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Performance Comparison between Java and Node.js in terms of Scaling in Cloud Foundry

Zheng Zeng

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Tutors

Prof. Peter Knauber, Hochschule Mannheim

Jens Keller, SAP SE

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Abstract

Java and Node.js are two of the most popular languages for web oriented applications. While Java is capable of multi-threading and CPU efficient, Node.js is single-threaded and uses an event-driven, non-blocking I/O model. This thesis has conducted a series of load tests on the two technologies to compare how well they handle high loads and find the best strategy to scale them in Cloud Foundry. Both technologies show a quite high performance in the context of single transaction operations. It is safe to say they are both good candidates to implement applications of SAP business use case. Node.js is found excellent in CPU and memory utilization. With its single thread architecture, horizontal scaling is the best choice. Although Java is more memory-consuming, it is capable of utilizing multiple CPUs in one single application. It is best suitable for vertical scaling if it can make good use of all available CPU resources through proper optimization.

Contents

1 Introduction **1**

2 Related Work **3**

3 Load Generating Tool **4**

3.1 JMeter 4
3.2 nGrinder 5
3.3 hey 5
3.4 A self implemented scalable client 6
3.4.1 Features 6
3.4.2 Limitations 7

4 Measuring Tool **9**

4.1 Average response time and throughput 9
4.1.1 Recording with Load Generator and its limitations 10
4.1.2 Retrieving response time from Logstash and its limitations . 11
4.1.3 Recording data inside the application and its limitations . . 12
4.2 CPU and Memory consumption 13
4.2.1 Cloud Foundry CLI and its limitations 13
4.2.2 Memory consumption 14
4.3 Access data from backing service 15

5 Experimental Environment **16**

5.1 Server in local machine 16
5.2 Server running environment - Cloud Foundry 16
5.2.1 Cloud Foundry at SAP 17
5.2.2 Backing services, service plans, and scaling 17
5.2.3 Limitations 18
5.3 Client running environments 21
5.3.1 Client in the local machine 21
5.3.2 Client in Cloud Foundry 21
5.4 Server and client configuration in the thesis 22

6 Implementation of Applications **24**
6.1 Implementation Configuration 24
6.2 Optimize the Java implementation 25
6.3 Optimize the Node.js implementation 27

7 Test Strategy, Results and Analysis **28**
7.1 Test strategy 28
7.2 Test with 100% CPU consumption 29
7.3 Test with real load 30
7.3.1 Test configuration 30
7.3.2 Test result 31

8 Conclusion **35**

9 Future Work **37**

Abbreviations **v**

List of Tables **vi**

List of Figures **vii**

Bibliography **viii**

Chapter 1

Introduction

The promise of cloud has ushered the software engineering into a new era. Technology is to be used anytime and anywhere to untangle issues, provide solutions, bring people together and change their ways of living. This new era of net-centric web-based applications redefines how software is delivered to a customer and how the customer uses the delivered software. The digitization of economy impacts everyone. New businesses and leaders are emerging from everywhere. Companies appear and disappear much faster than ever before.

SAP, a company which has been renown for its on premise ERP solutions, also faces the pressure from customers to reduce Total Cost of Ownership (TCO) and increase agility. It has since long announced its cloud strategy to help customer master the digital economy. The reach of SAP systems is to be extended through cloud based access, ultimately reaching everybody everywhere in entirely new ways. Cloud computing allows on demand software provisioning with Zero-Installation and automatic configuration at low cost and immediate access in ultra-scalable data centers, which leads to the next generation networked solutions. In the process of leverage cloud infrastructure to increase the business agility and to lower the TCO of customers, ultimately new types of applications are enabled.

Cloud solutions come with new capabilities and technical challenges for cloud software development. Different cloud software development platforms and frameworks applied with different programming languages are used inside SAP. Java and Node.js are the most prominent ones. There have been on-going discussions about how to take a choice between them for SAP applications considering the SAP environment.
Among all the major advantages brought by the cloud paradigm, scalability is the

one that makes cloud computing different to an "advanced outsourcing" solution. It's no secret: high-performance website and web applications drive more traffic, engagement, and increase brand loyalty. In this age where customers are won and lost in a second, continual evaluation and optimization of web properties is essential. Performance affects customer satisfaction. Slowdowns and/or downtime can cost companies thousands of dollars.

On account of all the factors named above, the thesis aims to compare the two server-side technologies: Java and Node.js, in terms of their respective performance and scalibility in a PaaS cloud offering: Cloud Foundry.

Chapter 2

Related Work

Extensive research has been done in the field of comparative studies of programming language. There have been lots of studies evaluating and analyzing Web server performance. Lei, Ma and Tan has studied and compared the performance of Node.js, Python-Web and PHP using benchmark tests and scenario tests[17]. The result shows that Node.js is an idea fit for I/O intensive websites. A comparison betwwen Java and PHP is conducted by Neves, Paiva and Duraes in terms of performance and security[19]. It is concluded that Java is more scalable and secure than PHP.
Although the comparison between Java and Node.js are quite rare among published paper and technological reports, a quite thorough comparison for almost all the web technologies are done by the TechEmpower [22]. The tests are conducted in physical and cloud environment. From the results, one can see Java exceeds the Node.js in almost all aspects of performance.
In comparison with all the work mentioned above, this thesis has regulated the tests in a PaaS cloud offering. In addition to the performance of single application, the scalability is also identified. The focus of this thesis is set on single transaction which is a main SAP business scenario.

Chapter 3

Load Generating Tool

Performance and load testing has always accompanied application development. There is a sea of different tools that can fulfill the task of simulating virtual end users. In the case of this thesis, the server's capacity is going to be stretched to its limit, after which instead of staying overloaded, it will try to scale and handle more clients. This requires the testing tool to be capable of generating a large amount of requests.

3.1 JMeter

One of the most popular testing tools is JMeter which is based on Java and cross-platform. It supports multiple protocols and has a very user-friendly UI to configure test plans. It even produces aggregated test results in different type of graphs. It seems JMeter has everything one asks for except scalibility. When the test requires a bigger scale, JMeter client machine quickly runs into issue that it is unable, performance-wise, to simulate enough users to stress the server or is limited at network level. An option to work around this performance limitation is to utilize remote/distributed testing [1] to control multiple remote JMeter engines from a single JMeter client. In this way, one can replicate a test across many low-end computers and thus simulate a larger load on the server. However, remote mode does use more resources than running the same number of non-GUI tests independently. If many server instances are used, the client JMeter can become overloaded, as can the client network connection. Another inconvenience of using JMeter is to find a ideal environment to host it. While one can execute the JMeter engine on the application server, one can not ignore the fact that this will be adding processing overhead on the application server, consequently the testing results will be somewhat tainted. All put together, it is decided not to use JMeter as load generating and testing tool in the thesis.

3.2 nGrinder

nGrinder [20] is a platform for stress tests that enables you to execute script creation, test execution, monitoring, and result report generator simultaneously. nGrinder consists of two major components. One is controller, a web application that enables the performance tester to create a test script and configure a test run. One is agent, a virtual user generator that creates loads. The performance team of Cloud Foundry in SAP has conducted their load test on router with nGrinder. The controller operates in a dedicated AWS c3.xlarge instance with 4 CPUs and 7.5 GB memory. Four agents are installed to create loads. Two of those agents are running on the host machine with controller and two others are distributed to another AWS c3.xlarge virtual machine. It manages to produce a load of 8500 requests per second to be handled by a router instance with 16 CPUs and 30 GB memory. nGrinder is considered too resource consuming and therefore not chosen in this thesis. Other comparatively more light-weight test frameworks like Locust also came into view but not decided for due to the complexity to scale the client.

3.3 hey

The Cloud Foundry Routing team has approached the load generating in a way similar to this thesis. They used a simple utility called *hey* [16]. The tool is written in Go which accomplishes two tasks: generate a given number of requests and aggregate a simple report at the end of the test. It occupies next to nothing of the memory (less than 10m) and is intended to quickly smoke-test a web-application. Thus it is not a complex tool which can define a desired user behavior. It is actually quite fit for the use case of this thesis except that the original implementation of the tool persist no test results in database to facilitate its lightweight. To enhance the tool with desired database connection would be too time consuming because the existence of this tool comes into knowledge at a late point of this thesis. By then, another similar functioning tool in Node.js is already maturely implemented and in use.

3.4 A self implemented scalable client

As mentioned above, most existing load generating tools require comparatively powerful computing unit to host them. In this project, it is not realistic to host such a vigorous load generator because of the cost and complexity for extra virtual machines. Additionally, if client and server are running in the same cluster, unwelcome network overhead can be avoided in some extent. Although self implemented load generator is limited in its capacity, it can be made up through scaling the load generator instance. As figure 3.1 shows, enough load can be brought about by parallel running multiple instances of the load generator application.

