COMP 410 - Fall 2014
Programming Assignment 2

PROJECT DESCRIPTION

All the sorting algorithms we have discussed in class require that the input to be sorted fits entirely into main memory prior to being sorted. There are, however, applications where the input is much too large to fit into memory. Such inputs are sorted using what are called **external sorting algorithms**. In this assignment, we will simulate a simple external sorting algorithm that assumes that its input is provided on a *magnetic tape*, which can only be accessed sequentially.

Read Sections 7.12.1 – 7.12.3 of your text (reproduced here in the appendix) and make sure that you understand the simple sorting algorithm using 4 tapes that is described there.

Some classes are provided to you. You are to implement methods in these classes, which will help you program the external sort algorithm. Within the `.java` files there are comment for each method describing what you are to do. There are two classes:

- `TapeDrive.java`
- `TapeSorter.java`

For this assignment you are to complete the implementation of the `TapeDrive` and the `TapeSorter` classes. Specifically,

1) Write the `generateRandomTape()` method in `TapeDrive.java` that creates a new `TapeDrive` and populates it with random integers.
2) Write the `quicksort()` method in `TapeSorter.java` that sorts the in-memory data via the quicksort algorithm.
3) Write the `initialPass()` method in `TapeSorter.java` that reads data from a tape drive into memory, sorts it, then writes the sorted data out to another tape drive.
4) Write the `mergeChunks()` method in `TapeSorter.java` that combines two chunks, each from a different tape drive, and writes the result to another tape drive.
5) Write the `doRun()` method in `TapeSorter.java` that merges all chunks on two drives and writing the results to another tape drive.
6) Write the `sort()` method in `TapeSorter.java` that sorts the provided tape drive by using three additional drives and the system memory.

Parts 2 through 5 in the above list are helper methods, which each perform an operation specific to the sort algorithm. Part 6, the `sort()` method, will perform the whole algorithm. By calling `sort()` the helper methods will be invoked as well. See the book excerpts which describes the sort algorithm.

You may declare an additional ***constant***[1] number of variables. You may write additional helper methods, define additional classes, etc. You may NOT modify the TapeDrive class in any manner except for implementing the `generateRandomTape()` method. You may NOT change any of the method signatures for either class.

NOTE

Do *not* use any in-built Java implementation (e.g., Stack, Queue, Lists, ArrayList, etc) from the java.util.* API. You *must* implement the above from scratch. The only exception is `java.util.Random` which you will use when creating a TapeDrive filled with random integers.

Credit will be awarded for efficiency in implementation – make your implementation efficient in terms of both run-time and memory usage.

The source code of the above classes will be provided for your convenience.

1. I.e., not depending on the input size.

GRADING RUBRIC

- (10 points) Correct implementation of `generateRandomTape`
- (10 points) Correct implementation of `quicksort`
- (15 points) Correct implementation of `initialPass`
- (10 points) Correct implementation of `mergeChunks`
- (15 points) Correct implementation of `doRun`
- (15 points) Correct implementation of `sort`
- (15 points) Efficiency, both runtime and memory usage
- (10 points) Good, readable code

RECOMMENDED APPROACH

Before you begin programming, it's important and vital that you understand the algorithm. Read the section from the book that describes the sort algorithm (attached). Before you even touch your computer, figure it out on paper. For each step ask yourself: How many times do you loop? How many numbers do I move? Which tape drives are the numbers coming from/going to? Once you have a good understanding of how it works, then begin programming. It's recommended that you implement the functionality little by little, in the following order:

1) Implement `generateRandomTape` and verify/test
2) Implement `quicksort` and verify/test
3) Implement `initialPass` and verify/test
4) Implement `mergeChunks` and verify/test
5) Implement `doRun` and verify/test
6) Implement `sort` and verify/test

Come up with as many different tests and corner cases you can think of for each part just to make sure that it all works.

