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

A dissertation submitted in partial fulfilment of the requirements for the degree of BACHELOR OF ENGINEERING in Computer Science

in

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by

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# Abstract

* 100 word outline of subject matter/findings

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# Introduction and Problem Specification

Background material which introduces the problem area, context, and background.

Identify my problem

Systematically researched and fully analysed the problem

# System Requirements Specification

Precise description of the system developed. Should be updated for the final system delivered. List assumptions made about the problem and any system constraints(RAM?)

Functional and non-functional requirements should be complete, clear, accurate, feasible and objectively verifiable.

Read req’s for list of what can be included in this section

# Design

## Architectural Description



The entry point for the system is the Electron Application which runs on the Client Raspberry Pi. There are 4 pages that the user can access from the homepage. Traffic from each application is colour coded.

The Edge is comprised of 3 Raspberry Pi’s which form a Docker swarm. The applications run in containers that can be running on any of the Raspberry Pi worker nodes and have multiple instances depending on the deployment.

There are multiple data centres depending on what application is making the request. The WebAPI project is hosted in IIS and has multiple endpoints.

## User Interface Design



The purpose of the graphical user interface (GUI) was to allow interaction with the Edge Nodes and Data Centre to perform tests and demonstrate functionality.

The caching application was required to have a place to type a URL and buttons to navigate to the stated website, navigate back to the homepage or clear the cache on the Edge Application. There is a section below the URL bar that presents the user with the time it took to complete the request.



The voice recognition application required more interaction from the user to execute a test. This meant that the GUI contained more elements. There was a home button that was consistent throughout the entire application as a means of navigating back to the homepage. There was a button for the user to record their voice for the system to process. The two buttons below the recording button would allow the user to choose whether the voice recording was executed locally or remotely. The checkbox below the remote button was a modifier that would indicate if the request should be pre-processed on the Edge or processed at the Data Centre. The results of the experiments are shown in an easy to read table.



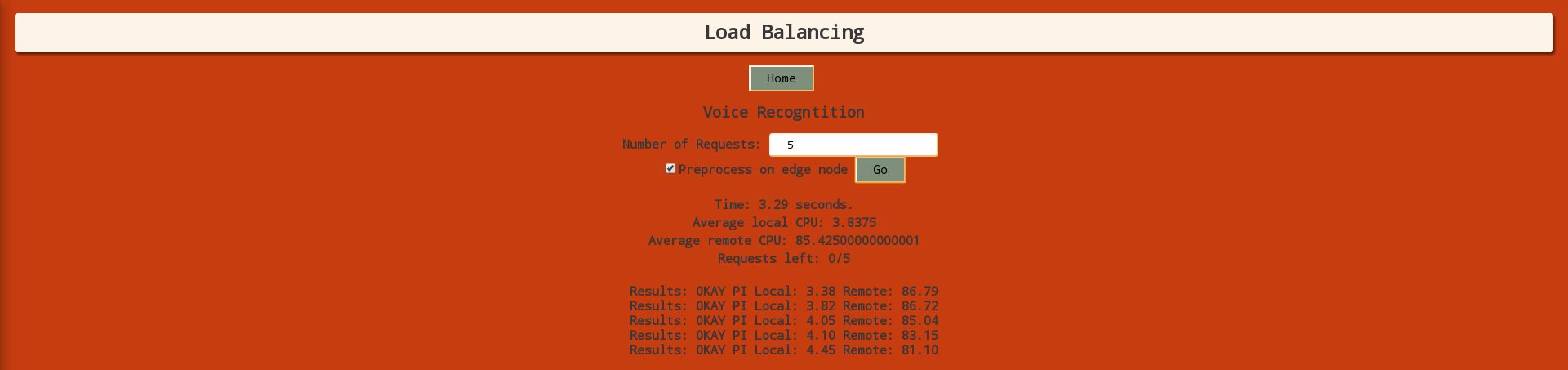
When the machine learning application is first launched, the user is asked to enter their username;



After the user enters their username the screen is populated with the average of their previous results and a recommendation. There are two buttons available for the user to press, one is to watch a movie at random and the other is to watch the recommendation that was produced for them.



The final link from the homepage brings the user to a load balancing application. This application has the standard home button, it them had a space for a user to enter a numerical value. This value will dictate the number of lines displayed to the user in the results section. The checkbox here performs the same action as it does in the voice recognition page, it dictates if the requests will be pre-processed or not. The “Go” button then starts the requests and the screen is updated as each request finishes. There is a standard results section just below the “Go” button that displays statistics about the load balancing as a whole such as total time and average CPU use.



