CSE 331 Software Design and Implementation

Homework 6: ***Generics and Least-Cost Paths***
Due: Tuesday, May 21 @ **11pm**

Handout H6

Contents:

Introduction

This assignment lays the groundwork for an application you'll build in Homeworks 7 and 8 called Campus Paths. Using your graph as the underlying data structure, Campus Paths generates directions between buildings on campus to help students and visitors find their way around.

This assignment has two main parts. In the first part, you will make your graph class(es) generic. In the second part, you will implement a different pathfinding algorithm for graphs known as Dijkstra's algorithm. These parts are not directly related to each other, but both are necessary for Homework 7.

Augmenting Your Graph and Marvel Paths

Problem 1: Making Your Graph Generic [30 points]

In Campus Paths, your mission is to find the shortest walking route between points on the UW campus. A graph is an excellent representation of a map, and luckily you have already

specified and implemented a graph. Unfortunately, your graph only stores `String`s, whereas Campus Paths needs to store non-String data types in the nodes and edges, such as coordinate pairs and physical distances. More generally, your graph would be much more widely useful if only the client could choose the data types to be stored in nodes and edges. Herein lies the power of generics!

Your task is to convert your graph ADT to a generic class. Rather than always storing the data in nodes and edge labels as `String`s, it should have two type parameters representing the data types to be stored in nodes and edges. Directly modify your existing classes under `hw4` - there is no need to copy or duplicate code.

When you are done, your previously-written HW4 and HW5 tests and test driver and `MarvelPaths` will no longer compile. Modify these classes to construct and use graph objects parameterized with Strings. All code must compile and all tests must pass when you submit your homework. In particular, your test drivers for both Homework 4 and 5 must work correctly so we can test your code. Depending on your changes, some of your implementation tests may no longer be valid. Try to adapt your implementation tests to your new implementation, or discard them and write new ones: they should help you build confidence in your implementation. But, don't overdo it: as with any testing, stop when you feel that the additional effort is not being repaid in terms of increased confidence in your implementation. Learning when to stop working on a given task is an important skill.

Build tools and generic code

Double-check that you have configured Eclipse to issue errors for improper use of generic types.

Very important warning! Eclipse's built-in compiler sometimes handles generics differently from `javac`, the standard command-line compiler. This means code that compiles in Eclipse may *not* compile when we run our grading scripts, leaving us unable to test your code and significantly impacting your grade. **You MUST periodically make sure your code compiles (builds) with `javac`** by running `ant build` from the `hw6` directory (which will also build `hw4` and `hw5` automatically). You can do this in one of two ways:

- **Through Eclipse:** Right-click `build.xml` under `hw6` and click `Run As >> Ant Build...` (note the ellipsis). In the window that appears, select `build [from import ../common.xml]` and hit `Run`.
- **At the command line:** Run `ant build` from the `hw6` directory.

If Ant reports that the build succeeded, all is well: your code compiles with `javac`.

Hint: after encountering build errors in Ant, you may find that classes which previously compiled are now reporting "[some class] cannot be resolved" errors in Eclipse. You can fix these errors by doing a clean build: go to `Project >> Properties >> Clean...`, select your `cse331` project, and hit `OK`. If you are encountering these errors on the command line, run `ant clean` prior to running `ant build`.

Problem 2: Weighted Graphs and Least-Cost Paths [30 points]

In a *weighted graph*, the label on each edge is a *length*, *cost*, or *weight* representing the cost of traversing that edge. Depending on the application, the cost may be measured in time, money, physical distance, etc. The total cost of a path is the sum of the costs of all edges in that path, and the *minimum-cost path* between two nodes is the path with the lowest total cost between those nodes.

In Homework 7, you will build a edge-weighted graph where nodes represent locations on campus and edges represent straight-line walking segments connecting the two locations. The cost of an edge is the physical length of that straight-line segment. Finding the shortest walking route between two locations is a matter of finding the minimum-cost path between them.

