How Can Web Developers Optimise for Lower-Power Smartphones in the Developing World?

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Applicant:

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Project Title:

How Can Web Developers Optimise for Lower Power Smartphones in the Developing World?

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Abstract

This paper looks at methods for optimising modern web applications for users with low-powered smartphones. The research focuses on front-end optimisations, in particular bundlers, and JavaScript user interface frameworks. By analysing a testbed realtime chatting applications, built with different frameworks, socket.io and Node.js, it is discovered that performance optimisations can be made without sacraficing user or developer experience. This was found using the Google Development Tools to analyse the testbed application being created with different frameworks, bundlers and running at different simulated CPU speeds.

Keywords: Mobile, Optimisation, Web, JavaScript, Bundling, Framework

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Contents

1 Introduction

Developers take advantage of the outstanding capabilities present in modern smartphones. With a popular comparison being a current smartphone versus the Apollo-mission-era computers, the iPhone 6 processor clock speed is 32,600 times faster than the Apollo-era processors (Puiu 2019). Whilst not quite the same scale of gulf - there exists a distinct difference between the quality of smartphone in popular usage across developing countries versus smartphones in popular usage across developing countries (Hiscott 2016). Additionally, there is a distinct lack of research into optimising web applications for lower power smartphones - contextualising the importance of this subject topic.

With Google, Mozilla, Microsoft and Huawei all releasing cheap smartphones for developing countries, it is likely the developing world's mobile device population will follow a trend of being considerably less powerful than the mobile device population of developed countries (Hiscott 2016). With over 98% mobile phone adoption in developing countries (Sharwood, 2017) this offers a large market of potential users for web applications.

A future high speed networks and lower-powered CPU's (more detail in chapter 2), there is a strong possibility that a trend of developing for lower-powered CPU's may form. In anticipation of such a trend, this research is focused around performing an analysis of two major components to modern web applications: bundlers and JavaScript user interface frameworks.

Older devices also means a lack of compatibility with the newest browsers, meaning that for global usage, developers must make their applications work on older versions of browsers. To mitigate a loss of quality of the application, the tests should be performed on an application built with modern front-end frameworks, as a realistic benchmark. Then metrics can be gathered by measuring performance of applications even when converted into older versions of JavaScript that are compatible with older browsers - and making sure the application runs on those versions.

In summary - the applications must be browser compatible for older browsers, and should be made with modern JavaScript frameworks and techniques, as not to hinder potential developers.

These objectives will be tested by using the Google Chrome Devtools to monitor the CPU-throttled performance, and different technology implementations that allow comprehensive browser compatibility. There is an expectation that the lighter front-end frameworks perform best.

1.1 Dissertation Structure

The Literature Review explores a selection of the relevant existing literature surrounding and encapsulating the topic, establishing its context. Due to the

subject being in its infancy in relation to most areas of Computer Science - there is a distinct lack of relevant literature. Network-based optimisations are a popular article subject - but as it bears little need in developed countries - optimisations for low-powered CPU's is not a thriving research topic.

The Methodology chapter lays the ground work for the experiments to be conducted. It shows the techniques used to gain data, explains how they work, and justifies their selection for this project. The experiments are split up into component sections, each identifying a different area for potential optimisation. Each section has a brief summary, a prediction of the expected results upon modification and re-profiling, and the actual results, how the compare, and why they might differ to the predictions.

The Design and Implementation chapter describes exactly how the experiments were conducted, along with the results. The experiments are split into two case studies, analysing bundler performance, and analysing front-end JavaScript framework performance.

The Discussion chapter begins to weave the results into an argument which responds to the initial research question, along with providing assessment on the quality and validity of this research. It also highlights further areas for study regarding this research.

The Project Management chapter provides clarity and reflection on the process of creating this project, and the methodologies employed to ensure completion within the timeframe given.

The Conclusion highlights the extent to which the findings provide a suitable answer to the initial research question.

1.2 Terminology

Term	Definition
0x	No CPU throttling being applied
4x	Four times CPU throttling being applied
6x	Six times CPU throttling being applied
Chrome	Google Chrome Browser
DevTools	Google's suite of developer tools built directly into Chrome
CDN	Content Delivery Network
ES5	ECMAScript 5
ES2015	ECMAScript 2015, the version after ES5
Babel	JavaScript compiler, often used for converting ES2015+ to ES5
Polyfill	Browser feature implementation that isn't naturally supported
Node	Nodejs, a JavaScript runtime built on Chrome's V8 engine

1.2.1 DevTools-Specific Terminology

Metric	Description
Load time	Total load time for page resources to be rendered
TTI	Time to interactive (e.g When the user can interact with page)
Page Weight	Accumulated total file size
Loading	Parsing, sending/receiving requests
Scripting	Compiling and evaluating scripts
Rendering	Executing page layout
Painting	Drawing the render to the screen
Idle	Time spent waiting

2 Literature Review

2.1 Introduction

As of 2018, there were 3.7 billion mobile devices connecting to the internet (Stevens, 2018) showing global usage and coverage, and according to Poushter and the research undertaken by PewResearchCentre - in 12 developing countries that were surveyed in 2014 and 2015, there were "significant" increases in adult mobile phone users. This gives credibility to the claim that there is a likely upwards trend in smartphone users in the developing world.

Where there are users, there is also likely to be dissatisfaction, and Google estimate that a 400ms delay can see a drop off of 0.44% (Brutlag 2009). It has also been found that 90% of users stop using an app due to poor performance, and 86% will uninstall the app altogether (AppDynamics and University of London 2014), there is the possibility for unoptimised web apps to lose huge numbers of potential users due to the app performance not meeting modern web application performance. This research reinforces the statement that poor performing applications negatively impacts the number of users - making the topic of optimising applications to avoid this a valid and useful area for research.

Nejati and Balasubramanian discuss the difficulty in isolating the effects of the mobile browser in determining the root of poor performance (Nejati, Balasubramanian 2016). This project will differ from that research by making use of the DevTools mobile simulator - taking many of the factors out of consideration, allowing isolation on only changes to the CPU performance. They also identify the issue of mobile browsers being much slower than desktop, as agreed with in other research on mobile optimisations in the cloud era (Wang et al. 2013), a problem given the dramatic increase in mobile devices globally.

2.2 CPU

It is suggested that network round-trip time is a major problem. Whilst this may have been true at the time, due to the increase in network capacity, and the trends shown so far, it could be assumed that time-based network problems become increasingly less relevant, with the hardware-based issues becoming more prominent. Particularly in developed countries, modern smartphones with the latest hardware are readily available, which is why this project focuses on mobile phones in usage in the developing world. This evidence is collected through a well-thought out series of experiments resulting in consistent, communicated correctly with no evident omissions. This gives credibility to these results.

Over the last 20 years, Moore's Law has begun to plateau (Simonite 2016), demonstrated by Figure 1 and hardware capability increases along with it.

Networks on the other hand are continuing to get faster and offer better coverage.

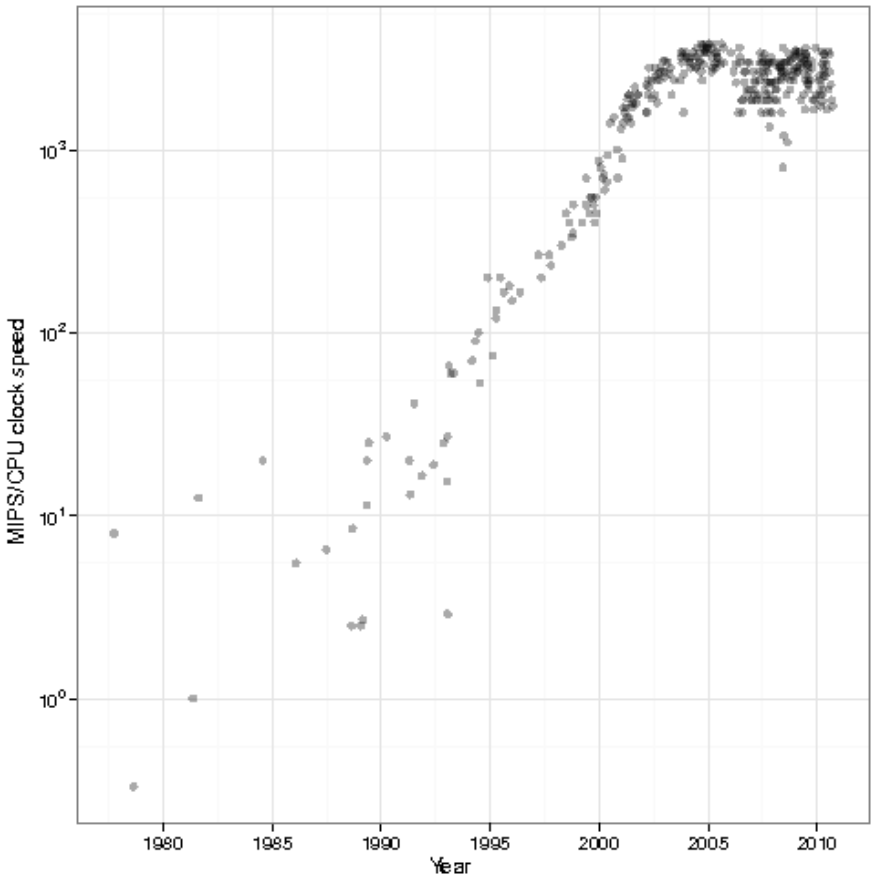

Figure 1: Moore's Law Plateau

Taking Kenya (a developing country) as an example, Figure 2 shows that network speeds are continuing to increase over time.

Together, Figures 1 and 2 allude to the likely outcome of a fast-network, slow CPU future.

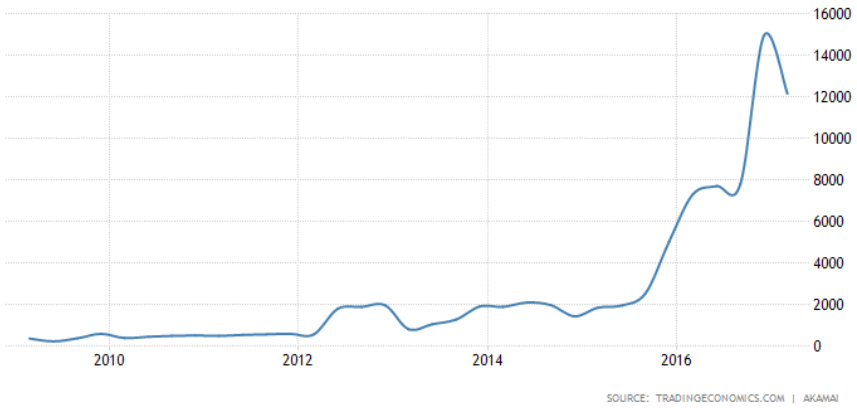

Figure 2: Kenyan Network Speeds

"Of all ITU [International Telecommunication Union] regions, the strongest growth was reported in Africa, where the percentage of people using the Internet increased from just 2.1% in 2005 to 24.4% in 2018" (ITWeb, 2018). Containing a large number of developing countries, by looking at Africa as a whole, and Kenya as a microcosm - we can see there is a likelihood of a fast network future. With the plateau in Moore's Law, a likelihood of stagnation in CPU performance increases.