There is a consistent theme kept throughout the application, both in the colour scheme and the layout. It was designed to be clear and functional as to keep focus on what the applications were trying to achieve.

## Software System Design

ENSURE CONSISTANT USE OF “WILL” AND “SHOULD” RATHER THAN “DOES”

(iii) Software System Design.

The role of each component and the interfaces between components should be described. There should be a clear correlation between your design and your specification.

The design should be linked to requirements and, where applicable give a critical discussion of key design decisions/styles/patterns used. There might be a data model, a UI design, details of external interfaces, and of other important issues e.g. concurrency, event handling, error and exception handling, security, data persistence. No particular notation or tool is mandated.

### Client

The role of the Client Application is to run tests and get results from the Edge and the Data Centre. It was 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 is achieved by providing separate pages for each of the services running on the Edge Node as to keep everything distantly separate but accessible.

Caching

The caching page is the first page to be implemented. A distinct HTML and JavaScript file should exist for every individual page. A “Common” JavaScript file should exist that gets reused throughout the application. The caching application requires an input area and buttons for navigating back home, executing the request, and clearing the cache. The clear cache button should send a request to the edge application for it to clear the cache. Once the request has finished executing the result should be displayed to the user.

Voice Recognition

Next comes the voice recognition page. It requires more elements such as the ability to record your voice and use this recording for executing experiments. The results section 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.

The local processing button should execute a script locally and display the results. The remote processing button should send a request to the data centre and take into account the checkbox for pre-processing. This request will also display results to the user once completed.

Machine Learning

The machine learning page when first launched will contain only a button to navigate home, a textbox, and a login button. The user must enter these details before they can test this system. After these have been entered a request should be sent to the data centre to obtain the user’s previously watched movies. This can then be used to get a recommendation request from the edge node. This should happen without any user intervention so that they see the results of the operations displayed. There should be two buttons available to the user, once to watch a movie at random and one to watch the movie that was returned as a recommendation. Each of these buttons should also update the user’s average results with the new movie included.

### Edge

The role of the Edge Service is to pre-process requests for the user. It was 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 Node is the ability to run multiple application on the same Edge Node to allow for extensibility. This is achieved by running the applications in Docker Swarm and hosting them on unique ports. Node.js was picked as the web server that would host the code for each edge application.

Caching

The caching application should be running behind a proxy, this means that the client can send a request to the edge with the intention of it being forwarded elsewhere and the caching application will be able to read this URL and use that to return data to the user.

As the caching application will be using Redis there needs to be a mechanism in place to allow the user to clear the cache, this will be implemented by using the Redis Command Line Interface (CLI). To make this easier for deployment and to keep with the guidelines of Docker a caching base image will be created that will contain the Redis CLI. This means that all further development can be layered upon this image.

The caching application will have to be able to receive proxied requests and use this information to query the Redis cache. 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 container should be available across all the edge nodes and the caching application should access each of these directly and in a fair manner. This is to utilise the resources available in the edge node swarm and not burden one entry point with requests.

Voice Recognition

When a request is received from the client the voice data should be saved to disk. The file that is saved to disk should be named something unique so that multiple requests can be handled at once. A flag will be checked in the request to check if the application needs to pre-process the request or forward the data to the data centre for processing. If the request needs to be pre-processed the application should spawn a process and execute the voice recognition and forward the pre-processed data to the data centre along with a flag that states the data was pre-processed. If the request does not need to be pre-processed the request should be forwarded to the data centre right away.

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 the threshold the request will be forwarded to the data centre anyway.

The voice recognition should be performed by PocketSphinx.

Machine Learning

Upon deployment, the edge machine learning application will request a subset of movies from the data centre to store locally. It will later use this data to produce recommendations. The full list of movies will be stored at the data centre.

The machine learning application should only ever receive post requests, the request should 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 handled 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 edge machine learning application is to produce recommendations based on the data received from the user. The edge application should never keep any user specific data locally as this would mean it is vulnerable to attack, the data it uses to produce a recommendation is stored at the data centre and the client application. The application will receive an average of all the users movies and use this information to return a movie recommendation to the requesting client.

### Data Centre

The role of the data centre is to . For example 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, all they want is the result of the request.

The Data Centre was designed and implemented utilising dependency injection, this makes it easier to maintain and control dependencies and code reuse.

Voice Recognition

The voice recognition being performed should be the same as that being performed on the edge node. The data centre will know if the data has been pre-processed or not, 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.

