3.49 | | | 28.89 | 0.14 | | | 0.54 | | | 6.34 | 246051 | | 7 | | | 245804 |
| 0.817 | | 3.43 | | | | 3.61 | | | 34.65 | 0.14 | | | 0.54 | | | 6.29 | 246051 | | 7 | | | 245804 |
| 0.8589 | | 4.763 | | | | 2.674 | | | 31.569 | 0.148 | | | 0.54 | | | 6.347 | 246051 | | 7 | | | 245804 |
| 0.041709178 | | 2.107521 | | | | 1.493521 | | | 4.39848825 | 0.0042164 | | | 0 | | | 0.056578363 | 0 | | 0 | | | 0 |
| Remote request without pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | Local CPU | | | | Edge CPU | | | Data Centre CPU | Local RAM | | | Edge RAM | | | Data Centre RAM | Data Received At DC | | Data Sent From DC | | | File Size |
| 0.955 | | 8.95 | | | | 1.66 | | | 25.76 | 0.15 | | | 0.54 | | | 6.37 | 246051 | | 7 | | | 245804 |
| 0.808 | | 4.7 | | | | 1.81 | | | 22.48 | 0.15 | | | 0.54 | | | 6.37 | 246051 | | 7 | | | 245804 |
| 0.828 | | 4.26 | | | | 2.06 | | | 25.14 | 0.15 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 0.754 | | 5.94 | | | | 5.81 | | | 28.19 | 0.15 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 0.728 | | 5.15 | | | | 2.42 | | | 28.59 | 0.15 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 0.699 | | 5.04 | | | | 4.38 | | | 22.33 | 0.15 | | | 0.54 | | | 6.32 | 246051 | | 7 | | | 245804 |
| 0.831 | | 4.53 | | | | 1.71 | | | 27.61 | 0.14 | | | 0.54 | | | 6.34 | 246051 | | 7 | | | 245804 |
| 0.91 | | 3.06 | | | | 3.33 | | | 33.3 | 0.14 | | | 0.54 | | | 6.3 | 246051 | | 7 | | | 245804 |
| 0.785 | | 5.1 | | | | 2.73 | | | 27.18 | 0.14 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 0.691 | | 5.11 | | | | 2.34 | | | 28.71 | 0.14 | | | 0.54 | | | 6.32 | 246051 | | 7 | | | 245804 |
| 0.7989 | | 5.184 | | | | 2.825 | | | 26.929 | 0.146 | | | 0.54 | | | 6.334 | 246051 | | 7 | | | 245804 |
| 0.086621078 | | 1.520813 | | | | 1.341949 | | | 3.234345031 | 0.005164 | | | 0 | | | 0.021705094 | 0 | | 0 | | | 0 |
| Remote request without pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | Local CPU | | | | Edge CPU | | | Data Centre CPU | Local RAM | | | Edge RAM | | | Data Centre RAM | Data Received At DC | | Data Sent From DC | | | File Size |
| 2.905 | | 5.87 | | | | 2.37 | | | 26.13 | 0.14 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 2.295 | | 3.26 | | | | 0.46 | | | 15.45 | 0.14 | | | 0.54 | | | 6.33 | 246051 | | 7 | | | 245804 |
| 2.944 | | 2.21 | | | | 0.44 | | | 16.91 | 0.14 | | | 0.54 | | | 5.78 | 246051 | | 7 | | | 245804 |
| 0.88 | | 5.16 | | | | 3.4 | | | 24.87 | 0.14 | | | 0.54 | | | 5.77 | 246051 | | 7 | | | 245804 |
| 1.037 | | 5.81 | | | | 3.28 | | | 33.79 | 0.14 | | | 0.54 | | | 5.77 | 246051 | | 7 | | | 245804 |
| 3.374 | | 1.71 | | | | 1.23 | | | 19.29 | 0.14 | | | 0.54 | | | 5.64 | 246051 | | 7 | | | 245804 |
| 2.55 | | 2.36 | | | | 0.52 | | | 17.44 | 0.14 | | | 0.54 | | | 5.74 | 246051 | | 7 | | | 245804 |
| 2.478 | | 2.92 | | | | 0.53 | | | 16.54 | 0.14 | | | 0.54 | | | 5.73 | 246051 | | 7 | | | 245804 |
| 1.344 | | 3.18 | | | | 0.8 | | | 18.38 | 0.14 | | | 0.54 | | | 5.82 | 246051 | | 7 | | | 245804 |
| 1.833 | | 2.6 | | | | 0.99 | | | 17.03 | 0.14 | | | 0.54 | | | 6.06 | 246051 | | 7 | | | 245804 |
| 2.164 | | 3.508 | | | | 1.402 | | | 20.583 | 0.14 | | | 0.54 | | | 5.897 | 246051 | | 7 | | | 245804 |
| 0.855510244 | | 1.534136 | | | | 1.172308 | | | 5.857418942 | 2.926E-17 | | | 0 | | | 0.252104476 | 0 | | 0 | | | 0 |
| Remote request without pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | Local CPU | | | | Edge CPU | | | Data Centre CPU | Local RAM | | | Edge RAM | | | Data Centre RAM | Data Received At DC | | Data Sent From DC | | | File Size |
| 1.075 | | 14.86 | | | | 1.58 | | | 30.19 | 0.14 | | | 0.54 | | | 5.71 | 246051 | | 7 | | | 245804 |
| 0.819 | | 8.21 | | | | 1.75 | | | 35.57 | 0.14 | | | 0.54 | | | 5.7 | 246051 | | 7 | | | 245804 |
| 0.779 | | 6.17 | | | | 1.05 | | | 47.24 | 0.14 | | | 0.54 | | | 5.72 | 246051 | | 7 | | | 245804 |
| 0.843 | | 6.55 | | | | 1.63 | | | 34.34 | 0.14 | | | 0.54 | | | 5.73 | 246051 | | 7 | | | 245804 |
| 0.859 | | 5.56 | | | | 1.26 | | | 29.23 | 0.14 | | | 0.54 | | | 5.73 | 246051 | | 7 | | | 245804 |
| 0.82 | | 5.59 | | | | 0.99 | | | 34.49 | 0.14 | | | 0.54 | | | 5.73 | 246051 | | 7 | | | 245804 |
| 0.928 | | 4.89 | | | | 1.98 | | | 32.76 | 0.14 | | | 0.54 | | | 5.78 | 246051 | | 7 | | | 245804 |
| 0.883 | | 4.3 | | | | 0.6 | | | 37.74 | 0.14 | | | 0.54 | | | 5.77 | 246051 | | 7 | | | 245804 |
| 0.81 | | 5.64 | | | | 0.66 | | | 26.74 | 0.14 | | | 0.54 | | | 5.77 | 246051 | | 7 | | | 245804 |
| 0.881 | | 4.6 | | | | 0.93 | | | 32.92 | 0.14 | | | 0.54 | | | 5.75 | 246051 | | 7 | | | 245804 |
| 0.8697 | | 6.637 | | | | 1.243 | | | 34.122 | 0.14 | | | 0.54 | | | 5.739 | 246051 | | 7 | | | 245804 |
| 0.084004034 | | 3.095352 | | | | 0.473335 | | | 5.623735018 | 0 | | | 0 | | | 0.02726414 | 0 | | 0 | | | 0 |
| Remote request without pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | Local CPU | | | | Edge CPU | | | Data Centre CPU | Local RAM | | | Edge RAM | | | Data Centre RAM | Data Received At DC | | Data Sent From DC | | | File Size |
| 0.853 | | 14.84 | | | | 2.4 | | | 25.88 | 0.14 | | | 0.54 | | | 6.01 | 246051 | | 7 | | | 245804 |
| 0.767 | | 6.58 | | | | 1.36 | | | 31.35 | 0.14 | | | 0.54 | | | 6.02 | 246051 | | 7 | | | 245804 |
| 0.625 | | 6.88 | | | | 2.61 | | | 28.67 | 0.14 | | | 0.54 | | | 6.11 | 246051 | | 7 | | | 245804 |
| 0.653 | | 8.11 | | | | 2.26 | | | 25.76 | 0.14 | | | 0.54 | | | 6.07 | 246051 | | 7 | | | 245804 |
| 0.714 | | 4.64 | | | | 2.3 | | | 34.51 | 0.14 | | | 0.54 | | | 6.07 | 246051 | | 7 | | | 245804 |
| 0.697 | | 4.03 | | | | 2.75 | | | 27.52 | 0.14 | | | 0.54 | | | 6.06 | 246051 | | 7 | | | 245804 |
| 0.695 | | 6.2 | | | | 1.25 | | | 32.03 | 0.14 | | | 0.54 | | | 6.05 | 246051 | | 7 | | | 245804 |
| 0.733 | | 4.83 | | | | 3.89 | | | 34.84 | 0.14 | | | 0.54 | | | 6.05 | 246051 | | 7 | | | 245804 |
| 0.582 | | 7.86 | | | | 1.5 | | | 38.23 | 0.14 | | | 0.54 | | | 6.03 | 246051 | | 7 | | | 245804 |
| 0.551 | | 7.87 | | | | 4.85 | | | 18.62 | 0.14 | | | 0.54 | | | 6.02 | 246051 | | 7 | | | 245804 |
| 0.687 | | 7.184 | | | | 2.517 | | | 29.741 | 0.14 | | | 0.54 | | | 6.049 | 246051 | | 7 | | | 245804 |
| 0.089122886 | | 3.051154 | | | | 1.130192 | | | 5.668106582 | 0 | | | 0 | | | 0.030349812 | 0 | | 0 | | | 0 |
| Remote request with pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | | Local CPU | Edge CPU | | | Data Centre CPU | | | | Local RAM | | | Edge RAM | Data Centre RAM | | | Data Received At DC | | Data Sent From DC | File Size | |
| 2.058 | | | 4.88 | 18.83 | | | 86.086 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 1.957 | | | 2.7 | 20.16 | | | 34.38 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.978 | | | 1.66 | 20.73 | | | 10.07 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.982 | | | 1.53 | 20.18 | | | 33.24 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 1.995 | | | 3.4 | 19.92 | | | 59.54 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 2.024 | | | 2.97 | 18.83 | | | 77.08 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 2.062 | | | 2.93 | 18.9 | | | 46.51 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 2.082 | | | 1.09 | 19.24 | | | 53.78 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 2.004 | | | 2.14 | 21.32 | | | 23.38 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 2.042 | | | 2.57 | 19.59 | | | 83.06 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 2.0184 | | | 2.587 | 19.77 | | | 50.7126 | | | | 0.14 | | | 0.54 | 6.264 | | | 8 | | 7 | 245804 | |