A fast network future may lead to an emergence in prioritisation of CPU-based optimisation. There has also been extensive research on optimization over networks already - reducing content, using CDN's, compressing content, utilising browser caching techniques (Iliev 2014), and front end optimisations for modern devices. This research will avoid liminality by relying on the research already conducted on networks, and instead fill the gap left for optimising web applications to perform highly for low-end smartphones. With mobile web browsers being intensive programs for CPU's (Meyerovich and Bodík 2010), there is evidence that opimisations are justified in this field.

Nejati and Balasubramanian provide research around locating mobile browser bottlenecks. They concludes that computational activities are the main bottlenecks, highlighting the need for research on optimising for lower-powered CPU devices, where the effects of computational bottlenecks will be be exceedingly more relevant.

It also states that this is not the case for desktops, where network activity

is the dominant bottleneck - also emphasizing the importance of optimising CPU-intensive applications for mobile devices. Wang et al. suggest that the most costly area for TTI is resource loading - which, as the sources are credible, makes sense - however no speculation is offered about the state of the future of processors and networks, making the research presently relevant, but perhaps not in years to come. These conclusions are the result of an experiment conducted by the authors, and backed up consistently by relevant academic papers.

In summary - the browser is an intensive program, and heavy computational activities are the main bottlenecks.

2.3 Mobile Web Browser

There are also many comparisons made between the mobile browser and desktop browser, over the same network speed - finding that the mobile version can take up to nine times as long to load (Wang et al. 2013). As they are on the same network - we know that this is therefore down to the hardware and mobile browser - not server-to-client issues. Suggestions have been made that more effort should be put into making mobile browser optimisations - with which future developers could utilise to make web applications more globally usable. Whilst this research is not founded on data collected first-hand, it is rigorously supported by multiple credible academic sources.

2.4 Development Issues

Thiagarajan et Al. show that reducing JavaScript and utilising HTML functionality leads to a less power-hungry application. JavaScript being the most power-hungry part of the traditional web application. It also shows the importance of optimising CSS rules, with a reduction to only necessary rules, along with the migration of multiple CSS files into one file for a given page seeing a drop of 5 Joules from the power supply.

It also looks at the benefits of web page prefetching by predicting which links the user will click, and prefetching/loading the relevant data to render the page should the link be clicked more quickly. Does low CPU capability make this a relevant point or not?

The other large aspect they discuss, is the usage of cloud-based architecture. This might increase network latency, and there are other potential security issues, but focusing purely on optimisation, this style of architecture allows processing to be partially taken away from client devices, reducing the workload of the client CPU's. This could be introduced into the chat web app by analysing the impact of moving some intensive functionality from the client to the server.

To keep this research focused into a more specific topic area - architecture optimisations will not be analysed. The topics will be strictly front-end focused.

In summary - whilst prefetching and cloud-based architecture are useful avenues for exploration with regards to mobile optimisation, this research will focus on JavaScript reduction to help lower the load on the CPU.

2.5 Summary

Optimisation over networks is a popular topic, with an array of literature covering the subject. This helps guide this research in starting to fill the gap in front-end optimisations. Following on from the research conducted by Thiagarajan et al, this project will look at ways to reduce JavaScript by using and comparing two different bundlers - Webpack and Rollup.

There is a distinct lack of literature based around front-end JavaScript frameworks, which, along with the bundlers creates the foundation of this research. The following chapter will outline how an experiment is created to test the performance of a testbed web application whilst using different technologies.

The experiments conducted in this dissertation shall be run using the Google Chrome browser. Not only does this browser give acces to the use of the comprehensive DevTools suite and Puppeteer, but it is also the most popular browser, with 62.63% of global traffic using it, ahead of Safari at 15.56% (GlobalStats 2019).

3 Methodology

3.1 Introduction

In order to perform detailed analysis on potential areas for optimisation, a web app would need to be studied and modified to gain insights. Rather than study an existing application, over which no control would be granted, a better solution would be to create a testbed application using modern technologies. In tandem with this, DevTools provides accurate and reliable analysis on browser applications, with the ability to throttle the CPU to judge performance on simulated lower-hardware. This would allow comparisons to be drawn across the different CPU throttle thresholds, but with no other parameter changes.

To understand the decision for the case study subjects, first there must be a basic grasp on the history and current usage of JavaScript and ECMAScript.

3.2 A Brief History and Analysis of JavaScript and ECMAScript

ECMAScript (European Computer Manufacturer's Association) was designed as a way to standardise JavaScript (a programming language created in 1995) - and was first released in 1997. Versions have been regularly released, with ES6/ES2015 being the current modern standard. Initially it was named ES6, but later renamed ES2015. For consistency, this dissertation will always refer to it as "ES2015". Whilst the 9th edition of ECMAScript (ES2018) was finalised in June 2018, browsers are some way behind, with only modern browsers supporting the features of ES2015 - limiting them to old features, or they can use a compiler such as Babel to compile their ES2015 code into valid and compatibile ES5 - ensuring cross-browser compatibility, whilst having use of ES2015 features.

3.3 Puppeteer

Puppeteer is a Node Library which provides a high-level API to control headless or non-headless Chrome instances over the DevTools protocol. This allows programmatic control over the browser, offering automation capabilities. The DevTools protocol has the ability to set the throttle speed of the browser when running a performance profile - lending itself perfectly for the experiment being conducted in the following chapter. Rather than manually opening the testbed application, selecting the throttle speed, and running a performance profile, Puppeteer allows all of this to be automated - with the resulting performance profile being saved into its own file. This increased the number of experiments it would be feasible to run - adding credibility to the results collected.

3.4 Testbed Application

3.4.1 System Requirements

The testbed application had to be:

- Made with modern JavaScript frameworks
- Browser compatible with older browsers
- Built with realistic dependencies
- Simulate heavy workload
- Functional

In order to comprehensively test the technologies being analysed, a testbed application was required. For the purposes of this project, realtime chatting application was created - an application with genuine purpose and functionality - requirements of the application.

Initially, the application was built with React, and later re-written several times using different front-end frameworks. Using bundlers meant it could be written in ES2015, but compiled to ES5 to run on older browsers - another system requirement. The app utilises Socket.io to communicate with a Node.js server also running Socket.io. On top of this, the app utilises several other libraries, such as Bootstrap, Moment, JQuery and Faker, giving a partially realistic build to the application. To simulate heavy workload, a factorial function was created, and called upon initialisation with an input of 1000. This gave the application a significant amount of work to do.

3.5 Case Study One: Effect of Bundlers on Performance

Case study 1 analyses the performance comparison between two popular bundlers - Webpack and Rollup. These bundlers are being tested using the testbed application with each framework to ensure consistency across all other parameters other than the bundler itself.

3.5.1 Bundlers

Adhering to modern programming conventions, developers tend to build applications out of many modules, but from a performance perspective - this has its own issues. To import a JavaScript file in HTML, a tag is used like so:

```
<script src="/path/to/file.js"></script>
<script src="/path/to/file2.js"></script>
etc.
```

If the applications is made up of 200 different files, the browser has to separately send a request for each file individually - consuming valuable time and resources

before the user can interact with the full application. This is where bundlers are used. The bundler can take all these files, and bundle them into one JavaScript file - which the browser then requests:

```
<script src="/path/to/bundle.js"></script>
```

This resolution leaves only one file request from the browser and does not sacrifice developing standards. Bundlers can do much more than just this however - they can also use plugins like Babel to convert ES2015 to ES5, making the application fully browser compatible, along with minification, setting up development servers and more. This leaves us being able to write modular code, in ES2015+, and still run the optimised app on older browsers. For the purpose of this project, two of the major bundlers were chosen to analyse: Webpack and Rollup.

3.5.1.1 Webpack Webpack is the bundler used by the tool `create-react-app`, popular amongst developers for quickly getting React Apps set up. Webpack turns each module into its own isolated function scope.

3.5.1.2 Rollup Rollup puts everything into the same function scope. When measuring the performance of Rollup - it is anticipated that the execution time should decrease, as its handles modules in a different style to Webpack (Lawson, 2016).

```
function foo(a, b) {
    function bar() {
        return a + b;
    }

    return bar();
}

let result = foo(1, 2);
```

When the JavaScript engine reaches this section of code, it creates a new function object in memory for `foo()`. When the engine reaches the line where `foo()` is called, it executes the function, which creates a new function: `bar()`. When the function execution finishes, the `bar()` object in memory is destroyed. This means if `foo()` is called 100 times, the `bar()` function is created and destroyed 100 times. This costs processing, making it generally slower than non-nested functions.

In each case, the bundler will:

- Bundle the JS files
- Bundle the CSS files
- Compile the JS into ES5
- Set up a server and serve the project

The configuration file for each bundler is in the Appendix.

3.6 Case Study Two: Effect of Different JavaScript Frameworks on Performance

Case study 2 analyses the performance difference between four different

3.6.1 Frameworks

Table 3: Framework Comparison

Framework	Size	Number of GitHub Stars
React	106.6KB	127,752
Preact	3KB	22,385
Inferno	48KB	13,619
Hyperappp	1KB	16,660

React has been chosen as the benchmark framework - as the current leader in industry, and will be compared to three other frameworks, designed as faster alternatives.

3.6.1.1 React "React is a declarative, efficient, and flexible JavaScript library for building user interfaces" (Reactjs.org) It was designed for component-based web development - making it easier for developers to create reusable components for the applications. It uses JSX, which allows usage of HTML tag syntax within components. At the time of writing, React is in use across 735,040 websites (https://www.similartech.com/technologies/react-js). As of January 28th, 2018, React had 1,786,699 downloads, a 152.2% increase from the previous year (https://jsreport.io/javascript-frameworks-by-the-numbers-winter-2018/). https://books.google.co.uk/books?hl=en&lr=&id=NZCKCgAAQBAJ&oi=fnd&pg=PR6&dq=React+js&ots=K
d&sig=GSstOX8Ag0OYJNGM8hT5nNDSlKU#v=onepage&q=React%20js&f=false

3.6.2 Preact

Preact is a fast alternative to React - using the same ES2015 API (Yomi 2017). The only changes from React are trivial, but most can be accessed by making use of `preact-compat` - an additional package that re-integrates removed features. As of 28th January 2018, Preact had 29,385 downloads, a 254.3% increase from the previous year.

