Development of a Concurrent Ruby Webserver using Behaviour-Driven Development

CMT4141

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Abstract

In this project, a concurrent webserver is implemented in Ruby using the Behaviour-Driven Development (BDD) method.

Topics relevant to the thesis, namely webservers, concurrent programming, the Ruby programming language and BDD are covered. The implementation of each requirement is described, along with selected technical problems and their solutions.

Yarn, the name of the produced webserver, is benchmarked to other Ruby webservers and the results revealed that for static requests it performed subpar other webservers, but for CPU intensive applications it performed quite well.

Using BDD enabled getting started on the implementation right away, without having to produce a big design upfront. This proved to be both a advantage and a disadvantage, as some design decisions which turned out not to work as expected, might have been avoided. As BDD employs a test-first approach, a large test-suite was produced and having many tests enabled for design changes late in the development, without having to worry about the correctness of the implementation.

Contents

Chapter 1

Introduction

As websites must be able to service multiple visitors at a time, the webserver serving it must employ some form of concurrency. Various concurrency models exist, and each comes with a set of advantages and disadvantages, all depending on the context of the webserver and the content being served.

This project concerns developing a concurrent webserver in the Ruby programming language, using Behaviour-Driven Development.

1.1 Readers Guide

Background information required for the remainder of the report is covered in Chapter 2. Chapter 3 covers the requirements for the software developed. Chapter 4 regards implementation specific aspects of the software and Chapter 5 describes the testing done during the development. In Chapter 6, the end product is demonstrated, evaluated through a series of benchmarks and compared to other Ruby webservers. In Chapter 7 the project process is reflected upon, and Chapter 8 concludes the project and suggests future improvements to the software.

For source code listings, the caption will show which file and on what line the code is taken from. The source code is included on a CD, and also available at `https://github.com/thejspr/yarn`.

1.2 Acknowledgements

I would like to thank Kai Xu for invaluable suporvision and feedback throughout this project.

Chapter 2

Background

This chapter covers technology and methods used throughout this project and looks at the current Ruby webservers. Initially, the development method is described, then the topics; webservers, concurrent programming and Ruby are briefly introduced.

2.1 Development Method

For a software project to be successful it is important to choose the right development method. Two methods were considered for this project; Behaviour-Driven Development (BDD) and Test-Driven Development (TDD).

BDD is an evolution of Test-Driven Development (TDD) which focus more on the behaviour of the software instead of the structure (units). The problem with TDD is that it focus on the internals of an object's implementation making tests fails even when the behaviour of the code hasn't changed. In short TDD tests what an object *is* and BDD tests what an object *does* [1]. Hence, BDD ensures business value is created and works as intended, and TDD ensures that the code is correct but is blind to whether it provides the intended business value.

BDD was chosen as the development method for this project due to it being an improvement on TDD and allowing for rapid development without needing to design the entire system up front. This agility makes it easier to spot difficulties and caveats early the process, leaving more room to adapt. With BDD (and TDD) the design is constantly evolving as more code is added and former code is constantly reviewed and refactored. This form of design is referred to as an emergent design. The following describes the BDD development cycle and the tools used [6].

2.1.1 Behaviour-Driven Development

Behaviour-driven Development (BDD) revolves around writing specifications for what a program is intended to do. This process is made up of an outer and an inner loop. The outer loop concerns passing an acceptance test covering one feature i.e.

logging functionality. The inner loop concerns passing RSpec behaviour specifications describing the behaviour of methods and objects. Figure 2.1 depicts the BDD cycle.

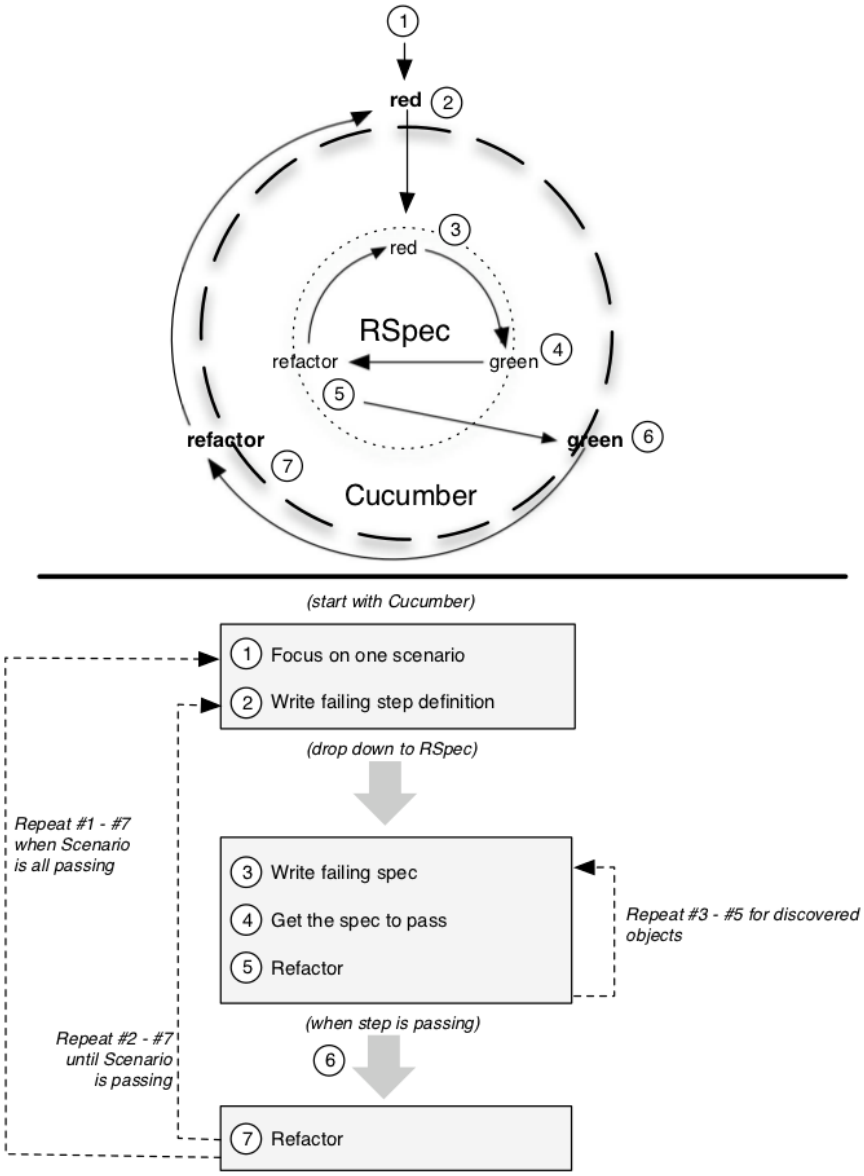


Figure 2.1: The BDD development cycle [1]

