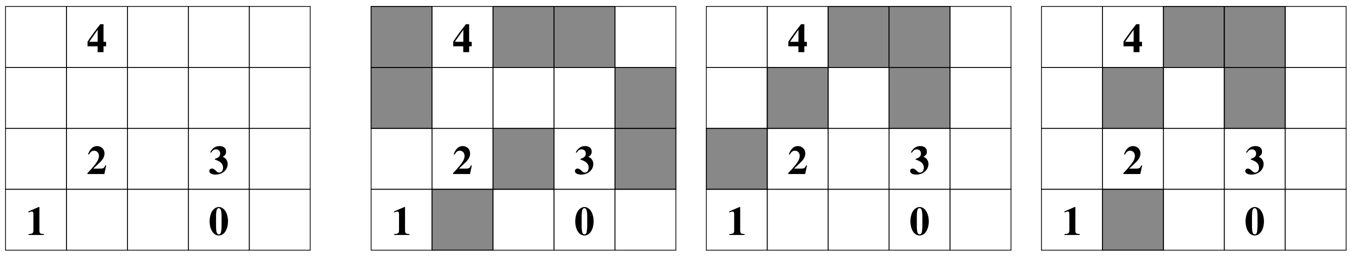
CSCI-1200 Data Structures — Fall 2024
Homework 6 — Recursive Kurotto Solver

In this homework we will develop a solver for a paper-and-pencil puzzle game named *Kurotto*. The input to Kurotto is a 2D rectangular grid where all the cells are initially *water*. Some of the cells in the grid are labeled with a non-negative integer. To solve the puzzle we will shade some of the un-numbered cells in the grid. Each cell we shade becomes *land*. Land cells that share a horizontal or vertical edge are joined to form `islands`. Cells that have numbers cannot be shaded, they will remain water. A Kurotto puzzle is *solved* if each numbered cell is touching (along horizontal or vertical edges) islands whose area sums exactly to the number in that cell. For our homework, we will work with inputs that may have no solutions, exactly one solution, or multiple solutions. The small example below has 3 different solutions! One of the solutions has 5 islands and the other two solutions have 3 islands.



You are encouraged to play through example puzzles so you understand the rules. First focus on verifying that a proposed solution of shaded cells is indeed a complete and valid solution. Then think about how you create a solution by filling in shaded cells yourself. Even though the rules are very simple, this puzzle is surprisingly difficult! *As you play, think about how you as a human solve these puzzles.* As the puzzles grow larger how and why does it become more challenging? Can you generalize your method of finding a solution so you can teach a friend how to play and ultimately, "teach" the computer to play? Here is a link with more information about the game and some medium and larger puzzles:

https://www.gmpuzzles.com/blog/kurotto-rules-and-info/

IMPORTANT NOTE: You may not search for, study, or use any code or techniques related to existing solvers for this puzzle game. *Please carefully read the entire assignment and study the examples before beginning your implementation.*

Command Line Arguments & Input/Output

```
+-----+
| 4   |
|     |
| 2 3 |
|1  0 |
+-----+
```

Your program will accept one or more command line arguments. The required first argument is the name of a puzzle board file. The input file for the puzzle in the diagrams above is shown on the right. The board is contained in a simple ASCII art frame. The space character represents water cells. The '`#`' character represents land. Digits '`0`' through '`9`' represent the numbered cells 0-9, and then we switch to letters: '`a`'=10, '`b`'=11, etc.

The output of your program will print to `std::cout`. We can use *file redirection* (`> output4.txt`) on the command line to write scoop up the output and save it to a file. See the provided output files for sample output from each of these command lines. If no other command line arguments are specified, your program should search for and print a single valid solution to the puzzle (if any exists). If there are multiple solutions, your code can print any solution. If the optional `--find_all_solutions` command line argument is specified, your program should output all solutions, they can be printed in any order.

```
./kurotto_solver.out input4.txt > output4.txt
./kurotto_solver.out input4.txt --find_all_solutions > output4_all.txt
```

```
+-----+
|#4## |
|#   #|
| 2#3#|
|1# 0 |
+-----+
ISLAND COUNT = 5
ISLAND:  (0,0) (0,1)
ISLAND:  (2,0) (3,0)
ISLAND:  (4,1) (4,2)
ISLAND:  (2,2)
ISLAND:  (1,3)
```

However, before you tackle finding one or all solutions, it is important that you can identify all of the islands in a proposed/possible solution. Since the input and output file formats match, we can actually feed a sample output file as input to the program and then compute and print information about the solution board. The optional command line argument `--no_solver` will skip the search to find solutions and instead just analyze the shaded land cells already on the board.