3.6.3 Inferno

Like Preact, Inferno is a lightweight JavaScript library that resembles React. It was created to examine analyse whether a UI library could improve web application experience on mobile devices by addresseing issues around battery drain, memory consumption and performance (Maida 2016). As of 28th January 2018, Inferno had 29,385 downloads, a 276.5% increase from the previous year.

3.6.4 Hyperapp

Hyperapp is a JavaScript framework for building web applications that uses the Elm-inspired approach to state management. GZipped and compressed, the framework is around 1KB (Bucaran 2018).

3.7 Performance Profiling

To collect accurate metrics about the performance of the testbed application, the DevTools were used. These tools allow for performance profiling, detailed audits for progressive web apps, and information about load times and page weight. Additionally, they have the capability for CPU throttling, which allows visualising the scale of performance difference between unthrottled and throttled CPU with the same application.

Initially, the unbundled version of the application was analysed, with an unthrottled CPU. This gives the initial set of metrics that can be measured. These are:

- Load time
- TTI
- Page Weight
- Loading
- Scripting
- Rendering
- Painting
- Other
- Idle

(These are defined in the section 1.2)

Then a CPU throttling was activated, and the profiling re-run, giving a new set of results. From here, it was possible to calculate the percentage increase from the unthrottled set to the throttled set.

$$PI = Percentage\ Increase$$
$$T = Throttled\ CPU\ result$$
$$U = Unthrottled\ CPU\ result$$
$$PI = \frac{T - U}{U} \times 100$$

Across the results, this gives the full range of percentage increases between the data with no CPU throttling and the application of the 4x throttle. Then the steps were repeated but with a 6x throttle applied, and once again calculated the percentage increase. Across multiple passes, the metrics with the largest percentage increase upon throttling the CPU was rendering, idling and other. Despite these being the largest percentage increases, it must also be taken into account the total time they are taking. A 10% increase of a task taking 1000ms will see a bigger performance hit than a 50% increase of a task taking 5ms. Given the results varied, more passes of the test under the same conditions will be conducted in order to provide the average metric.

To gain the data, Puppeteer was used to run a headless browser, navigate to the URL where the app was being hosted. At this point, the client emulation configuration was decided upon and sent to the headless browser. It could then apply the correct emulation, and begin a timeline trace. Once finished, the trace data would be written to a JSON file, and saved with a name of the current timestamp (to avoid any duplicate file names). The script would run the tracing 20 times each for non-throttled, 4 times throttling, and six times throttling. This reduced outliers, and an average for each metric was collected, before compiling into charts. This technique for data collection has not been used in any of the relevant academic papers found in Chapter 2. The code for this script is found in Appendix E.

As described in Figure 3, each version of the testbed application (e.g React, Hyperapp etc.) would be used as the input - hosting the app locally. Then the Puppeteer script would be run, loading the app and running a performance profile. The output of the script would be written to a file (using JavaScript's `date()` function to create unique file names. Each file could then be loaded into the DevTools and the inbuilt parser would display a summary of key information. This data was then written to a spreadsheet for further analysis.

Webpack supports all ES5-compliant browsers - and if developers wish to support browsers older than this - polyfills can be loaded to make the application compatible. When using Create React App, webpack's configuration is kept hidden as a way to abstract complexity away from the developer. If they want to, the developer can still edit the Webpack configuration files by "ejecting" their application.

For this reason, to avoid any bias, this project will not use `create-react-app` as the method of testing Webpack. Instead webpack will be added manually,

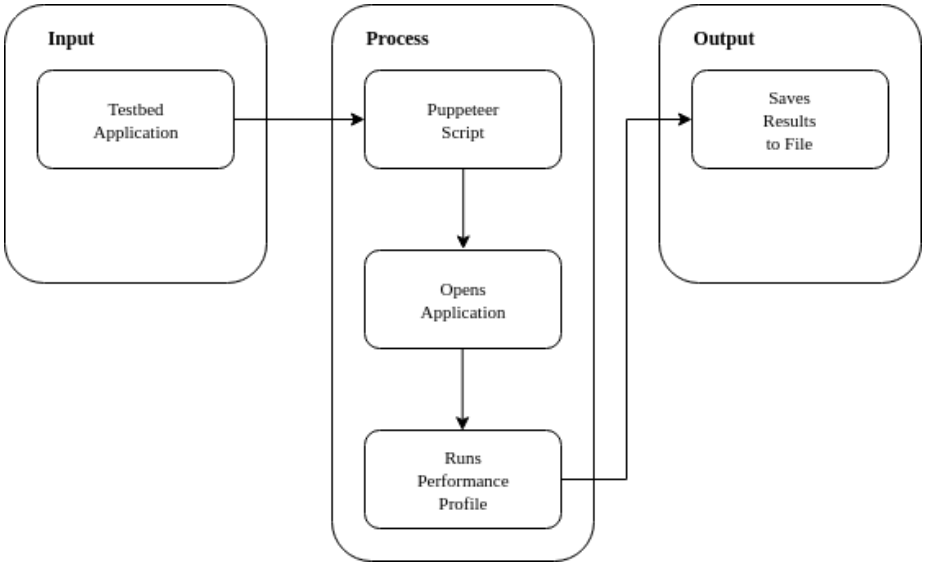

Figure 3: Experiment Flow Chart

allowing full control over the configuration file. This provides a closer and fairer comparison to Rollup.

4 Design and Implementation

4.1 Hardware Specifications

The experiment is being carried out on a machine running an AMD FX-8350 with the following specifications:

Table 4: CPU Specifications

Specification	Value
Processor Speed	4GHz
Processor Count	8
Processor Socket	Socket AM3+
Memory Type	DDR3 SDRAM
Wattage	25w

4.2 Testing Matrix

For the final results, each bundler would be tested with each framework about three throttling speeds - 0x, 4x and 6x.

Bundler	React	Preact	Inferno	Hyperapp
Webpack	0x, 4x, 6x	0x, 4x, 6x	0x, 4x, 6x	0x, 4x, 6x
Rollup	0x, 4x, 6x	0x, 4x, 6x	0x, 4x, 6x	0x, 4x, 6x

Using this final matrix, the tests were run with the hardware specified in table 4. Each combination of framework and bundler was tested 20 times separately in the headless Chrome browser. This eliminates the possibility of an outlier being used if a single measurement is taken.

4.3 Case 1 - Bundling

To test each bundlers performance, the testbed application was bundled using the configuration files in the appendix (Rollup configuration in Appendix G, Webpack configuration in Appendix H). One the application has been bundled and served, the Puppeteer scripts found in Appendix E was used to run the DevTools profiling.

4.3.1 Prediction

Upon bundling the app, there are expectations that the loading time reduces, along with the total page weight. There is anticipation that the rendering and painting times will not fluctuate much if at all - as the same content is still being calculated, and exactly the same page is still being painted onto the screen. Loading and scripting times are expected to be where the fluctuation will be seen. It is expected there will be a trade-off, and the final score will depend on the weighting of that trade-off. Whilst the browser must do some extra work when parsing the bundled version of the scripts, it also sees the performance benefits as described in section 3.4.1. This also backs up the prediction that of the two bundlers, Rollup should yield better performance.

4.4 Case 2 - Framework Analysis

With the application re-written in four different frameworks - React, Preact, Inferno and Hyperapp, the testing required using each version along with each bundler, and running the Puppeteer script on the resulting locally hosted application.

4.4.1 Prediction

It is expected that React will be the slowest - with all of the other frameworks marketing themselves as faster alternatives to React. With Hyperapp being the smallest of all of them, there is a marginal weighting to expect Hyperapp to be the best performer.

4.5 Summary

Before analysing the results, there are two key predictions - that Rollup should outperform Webpack - and Hyperapp is expected to be the best performing framework. This creates a concise summated prediction statement.

The optimal performance of the testbed application should be seen using the combination of Hyperapp and Rollup.

5 Evaluation and Results

To find an overall score for each combination, the 20 results collected were averaged to create a single score, before the average at each throttle threshold were accumulated to give a final overall score. This represents the overall time the CPU is processing. These final scores can then be compared to the other combinations.

5.1 Case Study 1: Bundlers

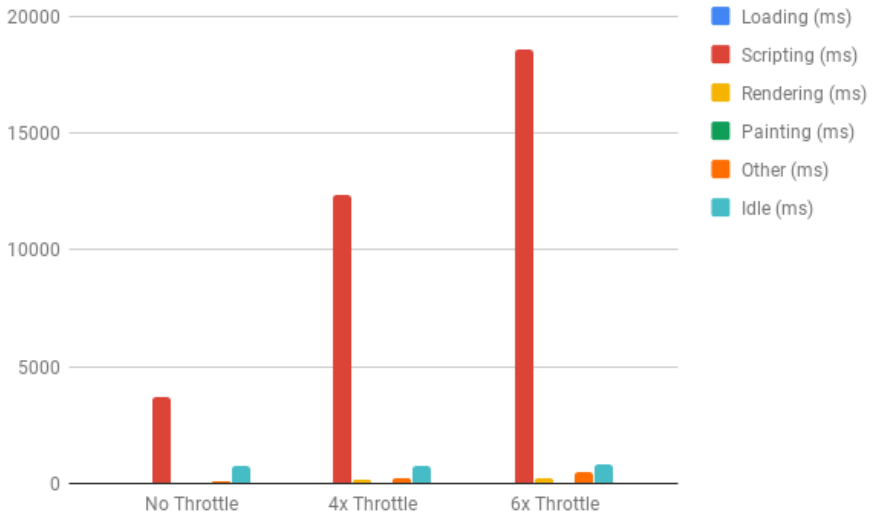

Figure 4: Unbundled Chart

5.1.1 Results of Webpack Bundling

Table 6: Webpack Results (cumulative ms)

React Webpack	Preact Webpack	Inferno Webpack	Hyperapp Webpack
0x	3553.43	3207.11	3158.77
4x	12461.31	12307.86	12454.80
6x	18414.10	18133.34	18261.34
Total	34428.84	33648.31	33874.905

5.1.2 Results of Rollup Bundling

Table 7: Rollup Results (cumulative ms)

