Programming Assignment 5

Relationship Graph Algorithms

In this assignment, you will implement some useful algorithms that apply to relationship graphs of the Facebook kind.

Worth 100 points (10% of course grade)

Posted Monday, July 30

Due Tuesday, August 14, 1:15 AM (WARNING!! NO GRACE PERIOD)

There is NO extended deadline!!

- You will work on this assignment individually. Read DCS Academic Integrity Policy for Programming Assignments - you are responsible for abiding by the policy. In particular, note that "**All Violations of the Academic Integrity Policy will be reported by the instructor to the appropriate Dean**".
- **IMPORTANT - READ THE FOLLOWING CAREFULLY!!!**

  Assignments emailed to the instructor or TAs will be ignored--they will NOT be accepted for grading.
  We will only grade submissions in Sakai.

  If your program does not compile, you will not get any credit.

  Most compilation errors occur for two reasons:

  1. You are programming outside Eclipse, and you delete the "package" statement at the top of the file. If you do this, you are changing the program structure, and it will not compile when we test it.
  2. You make some last minute changes, and submit without compiling.

  To avoid these issues, (a) START EARLY, and give yourself plenty of time to work through the assignment, and (b) Submit a version well before the deadline so there is at least something in Sakai for us to grade. And you can keep submitting later versions (up to 10) - we will accept the LATEST version.

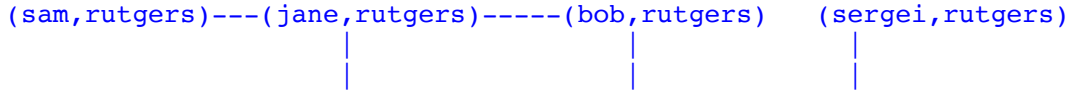
- Background
- Algorithms
- Implementation
- Submission

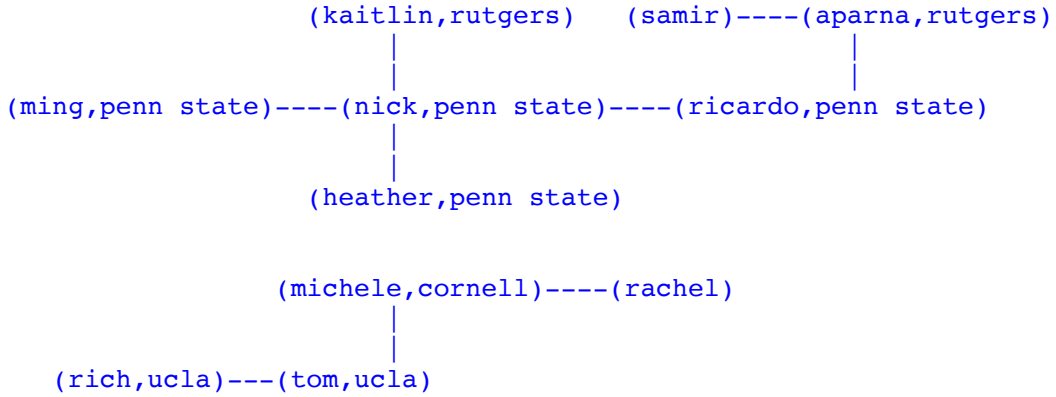
Background

In this program, you will implement some useful algorithms for graphs that represent relationships (e.g. Facebook). A relationship graph is an undirected graph without any weights on the edges. It is a simple graph because there are no self loops (a self loop is an edge from a vertex to itself), or multiple edges (a multiple edge means more than edge between a pair of vertices).

The vertices in the graphs for this assignment represent two kinds of people: students and non-students. Each vertex will store the name of the person. If the person is a student, the name of the school will also be stored.

Here's a sample relationship graph:





Note that the graph may not be connected, as seen in this example in which there are two "islands" or cliques that are not connected to each other by any edge. Also see that all the vertices represent students with names of schools, except for `rachel` and `samir`, who are not students.

Algorithms

1. **Shortest path: Intro chain**

   `sam` wants an intro to `aparna` through friends and friends of friends. There are two possible chains of intros:

   ```
   sam--jane--kaitlin--nick--ricardo--aparna

             or

   sam--jane--bob--samir--aparna
   ```

   The second chain is preferable since it is shorter.