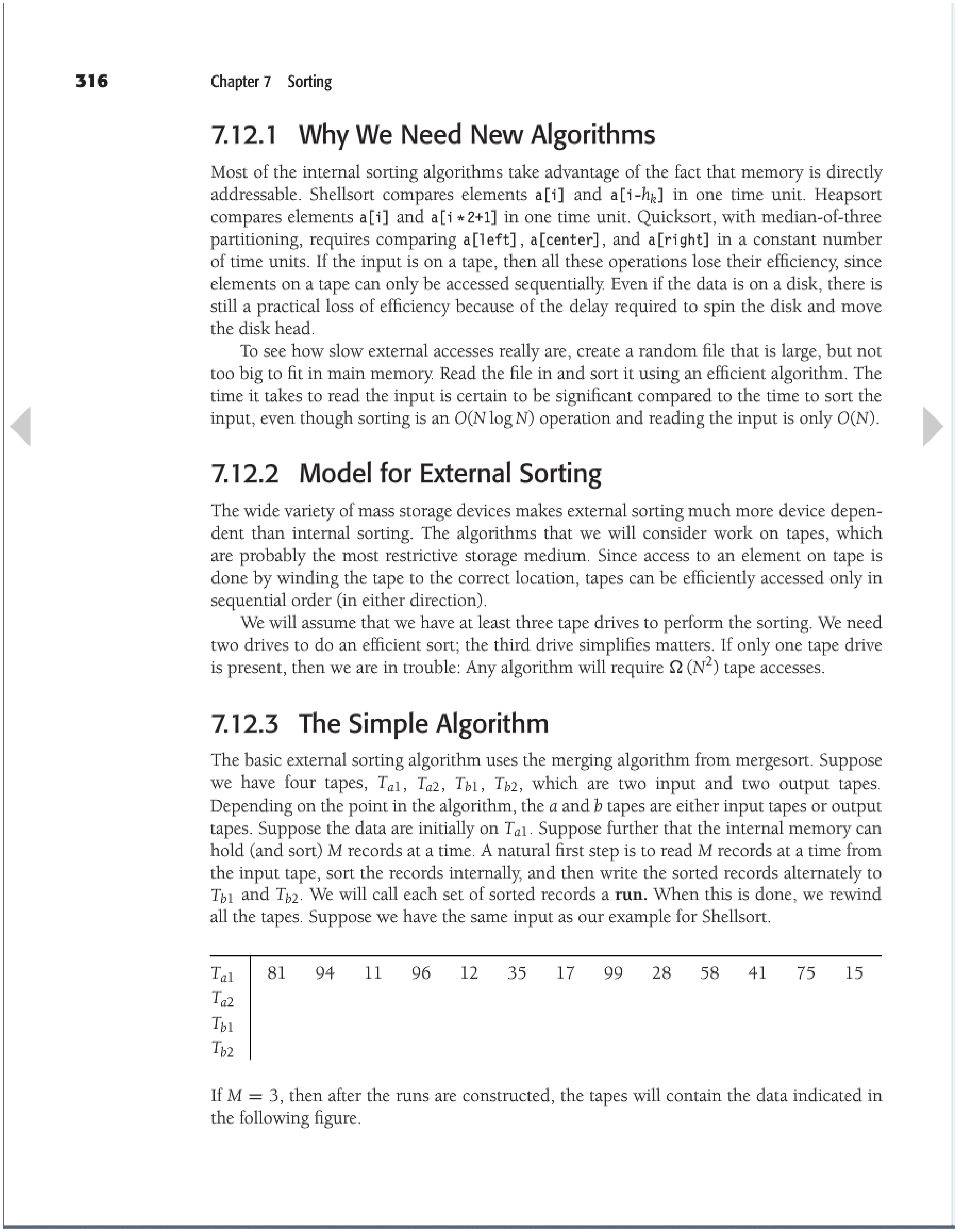
SUBMISSION INSTRUCTIONS

Upload all your source code in a `.zip` file to Sakai. You are responsible for ensuring that your program compiles and functions properly. Any non-functioning program will receive a zero.

HONOR CODE

Please review the honor code description from the course syllabus. No collaboration (with anyone) is permitted in assignments. Collaboration in assignments, or the use of code not the students own, constitutes an honor code violation. Any violation will be reported to the Student Attorney General.

