Web routers: An explorative performance review

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# Introduction

Web routers are the core technology that allow for execution of code to the mapped requests provided by an HTTP client. This process is more often known as the request response cycle of web applications. Web applications or web services as they are more commonly are known by are the fundamental way that the world wide web operates for when requiring some form of server side operations. This process uses the client-server topography to transmit and manage the control of information by a third party while also displaying content interactively to the user with the usage of HTML, Javascript and Cascading Style Sheets.

When used appropriately the technology stack allow for hundreds of thousands of connections every second to be served to clients simultaneously. Improper usage of the technology stack can result in extreme monetary costs associated with serving the content to clients as part of the HTTP request-response cycle beyond that which the bandwidth for the request and responses require.

The technology stack includes three different parts as part of standard operations. The client, server and server side handling code. The client which is most notable to most people would be a web browser with an execution engine for Javascript and rendering engine for HTML. The files that are served come from the server. The server operates as a means to map a single IP address to handle many different possible websites. Externally to the server is some code which operates within the confines of a singular web site context. This code allows for dynamic web pages and includes a secondary web router, commonly known as a web service or web application.

The focus of this dissertation proposal is upon the web router that is core to the web stack. Most developers do not place much importance on this part of the stack leading to some easy wins for performance increases.

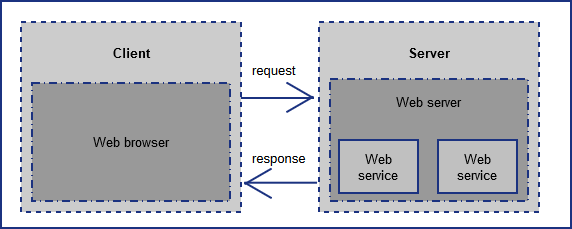
# Literature Review

The World Wide Web was conceptualized in 1989 (World Wide Web Consortium, n.d.) since then there has been a large uptake in its usage by everyone all across the globe to an estimate of 3.4 billion users as of October 8th of 2016 (Internet Live Stats, 2016). With every one of those users working with the standards of Uniform Remote Locator[[1]](#footnote-2), Hypertext Transfer protocol[[2]](#footnote-3) and Hypertext Markup Language[[3]](#footnote-4) in some form or another.

During the early days many different web browsers and servers were created. Majority of these have since long died off but the legacy that is the definition of each has not. As defined by the World Wide Web Consortium (W3C) (World Wide Web Consortium, 2014):

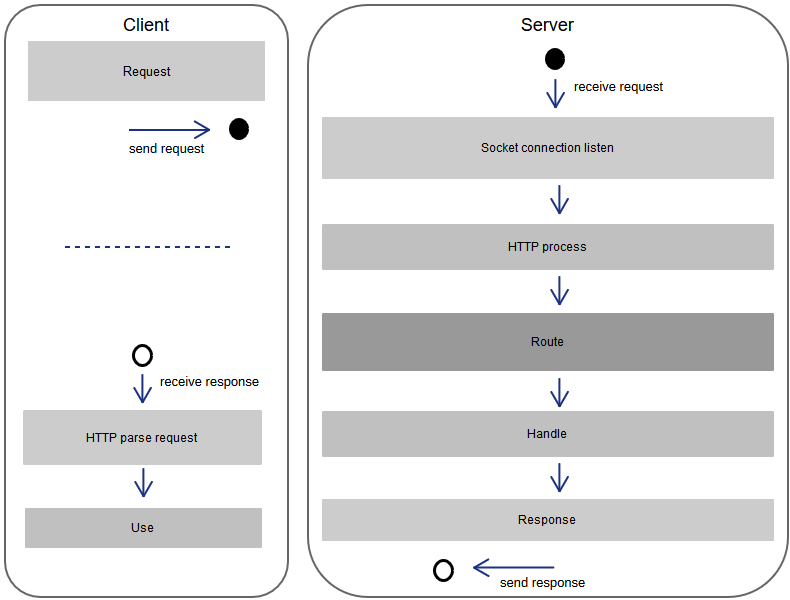
* Web browser  
  A program which allows the display and execution of a web page for a user. Interacts with a web server to provide any data required. This is the most common form of client.
* Web server  
  Retrieves files or resources from the file system or some form of backend such as a web application and sends them to the client as requested.
* Web Server API or service  
  A standalone piece of software that will dynamically create content to send to a client. It communicates in some form to the web server to serve up content to the client.