At the beginning of the iteration an acceptance test is written and executing it should reveal that the functionality is not yet implemented according to it's requirements. Cucumber is a framework for writing acceptance tests in a natural language as a set of steps in one or more scenarios. An example Cucumber acceptance test is included in Listing 2.1.

```
1  Feature: Logging
2    As a webdeveloper
3    I want to have logging of HTTP requests
4    In order to debug errors or attacks on the webserver
5
6    Scenario: Logging of HTTP requests
7      Given the webserver is running
8      When a user visits http://localhost/posts
9      Then the log should contain "GET /posts"
10     And the log should contain "SENT /posts SUCCESS"
```

Listing 2.1: Cucumber acceptance test example

The acceptance test covers the logging functionality of a webserver and tests it by starting the webserver, making a request and then checking whether the log contains the correct entry. The first line names the feature covered by the test. Lines 2 through 4 states the user of the feature, what it should do and lastly why and what business value it creates. Line 6 states a specific scenario, and often a feature has multiple scenarios and needs to test them separately. Scenarios contains separate steps which defines either a prerequisite (Given), an action (When) or a result (Then)[1]. The semantic of the steps are defined in a set of step definitions written in plain Ruby. Listing 2.2 is a step definition of the step used on line 9 in Listing 2.1.

```
1  Then /^the log should contain "([^"]*)"$/ do |entry|
2    Server::log.should have(entry)
3  end
```

Listing 2.2: Cucumber step definition

The step definition checks whether the server log contains given entry using RSpec. Steps are matched with regular expressions and `"([^"]*)"` matches the string "GET /posts" on line 9 in Listing 2.1. Step definitions returns true if it passes and false if it didn't, and in the case of a failure displays a detailed debug message.

RSpec is a BDD framework for Ruby used to write behaviour specifications (specs). Specs are to BDD what unit tests are to TDD. Once the acceptance test is written and run, steps will fail as they are not implemented (step 2 on Figure 2.1). Once implemented, steps might reveal application code which is not yet available and therefore fail. In the example above, this error could be caused by `Server` not having the method `log`. At this point (point 3 on Figure 2.1, an RSpec spec is needed to define the behaviour of the `log` method. Listing 2.3 shows how such a spec might look.

```
1  describe Server do
2    describe "#log" do
3      it "should return an array" do
```

[1] "And" continues the previous step type

```
4         Server.log << "Test string"
5         Server.log.should.return(["Test string"])
6       end
7     end
8   end
```

Listing 2.3: RSpec (spec) example

Lines 1 and 2 in Listing 2.3 describes that we are specifying the `log` method on the `Server` class. Line 3 describes the intended behaviour of the `log` method; namely that it should return an array. Then a test string is written to the log enabling the assertion that calling the `log` method should return that exact string. The next step in the BDD cycle is now to get the spec to pass (go from red to green) with the simplest solution possible. In case of the example this would require implementing the `log` method to return an array of log entries. Once the spec passes, the code can be refactored if possible, and then the developer moves on to the next failing step definition. This process is continued until the acceptance test passes, meaning the feature is done.

2.2 Webservers

The goal of a webserver is listen on a port for incoming requests, handle them by either returning the contents of a file, run a program and return it's output, or, if an error occurred, return an error message. Since the Internet was made public over 20 years ago there have been countless webservers created, most of which focus on handling websites written in a specific programming language or framework. Multi-core processors have long been available in server environments and hence, many webservers employ techniques to raise their performance by handling HTTP requests in parallel.

This section looks at some of the available Ruby webservers and the concurrency models they employ.

2.2.1 Rack

Rack is not an actual webserver, but an interface between webservers supporting Ruby and Ruby frameworks. It is covered here as some of the Ruby webservers covered next both implement it. Rack decouples the link between the webserver and web-application (written in one of the many Ruby frameworks) and hereby makes it possible to change webserver without having to make any changes to the web application. This is achieved by wrapping requests and responses in a Ruby object. By implementing the Rack interface, a webserver would immediately become compatible with more than 15 Ruby frameworks [2].

2.2.2 Thin

Thin is a webserver written in Ruby which include a HTTP parser written in C, implements the Rack interface and uses EventMachine to handle requests in a concurrent non-blocking manner [4]. EventMachine is a library which enables event-driven (non-blocking) I/O by utilizing the reactor design pattern. The reactor pattern works by having a dispatcher (reactor) passing on work to various handlers, which then in turn fire an event when finished. This enables Thin to focus on other requests instead of waiting on blocking actions such as waiting for a file to be written to disk or fetching data from a remote API [11].

Thin works by running the EventMachine event loop in a single thread, and does therefore not employ any parallel processing, but does allow for concurrency due to the asynchronous nature of the reactor pattern. Thin is usually setup as a cluster of processes behind a proxy server or load balancer.

2.2.3 WEBrick

WEBrick is a webserver which is included in the Ruby standard library. It is written entirely in Ruby and employs concurrency by creating a separate thread for each incoming request. Like Thin, multiple instances of WEBrick would be required to enable multiprocessing. WEBrick is mostly used as a development server as it does not perform well under heavy loads due to it's concurrency model [3].

2.2.4 Unicorn

Unicorn is a Ruby webserver which employs parallel processing by means of forking separate worker processes [14]. Like Thin, it also uses a C extension HTTP parser. By using processes, Unicorn allows for parallel processing without the need to used a proxy server or load balancer as load balancing is performed by the operating system.

2.3 Concurrent Programming

Concurrency refers to code which is executed simultaneously on one or more processors or cores in a single processor. Concurrent Programming refers to programming language constructs which enables code to be executed concurrently. Concurrent code executed on a single-core processor will look like it's executed at the same time, but in reality the processor executes increments of each piece of code by switching back and forth between them. The way a processor switches between concurrent tasks is referred to as context-switching, and can easily bog down a system as the context (program state and variables) needs to be loaded for every context-switch. Concurrent code executed on a multi-core processor has the potential to execute code in parallel, e.g. at the same instance in time. True concurrency can

occur on a computer with either multiple processors or one processor with multiple cores.

In most programming languages code is executed one statement at a time in a sequential manner. Most programming languages does however include constructs to allow for concurrent programming. One of the most common constructs is *threads*. A thread is an abstraction for a piece of code which is executed as a subroutine of the running program. This allows for executing several threads concurrently or in parallel on multiple processors. In Section 2.4, the constructs available in Ruby are covered in more detail.

Concurrency introduces several complications which must be taken into account, mainly; race conditions and deadlocks. A race condition occurs when two or more pieces of code tries to manipulate the same variable, and the outcome of the program changes depending on the order of the manipulations. An example would be if two threads, A and B, stored a counter in a global variable. Imagine thread A reads the value of the counter and then gets preempted and thread B changes the counter and saves it. Then when thread A gets resumed it would have an incorrect counter value, and changing the counter based on this would render thread B's previous change. Race conditions can be fixed by synchronizing access to shared resources such as variables. A common way too synchronize access to shared resources is to add a mutual exclusion lock (mutex) around the code which accesses the shared resource. A mutex could ensure that only one thread uses the shared counter variable at a time. Deadlocks can occur when shared resources gets locked by separate threads which then each waits for the other thread to release the resource.