| 0.041612498 | | | 1.085951 | 0.850111 | | | 25.96750706 | | | | 0 | | | 0 | 0.005163978 | | | 0 | | 0 | 0 | |
| Remote request with pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | | Local CPU | Edge CPU | | | Data Centre CPU | | | | Local RAM | | | Edge RAM | Data Centre RAM | | | Data Received At DC | | Data Sent From DC | File Size | |
| 1.738 | | | 8.13 | 23.11 | | | 49.98 | | | | 0.14 | | | 0.54 | 6.3 | | | 8 | | 7 | 245804 | |
| 1.739 | | | 1.89 | 22.27 | | | 32.57 | | | | 0.14 | | | 0.54 | 6.3 | | | 8 | | 7 | 245804 | |
| 1.716 | | | 2.2 | 24.11 | | | 17.08 | | | | 0.14 | | | 0.54 | 6.29 | | | 8 | | 7 | 245804 | |
| 1.7 | | | 3.28 | 22.61 | | | 43.86 | | | | 0.14 | | | 0.54 | 6.29 | | | 8 | | 7 | 245804 | |
| 1.728 | | | 2.91 | 22.84 | | | 28.42 | | | | 0.14 | | | 0.54 | 6.29 | | | 8 | | 7 | 245804 | |
| 1.855 | | | 2.3 | 23.96 | | | 14.91 | | | | 0.14 | | | 0.54 | 6.39 | | | 8 | | 7 | 245804 | |
| 1.66 | | | 3.77 | 23.34 | | | 46.92 | | | | 0.14 | | | 0.54 | 6.36 | | | 8 | | 7 | 245804 | |
| 1.774 | | | 2.83 | 21.59 | | | 29.76 | | | | 0.14 | | | 0.54 | 6.37 | | | 8 | | 7 | 245804 | |
| 1.672 | | | 2.11 | 23.11 | | | 57.1 | | | | 0.14 | | | 0.54 | 6.35 | | | 8 | | 7 | 245804 | |
| 1.763 | | | 3.29 | 21.91 | | | 35.03 | | | | 0.14 | | | 0.54 | 6.37 | | | 8 | | 7 | 245804 | |
| 1.7345 | | | 3.271 | 22.885 | | | 35.563 | | | | 0.14 | | | 0.54 | 6.331 | | | 8 | | 7 | 245804 | |
| 0.055733991 | | | 1.811356 | 0.819759 | | | 13.87091686 | | | | 0 | | | 0 | 0.04040077 | | | 0 | | 0 | 0 | |
| Remote request with pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | | Local CPU | Edge CPU | | | Data Centre CPU | | | | Local RAM | | | Edge RAM | Data Centre RAM | | | Data Received At DC | | Data Sent From DC | File Size | |
| 2.022 | | | 9.75 | 20.41 | | | 31.26 | | | | 0.14 | | | 0.54 | 6.05 | | | 8 | | 7 | 245804 | |
| 1.734 | | | 2.19 | 24.67 | | | 44.5 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.763 | | | 2.29 | 22.43 | | | 60.22 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.768 | | | 2.43 | 21.96 | | | 44.37 | | | | 0.14 | | | 0.54 | 6.03 | | | 8 | | 7 | 245804 | |
| 1.774 | | | 2.42 | 22.6 | | | 22.9 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.878 | | | 2.27 | 20.69 | | | 44.08 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.751 | | | 2.45 | 22.29 | | | 42.83 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.717 | | | 2.49 | 22.66 | | | 26.96 | | | | 0.14 | | | 0.54 | 6.04 | | | 8 | | 7 | 245804 | |
| 1.764 | | | 2.98 | 22.06 | | | 39.7 | | | | 0.14 | | | 0.54 | 6.03 | | | 8 | | 7 | 245804 | |
| 1.771 | | | 2.83 | 21.82 | | | 62.98 | | | | 0.14 | | | 0.54 | 6.02 | | | 8 | | 7 | 245804 | |
| 1.7942 | | | 3.21 | 22.159 | | | 41.98 | | | | 0.14 | | | 0.54 | 6.037 | | | 8 | | 7 | 245804 | |
| 0.090605126 | | | 2.311032 | 1.165356 | | | 12.91276801 | | | | 0 | | | 0 | 0.008232726 | | | 0 | | 0 | 0 | |
| Remote request with pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | | Local CPU | Edge CPU | | | Data Centre CPU | | | | Local RAM | | | Edge RAM | Data Centre RAM | | | Data Received At DC | | Data Sent From DC | File Size | |
| 1.814 | | | 9.21 | 22.59 | | | 25.36 | | | | 0.14 | | | 0.54 | 5.74 | | | 8 | | 7 | 245804 | |
| 1.768 | | | 2.01 | 22.01 | | | 11.79 | | | | 0.14 | | | 0.54 | 5.84 | | | 8 | | 7 | 245804 | |
| 1.76 | | | 2.87 | 21.99 | | | 59.06 | | | | 0.14 | | | 0.54 | 5.8 | | | 8 | | 7 | 245804 | |
| 1.882 | | | 3.31 | 22.28 | | | 36.38 | | | | 0.14 | | | 0.54 | 5.79 | | | 8 | | 7 | 245804 | |
| 1.75 | | | 3.02 | 21.94 | | | 48.6 | | | | 0.14 | | | 0.54 | 5.8 | | | 8 | | 7 | 245804 | |
| 1.712 | | | 3.23 | 23.02 | | | 33.7 | | | | 0.14 | | | 0.54 | 5.8 | | | 8 | | 7 | 245804 | |
| 1.745 | | | 3.16 | 22.39 | | | 32.82 | | | | 0.14 | | | 0.54 | 5.8 | | | 8 | | 7 | 245804 | |
| 1.674 | | | 2.56 | 23.35 | | | 19.96 | | | | 0.14 | | | 0.54 | 5.62 | | | 8 | | 7 | 245804 | |
| 1.747 | | | 2.86 | 21.73 | | | 44.96 | | | | 0.14 | | | 0.54 | 5.63 | | | 8 | | 7 | 245804 | |
| 1.921 | | | 1.97 | 20.24 | | | 32.59 | | | | 0.14 | | | 0.54 | 5.64 | | | 8 | | 7 | 245804 | |
| 1.7773 | | | 3.42 | 22.154 | | | 34.522 | | | | 0.14 | | | 0.54 | 5.746 | | | 8 | | 7 | 245804 | |
| 0.075267006 | | | 2.088226 | 0.841866 | | | 13.87544017 | | | | 0 | | | 0 | 0.083692559 | | | 0 | | 0 | 0 | |
| Remote request with pre-processing | | | | | | | | | | | | | | | | | | | | | | |
| Request Time | | | Local CPU | Edge CPU | | | Data Centre CPU | | | | Local RAM | | | Edge RAM | Data Centre RAM | | | Data Received At DC | | Data Sent From DC | File Size | |
| 1.775 | | | 4.56 | 23.31 | | | 46.01 | | | | 0.14 | | | 0.54 | 6.25 | | | 8 | | 7 | 245804 | |
| 1.748 | | | 3 | 22.49 | | | 20.84 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 1.755 | | | 2.16 | 24.08 | | | 46.54 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.741 | | | 2.32 | 22.22 | | | 46.35 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.746 | | | 2.72 | 22.73 | | | 18.84 | | | | 0.14 | | | 0.54 | 6.25 | | | 8 | | 7 | 245804 | |
| 1.846 | | | 2.19 | 22.44 | | | 77.08 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.757 | | | 2.15 | 22.12 | | | 20.58 | | | | 0.14 | | | 0.54 | 6.26 | | | 8 | | 7 | 245804 | |
| 1.717 | | | 2.2 | 23.53 | | | 35.8 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.809 | | | 2.9 | 21.62 | | | 52.03 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.726 | | | 2.91 | 22.41 | | | 48.04 | | | | 0.14 | | | 0.54 | 6.27 | | | 8 | | 7 | 245804 | |
| 1.762 | | | 2.711 | 22.695 | | | 41.211 | | | | 0.14 | | | 0.54 | 6.264 | | | 8 | | 7 | 245804 | |
| 0.03904698 | | | 0.73647 | 0.737492 | | | 17.94579954 | | | | 0 | | | 0 | 0.00843274 | | | 0 | | 0 | 0 | |

### Load Balancing Results

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Run 1 |  | |  | | |  | | | |  | | |  | | |  | | |  | |  | |
| Iteration | Load Balance 10 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | Avg Request Time | | | Avg Local CPU | | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | Avg Data Centre RAM | |
| 1 | 2.521 | | 2.092 | | | 5.46 | | | | 6.57 | | | 57.91 | | | 0.11 | | | 0.43 | | 10.08 | |
| 2 | 2.393 | | 1.939 | | | 7.29 | | | | 6.43 | | | 57.44 | | | 0.1 | | | 0.43 | | 10.05 | |
| 3 | 2.443 | | 1.81 | | | 6.83 | | | | 8.52 | | | 56.58 | | | 0.1 | | | 0.43 | | 10.07 | |
| 4 | 2.469 | | 2.102 | | | 6.42 | | | | 5.3 | | | 64.64 | | | 0.1 | | | 0.43 | | 10.03 | |
| 5 | 2.429 | | 1.839 | | | 6.79 | | | | 5.85 | | | 54.38 | | | 0.1 | | | 0.43 | | 10.05 | |
| 6 | 2.392 | | 1.95 | | | 7.44 | | | | 4.28 | | | 60.19 | | | 0.11 | | | 0.43 | | 10.05 | |
| 7 | 2.946 | | 2.24 | | | 6.61 | | | | 5.17 | | | 42.83 | | | 0.11 | | | 0.43 | | 10.06 | |
| 8 | 2.684 | | 2.036 | | | 7.06 | | | | 4.32 | | | 58.78 | | | 0.1 | | | 0.43 | | 10.04 | |
| 9 | 2.465 | | 1.912 | | | 6.97 | | | | 5.32 | | | 59.72 | | | 0.1 | | | 0.43 | | 10.03 | |
| 10 | 2.842 | | 2.086 | | | 6.84 | | | | 6.45 | | | 46.97 | | | 0.1 | | | 0.43 | | 10.03 | |
| Avg | 2.5584 | | 2.0006 | | | 6.771 | | | | 5.821 | | | 55.944 | | | 0.103 | | | 0.43 | | 10.049 | |
| SD | 0.197107 | | 0.133808487 | | | 0.549392594 | | | | 1.255516273 | | | 6.475710514 | | | 0.004830459 | | | 0 | | 0.017288403 | |
| Run 2 |  | |  | | |  | | | |  | | |  | | |  | | |  | |  | |
