Project 1 (Percolation) Checklist

Prologue

Project goal: write a program to estimate the percolation threshold of a system

Files

- `project1.pdf` (project description)
- `project1.zip` (starter files for the exercises/problems, `report.txt` file for the project report, `run_tests` file to test your solutions, and test data files)

Exercises

Exercise 1. (*Great Circle Distance*) Write a program `GreatCircle.java` that takes four doubles x_1, y_1, x_2, and y_2 representing the latitude and longitude in degrees of two points on earth as command-line arguments and writes the great-circle distance (in km) between them, given by the equation

$$d = 111 \arccos(\sin(x_1)\sin(x_2) + \cos(x_1)\cos(x_2)\cos(y_1 - y_2)).$$

```
>_ ~/workspace/project1

$ java GreatCircle 48.87 -2.33 37.8 -122.4
8701.389543238289
```

Exercises

GreatCircle.java

```java
package edu.umb.cs210.p1;

import stdlib.StdOut;

public class GreatCircle {
    // calculates the great circle distance given two sets of coordinates
    protected static double calculateGreatCircleDistance(String[] args) {
        // Get angles lat1, lon1, lat2, and lon2 from command line as
        // doubles.
        ...

        // Convert the angles to radians.
        ...

        // Calculate great-circle distance d.
        ...

        // Return d.
        ...
    }

    // Entry point. [DO NOT EDIT]
    public static void main(String[] args) {
        StdOut.println(GreatCircle.calculateGreatCircleDistance(args));
    }
}
```

Exercise 2. (*Counting Primes*) Implement the static method `isPrime()` in `PrimeCounter.java` that takes an integer argument x and returns `true` if it is prime and `false` otherwise. Also implement the static method `primes()` that takes an integer argument N and returns the number of primes less than or equal to N. Recall that a number x is prime if it is not divisible by any number $i \in [2, \sqrt{x}]$.

```
>_ ~/workspace/project1

$ java PrimeCounter 100
25
$ java PrimeCounter 1000000
78498
```

Exercises

PrimeCounter.java

```java
package edu.umb.cs210.p1;

import stdlib.StdOut;

public class PrimeCounter {
    // Checks if x is prime
    protected static boolean isPrime(int x) {
        // For each 2 <= i <= sqrt(x), if x is divisible by
        // i, then x is not a prime. If no such i exists,
        // x is a prime.
        ...
    }

    // Returns the number of primes <= N.
    protected static int primes(int N) {
        // For each 2 <= i <= N, use isPrime() to test if
        // i is prime, and if so increment a count. At the
        // end return count.
        ...
    }

    // Entry point. [DO NOT EDIT]
    public static void main(String[] args) {
        int N = Integer.parseInt(args[0]);
        StdOut.println(primes(N));
    }
}
```

Exercise 3. (*Euclidean Distance*) Implement the static method `distance()` in `Distance.java` that takes position vectors x and y — each represented as a 1D array of doubles — as arguments and returns the Euclidean distance between them, calculated as the square root of the sums of the squares of the differences between the corresponding entries.

```
>_ ~/workspace/project1

$ java Distance
5
-9 1 10 -1 1
5
-5 9 6 7 4
13.0
```

Exercises

Distance.java

```
package edu.umb.cs210.p1;

import stdlib.StdArrayIO;
import stdlib.StdOut;

public class Distance {
    // Returns the Euclidean distance between the position vectors x and y.
    protected static double distance(double[] x, double[] y) {
        // For each 0 <= i < x.length, add the square of
        // (x[i] - y[i]) to distance. At the end return
        // sqrt(distance).
        ...
    }

    // Entry point. [DO NOT EDIT]
    public static void main(String[] args) {
        double[] x = StdArrayIO.readDouble1D();
        double[] y = StdArrayIO.readDouble1D();
        StdOut.println(distance(x, y));
    }
}
```

Exercise 4. (*Matrix Transpose*) Implement the static method `tranpose()` in `Transpose.java` that takes a matrix x — represented as a 2D array of doubles — as argument and returns a new matrix that is its transpose.

```
>_ ~/workspace/project1

$ java Transpose
3 3
1 2 3
4 5 6
7 8 9
3 3
  1.00000   4.00000   7.00000
  2.00000   5.00000   8.00000
  3.00000   6.00000   9.00000
```