Race conditions occurring in a webserver could lead to erroneous data and deadlocks could result in the server becoming unresponsive. Hence, they should be avoided at all costs.

2.4 Ruby

Ruby is an dynamic, reflective object-oriented general-purpose programming language. It is dynamic in the sense that it is interpreted at runtime, and reflective in the sense that it can modify and inspect program behavior during runtime. Ruby has a dynamic type system where the type of the object is determined by what the object can do in terms of which methods are available for the object. This type system is referred to as duck typing, i.e. if it walks like a duck and talks like a duck, then the interpreter will treat it like a duck.

The latest version of Ruby, version 1.9, holds several improvements over the older but still maintained version 1.8. Besides small syntactic changes and including a new VM, Ruby 1.9 introduced the concept of fibers. Ruby 1.9 also includes RubyGems which enables easy packaging, installation and distribution of Ruby software. RubyGems, mostly referred to as *gems*, can be used to modify or extend functionality within a Ruby application or to split out reusable code for others to benefit from [9]. There are currently over 27.000 gems available and this greatly reduces the need to "reinvent the wheel", hence improving productivity.

Ruby was chosen for this project because it is dynamic, expressive, productive and terse, all adding to the speed and joyfulness of developing software. Furthermore, Ruby has several constructs available for concurrent programming which are covered below.

2.4.1 Concurrency in Ruby

Ruby comes with several constructs for concurrent programming; processes, threads and fibers. The following describes the advantages and possible disadvantages of each of these concepts.

Processes

A process is a running instance of a program, e.g. a running webserver or an open text editor. Processes are handled by the operating system (OS) which will utilize the available processors to run processes in parallel. Hence, parallelism is achieved by running multiple instances (processes) of the same program.

Ruby includes a library for creating, killing and inspecting processes. Creating a new process is done by *forking* a new process from the current one. Forking starts a new Ruby VM with the executing program as a new process. The forked and the original process does not have access to each other memory, and thereby eliminates many of the problems regarding race-conditions and deadlocks. The disadvantage of using multiple processes is that, as they cannot share state, they have to communicate through an explicit protocol [13].

Threads

A thread is an encapsulation of a set of instructions and it's execution can be managed. A thread can be seen as a lightweight process which has access to the current programs memory. Threads are managed by a thread-scheduler which decides when threads are executed and preempted to enable other threads to run. Using threads introduces complex issues as race-conditions can easily occur due to all threads having access to the same memory.

The advantages of using threads is that they can easily share data, but that is also one of it's disadvantages as it can easily become quite complex and bugs concerning multi-threaded code can be very hard to discover [13].

Fibers

A fiber in Ruby is a coroutine mechanism which enables pausing and resuming code blocks to achieve cooperative concurrency. A code block is a piece of ruby code encapsulated in an object, and can be passed into methods, saved in variables, and executed on demand. Fibers resembles threads in that they can be controlled from

outside, but whereas threads are managed by a scheduler, fibers must be scheduled by the programmer.

The advantages of fibers over threads are that they have a significantly lower memory footprint and doesn't introduce the complexity of a scheduler as threads do [10].

2.4.2 Ruby Implementations

Ruby code is run in a virtual machine (VM) of which there exists several implementations. The official Ruby VM, for Ruby 1.9, is called YARV (Yet Another Ruby VM). As there is no specification for Ruby, YARV serves as the reference implementation for the Ruby language. The following describes two widely used Ruby implementations, namely YARV and JRuby, and how they differ regarding concurrent programming.

Yet Another Ruby VM

YARV is developed an maintained as the official Ruby implementation and replaced the old VM MRI (Matz[2] Ruby Interpreter) as of Ruby version 1.9. Given YARV is the one driving the Ruby language implementation, it always has the latest languages features and updates, whereas other Ruby implementations tend to be a bit behind. The latests stable version of YARV is 1.9.2, with 1.9.3 being just around the corner. YARV supports threads, fibers and processes, but includes a Global Interpreter Lock (GIL) which limits the Vm to only running one thread at a time. The GIL is included to ensure non-threadsafe C-extensions does not cause problems, and effectively bars YARV from untilizing true parallism from fibers and threads [13].

JRuby

JRuby is a Ruby implementation that runs on any Java Virtual Machine (JVM) and therefore enables using Java libraries from within Ruby. Java is a very mature and large ecosystem with many useful libraries, language constructs and concurrency models [7].

JRuby does not include a GIL as YARV does and therefore allows true parallelism for threads, as opposed to only having one thread/fiber run at a time. JRuby does however not support processes forking as it is not supported by the JVM [12].

[2]Yukihiro Matsumoto, a.k.a. Matz is the creator of the Ruby programming language

Chapter 3

Analysis

In order to have a clear goal of what the software produced in this project should do, a set of requirements are essential.

As covered in Sectionr̃efwebservers, the main purpose of a webserver is to listen to HTTP requests, locate, and then return the resource or a response according to the request. Hence, the webserver should be able to parse HTTP requests in order to know how to respond. The parser should parse HTTP requests according to the RFC 2616 specification.

In order to analyse and debug the webserver it should be able to log vital messages to the console. This feature would greatly improve troubleshooting and serve as a backlog of events in case of an error or an attack.

To increase the performance and throughput of the webserver it should handle multiple requests at a time in a non-blocking manner. This would solve a slow request blocking other requests from being processed.

The webserver should be able to serve static files like HTML, cascading stylesheets, JavaScript and images in order to make webpages work as expected. If no specific file is requested, then the webserver should return a HTML formatted directory listing with links to the files in the given folder.

If a resources doesn't exist, or an error occurs during processing, the webserver should return an error page with a short message on what went wrong.

The webserver should be able to webserver dynamic content by executing Ruby scripts and returning their output. This enables client interaction instead of simply being served static content.

In order to use the webserver with one of the many Ruby web-frameworks, it should implement the Rack interface. This would instantly enable developers to use the webserver with their web-applications.

3.1 Requirements Specification

The list below summarises the requirements for the webserver developed in this project.

- Parse HTTP/1.1 requests in accordance with RFC 2616.
- Logging of requests and responses.
- Handle concurrent requests in a non-blocking manner.
- Serve static files and directory listings.
- Return an error page if an error occurs.
- Serve dynamic content by executing Ruby scripts and returning the output.
- Implement the Rack interface

As this project was developed using BDD, the requirements specification was translated into a set of acceptance tests to get concrete feedback on completed requirements. The acceptance tests are included as Appendix **??**.

3.2 Project Planning

Prior to starting development, the requirements were estimated and the development split into several iterations, each driven by a requirement. Figure 3.1 shows the initial planning of the development.