React Rollup	Preact Rollup	Inferno Rollup	Hyperapp Rollup
0x	3099.51	3057.97	3081.70
4x	12088.92	12077.82	11947.46
6x	17711.29	17624.91	17694.07
Total	32899.72	32760.7	32723.23

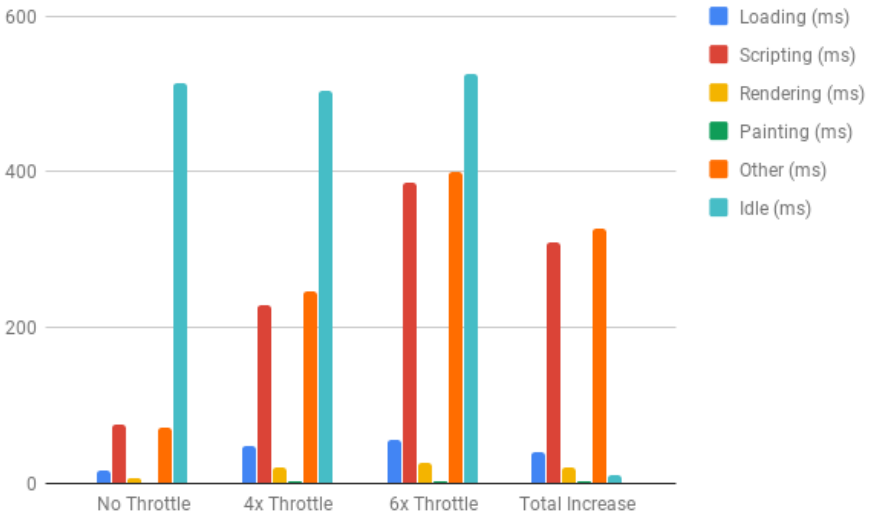

Figure 5: Rollup Chart

It is evident from profiling the application that has been bundled with Rollup has significantly reduced scripting times.

Figure 6 demonstrates that Rollup performs better than Webpack consistently in these tests, with between one and three seconds faster cumulative times over the three throttle thresholds.

5.2 Case Study 2: Frameworks

The framework performance can be analysed using exactly the same data, but for ease of visualisation, the axes have been swapped, and the range has been appropriately shifted and scaled. Figure 7 shows that regardless of the bundler used, Hyperapp has the best performance of all four frameworks.

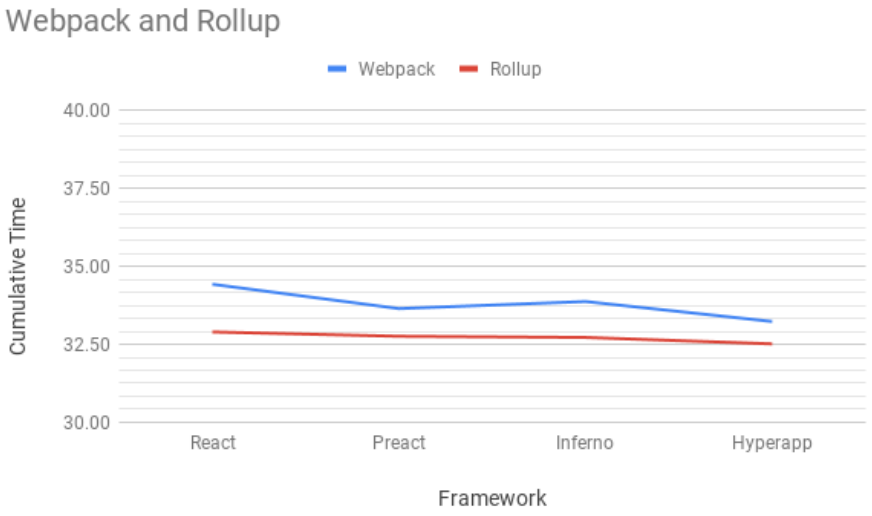

Figure 6: Webpack vs Rollup

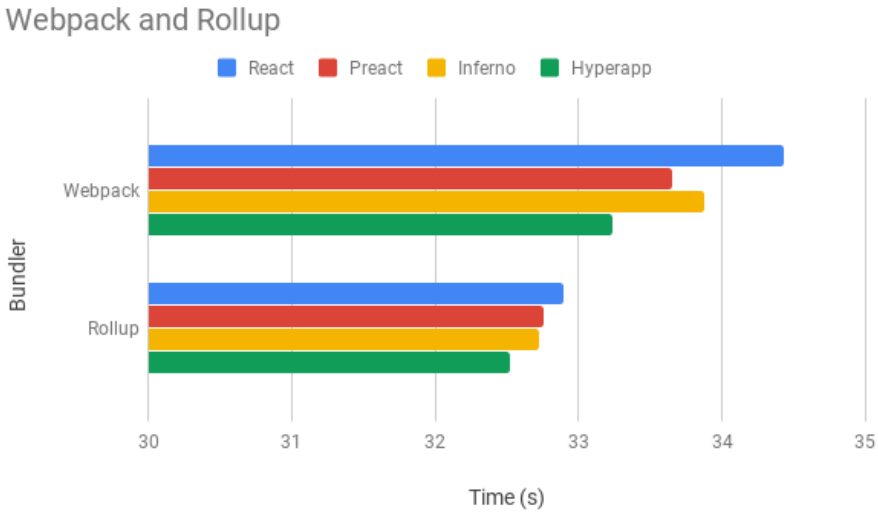

Figure 7: Frameworks

5.3 Summary

Whilst only seemingly negligible improvements are discovered when comparing these frameworks and bundlers, Google stated that a 400 millisecond delay correlates to a 0.44% drop in search volume (Brutlag 2009). With 3.896 billion internet users worldwide in 2018 (Statista 2019), that 0.44% represents 17.14 million users. This gives credibility to the marginal improvements found by using Hyperapp and Rollup.

6 Discussion and Future Research

Whilst useful data has been recorded in this project, the data could be substantially backed up with more experiments. Critically, testing the application across real mobile phones would further the claim that the conclusions were valid in specific relation to the original research question. Building on this - the experiment could also be carried out on specifically the most common devices being used in developing countries, with direct comparisons to performance on new smartphones. It may also positively impact the performance of Inferno, being specifically built for addressing battery drain, memory consumption and performance issues (Maida 2016).

Given more time, the author would have performed the same experiment again, using mobile devices running Android 8.0 and higher. This would allow the use of Chrome's remote debugging feature. Once setup on the device, it allows inspection and debugging of live content on an android device as well as screencasting content from the device onto a DevTools instance (Basques 2019). Alongside this, doing the same tests across multiple versions of Chrome to verify that the application is still fully compatible - as at this stage, its compatibility is rooted in theory, and has not been tested for verification. Whilst this data would be useful - it would have also been time-consuming to collect, with other browsers development tools not being the same as Chrome, meaning at the very least, the Puppeteer script would need to be rewritten to ensure compatibility, and at worst an entirely new method for collecting the data needed.

In addition to this, if a way was found to automate getting the summary data from the performance profile result, the experiment could be entirely automated, and therefore collect substantially more results to further the evidence for the discovered outcome.

Another useful avenue for testing could be to utilise a more substantial open source application, for example the Hacker News clone on GitHub at https://github.com/vuejs/vue-hackernews-2.0. This would also reinforce the conclusions being made in this dissertation, with no uncertainty based on the validity of the testbed application as a source of potential outlying results.

In summary, the project could be improved or extended by looking into any of the following methods:

- Testing on real mobile devices
- Testing across more browsers and browser versions
- Automate all data collection
- Use more substantial testbed applications

7 Project Management

7.1 Summary and Methodology

A project with multiple complex elements requires careful planning and preparation to be successful, and avoid wasted time in the future. Whilst generally proceedings went smoothly, there were definite lessons learned from this project that can and will be applied to future endeavours. To build the testbed application - the iterative life cycle methodology was employed, allowing the application to quickly progress in the early stages, and gradually improve throughout the entire process. This is due to the acceptance that with an iterative lifecycle methodology there will be a lot of rework, particularly at the early stages of the project (Krutchen 2000).

With additions like the alternative frameworks, and the automated data collection script, making use of Puppeteer and the Devtools Web API - this method was effective, particularly for a one-person team. (This is where many of the other project management methodologies struggle to have an impact). The testbed application was also built making use of version control (Git) as a way of tracking code - helping progression on the practical elements of the project. With the iterative lifecyle methodology being applied at both a micro and macro level, the kanban approach was employed to supplement it, utilising the GitHub Projects interface. Combined, these approaches helped the practical elements of the project to be completed earlier than initially planned - with only minor tweaks added throughout the later stages of the project.

7.2 Timeline

To create a visual aid for the project timeline, teamgantt.com was used. This create my initial Gantt chart (Figure 8). Whilst the Gantt chart did evolve to become less abstracted - retrospecitvely, the project should have been planned in greater detail from an earlier stage, making definitive goal setting more achievable. Alongside this, the supervisor meetings were utilised to define goals and criteria to have achieved by the following session. This helped to split the project into weekly chunks that were integrated into the continually evolving Gantt Chart - laying out a clear and concise overall plan for project completion. Supplementing the supervisor sessions, an (almost) weekly diary was kept to track project progress, available in Appendix F.

7.3 Communication

Whilst it took longer than planned to contact the project supervisor - a recognised mistake from the author, when meetings became a regular occurence, the project began to build steadily and effectively. The supervision was of pivotal importance

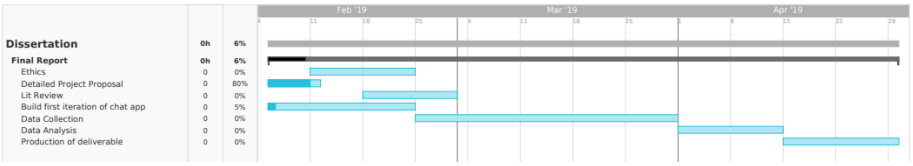

Figure 8: Initial Gantt Chart

in relation to this project, with a prediction of difficulty progressing effectively during the early stages without it.

Evidence of the meetings with the supervisor is located in Appendix A.

7.3.1 Presentation Feedback

After the presentation, the decision was made to change the focus of case study 2. Whilst partially relevant - the research would have shown that web apps perform better with heavy processing done on a server, leaving the client with a light load, and that a server could send a more optimised bundle for a device. Whilst achievable as an experiment - this research would likely not have shed any new light on the area - therefore the JavaScript frameworks comparison became the new subject for case study 2. Alongside this, whilst the topic for case study 2 had changed, the feedback on the justification was still valid - therefore this has been amended in section 3.6. In addition to this, Figure 3 was created to help the reader visualise the experimentation process.

