CS271: Data Structures

Instructor: Dr. Stacey Truex

Project #6

This project is meant to be completed in groups. You should work in your Unit 4 groups. Implementation solutions should be written in `C++`. Only one submission (the last submission uploaded to canvas) will be graded per group. Submissions should be a compressed file following the naming convention: `NAMES_cs271_project6.zip` where `NAMES` is replaced by the first initial and last name of each group member. For example, if Dr. Truex and Dr. Kretchmar were in a group they would submit one file titled `STruexMKretchmar_cs271_project6.zip.` **You will lose points if you do not follow the course naming convention**. Your `.zip` file should contain a *minimum* of 4 files:

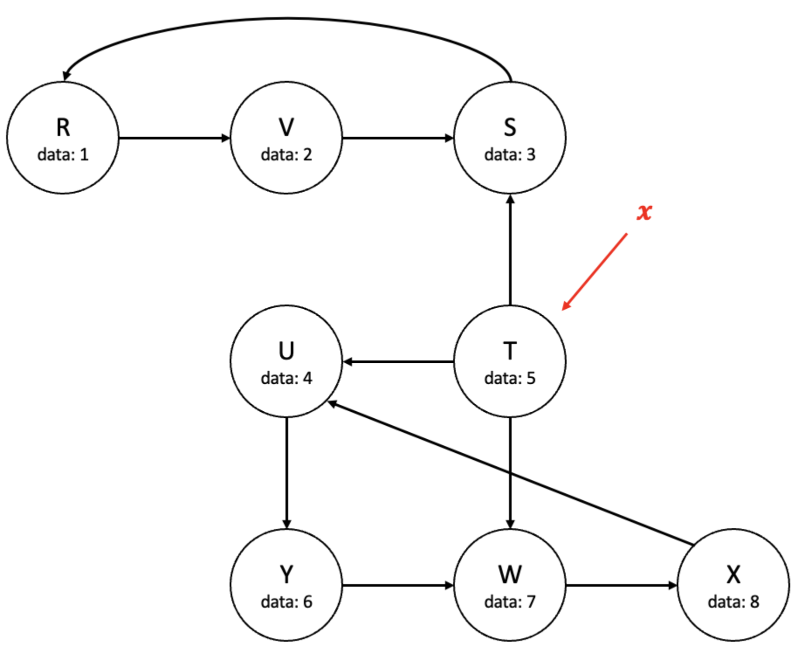
1. `makefile`
2. `graph.cpp`
3. `test_graph.cpp`
4. `commits.pdf`: a commit history for your GitHub project

Additional files such as a `graph.h` header file or `README.md` are welcome. The above merely represent the minimum files required for project completion. Your code is expected to implement a `Graph` class. Details for each part of the project are as follows.

Graphs

Implement a `Graph` class using **two** templates - one for the data associated with each `Graph` vertex and one for the key associated with each vertex. In your implementation, denote the data template first. Your class should, at a minimum, support the following operations:

- get(`k`): `G.get(k)` should return a *pointer* to the vertex corresponding to the key `k` in the graph `G`. For example, consider the following graph:



Given the above,

```
Graph<int,string> G;
// populate graph G with vertices and edges corresponding to graph above
cout << G.get("T") -> data << endl;
cout << G.get("T") -> key << endl;
```

should print the integer value 5 and the string "T" respectively as the command `G.get("T")` returns the equivalent of x from the image above.

- reachable(`u`, `v`): `G.reachable(u, v)` should indicate if the vertex corresponding to the key `v` is reachable from the vertex corresponding to the key `u` in the graph `G`. For example, using the graph `G` from above:

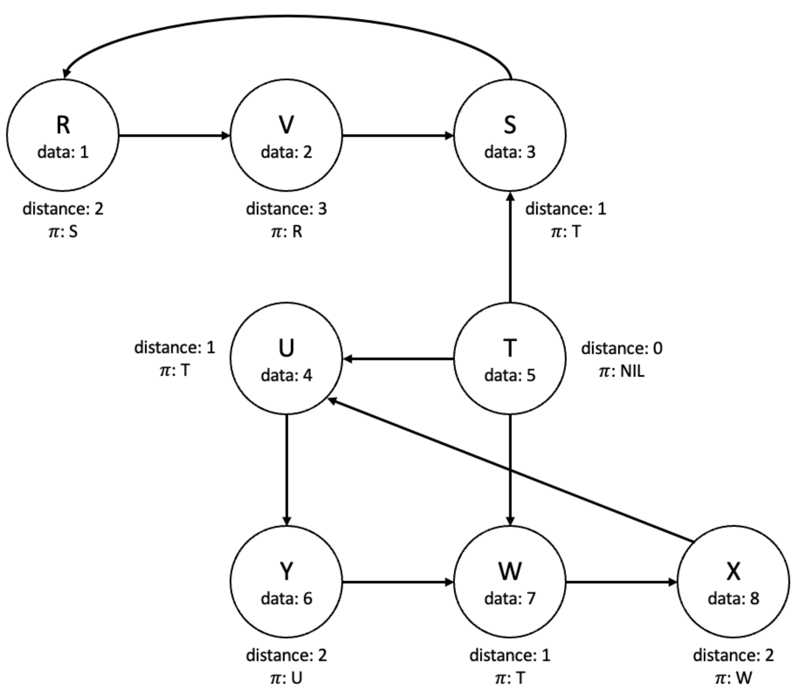
```
if(G.reachable("T",  "X")) {
    cout << "X is reachable from T" << endl;
}
if(G.reachable("X",  "T")) {
    cout << "T is reachable from X" << endl;
}
```

should *only* print the string "X is reachable from T"

- bfs(`s`): `G.bfs(s)` should execute the breadth-first search algorithm for the graph `G` from the source vertex corresponding to the key value `s`. For example, using the graph above:

```
G.bfs("T");
```

should result in the following internal representation of the graph:



- print_path(u, v): `G.print_path(u, v)` should print a shortest path from the vertex in `G` corresponding to the key `u` to the vertex in `G` corresponding to the key `v`. For example:

  ```
  G.print_path("U", "X");
  ```

  should result in the printing of the string `"U -> Y -> W -> X"`. Paths should be printed as the keys of the vertices along the path separated by a space, `->`, and another space. Adhering to this formatting is required to pass testing.

- edge_class(u, v): `G.edge_class(u, v)` should return the string representation of the edge classification (tree edge, back edge, forward edge, cross edge, or no edge) of the edge from vertex `u` to `v`. For example, using the graph `G` from above:

  ```
  cout << G.edge_class("X", "U") << endl;
  cout << G.edge_class("V", "S") << endl;
  ```

  should print `"back edge"` and `"tree edge"` respectively. Note that returning the exact string `"tree edge"`, `"back edge"`, `"forward edge"`, `"cross edge"`, or `"no edge"` is required to pass testing.

- bfs_tree(s): `G.bfs_tree(s)` should **print** the bfs tree for the source vertex corresponding to the key `s`. Vertices in the bfs tree should be represented by their keys. Each depth level of the tree should be printed on a separate line with each vertex at the same depth being separated by a single space. For example, using the graph above:

  ```
  G.bfs_tree("T");
  ```

  should result in the printing of the following string:

  ```
  T
  S U W
  R Y X
  V
  ```

Unit Testing

In addition to the functionality above, you are expected to implement the following constructor:

```
Graph(vector<K> keys, vector<D> data, vector<vector<K>> edges)
```

where `keys` is a vector of vertex keys, `data` is a vector of the corresponding vertex data in matching order, and `edges` is a vector of vectors representing the adjacency lists of the vertices in matching order. For example, you should be able to construct the graph `G` from the specifications above via the following:

```
vector<string> keys = ["R", "S", "T", "U", "V", "W", "X", "Y"];
vector<int> data = [1, 3, 5, 4, 2, 7, 8, 6];
vector<vector<string>> edges = [["V"], ["R"], ["S", "U", "W"], ["Y"],
                                ["S"], ["X"], ["U"], ["W"]];
Graph<int,string> G(keys, data, edges);
```

Your implementation of this constructor will be required for your class to pass testing. Both $G.V$ and $G.Adj[u]$ for all $u \in G.V$ should be in ascending order by key. You may assume the `keys` vector passed to your constructor is also in such order.