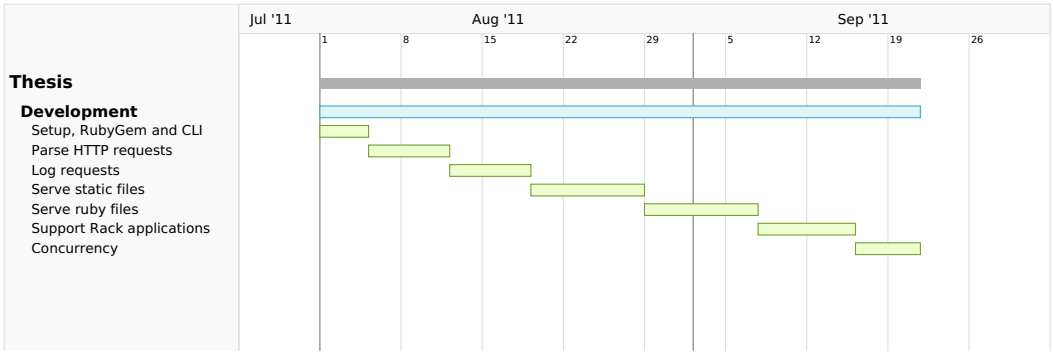


Figure 3.1: Development Gantt Planning

The development was planned to take place between August 1 and September 20. The first three days were to be spent setting up the project, RubyGems packaging and writing the command-line interface (CLI). Each requirement is then implemented in turn, with varying time set aside, depending on the complexity of the task.

As Behaviour-Driven Development was being used, no design was needed up-front, and development could start head on. Design and architectural decisions were to be made once the need arose, and tests were to be written prior to any implementation code.

Chapter 4

Implementation

Development of each requirement (see Section 3.1) was driven by aiming to satisfy an acceptance test which stated the behavior of the feature. The acceptance tests were written in a natural language using Cucumber, and once the acceptance test passed the feature was considered done. All requirements were satisfied, and this chapter covers some of the problems, and their solutions, that occured during the eight weeks of development.

Initially, an overview of the webserver, it's parts and how it works is described. Subsequently, selected interesting parts of the system is covered. The order of this chapter mirrors the order in which the features were developed.

4.1 System overview

The user interface with Yarn through a ruby script which accepts a hostname and port number for to listen for incoming requests on, the number of processes to fork and a Rack file. All parameters are optional, and default values are used if none are given. By default the webserver will listen on `127.0.0.1:3000`, with four worker processes serving static and dynamic content. If a Rack file is given, then Yarn will serve requests according to the Rack application. For debugging purposes, the user can supply a parameter to include debug messages in the log. The following describes how handles requests when serving static and dynamic files, and then how it serves Rack applications.

When Yarn is started it will create a TCP server that listens for connections on either the given or default port and hostname. If a Rack file is given, then the application will be loaded. Then the process will fork into the given number of workers and Yarn is ready to handle incoming requests. Each worker contains a loop which, when registering an incoming connection, will call either the `RequestHandler` or `RackHandler` depending on whether a Rack application is loaded or not. Listing 4.1 contains the loop run in each worker process.

```
1 loop do
```

```
2   handler ||= @app ? RackHandler.new(@app) : RequestHandler.new
3   session = @socket.accept
4   handler.run session
5 end
```

Listing 4.1: Worker loop (lib/yarn/server.rb:53)

For each iteration, the loop will wait at line 3 for an incoming connection, and not busy wait and run again. The handler classes takes care of all the rest and closes the connection when finished. If the user sends the interrupt signal (usually by pressing Ctrl-c), Yarn will kill the worker processes, close the TCP server and exit.

4.2 Parser

The HTTP request is received as a sting of text, and in order to know the how to respond, it needs to be checked for it's validity. Furthermore, it should be stored in a more convenient data format, to enable easier looking up request information.

4.2.1 HTTP Requests

The current version of the HTTP protocol, version 1.1, is well defined in a specification called RFC 2616 [5]. The specification clearly defines how a HTTP request is formed and what it consists of. Listing 4.2 is an excerpt from the specification and shows the overall structure of a HTTP request.

```
1 Request = Request-Line
2           *(( general-header
3            | request-header
4            | entity-header ) CRLF)
5           CRLF
6           [ message-body ]
```

Listing 4.2: HTTP request structure

Listing4.2 translates to a `Request-Line`, followed by zero or more headers, and after a `CRLF` an optional `message-body`. Headers include information such as cookies present in the browser, browser type, size of the `message-body` etc.. `CRLF` is a newline (line break), and is used to define the structure of the request, e.g. each header is a separate line and an empty line separate the last header and the `message-body`. The `Request-Line`, as shown in Listing 4.3, consists of a method, URI and HTTP version.

```
1 Request-Line = Method SP Request-URI SP HTTP-Version CRLF
```

Listing 4.3: HTTP Request-Line

Listing 4.4 shows an example HTTP request.

```
1 GET /path/file.html HTTP/1.1
2 User-Agent: Internet Explorer
3 Content-Length: 21
4
5 field=value&show=true
```

Listing 4.4: Example HTTP request

4.2.2 Parsing Strategy

The parser was written using a Ruby library named Parslet. Parslet works by defining a set of rules and then applying them to check whether the input satisfies the rules, and then extracts defined values. The rules consists of a mix of regular expressions and boolean logic.

Listing 4.2.2 shows the rule for the `Request-Line` as shown in Listing 4.3.

```
1 rule(:request_line) do
2   method.as(:method) >>
3   space >>
4   request_uri.as(:uri) >>
5   space >>
6   http_version.as(:version) >>
7   crlf.maybe
8 end
```

When a request is successfully parsed, a `Hash` containing the request data is returned. E.g. running the parser on the example from Listing **??** will produce the following `Hash`:

```
1 { :method=>"GET"@0,
2   :uri=>{:path=>"/path/file.html"@4},
3   :version=>"HTTP/1.1"@20,
4   :headers=>
5     { "User-Agent"=>"Internet Explorer",
6       "Content-Length"=>"21" },
7   :body=>"field=value&show=true"@105 }
```

Listing 4.5: Example `Parser` output

With the request nicely formatted in a `Hash` it becomes very easy to query information about it. The numbers in Listing 4.5 preluded by a denote the elements start position in the request.

4.3 Static and Dynamic Requests

Serving static and dynamic content was developed as two seperate features and handler classes `StaticHandler` and `DynamicHandler`, but later merged into what is

now the `RequestHandler` class. From the beginning it was clear that the handler classes would have much functionality such as reading the request, invoking the parser and returning the response in common, but also some distinct functionality. A good way to vary an algorithm whilst keeping much of the functionality the same is to use the Template Method design pattern. The process of handling requests can be split up into the following steps:

1. Parse the request
2. Prepare the response
3. Return the reponse to the client
4. Close the connection

Given this process, the part that differs between handling static and dynamic files is preparing the response. The Template Method makes provides a convenient way to vary the implementation of how the response is prepared [8]. Figure 4.1 shows how the relationship between the handler classes.