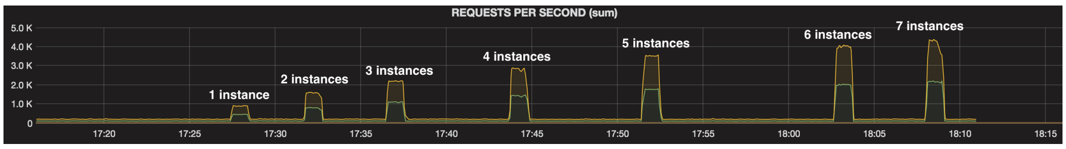


Figure 3.1: Load produced from different number of instances

Source: Grafana - Router Health

The load generator is implemented as a Node.js application. Figure 3.2 shows how it operates. It sends requests to the server, records the response time and stores them in database at the end of load generation. The application is deployed to Cloud Foundry and uses PostgreSQL database. A time-out mechanism is added to make sure load is generated in the given time frame. Except for producing fancy graphic analysis results, it pretty much accomplishes every thing a load generating tool can do. It is more flexible to work with raw data anyway.

3.4.1 Features

The majority of the load testing frameworks choose to generate a fixed number of total requests with given amount of concurrencies. For example, a typical *JMeter* test plan configures parameter *Number of Threads* as concurrent virtual users.

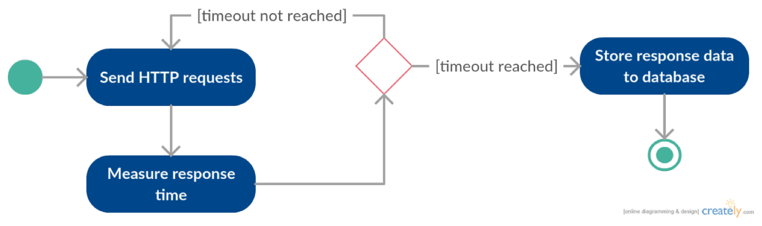


Figure 3.2: Activity diagram of load generator

Through *Loop Count*, the same concurrency is repeated so to reach the total number of requests. *Hey* defines the total requests together with concurrency degree and then carries out the load generating accordingly. The same principle behind them is that the period of time during which the tests are carried out is not measured, only the response time of individual request. So many requests shall be sent either ended with successful transaction or landed in error because of timeout or other various reasons.
The load generator used in this project produces load in two ways. One implementation also generates the load with a fixed number of requests. Another implementation brings about parallel requests in a given fixed time frame, for example in one minute. The load generator application will first pile up requests to a predefined parallel parameter. Whenever a request is successfully returned, a new one will be created to maintain the total parallel requests.

The proxy server limitation is discussed in 5.2.3. At the beginning the requests on the server was always brought about through establishing new connections. This has quickly hit the limit of what the HAProxy can handle. To work around it, the HTTP "keep-alive" is used. Although HAProxy has a strange setting of cutting off the connection after a period of time, when the duration of test is not set to this limit, it poses no problem.

3.4.2 Limitations

Since load generator is deployed as a worker in Cloud Foundry, it has little choice over database selection. In this thesis, a docker containerized database (PstgreSQL) is used owing to the fact that other dedicated backing services are not free of charge. There are times container's storage capacity is exceeded and refuse to store any more data.

Secondly, load generator can be resource consuming as already discussed. In Cloud Foundry, some cloud offering plan has only restricted size of memory to provide. It could be hard to scale the load generator to ideal capacity. In this thesis, for a period of time the load testing is conducted in a staging landscape of Cloud Foundry with a limited space quota of 10G memory. Imagine all the applications and load generators scaling together, the space limit is easily exceeded.
Last but not the least, there is a chance the load generator is running on the same node as applications which will directly influence the CPU share the application could obtain and result in tainted test results. In the thesis, this unlucky scenario is avoided by deploying the load generator in DEA cells while the application is running in Diego cell (DEA and Diego will be explained in 5.2.1).

Chapter 4

Measuring Tool

A critical part of performance testing is to ensure as few variables as possible change during each run of the experiment. This generates more consistent results, and allows easier comparison between test runs.
In a typical scientific experiment setup, the variables are separated into dependent, independent, and controlled variables. The dependent variables for this testing are of course the throughput and latency numbers that result from performance benchmarking, as well as the CPU and memory usage of the applications during the test runs. For independent variables, the implementation of the application: in Node.js or Java. The exact same tests are running against the two implementations. Besides these variables, everything else is controlled and kept static, for example, applications are deployed to the same cloud landscape to avoid possible falsified results from different network latencies.

4.1 Average response time and throughput

The average response time takes into consideration every round trip. The resulting metric is a reflection of the speed of the web application being tested – the best indicator of how the server is performing from the users' perspective. The average response time includes the delivery of all resource being used. Thus, the average will be significantly affected by any slow components.
In the thesis response time is measured in three different places as you can see from figure 4.1. The first measurement is done by load generator which records the true

end-to-end time and throughput. The second checkpoint is the response time retrieved from Logstash which present the round trip from router. Last measuring spot is inside the server itself. It reflects the round trip of a query in database. The end-to-end measuring result is used in the final performance analysis while the others serve as tool to determine where the bottleneck of the performance test is. Since the requests sent from the load generator contains a unique correlation id in its header, it is possible to track one request through all the measuring positions.

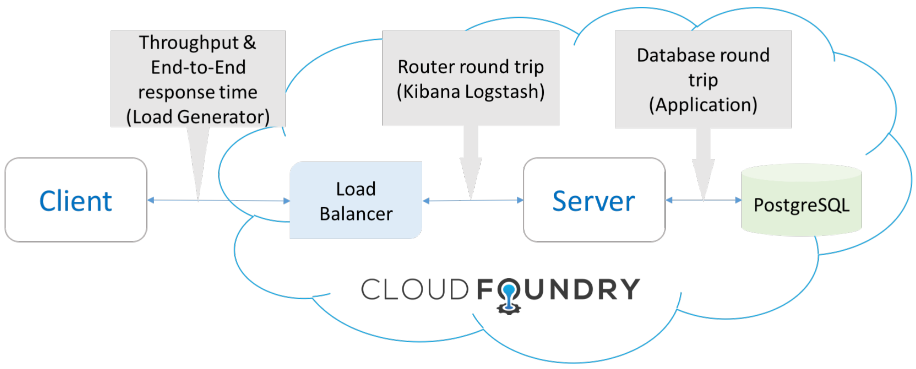

Throughput & End-to-End response time (Load Generator)
Router round trip (Kibana Logstash)
Database round trip (Application)
Client
Load Balancer
Server
PostgreSQL
CLOUD FOUNDRY

Figure 4.1: Measure response time three different places

Throughput is the measurement of bandwidth consumed during the test. It shows how much data is flowing back and forth from servers. The requests made to the server in the thesis do not consume data of any significant size, such as images. Therefore the throughput would directly reflect successfully handled amount of requests during the load testing.

4.1.1 Recording with Load Generator and its limitations

In chapter 3.4.1, it is discussed how the load generator drives loads. It carries another duty to record the end-to-end response time for each request. Together with response time it also stores the correlation id and the start time for each request. The data is first saved into an array and inserted into database at the end of load generation.
However, this information is not enough. It would also be great to know the stored result is resulted from which test settings, like how many application instances or how many parallel requests are sent. Therefore these meta information is given to

the load generator and saved along with response time. Since the load generator in this thesis is only a worker, it doesn't provide any API to call with given parameters. All the information external from the generator has to be given as start command. However, in Cloud Foundry one application's start command is defined when it is pushed. This means the generator has to be pushed anew to the Cloud Foundry every time the parameter is changed. A small shell script is written to fulfill the task of pushing.

It is easy to scale load generator according to what one needs. On the other hand, it also means the generator has to stay stateless, which results in certain amount of manual work. For example, the same test settings may be carried out in several rounds. The result of different rounds should be saved to compare with each other. Making *testround* a automatically incremented data type is what first comes to mind. Yet it can't be defined like that when there are more than one instance of the generator running. This parameter is hence manually given for every new round of test.

