Homework 4: Social networking and recommendation systems

Learning Objectives:

- gain experience with sets, dictionaries, and sorting in Python
- practice writing and using functions
- become familiar with a graph data structure in the NetworkX library in Python
- write Python code to analyze Facebook data

When you sign into Facebook, it suggests friends. In this assignment, you will write a program that reads Facebook data and makes friend recommendations.

(See advice from previous students about this assignment posted on NYU Classes.)

Background

Recommendation systems

Facebook suggests people you may be (or should be) friends with. Netflix suggests movies you might like. Amazon suggests products to buy. How do they do that? In this assignment, you will learn one simple way to make such suggestions, called **collaborative filtering**. The actual algorithms used by these companies are closely guarded trade secrets.

A computer system that makes suggestions is called a recommender system. As background, there are two general approaches: collaborative filtering and content-based filtering.

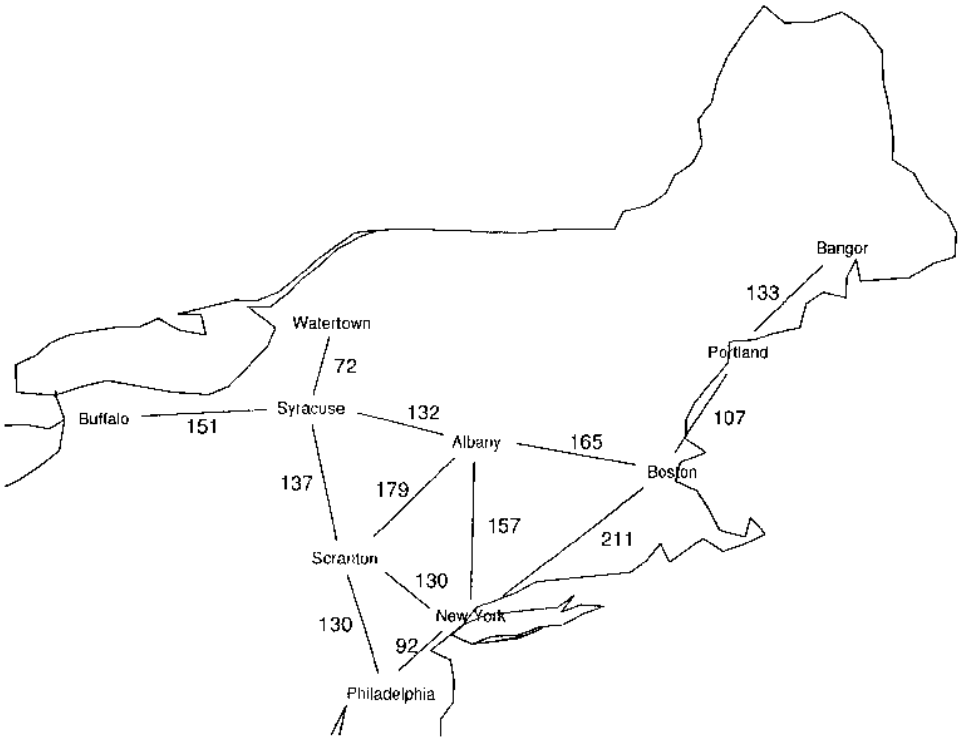
- **Collaborative filtering** says that, if your past behavior/preferences were like some other user's, then your future behavior may be as well. As a concrete example, suppose that you like John, Paul, and George, and other people like John, Paul, George, and Ringo. Then it stands to reason that you will like Ringo as well, even if you had never previously heard of him. The recommender system does not have to understand anything about what “John”, “Paul”, “George”, and “Ringo” are — they could even be brands of toilet paper, and the algorithm would work identically.
- **Content-based filtering** considers the characteristics of the things you like, and it recommends similar sorts of things. For instance, if you like “Billie Jean”, “Crazy Train”, and “Don't Stop the Music”, then you might like other songs in the key of F-sharp minor, such as Rachmaninoff's “Piano Concerto No. 1”, even if no one else has ever had that particular set of favorite songs before.