Machine Learning

The machine learning application must be able to return a subset of the movies to the edge node when it first gets deployed and periodically as more data gets added to the edge node.

# Implementation and Testing

You should describe any languages, packages, and libraries etc. that are used in the development of your system. There is no need to describe your code in detail. You may highlight data types and implementation techniques that are of special interest. If appropriate, you may provide:

(a) Choice of implementation language(s)/ development environment(s)

(b) Use of software libraries;

(c) Key implementation decisions

(d) A description of how some important functions and algorithms were implemented.

(e) A description of how each component is implemented.

(f) Discussion of Test Approach e.g. unit testing, system testing, regression testing etc; Test cases described; Testing tools used. Evidence that testing coverage was complete.

## Choice of implementation languages/dev environments

Client

The Client Application was written using Electron. This decision was made as Electron utilises NodeJS for the backend and it would allow the same application to run cross platform. The Electron framework can run in Windows, MacOS and Linux.

Edge

The Edge Node applications are written in JavaScript and run in a NodeJS environment. This was chosen because the Client was written in JavaScript and NodeJS it was a familiar language.

It was also easier to reuse code between the two applications such as the CPU library.

Node JS async calls rather than sync calls so that the server does not get held up with request

Data Centre

The Data Centre was written utilising WebAPI and hosted in IIS as this was readily available on a Windows environment.

## Use of software libraries

* Pocketsphinx for voice recognition (mention that a recording was used rather than continuous listening)
* Nodejs packages
  + NodeJS proxy
  + NodeRedis
  + Request
* JSON
* Redis

## Key implementation details

Docker… and deployment scripts. The UI that was written for ARM. How the docker file and base images work.

* Once I got the setup done.
* Deciding on redis because of docker image
* Deciding on node/webapi
* **Read notebook**
* Proxy instead of regular web server. This allows for extraction of URL’s on edge node and makes it seem more like real life

## How each component was implemented

Client

The Client was implemented by

Edge

Docker Scripts or base images. The Edge was implemented by

Multiple iterations of development after meetings

Need a decent sized section for refactor of the way the machine learning was going to happen

Data Centre

The Data Centre was implemented by

Slightly more challenging to get voice recognition working on windows

## Discussion of test approach

Because of the nature of the code it could prove difficult to test as it has to run in a Node.js server and made actual requests so there was a lot of manual testing. I tried to run tests using QUnit but the test would throw an exception as soon as the first NodeJS keyword (“require”) came up. This meant that manual testing was the approach that would be taken. This would be adequate as the system is for research purposes. Unit tests in WebAPI also proved difficult as a lot of the code deals with actual requests. The tests that were able to be written did not deal with request code.

## Caching System Tests

### Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can reach Caching Application page | Click on the Client 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 |  |
| URL bar is present | On the caching page ensure there is a URL bar | The URL bar is present |  |
| Can type into URL bar | Click into the URL bar and type an address | The address types will show up in the URL bar |  |
| Go button without URL typed | Click the Go button when there is no URL typed out | Nothing, there will be no error |  |
| 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 |  |
| 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 |  |
| The timer | Click the go button with a valid URL | The timer will start and when the request is finished will record the total time for the request to finish |  |
| Clear cache button | Click the clear cache button | Information will appear to indicate that the cache on the edge node was cleared successfully |  |
| Can connect to the proxy | Make a web request | Ensure that the proxy is utilised |  |

### Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Can connect to the Redis instance | Deploy the web server | The server will automatically connect to Redis |  |
| 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 |  |
| Receive 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. This information is then returned to the user |  |
| Receive new request | Call the Edge Node with a new URL | The content is retrieved, stored in Redis and returned to the client |  |
| Receive a request for the second time | Call the Edge Node with a URL that has already been requested | The content is retrieved from Redis and returned to the user |  |

## 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 |  |
| Home button | Click home button | Should be returned to the home page |  |
| Recording status after page launch | Launch the Voice Recognition application | The recording status should be “Not Recording” |  |
| Recording status after clicking record | Click the record button | The recording status should change to “Recording” |  |
| Recording status after stopping recording | Click the stop recording button after starting a recording | The recording status should change to “Finished recording” |  |
| Recording button when not recording | Stop a recording or don’t start a recording | The recording button should read to “Start Recording” |  |
| Recording button when recording | Start a recording or don’t stop a recording | The recording button should read “Stop Recording” |  |
| Execute local recognition button without recording | Press the Execute Local Recognition button without recording a phrase | Nothing should happen, no error should be thrown |  |
| 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 |  |
| Execute remote recognition button with no recording | Press the Execute Remote Recognition button without recording a phrase | Nothing should happen, no error should be thrown |  |
| 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 |  |
| 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 |  |
| 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 |  |
| Local Results section when the local evaluation has occurred | Perform local evaluation | The local results section should show statistics |  |
| 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 |  |
| Remote Results section when no remote evaluation has occurred | Perform remote evaluation | The remote results section should show statisticss |  |