With an upsurge in internet speeds during 1990s as demonstrated by Nielsen’s Law (Nielsen, 1998), companies and developers alike experimented with dynamic web pages allowing for user interactions not possible with static web pages alone. The Common Gateway Interface[[4]](#footnote-5) was created to allow for external program to be executed as part as the web page processing by a web server. From this point on existing programming languages gained uses that was not seen before which helped to introduce other new programming languages. An example of a new programming language spawned by this would be PHP (The PHP Group) which has the primary purpose of dynamic page creation on each request by the client.

  
Illustration 1: The web (HTTP) request + response cycle

Web servers and web (server side) APIs alike are a field of research that continues to introduce new areas of study for research in both a formal and an informal capacity. Combined they share a very similar technology set only with slightly different purposes and entry points. Of which the web router that resides on a server from which all fundamental mental models originate is conceived.

A web router, primary goal is to map any incoming request from a socket to a function process it. The execution and processing of a request once mapped can be done in any number of languages and quite commonly utilities other protocols such as a Fast-CGI to communicate to another process to execute the request. This is displayed as part of the Illustrationwhich is based upon HTTP 1.x.

  
Illustration 2: General HTTP request/response process

The tendency of web developers is to focus upon coding within the requests and manipulating of the response for the client side. For the server side the focus is upon handling the routes for a given purpose. When it comes to implementation of the libraries, frameworks and end code there is little consideration by those who use the implementation and along with it, its performance. This can cause problems such as the time it takes to handle a request from getting it to responding to it back the client. These existing algorithms and data structures are already well understood in the database field of research, but they are not maximized to there full potential given the performance tweaks and variations possible.

## The request-response cycle

At the core of a web router is the process of turning a request from Hyper Text Transfer Protocol (HTTP) 1.0/1.1/2.0 into a call to procedure by which handles the request and returns the result along with some meta information such as cache information. This process has several stages:

1. Socket listening
2. HTTP request processing
3. Routing to function call
4. HTTP response creation

The above list is a general overview of the different sequential parts that a request goes through on the server. Commonly it is separated out in for the implementation into:

1. Asynchronous socket listener
2. Thread/Fiber router (choose the thread to execute the request handling in)
3. HTTP request processing
4. Routing to function call
5. HTTP response creation and return

However this does not take into account the need for blocking actions such as file reading/writing and other socket related processing such as database access. So for this use case to get the best performance the usage of Fibers is commonly used. Fibers allow for using up as much of the time slice that the kernel is willing to give a thread while also switching out what code (and with it its stack) is being executed at any given moment. Improving the number of requests, a single thread is capable of execution before its time slice is ended or the blocking operations takes precedent.

Asynchronous execution along with threads and fiber handling is a complex topic that can affect performance between web servers quite significantly. This can be seen between Nginx and Apache2 httpd. Nginx uses asynchronous event based handling while Apache2 utilizes a thread based approach (DigitalOcean, 2015).

When a connection has been established and the handling code is available to being execution, it will translate the given binary stream into some form of programmatic representation such as classes or structs. Allowing for ease of use and modification by the routing engine. The handling code may be a wrapper to another protocol such as Fast-CGI to allow out of process execution and processing of the request.

The routing engine is responsible for manipulating this request representation into recognizing a specific route. This is primarily done by utilizing some kind of run-time look up and registration into the routing table. This allows for using language features such as attributes to map procedures to routes more organically. For example, the web server Nginx, utilizes Red-Black trees for files caches[[5]](#footnote-6) and Fast-CGI[[6]](#footnote-7) processing. From this the handling mechanism for the specific route is called with it.

## The routing problem

By using the definition of a router as the process to which the decision of which route handler is chosen per request and along with it the definition of what the routing problem is, it can be seen that this can be implemented in many different and varying ways. Because of this, the approaches can differ quite significantly. These different approaches each have a different set of costs and cannot be interchanged in a given context with the expectation of performance related problems appearing.

For example a regex based approach while producing simplified code will require a limited capability, subject only to the host name and URI path but will be subject to the overhead of the regex engine. Where as with custom engine, the utilization of a tree graph will allow for complex conditions but may result in slower and require more memory to be able to operate.

At the core of what a web router does is to take a set of known variables and return a function to execute with the potential to modify the known variables. These set of variables that must be utilized in each searching of the underlying structure is fairly unique compared to the research into data structures in Computer Science which focuses primarily upon a single value. With the extension of multiple variables to check and a more complex search algorithm that may need to repeat itself the usage of existing data structures and algorithms may be used.