4.1.2 Retrieving response time from Logstash and its limitations

It involves multiple components to accomplish one little task for an application, for example the application server, database, router and so on. Performance test can very easily hit limit of one of the components and converting the test of application into test of a router or database. In order to avoid such cases, finding and ruling out the bottleneck of all the components are carried out.
Network is one of the major causes of bottleneck. Is the router capable of taking in so many requests? The best way is to get the response time from router. Although router is not accessible as a component to the developers, Elasticsearch, Logstash, and Kibana (ELK) [27] is integrated into Cloud Foundry at SAP. Router response time is logged as default for every request. The logs produced in the application are saved in Logstash[12] and visualized in Kibana [13].
However, in order to compare the router response time with end-to-end response time, just reading the results from Kibana is not enough. To investigate what causes an exceedingly long response time, one has to look into the precise request and do the comparison. Kibana's visualization is pretty but more convenient would be

directly comparing the figures from Logstash. To retrieve the results, a script is written. It sends a json query to the logstash and then parse the query results and sort out the response time logged by router. Afterwards, the statistics are stored into a database.
Of course, the result from Logstash can be very large and it takes some time to retrieve it. More strangely the logs appeared to be incomplete. Especially when the load is large. Only ten percent of the requests are retrieved from Logstash. After ruling out there is anything wrong with the application that retrieves the result, it is observed that the logs are always retrieved as bundles of 1000 requests which can be clearly seen from visualization in Kibana. After inquiring the colleagues responsible for ELK on Cloud Foundry, it turns out there is quota for logs. They don't come unlimited. One can only get a certain number of logs preserved per hour or per day.
In spite of incomplete information from Logstash, the comparison from the retrieved data shows the router has no performance bottleneck, at least not at the scale this thesis is aiming for. This leads to the discovery of the HAProxy limitation discussed in chapter 5.2.3.

4.1.3 Recording data inside the application and its limitations

This would be a very simple task if there is no log limit in Logstash: just log the response time recorded in application and retrieve it from Logstash. With the restriction present, the data has to be saved in database. To elevate the performance of saving such large amount of entries, measures have to be taken: using batch in Java and manipulating array to realize a bulk insert in Node.js. In this thesis, the response time and correlation id are saved in an array for all the requests. Another endpoint is defined inside the application to transfer the statistics in array into database.
Looking into the response time from database also helps to discover whether the limitation of database is reached. For example, up to a certain number of parallel requests from load generator, the throughput of the application no longer increases while the average response time goes up, which indicates there is a bottleneck. If slower requests also has a longer database response time, it implies the bottleneck is resulted from database.
Another thing to be taken into consideration is the memory consumption which will grow infinitely if one does not transfer recorded data to database. As said above, the

information obtained from the application help to identify the efficiency of database. After the identification of limitation, one no longer needs to analyze the database response time. The information stored in array is not transferred to database any more. As a result, the array will accumulate, grow into a considerable size and eventually cause out-of-memory. For example, correlation id is saved as 36-letter *string* which consumes 36 * 2 byte memory. Response time is saved as *long* which takes 16 byte. Putting them together, a request needs 88 byte memory to store the response information. If one round of load test generates 100000 requests. it will result in occupying up to 8 MB memory. A Node.js application as a whole only needs maximum 100 MB to run. Therefore a switch should be built inside the application to turn off recording the data or there should be a central operational endpoint to clean up the array before each load testing.

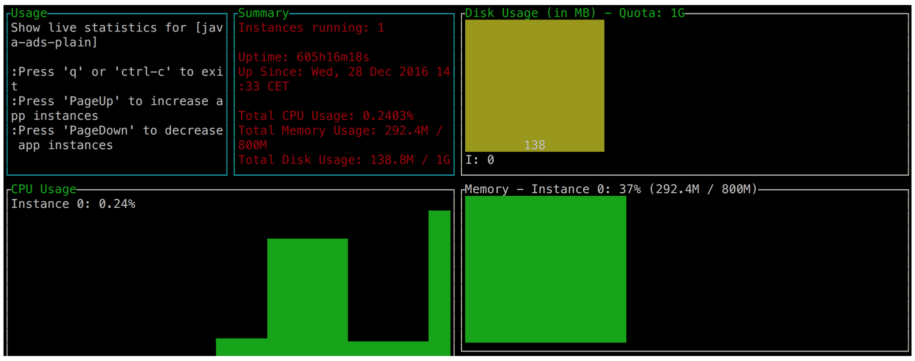
4.2 CPU and Memory consumption

In chapter 5.2.3, it is described how Cloud Foundry allocate its computing resource. In this thesis, tests are conducted on different days and sometimes we notice some out of ordinary fluctuations which can be resulted from reallocation of computing resource. Nevertheless, CPU and memory consumption are gathered as key metrics since they are directly related to todays cloud pricing mechanism.

4.2.1 Cloud Foundry CLI and its limitations

Since we have no direct os-level access to the virtual machine in Cloud Foundry, we can not investigate into the node. However, the Cloud Foundry command line interface provides simple command *cf app <app-name>* to check the metrics. However, it is extremely tedious and inconvenient to request for the information from command line. Luckily there is a plugin, *cf statistics* [15], which delivers real-time metrics and statistics data. This plugin displays a terminal dashboard showing current app usage metrics/statistics as shown in graph. It can also stream these metrics as JSON formatted output to stdout. It is decided to use the plugin in the thesis.

Although this tool is better than the command line, it still requires manual operation. The data gathered can not be stored into database along with other information. After all what the plugin does is only request the API of Cloud Controller [21] from



```
Usage
Show live statistics for [jav
a-ads-plain]

:Press 'q' or 'ctrl-c' to exi
t
:Press 'PageUp' to increase a
pp instances
:Press 'PageDown' to decrease
 app instances
```

```
Summary
Instances running: 1

Uptime: 605h16m18s
Up Since: Wed, 28 Dec 2016 14
:33 CET

Total CPU Usage: 0.2403%
Total Memory Usage: 292.4M /
800M
Total Disk Usage: 138.8M / 1G
```

```
Disk Usage (in MB) - Quota: 1G
138
I: 0
```

```
CPU Usage
Instance 0: 0.24%
```

```
Memory - Instance 0: 37% (292.4M / 800M)
```

Figure 4.2: cf statistics display

Cloud Foundry and gather them together. In the long run it would be advised to write a separate application which fetches the information from cloud controller's rest API as part of the load testing tool.

4.2.2 Memory consumption

The memory has double meaning in cloud foundry. One can assign a certain amount of max memory to the application which also decides the computing resource an application can get. However, the application doesn't necessarily consume that much. How much memory does an application need to run? It is known, at some point, when the heap reaches its maximum capacity, a full garbage collection will occur, which will bring down the size of the heap memory. Then it will start to grow again and the cycle should continue as long as the application is running. An application with no memory leaks should continue this cycle until the application is stopped.
For apps deployed on Cloud Foundry, one way to find out the actual memory to run the application is to let it run under load until the first full garbage collection occurs. The total used memory of the container will continue to grow until this first garbage collection occurs. After that, the memory utilization of the container will stabilize and will not grow any more with sustained load. Figure 4.3 shows how the load test is conducted to find out how much memory the application needs to run.

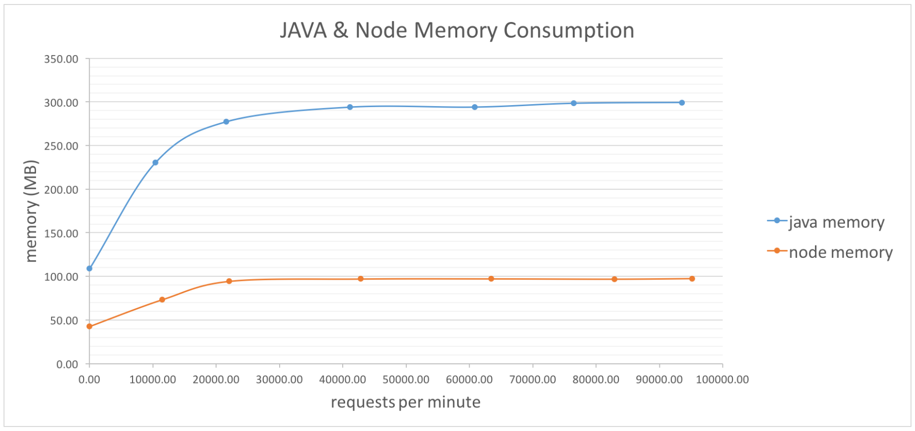


Figure 4.3: Find out the memory Java and Node.js applications need

4.3 Access data from backing service

In the thesis, raw data instead of aggregated data is collected and saved in database in Cloud Foundry.
Toad extension for eclipse [25] is used in the thesis to connect to database and query data. It has no problem connecting to local PostgreSQL using TCP connection, as long as information such as hostname, user, password etc. are provided. Run the command *cf env <application-name>* in Cloud Foundry, one can find a detailed information regarding the backing service. For PostgreSQL, the information one needs to establish connection is all listed. It seems to be only straightforward to get into the database. However, direct TCP connection to PostgreSQL in Cloud Foundry is not possible as the database resides inside the Cloud's subnetwork.
Cloud Foundry has provided a solution. It has enabled SSH access to the services in Diego cell [11]. However, if one is behind a cooperate proxy, for example, SAP proxy, the SSH connection cannot be established.
Finally, Chisel [18] comes to rescue. It is an HTTP client and server which acts as a TCP proxy written in Go. It is an application to be deployed to Cloud Foundry and binded to the target backing service. By starting the application, it maps TCP endpoits of backing services to local workstation and ready to be connected from the toad extension.