7.4 Legal, Social and Ethical Implications

7.4.1 MIT License

All of the technologies being tested in this project are open source, and all licensed under the MIT license. This is one of the most permissive licenses, and means that the software created with these licenses can keep source code private when distributing software that makes use of any of these technologies. For many commercial companies - this is much more desirable than using any software licensed under less permissive licenses, such as the GPL version 2 - which would force them to make their source code available (GNU 1989).

Whilst now under the MIT license, it is worth noting that React used to be under the BSD+Patents license. which states the code is copyrighted by Facebook (the creators of React). If you sue Facebook for patent infringement, then your patent rights for React are automatically revoked (Kripalani 2017). The switch to licensing under the MIT license proved to be in response to the disappointment and uncertainty from its community (Wolff 2017).

7.4.2 Impact of Better User Experiences in the Developing World

Better web app design encourages growth of users. If developing countries were to see more web apps were catering for consumption on the popular lower-powered devices, evidence shows that more people would adopt devices. Alongside this, it has been shown that mobile phone adoption has a huge effect on economies. According to Dahir, in 2015 mobile services generated 6.7% of Africa's GDP, around $150 billion in economic value (Dahir 2016). With the findings mentioned in the Literature Review - faster, more optimised applications are more likely to retain users than applications that are slow (AppDynamics and University of London 2014).

8 Conclusion

Throughout the experiments put forward in this dissertation, several points can be identified. Firstly, the choice of bundler and framework do impact the performance of a web page - however, depending on the size of the app, the performance benefits may be negligible. As researched by Lawson, the choice of bundler becomes more integral upon scaling the usage of modules (Lawson 2016). When comparing each of the bundlers over multiple throttling thresholds, it was seen that Rollup was in fact demonstrating its marginal benefits - utilising the shared function scope bundling tactic.

As seen from Figure 7, the optimal solution when developing for users on lower-power smartphones is the combination of Hyperapp and Rollup. This combination sees the lowest overall score across multiple throttling thresholds. This validates the prediction made in section 4.5.

This leads to an answer to the original question - How Can Web Developers Optimise for Lower-Power Smartphones in the developing world?

They can choose their bundler carefully - based on the structure of their application - with very modular applications seeing large performance benefits from Rollup, and if further optimisation is desired, creating the project using Hyperapp will yield the greatest performance across all four of the tested frameworks.

Hopefully this is just one brick in the foundations of more research within this domain to create faster and better user experiences for global users - not just with the latest smartphones.

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10 Appendices

10.1 Appendix A: Evidence of Meetings

303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB

Student: EDWARD PRINCE

Date of meeting: 01/03/2019

Record of individual actions completed + notes:

COMPLETED CHAT APP, FOR DATA COLLECTION

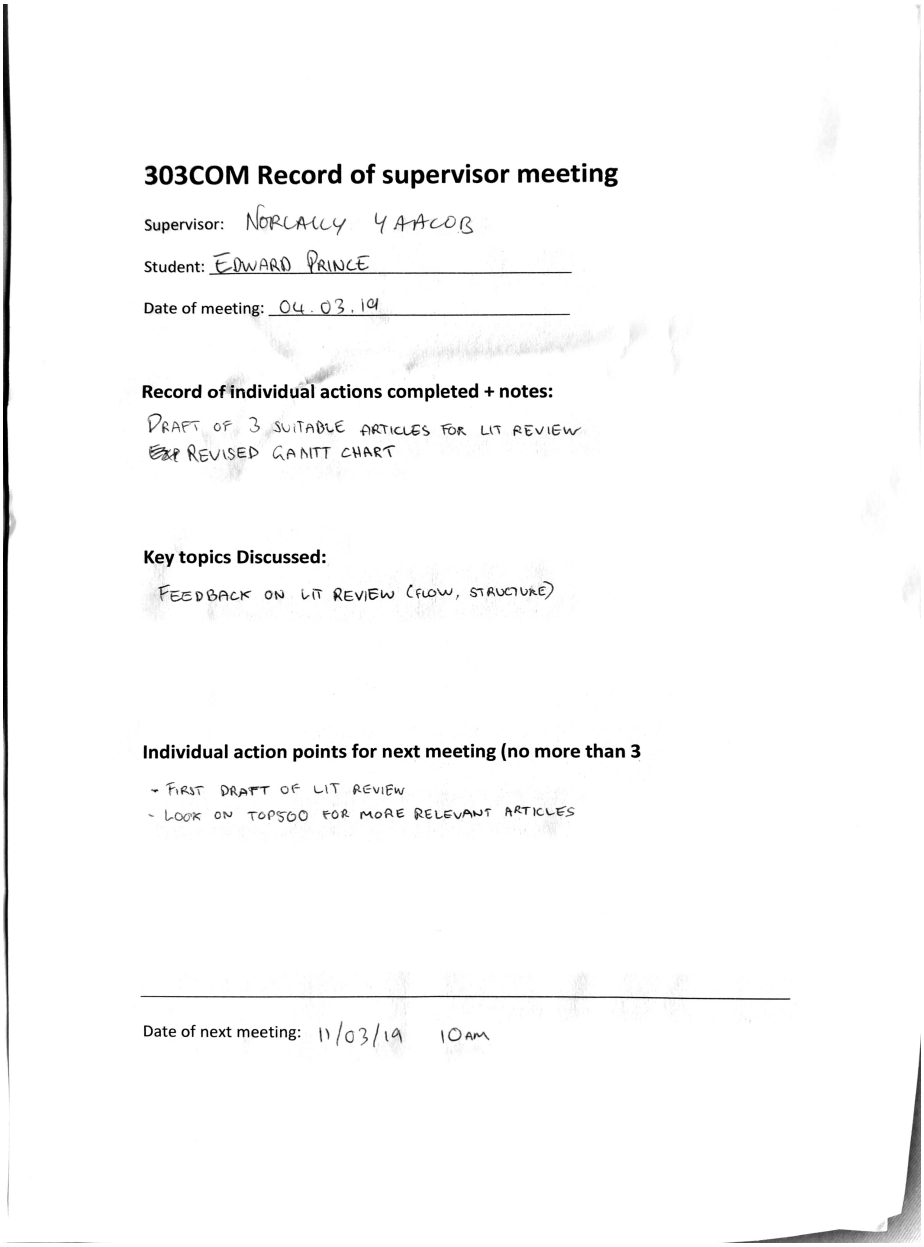
Key topics Discussed:

PROPOSAL FEEDBACK
DISCUSSE APP FUNCTIONALITY
CLARIFICATION OF TIMELINE

Individual action points for next meeting (no more than 3

- TO SELECT 3 SUITABLE ARTICLES FOR LIT REVIEW
- PRODUCE A DETAILED GANTT CHART

Date of next meeting: 04/03/2019 10AM



303COM Record of supervisor meeting

Supervisor: NORCALLY YAACOB

Student: EDWARD PRINCE

Date of meeting: 04.03.19

Record of individual actions completed + notes:

DRAFT OF 3 SUITABLE ARTICLES FOR LIT REVIEW
REVISED GANTT CHART

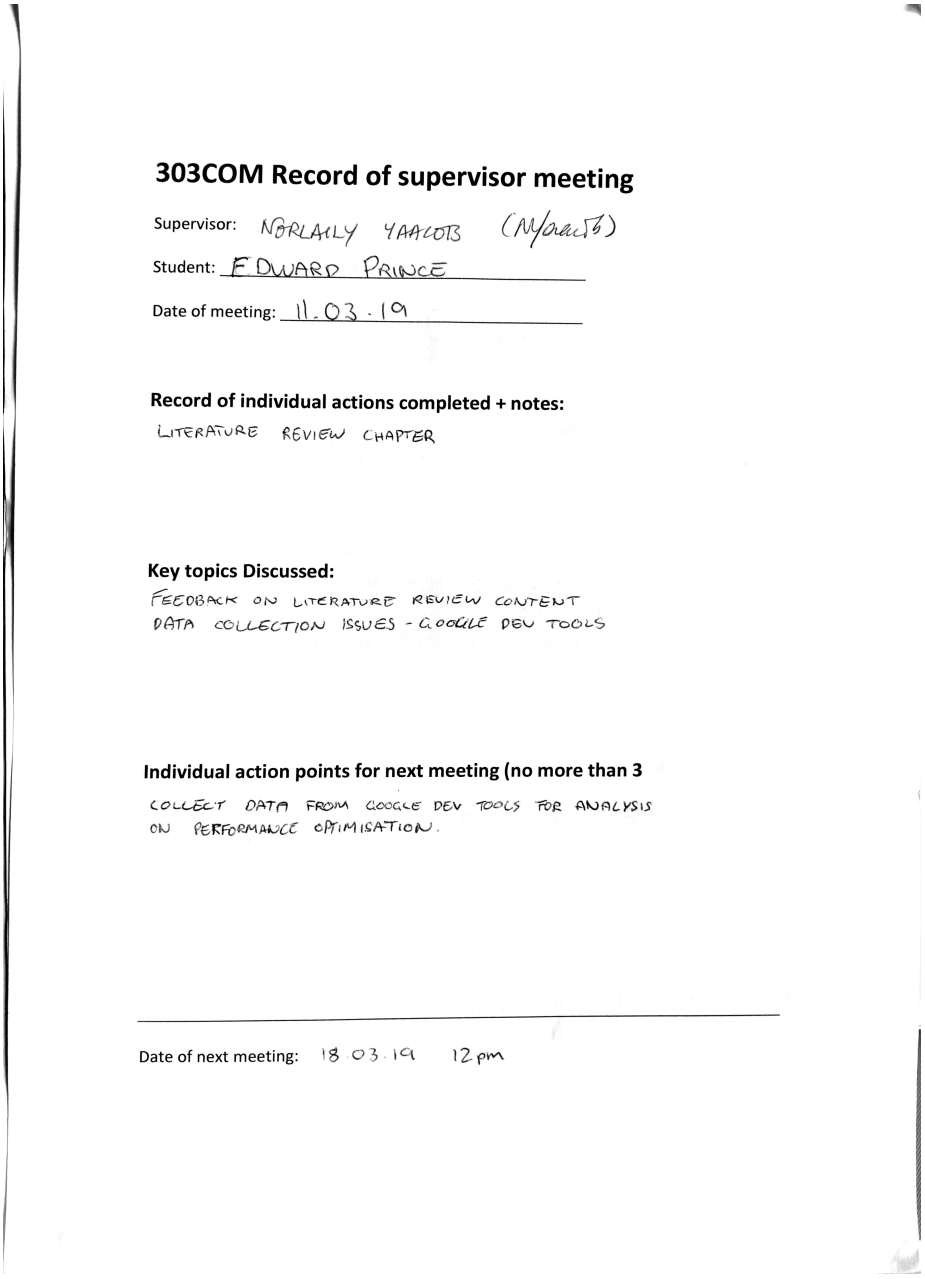
Key topics Discussed:

FEEDBACK ON LIT REVIEW (FLOW, STRUCTURE)

Individual action points for next meeting (no more than 3

- FIRST DRAFT OF LIT REVIEW
- LOOK ON TOP500 FOR MORE RELEVANT ARTICLES

Date of next meeting: 11/03/19 10AM



303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB (Myraci6)

Student: EDWARD PRINCE

Date of meeting: 11.03.19

Record of individual actions completed + notes:

LITERATURE REVIEW CHAPTER

Key topics Discussed:

FEEDBACK ON LITERATURE REVIEW CONTENT
DATA COLLECTION ISSUES - GOOGLE DEV TOOLS

Individual action points for next meeting (no more than 3

COLLECT DATA FROM GOOGLE DEV TOOLS FOR ANALYSIS ON PERFORMANCE OPTIMISATION.