| Iteration | Load Balance 10 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | Avg Request Time | | | Avg Local CPU | | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | Avg Data Centre RAM | |
| 1 | 3.827 | | 3.495 | | | 4.71 | | | | 2.89 | | | 49.48 | | | 0.1 | | | 0.43 | | 9.92 | |
| 2 | 2.741 | | 2.172 | | | 6.62 | | | | 4.66 | | | 49.56 | | | 0.1 | | | 0.43 | | 9.91 | |
| 3 | 2.605 | | 1.943 | | | 7.54 | | | | 5.46 | | | 48.34 | | | 0.1 | | | 0.43 | | 9.84 | |
| 4 | 2.541 | | 1.94 | | | 7.11 | | | | 5.57 | | | 50.95 | | | 0.09 | | | 0.43 | | 9.88 | |
| 5 | 2.795 | | 2.098 | | | 7.77 | | | | 4.36 | | | 45.05 | | | 0.11 | | | 0.43 | | 9.9 | |
| 6 | 2.597 | | 1.887 | | | 7.74 | | | | 5.5 | | | 48.46 | | | 0.1 | | | 0.43 | | 9.92 | |
| 7 | 2.671 | | 2.017 | | | 6.31 | | | | 5.13 | | | 42.1 | | | 0.1 | | | 0.43 | | 9.91 | |
| 8 | 2.817 | | 2.03 | | | 7.62 | | | | 5.78 | | | 48.73 | | | 0.1 | | | 0.43 | | 9.92 | |
| 9 | 2.672 | | 2.374 | | | 4.93 | | | | 4.1 | | | 54.86 | | | 0.1 | | | 0.42 | | 9.89 | |
| 10 | 2.611 | | 1.899 | | | 7.39 | | | | 5.4 | | | 44.47 | | | 0.1 | | | 0.42 | | 9.91 | |
| Avg | 2.7877 | | 2.1855 | | | 6.774 | | | | 4.885 | | | 48.2 | | | 0.1 | | | 0.428 | | 9.9 | |
| SD | 0.3759539 | | 0.483160256 | | | 1.136243323 | | | | 0.896093373 | | | 3.602770539 | | | 0.004714045 | | | 0.00421637 | | 0.024944383 | |
| Run 3 |  | |  | | |  | | | |  | | |  | | |  | | |  | |  | |
| Iteration | Load Balance 10 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | Avg Request Time | | | Avg Local CPU | | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | Avg Data Centre RAM | |
| 1 | 2.618 | | 1.971 | | | 7.85 | | | | 5.51 | | | 49.14 | | | 0.1 | | | 0.43 | | 9.89 | |
| 2 | 2.704 | | 2.202 | | | 6.32 | | | | 4.75 | | | 51.47 | | | 0.1 | | | 0.43 | | 9.88 | |
| 3 | 2.433 | | 1.784 | | | 7.2 | | | | 6.61 | | | 58.38 | | | 0.1 | | | 0.43 | | 9.91 | |
| 4 | 2.666 | | 2.247 | | | 6.71 | | | | 4.88 | | | 52.12 | | | 0.1 | | | 0.43 | | 9.83 | |
| 5 | 3.931 | | 3.459 | | | 4.22 | | | | 3.23 | | | 34.24 | | | 0.1 | | | 0.43 | | 9.87 | |
| 6 | 3.141 | | 2.057 | | | 5.79 | | | | 6.61 | | | 59.53 | | | 0.1 | | | 0.43 | | 9.87 | |
| 7 | 2.59 | | 1.977 | | | 6.28 | | | | 5.89 | | | 54.64 | | | 0.1 | | | 0.43 | | 9.89 | |
| 8 | 3.432 | | 2.351 | | | 5.93 | | | | 4.18 | | | 55.6 | | | 0.1 | | | 0.43 | | 9.9 | |
| 9 | 2.446 | | 1.928 | | | 8.2 | | | | 5.07 | | | 52.38 | | | 0.1 | | | 0.43 | | 9.91 | |
| 10 | 2.579 | | 2.057 | | | 6.1 | | | | 4.75 | | | 49.23 | | | 0.1 | | | 0.43 | | 9.91 | |
| Avg | 2.854 | | 2.2033 | | | 6.46 | | | | 5.148 | | | 51.673 | | | 0.1 | | | 0.43 | | 9.886 | |
| SD | 0.492042 | | 0.47141561 | | | 1.130329352 | | | | 1.052349752 | | | 7.055143199 | | | 0 | | | 0 | | 0.025033311 | |
| Run 4 |  | |  | | |  | | | |  | | |  | | |  | | |  | |  | |
| Iteration | Load Balance 10 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | Avg Request Time | | | Avg Local CPU | | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | Avg Data Centre RAM | |
| 1 | 2.609 | | 2.179 | | | 6.1 | | | | 5.01 | | | 69.09 | | | 0.1 | | | 0.43 | | 9.89 | |
| 2 | 10.259 | | 9.728 | | | 1.86 | | | | 1.55 | | | 47.51 | | | 0.09 | | | 0.43 | | 9.89 | |
| 3 | 2.687 | | 2.687 | | | 6.03 | | | | 5.48 | | | 47.63 | | | 0.1 | | | 0.43 | | 9.91 | |
| 4 | 3.037 | | 3.037 | | | 5.82 | | | | 4.06 | | | 42.47 | | | 0.11 | | | 0.43 | | 9.9 | |
| 5 | 2.547 | | 2.547 | | | 8.25 | | | | 5.53 | | | 45.7 | | | 0.1 | | | 0.43 | | 9.91 | |
| 6 | 2.823 | | 2.823 | | | 4.68 | | | | 4.08 | | | 50.64 | | | 0.1 | | | 0.43 | | 9.91 | |
| 7 | 2.56 | | 2.56 | | | 6.22 | | | | 5.33 | | | 59.12 | | | 0.1 | | | 0.43 | | 9.91 | |
| 8 | 2.405 | | 2.405 | | | 6.9 | | | | 5.07 | | | 49.72 | | | 0.09 | | | 0.43 | | 9.9 | |
| 9 | 2.828 | | 2.828 | | | 5.73 | | | | 3.84 | | | 49.78 | | | 0.09 | | | 0.43 | | 9.83 | |
| 10 | 2.71 | | 2.71 | | | 6.66 | | | | 5.39 | | | 48.92 | | | 0.1 | | | 0.43 | | 9.9 | |
| Avg | 3.4465 | | 3.3504 | | | 5.825 | | | | 4.534 | | | 51.058 | | | 0.098 | | | 0.43 | | 9.895 | |
| SD | 2.4002205 | | 2.253624449 | | | 1.668280885 | | | | 1.228542045 | | | 7.63849578 | | | 0 | | | 0 | | 0.024152295 | |
| Run 5 |  | |  | | |  | | | |  | | |  | | |  | | |  | |  | |
| Iteration | Load Balance 10 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | Avg Request Time | | | Avg Local CPU | | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | Avg Data Centre RAM | |
| 1 | 2.768 | | 2.239 | | | 4.81 | | | | 5.65 | | | 57.34 | | | 0.1 | | | 0.43 | | 9.86 | |
| 2 | 2.378 | | 1.828 | | | 6.74 | | | | 7.27 | | | 52.7 | | | 0.1 | | | 0.43 | | 9.86 | |
| 3 | 3.433 | | 2.901 | | | 4.45 | | | | 4.25 | | | 52.87 | | | 0.1 | | | 0.43 | | 9.86 | |
| 4 | 2.626 | | 2.11 | | | 6.28 | | | | 5.23 | | | 46.78 | | | 0.09 | | | 0.43 | | 9.86 | |
| 5 | 3.983 | | 3.235 | | | 3.68 | | | | 3.78 | | | 47.09 | | | 0.09 | | | 0.43 | | 9.86 | |
| 6 | 2.7 | | 2.073 | | | 6.09 | | | | 5.67 | | | 43.79 | | | 0.1 | | | 0.43 | | 9.88 | |
| 7 | 3.464 | | 2.606 | | | 5.06 | | | | 4.13 | | | 42.08 | | | 0.1 | | | 0.43 | | 9.88 | |
| 8 | 2.691 | | 2.108 | | | 5.7 | | | | 5.48 | | | 46.04 | | | 0.1 | | | 0.43 | | 9.88 | |
| 9 | 5.162 | | 3.813 | | | 3.94 | | | | 2.8 | | | 35.82 | | | 0.1 | | | 0.43 | | 9.88 | |
| 10 | 2.64 | | 2.146 | | | 5.96 | | | | 5.33 | | | 50.32 | | | 0.1 | | | 0.43 | | 9.86 | |
| Avg | 3.1845 | | 2.5059 | | | 5.271 | | | | 4.959 | | | 47.483 | | | 0.098 | | | 0.43 | | 9.868 | |
| SD | 0.8562567 | | 0.629726299 | | | 1.040271866 | | | | 1.249332711 | | | 6.173716781 | | | 0.00421637 | | | 0 | | 0.010327956 | |
| Load Balance 10 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.837 | | 5.502 | | | 3.44 | | | 91.86 | | | 70.82 | | | 0.1 | | | 0.4 | | | 9.9 | |
| 6.251 | | 5.455 | | | 4.52 | | | 90.79 | | | 56.51 | | | 0.1 | | | 0.41 | | | 9.91 | |
| 5.764 | | 5.463 | | | 3.2 | | | 91.95 | | | 70.29 | | | 0.1 | | | 0.41 | | | 9.91 | |
| 5.755 | | 5.371 | | | 3.46 | | | 91.35 | | | 46.72 | | | 0.1 | | | 0.4 | | | 9.85 | |
| 5.741 | | 5.433 | | | 4.09 | | | 93.74 | | | 70.39 | | | 0.1 | | | 0.41 | | | 9.91 | |
| 5.796 | | 5.503 | | | 3.45 | | | 91.94 | | | 45.56 | | | 0.1 | | | 0.41 | | | 9.91 | |
| 5.766 | | 5.383 | | | 3.2 | | | 93.04 | | | 58.86 | | | 0.1 | | | 0.4 | | | 9.91 | |
| 5.781 | | 5.508 | | | 4.46 | | | 91.56 | | | 61.28 | | | 0.1 | | | 0.41 | | | 9.9 | |
| 5.828 | | 5.566 | | | 3.8 | | | 89.33 | | | 59.33 | | | 0.1 | | | 0.41 | | | 9.89 | |
| 5.73 | | 5.463 | | | 3.01 | | | 91.52 | | | 63.91 | | | 0.1 | | | 0.41 | | | 9.89 | |
| 5.8249 | | 5.4647 | | | 3.663 | | | 91.708 | | | 60.367 | | | 0.1 | | | 0.407 | | | 9.898 | |
| 0.1536912 | | 0.059211579 | | | 0.533563492 | | | 1.18891921 | | | 9.099992735 | | | 0 | | | 0.004830459 | | | 0.018737959 | |
| Load Balance 10 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.654 | | 5.346 | | | 3.11 | | | 93.25 | | | 62.07 | | | 0.1 | | | 0.4 | | | 9.76 | |
| 6.585 | | 5.709 | | | 2.65 | | | 88.23 | | | 63.75 | | | 0.1 | | | 0.4 | | | 9.61 | |
| 5.618 | | 5.314 | | | 3.08 | | | 93.24 | | | 47.63 | | | 0.1 | | | 0.41 | | | 9.69 | |
| 5.87 | | 5.521 | | | 4.35 | | | 91.09 | | | 66.81 | | | 0.1 | | | 0.4 | | | 9.69 | |
| 5.703 | | 5.354 | | | 3.06 | | | 91.84 | | | 53.26 | | | 0.1 | | | 0.41 | | | 9.7 | |
| 5.701 | | 5.385 | | | 2.9 | | | 91.57 | | | 53.46 | | | 0.1 | | | 0.41 | | | 9.69 | |
| 5.86 | | 5.544 | | | 3.13 | | | 88.49 | | | 70.73 | | | 0.1 | | | 0.41 | | | 9.7 | |
| 5.634 | | 5.302 | | | 2.87 | | | 92.95 | | | 58.74 | | | 0.1 | | | 0.4 | | | 9.69 | |