Chapter 5

Experimental Environment

The experimental environment is of most importance for technical evaluation. It is also impossible to find a configuration which can do both technologies justice. One can easily end up trapped by some technical limitation of a framework that one uses or in the case of this thesis, confined by existing infrastructure provider. However, as the thesis is conducted under the company context, the limitations have to be accepted and taken into account.

5.1 Server in local machine

Locally a Virtual Box running in Ubuntu 14.04 with 4 CPUs and 12G memory is installed on host machine which is a Macbook Pro with 4 CPUs and 16G Memory. However, the application has to share the resource with database and load generator which is not at all a neat configuration.

5.2 Server running environment - Cloud Foundry

Cloud Foundry is an open source software bundle that allows you to run a polyglot Cloud Computing Platform as a Service (PaaS). Initially it was developed as a Java PaaS for Amazon EC2 by Chris Richardson, in 2009 acquired by SpringSource, which was then acquired by VMWare, then handed over to Pivotal. The Cloud Foundry Foundation [3] is now the maintainer of Cloud Foundry. More than 50 companies are members of this foundation, such as Pivotal, EMC, HP, IBM, Rackspace, SAP, or VMWare. The Cloud Foundry PaaS is a multi-component automation platform for application deployment. It provides a scalable runtime environment that can support most frameworks and languages that run on Linux. It also contains many components that simplify deployment and release of microservices applications (for instance, Router, Loggregator, Elastic Runtime (Droplet Execution Agents (DEA)), a message bus (NATS), Health Manager, Cloud Controller, etc.)

5.2.1 Cloud Foundry at SAP

Compared with other PaaS offerings, Cloud Foundry has some unique features: it has no limitation on language and framework support and does not restrict deployment to a single cloud. It is an open source platform that one can deploy to run his apps on his own computing infrastructure, or deploy on an IaaS like Amazon Web Service (AWS), vSphere, or OpenStack. In SAP, it is first integrated with SAP Monsoon, then later shifted to OpenStack and now hosted in AWS.
There are multiple landscapes of Cloud Foundry in SAP. One is called "AWS live". In this landscape, applications run inside containers managed by Warden [9] containerization (a visualization technique providing isolation on operating system level, which is more efficient than virtual machines). The Warden containers including the applications running inside are managed by DEA that also monitor the application health and provide the management interface to the Cloud Foundry platform.
Another landscape is called "AWS Canary". In addition to DEA, each application VM has a Diego Cell [7] that executes application start and stop actions locally, manages the VM's containers, and reports app status and other data to the Bulletin Board System (BBS) [8] and Loggregator. Instead of Warden, Garden [4] is used as the containers to create and manage isolated environments. Diego architecture improves the overall operation and performance, for example supporting Docker containers.

5.2.2 Backing services, service plans, and scaling

Services such as database and authentication form the core of a PaaS offering. Cloud Foundry emphasizes on its flexibility in terms of backing services. It distinguishes managed services that obey the Cloud Foundry management APIs, and User-provided Services that serve as adapters to external services. In context of

SAP, featured service like HANA database is offered along with other popular SQL and NoSQL databases. These services come with different plans, which define the size and capacity they are capable of offering. For example, PostgreSQL database has a service plan which is delivered in a docker container with predefined maximum number of connections. There are also other plans which provide PostgreSQL in dedicated VMs with different database sizes from extra small to extra large.
Service binding in Cloud Foundry is a simple way to provide the application connection information on certain backing service. With frameworks like Spring cloud, the actual database connection is extremely simple to establish and manage within application. In this thesis, as no extra frameworks are used, application parses the connection information from the environment variable *VCAP_SERVICES* .
Since applications and its essential external components are loosely coupled in the context of Cloud Foundry, it leads to easy scalibility which constitutes the ultimate goals of cloud. In short, everything is a service in Cloud Foundry: the application, platform functionality (backing services such as persistency, messaging...), and of course external services to use or integrate with. An application has its own data store, can be implemented and deployed independently, and communicates with other services using lightweight mechanisms. In this way, horizontal scaling of the system is supported. One can scale services up and down by adding or deleting service instances.

5.2.3 Limitations

As mentioned at the beginning of this chapter, it is impossible to have a perfect environment to conduct a evaluation of the performance of given technology. It is also not easy in Cloud Foundry.

Limitation of CPU resource

The first difficulty is to ensure that both Java and Node.js applications obtain the sufficient and comparable computing resources. Easiest way is to have Java and Node.js applications running on the same VM. However, in Cloud Foundry, applications are not confined to a single cloud. There is no way to regulate the deployment to a dedicated VM on which only the given applications are running. So if one doesn't know if application is running on the same VM, one tries to at least make sure both applications have the same CPU resources allocated. As mentioned above, Cloud Foundry uses containerization which provides operating-system-level virtualization instead of simulating bare computing hardware. This means multiple instances running in their respective containers share the same operating system. CPU shares instead of direct CPU time are first distributed. Each container is placed in its own cgroup. Cgroups make each container use a *fair share* of CPU relative to the other containers [6].This implies two layers of meanings. First, CPU shares are set aside for application according to the memory. Applications with larger amount of memory reservation receive more CPU shares. But does the applications have the same CPU resource when they occupy the same amount of memory? Not necessarily. The second step to designate CPU time is *relative to the other containers*. The following table 5.1 shows the CPU allocation for 3 applications running in the same VM.

Table 5.1: Example: allocate CPU time in Cloud Foundry

Application Name	Memory	CPU Shares	CPU Percentage	State
A	100 m	10	20%	running
B	200 m	20	40%	running
C	200 m	20	40%	running

Nevertheless, this schema of CPU allocation only shows when all the applications are running. If application A now starts idling, B and C will both get 50% of the CPU resources. If only C is running, it gains whole 100% of the computing power. This is why securing identical CPU resource for two applications deployed in Cloud Foundry is impossible.

Limitation of database service

Cloud Foundry backing services are very convenient to use but is often not free of charge when one needs a bit more performance. In this thesis, the docker container version of PostgreSQL is used owing to the fact that all other dedicated services cost. The database used in the thesis has a limited number of 100 connections per service instance. Luckily, with connection pooling one application barely needs so many connections. Nevertheless, it does set a threshold on how many instances the application can scale. Large number of scaling is not discussed in the thesis therefore the database is still chosen as default for the performance testing.

Limitation of proxy server

Scalibility certainly doesn't come for free. The cloud infrastructure also needs to cope with high load brought about by scaling of application. During the thesis, a strange scenario has occurred: the total number of throughput in a minute lingers around 21,000 to 23,000 when the parallel requests reach a certain number. There must be a bottleneck somewhere. Is it because of how the application is implemented? Then the throughput should rise when more application instances are there to handle requests. However, no matter how many application instances are running to relieve the stress, the result stays the same. The CPU usage of the application doesn't go beyond 20%. The load is no more than a scratch on the application.
Is it because the database simply no longer has enough connection? We can try to give application an additional database. To scale the database is somehow more complicated than scaling the application. Instead of adding one instance to the existing application, another identical application is deployed to Cloud Foundry with its own database instance. The same route is mapped to the new application. Load balancer distributes the requests between two applications. As there are two database instance now, the database capacity is doubled. However, this also changes nothing. To absolutely rule out the limitation is database, the application is pushed to cloud without database at all as a simplest "Hello World" application. The limit of throughput persists.
Finally, after some searching into existing issues reported from other users, it turns out the bottleneck is in network. Cloud Foundry has a router written in Go, called Gorouter [5] which does routing and load balancing. The router performs perfectly and can handle 5,000 requests per second without a hiccup. Nonetheless, Gorouter is not the only thing standing between client and application. The requests coming outside of Cloud Foundry are secured HTTPS calls to keep sensible information from hackers while routes are not encrypted during load balancing. This means before the request is routed to the destination, another server has to terminate SSL and change HTTPS calls to HTTP. This task is accomplished by High Availability Proxy (HAProxy) [10] by the time the thesis is finished. HAProxy is never meant

to be put in a productive Cloud Foundry landscape owing to its incapability of scaling. Every HAProxy can handle maximum 100 requests per second till its CPU consumption hits the ceiling. That is when it stops handling any more requests. In the current landscape, there are 4 HAProxy servers. Since they can not scale, it results in a network bottleneck where no more that 400 requests per second can be consumed. This is exactly why the strange scenario come into being. To overcome this restriction, either the proxy server should be changed into scalable ones, which is on the agenda of first quarter 2017 or keeping the connection to Gorouter alive and sending more requests in one decrypted connection. The latter choice is carried out in this thesis which is mentioned in 3.4.1.

