Distributed File System for Storage of Document with Gifford Read/Write Constraints

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1 Design Document: System Design

1.1 Design Overview

For this project I have implemented a distributed file system that serves a document and replicates that document between file server nodes. It allows the user to interact directly through the client to read and write to a shared and versioned document that exists on the distributed data store. This document is replicated throughout the file system on multiple file system nodes. When the user either requests a write or a read, their request is put into a queue of read/write requests. When the read/write request queue is ready to implement the requested action, a quorum of file system nodes are elected at random according to a defined number in a configuration file. If the number of read and write file server nodes obeys the Gifford Read/Write constraints [**?**]

The system consists of a set of clients, a set of file servers and a "Collector". The clients are the point of interaction with the system. The file servers are the entities that store the document. The collector is the point for the client to make requests and the entity that controls the election of read and write quora for the sake of distributed reads and writes to the file servers.

1.2 Write constraints and the *Collector*

Each component in the system needs to know where the Collector resides (its IP address and port number) since the Collector handles both the request queue and the assignment of the port numbers that the file server nodes use. The Collector is also responsible for the enforcement of the Gifford read/write constraints. When the client requests either a read or write, the Collector assures that the number of reads and the number of writes fall within the requirements that the number of writes exceeds half of the total number of file server nodes nodes for a write to take place and when a read takes place it ensures that the number of read nodes and the number of write nodes is greater than the total number of file server nodes.

1.3 Language and technical details

The system is implemented in the Java programming language and uses Remote Method Invocation (RMI) to handle the interaction between all components of the system.

The *Collector* class - which directly represents the Collector abstraction per the requirements for the assignment - maintains a *RequestQueue* object. This *RequestQueue* is a child class of a Java *Queue*, which maintains a set of *Request* values. The *Request* object contains an enumerated type of either *Read* or *Write* to maintain whether the request itself is either a read or a write request. This *Request* type also maintains a time, number and value fo the request. The value is used to store the *String* value of the write when a request is of the *write* type. The *RequestQueue* simply has the methods to either add a *Request* or get a *Request*.

When the *Collector* gets a read or write request, it first returns a request number to the client that is calling it. The client then uses this number to gather the results of the request when the Collector has determined that that particular request was the next request to be fulfilled. If the request is a read request, a *String* of the contents of the file system is returned and if the request was a write request, a boolean value indicating the success (or lack thereof) of the write to the distributed file system.

The file server is represented by the *File Server* class. It basically maintains a Serialized version of a document - the *Document* class. The *Document* class maintains a String, which is the document that is read and written, as well as a version number that increments each time the *Document* instance's *String* value changes.

1.4 The *Client* and user interaction

The *Client* abstraction is the user interface to the system. It takes the argument of where to find the *Collector* instance - just like the *FileServer* object does. There are two main ways of interacting with the client: the user can invoke the "interactive" mode of using the client and the user can use the client purely from the command line, passing in the read and write parameters to the program to execute a single read or write request (more detail about the use of the interaction of the user with the client is the the User Document).

2 User Document: System Usage

2.1 Building the System

To build the system, Java must be installed and the Ant build system must also be installed on the user's machine. Then the user must type:

```
ant jar
```

2.2 Basic System Startup

2.2.1 Single Command Startup

Scripts are provided for system startup. The main script, "run.sh" is provided as a means to start the entire system with just one command. This starts three clients, a collector and five file servers. The user is prompted at each step to start the components of the system in the proper order: first the Collector, then the File Servers and then the Client.

```
WHen collector has finished starting, hit [Enter]...
```

When the collector has finished, it will display a message indicating that it has finished:

```
INFO [main] - Collector finished with startup
```

At this point the user must hit *Enter* to continue with the startup of the File Servers (as indicated by the similar message as indicated above for the Collector).

When the five file servers have displayed the message as follows:

```
INFO [main] - File server at <port number> finished with startup
```

Then the user should hit *Enter* once more for the Client to start itself. At this stage, the user will be presented with the Client's *Interactive Mode* menu (more details below).

2.2.2 Multiple Command Startup

Alternatively, separate scripts can be used to start any combination of numbers of clients and file servers at any location. These scripts are "run_clients.sh", "run_fileservers.sh" and "run_collector.sh".