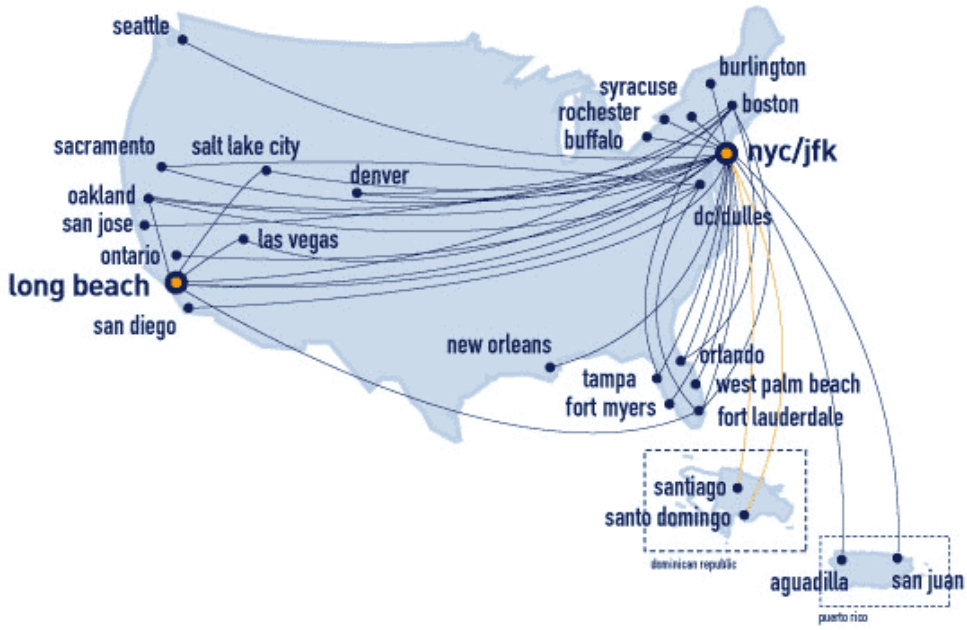
In this assignment, you will implement a **collaborative filtering** recommendation system for suggesting friends on Facebook.

Representing a social network as a graph

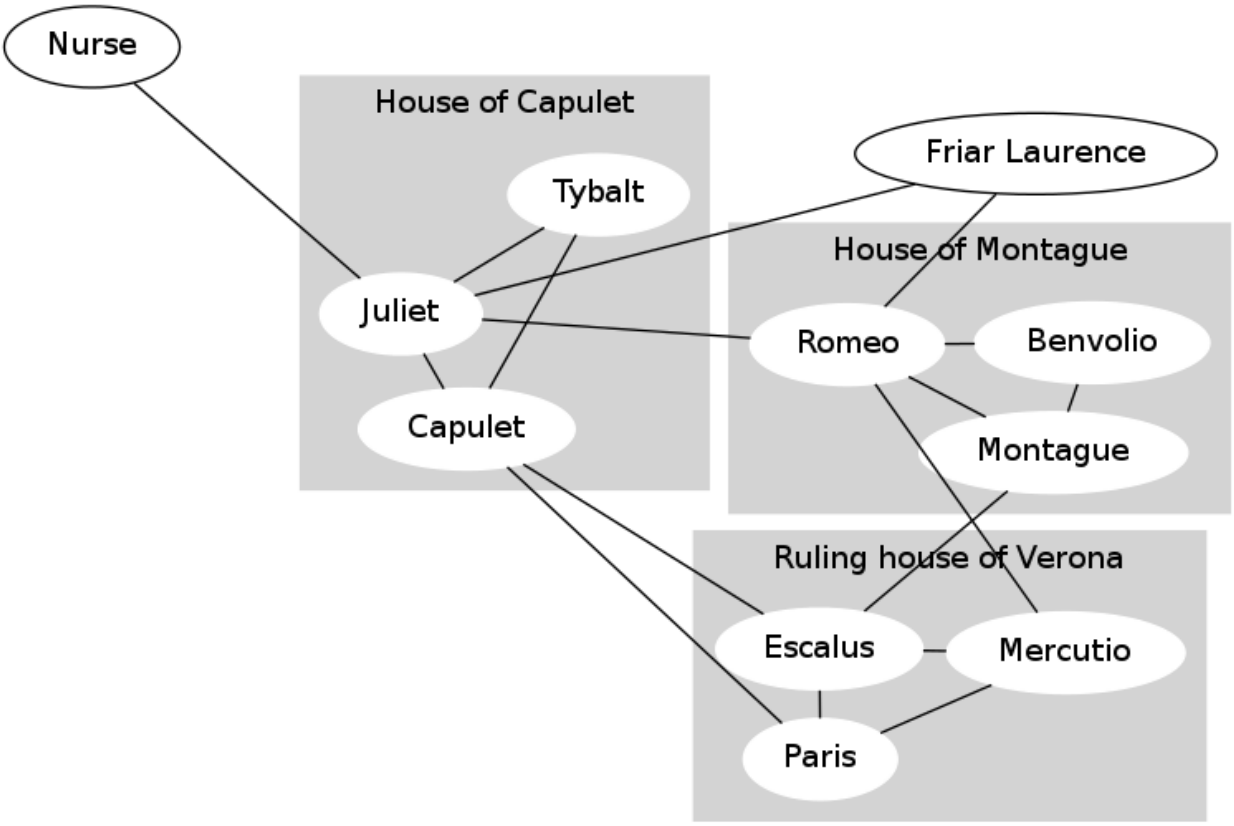
A *graph* or *network* represents relationships among things. The things are represented as *nodes* or *vertices*, and the relationships are represented as *edges*.