| 5.721 | | 5.335 | | | 3.64 | | | 92.62 | | | 38.61 | | | 0.1 | | | 0.41 | | | 9.7 | |
| 5.697 | | 5.39 | | | 2.88 | | | 92.62 | | | 64.67 | | | 0.1 | | | 0.4 | | | 9.71 | |
| 5.8043 | | 5.42 | | | 3.167 | | | 91.59 | | | 57.973 | | | 0.1 | | | 0.405 | | | 9.694 | |
| 0.2872467 | | 0.130571394 | | | 0.489445264 | | | 1.845775958 | | | 9.780444264 | | | 0 | | | 0.005270463 | | | 0.036270588 | |
| Load Balance 10 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.826 | | 5.395 | | | 3.47 | | | 91.89 | | | 52.21 | | | 0.1 | | | 0.4 | | | 9.67 | |
| 5.8 | | 5.543 | | | 3.3 | | | 89.56 | | | 65.66 | | | 0.1 | | | 0.41 | | | 9.68 | |
| 5.696 | | 5.381 | | | 3.49 | | | 94.18 | | | 52.68 | | | 0.1 | | | 0.4 | | | 9.7 | |
| 5.771 | | 5.465 | | | 5.59 | | | 91.63 | | | 63.3 | | | 0.09 | | | 0.41 | | | 9.69 | |
| 5.581 | | 5.298 | | | 2.89 | | | 93.7 | | | 48.51 | | | 0.09 | | | 0.4 | | | 9.73 | |
| 5.608 | | 5.152 | | | 3.92 | | | 94.61 | | | 50.2 | | | 0.1 | | | 0.4 | | | 9.73 | |
| 5.653 | | 5.329 | | | 3.2 | | | 93.62 | | | 43.65 | | | 0.1 | | | 0.4 | | | 9.73 | |
| 5.684 | | 5.324 | | | 3.15 | | | 91.76 | | | 58.03 | | | 0.1 | | | 0.4 | | | 9.73 | |
| 5.698 | | 5.392 | | | 3.44 | | | 92.16 | | | 50.53 | | | 0.1 | | | 0.4 | | | 9.73 | |
| 5.659 | | 5.372 | | | 3.03 | | | 92.1 | | | 59.16 | | | 0.1 | | | 0.41 | | | 9.73 | |
| 5.6976 | | 5.3651 | | | 3.548 | | | 92.521 | | | 54.393 | | | 0.098 | | | 0.403 | | | 9.712 | |
| 0.080035 | | 0.103522891 | | | 0.772554205 | | | 1.511448533 | | | 6.931871721 | | | 0.00421637 | | | 0.004830459 | | | 0.024404007 | |
| Load Balance 10 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.664 | | 5.289 | | | 3.9 | | | 93.18 | | | 51.18 | | | 0.1 | | | 0.41 | | | 9.7 | |
| 5.78 | | 5.436 | | | 3.12 | | | 91.95 | | | 81.84 | | | 0.1 | | | 0.42 | | | 9.72 | |
| 5.588 | | 5.235 | | | 3.54 | | | 93.08 | | | 53.67 | | | 0.1 | | | 0.41 | | | 9.74 | |
| 5.617 | | 5.34 | | | 3.16 | | | 92.81 | | | 63.73 | | | 0.1 | | | 0.41 | | | 9.72 | |
| 5.58 | | 5.308 | | | 3.16 | | | 93.58 | | | 44.46 | | | 0.1 | | | 0.42 | | | 9.72 | |
| 5.646 | | 5.314 | | | 3.35 | | | 92.7 | | | 68.11 | | | 0.1 | | | 0.42 | | | 9.72 | |
| 5.555 | | 5.187 | | | 3.73 | | | 93.52 | | | 78.58 | | | 0.1 | | | 0.41 | | | 9.71 | |
| 5.676 | | 5.374 | | | 3.08 | | | 92.9 | | | 51.2 | | | 0.1 | | | 0.42 | | | 9.72 | |
| 5.659 | | 5.387 | | | 3.22 | | | 92.36 | | | 50.45 | | | 0.1 | | | 0.42 | | | 9.71 | |
| 5.624 | | 5.257 | | | 3.39 | | | 93.9 | | | 40 | | | 0.09 | | | 0.41 | | | 9.71 | |
| 5.6389 | | 5.3127 | | | 3.365 | | | 92.998 | | | 58.322 | | | 0.099 | | | 0.415 | | | 9.717 | |
| 0.0633955 | | 0.075094089 | | | 0.278338323 | | | 0.58724971 | | | 14.14891264 | | | 0.003162278 | | | 0.005270463 | | | 0.010593499 | |
| Load Balance 10 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.61 | | 5.274 | | | 3.24 | | | 93.09 | | | 51.1 | | | 0.09 | | | 0.41 | | | 9.69 | |
| 5.705 | | 5.492 | | | 3.35 | | | 90.64 | | | 74.35 | | | 0.1 | | | 0.42 | | | 9.71 | |
| 5.572 | | 5.262 | | | 3.42 | | | 93.32 | | | 62.33 | | | 0.1 | | | 0.41 | | | 9.71 | |
| 5.578 | | 5.253 | | | 3.67 | | | 93.94 | | | 52.27 | | | 0.1 | | | 0.42 | | | 9.71 | |
| 5.699 | | 5.439 | | | 3.55 | | | 93.35 | | | 66.91 | | | 0.1 | | | 0.42 | | | 9.71 | |
| 6.029 | | 5.79 | | | 3.16 | | | 86.7 | | | 64.61 | | | 0.09 | | | 0.42 | | | 9.71 | |
| 5.553 | | 5.273 | | | 2.82 | | | 93.97 | | | 47.25 | | | 0.09 | | | 0.42 | | | 9.72 | |
| 5.721 | | 5.331 | | | 2.79 | | | 93.09 | | | 61.25 | | | 0.09 | | | 0.41 | | | 9.7 | |
| 5.935 | | 5.488 | | | 3.22 | | | 90.4 | | | 71.79 | | | 0.1 | | | 0.42 | | | 9.71 | |
| 5.677 | | 5.31 | | | 3.47 | | | 92.69 | | | 47.12 | | | 0.1 | | | 0.41 | | | 9.71 | |
| 5.7079 | | 5.3912 | | | 3.269 | | | 92.119 | | | 59.898 | | | 0.096 | | | 0.416 | | | 9.708 | |
| 0.1580488 | | 0.16818429 | | | 0.289768107 | | | 2.271066563 | | | 9.934418062 | | | 0.005163978 | | | 0.005163978 | | | 0.007888106 | |
| Load Balance 10 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 6.428 | | 5.387 | | | 3.99 | | | 91.94 | | | 32.79 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.657 | | 5.331 | | | 3.6 | | | 93.68 | | | 45.54 | | | 0.11 | | | 0.43 | | | 9.93 | |
| 5.614 | | 5.242 | | | 4.21 | | | 93.8 | | | 43.78 | | | 0.11 | | | 0.42 | | | 9.93 | |
| 5.629 | | 5.138 | | | 2.98 | | | 93.85 | | | 54.91 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.774 | | 5.404 | | | 2.97 | | | 91.81 | | | 43.33 | | | 0.1 | | | 0.42 | | | 9.91 | |
| 5.623 | | 5.23 | | | 2.73 | | | 93.5 | | | 67.41 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.785 | | 5.413 | | | 3.94 | | | 93.47 | | | 61.78 | | | 0.1 | | | 0.42 | | | 9.94 | |
| 5.609 | | 5.254 | | | 3.74 | | | 94.29 | | | 39.39 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.652 | | 5.211 | | | 4.13 | | | 93.43 | | | 51.36 | | | 0.11 | | | 0.42 | | | 9.93 | |
| 5.685 | | 5.289 | | | 3.71 | | | 94.43 | | | 35.3 | | | 0.11 | | | 0.43 | | | 9.93 | |
| 5.7456 | | 5.2899 | | | 3.6 | | | 93.42 | | | 47.559 | | | 0.104 | | | 0.422 | | | 9.929 | |
| 0.2478612 | | 0.091748993 | | | 0.526054497 | | | 0.879734809 | | | 11.23567973 | | | 0.005163978 | | | 0.00421637 | | | 0.007378648 | |
| Load Balance 10 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.577 | | 5.259 | | | 3.55 | | | 93.65 | | | 61.43 | | | 0.1 | | | 0.42 | | | 9.87 | |
| 5.611 | | 5.222 | | | 2.83 | | | 94.56 | | | 49.24 | | | 0.1 | | | 0.42 | | | 9.82 | |
| 5.711 | | 5.335 | | | 3.42 | | | 93.24 | | | 44.95 | | | 0.1 | | | 0.42 | | | 9.82 | |
| 5.621 | | 5.314 | | | 2.4 | | | 92.99 | | | 61.59 | | | 0.1 | | | 0.43 | | | 9.75 | |
| 5.585 | | 5.26 | | | 3.4 | | | 94.26 | | | 49.19 | | | 0.1 | | | 0.42 | | | 9.83 | |
| 5.621 | | 5.229 | | | 2.89 | | | 94.87 | | | 55.21 | | | 0.1 | | | 0.42 | | | 9.85 | |
| 5.534 | | 5.158 | | | 2.71 | | | 94.6 | | | 58.75 | | | 0.1 | | | 0.42 | | | 9.85 | |
| 5.686 | | 5.322 | | | 3.54 | | | 92.76 | | | 71.68 | | | 0.1 | | | 0.43 | | | 9.84 | |
| 5.634 | | 5.285 | | | 3.45 | | | 93.31 | | | 53.52 | | | 0.1 | | | 0.42 | | | 9.84 | |
| 5.646 | | 5.198 | | | 2.64 | | | 93.85 | | | 57.24 | | | 0.1 | | | 0.42 | | | 9.84 | |
| 5.6226 | | 5.2582 | | | 3.083 | | | 93.809 | | | 56.28 | | | 0.1 | | | 0.422 | | | 9.831 | |
| 0.0516338 | | 0.057379439 | | | 0.431896335 | | | 0.737088115 | | | 7.716232529 | | | 0 | | | 0.00421637 | | | 0.032128215 | |
| Load Balance 10 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.752 | | 5.32 | | | 3.12 | | | 91.78 | | | 50.08 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.663 | | 5.335 | | | 3.29 | | | 92.82 | | | 62.98 | | | 0.1 | | | 0.42 | | | 9.94 | |
| 5.597 | | 5.156 | | | 3.37 | | | 93.97 | | | 30.55 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 7.447 | | 6.167 | | | 2.7 | | | 81.32 | | | 48.05 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 7.527 | | 6.257 | | | 3.55 | | | 79.93 | | | 43.4 | | | 0.1 | | | 0.43 | | | 9.93 | |
| 5.69 | | 5.29 | | | 3.56 | | | 93.74 | | | 38.63 | | | 0.1 | | | 0.42 | | | 9.94 | |
| 5.509 | | 5.165 | | | 2.98 | | | 95.75 | | | 48.74 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 5.643 | | 5.282 | | | 3.31 | | | 93.5 | | | 57.37 | | | 0.1 | | | 0.42 | | | 9.92 | |
| 5.677 | | 5.324 | | | 3.47 | | | 93.85 | | | 56.98 | | | 0.1 | | | 0.43 | | | 9.92 | |
| 5.643 | | 5.292 | | | 2.58 | | | 93.1 | | | 56.97 | | | 0.1 | | | 0.42 | | | 9.94 | |