### 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 |  |
| Receive Get Request | Make a get request to the Edge Node | No error but no data returned |  |
| Receive Put Request | Make a put request to the Edge Node | No error but no data returned |  |
| Receive post request with invalid data | Make a post request with an invalid audio file or incorrect data | No error but no data is returned |  |
| 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 |  |
| 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 |  |
| 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 |  |
| 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 |  |
| Request information from the Data Centre when the WebAPI is published | Publish the WebAPI and make a request | The information should be returned correctly |  |
| Measure CPU use | Make a regular request | The CPU use on the edge node should be returned as part of the request |  |
| Measure Time of request | Make a regular request | The Time taken to process the request should be recorded |  |

### Data Centre Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
| Receive invalid request to process voice | Make a valid POST request with binary voice data | The voice is processed correctly and a valid response is produced |  |
| Receive valid request to process voice | Make an invalid POST request with invalid voice data | The voice request should be handled correctly and gracefully respond |  |
| Receive invalid request to record information | Make a valid POST request with textual data from a pre-processed request | The request should be processed correctly and a response generated |  |
| Receive valid request to record information | Make an invalid POST request without valid textual data | The request should be handled gracefully and a response sent |  |

## Machine Learning System Tests

### Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

### Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

### Data Centre Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

## Load Balancing System Tests

### Client Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

### Edge Node Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

### Data Centre Application

|  |  |  |  |
| --- | --- | --- | --- |
| Test Name | Method | Expected Results | Passed |
|  |  |  |  |

# System Evaluation

Not sure what’s included here

# Experimentation

A lot of the emphasis in this project will be here.

Provide empirical results and draw conclusions.

Describe methodology (use experiment methodology like goals and hypothesis, what’s measured/controlled)

When is it good to use edge node. When is it good to use DC? Not always good to use both

Read more in notes

## Caching Experimentation

### Does utilising Edge Computing reduce the latency of requests for the Client Device?

Setup;

* Run the Caching Application on the Client Device
* Deploy the Caching Service to one of the Edge Devices
* Deploy a Redis Instance to each of the Edge Devices

Isolate Variables;

Constants:

* Interface connecting Raspberry Pi to the router
* The web page being loaded
* The other applications deployed to the Edge Nodes

Variables

* Whether a webpage is cached or not

Method;

Measurements recorded will be the time between when the WebView element in the Client Application starts a request and ends a request.

After the Caching Service and Redis Service have been deployed, 10 warmup requests will performed without wiping the cache. The experiment will be performed with 10 iterations and an average will be taken.

An iteration will consist of an initial request to “http://www.bbc.co.uk” and then a subsequent request when the information is already cached on the edge node. The two times will then be recorded in seconds and the cache will be cleared ready for the next request

Hypothesis;

The hypothesis is that the cached request should take less time to execute than the initial request.

Results;

<Graph>

Analyse;

<Analysis of graph>

Conclusion;

## Voice Recognition Experimentation

### Does utilising Edge Computing reduce the computational load on the Client Device?

Setup;

* Run the Voice Recognition Application on the Client Device
* Save a Voice Recording using the Client Application
* Deploy the Voice Recognition Service to one of the Edge Device
* Publish the Data Centre WebAPI with the Voice Recognition endpoint

Isolate Variables;

Constants:

* The Voice Recording
* The Language Model and Dictionary being used for the processing
* The applications deployed to the Edge Nodes

Variables

* Where the voice processing is occurring

The variable in this experiment is whether I process the file locally on the Client Device, remotely pre-process it on the Edge Device or remotely process it on the Data Centre.

Method;

Measurements recorded will be:

* CPU load in a percentage of the total CPU on the Client Device
* CPU load in a percentage of the total CPU on the Edge Node
* Processing time in seconds
* File size
* Length of voice recording

After the Voice Recognition Service 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.

The measure of time will be recorded on the Client Device from as soon as the request starts to when the request finishes. The experiment will be repeated 10 times and an average will be taken.

The experiment will consist of a voice being recorded. The same recording will be used throughout the experiment to allow for a fair comparison of computational load.