One common use for a graph is to represent travel possibilities, such as on a road map or airline map. The nodes of the graph are cities, and the edges show which cities are directly connected. Then, you can use the graph to plan travel.





Another common use for a graph is to represent friendship among people in a social network. For example, here is the friendship graph for some of the characters of “Romeo and Juliet”:



An edge between person *A* and person *B* means that *A* considers *B* a friend, and *B* considers *A* a friend.

This graph is unable to represent certain information. For example, Count Paris wishes to wed Juliet, but she does not reciprocate his affection. You do not need to worry about this information, because Facebook does not represent this information either. (Some other social networking sites, such as Twitter and Google+, do permit one-way links.)

In the image above, ignore the gray background and the labels for the families ("houses"); those are there just to help you interpret the graph but are not part of the social network itself.

Recommending friends

In this assignment you will implement two mechanisms for recommending a new friend in a social network. A simple way to state this question is, “For user X, who is the best person to recommend for as a friend?”

You will answer a more comprehensive question: “For user X, list some *non-friends* in order, starting with the best friend recommendation and ending with the worst.” A non-friend is a user who is not X and is not a current friend of X. Depending on the recommendation algorithm, the list may include all non-friends of X or some of them.

For example, for Mercutio the list might be:

Capulet
Montague
Benvolio
Friar Laurence
Juliet

Further note that the recommendations might not be symmetric: the best friend recommendation for Montague might be Mercutio, but the best friend recommendation for Mercutio might be Capulet.

Your task will be to write code that, given a user U in the social network, produces friend recommendations for U, in order from best to worst. You will do this by assigning each potential friend a number called a score, where higher scores indicate a better match. Then you can sort your list according to the score. Given user X, if two people Y and Z would be equally good as new friends for X (they have the same score), then they should be listed in alphabetical order (for names as in Part I) or numerical order (for numerical user IDs as in Part II).

Logistics

Obtain the files, add your name

First, download the files posted on NYU Classes for HWK 4.

Output Format

By the **end** of the assignment, running social_network.py must produce output of the exact form:

Problem 4:

Unchanged Recommendations: ['____', '____', ...]
Changed Recommendations: ['____', '____', ...]

Problem 6:

...
____ (by number_of_common_friends): [____, ____, ____]
____ (by number_of_common_friends): [____, ____]
____ (by number_of_common_friends): [____, ____, ____, ____, ____]
...

Problem 7:

...
____ (by influence): [____, ____, ____, ____, ____, ____, ____, ____, ____]
____ (by influence): [____]
____ (by influence): [____, ____, ____, ____, ____, ____, ____, ____, ____, ____]
...

Problem 8:

Same: ___
Different: ___

Where ... indicates that there may be more of these lines, and where all the ____ are replaced by values that you will calculate. For problems 6 and 7 each line may have a different number of values than what is shown above, and you will be printing more than 3 lines of output - these are just examples. Of course, the exact values in each category will vary depending on the input data that you are using. **We expect the formatting of your program output to exactly match this.**

Install NetworkX

The PPT "Graphs" posted on NYU Classes explain how to install NetworkX in Enthought Python. **You will need to follow the directions on the slides to install NetworkX before you can do any part of this assignment.** The installation process is not complicated.