The components of the system must be started in the order:

1. Collector
2. File Servers
3. Client

To start the Collector, one must only type:

```
./run_collector
```

j

If the system is to be started up on multiple machines, the location of the collector (its IP address and its port number) must be noted and provided as arguments to the Client and File Server startup programs (this can be done within the “run_fileserversṡh” and “run_clientṡh” scripts under the environment variable values *COLLECTOR_IP* and *COLLECTOR_PORT*).

The File Server startup script takes an argument of the number of file servers to start on that particular machine. For example, if you want to start ten file servers on that machine, you would type:

```
./run_fileservers.sh 10
```

2.3 Client Interactive Mode

The clients are the processes with which the user interacts. The two mandatory arguments that are needed for startup of the client are the IP address and port number of the Collector. Upon starting a client, the user is presented with a menu of options as follows:

```
Would you like to:
(r) Request a read
(w) Request a write
(f) Query file servers through Collector
(q) Quit
```

This is the “interactive mode” of the client. The choices are self-explanatory: the user can request a read or write to the file system document, can quit the program or can do a query of the information of each file server that has been started in the system (through the Collector). The latter action prints the IP address, port and version number of the document that is stored on that particular file server. Note that if multiple clients are desired, they must be fed the appropriate IP address and port of where the collector is running. By default, there are three separate collector instances listening at the base port that the collector is defined on and two other ports - one higher than the base port and two higher than the base port, respectively. For example, if the base port that the collector is running on is 44555, then the collector will also be listening on ports 44556 44557 for additional client instances.

2.4 Client Batch Mode

An alternative way to use the client is in a non-interactive way. If one would like to do a read request, an extra parameter of “r” is added (in addition to the Collector IP address and port number) to the command-line invocation of the client script. This will cause a single read operation to be performed by the client on the file system. Similarly, a “w” along with a string (in double quotes) to write are passed as added arguments to the client and a single write operation of the given string is performed on the distributed file system. This type of usage of the client allows the user to do batch read and write operation requests to the file system from the command line.

2.5 Test Scripts

Test scripts are provided as a means for testing multiple read and write requests. Both a “Read-Heavy” and a “Write-Heavy” script are provided to test the system. To invoke these scripts, one must have already started the *Collector* as well as the number of *FileServer* objects that are desired for the tests. The provided test scripts are only invocations of the “Batch Mode” of the client called multiple times. The actual contents of the tests that are performed in these scripts is detailed in the *Testing Description* portion of this document.

2.5.1 Read-Heavy Tests

To invoke the “Read-Heavy Test” script, go to the base directory of the project, and type:

```
./test_read_heavy.sh
```

2.5.2 Write-Heavy Tests

To invoke the “Write-Heavy Test” script, go to the base directory of the project, and type:

```
./test_write_heavy.sh
```

3 Testing Description: System Tests

A series of tests were performed to verify the correctness of the system. Some of these tests were included with the packages for easy reproduction (see the *test_read_heavyṡh* and *test_write_heavyṡh* scripts). Some of the tests were performed to determine any patterns in whether a particular configuration of the number of nodes that were used in both the read quorum and the write quorum of file servers arose as the result of "ready-heavy" and "write-heavy" combinations of read and write requests as detailed below.

3.1 Performance Evaluation

A series of tests were performed to assess the behavior of various combinations of read and write quorums given a fixed size of file server nodes to store a document in the distributed file store system.

Scripts were created to be tested for the system timing of write and reading to the file store. The timing of the scripts was taking from the beginning of invoking the script in question to the time of completion using the *time* command that is available in Linux and OSX environments.

3.1.1 Read-Heavy Workloads

A so-called "read-heavy" workload was generated to test the time that it takes the distributed document system to have a significantly higher amount of read requests to the number of write requests that the batch-style client performs on the system.

The read-heavy test workload consists of reading and writing words in the following sequence (with R representing reads and W representing writes):

```
R10, W1, R40, W4, R10, W5, R40, W4.
```

In total, this results in 100 reads and 14 writes. This is the same total number of reads and writes as for the write-heavy workload below, which allows us to have an "apples to apples" comparison between the two types of workloads.