Date of next meeting: 18.03.19 12pm

303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB (Nyaab).

Student: EDWARD PRINCE

Date of meeting: 18.03.19

Record of individual actions completed + notes:

BROUGHT PERFORMANCE PROFILING RESULTS FROM DEV TOOLS

Key topics Discussed:

METHODOLOGY CHAPTER TO INCLUDE SYSTEM REQUIREMENTS

Individual action points for next meeting (no more than 3)

- PLAN TO PRODUCE AUTOMATED DEV TOOLS PROFILING SCRIPT
- COMPLETE INTRODUCTION CHAPTER

Date of next meeting: 25.03.19 12pm

303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB (NYaacob).

Student: EDWARD PRINCE

Date of meeting: 25.03.19

Record of individual actions completed + notes:

Extend to case 2 & 1 : Bundling performance analysis
Draft methodology chapter

Key topics Discussed:

- Feedback on case 1
- Document structuring

Individual action points for next meeting (no more than 3)

Case 2 : Decide + carry out analysis on selected parameters

Date of next meeting: 01.04.19 12pm

303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB (Norlaily) I/C.

Student: EDWARD PRINCE

Date of meeting: 01.04.19

Record of individual actions completed + notes:

- TESTED APPLICATION
- DECIDE ON DATA COLLECTION STRATEGY
- IMPLEMENT AUTOMATED SOLUTION
- COLLECT DATA ON WEBPACK BUNDLING
- ANALYSE RESULTS AND PRODUCE CHARTS.

Key topics Discussed:

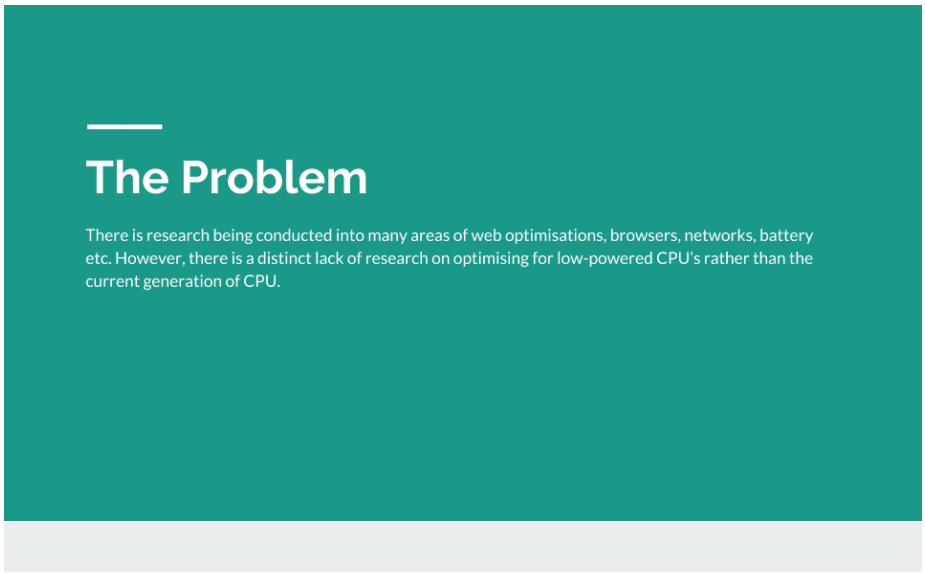
- DISCUSSION ON SUITABLE DECISION TOOLS IN RELATION TO CASE 2: SERVER-BASED DECISION TOOLS.
- TO INCLUDE TESTING SECTION IN THE REPORT (CASE 1, CASE 2)

Individual action points for next meeting (no more than 3

GATHER METRICS FOR OTHER BUNDLERS AND COMPARE RESULTS

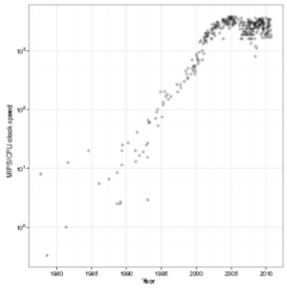
Date of next meeting: —

10.2 Appendix B: Evidence of Presentation



Moore's Law

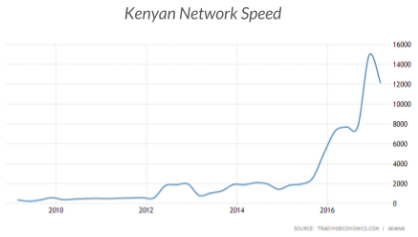
Over the last 10 years, Moore's Law has begun to plateau - and suggests at least in the near future, the little increase in computational power may continue to preside.

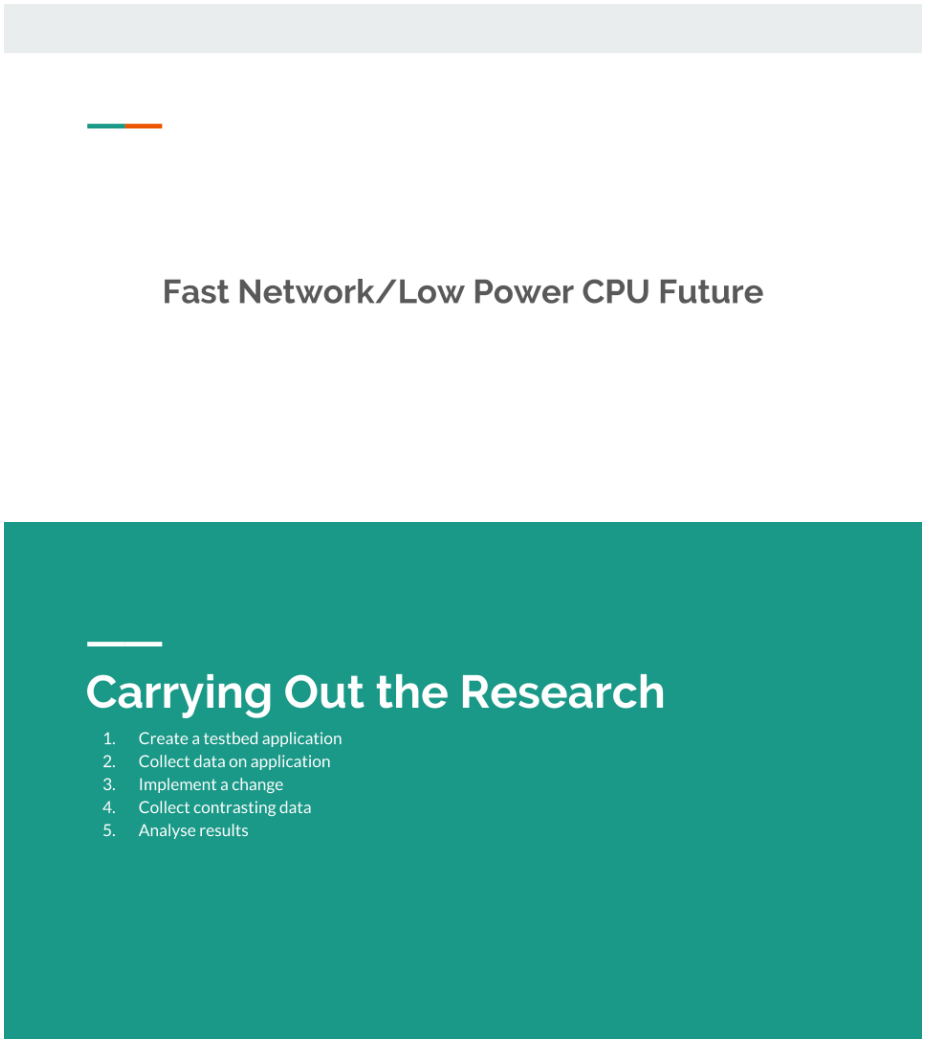


Network Speeds

In contrast to this - there has been a general shift in network speeds increase over the last 10 years in Kenya.

Should these trends continue - this would leave a fast-network/low-powered CPU future.




Fast Network/Low Power CPU Future
Carrying Out the Research
1. Create a testbed application
2. Collect data on application
3. Implement a change
4. Collect contrasting data
5. Analyse results

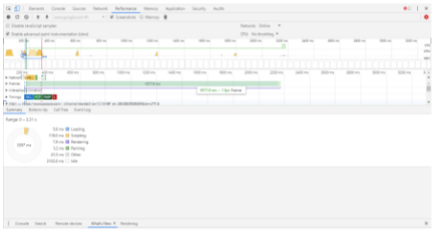
Testbed Application

A testbed realtime chatting application - utilising modern industry-standard technologies (React, Node.js, Express.js, Socket.io) was created with which to experiment - granting the ability to gather in-depth metrics upon applying new technologies (webpack, rollup, parcel, server-decision tools).

Google Chrome Devtools

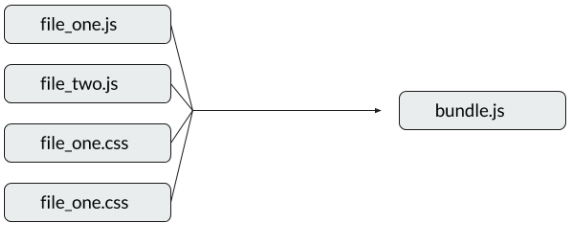
The Google Chrome Devtools is the industry standard set of tools that developers use in the browser to gain insights into how code is interacting with the browser.

There are also tools like Puppeteer to allow headless browser automation, giving easier access to more results within a given timeframe.