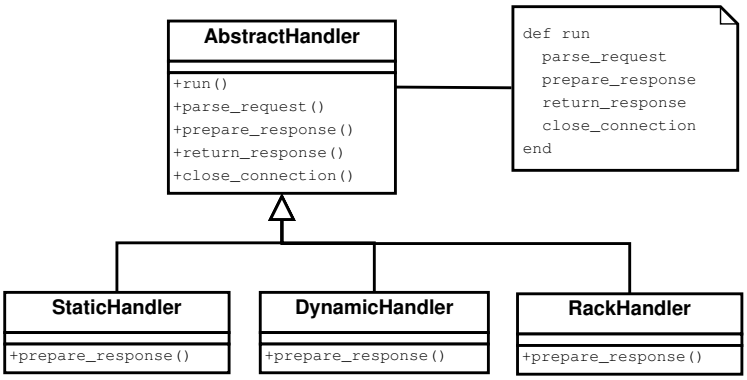


Figure 4.1: Initial handler implementation using the Template Method.

Invoking run on each handler class would then follow the same process, but each have their own implementation of `prepare_response` method. Once both handler classes were implemented it became clear that it would make more sense to merge the two together to mirror how Yarn can be run to serve either static and dynamic files or a Rack application. Figure 4.2 shows how the final handler classes were implemented (`RackHandler` is covered in Section 4.4).

4.3.1 RequestHandler

The `RequestHandler` works by checking whether the requested path is a file or a directory. Listing 4.6 show the logic determining what is being served.

```
1 begin
2   if File.directory?(path)
3     serve_directory(path)
```

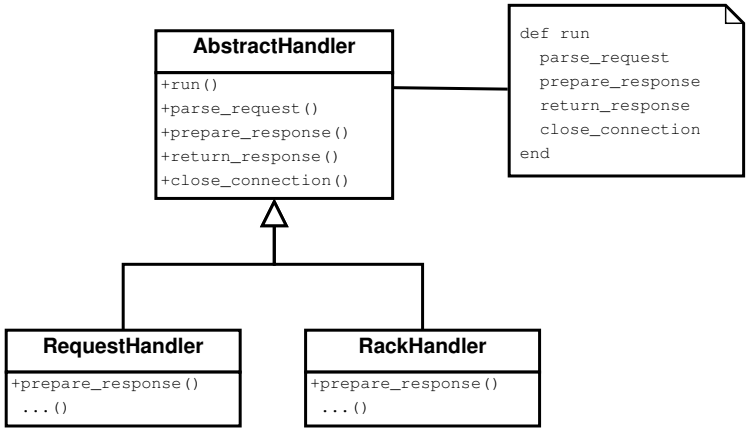


Figure 4.2: Final handler implementation using the Template Method.

```
4    elsif File.exists?(path)
5      path =~ /.*\.rb$/ ? serve_ruby_file(path) : serve_file(path)
6    else
7      serve_404_page
8    end
9  rescue ProcessingError
10   log "An error occured processing #{path}"
11   serve_500_page
12 end
```

Listing 4.6: `RequestHandler` logic. (lib/yarn/request_handler.rb:8)

If the requested path is a directory, then a directory listing is served. In case the requested file is ends with `.rb`, then it is executed and the result is returned. In case the file does not exist or an error occurs executing a Ruby file, then an error page is returned. Ruby files are executed in the `execute_script` method by evaluating the file using a new Ruby VM and the result stored as the response body.

4.4 Rack Applications

Implementing support for Rack applications consisted of two parts; loading the Rack application and communicating requests and responses between the server and the application.

Rack application are specified in a Ruby file which needs to be evaluated to load the application. An example application is included which simply returns a static array is included in Listing 4.7.

```
1 run Proc.new { |env|
2   [200, {'Content-Type' => "text/plain"}, ["Rack works"]]
3 }
```

Listing 4.7: Sample Rack application. (test_objects/config.ru:4)

When a Rack application file is supplied when running Yarn, the contents of the file is read, passed into the `Rack::Builder` constructor which is then evaluated. Listing 4.8 contains the line where the Rack is loaded.

```
1  config_file = File.read(app_path)
2  rack_application = eval("Rack::Builder.new { #{config_file} }")
```

Listing 4.8: Loading a Rack application. (lib/yarn/server.rb:31)

Once loaded a Rack application is invoked with a `call` method which returns an array containing the HTTP status code, HTTP headers and message body. The The `call` method takes one parameter which is a `Hash` of values the Rack application needs such as the path, hostname, port, request body etc. [2].

4.5 Concurrency

Concurrency was developed lastly as to be able to properly test it with both Rack applications and static and dynamic files. This section covers the stages of development the concurrency feature went though, from using threads to switching to processes.

4.5.1 Initial Thread-per-request Implementation

The initial implementation handle each incoming request in a new thread. This quickly proved to introduce too much overhead in creating a new thread for each request. Furthermore, as the amount of threads hobbed up, memory usage would rise and eventually bog down the system. It became clear that another solution was needed, and a system devised of a thread-pool and a job queue was devised.

4.5.2 Thread-pool and Job Queue Implementation

The thread-pool was an array of threads, each running a handler which listened for jobs to be added to the job queue. Each incoming request would be added to the job queue and then processed by one of the workers. The pros of this solution was that, with a fixed number of threads, memory usage was limited. Furthermore, the job queue made sure that no requests were dropped if all threads were busy.

Once implemented, several issues occurred which led to a rethink of the chosen concurrency model. One problem was that requests would often hang indefinitely and never return any content to the client. Exactly what caused this bug was never discovered though many hours were spent trying the track it down. It was suspected that the threads somehow created a deadlock which in turn would make the client wait until the browser timed out. Never discovering the cause of the bug illustrates one of the key problems of threaded programming; bugs are often very hard to replicate due to the complexity of the thread model and the thread scheduler.

Another problem with the thread-pool implementation was that it performed sub par to the initial implementation of creating a new thread for each request. This seemed to be caused by the way threads were scheduled, but again it proved too difficult to pinpoint exactly the cause of the slow performance.

Given the difficulty of a thread-based approach, it was decided to implement the concurrency feature using processes.

4.5.3 Process-based Implementation

Implementing a process-based solution turned out to have many benefits, as it both reduced the complexity of Yarn, but also greatly improved upon it's performance.

The process-based solution was implemented by using `Process::fork` from the Ruby standard library to create a process of the server. Each forked process listens for incoming requests and one handler to respond with. Listing 4.9 shows the logic for creating new processes.

```
1  def init_workers
2    @num_workers.times do
3      @workers << fork_worker
4    end
5  end
6
7  def fork_worker
8    fork { worker }
9  end
10
11 def worker
12   trap("INT") { exit }
13   loop do
14     @handler ||= @app ? RackHandler.new(@app,@opts) : RequestHandler.
           new
15     session = @socket.accept
16     @handler.run session
17   end
18 end
```

Listing 4.9: Process-based implementation (lib/yarn/server.rb:52)