5.3 Client running environments

Where the client is running can influence greatly the performance of the server. What is the network latency? Do they share the same computing resource? To minimize all the influence to zero is next to impossible. Different approaches are discussed in the following.

5.3.1 Client in the local machine

Putting the client and server physically in one machine can almost eliminate the network overhead. However, they consume the same computing resource and inevitably will be affected by other processes simultaneously operating. One client instance won’t be enough to generate sufficient load to stress the server application. The moment one tries to scale up the total number of client application, it starts to compete resource with the server application. This leads to tainted test results.
If the client is operating in a local machine and sending requests to a server in cloud, the network latency will be too high to ignore.

5.3.2 Client in Cloud Foundry

Running the client in Cloud Foundry poses less network overhead for the request, although requests still have to go through HAProxy to arrive at Gorouter despite the fact that client and server are under same domain or even running on the same

VM. Another convenience to run client on Cloud Foundry is that it is simple to scale. One client instance will have its limitation in sending parallel requests, but one can have as many instances as needed. This is powerful and essential for this thesis. However, client and server may still compete for resources if they happen to be deployed to the same VM. Measures have to be taken to best prevent it from happening.

5.4 Server and client configuration in the thesis

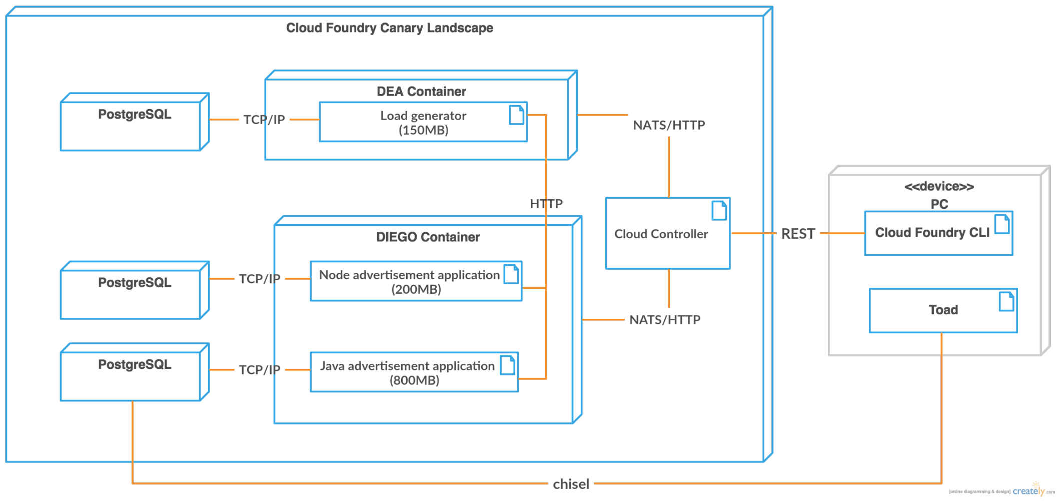


Figure 5.1: Deployment diagram for test environment

With all the matters considered, figure 5.1 shows the final setting of testing environment. First, both client and server are deployed in the same landscape in Cloud Foundry in order to minimize possible network overhead. Second, to avoid the scenario that load generator is running in the same VM as the applications, the client and server are deployed into different containers. Clients are in DEA while applications are deployed to Diego. In addition, separate PostgreSQL database services are assigned to applications so that the load on the database is distributed. To retrieve data from database, chisel is used to bring TCP tunnel over HTTP, so that Toad extension on local machine can access the test results. Finally, through Cloud Foundy CLI, requests on application health are made and CPU and memory consumption information is gathered.
Another thing to pay attention to is how much memory the applications are allocated. For Java application, 800MB memory is set aside. As mentioned in 4.3,

it turns out Java needs about 300MB. However, since Java relies heavily on CPU shares allocated to it, more memory is alloted to ensure it has enough CPU even in a crowded node. On the contrary, Node.js application is given 200MB for the reason that it is single-threaded and more memory doesn't help it gain more computing resource. For the sake of not running into situation of not having enough memory due to operational overhead in application such as garbage collector, memory is given quite generously to both applications.

Chapter 6

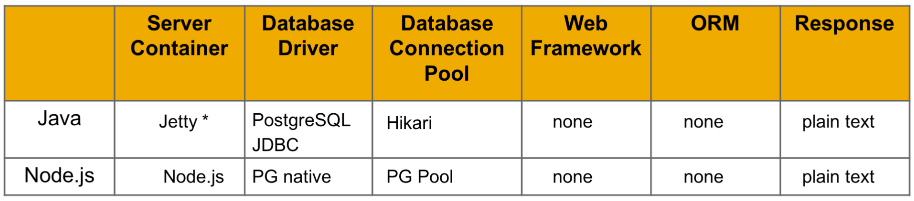
Implementation of Applications

Store the current order of product and its meta information, find which shelf stores the current requested product, assign an idling logistic unit to pick up the itinerary ... I/O intensive operations make up the majority of SAP business scenarios. In the load test conducted in this paper, applications are built to realize such a scenario: advertisements are published in a bulletin board and clients can browse through the items.

The PostgreSQL backing service from Cloud Foundry is used as the database. As the goal is to test how the application handles large amount of concurrency instead of the database efficiency, data will not be queried in high quantity or by complicated SQL actions in the test.

6.1 Implementation Configuration

To bring Java and Node.js to a comparable level, the applications are implemented with minimum use of frameworks so that the overhead or any other influential factors on performance can be first taken off the table.



	Server Container	Database Driver	Database Connection Pool	Web Framework	ORM	Response
Java	Jetty *	PostgreSQL JDBC	Hikari	none	none	plain text
Node.js	Node.js	PG native	PG Pool	none	none	plain text

Figure 6.1: Implementation configuration

As table 6.1 shows, the implementation of both applications utilize no REST or any other kind of web framework. No ORM is applied. Response is sent as plain text to the client to avoid overhead brought by using framework to do JSON serialization/deserialization.
Java application uses embedded Jetty server to handle plain HTTP requests because its lightweight. (* There is an even simpler built-in HTTP server from Oracle JRE. However, the build pack used in Cloud Foundry is OpenJDK JRE.) Node.js application uses its embedded web platform. The connection with database is plain JDBC for Java while Node.js uses a popular PostgreSQL library: PG. Since the data structure is intentionally kept simple: only one table and with no complex data types, the application without ORM doesn't bring about a lot of boiler plate code.

6.2 Optimize the Java implementation

All possible attempts are made to bring about every potential performance of the application. Since there is no complex logic, the focus of optimization lays on the interaction between applications and database. In case of Java implementations, to set a optimal thread pool configuration is also investigated.
The first checkpoint is database connection which greatly affect performance since it is the most expensive operation in the application without a complicated computing logic. Opening a connection and closing it with every request would gigantically slow down the application. Therefore connection pool is a key component in the implementation. It turns out there are quite a few libraries which handles connection pooling. In the thesis, three different libraries are tried out. *PGPoolingDataSource* [26] comes with default PostgreSQL JDBC driver. *commons-dbcp2* [23] is from Apache Software Foundation. *HikariCP* is a "zero-overhead" production ready connection pool. It turns out *HikariCP* [29] has outperformed the other two.
The next thing is to find an ideal configuration for the connection pool size. In an article from Brett Wooldridge [28], it is pointed out larger connection pool size configuration doesn't necessarily lead to a better performance. Single core can only execute one thread at a time; then the OS switches contexts and that core executes code for another thread, and so on. Given a single CPU resource, executing A and B sequentially will always be faster than executing A and B "simultaneously" through

time-slicing. Theoretically, the database will be slowed down the moment connection pool size exceeds the total core number. However, there are a few other factors at play. For example, databases typically store data on a disk, which traditionally is comprised of spinning plates of metal with read/write heads mounted on a stepper-motor driven arm. So there is a time cost for disk "I/O wait". During this time the OS could put that CPU resource to better use by executing some more code for another thread. Because threads become blocked on I/O, more work can be done by having a number of connections/threads that is greater than the number of physical computing cores. In the case of thesis, database is running in Diego cell which con-