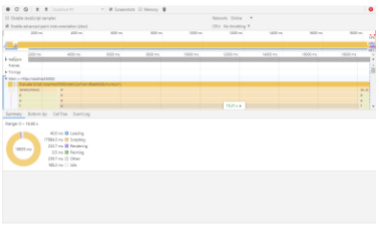
Case 1: Bundling an Application

What is bundling?



Webpack

Data Collection with Chrome Devtools

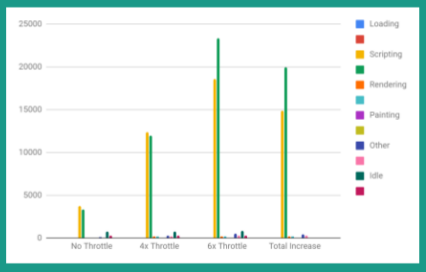


Running the app in its current state through the Devtools performance profiler yields useful data about the load times and performance metrics.

This data can then be scraped and put into a spreadsheet for further analysis.

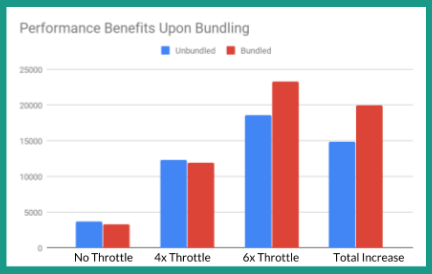
Using a custom script - much of this process could be automated for faster collection - meaning more results could be collected.

Results

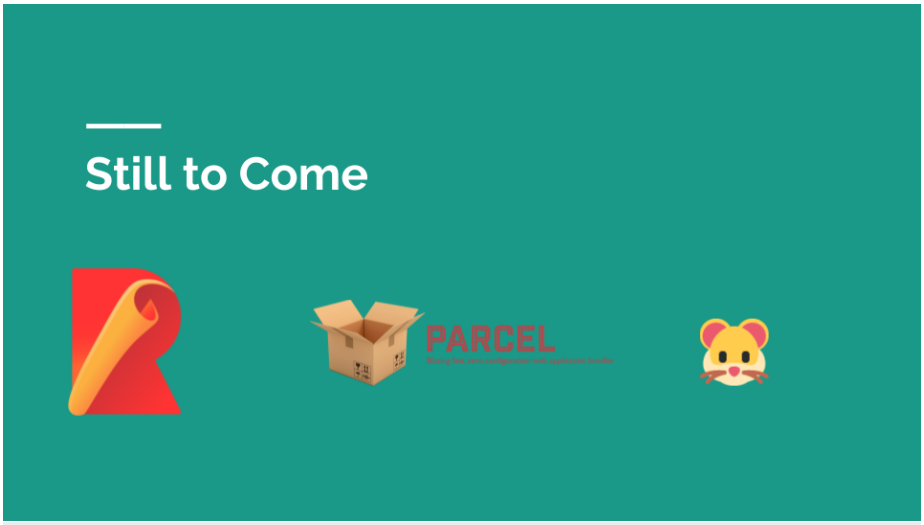


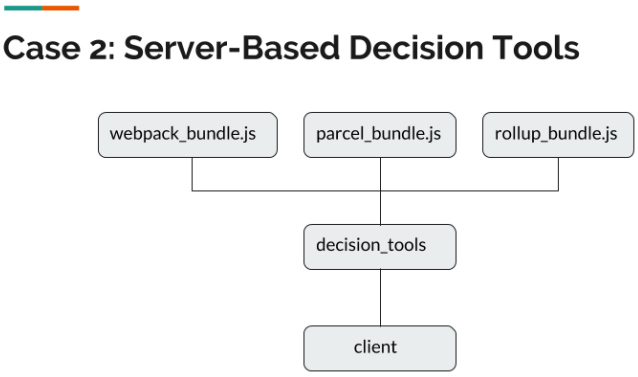
Compiling the results into a spreadsheet, and consequently into a chart showed that compared to processes that occurred in the scripting heading, loading, rendering, painting, idling, and other task performance was negligible. This gave a key area of optimisation to focus on.

Scripting in isolation



Whilst at no throttle or a 4x throttle, the bundled version does perform marginally more efficiently - at a 6x throttle, the bundled version takes a large hit, leaving the total increase from no throttle to 6x throttle a large difference.


Still to Come
PARCEL


Case 2: Server-Based Decision Tools
webpack_bundle.js
parcel_bundle.js
rollup_bundle.js
decision_tools
client

Client vs Server-Based Architecture

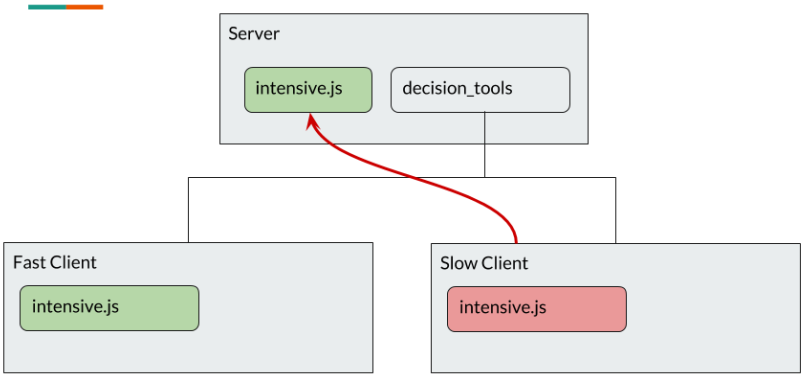
Web technology has seen shifts in desires for architecture to be client and server based. With powerful modern devices - it is becoming more common for the heavy lifting to be done on the client - leaving the server running lightly to keep high speeds with high volumes of traffic.

With low-powered devices, if developers wish for fast user experiences, then the server-based architecture become relevant again.

Accessing the Client

JavaScript is now capable of acquiring an estimate of the processor speed that is executing the script. This means an application can tell the server basic information about the device - allowing the server to make useful decisions on what it should and shouldn't send/process.

This optimises processes for specific devices, keeping servers quick and using client-based architecture where devices are capable - and switching to server-based architecture and optimised bundles for older browsers and slower architecture.



TODO

- ~~Create testbed application~~
- ~~Decide on data collection strategy~~
- ~~Implement automated solution~~
- ~~Collect data on webpack bundling~~
- ~~Analyse results and produce charts~~
- Gather metrics for other bundlers and compare results
- Implement server-side decision tools and analyse usage results
- Complete write up and formalities (statement of originality etc.)

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10.3 Appendix C: Evidence of Presentation Feedback

303COM Record of supervisor meeting

Supervisor: NORLAILY YAACOB (NYaacob) N/A

Student: EDWARD PRINCE

Date of meeting: 01.04.19 (PROJECT PRESENTATION)

Record of individual actions completed + notes:

PRESENTATION

Key topics Discussed:

PRESENTATION FEEDBACK

1. PRODUCE AN OVERALL BLOCK DIAGRAM OF DESIGN PROCESS FOR PROPOSED WEB OPTIMISATION TECHNIQUES.
2. TO JUSTIFY THE FUNCTION OF DECISION TOOLS IN CASE 2: SERVER-BASED DECISION TOOLS.
3. TO INCLUDE SOCIAL, LEGAL AND ETHICAL IMPLICATIONS IN RELATION TO THE PROJECT.

Individual action points for next meeting (no more than 3

Date of next meeting: –

Figure 9: Presentation Feedback

10.4 Appendix D: Experiment Results

10.5 Unbundled Profiling

10.5.1 At No Throttle

Table 8: Unbundled at No Throttle

Run (0x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	4.7	3111.8	43.4	0.6	60.9	453.4
2	4.1	3431.6	48.2	0.7	62.4	5100
3	4.8	3180.1	47.4	0.9	65.6	440.6
4	1	3197.6	50.7	0.4	36.1	156.2
5	4.7	3899.6	77.9	0.7	72.8	539.3
6	7	3834.2	54.9	1.3	88.1	477.8
7	4.9	3941.5	62.4	12.8	83.9	617.5
8	5.3	3694.9	53.2	1.4	94.1	515.8
9	5.2	4164.4	59.1	0.7	84.2	670.3
10	5.7	3434.5	59.3	3	157	804.3
11	4.6	3581.2	55.8	2.6	77.2	682.4
12	4.2	3206.8	45.5	0.6	71.9	524.1
13	5.8	4151.7	53.5	0.7	88.5	500.6
14	4.1	4656.3	59.2	0.8	78.9	555.5
15	12	4185.6	57.1	1.2	80.9	664.8
16	4.2	3698.1	51.7	1.1	84.2	492.3
17	4.3	3724.6	49.5	2.6	78.6	496.5
18	5.4	3618.6	53.3	0.9	83.2	496.6
19	5.4	4018.2	57.1	1	85.8	525
20	4.6	3551.9	50.9	0.7	82.7	490.1
Average	5.1	3714.16	54.505	1.735	80.85	760.155

10.5.2 At 4x Throttle

Table 9: Unbundled at 4x Throttle

Run (4x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	15.5	12827.6	164.2	2.1	186.8	645.7
2	6.2	10566.3	159.9	1.9	214.1	734.5
3	12.9	13499	155.4	2.1	205.1	671
4	19.8	12701.8	155.1	2.2	193.6	898

Run (4x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
5	10.7	9852.5	187.1	6.7	372	713.9
6	11	12833.3	178.4	7.9	261.2	947.5
7	7.2	11398	180.7	6.7	290.4	661.1
8	16.1	12382.4	165.8	2.4	192.2	799.7
9	12.1	12313.2	181.9	2.3	313.2	932.5
10	15.8	14077.1	180.6	2.1	274.5	750.2
11	18.3	7225.1	169.9	2.3	190.4	774.6
12	9.3	13893.1	187.2	2.4	121.5	594.6
13	13.2	13131.3	199.9	5.2	234.9	789.8
14	9.8	14363.4	167.2	1.7	199.9	967.2
15	19	11134.7	168.8	6.6	219	553
16	19.5	12194.9	177.9	3.7	235	627.1
17	11.8	12514.6	187	2.8	186.3	942.6
18	14.6	12724.4	160.5	3	282.4	797.2
19	26.1	15305.5	172.1	3.2	398	816.5
20	16.3	12208.5	176.5	6.3	242.7	584.7
Average	14.26	12357.335	173.805	3.68	240.66	760.07

