

# Homework 3: due by 11:59pm on Friday, March 4, 2022

(Total: 100 points)

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Commit all work to the github classroom hw3 repo at [https://classroom.github.com/a/Ez\\_y3w1U](https://classroom.github.com/a/Ez_y3w1U) that we created for you. In case of problems committing your files, please contact the teaching staff at [comp322-staff@mailman.rice.edu](mailto:comp322-staff@mailman.rice.edu) before the deadline to get help resolving your issues.

Your solution to the written assignment should be submitted as a PDF file named `hw3_written.pdf` in your github classroom hw3 top level directory. This is important — you will be penalized 5 points if you place the file in some other folder or with some other name. The PDF file can be created however you choose. If you scan handwritten text, make sure that the writing is clearly legible in the scanned copy. Your solution to the programming assignment should be submitted in the appropriate location in the hw3 directory.

The slip day policy for COMP 322 is similar to that of COMP 321. All students will be given 3 slip days to use throughout the semester. When you use a slip day, you will receive up to 24 additional hours to complete the assignment. You may use these slip days in any way you see fit (3 days on one assignment, 1 day each on 3 assignments, etc.). If you plan to use a slip day, you need to say so in an github committed `README.md` file before the deadline. You should specifically mention how many slip days you plan to use. The `README.md` file should be placed in the top level directory (e.g. `hw3`). Other than slip days, no extensions will be given unless there are exceptional circumstances (such as severe sickness, not because you have too much other work). Such extensions must be requested and approved by the instructor (via e-mail, phone, or in person) before the due date for the assignment. Last minute requests are likely to be denied.

If you see ambiguity or inconsistency in a question, please seek clarification on Piazza (remember not to share homework solutions in public posts) or from the teaching staff. If it is not resolved through those channels, you should state the ambiguity/inconsistency that you see, as well as any assumptions that you make to resolve it.

*Honor Code Policy:* All submitted homework is expected to be the result of your individual effort. You are free to discuss course material and approaches to problems with your other classmates, the teaching assistants and the instructors, but you should never misrepresent someone else's work as your own. If you use any material from external sources, you must provide proper attribution.

## 1 Written Assignments (50 points total)

As mentioned earlier, your solution to the written assignment should be submitted as a PDF file named `hw3_written.pdf` in the `hw3` directory.

### 1.1 Amdahl's Law (25 points)

In Lecture 13 (Topic 1.5), you will learn the following statement of Amdahl's Law:

If  $q \leq 1$  is the fraction of WORK in a parallel program that must be executed sequentially, then the best speedup that can be obtained for that program, even with an unbounded number of processors, is Speedup  $\leq 1/q$ .

Now, consider the following generalization of Amdahl's Law. Let  $q_1$  be the fraction of WORK in a parallel program that must be executed sequentially,  $q_2$  be the fraction of WORK that can use at most 2 processors, and  $(1 - q_1 - q_2)$  the fraction of WORK that can use an unbounded number of processors. The fractions of

WORK represented by  $q_1$ ,  $q_2$ , and  $(1 - q_1 - q_2)$  are disjoint, and cannot be overlapped with each other in a parallel execution. Your assignment is as follows:

1. (10 points) Provide the best possible (smallest) upper bound on the Speedup as a function of  $q_1$  and  $q_2$ .
2. (15 points) Explain your answer, and justify why it is a correct upper bound. Use the cases when  $q_1 = 0$ ,  $q_2 = 0$ ,  $q_1 = 1$  or  $q_2 = 1$  to explain why your bound is correct.

Hints:

- As with Amdahl's Law, your answer should not include the number of processors,  $P$ . It should be an upper bound that applies to all values of  $P$ .
- To check your answer, consider the cases when  $q_1$  or  $q_2$  are equal to 0 or 1.