Dijkstra's algorithm

You will implement Dijkstra's algorithm, which finds a minimum-cost path between two given nodes in a graph with all nonnegative edge weights. Below is a pseudocode algorithm that you may use in your implementation. You are free to modify it as long as you are essentially still implementing Dijkstra's algorithm. Your implementation of the algorithm may assume a graph with `Double` edge weights.

The algorithm uses a data structure known as a priority queue. A priority queue stores elements that can be compared to one another, such as numbers. A priority queue has two main operations:

- `add()`: Insert an element.
- `remove()`: Remove the least element. (This is sometimes called removeMin, for emphasis.)

For example, if you inserted the integers 1, 8, 5, 0 into a priority queue in that order, they would be removed in the order 0, 1, 5, 8. It is permitted to interleave adding and removing. The standard Java libraries include an implementation of a `PriorityQueue`.

```
Dijkstra's algorithm assumes a graph with all nonnegative edge weights.

start = starting node
dest = destination node
active = priority queue.  Each element is a path from start to a given node.
         A path's "priority" in the queue is the total cost of that path.
         Nodes for which no path is known yet are not in the queue.
finished = set of nodes for which we know the minimum-cost path from start.

// Initially we only know of the path from start to itself, which has a cost
// of zero because it contains no edges.
Add a path from start to itself to active

while active is non-empty:
    // minPath is the lowest-cost path in active and is the minimum-cost
    // path for some node
    minPath = active.removeMin()
    minDest = destination node in minPath

    if minDest is dest:
        return minPath

    if minDest is in finished:
        continue

    for each edge e = ?minDest, child?:
        // If we don't know the minimum-cost path from start to child,
        // examine the path we've just found
        if child is not in finished:
            newPath = minPath + e
            add newPath to active

    add minDest to finished

If the loop terminates, then no path exists from start to dest.
The implementation should indicate this to the client.
```

Dijkstra's Algorithm in Marvel Paths

You will write a modified version of your Marvel Paths application in which your application finds its paths using Dijkstra's algorithm instead of BFS. Dijkstra's algorithm requires

weighted edges. To simulate edge weights over the Marvel dataset, the weight of the edge between two characters will be based on how well-connected those two characters are. Specifically, the weight is the inverse of how many comic books two characters are in together (equivalently, the weight is the multiplicative inverse of the number of edges in the multigraph between them). For example, if Amazing Amoeba and Zany Zebra appeared in 5 comic books together, the weight of the edge between them would be 1/5. Thus, the more well-connected two characters are, the lower the weight and the more likely that a path is taken through them. In summary, the idea with the Marvel data is to treat the number of paths from one node to another as a "distance" - if there are several edges from one node to another then that is a "shorter" distance than another pair of nodes that are only connected by a single edge.

Things to note:

- A path from a character to itself is defined to have cost 0.0.
- Calculations for the weight of the edges in your graph should be done when the graph is loaded. This assignment is different from the last one in that when the graph is initialized there is only one edge between nodes and that edge is the weighted edge. The one edge between any two characters will be the label containing the multiplicative inverse of how many books they share.
- If an edge is added to your graph after its initialization and it contains a lower weight, then the new edge is the one that would be used in calculating paths. In other words once the weight of edges are calculated when a graph is initialized, those edges will remain unchanged throughout the duration of the program and your program will not re-calculate the weight of the graph's edges.

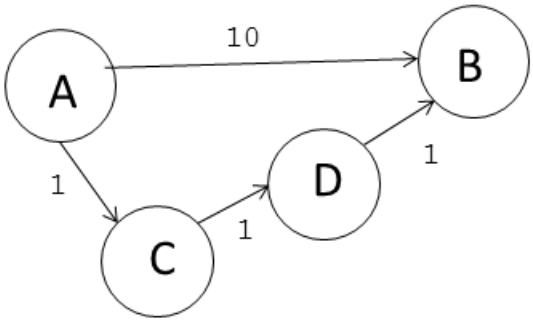
Place your new Marvel application in `hw6/MarvelPaths2.java`. In choosing how to organize your code, remember to avoid duplicating code as much as possible. In particular, reuse existing code where possible, and keep in mind that you will need to use the same implementation of Dijkstra's algorithm in a completely different application in Homework 7.