The NetworkX tutorial

The NetworkX library represents a graph in Python. Interact with your classmates as much as you can to share your knowledge, as well as your questions. Skim through the website and understand how to use nodes and edges. Be sure you understand add_edge(), add_node(), edges(), nodes(), and neighbors(). The tutorial discusses more operations than you need to know. Do not worry if you do not understand all the details in the tutorial (e.g. you can ignore nbunches and ebunches). You may also want to browse the "Drawing graphs" section.

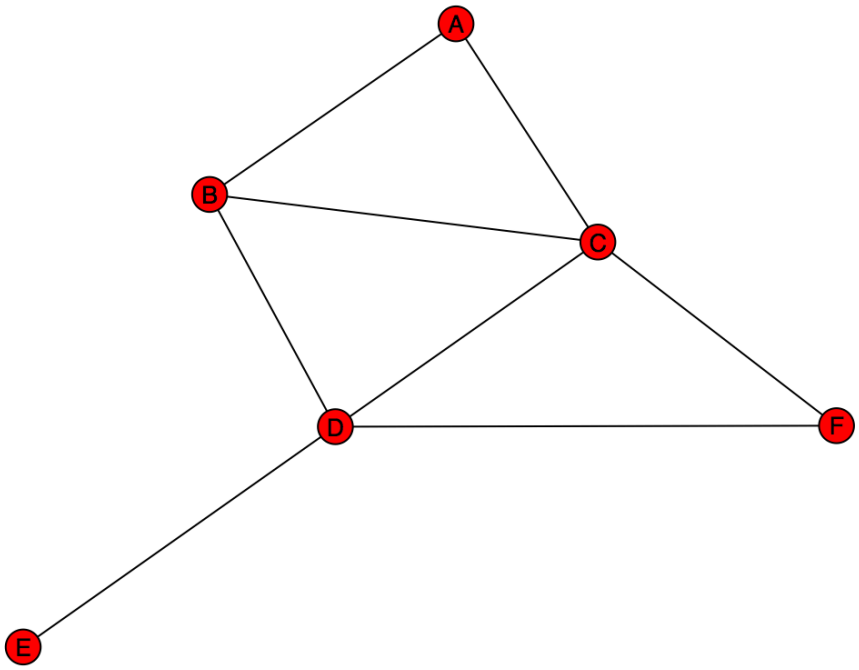
As you will see on PPT "Graphs" posted on NYU Classes, as well as on NetworkX website, to use the networkx library in a program, write import networkx or import networkx as nx near the top of your program. The latter has already been done for you in the supplied social_network.py, so you can use shorter commands like nx.draw_networkx(...) instead of the (slightly longer) networkx.draw_networkx(...). There is nothing to turn in for this step.

Part I: Creating and Analyzing Small Graphs

Problem 1: Create graphs

It is always a good idea to test your code on a dataset that is small enough for you to manually compute the results. You will create two such datasets for testing.

Problem 1a: A small practice graph



Create the above graph and store it in a variable named practice_graph. Note that there are letters inside each node (these may not show up in a printout of the assignment.) Use the Graph class (not DiGraph, MultiGraph, or MultiDiGraph).

To help you verify that your graph is correct, the provided code draws the graph to a window. **The graph may be hidden behind other windows, so look for it!** Compare your graph to the figure above. **The nodes may appear in different locations; that's fine so long as the same nodes exist, and they are connected in the same way by the edges.** Note that if you redraw this graph the nodes may plotted using a different layout each time - this is also fine!

Note that your program will pause until you close the window that contains the graph drawing.

When you are happy with your graph, comment out the call to draw_practice_graph() (not the definition of the draw_practice_graph function). The reason is so that you don't have to close the window every time you run your program.

Note that you may find several assertions further down in the program failing at this point. This is to be expected since you have not implemented those parts of the program yet! In fact, this will continue to happen as you progress through the problems. Success usually means you are no longer failing the same assertion, but that instead a different assertion is failing further down in the program.

Problem 1b: The Romeo and Juliet graph

Create a graph named “rj” corresponding to the Romeo and Juliet graph above (ignoring the shaded family/house information).