| 6.0148 | | 5.4588 | | | 3.193 | | | 90.976 | | | 49.375 | | | 0.1 | | | 0.422 | | | 9.931 | |
| 0.778691 | | 0.402356061 | | | 0.343642256 | | | 5.556136147 | | | 9.847324792 | | | 0 | | | 0.00421637 | | | 0.007378648 | |
| Load Balance 10 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 6.152 | | 5.794 | | | 3.21 | | | 86.92 | | | 56.01 | | | 0.1 | | | 0.43 | | | 9.9 | |
| 7.706 | | 6.489 | | | 3.01 | | | 76.82 | | | 33.75 | | | 0.1 | | | 0.43 | | | 9.91 | |
| 6.236 | | 5.822 | | | 3.1 | | | 58.72 | | | 62.91 | | | 0.1 | | | 0.43 | | | 9.92 | |
| 7.153 | | 5.982 | | | 3.29 | | | 83.4 | | | 49.57 | | | 0.1 | | | 0.42 | | | 9.93 | |
| 6 | | 5.38 | | | 3.02 | | | 89.52 | | | 45.87 | | | 0.1 | | | 0.42 | | | 9.91 | |
| 5.789 | | 5.341 | | | 3.71 | | | 92.29 | | | 72.67 | | | 0.1 | | | 0.42 | | | 9.92 | |
| 6.144 | | 5.785 | | | 2.69 | | | 86.66 | | | 58.2 | | | 0.1 | | | 0.43 | | | 9.91 | |
| 5.621 | | 5.173 | | | 2.9 | | | 93.78 | | | 34.21 | | | 0.09 | | | 0.42 | | | 9.92 | |
| 6.13 | | 5.724 | | | 2.99 | | | 86.25 | | | 46.05 | | | 0.1 | | | 0.43 | | | 9.92 | |
| 5.656 | | 5.282 | | | 3.26 | | | 93.53 | | | 43.02 | | | 0.1 | | | 0.42 | | | 9.92 | |
| 6.2587 | | 5.6772 | | | 3.118 | | | 84.789 | | | 50.226 | | | 0.099 | | | 0.425 | | | 9.916 | |
| 0.6661266 | | 0.396106271 | | | 0.274339611 | | | 10.49388123 | | | 12.37559265 | | | 0.003162278 | | | 0.005270463 | | | 0.00843274 | |
| Load Balance 10 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 5.653 | | 5.309 | | | 2.67 | | | 93.77 | | | 45.88 | | | 0.1 | | | 0.43 | | | 9.86 | |
| 6.026 | | 5.663 | | | 2.72 | | | 88.18 | | | 63.37 | | | 0.1 | | | 0.43 | | | 9.89 | |
| 5.538 | | 5.121 | | | 3.38 | | | 94.1 | | | 40.79 | | | 0.1 | | | 0.42 | | | 9.89 | |
| 5.601 | | 5.209 | | | 3.94 | | | 93.78 | | | 67.42 | | | 0.09 | | | 0.42 | | | 9.9 | |
| 5.76 | | 5.404 | | | 3.13 | | | 91.99 | | | 39.32 | | | 0.11 | | | 0.43 | | | 9.9 | |
| 5.814 | | 5.398 | | | 3.15 | | | 92.29 | | | 46.11 | | | 0.1 | | | 0.43 | | | 9.89 | |
| 5.467 | | 5.147 | | | 3.12 | | | 94.94 | | | 50.31 | | | 0.1 | | | 0.42 | | | 9.9 | |
| 5.595 | | 5.268 | | | 3.56 | | | 93.56 | | | 43.05 | | | 0.1 | | | 0.42 | | | 9.84 | |
| 5.559 | | 5.237 | | | 4.08 | | | 93.7 | | | 46.05 | | | 0.1 | | | 0.42 | | | 9.84 | |
| 5.605 | | 5.26 | | | 2.8 | | | 93.63 | | | 60.78 | | | 0.1 | | | 0.42 | | | 9.87 | |
| 5.6618 | | 5.3016 | | | 3.255 | | | 92.994 | | | 50.308 | | | 0.1 | | | 0.424 | | | 9.878 | |
| 0.1635555 | | 0.157257185 | | | 0.48749359 | | | 1.889492583 | | | 9.958062953 | | | 0.004714045 | | | 0.005163978 | | | 0.02394438 | |
| Run 1 |  | | |  | | |  | |  | | |  | | |  | | |  | | |  | |
| Iteration | Load Balance 30 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | | Avg Request Time | | | Avg Local CPU | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 1 | 8.884 | | | 6.164 | | | 6.74 | | 6.06 | | | 43.74 | | | 0.11 | | | 0.17 | | | 8.96 | |
| 2 | 8.079 | | | 5.951 | | | 6.76 | | 6.45 | | | 43.03 | | | 0.11 | | | 0.17 | | | 8.97 | |
| 3 | 7.677 | | | 5.396 | | | 6.97 | | 6.71 | | | 44.14 | | | 0.11 | | | 0.17 | | | 8.97 | |
| 4 | 10.336 | | | 7.736 | | | 5.01 | | 4.52 | | | 38.03 | | | 0.11 | | | 0.17 | | | 8.97 | |
| 5 | 6.954 | | | 5.089 | | | 7.72 | | 6.12 | | | 49.79 | | | 0.11 | | | 0.17 | | | 8.96 | |
| 6 | 7.284 | | | 5.337 | | | 7.31 | | 5.71 | | | 47.35 | | | 0.11 | | | 0.17 | | | 8.94 | |
| 7 | 6.777 | | | 5.006 | | | 7.02 | | 5.88 | | | 48.45 | | | 0.1 | | | 0.17 | | | 9.01 | |
| 8 | 7.133 | | | 5.413 | | | 6.61 | | 5.19 | | | 49.58 | | | 0.11 | | | 0.17 | | | 9.02 | |
| 9 | 8.456 | | | 6.304 | | | 6.13 | | 5.49 | | | 39.96 | | | 0.1 | | | 0.17 | | | 9.01 | |
| 10 | 6.712 | | | 4.965 | | | 7 | | 5.98 | | | 53.22 | | | 0.11 | | | 0.17 | | | 9.03 | |
| Avg | 7.8292 | | | 5.7361 | | | 6.727 | | 5.811 | | | 45.729 | | | 0.108 | | | 0.17 | | | 8.984 | |
| SD | 1.1439826 | | | 0.84833909 | | | 0.735210476 | | 0.630069661 | | | 4.758502215 | | | 0.00421637 | | | 0 | | | 0.030623158 | |
| Run 2 |  | | |  | | |  | |  | | |  | | |  | | |  | | |  | |
| Iteration | Load Balance 30 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | | Avg Request Time | | | Avg Local CPU | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 1 | 7.519 | | | 5.36 | | | 9.3 | | 6.92 | | | 46.05 | | | 0.11 | | | 0.17 | | | 8.8 | |
| 2 | 7.43 | | | 5.438 | | | 9.31 | | 6.73 | | | 48.05 | | | 0.11 | | | 0.17 | | | 8.86 | |
| 3 | 8.041 | | | 6.115 | | | 5.46 | | 5.41 | | | 40.79 | | | 0.11 | | | 0.17 | | | 8.83 | |
| 4 | 8.62 | | | 6.239 | | | 6.35 | | 5.73 | | | 46.15 | | | 0.11 | | | 0.17 | | | 8.86 | |
| 5 | 8.663 | | | 6.25 | | | 6.57 | | 5.9 | | | 45.64 | | | 0.11 | | | 0.17 | | | 8.85 | |
| 6 | 7.947 | | | 5.681 | | | 7.49 | | 5.67 | | | 43.5 | | | 0.11 | | | 0.17 | | | 8.83 | |
| 7 | 7.335 | | | 5.133 | | | 7.81 | | 6.08 | | | 43.35 | | | 0.1 | | | 0.16 | | | 8.83 | |
| 8 | 10.061 | | | 7.903 | | | 5.2 | | 3.73 | | | 46.44 | | | 0.11 | | | 0.17 | | | 8.82 | |
| 9 | 8.564 | | | 5.909 | | | 6.67 | | 6.28 | | | 40.9 | | | 0.11 | | | 0.17 | | | 8.8 | |
| 10 | 8.15 | | | 5.917 | | | 6.71 | | 5.59 | | | 43.65 | | | 0.11 | | | 0.17 | | | 8.8 | |
| Avg | 8.233 | | | 5.9945 | | | 7.087 | | 5.804 | | | 44.452 | | | 0.109 | | | 0.169 | | | 8.828 | |
| SD | 0.8077659 | | | 0.770859297 | | | 1.408648288 | | 0.878182466 | | | 2.41607487 | | | 0.003162278 | | | 0.003162278 | | | 0.023475756 | |
| Run 3 |  | | |  | | |  | |  | | |  | | |  | | |  | | |  | |
| Iteration | Load Balance 30 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | | Avg Request Time | | | Avg Local CPU | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 1 | 8.327 | | | 5.73 | | | 6.89 | | 5.96 | | | 42.31 | | | 0.11 | | | 0.17 | | | 8.78 | |
| 2 | 8.291 | | | 5.674 | | | 6.85 | | 5.78 | | | 41.59 | | | 0.11 | | | 0.17 | | | 8.79 | |
| 3 | 9.77 | | | 7.088 | | | 6.05 | | 4.8 | | | 41.28 | | | 0.11 | | | 0.16 | | | 8.87 | |
| 4 | 9.23 | | | 6.887 | | | 6.15 | | 4.78 | | | 46.19 | | | 0.11 | | | 0.17 | | | 8.77 | |
| 5 | 7.823 | | | 5.519 | | | 7.27 | | 6.57 | | | 44.27 | | | 0.1 | | | 0.17 | | | 8.78 | |
| 6 | 8.238 | | | 5.943 | | | 6.82 | | 5.66 | | | 45.17 | | | 0.11 | | | 0.16 | | | 8.77 | |
| 7 | 10.61 | | | 8.348 | | | 5.14 | | 3.91 | | | 42.02 | | | 0.11 | | | 0.17 | | | 8.76 | |
| 8 | 8.599 | | | 6.415 | | | 6.45 | | 5.26 | | | 41.08 | | | 0.1 | | | 0.17 | | | 8.76 | |
| 9 | 7.518 | | | 5.223 | | | 7.98 | | 6.29 | | | 41.49 | | | 0.11 | | | 0.17 | | | 8.77 | |
| 10 | 8.28 | | | 6.124 | | | 5.63 | | 5.52 | | | 43.46 | | | 0.1 | | | 0.16 | | | 8.76 | |
| Avg | 8.6686 | | | 6.2951 | | | 6.523 | | 5.453 | | | 42.886 | | | 0.107 | | | 0.167 | | | 8.781 | |
| SD | 0.9390745 | | | 0.932016506 | | | 0.822530648 | | 0.792815657 | | | 1.792857434 | | | 0.004830459 | | | 0.004830459 | | | 0.032812599 | |
| Run 4 |  | | |  | | |  | |  | | |  | | |  | | |  | | |  | |
| Iteration | Load Balance 30 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | | Avg Request Time | | | Avg Local CPU | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 1 | 7.54 | | | 5.296 | | | 7.46 | | 6.95 | | | 50.22 | | | 0.11 | | | 0.17 | | | 8.68 | |
| 2 | 7.82 | | | 5.688 | | | 6.84 | | 6.34 | | | 43.43 | | | 0.11 | | | 0.16 | | | 8.7 | |
| 3 | 7.065 | | | 5.04 | | | 6.55 | | 6.18 | | | 49.73 | | | 0.11 | | | 0.16 | | | 8.69 | |
| 4 | 8.507 | | | 6.134 | | | 6.77 | | 5.47 | | | 43.54 | | | 0.11 | | | 0.16 | | | 8.68 | |