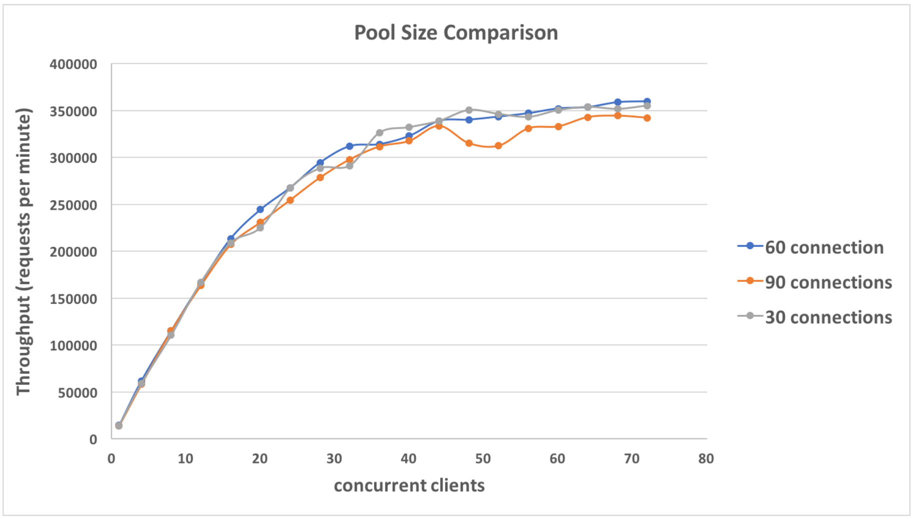


Figure 6.2: Database connection pool size comparison

tains 4 CPUs. In order to verify and find the best fit for the load the thesis intend to generate, an experiment is conducted with connection pool size of 30, 60, and 90. Figure 6.2 shows a slight difference can be deducted that the pool size of 90 reaches the upper limit of total transaction slightly earlier than the other configurations. A little bit better is the performance from a connection pool size of 60 than that of 30. Then we compared the end-to-end response time with the data base response time. As figure 6.3 shows, when the response time peaks, the database response time stays stable and can hardly be considered responsible for the peak. Since the database pool size doesn't pose a conspicuous difference, we can draw the conclusion that the database is working at a high speed with no noticeable delay. The pool size setting is not a deciding bottleneck at all. It could be because the database is a docker container version and has no dedicated virtual machine. Thus it lies likely quite near the application and has little network overhead.

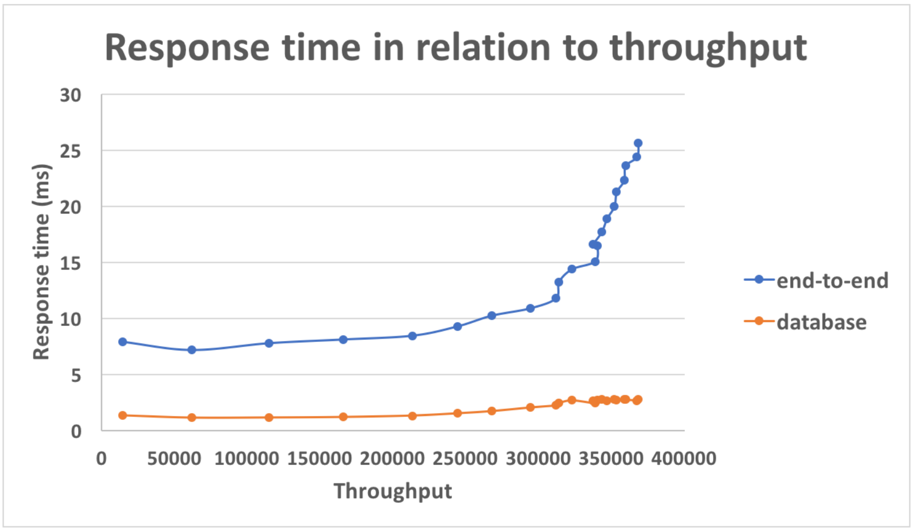


Figure 6.3: Comparing end-to-end response time with database response time

Thread pool size is also scrutinized for Java application and following the recommendation made by Jetty [24], the size is set from 10 to 400.

6.3 Optimize the Node.js implementation

Node.js application basically faces the same configuration of connection pool in database. In the thesis, also three different libraries are tried out. Unlike Java libraries, there is some overlapping with regard to the Node.js libraries. In npm, one can find a number of PostgreSQL drivers. However, majority of them are built on the basis of one library: "node-postgres/pg" [2]. They are either wrappers or additional implementation with "promise" or "async/wait". For example, a great difference can not be derived from using of "node-postgres/pg" and "pg-promise" in the scenario in this thesis. The comprehensive research on framework benchmarking [22] uses "Sequelize", which is also tried out in the thesis. However, it yields even a worse performance result because the object mapping costs indisputably computing time. In the end, the suggestion from "node-postgres/pg" writer is adopted to use "pg-native" which can boost a 20-30% increase in parsing speed.

Chapter 7

Test Strategy, Results and Analysis

7.1 Test strategy

At the beginning of the testing phase of the thesis, both applications are given the same amount of memory to ensure they have the same CPU share. It turns out, Java has nearly twice as much throughput as the Node.js application. It seems we are comparing something which is totally not comparable at all. It is also quite far away from expectation. Things are tried and investigations are made to identify the cause.
The monitoring on CPU usage shows that the Java application can utilize up to 250%. In contrast the Node.js application barely exceeds the limit of 100%. This has everything to do with the single-threaded architecture of Node.js platform. While Java application is through adding CPU and memory vertical scalable, Node.js is single-threaded and scales by creating multiple-node processes. It is only fair to test both application when they utilize the same amount of CPUs. However, the Cloud Foundry's specific way of designating computing resources ensures there is no neat cut of a piece of CPU unless one is completely alone in the landscape. Therefore, multiple configurations of tests are conducted and described in this chapter so one can analyze the results from different aspects.

7.2 Test with 100% CPU consumption

In this test, the fixed variable is average end-to-end response time which is kept under 10 ms as a criteria for optimal performance. An additional bar is set on the CPU consumption which should not exceed 100%.

In the context of Cloud Foundry, it is impossible to assure an application using only one CPU. Although setting the memory of application can limit the CPU shares it can get, if other applications on the same node are idling, even the tiniest application can get all the 4 CPUs of the node. In terms of the Java application, it consumes already much more memory than the Node.js application as shown in 4.3. Hence it is unlikely only one CPU is given to the application. What one witnesses as a 70% CPU is also very likely distributed across several CPUs.

Figure 7.1 shows the result of the test described above. It can be deducted from the graph, that Java has a better performance because the same percentage of CPU brings about more throughput in Java application than in Node.js. Since the CPU distribution is unclear, it can be accounted for that the Java application is likely running with 4 or 2 very relaxed CPUs while Node.js is grabbing every bit of computing resource from that single CPU. We can clearly observe that the growing tendency in throughput from Node.js becomes weaker when the CPU usage approaches 100%. This shows Node.js already operates on tight CPU resources and has to split part of its processing power for garbage collecting or other operations. This also leads to the reflection on the results of benchmarking from TechEmpower [22]. It has concluded that in terms of applications on cloud, Java is twice more efficient than Node.js. It is possible the CPU distribution is not taken into consideration at all.

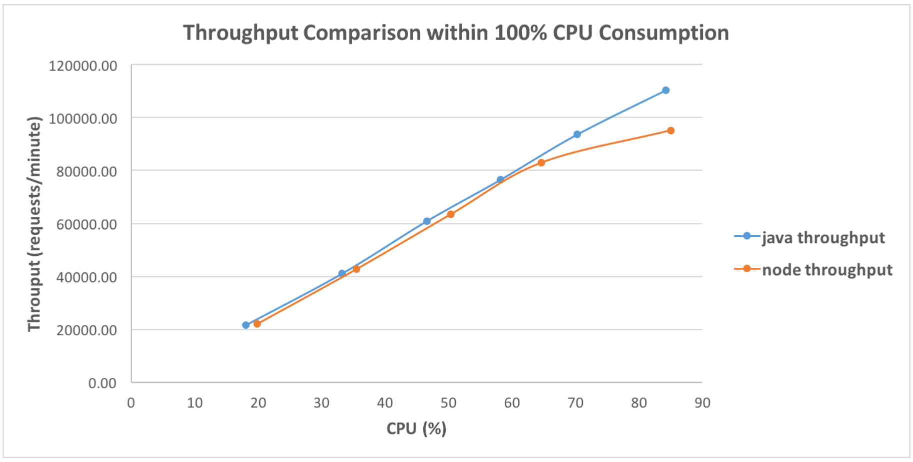


Figure 7.1: Compare throughput under 100 CPU consumption

7.3 Test with real load

7.3.1 Test configuration

In this round of test, applications are going to scale. How should it be determined whether two applications are equally scaled? As found out earlier, one Java instance utilizes more CPU while one Node.js employs only one, which leads the test to comparing vertical scaling in Java application with horizontal scaling in Node.js. This is still feasible if one can be sure Java always obtains the same amount of CPUs. However, figure 7.2 shows, that Java application never get to use all of its 4 CPUs. The database connection and router load are checked and they are not under stress at all.