To help you verify that your graph is correct, the provided code draws the graph to a window and to a file romeo-and-juliet.pdf. Compare your graph to the Romeo and Juliet graph above. **The nodes may appear in different locations; that's fine so long as the same nodes exist, and they are connected in the same way by the edges.** (We added assert statements to check this for you.)

When you are happy with your graph and the romeo-and-juliet.pdf file, **comment out the call to draw_rj()** (not the definition of the draw_rj function). The reason is so that you don't have to close the window every time you run your program.

Problem 2: Recommend by number of common friends

If non-friend Y is your friend's friend, then maybe Y should be your friend too. If person Y is the friend of many of your friends, then Y is an even better recommendation. The best friend recommendation is the person with whom you have the largest number of mutual friends. You will implement this heuristic.

As a concrete example, consider "A" in practice_graph. Say we are interested in giving "A" recommendations of people that they might want to be friends with. By this algorithm, the number of friends you have in common with someone is a measure of how likely it is that they would be a good friend recommendation for you. Thus, the more friends someone has in common with you, the better their "friendship score" is. We will use the number of friends in common as the friendship score itself. Thus, we want to find out who has the most friends in common with "A".

A has one friend in common with B (namely, C).
A has one friend in common with C (namely, B).
A has two friends in common with D (namely, B and C).
A has no friends in common with E.
A has one friend in common with F (namely, C).

D is the best recommendation for A, F is the second-best recommendation. We would not recommend B or C because A is already friends with them. We also would not recommend E because A has no friends in common with E.

Similarly, consider Mercutio in the Romeo and Juliet graph.

Mercutio has two friends in common with Capulet (Escalus and Paris).
Mercutio has two friends in common with Montague (Escalus and Romeo).
Mercutio has one friend in common with Friar Laurence (Romeo).
Mercutio has one friend in common with Benvolio (Romeo).
Mercutio has one friend in common with Juliet (Romeo).
Mercutio has no friends in common with the Nurse.
Mercutio has no friends in common with Tybalt.

Therefore, Capulet and Montague are the best friend recommendations for Mercutio, and the Nurse and Tybalt are the worst friend recommendations. (In fact, the Nurse and Tybalt are such poor friend recommendations that your program will not even suggest them.) Note that we are not listing Paris, Escalus or Romeo who are already friends of Mercutio. So, our algorithm would want to return to Mercutio this list ordered from best recommendation to worst. In the case of ties in friendship score (such as between Capulet and Montague, or between Benvolio, Friar Laurence, Juliet), we list people alphabetically. Thus, we would return:

['Capulet', 'Montague', 'Benvolio', 'Friar Laurence', 'Juliet']

Now let's think about how we might create this list. Obviously, we will need to calculate these "friendship scores" for some set of people in the graph. By this "number of common friends" metric, for a given person, we only care about calculating such scores for people that are "friends of our current friends" who are not yet our friends. (There could be many people in a large graph, so we do not want to simply calculate friendship scores for every person in the graph as many of those scores are likely to be zero.) So it would be useful to be able to calculate the set of "friends of friends" for a given user. For each of those friends-of-friends we will want to be able to calculate the set of friends that they have in common with the user. If we want to return to the user a ranked list of recommendations from best recommendation to worst, then it would be useful to have a data structure to keep track of the mapping of "friend of friend" to friendship score. Finally, given this mapping of people to friendship scores, we will want to sort the potential friends from best to worst before presenting it to the user. (Hint: Remember that a dictionary is often called a "map".)

For this problem, you need to **write the following 5 functions**, whose documentation strings appear in the template file social_network.py that you were provided.

- friends_of_friends(graph, user)
- common_friends(graph, user1, user2)
- number_of_common_friends_map(graph, user)
- number_map_to_sorted_list(map)
- recommend_by_number_of_common_friends(graph, user)

The template file defines a helper function, friends (graph, user), that you may find useful.

The template file also contains assert statements to help you test your code. We strongly encourage you to **write additional tests** as well, in order to verify that your code is correct. **You may also find the assertions useful for clarifying what the function is supposed to return.** Remember an assertion states something that is supposed to be true. So, when passed the parameters listed in the assertion, we expect your function to return the values listed to the right of the ==.