| 5 | 7.46 | | | 5.114 | | | 6.07 | | 6.27 | | | 44.05 | | | 0.1 | | | 0.16 | | | 8.67 | |
| 6 | 7.869 | | | 5.785 | | | 6.67 | | 5.79 | | | 51.22 | | | 0.11 | | | 0.17 | | | 8.66 | |
| 7 | 8.184 | | | 5.853 | | | 5.73 | | 6 | | | 45.9 | | | 0.1 | | | 0.16 | | | 8.65 | |
| 8 | 9.852 | | | 7.292 | | | 4.74 | | 4.63 | | | 40.28 | | | 0.1 | | | 0.16 | | | 8.65 | |
| 9 | 7.95 | | | 5.726 | | | 7.29 | | 6.87 | | | 47.09 | | | 0.1 | | | 0.16 | | | 8.65 | |
| 10 | 8.028 | | | 5.741 | | | 6.45 | | 6.82 | | | 48.22 | | | 0.1 | | | 0.17 | | | 8.65 | |
| Avg | 8.0275 | | | 5.7669 | | | 6.457 | | 6.132 | | | 46.368 | | | 0.105 | | | 0.163 | | | 8.668 | |
| SD | 0.7559774 | | | 0.637129927 | | | 0.790570118 | | 0.713392521 | | | 3.542117383 | | | 0.005270463 | | | 0.004830459 | | | 0.018737959 | |
| Run 5 |  | | |  | | |  | |  | | |  | | |  | | |  | | |  | |
| Iteration | Load Balance 30 requests - no pre-process | | | | | | | | | | | | | | | | | | | | | |
|  | Total Time | | | Avg Request Time | | | Avg Local CPU | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 1 | 8.037 | | | 5.586 | | | 6.63 | | 6.22 | | | 40.2 | | | 0.11 | | | 0.16 | | | 8.59 | |
| 2 | 8.702 | | | 6.357 | | | 6.55 | | 5.36 | | | 43.55 | | | 0.11 | | | 0.16 | | | 8.61 | |
| 3 | 8.763 | | | 6.351 | | | 5.79 | | 5.18 | | | 38.04 | | | 0.1 | | | 0.16 | | | 8.61 | |
| 4 | 9.805 | | | 7.281 | | | 6.09 | | 4.63 | | | 41.17 | | | 0.1 | | | 0.16 | | | 8.54 | |
| 5 | 8.663 | | | 5.915 | | | 7.21 | | 6.89 | | | 40.52 | | | 0.1 | | | 0.16 | | | 8.61 | |
| 6 | 8.968 | | | 6.36 | | | 6.03 | | 5.77 | | | 35.06 | | | 0.1 | | | 0.16 | | | 8.6 | |
| 7 | 9.846 | | | 7.022 | | | 6.08 | | 5.6 | | | 35.88 | | | 0.11 | | | 0.17 | | | 8.66 | |
| 8 | 8.93 | | | 6.224 | | | 6.81 | | 5.95 | | | 39.35 | | | 0.1 | | | 0.17 | | | 8.65 | |
| 9 | 8.079 | | | 5.511 | | | 6.72 | | 6.01 | | | 37.63 | | | 0.1 | | | 0.17 | | | 8.64 | |
| 10 | 7.772 | | | 5.512 | | | 6.78 | | 6.15 | | | 43.86 | | | 0.1 | | | 0.17 | | | 8.63 | |
| Avg | 8.7565 | | | 6.2119 | | | 6.469 | | 5.776 | | | 39.526 | | | 0.103 | | | 0.164 | | | 8.614 | |
| SD | 0.6927304 | | | 0.607612898 | | | 0.447994296 | | 0.626776586 | | | 2.947572259 | | | 0.004830459 | | | 0.005163978 | | | 0.034383459 | |
| Load Balance 30 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 16.358 | | 14.795 | | | 3.68 | | | 95.54 | | | 54.16 | | | 0.11 | | | 0.14 | | | 8.95 | |
| 16.389 | | 14.615 | | | 3.38 | | | 95.57 | | | 53.89 | | | 0.11 | | | 0.13 | | | 8.96 | |
| 16.378 | | 14.757 | | | 3.58 | | | 95.95 | | | 58.01 | | | 0.11 | | | 0.13 | | | 8.9 | |
| 16.23 | | 14.719 | | | 3.45 | | | 96.07 | | | 52.21 | | | 0.11 | | | 0.14 | | | 8.93 | |
| 16.177 | | 14.536 | | | 3.27 | | | 96.32 | | | 58.73 | | | 0.11 | | | 0.13 | | | 8.92 | |
| 16.189 | | 14.443 | | | 4.02 | | | 96.24 | | | 66.64 | | | 0.11 | | | 0.13 | | | 8.93 | |
| 16.175 | | 14.515 | | | 3.51 | | | 96.44 | | | 47.69 | | | 0.11 | | | 0.13 | | | 8.92 | |
| 17.339 | | 15.092 | | | 3.65 | | | 93.63 | | | 54.09 | | | 0.11 | | | 0.14 | | | 8.89 | |
| 16.191 | | 14.667 | | | 3.13 | | | 96.04 | | | 51.46 | | | 0.11 | | | 0.13 | | | 8.89 | |
| 16.365 | | 14.613 | | | 3.83 | | | 95.44 | | | 53.6 | | | 0.11 | | | 0.14 | | | 8.82 | |
| 16.3791 | | 14.6752 | | | 3.55 | | | 95.724 | | | 55.048 | | | 0.11 | | | 0.134 | | | 8.911 | |
| 0.3493491 | | 0.183545816 | | | 0.262974439 | | | 0.811571863 | | | 5.130704522 | | | 0 | | | 0.005163978 | | | 0.039567102 | |
| Load Balance 30 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 16.303 | | 14.686 | | | 3.57 | | | 95.95 | | | 51.72 | | | 0.11 | | | 0.13 | | | 8.89 | |
| 16.231 | | 14.757 | | | 3.17 | | | 95.99 | | | 54.48 | | | 0.11 | | | 0.13 | | | 8.88 | |
| 16.566 | | 14.81 | | | 3.57 | | | 95.59 | | | 51.4 | | | 0.11 | | | 0.13 | | | 8.78 | |
| 16.603 | | 14.683 | | | 3.28 | | | 95.49 | | | 49.88 | | | 0.11 | | | 0.13 | | | 8.81 | |
| 17.094 | | 15.07 | | | 3.03 | | | 95.15 | | | 49.22 | | | 0.11 | | | 0.14 | | | 8.85 | |
| 16.945 | | 15.078 | | | 3.59 | | | 93.39 | | | 54.99 | | | 0.11 | | | 0.15 | | | 8.84 | |
| 16.645 | | 15.064 | | | 3.87 | | | 94.73 | | | 46.96 | | | 0.11 | | | 0.14 | | | 8.84 | |
| 16.262 | | 14.62 | | | 4.5 | | | 96.23 | | | 51.79 | | | 0.11 | | | 0.13 | | | 8.83 | |
| 16.667 | | 15.001 | | | 3.07 | | | 94.89 | | | 51.77 | | | 0.11 | | | 0.14 | | | 8.83 | |
| 17.737 | | 15.177 | | | 3.1 | | | 92.44 | | | 51.79 | | | 0.11 | | | 0.14 | | | 8.83 | |
| 16.7053 | | 14.8946 | | | 3.475 | | | 94.985 | | | 51.4 | | | 0.11 | | | 0.136 | | | 8.838 | |
| 0.4584081 | | 0.203838825 | | | 0.456027533 | | | 1.212648616 | | | 2.349808503 | | | 0 | | | 0.006992059 | | | 0.031552426 | |
| Load Balance 30 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 16.382 | | 16.748 | | | 3.03 | | | 95.6 | | | 54.04 | | | 0.1 | | | 0.13 | | | 8.76 | |
| 18.757 | | 16.378 | | | 3.52 | | | 87.34 | | | 55.68 | | | 0.11 | | | 0.15 | | | 8.76 | |
| 16.832 | | 15.034 | | | 2.74 | | | 94.06 | | | 50.56 | | | 0.11 | | | 0.15 | | | 8.7 | |
| 16.295 | | 14.467 | | | 3.52 | | | 95.65 | | | 48.48 | | | 0.11 | | | 0.13 | | | 8.75 | |
| 16.385 | | 14.712 | | | 3.32 | | | 95.49 | | | 43.69 | | | 0.11 | | | 0.13 | | | 8.73 | |
| 16.503 | | 14.698 | | | 3.44 | | | 95.68 | | | 58.52 | | | 0.1 | | | 0.13 | | | 8.73 | |
| 20.538 | | 16.408 | | | 3.46 | | | 87.67 | | | 40.51 | | | 0.11 | | | 0.14 | | | 8.74 | |
| 25.465 | | 20.267 | | | 3.07 | | | 74 | | | 44.83 | | | 0.11 | | | 0.16 | | | 8.73 | |
| 16.424 | | 14.661 | | | 3.5 | | | 95.67 | | | 52.03 | | | 0.1 | | | 0.13 | | | 8.73 | |
| 16.525 | | 14.935 | | | 3.62 | | | 94.83 | | | 46.5 | | | 0.11 | | | 0.14 | | | 8.74 | |
| 18.0106 | | 15.8308 | | | 3.322 | | | 91.599 | | | 49.484 | | | 0.107 | | | 0.139 | | | 8.737 | |
| 2.9653068 | | 1.774961458 | | | 0.282716977 | | | 6.99668882 | | | 5.71656307 | | | 0.004830459 | | | 0.011005049 | | | 0.017669811 | |
| Load Balance 30 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 16.068 | | 14.37 | | | 6.17 | | | 96.5 | | | 58.67 | | | 0.1 | | | 0.13 | | | 8.65 | |
| 16.075 | | 16.616 | | | 3.51 | | | 96.38 | | | 49.35 | | | 0.11 | | | 0.13 | | | 8.65 | |
| 16.709 | | 14.955 | | | 3.88 | | | 94.18 | | | 54.2 | | | 0.11 | | | 0.14 | | | 8.64 | |
| 16.806 | | 15.075 | | | 3.63 | | | 93.55 | | | 47.27 | | | 0.11 | | | 0.14 | | | 8.64 | |
| 16.227 | | 14.761 | | | 3.31 | | | 96.11 | | | 57.01 | | | 0.1 | | | 0.13 | | | 8.63 | |
| 16.153 | | 14.624 | | | 3.22 | | | 96.3 | | | 58.59 | | | 0.11 | | | 0.12 | | | 8.63 | |
| 16.261 | | 14.723 | | | 3.69 | | | 96.06 | | | 53.28 | | | 0.1 | | | 0.13 | | | 8.56 | |
| 17.03 | | 14.881 | | | 3.54 | | | 95.58 | | | 48.18 | | | 0.11 | | | 0.13 | | | 8.63 | |
| 16.77 | | 15.134 | | | 3.55 | | | 94.04 | | | 65.71 | | | 0.1 | | | 0.14 | | | 8.61 | |
| 16.255 | | 14.757 | | | 3.63 | | | 95.72 | | | 51.89 | | | 0.11 | | | 0.13 | | | 8.62 | |
| 16.4354 | | 14.9896 | | | 3.813 | | | 95.442 | | | 54.415 | | | 0.106 | | | 0.132 | | | 8.626 | |
| 0.3541372 | | 0.612945203 | | | 0.897566154 | | | 1.095331507 | | | 5.707083805 | | | 0.005163978 | | | 0.006324555 | | | 0.026331224 | |
| Load Balance 30 requests - pre-process (w/o load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 17.334 | | 15.614 | | | 3.55 | | | 92.02 | | | 57.59 | | | 0.11 | | | 0.14 | | | 8.53 | |
| 16.694 | | 15.045 | | | 3.4 | | | 94.05 | | | 54.39 | | | 0.1 | | | 0.14 | | | 8.56 | |
| 16.169 | | 14.42 | | | 3.53 | | | 96.57 | | | 51.16 | | | 0.11 | | | 0.12 | | | 8.56 | |