The initial hypothesis in performing a read-heavy workload on the distributed system would be that the time that it takes to finish the workload would be lower in general than the write-heavy workload scenario, since the need for updating all file server nodes would cause more of a detrimental performance impact on the system than simply reading from the most updated copy of the document in the distributed file system as in the case for performing a read operation.

Additionally, it would not be expected that the number of either the write quorum or the read quorum would have a significant impact on the performance of the distributed document file system - we would expect that the timing-readings would be relatively flat.

The result of the experiment are summarized in the following table:

N	*Nw*	*Nr*	*system time*
5	5	1	12.824
5	5	2	12.699
5	5	3	12.757
5	5	4	12.335
5	5	5	12.253
5	4	5	12.306
5	3	5	12.358

3.1.2 Write-Heavy Workloads

Similar to the idea of the "read-heavy" workload discussed previously, a "write-heavy" workload was generated to evaluate the performance of the distributed file system in a situation where many write requests were committed to the distributed document.

The write-heavy workload consists of a test of reading and writing words in the following sequence (with R representing reads and W representing writes):

```
W10,R1, W40, R4, W10, R5, W40, R4
```

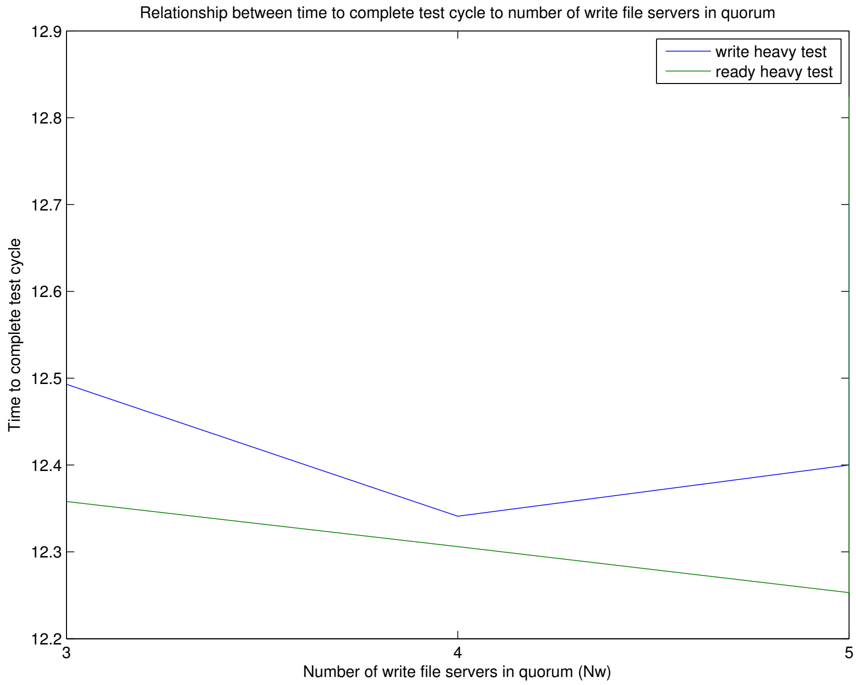
In total, as in the case of the "write-heavy" workload, this gives us 100 writes and 14 reads.