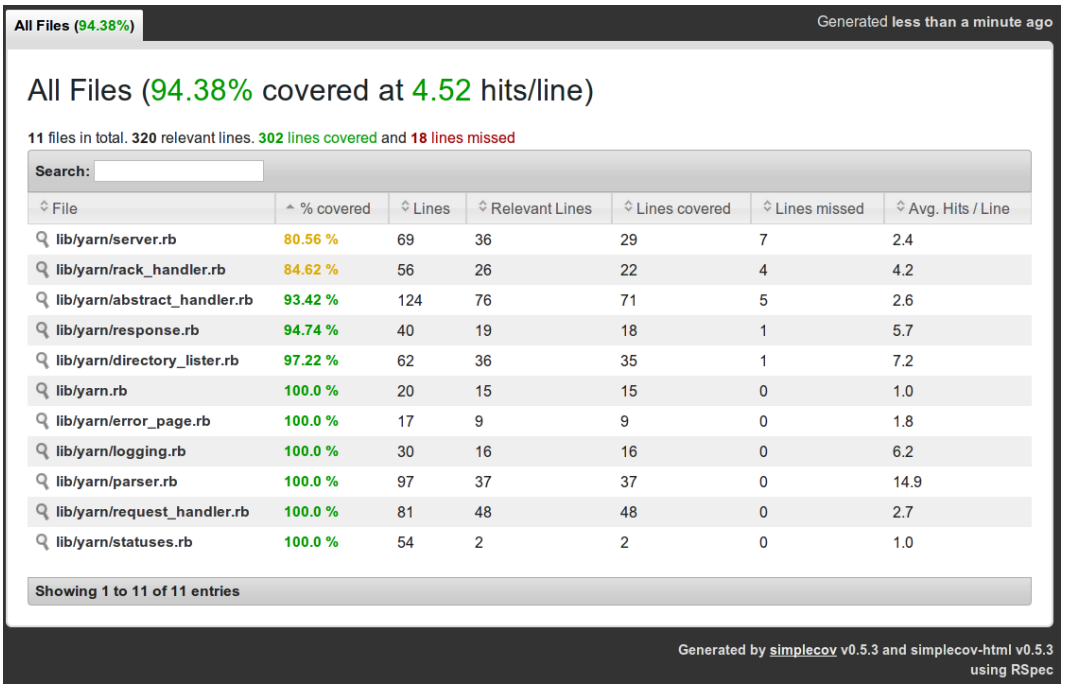
Once the `fork` method is called on line 8, a new process is started with a separate Ruby VM and the continue from that point. Meaning, each process would contain the worker loop on line 13 through 17. On line 12, the interrupt signal (INT) is trapped, such that when the user presses `Ctrl-c`, then all processes will exit and Yarn will stop.

The process-based implementation improved the performance from ~250 requests/second to ~800 requests/second. The performance is covered in more detail in Section 6.2.

Chapter 5

Testing

Throughout the development of Yarn, acceptance tests and specifications were written prior to developing a feature. This provided a solid test coverage which in turn allowed for some radical refactorings to improve the quality, readability and performance of the system. By the end of development, all 13 acceptance tests (Cucumber features) and 77 specifications (RSpec specs) passed. The final test coverage was 94.38%, as depicted on Figure 5.1.



All Files (94.38%) — Generated less than a minute ago

All Files (94.38% covered at 4.52 hits/line)

11 files in total. 320 relevant lines. 302 lines covered and 18 lines missed

Search:

File	% covered	Lines	Relevant Lines	Lines covered	Lines missed	Avg. Hits / Line
lib/yarn/server.rb	80.56 %	69	36	29	7	2.4
lib/yarn/rack_handler.rb	84.62 %	56	26	22	4	4.2
lib/yarn/abstract_handler.rb	93.42 %	124	76	71	5	2.6
lib/yarn/response.rb	94.74 %	40	19	18	1	5.7
lib/yarn/directory_lister.rb	97.22 %	62	36	35	1	7.2
lib/yarn.rb	100.0 %	20	15	15	0	1.0
lib/yarn/error_page.rb	100.0 %	17	9	9	0	1.8
lib/yarn/logging.rb	100.0 %	30	16	16	0	6.2
lib/yarn/parser.rb	100.0 %	97	37	37	0	14.9
lib/yarn/request_handler.rb	100.0 %	81	48	48	0	2.7
lib/yarn/statuses.rb	100.0 %	54	2	2	0	1.0

Showing 1 to 11 of 11 entries

Generated by simplecov v0.5.3 and simplecov-html v0.5.3 using RSpec

Figure 5.1: Yarn test coverage screenshot.

During the development, the test coverage was continously monitored to ensure all parts of the system was exercised in the test suite. The test coverage analysis is available on the CD in the `coverage` folder. The following looks at how testing for concurrency was performed, and how the HTTP parser was developed with BDD.

5.1 Testing for Concurrency

Some features were harder to test than others, and testing for concurrency was especially tricky. The solution was to invoke two requests to a Ruby file ,which invoked the `sleep` method for a given amount of time before returning the response. Firing a request which slept for a second would block other requests from being served during that second. But if the server could handle concurrent requests, a fast request fired after the slow request, should be able to get it's response prior to the slow request completing. Listing 5.1 shows the acceptance test for concurrent requests.

```
1 Scenario: Perform two requests in parallel
2   Given the server is running
3   Given a client "A"
4   And a client "B"
5   When client "A" makes a "1" second request
6   And client "B" makes a "0.1" second request
7   Then client "B" receives a response before client "A"
```

Listing 5.1: Concurrency acceptance test (features/concurrency.feature:7)

Having this acceptance test proved especially valuable during the reimplementation of the concurrency feature from using threads to using processes.

5.2 Testing the HTTP Parser

The development of the HTTP parser was initiated by writing an acceptance test as shown in Listing 5.2.

```
1 Scenario: Parse HTTP request
2   Given a HTTP request "GET /index.html HTTP/1.1\r\nUser-Agent:
        cucumber\r\n"
3   And a parser
4   When I feed the request to the parser
5   Then the result "method" should be "GET"
6   And the result "uri" should include "path" with "/index.html"
7   And the result "version" should be "HTTP/1.1"
8   And the result "headers" should have "User-Agent" with "cucumber"
```

Listing 5.2: HTTP parser acceptance test (features/parser.feature:7).

The acceptance test exercises the parser by supplying it with a HTTP request string, and then expects the result to contain the values of the request. Running the acceptance test revealed that the steps were not defined, and implementing them was the next step. Listing 5.3 shows two of the step definitions.

```
1 Given /^a parser$/ do
2   @parser = Yarn::Parser.new
3 end
```

```
4
5 When /^I feed the request to the parser$/ do
6   @result = @parser.run(@request)
7 end
```

Listing 5.3: Parser step definitions excerpt (features/step_definitions/parser_steps.rb:1).

With all the step definitions implemented, running the acceptance test again revealed that the class `Yarn::Parser` did not exist. Creating the class and running the test again revealed that the class did not have a method named `run`. The development continued in this loop of first asserting certain behavior from the code, discovering it did not behave as asserted, and then implementing the expected behaviour.

Each element which should be parsed was added incrementally by first writing a RSpec specification, and then adding the behaviour to the `Parser` class. For instance, then expected behaviour of being able to parse query parameters was written in a specification (Listing 5.4).

```
1 it "parses query parameters in the URL" do
2   result = Parser.new.run("GET /page?param1=1&param2=2 HTTP/1.1\n")
3   result[:uri][:query].should == "param1=1&param2=2"
4 end
```

Listing 5.4: Parser query parameter support specification (spec/yarn/parser_spec.rb:54).