| 16.7 | | 15.083 | | | 3.64 | | | 94.23 | | | 61.02 | | | 0.1 | | | 0.14 | | | 8.54 | |
| 18.202 | | 15.732 | | | 2.98 | | | 89.96 | | | 48.93 | | | 0.11 | | | 0.13 | | | 8.52 | |
| 16.743 | | 15.032 | | | 2.94 | | | 94.38 | | | 49.11 | | | 0.1 | | | 0.13 | | | 8.66 | |
| 16.087 | | 14.323 | | | 3.38 | | | 96.69 | | | 56.37 | | | 0.11 | | | 0.13 | | | 8.59 | |
| 16.627 | | 14.796 | | | 3.22 | | | 95.29 | | | 46.67 | | | 0.1 | | | 0.13 | | | 8.58 | |
| 17.055 | | 14.789 | | | 3.67 | | | 96.21 | | | 59.77 | | | 0.11 | | | 0.13 | | | 8.57 | |
| 16.967 | | 14.504 | | | 3.43 | | | 96.01 | | | 49.21 | | | 0.1 | | | 0.13 | | | 8.56 | |
| 16.8578 | | 14.9338 | | | 3.374 | | | 94.541 | | | 53.422 | | | 0.105 | | | 0.132 | | | 8.567 | |
| 0.6028829 | | 0.472089398 | | | 0.254916108 | | | 2.158813717 | | | 5.079863953 | | | 0.005270463 | | | 0.006324555 | | | 0.039171985 | |
| Load Balance 30 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 12.673 | | 8.29 | | | 5.74 | | | 89.76 | | | 57.68 | | | 0.11 | | | 0.11 | | | 8.52 | |
| 13.369 | | 10.275 | | | 4.29 | | | 92.69 | | | 52.4 | | | 0.11 | | | 0.11 | | | 8.48 | |
| 16.411 | | 14.702 | | | 3.35 | | | 94.65 | | | 52.44 | | | 0.11 | | | 0.11 | | | 8.52 | |
| 9.832 | | 6.822 | | | 6.82 | | | 94.55 | | | 51.84 | | | 0.11 | | | 0.11 | | | 8.49 | |
| 12.41 | | 7.421 | | | 5.55 | | | 90.86 | | | 48.08 | | | 0.11 | | | 0.11 | | | 8.49 | |
| 10.824 | | 6.54 | | | 5.72 | | | 90.16 | | | 49.5 | | | 0.11 | | | 0.11 | | | 8.48 | |
| 13.033 | | 9.581 | | | 4.96 | | | 92 | | | 57.81 | | | 0.11 | | | 0.11 | | | 8.47 | |
| 13.963 | | 11.065 | | | 4.6 | | | 87 | | | 49.92 | | | 0.1 | | | 0.12 | | | 8.51 | |
| 13.304 | | 9.609 | | | 5.06 | | | 93.81 | | | 52.26 | | | 0.11 | | | 0.11 | | | 8.45 | |
| 15.346 | | 11.803 | | | 4.03 | | | 89.29 | | | 43.99 | | | 0.11 | | | 0.11 | | | 8.5 | |
| 13.1165 | | 9.6108 | | | 5.012 | | | 89.29 | | | 51.592 | | | 0.109 | | | 0.111 | | | 8.491 | |
| 1.9260258 | | 2.51726844 | | | 1.000675328 | | | 2.507517808 | | | 4.148675291 | | | 0.003162278 | | | 0.003162278 | | | 0.022335821 | |
| Load Balance 30 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 12.817 | | 9.3 | | | 4.81 | | | 91.62 | | | 57.37 | | | 0.1 | | | 0.11 | | | 8.36 | |
| 8.8 | | 6.112 | | | 6.97 | | | 94.84 | | | 48.94 | | | 0.11 | | | 0.11 | | | 8.34 | |
| 13.241 | | 9.431 | | | 5.69 | | | 90.16 | | | 49 | | | 0.11 | | | 0.11 | | | 8.36 | |
| 12.474 | | 8.976 | | | 5.88 | | | 92.85 | | | 65.83 | | | 0.1 | | | 0.1 | | | 8.39 | |
| 11.806 | | 8.072 | | | 6.16 | | | 91.8 | | | 56.38 | | | 0.1 | | | 0.11 | | | 8.42 | |
| 11.345 | | 7.93 | | | 6.45 | | | 93.45 | | | 52.32 | | | 0.1 | | | 0.1 | | | 8.38 | |
| 8.956 | | 6.775 | | | 6.16 | | | 94.11 | | | 56.9 | | | 0.11 | | | 0.11 | | | 8.38 | |
| 13.861 | | 10.974 | | | 4.24 | | | 93.52 | | | 57.97 | | | 0.1 | | | 0.11 | | | 8.39 | |
| 11.689 | | 8.321 | | | 5.93 | | | 93.38 | | | 52.75 | | | 0.11 | | | 0.1 | | | 8.38 | |
| 11.091 | | 7.774 | | | 5.81 | | | 93.58 | | | 46.89 | | | 0.1 | | | 0.11 | | | 8.37 | |
| 11.608 | | 8.3665 | | | 5.81 | | | 92.931 | | | 54.435 | | | 0.104 | | | 0.107 | | | 8.377 | |
| 1.6751294 | | 1.391288791 | | | 0.781650675 | | | 1.372600533 | | | 5.625235304 | | | 0.005163978 | | | 0.004830459 | | | 0.021628171 | |
| Load Balance 30 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 8.733 | | 6.605 | | | 6.83 | | | 95.27 | | | 48.95 | | | 0.11 | | | 0.11 | | | 8.29 | |
| 13.717 | | 10.41 | | | 5 | | | 93.02 | | | 56.87 | | | 0.1 | | | 0.11 | | | 8.27 | |
| 12.292 | | 8.738 | | | 5.42 | | | 91.93 | | | 51.84 | | | 0.1 | | | 0.11 | | | 8.32 | |
| 16.811 | | 15.409 | | | 3.09 | | | 93.46 | | | 58.54 | | | 0.1 | | | 0.12 | | | 8.33 | |
| 12.308 | | 8.865 | | | 5.17 | | | 93.34 | | | 49.9 | | | 0.11 | | | 0.1 | | | 8.32 | |
| 12.917 | | 9.6 | | | 5.19 | | | 93.75 | | | 55.73 | | | 0.1 | | | 0.1 | | | 9.19 | |
| 10 | | 6.789 | | | 6.13 | | | 93.43 | | | 49.57 | | | 0.11 | | | 0.11 | | | 9.42 | |
| 16.59 | | 15.201 | | | 2.99 | | | 94.9 | | | 58.61 | | | 0.1 | | | 0.11 | | | 9.39 | |
| 11.275 | | 7.17 | | | 5.77 | | | 89.12 | | | 51.96 | | | 0.1 | | | 0.11 | | | 9.33 | |
| 11.083 | | 7.597 | | | 5.84 | | | 93 | | | 47.94 | | | 0.1 | | | 0.1 | | | 9.33 | |
| 12.5726 | | 9.6384 | | | 5.143 | | | 93.122 | | | 52.991 | | | 0.103 | | | 0.108 | | | 8.819 | |
| 2.6022218 | | 3.228845002 | | | 1.231503598 | | | 1.696020178 | | | 4.087934686 | | | 0.004830459 | | | 0.006324555 | | | 0.544210948 | |
| Load Balance 30 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 12.858 | | 9.487 | | | 4.8 | | | 93.3 | | | 51.65 | | | 0.1 | | | 0.1 | | | 9.31 | |
| 11.17 | | 7.351 | | | 6.52 | | | 93.38 | | | 51.5 | | | 0.11 | | | 0.1 | | | 9.29 | |
| 15.224 | | 10.365 | | | 4.36 | | | 90.17 | | | 49.63 | | | 0.1 | | | 0.11 | | | 9.3 | |
| 16.679 | | 15.159 | | | 3.45 | | | 93.64 | | | 52.35 | | | 0.11 | | | 0.12 | | | 9.22 | |
| 11.626 | | 7.959 | | | 6.36 | | | 92.3 | | | 52.25 | | | 0.1 | | | 0.11 | | | 9.27 | |
| 11.982 | | 8.637 | | | 6.23 | | | 93.29 | | | 54.71 | | | 0.11 | | | 0.11 | | | 9.26 | |
| 9.576 | | 6.319 | | | 6.64 | | | 93.08 | | | 51.97 | | | 0.1 | | | 0.1 | | | 9.25 | |
| 10.362 | | 7.373 | | | 5.58 | | | 94.27 | | | 50.15 | | | 0.11 | | | 0.1 | | | 9.26 | |
| 12.241 | | 8.681 | | | 6.12 | | | 92.18 | | | 46.26 | | | 0.1 | | | 0.11 | | | 9.28 | |
| 17.092 | | 15.114 | | | 3.05 | | | 94.1 | | | 68.72 | | | 0.11 | | | 0.11 | | | 9.25 | |
| 12.881 | | 9.6445 | | | 5.311 | | | 92.971 | | | 52.919 | | | 0.105 | | | 0.107 | | | 9.269 | |
| 2.5956424 | | 3.111487149 | | | 1.318277074 | | | 1.188850519 | | | 5.972178925 | | | 0.005270463 | | | 0.006749486 | | | 0.026853512 | |
| Load Balance 30 requests - pre-process (w load balancing) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 14.249 | | 10.835 | | | 4.89 | | | 91.4 | | | 57.91 | | | 0.1 | | | 0.11 | | | 9.09 | |
| 13.342 | | 10.266 | | | 5.01 | | | 94.07 | | | 53.5 | | | 0.11 | | | 0.1 | | | 9.13 | |
| 13.135 | | 9.679 | | | 4.65 | | | 91.95 | | | 54.23 | | | 0.1 | | | 0.1 | | | 9.11 | |
| 12.421 | | 9.072 | | | 5.41 | | | 93.41 | | | 51.13 | | | 0.11 | | | 0.1 | | | 9.12 | |
| 16.731 | | 12.76 | | | 4.55 | | | 87.41 | | | 39.07 | | | 0.1 | | | 0.12 | | | 9.14 | |
| 11.792 | | 8.359 | | | 6.18 | | | 93.81 | | | 43.51 | | | 0.11 | | | 0.11 | | | 9.14 | |
| 7.388 | | 5.597 | | | 7.03 | | | 94.64 | | | 54.79 | | | 0.1 | | | 0.12 | | | 9.13 | |
| 14.22 | | 11.61 | | | 4.38 | | | 94.91 | | | 60.84 | | | 0.1 | | | 0.11 | | | 9.14 | |
| 10.226 | | 6.968 | | | 5.69 | | | 93.08 | | | 49.34 | | | 0.1 | | | 0.11 | | | 9.12 | |
| 12.788 | | 9.513 | | | 5.52 | | | 93.47 | | | 50.96 | | | 0.11 | | | 0.1 | | | 9.11 | |
| 12.6292 | | 9.4659 | | | 5.331 | | | 92.815 | | | 51.528 | | | 0.104 | | | 0.108 | | | 9.123 | |
| 2.5112656 | | 2.123905232 | | | 0.820155134 | | | 2.188415205 | | | 6.446635298 | | | 0.005163978 | | | 0.007888106 | | | 0.016363917 | |
| Load Balance 30 requests - pre-process (w/o load balancing) (3 instances of application) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 8.65 | | 7.15 | | | 6.13 | | | 71.87 | | | 53.83 | | | 0.12 | | | 0.11 | | | 8.04 | |
| 7.677 | | 6.362 | | | 6.58 | | | 80.8 | | | 53.21 | | | 0.12 | | | 0.11 | | | 8.06 | |
| 7.631 | | 6.311 | | | 6.45 | | | 80.9 | | | 63.29 | | | 0.12 | | | 0.11 | | | 8.06 | |
| 9.259 | | 6.514 | | | 6.59 | | | 78.7 | | | 45.99 | | | 0.12 | | | 0.11 | | | 8.11 | |