   If `sam` wants to be introduced to `michele` through a chain of friends, he is out of luck since there is no chain that leads from `sam` to `michele` in the graph.

   Note that this algorithm does NOT have any restriction on the composition of the vertices: a vertex along the shortest chain need NOT be a student at a particular school, or even a student. In other words, this algorithm is not about students, let alone students at a particular school. So, for instance, you may need to find the shortest path (intro chain) from `nick` to `samir`, which will be:

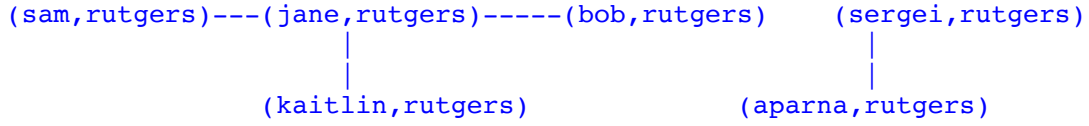
   ```
   nick--ricardo--aparana--samir
   ```

   which consists of two penn state students, one rutgers student, and one non-student.

2. **Cliques: Student cliques at a school**

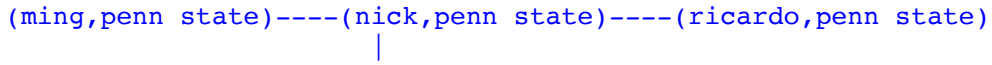
   Students tend to form cliques with their friends, which creates islands that do not connect with each other. If these cliques could be identified, particularly in the student population at a particular school, introductions could be made between people in different cliques to build larger networks of relationships at that school.

   In the sample graph, there are two cliques of students at rutgers:

   Note that in the graph these are not islands since `samir` connects them. However, since `samir` is not a student at rutgers, it results in two cliques of rutgers students that don't know each other through another rutgers student.

   At penn state, there is a single clique of students:


```
                    |
          (heather,penn state)
```

Also, a single clique of students at ucla:

```
(rich,ucla)---(tom,ucla)
```

And a single clique of students at cornell:

```
(michele,cornell)
```

3. **Connectors: Friends who keep friends together**

If `jane` were to leave rutgers, `sam` would no longer be able to connect with anyone else--`jane` was the "connector" who could pull `sam` in to hang out with her other friends. Similarly, `aparna` is a connector, since without her, `sergei` would not be able to "reach" anyone else. (And there are more connectors in the graph...)

On the other hand, `samir` is not a connector. Even if he were to leave, everyone else could still "reach" whoever they could when `samir` was there, even though they may have to go through a longer chain.

Definition: In an undirected graph, vertex `v` is a connector if there are at least two other vertices `x` and `w` for which *every* path between `x` and `w` goes through `v`.

For example, `v=jane`, `x=sam`, and `w=bob`.

Finding all connectors in an undirected graph can be done using DFS (depth-first search), by keeping track of two additional quantities for every vertex `v`. These are:

- `dfsnum(v)`: This is the dfs number, assigned when a vertex is visited, dealt out in increasing order.
- `back(v)`: This is a number that is initially assigned when a vertex is visited, and is equal to `dfsnum`, but can be changed later as follows:
  - When the DFS backs up from a neighbor, `w`, to `v`, if `dfsnum(v)` > `back(w)`, then `back(v)` is set to min(`back(v)`,`back(w)`)
  - If a neighbor, `w`, is already visited then `back(v)` is set to min(`back(v)`,`dfsnum(w)`)

> When the DFS backs up from a neighbor, `w`, to `v`, if `dfsnum(v)` ≤ `back(w)`, then `v` is identified as a connector, IF `v` is NOT the starting point for the DFS.
>
> If `v` is a starting point for DFS, it can be a connector, but another check must be made - see the examples below. The examples don't tell you how to identify such cases--you have to figure it out.

Here are some examples that show how this works.