To begin with the parser is executed with a HTTP request. Then the result `Hash` is inspected to see whether the values match. Running the above specification would output an error message as the parser could not yet handler the query parameter. The behaviour, Listing 5.5 was then added to the `Parser` class.

```
1 rule(:path) do
2   match['^\?'].repeat(1).as(:path) >>
3   str("?") >>
4   query.as(:query) | match['^\s'].repeat(1).as(:path)
5 end
6
7 rule(:query) do
8   match['\S+'].repeat(1)
9 end
```

Listing 5.5: URL query parameter support (lib/yarn/parser.rb:31).

The behaviour added was lines 3,4 and lines 7 through 9. The path is checked for the occurrence of a question mark, and if it is found the sequence of characters until a whitespace character is parsed as the query string (line 8).

Chapter 6

Demonstration and Benchmark

6.1 Demonstration

For ease of use, Yarn exposes a help command to show the options available when launching the server. Figure 6.1 shows the output of the help command.

```
[~]$ yarn --help
Yarn v0.1.0 is a multiprocess webserver written in Ruby 1.9

Usage: yarn [options]
where [options] are:
     --host, -h <s>:   Hostname or IP address of the server (default: 127.0.0.1)
     --port, -p <i>:   Port number to listen on for incomming requests (default: 3000)
  --workers, -w <i>:   Number of worker threads (default: 4)
     --rack, -r <s>:   Rackup file <config.ru> (default: off)
          --log, -l:   Enable logging
        --debug, -d:   Output debug messages
      --version, -v:   Print version and exit
         --help, -e:   Show this message
```

Figure 6.1: Yarn help output.

Figure 6.2 shows the output when Yarn is serving static and Ruby files with 32 worker processes and logging enabled.

```
[~]$ yarn -l -w 32
11/10/11 08:38:59 - Yarn started 32 workers and is listening on 127.0.0.1:3000
11/10/11 08:39:28 - OK 127.0.0.1 /
11/10/11 08:39:49 - OK 127.0.0.1 /test_objects
11/10/11 08:40:06 - OK 127.0.0.1 /test_objects/app.rb
11/10/11 08:40:46 - OK 127.0.0.1 /README.md
^C 11/10/11 08:40:52 - Server stopped. Have a nice day!
```

Figure 6.2: Yarn static/dynamic output.

Figure 6.3 shows Yarn serving a sample Ruby on Rails application.

Yarn can easily be installed using RubyGems which is included in Ruby as of version 1.9. To install Yarn run the following command `gem install yarn`, and now Yarn is available from the command-line.

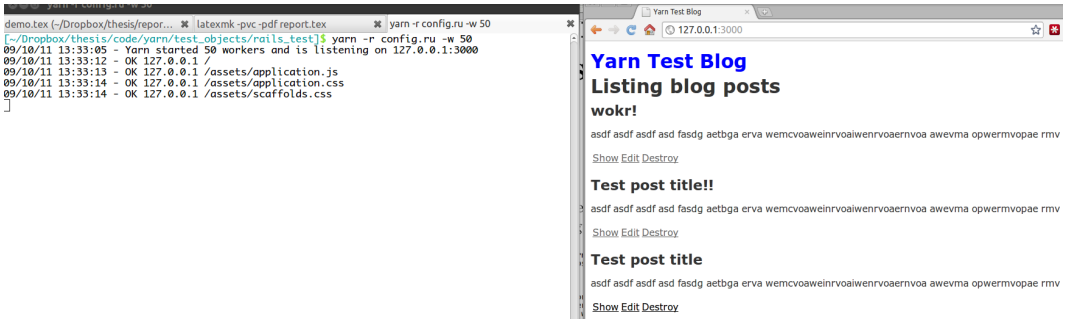


Figure 6.3: Yarn Rack application output.

6.2 Benchmark

The benchmarks analyses the performance and scalability (handling concurrent requests) aspects of Yarn, WEBrick, Thin and Mongrel. It does not include topics like security and stability, which are important for webservers, but out of scope for this project.

To evaluate Yarn, it's performance will be analyzed first by itself, then it is compared to the other Ruby webservers covered in Section 2.2. The measure of performance is how many requests the webserver can handle per second. The tests were run on a Linux 64-bit machine with four cores and 8GB RAM using Ruby (YARV) 1.9.3-rc1.

The benchmarks were performed using Apache Bench, which is a tool made to measure the number of requests per second a webserver can perform.

6.2.1 Yarn Performance

To get an idea of the performance of Yarn, it was measured how many requests per second (req/sec) it could handle at different counts of worker processes. Figure 6.4 plots Yarn performance.

Test runs above 256 processes bogged the computer down and were not included. The result of this was, context-switching and memory usage exceeded the capabilities of the system. The best result was achieved with 32 worker processes which maxed at 808 req/sec, and on average Yarn performed 706 req/sec. The test consisted of making 2000 requests, 200 at a time, to Yarn serving a simple Rack application (test_objects/config.ru).

6.2.2 Yarn Vs. Other Ruby Webservers

The following benchmarks compares Yarn's relative performance compared to other Ruby webservers. Listing 6.5 shows the results of measuring the webservers performance serving a simple static Rack application. The test was performed doing

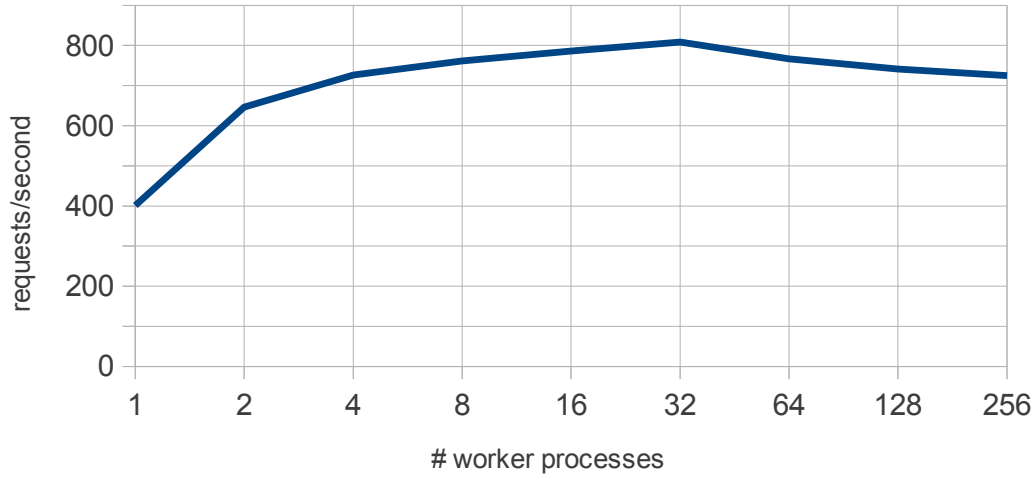


Figure 6.4: Yarn performance

2000 requests, 20 at a time. The average of four test runs was used to minimize outside factors from polluting the results.

