Web routers: An explorative performance review

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# Introduction

Web routers are the core technology that allow for execution of code in response to requests by a Hyper Text Transfer Protocol (HTTP) client. A web router is not interacted with directly by a user, instead it is configured by descriptions of websites or by some form of framework. Web applications or web services as they are more commonly known by are what developers implement to produce dynamic content for a website. Dynamic content as well as unchanging static content, utilize a router to locate the resource handling mechanism to execute to produce a response to the HTTP request.

HTTP is not the only technology used commonly in this process. Hypertext Markup Language (HTML), Javascript and Cascading Style Sheets (CSS) are also used as a rendering specification for the client. To interact with the HTTP request/response cycle occurs to retrieve resources from the server to display in some form.

The client side technologies is an ever changing landscape; the focus of this research is into the web router that processes these requests that are already gathered by a server. There was little discovered research done into the web router as part of this work, for this reason the performance costs involved in a web router need to be investigated into how much an implementation actually matters.

The main set of technologies used in websites are: a client, server and possibly many web applications. The client interacts with the user in some form, most often the usage of a web browser is the preferred client. A web application is a separate program running in parallel to the web server. It could be a blog or a script doing administrative tasks on command. The web server creates an instance of a web application to connect to it and by doing this, integrating its routes and processes into itself.

# 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.



Figure 1The web (HTTP) request + response cycle

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 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.

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, with only 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.



Figure 2 General HTTP request + response processing activites

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 shown in Figure 2 is based upon HTTP 1.x diagram.

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 user code there is little consideration by those who use a specific 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 were created for the usage within a database engine. In the context of a database they have been optimized and analyzed for best performance. For a web server these algorithms and data structures may have improved performance once they have been analyzed with optimizations for this use case.

## The request-response cycle

At the core of a web router is the process of turning an HTTP request into a call to a procedure to handle the request and return the result along with some meta information (e.g. how long to cache it for). This process has several stages:

1. Socket listening & connection
2. HTTP request received
3. Routing to function call & execution of function
4. HTTP response creation
5. Response sending

The above list is a general overview of the different sequential parts that a request goes through on the server. Commonly it is implemented as:

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

This overview does not take into account some of the problems faced by all implementations. Not all information that is required to complete a request is held within memory while the program is executing. Instead it relies upon other software (e.g. a database) to hold it. The process to communicate and retrieve this extra information is expensive compared to the time it would have been if it was in memory at the time of request. The usage of external resources is commonly implemented using blocking operations. A good example of this is file reading and writing which is critical to web servers if they serve content held within the file system. Blocking operations prevent other requests from being concurrently served.

Asynchronous execution of requests is a complex topic that can affect performance between web servers quite significantly. The difference is exemplified by 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 executed, 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.

## Current routing approaches

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 route is. The approaches that are available to implement the routing can differ quite significantly in there behaviors. These different approaches each have a different set of costs and cannot be interchanged in a given context with the expectation of performance related changes occurring.

There is a variety of different methods used in implementing a web router. Common ones include: tree graphs such as a Red-Black tree graph or using a single Regular Expression (regex). A single regex can simplify the code required but will result in a limited capability. With only the host name and URI path being validated against.

TODO: needs references, Nginx for RB-Tree, PHP reference for regex expressions in a router

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 are unique when compared with existing research into data structures which focuses primarily upon a single variable. The extension to multiple variables to check and a more complex search algorithm that may need to repeat itself mean existing data structures and algorithms may be used but modified to take into account that simple comparisons do not correctly relate entries to the search parameters.

Current implementations typically use with the path from the HTTP header to perform lookups. These require the least extension to existing data structures and algorithms. Regular expressions are typically used to implement them. These cover most cases; by utilizing multiple instances of the router implementation it can be used for different HTTP methods such as GET and POST without direct support within the elements of the data structure.

Some servers support a feature known as rewriting. Rewriting is the process by which requests are modified into being another; however only internally. After a ‘rewrite’ of a request takes place it must be evaluated out as if it was a new request. Most web routers do not implement this feature because of its complex nature. The rules by which it can modify the request by can include the path, domain, time stamp, client IP address and any other HTTP request field.

In non-regex approaches, more information is stored using data structures. Such as a key in a map or to wrap the reference to the handler function. This allows the routing algorithm 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 (Ross & Rao, 2000).

# 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 total performance of the web request processing cycle with little investigation into optimization of server side performance in terms of the web router.

The overarching goal is to determine the performance of various web router algorithms for a given set of circumstances; what is the performance of a set of web router algorithm implementations?

From this a set of sub-questions is formulated to help reach the overall research goal.

* What are the current performance metrics associated with the request/response cycle?
* What are common algorithms that web routers use and how do they relate to those used in other fields?
* What are the performance characteristics of commonly used algorithms to implement a web router given a range of routing scenarios as input?

These sub-questions will allow the performance of each algorithm to be characterized allowing analysis to determine the focus for improvement.

# Method

The research being undertaken will be utilizing a benchmark harness to execute all tests to determine a common set of metrics and this includes how long it took to perform. The harness will provide a common interface to allow for the metrics to be gathered the same way for each implementation being tested and compared against.

Each implementation is expected to run solely within a single thread. All input sets currently within memory prior to the execution and pre-start procedures having been executed. Each input set is executed in multiples of a hundred, each result is averaged for the purpose of analyzing the time it took to execute that set compared to other iterations as well as other sets.

The input data sets as per the benchmarking comprises two different sets of information. The first is the routes to be emplaced into the relevant data structure (implementation of the router) and the sets of requests to be executed by the router implementation. The routes get emplaced pre-start of testing and should be fully optimized before the execution of the benchmarking.

The computer that will perform the benchmarking has the following specification with regards to parts being used for the analysis:

* **CPU:** Intel Xeon v3 E5-2630, 8 cores at 2.4ghz base frequency and 20mb cache
* **Memory:** DDR4 64GB at 3200mhz
* **OS:** Windows 10

Storage of results and input will be done within memory. This will prevent performance penalties associated with long term storage drives appearing in results.

# Time line

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| --- | --- | --- |
| **Task** | **Week of** | **Expected length of time** |
| Router implementation (1)  Flat array | December 5th | 1 week |
| Benchmark 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 |
| Benchmark harness revision  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 | 5 weeks |
| Writing of dissertation  Expected time line for the different portions of the dissertation:   |  |  | | --- | --- | | Introduction/Abstract | 2-4 weeks | | Literature review | 3-4 weeks | | Method | 6-8 weeks | | Analysis | 4-5 weeks | | Conclusion | 3 weeks |   All of the above parts will be done in parallel of each other. To complete it within the given time slot. | March 6th | 11 weeks |
| Final feedback and revisions | May 22nd | 5 weeks |
| All work must be completed by this week. | June 26th – July 2nd |  |

# Budget

A printing budget of $100 will be needed for final copies for submission of the dissertation.

No other expenses are expected.

# 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)
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