- Example 1: (B is a connector)

```
A--B--C
```

Neighbors for a vertex are stored in adjacency linked lists like this:

```
A: B
B: C,A
C: B
```

The DFS starts at A.

```
dfs @ A  1/1  (dfsnum/back)
    dfs @ B 2/2
        dfs @ C 3/3
            neighbor B is already visited => C 3/2
        dfsnum(B) <= back(C) [B is a CONNECTOR]
        nbr A is already visited => B 2/1
    dfsnum(A) <= back(B) [A is starting point of DFS, NOT connector in this case]
```

- Example 2: (B is a connector)

```
 A--B--C
```

The same example as the first, except DFS starts at B. This shows how even thought B is the starting point, it is still identified (correctly) as a connector. The trace below is not complete because it does not show HOW B is determined to be a connector in the last line - that's for you to figure out. Neighbors are stored in adjacency linked lists as in Example 1.

```
dfs @ B  1/1
    dfs @ C 2/2
        nbr B is already visited => C 2/1
    dfsnum(B) <= back(C) [B is starting point, NOT connector]
    dfs @ A 3/3
        nbr B is already visited => A 3/1
    dfsnum(B) <= back(A) [B is starting point, but IS a CONNECTOR in this case]
```

- Example 3: (B and D are connectors)

```
  A---B---C
      |   |
      E---D---F
```

Neighbors stored in adjacency linked lists like this:

```
A: B
B: E,C,A
C: D,B
D: F,E,C
E: D,B
F: D
```

DFS starts at A.

```
dfs @ A 1/1
    dfs @ B 2/2
        dfs @ E 3/3
            dfs @ D 4/4
                dfs @ F 5/5
                    nbr D is already visited => F 5/4
                dfsnum(D) <= back(F) [D is a CONNECTOR]
                nbr E already visited => D 4/3
                dfs @ C 6/6
                    nbr D already visited => C 6/4
                    nbr B already visited => C 6/2
                dfsnum(D) > back(C) => D 4/2
            dfsnum(E) > back(D) => E 3/2
            nbr B is already visited => E 3/2
        dfsnum(B) <= back(E) [B is a CONNECTOR]
        nbr C is already visited => B 2/2
        nbr A is already visited => B 2/1
    dfsnum(A) <= back(B) [A is starting point, NOT a connector in this case]
```

- Example 4: (B and D are connectors)

```
  A---B---C
      |   |
      E---D---F
```

Same graph as in Example 3, but neighbors are stored in adjacency linked lists in a different sequence:

```
A: B
B: A,C,E
C: B,D
D: C,E,F
```

```
E: B,D
F: D
```

DFS starts at D, Connectors are still correctly identified as B and D.

```
dfs @ D 1/1
    dfs @ C 2/2
        dfs @ B 3/3
            dfs @ A 4/4
                nbr B is already visited => A 4/3
            dfsnum(B) <= back(A) [B is a CONNECTOR]
            nbr C is already visited => B 3/2
            dfs @ E 5/5
                nbr B is already visited => E 5/3
                nbr D is already visited => E 5/1
            dfsnum(B) > back(E) => B 3/1
        dfsnum(C) > back(B) => C 2/1
        nbr D is already visited => C 2/1
    dfsnum(D) <= back(C) [D is starting point, NOT connector]
    dfs @ F 6/6
        nbr D is already visited => F 6/1
    dfsnum(D) <= back(F) [D is starting point, is a CONNECTOR]
```

Implementation

Download the attached `friends_project.zip` file to your computer. DO NOT unzip it. Instead, follow the instructions on the Eclipse page under the section "Importing a Zipped Project into Eclipse" to get the entire project, called `Friends`, into your Eclipse workspace.

Here are the contents of the project:

- A class, `apps.Friends`. This is where you will fill in your code, details follow.
- A class, `apps.Graph`, that holds the graph on which the the friends algorithms operate.
    - The file `Graph.java` defines supporting classes `Friend` and `Person` that are used to store a graph in adjacency linked lists format.
    - The file `Graph.java` also defines a class called `Edge` that you are free to use in your implementation in the `Friends` class.

  You will NOT change ANY of the contents of `Graph.java`.
- Classes `structures.Queue` and `structures.Stack` that you may use in your implementation in the `apps.Friends` class. You will NOT change ANY of the contents of `Stack.java` and `Queue.java`.

NOTE: You will need to write your own driver to test your implementation.