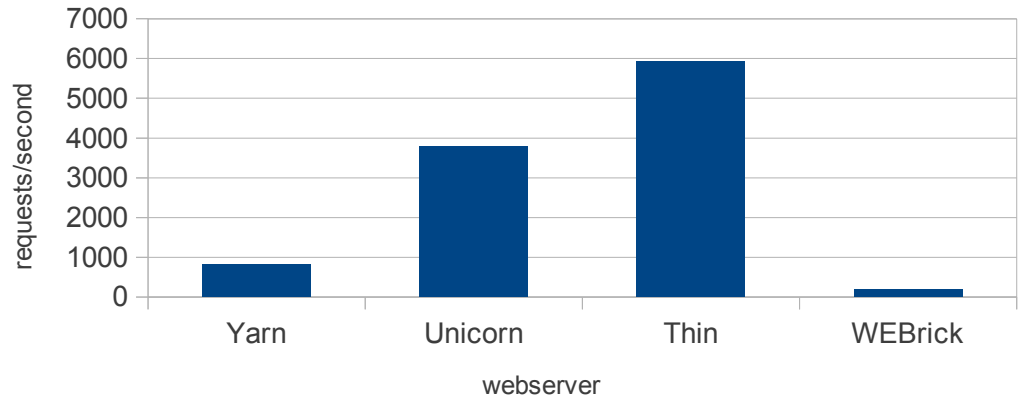


Figure 6.5: Serving a static Rack application

Benchmarking with a static Rack application revealed that this was something that Thin managed really well with 5915 req/sec on average. Unicorn came second with 3792 req/sec, Yarn third with around 820 req/sec and WEBrick last with 180 req/sec.

Thin's excellent performance is interpreted to be the result of not having to do any context-switching as all requests are handled in one thread. Furthermore, the impact of Thin's and Unicorn's fast C HTTP parser has a higher impact when the time spent parsing the request relatively high compared to the amount of time spent creating the response.

The results were quite different when a CPU intensive Rack application was

used. Listing 6.6 shows the results of benchmarking with a Rack application that calculates the Fibonacci series up to 10000.

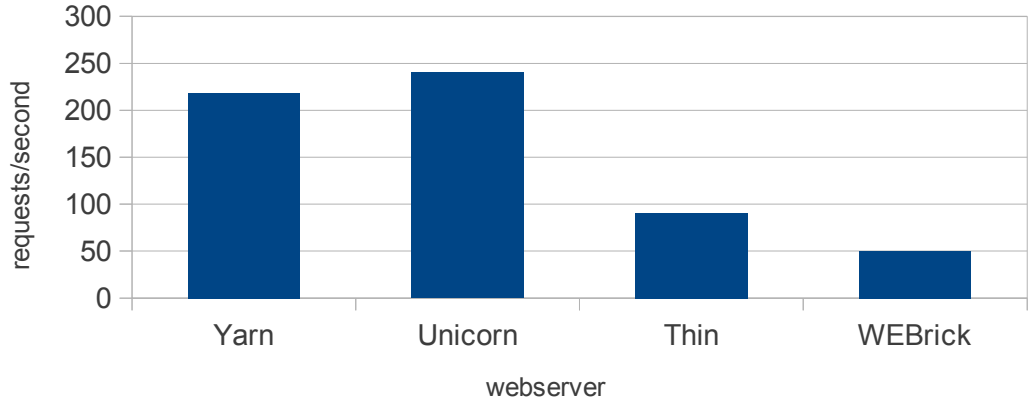


Figure 6.6: Serving a CPU intensive Rack application

With each request now having to run a CPU intensive computation, Unicorn came in first with 240 req/sec, Yarn second with 218 req/sec, then Thin with 90 req/sec and lastly WEBrick with 50 req/sec. With a CPU intensive application, the benefits of parallel processing is clearly noticed, as is the case with Unicorn and Yarn. Thin and WEBrick would probably perform similarly if multiple instances and a load balancer was used.

Chapter 7

Critical Evaluation

This chapters looks critically at the final product and reflects upon the project process using Behaviour-Driven Development.

7.1 Product Evaluation

The final version of Yarn (0.1.0) includes all features from the requirement specification, and all acceptance tests and specifications passes.

Yarn is stable with >10 worker processes and at low request volumes. However, when the requests to worker process ratio becomes too high, some TCP connections are dropped and no content is delivered to the client. It was not possible to fix this bug as no more time was left for development.

The performance of Yarn is quite satisfying for CPU intensive applications, but for static content it performs subpar to other Ruby webservers. **FiXme Fatal: blame parser?**

7.2 Process Reflection

Developing software tests first proved to be difficult at times when it was hard to figure out how a piece of code would even work. Having done mostly non-test-first development prior to this project, it required a continous concious effort to stick to writing tests before implementing features. Late in the development phase, it became a more natural effort to drive the implementation thorugh testing, and the advantages of the workflow were proved a great asset. Having the tests provided the courage which was sometimes needed prior to a large rewrite of refactoring of a feature, as it was always easy to see whether the changes had broken the system. Furthermore, by writing the tests first, it was always clear what the next step was as running the test would reveal exactly what was missing in the implementation.

Given there was no design phase prior to starting the development, the design desicions were made continously throughout the development. This resulted in some

desicions made early on which later proved to be less fortunate. But due to the agile nature of BDD, and the confidence achieved by having a big test suite, drastic design changes late in the process were possible. Had the system been thoroughly designed upfront, such drastic changes might have been fatal to the success of the project.

Chapter 8

Conclusion

A working webserver was created and all requirements were met. Yarn features logging, serving static and dynamic content, Rack applications and parallel processing of requests. The performance fared well when serving CPU intensive applications, but left room for improvements when serving static content. Using processes for concurrency gave the best results, as the threaded implementation was error-prone and did not perform well.

BDD works well, but using a test-first approach can be hard with new technology. Design flaws were detected late in the development phase, which might have been prevented with a more thorough design upfront. Having a thougough test suite did however make late desing changes possible, and did also ensure that changes in general did not cause regressions.

8.1 Future Work

Given more time for development, there are a number of imminent features and a bug which should be added or fixed before Yarn will be stable enough to be used in a production environment.

The bug regarding dropped TCP connections should be fixed, possibly by queuing incoming requests to make sure they are being properly served even at hight volumes. Implementing a request queue with the current process concurrency model will require some form of inter-process communication protocol.

Yarn currently does not support persistent TCP connections, and for each request, a new TCP connection is used. This creates an overhead which could be spared by allowing clients to reuse existing connections.

The source-code for Yarn is open-source and publicly available on Github which is a web-based collaborative Git hosting site. This enables anyone to suggest or add improvements and features to the project for the good of all Yarn users. Given time to mature and possible interest from the Ruby community, Yarn might evolve to be a prominent Ruby webserver.

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List of Corrections