For all these functions, we **strongly** suggest (as do students who completed a similar assignment last year - based on their reflection statements) that you start trying to **write them on paper first**. You should write at least an outline on paper, but it is good practice to write a draft of the code on paper too. This outline is probably a good starting point for the comments you should have inside of the functions.

Hint: Remember that when Python tests sets or dictionaries for equality, it ignores the order of elements. A consequence of this is that two sets can print differently but be equal because they represent the same set, and likewise for dictionaries. For example, this Python expression evaluates to True:

{ 'Capulet', 'Escalus', 'Montague' } == { 'Montague', 'Capulet', 'Escalus' }

Hint: Throughout this assignment, you are permitted, but not required, to define additional functions beyond the required ones.

Hint: Throughout this assignment, use good variable naming! Names like friends_list or friends_set for example may help you remember what *type* a particular variable is referring to (e.g. a list or a set).

Hints for friends_of_friends and common_friends: When defining these two functions, you should not use any data structures other than sets. **If you find yourself using even one list or dictionary, then you are doing the problem wrong.** The reason to use sets is that the code is much shorter and simpler. In fact, a solution to friends_of_friends can be as short as 4 lines long, and a solution to common_friends could be only 1 line long. Longer solutions are possible and can also be good style, but the point is that these are small, simple functions. The other functions you will define are little, if any, longer.

Hints for number_map_to_sorted_list:

- You may find the items() function (that returns the contents of a dictionary as a list of (key, value) pairs or 2-tuples) useful.
- You may want to use the key argument to the sort routine. Furthermore, you may find the operator.itemgetter routine useful as the key argument. For details, see the Python Sorting HowTo.
- It is probably a good idea to review the lecture slides on sorting.

Problem 3: Recommend by influence

We will now give a different algorithm for computing a friendship score.

Consider the following hypothetical situation.

Two of your friends are J.D. Salinger and Tim Kinsella.
J.D. Salinger has only two friends (you and one other person).
Tim Kinsella has 7 billion friends.
J.D. and Tim have no friends in common (besides you).

Since J.D. is highly selective in terms of friendship, and is a friend of yours, you are likely to have a lot in common with J.D.'s other friend. On the other hand, Tim is indiscriminate and there is little reason to believe that you should be friendly with any particular one of Tim's other friends.

Incorporate the above idea into your friend recommendation algorithm. Here is the concrete way that you will do so. We call the technique “influence scoring”.
Suppose that user1 and user2 have three friends in common: f1, f2, and f3. In Problem 2, the score for user2 as a friend of user1 is 1+1+1: each common friend contributes 1 to the score. **In this problem, the score for user2 as a friend of user1 is 1/numfriends(f1) + 1/numfriends(f2) + 1/numfriends(f3), where numfriends(f) is the number of friends that f has.** In other words, each friend *F* of user1 has a total influence score of 1 to contribute and divides it equally among all of *F*'s friends.

In the example above, J.D. Salinger's other friend would have a score of 1/2, and each of Tim Kinsella's friends would have a score of 1/7000000000.

We recommend that you calculate by hand what the friendship scores would be for each of the friend recommendations that would be returned to Mercutio using this same metric. To see what the right answer should be, look at the assert statement for the influence_map function in the file social_network.py.

****** An example of recommend by influence is part of the HWK material.**

The social_network.py file gives **two functions (influence_map and recommend_by_influence) that you should implement**. You may find that their implementations are quite similar to code that you have already written in Problem 2; that is OK. The file also gives one test case for each of the two functions.

Do not change the code that you wrote for Problem 2. However, you will find that you can call many of the functions you wrote for Problem 2. You can solve the problem with just the two new functions (influence_map and recommend_by_influence), plus re-using some unchanged functions from Problem 2.

Problem 4: Does the recommendation algorithm make a difference?

Does the change of recommendation algorithm make any difference? Maybe not: you can see by looking at the assert statements in social_network.py that Mercutio should get the same friend recommendations with both recommendation approaches. Does everyone get identical results with the two recommendation approaches?

Write code to print a list of people for whom the two approaches make the same recommendations, then print a list of people for whom the two approaches make different recommendations. Each list should be sorted in alphabetical order.

Print out the results for the Romeo and Juliet graph. The format of this problem's printed output is given above, near the beginning of the assignment.