Most implementations only work with the path from the HTTP header and because of this require the least amount of extensions to existing data structures and algorithms. This allows them to be implemented using only regular expressions (regex) or other more limited approaches. This does cover most cases; by utilizing multiple instances it can be used for different HTTP methods such as GET and POST. However other rules such as rewriting are not possible and this is where tree graphs become quite useful.

When it comes to other than regex approaches, generally quite a bit more information is stored associated with a single router handler function. This can be done by using another data structure as a key in a map or to wrap the reference to the handler function. This allows it to use other conditions such as the HTTP request fields of User-Agent, Referer or Host. Support of this is a significant complexity increase and limited research into this area was discovered in the creation of this proposal.

The implementation of the storage mechanism that the web router utilizes can take many forms including a list or a tree graph. These data structures are fairly simple in design but have many optimization opportunities such as cache locality for children in a tree graph which can improve performance by many magnitudes.

TODO: reference Making B+- trees cache conscious in main memory, Jun Rao and Kenneth A. Ross, <http://dl.acm.org/citation.cfm?id=335449>

# Research context

The research proposal being presented here has the end goal of trying to make the world wide web faster, in general better for developers and businesses in terms. The classification for better in this case is the monetary cost of serving requests to the clients. In previous work a considerable amount of research has gone into making the web faster by focusing upon the in total of the cycle with few amount of it investigating the application within the server side performance in terms of the web router.

Ultimately with the goal of being able to determine the performance loss that occurs within the web router and how to mitigate it given a set of circumstances; what is the cost for a set of implementations? From this a set of questions is formulated to help answer it.

* What are the current cost metrics associated with web technologies usage within the request → response cycle?
* What are common designs in existence that web routers use and how they relate to other fields?
* Apply the cost metrics to existing designs of web routers to determine the outliers for particular input data sets i.e. routes.

In total this should answer the question of how much performance loss is actually being incurred by common algorithms and where the focus should be on to where to improve them.

# Method

This proposal presents a method for determining the performance of a set of web routers and determining there individual performance capabilities compared to one-another. To do this it is split up into the router implementations and the harness that executes upon each of these.

Each implementation of router provides a generic interface that hides the implementation details but allows for an optimization phase following the addition of all the routes. On top of this is the harness which operates upon the generic interface. The harness allows for testing routes against search patterns.

Once the routes and test patterns are created, the routes are emplaced into the resulting implementations. Each pattern is tested a number of times to determine the overall speed and overhead depending upon the input routes.

The analysis of each web router is implemented by comparing each implementation against each other, by using the recorded values and calculating the difference between the test sets.

# Time line

|  |  |  |
| --- | --- | --- |
| **Task** | **Week of** | **Expected length of time** |
| Router implementation(1)  Flat array | December 5th | 1 week |
| Test harness  Initial creation. This is expected to be a very rough implementation that does not get anywhere close to what is needed. | December 12th | 2 weeks |
| Router implementation(2)  Tree graph, no optimizations | January 2nd | 1 week |
| Router implementation(3)  Tree graph, optimizations | January 9th | 2 weeks |
| Router implementation(4)  Regex | January 16th | 1 week |
| Test harness update  Updates based upon what has been implemented with the routers. As well as include new features to make it more complete based upon what the routers are doing. | January 23rd | 2 weeks |
| Analysis upon router implementations performance | January 30th | Unknown |

# Budget

It is expected that a printing budget of $100NZD will be needed for final copies available for submission.

No other expenses has been expected to be incounted.

# References

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1. https://tools.ietf.org/html/rfc3986 [↑](#footnote-ref-2)
2. https://tools.ietf.org/html/rfc2616 [↑](#footnote-ref-3)
3. https://www.w3.org/MarkUp/draft-ietf-iiir-html-01 [↑](#footnote-ref-4)
4. https://tools.ietf.org/html/rfc3875 [↑](#footnote-ref-5)
5. <https://trac.nginx.org/nginx/browser/nginx/src/http/ngx_http_file_cache.c?rev=953512ca02c6f63b4fcbbc3e10d0d9835896bf99> [↑](#footnote-ref-6)
6. <https://trac.nginx.org/nginx/browser/nginx/src/http/modules/ngx_http_fastcgi_module.c?rev=953512ca02c6f63b4fcbbc3e10d0d9835896bf99> [↑](#footnote-ref-7)