Exercises

Transpose.java

```java
package edu.umb.cs210.p1;

import stdlib.StdArrayIO;

public class Transpose {
    // Returns a new matrix that is the transpose of x.
    protected static double[][] transpose(double[][] x) {
        // Create a new 2D matrix t (for transpose) with
        // dimensions n x m, where m x n are the dimensions
        // of x.
        ...

        // For each 0 <= i < m and 0 <= j < n, set t[j][i]
        // to x[i][j].
        ...

        // Return t.
        ...
    }

    // Entry point. [DO NOT EDIT]
    public static void main(String[] args) {
        double[][] x = StdArrayIO.readDouble2D();
        StdArrayIO.print(transpose(x));
    }
}
```

Exercises

Exercise 5. (*Rational Number*) Implement a data type `Rational` in `Rational.java` that represents a rational number, ie, a number of the form a/b where a and $b \neq 0$ are integers. The data type must support the following API:

Method	Description
`Rational(long x)`	constructs a rational number whose numerator is the given number and denominator is 1
`Rational(long x, long y)`	constructs a rational number given its numerator and denominator†
`Rational add(Rational that)`	returns the sum of *this* and *that* rational number
`Rational multiply(Rational that)`	returns the product of *this* and *that* rational number
`boolean equals(Rational that)`	checks if *this* rational number is the same as *that*
`String toString()`	returns a string representation of *this* rational number

† Use the private method `gcd()` to ensure that the numerator and denominator never have any common factors. For example, the rational number 2/4 must be represented as 1/2.

```
>_ ~/workspace/project1

$ java Rational 10
true
```

Exercises

Rational.java

```java
package edu.umb.cs210.p1;

import stdlib.StdOut;

// A data type representing a rational number.
public class Rational {
    private long x; // numerator
    private long y; // denominator

    // Constructs a rational number whose numerator is x and
    // denominator is 1.
    public Rational(long x) {
        // Set this.x to x and this.y to 1.
        ...
    }

    // Constructs a rational number given its numerator and
    // denominator.
    public Rational(long x, long y) {
        // Set this.x to x / gcd(x, y) and this.y to
        // y / gcd(x, y).
        ...
    }

    // Returns the sum of this and that rational number.
    public Rational add(Rational that) {
        // Sum of rationals a/b and c/d is the rational
        // (ad + bc) / bd.
        ...
    }

    // Returns the product of this and that rational number.
    public Rational multiply(Rational that) {
        // Product of rationals a/b and c/d is the rational
        // ac / bd.
```

Exercises

Rational.java

```java
        ...
    }

    // Checks if this rational number is the same as that.
    public boolean equals(Rational that) {
        // Rationals a/b and c/d are equal iff a == c
        // and b == d.
        ...
    }

    // Returns a string representation of the rational number.
    public String toString() {
        long a = x, b = y;
        if (a == 0 || b == 1) {
            return a + "";
        }
        if (b < 0) {
            a *= -1;
            b *= -1;
        }
        return a + "/" + b;
    }

    // Returns gcd(p, q), computed using Euclid's algorithm.
    private static long gcd(long p, long q) {
        return q == 0 ? p : gcd(q, p % q);
    }

    // Test client. [DO NOT EDIT]
    public static void main(String[] args) {
        int n = Integer.parseInt(args[0]);
        Rational total = new Rational(0);
        Rational term = new Rational(1);
        for (int i = 1; i <= n; i++) {
            total = total.add(term);
```

Rational.java

```java
            term = term.multiply(new Rational(1, 2));
        }
        Rational expected = new Rational((long) Math.pow(2, n) - 1,
                (long) Math.pow(2, n - 1));
        StdOut.println(total.equals(expected));
    }
}
```

Exercise 6. (*Harmonic Number*) Write a program `Harmonic.java` that takes an integer n as command-line argument, and uses the `Rational` data type from the previous exercise to compute and write the nth harmonic number H_n as a rational number. H_n is calculated as

$$H_n = 1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{n-1} + \frac{1}{n}.$$

```
>_ ~/workspace/project1

$ java Harmonic 5
137/60
```

Exercises

Harmonic.java

```java
package edu.umb.cs210.p1;

import stdlib.StdOut;

public class Harmonic {
    // Computes the nth harmonic number, where n is passed in through args
    protected static Rational harmonicSum(String[] args) {
        // Get n from command line as integer.
        ...

        // Set total to the rational number 0.
        Rational total = ...;

        // For each 1 <= i <= n, add the rational term
        // 1 / i to total.
        for (...) {
            Rational term = ...;
            total = ...;
        }

        // return total.
        ...
    }

    // Entry point. [DO NOT EDIT]
    public static void main(String[] args) {
        StdOut.println(Harmonic.harmonicSum(args));
    }
}
```

Problems

The guidelines for the project problems that follow will be of help only if you have read the description of the project and have a general understanding of the problems involved. It is assumed that you have done the reading.