## 1.2 Finish Accumulators (25 points)

Consider the pseudocode shown below in Listing 1 for a Parallel Search algorithm that is intended to compute  $Q$ , the number of occurrences of the pattern array in the text array. What possible values can variables  $count0$ ,  $count1$ , and  $count2$  contain at line 16? Write your answers in terms of  $M$ ,  $N$ , and  $Q$ , and explain your answers.

```

1 // Assume that count0, count1, count2 are declared
2 // as object/static fields of type int
3 . .
4 count0 = 0;
5 accumulator a = new accumulator(SUM, int.class);
6 finish (a) {
7     for (int i = 0; i <= N - M; i++)
8         async {
9             int j;
10            for (j = 0; j < M; j++) if (text[i+j] != pattern[j]) break;
11            if (j == M) { count0++; a.put(1); } // found at offset i
12            count1 = a.get();
13        } // for-async
14    } // finish
15    count2 = a.get();
16    // Print count0, count1, count2

```

Listing 1: Parallel Search using Finish Accumulators

*Hints based on common errors from past years:* Be sure to include exactly all possible values for the variables, not a subset or superset of the values. Remember to use  $Q$  in your answers, even though  $Q$  can have different values for different values of the `text[]` and `pattern[]` arrays (even for the same values of  $M$  and  $N$ .) Finally, don't forget to explain your answers.

## 2 Programming Assignment (50 points)

### 2.1 Habanero-Java Library (HJ-lib) Setup

See the Lab 1 handout for instructions on HJ-lib installation for use in this homework, and Lecture 3 for information on abstract execution metrics.

## 2.2 Parallel Sort (50 points)

In this homework, we have provided you with sequential implementations of two sorting algorithms. Both sorting algorithms have been implemented in a file of their own, e.g. `QuickSort.java` and `MergeSort.java`,

*Your assignment is to write a correct parallel version of any sort algorithm that you choose by overriding the `parSort()` method. The goal is to obtain the smallest possible CPL value that you can for the given input, as measured using abstract execution metrics. A secondary goal is to not increase the WORK value significantly when doing so, but some increase is fine. Your edits should be restricted to the file for that given sort algorithm and the `sortInstance()` method in `Homework3.java`.* A correct parallel program should generate the same output as the sequential version, and should not exhibit any data races. The parallelism in your solution should be expressed using only `async` and `finish` constructs. It should pass the unit tests provided, and other tests that the teaching staff may use while grading.

For the abstract metrics in this assignment, we only count 1 unit of work for each call to `compareTo()`. We'll ignore the cost of everything else. While this seems idealistic, it is a reasonable assumption when sorting is performed on objects with large keys.

Your submission should include the following in the `hw3` directory:

1. (25 points) A complete parallel solution for a sorting algorithm of your choice in a modified Java file. For example, if you chose to parallelize Merge Sort, you need to ensure `MergeSort.java` is included in your submission. In addition, you will need to edit the `sortInstance()` method in `Homework3.java` to return an instance of `MergeSort`. We will only evaluate its performance using abstract metrics, and not its actual execution time.
  - (a) 15 points will be allocated based on the ideal parallelism that you achieve. You will get the full 15 points if you achieve a CPL of  $O(n)$  or better for an array of  $n$  elements.
  - (b) 10 points will be allocated for coding style and documentation. We have provided the basic checkstyle rules as part of your Maven project. At a minimum, all code should include basic documentation for each method in each class. You are also welcome to add additional unit tests to test corner cases and ensure the correctness of your implementation.
2. (15 points) A report file formatted as a PDF file named `hw3_report.pdf` in the `hw3` top level directory. The report should contain the following:
  - (a) A summary of your parallel algorithm. You should write a few sentences describing the approach and the algorithm.
  - (b) An explanation as to why you believe that your implementation is correct and data-race-free.
  - (c) An explanation of what values of WORK and CPL (as formulae of  $n$ ) you expect to see from your algorithm.
3. (10 points) The report file should also include test output for sorting an array of size  $n = 1024$  (i.e. the unit test name `testRandomDataInput1K`). The test output should include the WORK, CPL, and IDEAL PARALLELISM (= WORK/CPL) values.

## 3 Submitting Your Assignment

You will need to add, commit, and push all work to the github classroom `hw3` repository at [https://classroom.github.com/a/Ez\\_y3w1U](https://classroom.github.com/a/Ez_y3w1U). You should have both a `hw3_written.pdf` and a `hw3_report.pdf` file in the `hw3` top level directory. Please open a browser, navigate to the url, and verify that you successfully committed your homework. Don't forget to modify the `README.md` file if you plan to use slip days.