There will be a round of 10 experiments run on the Client Device, then a round of 10 where the device is pre-processed on the Edge Node, and a final 10 where the request is processed on the Edge Device.

Hypothesis;

The hypothesis is that the Data Centre should process the request the fastest as it has the most powerful CPU but the CPU strain on the Client Device should be reduced regardless of the request being pre-processed on the Edge Device or the Data Centre.

Results;

<Graph>

Analyse;

<Analyse graph>

Conclusion;

### Does utilising Edge Computing increase the latency of the request for the Client Device?

Setup;

* Run the Voice Recognition Application on the Client Device
* Save a Voice Recording using the Client Application
* Deploy the Voice Recognition Service to one of the Edge Device
* Publish the Data Centre WebAPI with the Voice Recognition endpoint

Isolate Variables;

Constants:

* The Voice Recording
* The Language Model and Dictionary being used for the processing
* The applications deployed to the Edge Nodes

Variables

* Where the voice processing is occurring

The variable in this experiment is whether I process the file locally on the Client Device, remotely pre-process it on the Edge Device or remotely process it on the Data Centre.

Method;

Measurements recorded will be:

* CPU load in a percentage of the total CPU on the Client Device
* CPU load in a percentage of the total CPU on the Edge Node
* Processing time in seconds
* File size
* Length of voice recording

After the Voice Recognition Service 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.

The measure of time will be recorded on the Client Device from as soon as the request starts to when the request finishes. The experiment will be repeated 10 times and an average will be taken.

The experiment will consist of a voice being recorded. The same recording will be used throughout the experiment to allow for a fair comparison of computational load.

There will be a round of 10 experiments run on the Client Device, then a round of 10 where the device is pre-processed on the Edge Node, and a final 10 where the request is processed on the Edge Device.

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’s however the request should be processed much quicker on the Data Centre as it has a faster processor although this means that the Data Centre is performing more work.

Results;

<Graphs>

Analyse;

<Analysis of graphs>

Conclusion;

## Machine Learning Experimentation

### Does utilising Edge Computing reduce the Network Utilisation? (not sure what to do with this one so far)

Setup;

Isolate Variables;

Constants:

Variables

Method;

Hypothesis;

Results;

<Graph>

Analyse;

<Analysis of graph>

Conclusion;

## Load Balancing Experimentation

### Do the benefits of utilising Edge Computing deteriorate when multiple requests are made concurrently? Can this be improved with a custom load balancing aspect?

Setup;

* Run the Load Balancing application on the Client Device
* Deploy the Voice Recognition Service to one of the Edge Nodes
* Publish the Data Centre WebAPI with the Voice Recognition endpoint

Isolate Variables;

Constants;

* The Voice Recording
* The software package being used
* The Language Model and Dictionary being used for Processing
* The CPU use from other applications

Variables;

* Number of requests
* Whether the deployed Edge Node service is utilising custom Load Balancing

Method;

Measurements recorded will be:

* Average CPU load in a percentage of the total CPU on the Client Device
* Average CPU load in a percentage of the total CPU on the Edge Node
* Processing time in seconds for all requests to finish

The experiment will consist of a voice being recorded. The same recording will be used throughout the experiment to allow for a fair comparison of computational load.

Deploy the Voice Recognition Service to the Edge Node without custom load balancing enabled and perform 2 sets of 10 warm up requests.

Perform the experiment 10 times with varying number of requests, from 10 to 50 in increments of 10. Repeat all 5 experiments after deploying the Service to the Edge Node with load balancing enabled and performing the warmup again.

Hypothesis;

Adding load balancing will improve response times (over 70% CPU utilisation the request gets sent to the Data Centre)

Results;

Analyse;

Conclusion

# Conclusion

General summary of the success of the project with respect to criteria identified in the intro

Discussion of significance of experimental results. Agree with others work?

Strengths and weaknesses

Evaluation of hardware/software

Looking for critical appraisal and significance of contribution in the context of wider work.

# References

[1]"Final Year Project Repository", *GitLab*, 2017. [Online]. Available: https://gitlab.eeecs.qub.ac.uk/40103631/FinalYearProject. [Accessed: 21- Mar- 2017]

# Copyright

* Electron
* Nodejs/ Nodejs libraries
  + Node JS proxy
* Pocketsphinx
* Testing Suites
* Redis/Docker src images
* JSON
* Check licence file in Client src folder

# Appendices

## User manual

## Test Results

Excel results?

## Minutes of meetings