Every graph that on which you might want to run your algorithms will have the following input format - the sample graph input here is for the relationship graph shown in the `Background` section above. (The `Graph` class constructor should be passed a `Scanner` with the input file as its target.)

```
15
sam|y|rutgers
jane|y|rutgers
michele|y|cornell
sergei|y|rutgers
ricardo|y|penn state
kaitlin|y|rutgers
samir|n
aparna|y|rutgers
ming|y|penn state
nick|y|penn state
bob|y|rutgers
heather|y|penn state
rachel|n
rich|y|ucla
tom|y|ucla
```

```
sam|jane
jane|bob
jane|kaitlin
kaitlin|nick
bob|samir
sergei|aparna
samir|aparna
aparna|ricardo
nick|ricardo
ming|nick
heather|nick
michele|rachel
michele|tom
tom|rich
```

The first line has the number of people in the graph (15 in this case).

The next set of lines has information about the people in the graph, one line per person (15 lines in this example), with the '|' used to separate the fields. In each line, the first field is the name of the person. Names of people can have any character except '|', and are case *insensitive*. The second field is 'y' if the person is a student, and 'n' if not. The third field is only present for students, and is the name of the school the student attends. The name of a school can have any character except '|', and is case *insensitive*. No two people will have the same name.

The last set of lines, following the people information, lists the relationships between people, one relationship per line. Since relationship works both ways, any relationship is only listed once, and the order in which the names of the friends is listed does not matter.

You will complete the following static methods in the `apps.Friends` class, to implement the three algorithms in the previous section. (All of these methods take a `Graph` instance as a parameter, aside from other possible inputs detailed below.)

Methods

1. **(35 pts) shortestPath**

   - Input: Name of person who wants the intro, and the name of the other person. For instance, inputs could be "sam" and "aparna" for the graph in the `Background` section. (Neither of these, nor any of the intermediate people in the chain, are required to be students, in the same school or otherwise.)
   - Result: The shortest chain (list) of people in the graph starting at the first and ending at the second, returned in an array list.

     For example, if the inputs are `sam` and `aparna` (`sam` wants an intro to `aparna`), then the shortest chain from `sam` to `aparna` is `[sam,jane,bob,samir,aparna]`

     (This represents the path `sam--jane--bob--samir--aparna`)

     If there is more than one shortest path, ANY of them is acceptable.

     If there is no way to get from the first person to the second person, then the returned list is empty (null or zero-sized array list).

2. **(25 pts) cliques**

   - Input: Name of school for which cliques are to be found, e.g. "rutgers"
   - Result: The names of people in each of the cliques, in any order, returned in an array list of array lists. Moreover, the cliques themselves could be in any order in the top level array list.

     For the example cited in the `Cliques` part of the `Algorithms` section above, with input `rutgers`, the result is:

     ```
     [[sam,jane,bob,kaitlin],[sergei,aparna]]
     ```

     In other words, an array list that has two cliques, each of which is an array list.

The names in the clique array list can be in any order. So, the same cliques could have been returned as:

```
[[jane,sam,kaitlin,bob],[aparna,sergei]]
```

and it would be correct.

The cliques themselves can be in any order within the top level array lists, so the following variation (for example) is also acceptable:

```
[[sergei,aparna],[sam,jane,bob,kaitlin]]
```

However, names must not be repeated in a clique.

If there are no students in the input school, the result is empty (null or zero-sized array list).

3. **(40 pts) connectors**

   - Input: None
   - Result: Names of all connectors, in any order, returned in an array list.

     In the sample relationship graph of the `Background` section, the connectors list is `[jane,aparna,nick,tom,michele]`. Any other perumtation of the names in the list is fine, since the order does not matter.

     Names in the list must not be repeated.

Implementation Rules

Do NOT change ANY of the contents of `Graph.java`, `Queue.java`, and `Stack.java`.

In `Friends.java`:

- Do NOT change the package name on the first line.
- Do NOT add or remove any import statements. (The existing `import java.util.*` statement allows you to use any class in the `java.util` package.
  Note: `java.util` defines a `Stack` class, but it will be overridden by the `structures.Stack` class that is imported.
- Do NOT change the headers of any of the existing methods in ANY way.
- Do NOT add any class fields or inner classes.
- You MAY add helper methods, but you must make them `private`.

Submission

Submit your `Friends.java` file.