Database Systems Architecture

Algorithms in Secondary Memory

Project Assignment

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# Introduction and Environment

## Outline

This report analyzes the performance of write/read file and External Merge-Sort in JAVA through graphs. The graphs compare the performance of four methods, and represent with changing one variable and fixing the others.

## Motivation

Reading and writing data from/to external memory is one of the most costly operations in computer transaction. Data contained in blocks moves in different speed between memory hierarchies of computer instead of same access cost. In order to get a better understanding on how different parameters affect the performance of an external memory related transaction, we will implement an External Merge-Sort(1) algorithm in Java, and then analyze the performance of this algorithm by changing the value of the parameters. Three parameters used are number of memory available (M), number of streams to merge in one pass (d) and the size of input file (N). Before implementing an External Merge-Sort, considering Java has different ways to read/write file, first we analyze four different methods of writing/reading integer binary file and then use the method with best performance to implement the External Merge-Sort algorithm.

Those four methods are:

* FileInputStream/FileOutputStream with byte reads/writes
* BufferedInputStream/BufferedOutputStream with byte reads/writes
* BufferedInputStream/BufferedOutputStream with variable buffer size
* FileInputStream/FileOutputStream with byte array reads/writes

## Environment

The experiments to analyze the methods and algorithm are conducted on the following environment:

control

To support the implementation, the following Java libraries are needed:

|  |  |
| --- | --- |
| **I/O streams** | **External Merge-Sort** |
| java.io.File; java.io.IOException; java.io.FileNotFoundException; java.io.RandomAccessFile; java.nio.MappedByteBuffer; java.nio.channels.FileChannel.MapMode; java.io.FileOutputStream; java.io.BufferedOutputStream; java.io.DataOutputStream; java.io.OutputStream;  java.io.DataInputStream; java.io.FileInputStream;  java.io.InputStream; java.io.BufferedInputStream; |  |

Since the experiment to read and write the file is conducted separately (one method is used to read file and another method is used to write file), the test data was generated by executing the method to write file first and then the read method will use the same file generated to be read. The integer file in test data are generated randomly using Random() class with minimum integer value 0 and maximum integer value control

The sizes of test data used in the experiment are 1 kB, 10 kB, 100 kB.

# Observation on Streams

## Expected Behavior

**FileInputStream/FileOutputStream with byte reads/writes**

This method is implemented using FileInputStream and DataInputStream for reading file and FileOutputStream and DataOutputStream for writing file. The DataInputStream and DataOutputStream class allow the application to read and write one integer from/to file each time. Using this method, each time we read or write the disk is accessed to get the integer value. Therefore, we assume that this method will give the worst performance compare to other method.

|  |
| --- |
| 螢幕快照 2016-01-02 上午1.04.59.png |

**BufferedInputStream/BufferedOutputStream with byte reads/writes**

This method is implemented using BufferedInputStream and BufferedOutputStream to read/write file. The implementation is basically similar to the first method in the sense that we still use FileInputStream, FileOutputStream, DataInputStream and DataOutputStream class. The difference is that when we use BufferedInputStream and BufferedOutputStream, a buffer will be created in the memory. When reading or writing the integer will be buffered in the memory until it reaches a certain buffer capacity (default buffer size: 8 kB).

|  |
| --- |
| 02.png |

Since this method uses buffer, it means disk is not accessed as often as the first method. Hence we expect that the second method will have better performance compared to first method.

**BufferedInputStream/BufferedOutputStream with variable buffer size**

The third method is the same with the second method with additional parameter buffer size. With this method, we can decide the size of the buffer and during the experiment we will analyze how different buffer size influences the performance.

|  |
| --- |
| 03.png |

Considering that we can define the buffer size, compared to the second method, the third method is expected to give a better performance if we put buffer size > 8 kB because it’s the default value in JAVA.

The following table summarizes the expected performance for all methods.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Method** | **First** | **Second** | **Third** | **Fourth** |
| Performance |  |  |  |  |

## Experimental Observations

To analyze which method has the best performance, we conduct the experiment in three parts. In the first part we vary the number of stream (k), in the second part we vary the buffer size (B), and in the third part we vary the number of integer read/written (N).

### Various Streams Numbers (k)

We try to show how different numbers of k changes performance of reading/writing for IO methods.

Firstly we would like to give an overall idea to show which the best option for IO operation is. In order to do that, we get make tests for changing “k” values from 1 to 35. We also wanted to see effects of buffer size and integer number in a file. We measured all of those parameters, firstly we would like to show which is the roughly best for average conditions in our assumption.

* K values: 1 to 35.
* File Size (integer number in a file): 100,1000,10000.
* Buffer Size: 8, 512, 1024, 2048, 4096, 8192, 16384.

In order to make analyses more understandable, we used ranges for different k values such as 1-5, 6-10… 31-35.

While we get logs, we compute values for 4 times and get the averages to get more appropriate results and get rid of temporal performance issues.

Average elapsed time (milliseconds) for each file to read/write and different k ranges are seen respectively on y axis and x axis.

For very roughly we can say that IO4 is the best option for reading and IO2 is the best options for overwriting. On the other hand it is easily seen that first IO method is not so performant in any case. But we have to mention that on above graph either k (file number), N (file size) or B (buffer size) are variables, graph just shows averages to give an overall idea.