When the optional command line argument `--print_islands` is specified, your program should collect the `land` cells within the diagram, group them into islands, and then print this information. An example of this output is shown on the left. Note that you can print the islands in any order, and likewise the *col, row* grid positions within each island can be printed in any order.

```
./kurotto_solver.out output4.txt --no_solver --print_islands > output4_print_islands.txt
./kurotto_solver.out output4.txt --no_solver --print_check_solution
                                                     > output4_print_check_solution.txt
./kurotto_solver.out input4_buggy.txt --no_solver --print_check_solution
                                                  > output4_buggy_print_check_solution.txt
```

```
+-----+
|#4## |
|#   #|
| 2#3#|
|1# 0 |
+-----+
Location (1,0) = 4
Location (1,2) = 2
Location (3,2) = 3
Location (0,3) = 1
Location (3,3) = 0
Puzzle is solved
```

Once you have correctly identified the islands on the board, you can proceed to verify that each numbered cell is satisfied. When the optional command line argument `--print_check_solution` is provided the program should output information about each numbered location on the board and the total area of adjacent islands.

```
+-----+
|#4## |
|  # #|
| 2 3#|
|1# 0 |
+-----+
Location (1,0) = 4
Location (1,2) should be 2 is 1
Location (3,2) should be 3 is 2
Location (0,3) = 1
Location (3,3) = 0
Puzzle is NOT SOLVED
```

If we load a board with a partial solution (e.g., it already has some # symbols indicating land cells), and we *do not* specify the `--no_solver` option, the program should only add land cells (it should not remove land cells) as you search for solution(s). And finally, here is an example command line using the final optional command line argument `--print_solution_count`. Be sure to study the sample input and output files on the website.

```
./kurotto_solver.out input4.txt --find_all_solutions --print_islands
                --print_check_solution --print_solution_count > output4_all_print.txt
```

We provide basic code to handle the required and optional command line arguments and a function to read the puzzle board. You may modify the provided code as necessary to complete the assignment.

Additional Requirements: Recursion & Big O Notation

You must use recursion in a non-trivial way in your solution – e.g., for detecting islands, for shading land blocks, and for enumerating all possible solutions to the puzzles. As always, we recommend you work on this program in logical steps. *IMPORTANT NOTE: This problem is computationally expensive, even for medium-sized puzzles! Be sure to create your own simple test cases as you debug your program.*

As always, use good coding style when you design and implement your program. You are encouraged but not required to write one or more new classes for this assignment. Make thoughtful decisions about how to efficiently use the STL classes we have discussed in lecture and lab.

Once you have finished your implementation, analyze the performance of your program using Big O Notation. What important variables control the complexity of a particular problem? The dimensions of the board (w and h)? How many cells are labeled with numbers (n)? The average or maximum value of cell number labels (v)? The area of the largest island in the solution (a)? In your `README.txt` file write a concise paragraph (< 200 words) justifying your answer. Include a table summarizing the running time and number of solutions found by your program on each of the provided examples and your own new test cases for the different command line arguments. *Note: It's ok if your program can't solve the medium or big puzzles in a reasonable amount of time.*

You must do this assignment on your own, as described in the "Collaboration Policy & Academic Integrity" handout. If you did discuss this assignment, problem solving techniques, or error messages, etc. with anyone, please list their names in your `README.txt` file.

Homework 6 Kurotto Solver Contest Rules

- All students are required to submit their program to the contest. Extra credit will be awarded for programs that have a strong performance in the contest.
- Members of the teaching staff will also be submitting to the contest... who will win???
- Contest submissions are a separate Submitty gradeable. Contest submissions are due Tuesday, October 29th at 11:59pm. You may not use late days for the contest. (The regular homework deadline is Thursday, Oct 24th at 11:59pm and late days are allowed for the regular homework submissions.)
- You may submit the same code for both the regular homework submission and the contest. Or you may make a small or significant change for the contest.
- Contest submissions *do not* need to use recursion.
- We will compile your code with optimizations enabled (`g++ -O3 *.cpp`) and run all submitted entries on the homework server.
- Programs must be single-threaded and single-process.
- We will run your program by *redirecting* `std::cout` to a file and measure performance with the UNIX `time` command. For example:

```
time ./kurotto_solver.out input4.txt --find_all_solutions > output4_all.txt
```

- You may want to use a *C++ code profiler* to measure the efficiency of your program and identify the portions of your code that consume most of the running time. A profiler can confirm your suspicions about what is slow, uncover unexpected problems, and focus your optimization efforts on the most inefficient portions of the code.
- We will be testing with and without the optional command line arguments `--no_solver`, `--print_islands`, `--print_check_solution`, `--print_solution_count`, and `--find_all_solutions` and will highlight the most correct and the fastest programs.
- You may submit one or two new Kurotto puzzle board file *with your regular homework submission* for possible inclusion in the contest. Name these test files: `puzzle_smithj_1.txt` and `puzzle_smithj_2.txt` (where `smithj` is your RCS username). Extra credit will be awarded for interesting test cases that are used in the contest. Caution: Don't make the test cases so difficult that your own program cannot solve them in a reasonable amount of time!
- In your `README_contest.txt` file, describe the optimizations you implemented for the contest and summarize the performance of your program on all test cases.