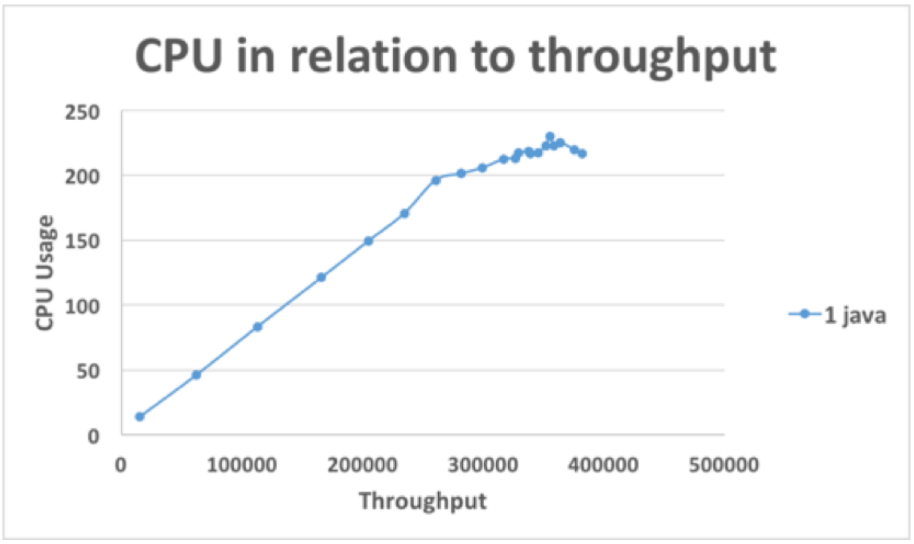


Figure 7.2: Limited CPU usage in Java application

An abnormal increase in memory is observed in figure 7.3 which indicates something suspicious in the application. The implementation is scrutinized, nevertheless, in the thesis no obvious cause is found. This leads to the realization that even though one Java instance gains 4 CPUs, it doesn't equal to four one-CPU Node.js instances. Therefore the comparison in the thesis would not be restricted to one Java instance against multiple instances from Node.js. Load will be continuously added on to the application. Then the applications will scale when the response time shows a clear tendency to climb. At the end, an aggregated comparison will be made.
Load is brought about through sending one request to the application per instance of load generator. It is decided not to send parallel requests so as to guarantee each instance of the generator is simulating one end user. With each new round of test, 4

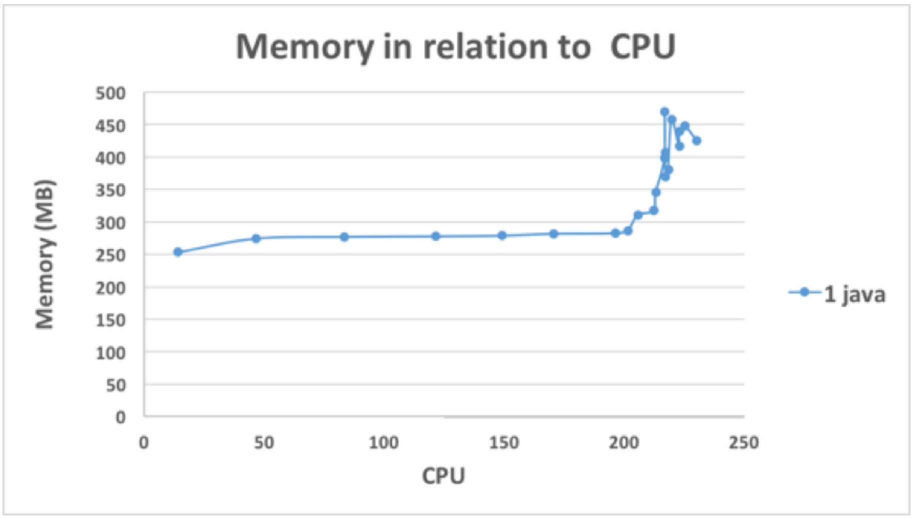


Figure 7.3: Abnormal surge in memory

instances will be added to the existing running load generator. The maximum load generator instances will be 96 so that the limit of database connection will not be exceeded.
Java application will stop scaling when router has reached its limit (70% load). For Node.js applications, we stop the scaling when the CPU usage reaches the maximum CPU usage of Java applications tested previously.

7.3.2 Test result

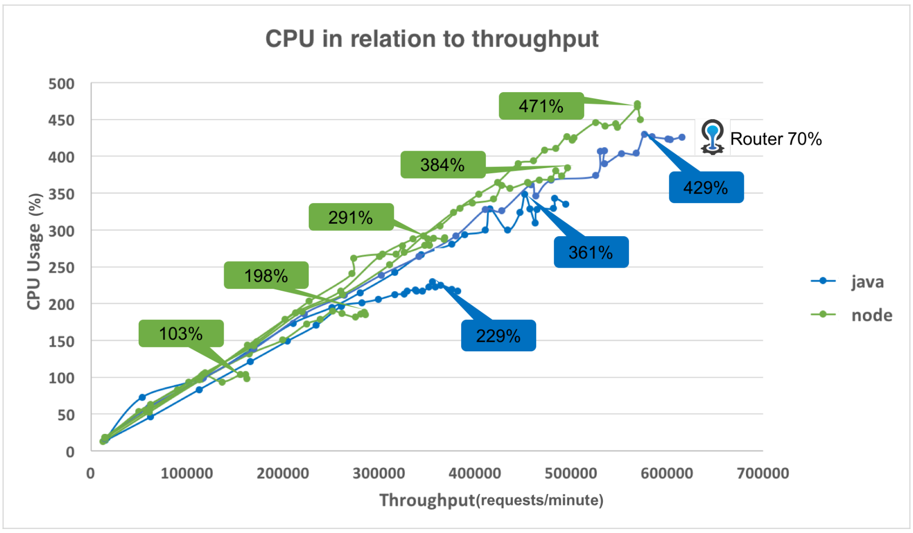


Figure 7.4: Throughput in relation to CPU

In figure 7.4, it is illustrated the throughput in relation to the CPU usage. Java applications are shown in blue lines. Tests are conducted on running instance numbers of 1, 2, and 3. The xx axis displays the throughput , the yy axis lists the CPU consumption. When 3 Java applications are running, the router reaches its maximum capacity and becomes bottleneck because no more requests can be handled efficiently by the router. Marked also in figure 7.4 are the maximum CPU usage. As summarized in table 7.1, for the Java application, with every increase of instance, the CPU usage from total available CPU decreases, which indicates the application doesn't scale horizontally by adding more instances.

Table 7.1: Percentage of utilized CPU

Application type	Instance Number	Max. CPU Usage%	Max. Available CPU%	Utilization
Java	1	229	400	57%
Java	2	361	800	45%
Java	3	429	1200	35%
Node.js	1	103	100	103%
Node.js	2	198	200	99%
Node.js	3	291	300	97%
Node.js	4	384	400	96%
Node.js	5	471	500	94%

The same performance information of Node.js application is also depicted in figure 7.4 in green lines. The test ends with 5 instances of Node.js application. It is when the CPU usage is in the same range of maximum CPU usage occurred in Java tests. As put together in table 7.1, application shows a quite steady utilization of more than 90% of the available CPU resources. It implies a horizontal scaling towards adding instances. If we draw a line down to the xx axis to see the corresponding throughput like 7.5, we can see the throughput scales also with adding instances. Since every instance makes full use of the CPU, the throughput scales also linear per CPU.

Although we observe an inefficient utilization of available CPU from Java application, we still want to know whether the applied computing resource is efficiently used. In figure 7.6, we also draw four lines down from 100% to 400% CPU usage respectively to show the throughput it handles. As presented in the chart, with increase of CPU, throughput scales almost linear.