For this assignment, your program must be able to construct the graph and find a path in less than **10** seconds on attu using the full Marvel dataset. `ScriptFileTests` is set to put a 1000 ms (10 second) timeout for each test, run without assertions enabled. As suggested in hw5, running `ant test` is a convenient way to time your program.

As before, you are welcome to write a `main()` method for your application, but you are not required to do so.

Why not breadth-first search?

This assignment does not reuse your breadth-first search algorithm. A breadth-first search between two nodes finds the path with the fewest number of edges. In a weighted graph, it does not always find the minimum-cost path. In the example below, a breadth-first search from A to B would find the path `{?A,B?}` with total cost 10. But the alternative path `{?A,C?,?C,D?,?D,B?}` has a total cost of 3, making it a lower-cost path even though it has more edges.



A graph whose minimum-cost path is not found by BFS.

Breadth-first search gives the same results as Dijkstra's algorithm when all edge weights are 1.

Problem 3: Testing Your Solution [13 points]

The format for writing tests follows the usual specification/implementation structure. You should write the majority of your tests as specification tests according to the test script file format defined below, specifying the test commands, expected output, and graph data in `*.test`, `*.expected`, and `*.tsv` files, respectively. The `*.tsv` files should be structured in the same format as `marvel.tsv`. As usual, you will also write a class `HW6TestDriver` to run your specification tests. We provide a starter file for the test driver which you are free to modify or replace.

If your solution has additional implementation-specific behavior to test, write these tests in a regular JUnit test class or classes and add the class name(s) to `ImplementationTests.java`.

The specification tests do not directly test the property that your graph is generic. However, the Homework 4 and Homework 5 test scripts use String edge labels, while Homework 6 uses numeric values. Supporting all three test drivers implicitly tests the generic behavior of your graph.

Reflection [1 point]

Please answer the following questions in a file named `reflection.txt` in your `answers/` directory. Answer briefly, but in enough detail to help you improve your own practice via introspection and to enable the course staff to improve CSE 331 in the future.

a. In retrospect, what could you have done better to reduce the time you spent solving this assignment?
b. What could the CSE 331 staff have done better to improve your learning experience in this assignment?
c. What do you know now that you wish you had known before beginning the assignment?

Collaboration [1 point]

Please answer the following questions in a file named `collaboration.txt` in your `answers/` directory.

The standard collaboration policy applies to this assignment.

State whether or not you collaborated with other students. If you did collaborate with

other students, state their names and a brief description of how you collaborated.

Time Spent

Tell us how long you spent on this homework via this catalyst survey: https://catalyst.uw.edu/webq/survey/mernst/198078.

Returnin [25 points]

After you receive your corrected assignment back from your TA, you will need to resubmit a corrected version of the code. You will have until Thursday, May 30 at 11pm to returnin your code. The returnin script will be enabled a week earlier, at 11pm Thursday, May 23.

You will only receive credit if you pass all the tests, and you have a fixed number of trials without penalty. See the returnin331 documentation for details.

Test script file format

The test script file format for Homework 6 uses exactly the same commands and format as Homework 5, but with a few differences in arguments and output:

- Edge labels are `Double`s instead of `String`s. If an edge label in a test script cannot be parsed as a number, the output is undefined. For **ListChildren**, the same rules as before apply for ordering output by nodes and edges, except that edges are now ordered numerically instead of lexicographically.
- **LoadGraph** is still in use, but because there are multiple approaches to generating a weighted graph from the unweighted Marvel graph, the output of ListNodes and ListChildren are undefined after LoadGraph. Also, your program needs to look for data files in `src/hw6/data` this time.
- **FindPath** searches with Dijkstra's algorithm instead of BFS and prints its output in the form:

```
path from CHAR 1 to CHAR N:
CHAR 1 to CHAR 2 with weight w1
CHAR 2 to CHAR 3 with weight w2
...
CHAR N-1 to CHAR N with weight wN-1
total cost: W
```

  where *W* is the sum of *w1, w2, ..., wN-1*.