Problems

Problem 1. (*Model a Percolation System*) To model a percolation system, create a data type `Percolation` with the following API:

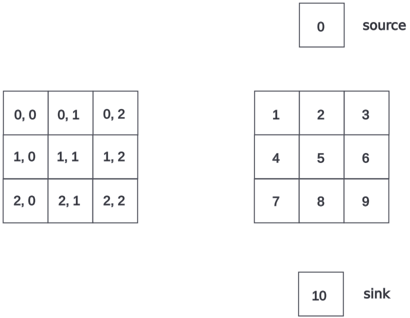
Method	Description
`Percolation(int N)`	creates an N-by-N grid, with all sites blocked
`void open(int i, int j)`	opens site (i, j)
`boolean isOpen(int i, int j)`	returns `true` if site (i, j) is open, and `false` otherwise
`boolean isFull(int i, int j)`	returns `true` if site (i, j) is full, and `false` otherwise
`int numberOfOpenSites()`	returns the number of open sites
`boolean percolates()`	returns `true` if the system percolates, and `false` otherwise

Hints

- $\rightsquigarrow$ Model percolation system as an $N \times N$ array of booleans (`true` $\implies$ open site and `false` $\implies$ blocked site)
- $\rightsquigarrow$ Can implement the API by scanning the array directly, but that does not meet all the performance requirements; use Union-find (`UF`) data structure instead
- $\rightsquigarrow$ Create an `UF` object with $N^2 + 2$ sites and use the private `encode()` method to map sites $(0, 0), (0, 1), \ldots, (N-1, N-1)$ of the array to sites $1, 2, \ldots, N^2$ of the `UF` object; sites 0 (source) and $N^2 + 1$ (sink) are virtual, ie, not part of the percolation system

Problems

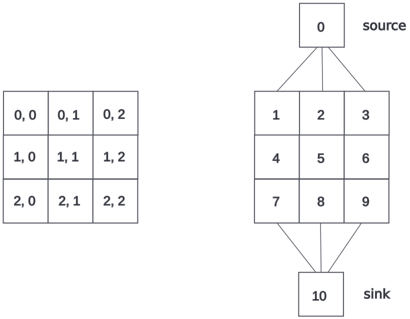
- A 3×3 percolation system and its UF representation



- Instance variables
  - Percolation system size, `int N`
  - Percolation system, `boolean[][] open`
  - Number of open sites, `int openSites`
  - Union-find representation of the percolation system, `WeightedQuickUnionUF uf`

Problems

- `private int encode(int i, int j)`
  - Return the UF site $(1 \dots N)$ corresponding to the percolation system site (i, j)
- `public Percolation(int N)`
  - Initialize instance variables
  - Connect the sites corresponding to first and last rows of the percolation system with the source and sink sites respectively
  - The 3×3 system with its top and bottom row sites connected to the source and sink sites respectively

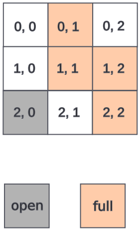


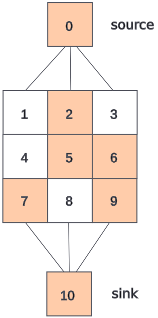
Problems

- `void open(int i, int j)`
  - Open the site `(i, j)` if it is not already open
  - Increment `openSites` by one
  - Check if any of the neighbors to the north, east, west, and south of `(i, j)` is open, and if so, connect the site corresponding to `(i, j)` with the site corresponding to that neighbor
- `boolean isOpen(int i, int j)`
  - Return whether site `(i, j)` is open or not
- `boolean isFull(int i, int j)`
  - Return whether site `(i, j)` is full or not; a site is full if it is open and its corresponding site is connected to the source site
- `int numberOfOpenSites()`
  - Return the number of open sites
- `boolean percolates()`
  - Return whether the system percolates or not; the system percolates if the sink site is connected to the source site

Problems

- Using virtual source and sink sites introduces what is called the *back wash* problem
- In the 3×3 system, consider opening the sites $(0, 1)$, $(1, 2)$,$(1, 1)$, $(2, 0)$, and $(2, 2)$, and in that order; the system percolates once $(2, 2)$ is opened





- The site $(2, 0)$ is technically not full since it is not connected to an open site in the top row via a path of neighboring (north, east, west, and south) open sites, but the corresponding site (7) is connected to the source, so is incorrectly reported as being full — this is the back wash problem
- To receive full credit for the problem, you must address the back wash problem