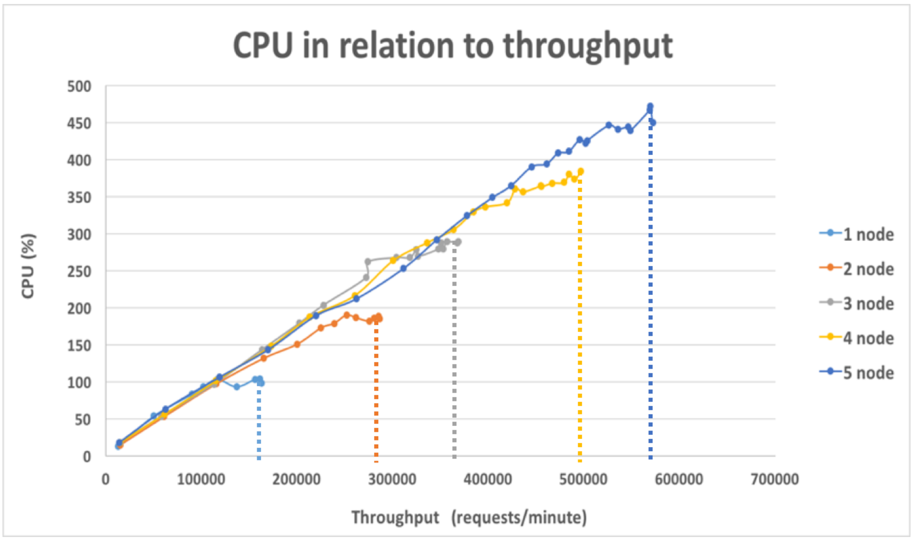


Figure 7.5: cpu efficiency of Node.js application

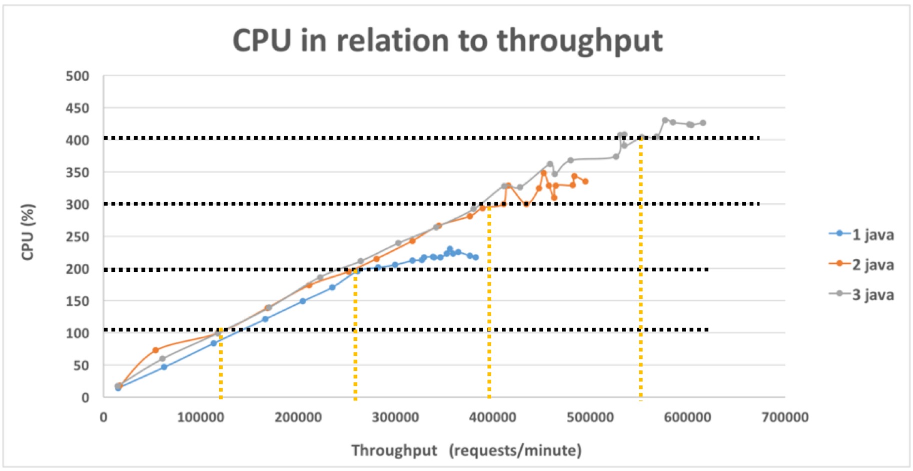


Figure 7.6: cpu efficiency of 3 Java instances

The last metric to check is memory consumption. As displayed in figure 7.7, Node.js shows excellent memory utilization for the whole test range while Java is quite memory demanding. Although it offers some performance gains in terms of handling more requests than the Node.js, it is not in proportion with the memory consumption.

However, the sudden surge in the case of one running Java instance should acquire our attention. This might reveal some cause for the incapability of using all the CPU power assigned to the application. If the memory consumption fluctuation and inefficient CPU utilization can be resolved, Java would demonstrate a great vertical scalability. Although Node.js needs less memory for a single instance, the

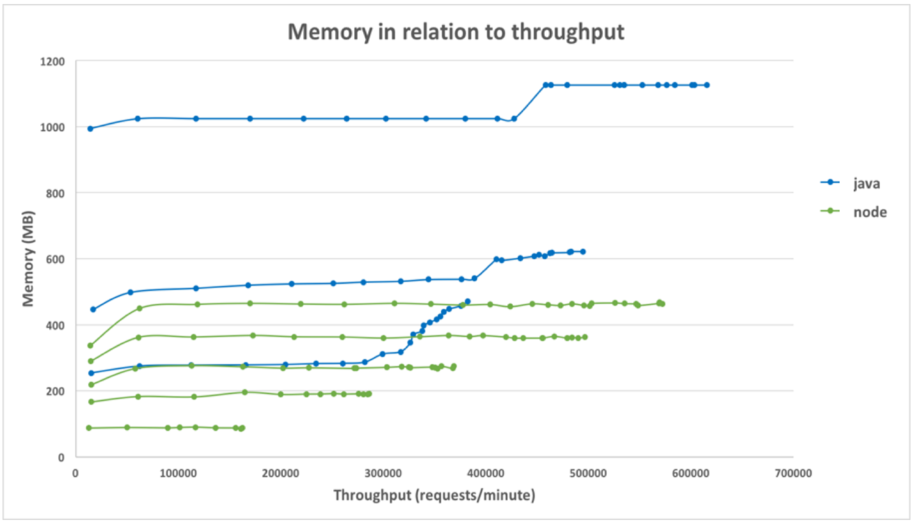


Figure 7.7: Memory in relation to throughput

horizontal scaling requires the memory consumption to multiply itself. In the end, one Java instance which make full use of 12 CPUs would be much more memory efficient that 12 small Node.js instances.

Chapter 8

Conclusion

The aim of the thesis is to compare the performance of Java and Node.js with the focus on SAP use case in Cloud Foundry. The example applications are of minimum complexity and functionality. The consumption of resources are also kept at a low level. Still, both technologies have reached 20% of average requests handling of Google.com[14]. This is a quite good and firm performance for SAP business scenario. The CPU usage would rarely reach 100% before a limitation in the database or router surfaces first. Of course, the application should be properly optimized first and have an efficient CPU usage.

The Node.js application has demonstrated a very high utilization of available CPU and memory efficiency, which also makes it suitable for gaining more performance through horizontal scaling. This also have some implications for developers regarding component design. If the cloud application needs to be horizontally scaled up or down at any moment according to the load condition, the components should be designed to be as stateless as possible.

Java exhibits a very good CPU efficiency. If the cloud provider charges the cost according to consumed CPU resources instead of reserved CPU total, Java definitely offers a better performance gain. However, if it is not the case, a deep investigation should be conducted into the CPU utilization of the application. If Java can efficiently consume all available CPU power, it offers a great vertical scalability. Despite of the fact that one Java instance consumes more memory, if it can make good use of 64-core system, it would outperform 64 small Node.js instances in terms of memory and CPU. As for horizontal scaling for an optimized Java application, it will achieve possibly the same computing capability but needs a much higher memory consumption.

However, no matter Java or Node.js, the scaling competence goes beyond application itself in context of cloud. In the thesis, we have faced a bottleneck imposed from HA-Proxy before we even scale the application at all. This limitation can only be work around at the application level with reusing established connections. There is nothing one can do at the infrastructure level which would mean to rebuild the system since HA-proxy is not built scalable. In comparison, the scaling of Gorouter is done in one day and has been operating perfectly ever since. There are even more to the scaling in cloud: the VMs or container, the database... Every scaling also puts demand on operation and monitoring. For example, high load could cause a defect in monitoring if it is not built to cope with a sudden large amount of reading and writing data entries. It will trigger false alarms and result in false evaluation of cloud platform health.

Chapter 9

Future Work

Scalability of cloud applications is an enormous topic. The thesis has only scratched the surface a little bit. There are several additional future directions that can be explored. In order to eliminate overhead brought by framework, the applications have a minimum utilization of them. It would be interesting to know what kind of influence they might bring about. However, in this case, instead of testing the technology itself, the framework competence is tested. Some work has been done by TechEmpower [22]. They have benchmarked the library and framework overhead for single application. It would be interesting to know if there is any variation in respect to scaling. The testing scenario could also be expanded to computation intensive cases, for example machine learning and see how the two technologies cope with calculation.

Regarding applications, research can be conducted in whether a cluster module of Node.js application can still demonstrate a high utilization of processing power and the strange phenomenon of Java's inefficient consumption of available computing resource is also worth looking into. Load generation concept in the thesis has fulfilled some requirements that are overseen by the existing tools. It would be nice to have a further development of load generator to enrich its functionality and eliminate manual process like monitoring and recording CPU and memory consumption.

Abbreviations

DEA	Droplet Execution Agents
PaaS	Platform as a Service
AWS	Amazon Web Service
BBS	Bulletin Board System
ELK	Elasticsearch, Logstash, and Kibana
TCO	Total Cost of Ownership
HAProxy	High Availability Proxy

List of Tables

5.1 Example: allocate CPU time in Cloud Foundry 19
7.1 Percentage of utilized CPU 32

List of Figures

3.1 Load produced from different number of instances 6
3.2 Activity diagram of load generator 7

4.1 Measure response time three different places 10
4.2 cf statistics display 14
4.3 Find out the memory Java and Node.js applications need 15

5.1 Deployment diagram for test environment 22

6.1 Implementation configuration 24
6.2 Database connection pool size comparison 26
6.3 Comparing end-to-end response time with database response time . 27

7.1 Compare throughput under 100 CPU consumption 29
7.2 Limited CPU usage in Java application 30
7.3 Abnormal surge in memory 31
7.4 Throughput in relation to CPU 31
7.5 cpu efficiency of Node.js application 33
7.6 cpu efficiency of 3 Java instances 33
7.7 Memory in relation to throughput 34

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