  In other words, the only changes in output from HW5 are the way the edge labels are printed and the addition of a "total cost" line at the bottom. The output should remain the same as before when no path is found or the characters are not in the graph: in particular, do not print the "total cost" line in those cases. Also as before, underscores in node names are replaced by spaces for this command.

  If there are two minimum-cost paths between *CHAR 1* and *CHAR N*, it is undefined which one is printed.

  What if the user asks for a path from a building to itself in the dataset? We offer the same advice as in Homework 5: revisit the pseudocode algorithm. What value does it say to return in this case, and how would this return value be handled by the FindPath command? (A well-written solution requires no special handling of this case.)

- For readability, the output of **ListChildren**, **AddEdge**, and **FindPaths** should print numeric values with exactly 3 digits after the decimal point, rounding to the nearest value if they have more digits. The easiest way to specify the desired format of a value is using format strings. For example, you could create the String *"Weight of 1.760"* by writing:

  ```
  String.format("Weight of %.3f", 1.759555555555);
  ```

  In **FindPaths**, the total cost should be computed by summing the full values of the individual weights, not the rounded values.

- As in Homework 5, a path from a character to itself should be treated as a trivially empty path. Because this path contains no edges, it has a cost of zero. (Think of the path as a list of edges. The sum of an empty list is conventionally defined to be zero.) So your test driver should print the usual output for a path but without any edges, i.e.:

  ```
  path from C to C:
  total cost: 0.000
  ```

  This only applies to characters in the dataset: a request for a path from a character that is not in the dataset to itself should print the the usual "unknown character C" output.

- Also as in Homework 5, if the user gives two valid node arguments *CHAR_1* and *CHAR_2* that have no path in the specified graph, print:

  ```
  path from CHAR 1 to CHAR N:
  no path found
  ```

Sample testing files

Several sample test files demonstrating the changes in format are provided in `hw6/test`.

Hints

Documentation

When you add generic type parameters to a class, make sure to describe these type parameters in the class's Javadoc comments so the client understands what they're for.

As usual, include an abstraction function, representation invariant, and checkRep in all classes that represent an ADT. If a class does not represent an ADT, place a comment that explicitly says so where the AF and RI would normally go. (For example, classes that contain only static methods and are never constructed usually do not represent an ADT.) Please come to office hours if you feel unsure about what counts as an ADT and what doesn't.

Code Organization

In deciding how to organize your code, remember that you will need to reuse Dijkstra's algorithm in Homework 7. That assignment has nothing to do with Marvel and, depending on your implementation, might use a different generic type for nodes. How can you

structure your code so that your implementation of Dijkstra's algorithm is convenient to use for both assignments?

What to Turn In

You should add and commit the following files to SVN:

- `hw6/MarvelPaths2.java`
- `hw6/*.java` *[Other classes you create, if any]*
- `hw6/test/*.test`
- `hw6/test/*.expected`
- `hw6/test/*.tsv`
- `hw6/test/*Test.java` *[Other JUnit test classes you create, if any]*
- `hw6/answers/reflection.txt`
- `hw6/answers/collaboration.txt`

Additionally, be sure to commit any updates you make to the following files:

- `hw4/*` *[Your graph ADT and test classes]*
- `hw5/*` *[Your Marvel Paths application]*
- `hw6/HW6TestDriver.java`
- `hw6/test/ImplementationTests.java`

Finally, remember to run `ant validate` to verify that you have submitted all files and that your code compiles and runs correctly when compiled with `javac` on attu (which sometimes behaves differently from the Eclipse compiler).

Errata

None yet.

Q & A

None yet.