Problem 2. (*Estimate Percolation Threshold*) To estimate the percolation threshold, create a data type `PercolationStats` with the following API:

Method	Description
`PercolationStats(int N, int T)`	performs T independent experiments on an N-by-N grid
`double mean()`	returns sample mean of percolation threshold
`double stddev()`	returns sample standard deviation of percolation threshold
`double confidenceLow()`	returns low endpoint of 95% confidence interval
`double confidenceHigh()`	returns high endpoint of 95% confidence interval

Hints

- Instance variables
  - Number of independent experiments, `int T`
  - Percolation thresholds for the `T` experiments, `double[] p`

Problems

- `PercolationStats(int N, int T)`
  - Initialize instance variables
  - Perform the following experiment `T` times
    - Create an $N \times N$ percolation system
    - Until the system percolates, choose a site (i, j) at random and open it if it is not already open
    - Calculate percolation threshold as the fraction of sites opened, and store the value in `p[]`
- `double mean()`
  - Return the mean μ of the values in `p[]`
- `double stddev()`
  - Return the standard deviation σ of the values in `p[]`
- `double confidenceLow()`
  - Return $\mu - \frac{1.96\sigma}{\sqrt{T}}$
- `double confidenceHigh()`
  - Return $\mu + \frac{1.96\sigma}{\sqrt{T}}$

Problems

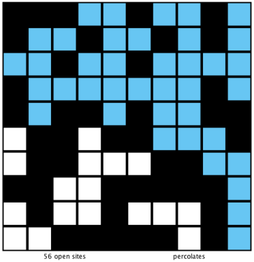
The `data` directory contains some input files for use with the percolation clients, and associated with most input `.txt` files are output `.png` files that show the desired output; for example

```
>_ ~/workspace/project1

$ more data/input10.txt
10
9 1
1 9
...
3 4
7 9
```

```
>_ ~/workspace/project1

$ display data/input10.png
```

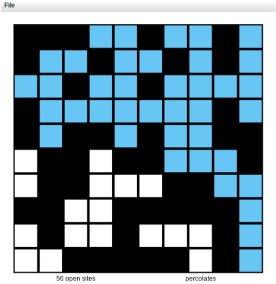


Problems

The visualization client `PercolationVisualizer` takes as command-line argument the name of a file specifying the size and open sites of a percolation system, and visually reports if the system percolates or not

```
>_ ~/workspace/project1

$ java PercolationVisualizer data/input10.txt
```

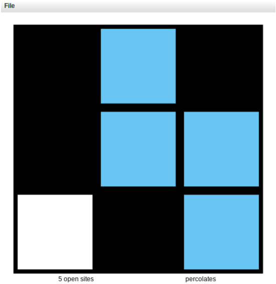


Problems

The visualization client `InteractivePercolationVisualizer` constructs an N-by-N percolation system, where N is specified as command-line argument, and allows you to interactively open sites in the system by clicking on them and visually inspect if the system percolates or not

```
>_ ~/workspace/project1

$ java InteractivePercolationVisualizer 3
3
0 1
1 2
1 1
2 0
2 2
```



Epilogue

Use the template file `report.txt` to write your report for the project

Your report must include

- Time (in hours) spent on the project
- Difficulty level (1: very easy; 5: very difficult) of the project
- A short description of how you approached each problem, issues you encountered, and how you resolved those issues
- Acknowledgement of any help you received
- Other comments (what you learned from the project, whether or not you enjoyed working on it, etc.)

Epilogue

Before you submit your files

- Make sure your programs meet the style requirements by running the following command on the terminal

```
>_ ~/workspace/project1
$ check_style <program>
```

  where <program> is the fully-qualified name of the program

- Make sure your programs meet the input and output specifications by running the following command on the terminal

```
>_ ~/workspace/project1
$ bash ./run_tests
```

  where the optional argument <items> lists the exercises/problems (`Exercise1`, `Problem2`, etc.) you want to test, separated by spaces; all the exercises/problems are tested if no argument is given

- Make sure your code is adequately commented, is not sloppy, and meets any project-specific requirements, such as corner cases and running time
- Make sure your report uses the given template, isn't too verbose, doesn't contain lines that exceed 80 characters, and doesn't contain spelling mistakes

Files to submit

1. `GreatCircle.java`
2. `PrimeCounter.java`
3. `Distance.java`
4. `Transpose.java`
5. `Rational.java`
6. `Harmonic.java`
7. `Percolation.java`
8. `PercolationStats.java`
9. `report.txt`