10.5.3 At 6x Throttle

Table 10: Unbundled at 6x Throttle

Run (6x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	8.5	19643.1	211.8	2.4	246.7	577.7
2	6.4	14932.7	191.6	2.6	644.9	631.9
3	23.7	19366.7	254.1	3.3	244.1	552.2
4	18.3	19754.3	184.8	4.3	351.3	538
5	11.4	19008.9	227.9	2.9	715.7	668.5
6	25.9	21328.3	108.5	14.9	1622.9	1117.2
7	9.6	14051.8	239.6	3.1	365	1273.9
8	9.2	19393.9	188.9	4.9	334.8	715.2
9	17.5	21682.2	271.2	4.1	529.6	980.9
10	21.3	22173.7	243.6	4	835.8	851.5
11	9.2	17532.4	256	4.4	320.8	921.1
12	8.2	19373.5	251.3	2.7	213.5	654.6
13	8	17301	224.3	1.8	387.6	1423.8
14	11.2	20298.6	118	2.9	512.2	1036.1
15	11.5	16325	232.9	10.1	220.3	797.8
16	9.8	18459.1	178.3	1.4	303.8	684.5
17	22.3	18405.5	380.6	3.9	249.3	852.9

Run (6x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
18	28.6	19070.7	224.5	1.9	1249.2	562.1
19	15.2	13584.4	177.1	1.1	307.5	794.6
20	10.1	20168.3	260	3.1	319	662.9
Average	14.295	18592.705	221.25	3.99	498.7	814.87

10.6 React Webpack

10.6.1 At No Throttle

Table 11: Bundled at No Throttle

Run (0x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	12.2	2852.9	54.7	1.3	45.9	524.6
2	13.1	3011.8	67.6	1.0	41.6	466.0
3	13.4	2916.5	52.7	1.0	43.3	465.9
4	12.1	2790.0	51.6	0.7	41.5	479.0
5	13.5	2952.6	54.9	0.8	43.3	500.5
6	13.6	2769.9	55.6	0.8	41.6	558.1
7	13.8	2935.2	53.6	0.9	57.3	454.2
8	11.2	2869.7	56.3	0.8	50.4	520.7
9	13.2	3969.4	51.3	0.6	48.9	568.5
10	13.5	2838.4	52.9	0.8	45.2	436.2
11	13	2867	54.7	0.8	42.7	454.7
12	12.8	2826.9	50	0.6	46	492.1
13	12.1	2902.6	50.5	0.9	45.8	490.6
14	12.5	2929.5	50.7	1	46.1	469.7
15	12.2	2960.9	58.4	0.7	43.5	573.8
16	13.2	2844.5	50.3	1.2	55.6	476.6
17	11.9	2934.4	51.4	0.7	42.5	475.6
18	12.5	2965.1	51.5	0.7	43.8	450.5
19	13.2	2968.4	52.2	1.4	48.4	438.2
20	12.7	2930.3	52.6	1	45.1	471.6
Average	12.785	2951.8	53.675	0.885	45.925	488.355

10.6.2 At 4x Throttle

Table 12: Bundled at 4x Throttle

Run (4x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	21	12102.7	180.8	3.4	91.2	638.8
2	55.2	10741.4	186	0.2	228.3	401.6
3	41.4	10910.9	176	1.8	106.8	431.7
4	58.4	12146.9	184.8	0.6	86.3	509.5
5	40.3	10720.5	181.9	0.8	97.9	454.6
6	42.2	11731.6	184.5	1.6	102.2	503.4
7	40.4	11037.4	196	0.6	99.4	495
8	32.3	12096.9	188.9	1.3	78	515.9
9	34.2	11619.8	179.9	0.5	119.5	649
10	38.7	11833.5	174.1	0.5	156.8	529
11	35.2	11706.1	178.4	0.7	131.6	445.2
12	44.7	12340.6	193.7	6.4	132.9	446.4
13	101.3	12052.7	172.7	1	85	422.4
14	64.2	11944.8	190.9	1.3	91.5	542.7
15	51.8	11049.8	179.3	0.4	86.6	482.5
16	45.5	12259.8	187.5	0.3	80.3	430.5
17	47.1	11224.3	182.4	2	172.3	434
18	43.5	11544.7	188.6	1.4	108	405.9
19	26.9	11722.5	184.7	2.3	112.6	529.3
20	34.7	11774.3	181	0.8	120.8	510.6
Average	44.95	11628.06	183.605	1.395	114.4	488.9

10.6.3 At 6x Throttle

Table 13: Bundled at 6x Throttle

Run (6x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
1	58.7	18068.7	166.6	2.6	198	472.7
2	54.8	18064.4	269.8	0.4	442.1	467.8
3	25.8	16431.1	218.1	7	113.9	482.1
4	51.3	18038	228.6	1	242.2	447.1
5	39.2	16284.8	226.5	5.5	114.6	570.7
6	43.7	18446.5	360.7	3	340.1	355.3
7	64.2	16201.7	234.2	2.2	370.6	559.4
8	32.5	18417.2	255.2	7	179	389.6
9	93.8	16435.9	229.9	1.8	208.8	530.6
10	24	17649.1	216.2	0.4	175.8	470.5
11	88.5	17280.8	216.9	3.3	200.7	422.4

Run (6x)	Loading (ms)	Scripting (ms)	Rendering (ms)	Painting (ms)	Other (ms)	Idle (ms)
12	30.3	17540.1	220.3	1.6	216.1	525.5
13	109.3	18272.8	381.6	7.3	253.3	406
14	46	17913.8	245.8	2.1	250.7	510.1
15	81.5	16256.5	236.4	0.7	122.8	570.3
16	26.4	18408.6	136	0.3	261.7	493.8
17	46.1	16755.5	223.5	0.4	133.4	451.9
18	39.8	17334.5	246	0.9	160.4	454
19	37.8	16258.8	211.5	0.4	95.8	456.7
20	35.8	18704.1	223.3	0.8	199.4	386.3
Average	51.475	17438.145	237.355	2.435	213.97	471.14

10.7 Appendix E: Automation Code

```
const puppeteer = require('puppeteer');
let i = 0;
const DIR = 'hyperapp-rollup';
const URL = 'http://localhost:5000';

let loop = setInterval(async () => {
    if (i === 19) {
        clearInterval(loop);
    }
    throttleSix(i);
    throttleFour(i);
    throttleNone(i);
    i++;
}, 20000)

async function throttleSix(i) {
    const browser = await puppeteer.launch();
    const page = await browser.newPage();
    const client = await page.target().createCDPSession();
    await client.send('Emulation.setCPUThrottlingRate', { rate: 6 });
    await page.tracing.start({
      path: `traces/${DIR}/6x/${i}profile-${Date.now()}.json`
    });
    await page.goto(URL);
    await page.tracing.stop();
    await browser.close();
}
```

```
async function throttleFour(i) {
    const browser = await puppeteer.launch();
    const page = await browser.newPage();
    const client = await page.target().createCDPSession();
    await client.send('Emulation.setCPUThrottlingRate', { rate: 4 });
    await page.tracing.start({
      path: `traces/${DIR}/4x/${i}profile-${Date.now()}.json`
    });
    await page.goto(URL);
    await page.tracing.stop();
    await browser.close();
}

async function throttleNone(i) {
    const browser = await puppeteer.launch();
    const page = await browser.newPage();
    const client = await page.target().createCDPSession();
    await page.tracing.start({
      path: `traces/${DIR}/0x/${i}profile-${Date.now()}.json`
    });
    await page.goto(URL);
    await page.tracing.stop();
    await browser.close();
}
```

10.8 Appendix F: Project Diary

10.8.1 First Entry

28/01/2019
I had a meeting with my supervisor today. We discussed current progress and direction. I will be working on producing a more highly detailed Gantt chart to demonstrate how I will work to the project timeline. I am also going to be working on the literature review.

10.8.2 Current Progress

05/02/2019
The testbed web application has been built, utilising socket.io for realtime chatting functionality. I used React (a widely used modern front end JavaScript framework) to build the front end, and Express.js (popular backend Node.js library) for backend programming. I am using GitHub to version control the application, and the server is designed distinctly as its own entity - not tied to the front end at all - meaning they are not reliant on the other to work. To help

isolate the problems - I am going to focus attention on optimising the front end - not the server.

The report is coming along slowly - I now have a bare skeleton of the entire report, with elements from the project proposal being dropped in. I am going to work on some padding out of the literature review I conducted, and try to get a structure for the main literature review sorted.

10.8.3 Script

12/02/2019
I have created a script that uses Puppeteer to open a headless browser with the application running, then automatically perform a trace, with simulated throttled CPU's, and writes the resulting data into a JSON file and saves the file into the repository. I can then load up each of the JSON files into the Chrome Dev Tools, and it produces summary data on the trace. I can then write the results into a Google Sheet to generate averages and compare results. I have also mostly finalised the literature review, and have begun work on the Methodology Chapter.

10.8.4 Testbed Factorial

20/02/2019
In order to make the testbed application somewhat more realistic, I needed to get the app to do some heavy lifting upon loading. To simulate this, I wrote a Factorial calculator function, and made the application solve factorial(1000) upon initialising. This gave a more realistic set of metrics on how the bundlers and frameworks perform at a higher stress load. After the meeting with my supervisor, we finalised what would go into the Methodology, and that splitting into a Methodology Chapter and a Design & Implementation Chapter would allow for a better report. The methodology will now just contain the relevant information about how and why the experiment was conducted in the manner it way - but not detailed information into the experiment. Alongside this, I tried to improve the automated script to not only collect the data, but automatically parse the profiles to output the relevant data. After spending several days researching and attempting an implementation - I decided to move on. This meant that for each performance profile that was collected, I needed to open the file in the Devtools and copy the relevant statistics over into a Google Spreadsheet.

10.8.5 Bundler Implementation

01/03/2019
I have changed from using create-react-app to using a custom webpack configu-

ration file to allow for more comparable results to Rollup. The create-react-app webpack configuration is all hidden, and has a lot of extra stuff that Rollup doesn't do by default. Alongside this, I have been working on the Methodology chapter.

10.8.6 Rollup

08/03/2019
I have now got both Webpack and Rollup implemented so the testbed application can be bundled using either, allowing for comparisons to be made.

10.8.7 Frameworks

17/03/2019
There is now implementations of the testbed application written in React, Preact, Inferno and Hyperapp to allow performance profiling across all four frameworks. Using my automated script, I can make the app compile from any of the frameworks using either of the bundlers, before automatically collecting data on the performance, and saving to a Google Sheet. In addition to this, I have been researching legal and ethical implications of the project - but finding it difficult to find much relevant information.

10.8.8 Data Collection

01/04/2019
I have now collected all of the relevant data for each combination of framework and bundler, and gather metrics for no throttling, 4x throttling and 8x throttling. All the data is saved in Google Sheets to allow for chart generation to help visualize the results. I have also been finalising the Methodology and Design & Implementation chapters - now having all of the information required to finish them.