APPENDIX – THE RELEVANT SECTIONS OF THE TEXT



7.12.1 Why We Need New Algorithms

Most of the internal sorting algorithms take advantage of the fact that memory is directly addressable. Shellsort compares elements `a[i]` and `a[i-`h_k`]` in one time unit. Heapsort compares elements `a[i]` and `a[i*2+1]` in one time unit. Quicksort, with median-of-three partitioning, requires comparing `a[left]`, `a[center]`, and `a[right]` in a constant number of time units. If the input is on a tape, then all these operations lose their efficiency, since elements on a tape can only be accessed sequentially. Even if the data is on a disk, there is still a practical loss of efficiency because of the delay required to spin the disk and move the disk head.

To see how slow external accesses really are, create a random file that is large, but not too big to fit in main memory. Read the file in and sort it using an efficient algorithm. The time it takes to read the input is certain to be significant compared to the time to sort the input, even though sorting is an $O(N \log N)$ operation and reading the input is only $O(N)$.

7.12.2 Model for External Sorting

The wide variety of mass storage devices makes external sorting much more device dependent than internal sorting. The algorithms that we will consider work on tapes, which are probably the most restrictive storage medium. Since access to an element on tape is done by winding the tape to the correct location, tapes can be efficiently accessed only in sequential order (in either direction).

We will assume that we have at least three tape drives to perform the sorting. We need two drives to do an efficient sort; the third drive simplifies matters. If only one tape drive is present, then we are in trouble: Any algorithm will require $\Omega(N^2)$ tape accesses.

7.12.3 The Simple Algorithm

The basic external sorting algorithm uses the merging algorithm from mergesort. Suppose we have four tapes, T_{a1}, T_{a2}, T_{b1}, T_{b2}, which are two input and two output tapes. Depending on the point in the algorithm, the a and b tapes are either input tapes or output tapes. Suppose the data are initially on T_{a1}. Suppose further that the internal memory can hold (and sort) M records at a time. A natural first step is to read M records at a time from the input tape, sort the records internally, and then write the sorted records alternately to T_{b1} and T_{b2}. We will call each set of sorted records a **run.** When this is done, we rewind all the tapes. Suppose we have the same input as our example for Shellsort.

T_{a1}	81	94	11	96	12	35	17	99	28	58	41	75	15
T_{a2}													
T_{b1}													
T_{b2}													

If $M = 3$, then after the runs are constructed, the tapes will contain the data indicated in the following figure.

T_{a1}							
T_{a2}							
T_{b1}	11	81	94	17	28	99	15
T_{b2}	12	35	96	41	58	75	

Now T_{b1} and T_{b2} contain a group of runs. We take the first run from each tape and merge them, writing the result, which is a run twice as long, onto T_{a1}. Recall that merging two sorted lists is simple; we need almost no memory, since the merge is performed as T_{b1} and T_{b2} advance. Then we take the next run from each tape, merge these, and write the result to T_{a2}. We continue this process, alternating between T_{a1} and T_{a2}, until either T_{b1} or T_{b2} is empty. At this point either both are empty or there is one run left. In the latter case, we copy this run to the appropriate tape. We rewind all four tapes and repeat the same steps, this time using the *a* tapes as input and the *b* tapes as output. This will give runs of $4M$. We continue the process until we get one run of length N.

This algorithm will require $\lceil \log(N/M) \rceil$ passes, plus the initial run-constructing pass. For instance, if we have 10 million records of 128 bytes each, and four megabytes of internal memory, then the first pass will create 320 runs. We would then need nine more passes to complete the sort. Our example requires $\lceil \log 13/3 \rceil = 3$ more passes, which are shown in the following figures.

T_{a1}	11	12	35	81	94	96	15
T_{a2}	17	28	41	58	75	99	
T_{b1}							
T_{b2}							

T_{a1}												
T_{a2}												
T_{b1}	11	12	17	28	35	41	58	75	81	94	96	99
T_{b2}	15											

T_{a1}	11	12	15	17	28	35	41	58	75	81	94	96	99
T_{a2}													
T_{b1}													
T_{b2}													

7.12.4 Multiway Merge

If we have extra tapes, then we can expect to reduce the number of passes required to sort our input. We do this by extending the basic (two-way) merge to a *k*-way merge.

Merging two runs is done by winding each input tape to the beginning of each run. Then the smaller element is found, placed on an output tape, and the appropriate input