### Various Buffer Sizes (B)

### Various File Sizes (N)

If we want to show how IOs work on different file sizes we can check above graph. For relatively small amount of data (100 row on left) each of methods gives almost same values that means we can use any of them. Once we have bigger files, we can see disadvantage of first method. For writing data even for the big files method 2 and 3 are preferable with IO4 but for reading IO4 should be used. We should mention that buffer sizes and k values are also varying in that graph and values shows the average.

To see the effect of the buffer sizes we can check below graph:

## Discussions

The following table summarizes the ranking for each method based on the variable parameter used during the experiment compared to the ranking expected:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Method | First | Second | Third | Fourth |
| Expected |  |  |  |  |
| Read File: Variable k, Fixed B,N |  |  |  |  |
| Write File: Variable k, Fixed B,N |  |  |  |  |
| Read File: Variable B, Fixed k,N |  |  |  |  |
| Write File: Variable B, Fixed k,N |  |  |  |  |
| Read File: Variable N, Fixed k,B |  |  |  |  |
| Write File: Variable N, Fixed k,B |  |  |  |  |

# Observations on Multi-way Merge Sort

## Expected Behavior

The External Merge-Sort algorithm is implemented in Java in the following steps:

* Split file:

Input file with size N is split into several smaller file with size M (size of the memory available). After splitting we will have (N/M) smaller file.

* Merge and Sort the sub file:

1. Load the first d (number of stream to merge in one pass) streams.
2. Merge the integers. Since the integers are already sorted in each stream, we need to compare the integer in each stream before merging them.The first integers in each stream are compared. The smallest integer is then written to the buffer. Each time the smallest integer is identified, the pointer of the stream where the integer is in is moved to the next integer. Compare the integers again.
3. When the buffer is full, write the merged integers to a new file.
4. Repeat step b and c until there is no integer left in each stream. Load the next d streams and repeat the process.
5. Each time we load a file, we remove the filename from the queue. Each time we write the merged integers, the name of this new file is added to the queuecas reference. Repeat a, b, c, and d until there is only one file left in queue.

From this implementation, we expect that the bigger the size of the file (N), the more the I/Os. Since bigger file size require more reading and writing process. On the other hand, the more memory we have, then the I/O operations will be smaller considering that we read and write less from/to the disk. The more number of stream to merge in one pass, then the smaller the I/O will be because there will be less reading and writing operation from/to disk.

The total cost of the operation is (1): **2B(R)⌈log B(R)⌉**which can be written as **2N⌈⌈log MMN⌉**. This formula means that the cost of sorting operation equal to two times of number of integer (one for reading from disk and one for writing it back to disk) times the number of passes required. It suggests that the cost of sorting operation is linear to the value of N and M.

## Experimental Observations

### Graph Representation

We conduct the experiment in three parts. In the first part we vary the file size (N), in the second part we vary number of memory available (M), and in the third part we vary the number of streams to merge in one pass (d).

## Discussions

# Overall Conclusion

The experiment for choosing the best read/write file method has also help to understand that indeed disk access contribute the most to operation cost. The more we access the disk means the more cost will be needed which is depicted by the more time we need to complete the operation.

1. Reference

1.Memory Mapped File in Java, from

<http://www.codeproject.com/Tips/683614/Things-to-Know-about-Memory-Mapped-File-in-Java>

<http://howtodoinjava.com/2015/01/16/java-nio-2-0-memory-mapped-files-mappedbytebuffer-tutorial/>

2.K-way Merge,from

<http://www.sinbadsoft.com/blog/sorting-big-files-using-k-way-merge-sort/>

<http://stackoverflow.com/questions/5055909/algorithm-for-n-way-merge>

3.Sorting and Priority Queues, from

<http://algs4.cs.princeton.edu/20sorting/>

<https://github.com/vbohush/SortingAlgorithmAnimations/blob/master/src/net/bohush/sorting/MergeSortPanel.java>

4.Merge-Sort, from

<http://interactivepython.org/runestone/static/pythonds/SortSearch/TheMergeSort.html>

<http://www.cs.umd.edu/~meesh/351/mount/lectures/lect6-divide-conquer-mergesort.pdf>

5.Included code in java:

<http://www.vogella.com/tutorials/JavaAlgorithmsMergesort/article.html#mergesort>

6.Memory Mapped I/O:

<http://www.developer.com/java/other/article.php/10936_1548681_4/Introduction-to-Memory-Mapped-IO-in-Java.htm>

Past notes:

Introduction and Environment

Windows, Java,

Input Files

Observations on streams

For this particular implementation you are required to do a little research on what

memory mapping actually is; you are expected to explain this concept in your report.

This are useful links for these explanations and it looks like 4th method is much better for big files:

\* use a MappedByteBuffer to wrap a huge file. Using a MappedByteBuffer does

\* not load the file in JVM but reads it directly off the file system

\* memory. The file can be opened in read, write or private mode.

<http://www.javacodegeeks.com/2013/05/power-of-java-memorymapped-file.html>

<http://www.linuxtopia.org/online_books/programming_books/thinking_in_java/TIJ314_029.htm>

<http://www.studytrails.com/java-io/Channels.jsp>