| 8.699 | | 7.354 | | | 5.39 | | | 70.18 | | | 54.94 | | | 0.12 | | | 0.11 | | | 8.08 | |
| 7.516 | | 6.231 | | | 6.73 | | | 81.91 | | | 52.44 | | | 0.12 | | | 0.11 | | | 8.08 | |
| 7.513 | | 6.171 | | | 6.62 | | | 82.54 | | | 52.39 | | | 0.11 | | | 0.11 | | | 8 | |
| 7.802 | | 6.391 | | | 6.13 | | | 80.33 | | | 60.29 | | | 0.12 | | | 0.11 | | | 8.1 | |
| 8.674 | | 7.206 | | | 4.97 | | | 71.17 | | | 52.29 | | | 0.12 | | | 0.11 | | | 8.07 | |
| 7.547 | | 6.322 | | | 6.14 | | | 80.96 | | | 63.89 | | | 0.12 | | | 0.11 | | | 8.15 | |
| 8.0968 | | 6.6012 | | | 6.173 | | | 77.936 | | | 55.256 | | | 0.119 | | | 0.11 | | | 8.075 | |
| 0.650904 | | 0.450550971 | | | 0.576523104 | | | 4.855322852 | | | 5.593164876 | | | 0.003162278 | | | 0 | | | 0.040620192 | |
| Load Balance 30 requests - pre-process (w/o load balancing) (3 instances of application) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 7.537 | | 6.534 | | | 6.7 | | | 77.94 | | | 50.37 | | | 0.12 | | | 0.11 | | | 7.93 | |
| 9.621 | | 8.8 | | | 5.43 | | | 66.94 | | | 61.58 | | | 0.12 | | | 0.11 | | | 7.96 | |
| 8.725 | | 7.722 | | | 4.93 | | | 65.7 | | | 76.34 | | | 0.11 | | | 0.11 | | | 9.94 | |
| 7.745 | | 6.695 | | | 6.16 | | | 76.34 | | | 73.17 | | | 0.12 | | | 0.11 | | | 9.97 | |
| 7.533 | | 6.579 | | | 6.18 | | | 73.17 | | | 51.26 | | | 0.12 | | | 0.11 | | | 8.02 | |
| 9.564 | | 7.566 | | | 5.26 | | | 51.26 | | | 65.03 | | | 0.11 | | | 0.11 | | | 8 | |
| 10.572 | | 8.528 | | | 5.3 | | | 65.03 | | | 61.45 | | | 0.12 | | | 0.11 | | | 8.03 | |
| 7.787 | | 6.842 | | | 6.76 | | | 61.45 | | | 58.24 | | | 0.12 | | | 0.11 | | | 8.08 | |
| 7.4 | | 6.381 | | | 6.03 | | | 58.24 | | | 65.25 | | | 0.11 | | | 0.11 | | | 8.09 | |
| 9.221 | | 6.999 | | | 5.69 | | | 65.25 | | | 65.09 | | | 0.12 | | | 0.11 | | | 8.01 | |
| 8.5705 | | 7.2646 | | | 5.844 | | | 66.132 | | | 62.778 | | | 0.117 | | | 0.11 | | | 8.403 | |
| 1.123167 | | 0.857116639 | | | 0.622418223 | | | 8.17434034 | | | 8.292326841 | | | 0.004830459 | | | 0 | | | 0.819404255 | |
| Load Balance 30 requests - pre-process (w/o load balancing) (3 instances of application) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 7.636 | | 6.629 | | | 6.36 | | | 76.8 | | | 53.36 | | | 0.11 | | | 0.11 | | | 7.88 | |
| 7.627 | | 6.603 | | | 6.59 | | | 76.82 | | | 60.27 | | | 0.11 | | | 0.1 | | | 7.96 | |
| 7.777 | | 6.84 | | | 5.97 | | | 74.72 | | | 56.25 | | | 0.12 | | | 0.11 | | | 7.79 | |
| 7.875 | | 6.772 | | | 6.06 | | | 75.07 | | | 56.43 | | | 0.11 | | | 0.11 | | | 7.85 | |
| 7.365 | | 6.375 | | | 5.81 | | | 79.52 | | | 59.91 | | | 0.11 | | | 0.11 | | | 7.82 | |
| 7.943 | | 6.96 | | | 5.94 | | | 73.74 | | | 64.96 | | | 0.11 | | | 0.11 | | | 7.82 | |
| 9.6 | | 8.319 | | | 5.08 | | | 61.67 | | | 54.52 | | | 0.11 | | | 0.11 | | | 7.91 | |
| 7.686 | | 6.615 | | | 5.67 | | | 76.85 | | | 74.03 | | | 0.11 | | | 0.1 | | | 7.92 | |
| 7.405 | | 6.463 | | | 5.83 | | | 79.15 | | | 60.28 | | | 0.11 | | | 0.1 | | | 7.9 | |
| 7.552 | | 6.484 | | | 5.5 | | | 78.15 | | | 65.75 | | | 0.11 | | | 0.1 | | | 8 | |
| 7.8466 | | 6.806 | | | 5.881 | | | 75.249 | | | 60.576 | | | 0.111 | | | 0.106 | | | 7.885 | |
| 0.6430364 | | 0.560883232 | | | 0.423541943 | | | 5.123910074 | | | 6.256321603 | | | 0.003162278 | | | 0.005163978 | | | 0.066374359 | |
| Load Balance 30 requests - pre-process (w/o load balancing) (3 instances of application) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 8.615 | | 7.617 | | | 5.44 | | | 66.84 | | | 61.53 | | | 0.12 | | | 0.11 | | | 7.86 | |
| 8.133 | | 7.063 | | | 5.65 | | | 72.29 | | | 51.86 | | | 0.11 | | | 0.1 | | | 7.84 | |
| 7.328 | | 6.323 | | | 6.01 | | | 79.88 | | | 68.19 | | | 0.12 | | | 0.1 | | | 7.84 | |
| 7.973 | | 6.927 | | | 5.38 | | | 73.41 | | | 58.44 | | | 0.12 | | | 0.1 | | | 7.75 | |
| 10.73 | | 9.082 | | | 5.17 | | | 56.74 | | | 59.11 | | | 0.12 | | | 0.11 | | | 7.92 | |
| 7.741 | | 6.663 | | | 5.73 | | | 76.56 | | | 69.88 | | | 0.11 | | | 0.1 | | | 7.92 | |
| 7.513 | | 6.484 | | | 6.31 | | | 78.14 | | | 71.52 | | | 0.12 | | | 0.1 | | | 7.92 | |
| 7.919 | | 6.827 | | | 5.67 | | | 75.37 | | | 72.63 | | | 0.11 | | | 0.1 | | | 7.9 | |
| 7.454 | | 6.428 | | | 5.91 | | | 78.43 | | | 54.98 | | | 0.11 | | | 0.1 | | | 7.9 | |
| 7.898 | | 6.794 | | | 5.69 | | | 75.76 | | | 61.79 | | | 0.11 | | | 0.11 | | | 7.9 | |
| 8.1304 | | 7.0208 | | | 5.696 | | | 73.342 | | | 62.993 | | | 0.115 | | | 0.103 | | | 7.875 | |
| 0.9860368 | | 0.813639806 | | | 0.347742721 | | | 6.920041426 | | | 7.207773658 | | | 0.005270463 | | | 0.004830459 | | | 0.054006172 | |
| Load Balance 30 requests - pre-process (w/o load balancing) (3 instances of application) | | | | | | | | | | | | | | | | | | | | | |
| Total Time | | Avg Request Time | | | Avg Local CPU | | | Avg Edge CPU | | | Avg Data Centre CPU | | | Avg Local RAM | | | Avg Edge RAM | | | Avg Data Centre RAM | |
| 7.359 | | 6.378 | | | 6.91 | | | 79.67 | | | 57.56 | | | 0.12 | | | 0.1 | | | 7.88 | |
| 8.917 | | 6.69 | | | 6.01 | | | 76.76 | | | 57.68 | | | 0.12 | | | 0.1 | | | 7.89 | |
| 7.219 | | 6.224 | | | 5.95 | | | 80.83 | | | 68.58 | | | 0.11 | | | 0.1 | | | 7.93 | |
| 7.816 | | 6.482 | | | 5.57 | | | 78.15 | | | 62.63 | | | 0.12 | | | 0.1 | | | 7.93 | |
| 7.356 | | 6.304 | | | 6.6 | | | 79.7 | | | 55.13 | | | 0.12 | | | 0.1 | | | 7.92 | |
| 7.314 | | 6.331 | | | 5.4 | | | 79.66 | | | 59.09 | | | 0.11 | | | 0.1 | | | 7.91 | |
| 7.271 | | 6.278 | | | 6.38 | | | 80.61 | | | 55.22 | | | 0.12 | | | 0.1 | | | 7.94 | |
| 7.306 | | 6.354 | | | 5.72 | | | 79.38 | | | 51.74 | | | 0.11 | | | 0.1 | | | 7.89 | |
| 7.491 | | 6.537 | | | 6.8 | | | 78.68 | | | 52.62 | | | 0.11 | | | 0.11 | | | 7.99 | |
| 7.742 | | 6.449 | | | 5.8 | | | 79.29 | | | 66.63 | | | 0.11 | | | 0.1 | | | 7.98 | |
| 7.5791 | | 6.4027 | | | 6.114 | | | 79.273 | | | 58.688 | | | 0.115 | | | 0.101 | | | 7.926 | |
| 0.5107808 | | 0.139187364 | | | 0.527935181 | | | 1.185149311 | | | 5.663706678 | | | 0.005270463 | | | 0.003162278 | | | 0.036878178 | |

### Machine Learning Results

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Iteration | 1,000 movies on edge | | | 10,000 movies on edge | | | 100,000 movies on edge | | |
|  | Time | Processor | Euclidian distance | Time | Processor | Euclidian distance | Time | Processor | Euclidian distance |
| 1 | 0.312 | 26.23 | 0.542436677 | 1.33 | 25.92 | 0.391008901 | 10.593 | 25.41 | 0.278475994 |
| 2 | 0.212 | 26.79 | 0.542436677 | 1.197 | 29.13 | 0.391008901 | 9.84 | 25.73 | 0.278475994 |
| 3 | 0.226 | 25 | 0.542436677 | 1.134 | 25.42 | 0.391008901 | 10.302 | 25.52 | 0.278475994 |
| 4 | 0.245 | 25.71 | 0.542436677 | 1.139 | 26.12 | 0.391008901 | 9.624 | 25.46 | 0.278475994 |
| 5 | 0.218 | 29.27 | 0.542436677 | 1.135 | 25.54 | 0.391008901 | 9.79 | 25.61 | 0.278475994 |
| 6 | 0.203 | 31.25 | 0.542436677 | 1.09 | 25.81 | 0.391008901 | 9.759 | 25.47 | 0.278475994 |
| 7 | 0.235 | 30 | 0.542436677 | 1.133 | 26.35 | 0.391008901 | 10.08 | 25.5 | 0.278475994 |
| 8 | 0.252 | 28.3 | 0.542436677 | 1.012 | 24.93 | 0.391008901 | 10.141 | 25.45 | 0.278475994 |
| 9 | 0.232 | 29.03 | 0.542436677 | 1.057 | 28.18 | 0.391008901 | 9.992 | 25.31 | 0.278475994 |
| 10 | 0.248 | 29.79 | 0.542436677 | 1.057 | 25.51 | 0.391008901 | 10.161 | 25.53 | 0.278475994 |
| Avg | 0.2383 | 28.137 | 0.542436677 | 1.1284 | 26.291 | 0.391008901 | 10.0282 | 25.499 | 0.278475994 |
| SD | 0.03039 | 2.086566 | 0 | 0.08868 | 1.325598 | 0 | 0.289889558 | 0.113279 | 0 |

## Minutes of meetings