For each Graph method included in your Graph class, write a unit test method in a separate unit test file that *thoroughly* tests that method. Think, in addition to common cases: what are my boundary cases? edge cases? disallowed input? Each method should have *its own* test method.

An example test file `test_graph_example.cpp` has been provided along with an example graph specified in `graph_description.txt`. The example test file demonstrates (1) a general outline of what is expected in a test file and (2) a guide on how your projects will be tested after submission. The tests included in `test_graph_example.cpp` are not exhaustive. The unit testing in your `test_graph.cpp` file should be much more complete. Additionally, for grading purposes, your code will be put through significantly more thorough testing than what is represented by `test_graph_example.cpp`. Passing the tests in this example file should be viewed as a lower bound.

Finally, **please use `-1` to represent ∞** whenever necessary in your code.

Documentation

The expectation of all coding assignments is that they are well-documented. This means that logic is documented with line comments and method pre- and post- conditions are properly documented immediately after the method's parameter list.

Pre-conditions and post-conditions are used to specify precisely what a method does. However, a pre-condition/post-condition specification does not indicate how that method accomplishes its task (if such commenting is necessary it should be done through line level comments). Instead, pre-conditions indicate what must be true before the method is called while the post-condition indicates what will be true when the method is finished.

Makefile

With each project you should be submitting a corresponding makefile. Once unpacking your `.zip` file, the single command `make` should create a `test` executable. The command `./test` should then run all the unit tests in your `test_graph.cpp` file evaluating your `Graph` class.

Efficiency

Each project in this course will additionally be evaluated for efficiency. Each method detailed in the Graph class methods section of this document will be called 1 time using a very large example. The total time to execute all methods will be clocked.

Rubric

Note that any coding projects that do not compile with the provided `test_graph_example.cpp` file will be given a 0. All project that are able to be successfully compiled will be graded using the following rubric.

<table>
<tr><td rowspan="22">C++ Implementation</td><td colspan="3">does not compile: 0/40</td></tr>
<tr><td colspan="3">40 Total Points</td></tr>
<tr><td rowspan="3">Code</td><td>Completeness
met submission requirements</td><td>10 pts</td></tr>
<tr><td>Correctness
passes unit testing</td><td>22 pts</td></tr>
<tr><td>Validation
implementation deductions
ex: compile error when key template is not <code>string</code></td><td>——</td></tr>
<tr><td rowspan="5">Efficiency</td><td>Time Test</td><td>2 pts</td></tr>
<tr><td>encountered error - could not complete time test</td><td>0/2</td></tr>
<tr><td>takes over 2x fastest submission</td><td>1/2</td></tr>
<tr><td>within 2x fastest submission</td><td>2/2</td></tr>
<tr><td>fastest submission</td><td>3/2</td></tr>
<tr><td rowspan="5">Documentation</td><td>Documentation</td><td>3 pts</td></tr>
<tr><td>extremely sparse documentation</td><td>0/3</td></tr>
<tr><td>missing comments or pre- and post-conditions</td><td>1/3</td></tr>
<tr><td>documentation lacks detail in areas</td><td>2/3</td></tr>
<tr><td>detailed comments & pre- and post-conditions</td><td>3/3</td></tr>
<tr><td rowspan="5">Testing</td><td>Unit tests</td><td>3 pts</td></tr>
<tr><td>does not expand on example test file</td><td>0/3</td></tr>
<tr><td>not all functions tested or
testing not implemented as unit testing or
no variation in templates</td><td>1/3</td></tr>
<tr><td>caught some of the bugs in classmates' code</td><td>2/3</td></tr>
<tr><td>caught most bugs in classmates' code</td><td>3/3</td></tr>
</table>