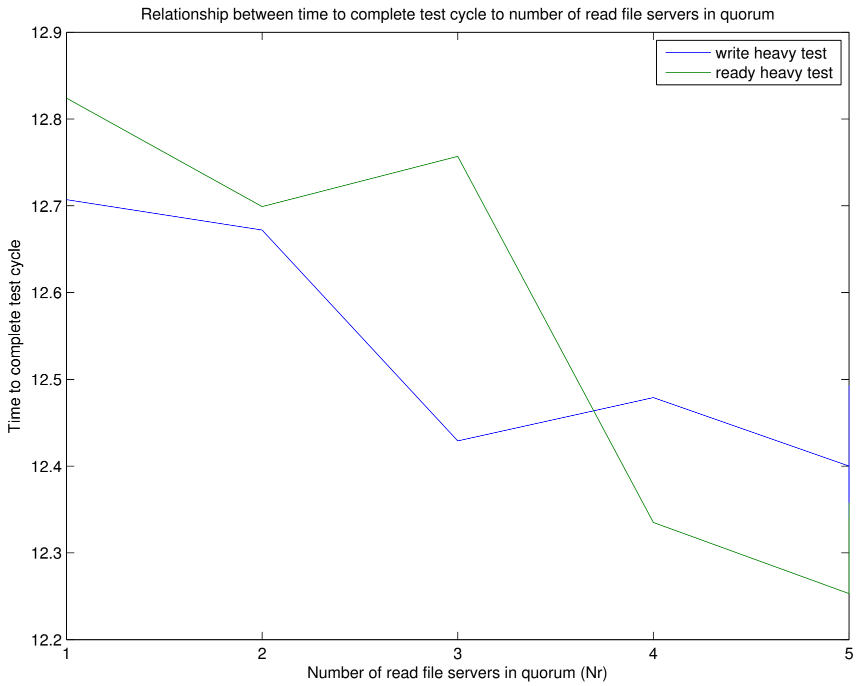
The initial hypothesis would be that we would see more of an impact of the number of values that are elected in the quora than in the "read-heavy" workload example. This would be due to the fact that, as the document in the distributed file system is changed due to write requests, the number of updates to documents in the file store would need to be spread and committed to the replicated file server nodes.

The result of the experiment are summarized in the following table and plot:

N	*Nw*	*Nr*	*system time (s)*
5	5	1	12.707
5	5	2	12.672
5	5	3	12.429
5	5	4	12.479
5	5	5	12.400
5	4	5	12.341
5	3	5	12.493

Plots of the relationship between the number of read file server nodes in the quorum versus the time that it took for both the read-heavy and the write-heavy operations to complete are shown in the below figures:





We stated in the initial hypotheses that the impact of the number of file server nodes that are used in the quora for read and write requests would be more significant for write-heavy requests than for read-heavy requests. From the plots, this does not appear to be the case. If it were the case, we would see that the write-heavy requests would consistently take more time than the read-heavy requests. While this is the case when looking at the first plot (i.e. the blue line representing the write-heavy requests is always above the green line representing the read-heavy requests), it is not consistently the case in the lower plot.

One factor that may explain this discrepancy with the initial hypothesis is that, when performing a read request, the client prints the contents of the document to standard-out for review of the document itself. This printing to screen can take significantly longer when we have a significant amount of text stored in the document and thus obscure the actual costs of reads versus writes to the distributed file system.

A trend that becomes apparent when looking at the values and the plots that compare the read-heavy and write-heavy tests is that the time that the tests take is less for more read file servers nodes that are used in the quorum (as seen in the lower plot). This is regardless of whether we are doing a read-heavy or write-heavy set of test requests. This is also the case when looking at the number of increasing number of file server write nodes in the quorum, but to a lesser degree than that of looking at the number of read file server nodes that are elected to the quorum.

A possible explanation for the tendency to have more read nodes in the quorum to have a beneficial impact on the system performance would depend on the hypothesis just mentioned that reads are a more significant sink on the systems performance due to the time that it takes the document in the distributed file store to be printed to standard out. If this is in fact the case, we can say that reads have more of an impact on the system's performance. As such, improvements to the read action of the system would have a significant impact. An improvement on read performance is the ability to quickly get a copy of the document that is stored on the distributed file system, and having more designated "read" file server nodes in the elected read quorum allows quicker access to the most recent version of the document in the file store. However, if the largest impact is on the printing of the document to the user's screen, accessing the document may have little impact on the ability of the system to have better time performance due to the quick access of the document itself. It is also possible that the performance of the system was affected by other processes and that the trend is something of a "red herring" - in reality there is no such trend and the other processes on the system affected the timing in an arbitrary manner. A more rigorous test to determine whether this trend is, in fact, a true trend would be to run multiple, identical such read-heavy and write-heavy scripts at different and randomized times throughout the day. This would have the effect of randomizing the affect of processes on the performance of the distributed file server system. An obvious alternative would be to assure that no other processes were running at the same time, but this is a less feasible way to isolate the purported trend versus the concept of just randomizing the impact of other processes on the distributed file server system.