Hint: In the Romeo and Juliet graph there are 5 people for whom the recommendations are the same, and 6 people for whom the recommendations are different.

Submit the following files:

- romeo-and-juliet.pdf
- social_network.py

Now you are done with Part I! On to Part II!

Part II: Work with the Facebook graph

Problem 5: Create a Facebook graph

Create a graph named facebook from the Facebook data in file facebook-links.txt. As above, use the Graph class.

You do not need to read in the file name from the command line as we did in hw2 and hw3. Instead you can just assume that the file facebook-links.txt will be present in the same directory as social_network.py and use the filename as "facebook-links.txt" in your program as needed. When running in Canopy, if you get: "No such file or directory" then you will want to right click in the python interpreter window and select "Keep Directory Synched to Editor" and this should allow it to find the facebook-links.txt file (assuming it is in the same

directory as social_network.py). Of course you can also run the program from the command line and again, assuming facebook-links.txt is in the same directory as social_network.py, it should be able to find it.

Looking at the assert statements in social_network.py notice that the number of nodes in your facebook graph should be 63731.

The facebook-links.txt file in your homework4 directory is courtesy of the Max Planck Institute for Software Systems. Here is a slightly clarified version of the documentation for this file:

File facebook-links.txt contains a list of all the user-to-user links from the Facebook New Orleans networks. These links are undirected on Facebook.

Format: Each line contains two **numeric** user identifiers, meaning the second user appeared in the first user's friend list, *and* the first user appeared in the second user's friend list. Finally, the third column is a UNIX timestamp with the time of link establishment (if it could be determined, otherwise it is '\N').

A Unix timestamp is the number of seconds since January 1, 1970. You may ignore timestamps in this assignment. (Facebook does use the recency of your activity to help it in making recommendations.)

A snippet of the file appears below:

```
35467    17494    1197992662
35467    4190     \N
35467    18822    1209937599
37188    7741     1219156787
37188    8561     1199853037
```

When reading in this data you should be sure to convert the numeric user identifiers into ints. Storing them as ints will make your life easier and is the output format that we require for printing (Do NOT print a user ID as '19611' instead print as 19611.) This means your code should work whether nodes are named with strings (as we did with the practice graphs) or ints (as we are doing with the facebook data). In NetworkX nodes can be strings or integers.

Hint: You may find it useful to refer to the slides “File input-output.”

Hint: Don't be alarmed if reading the Facebook data takes a little while. The file is large, and it may take up to a minute for your program to read it. However, **do not try to draw the Facebook graph**. This may cause your computer to hang, and even if it were successful, you would not learn much from a tangled mess of 817,090 edges.

Problem 6: Recommend by number of common friends for Facebook

For every Facebook user with a user id that is a multiple of 1000, print a list containing the first 10 friend recommendations, as determined by "number of common friends" friendship score. If there are fewer than 10 recommendations, print all the recommendations.

Note that the first userID in the Facebook data is 1 (there is no user 0). We will let it be o.k. for this assignment if your code only works on the set of facebook data we have given you.

You can review more details about the format for the printed output at the beginning of the assignment. This is a sample of *part of* what you would expect for your output (you should be printing more lines than this, but they should be listed in ascending order of userID as shown below):

```
...
 28000 (by number_of_common_friends): [23, 1445, 4610, 7996, 10397, 11213, 56, 85, 471, 522]
 29000 (by number_of_common_friends): [28606]
 30000 (by number_of_common_friends): [862, 869, 919, 941, 3154, 8180, 8269, 8614, 14473, 14495]
...
```

Hint: “List slides” slides may be useful for Problem 6 and 7.

Problem 7: Recommend by influence for Facebook

For every Facebook user with a user id that is a multiple of 1000, print a list containing the first 10 friend recommendations, as determined by the "influence" friendship score. If there are fewer than 10 recommendations, print all the recommendations.

You can review more details about the format for the printed output at the beginning of the assignment. This is a sample of *part of* what you would expect for your output (you should be printing more lines than this, but they should be listed in ascending order of userID as shown below):

```
...
28000 (by influence): [7033, 17125, 15462, 33049, 51105, 16424, 23, 7996, 725, 1539]
29000 (by influence): [28606]
30000 (by influence): [862, 869, 919, 941, 3154, 8269, 14473, 14495, 17951, 19611]
...
```

Problem 8: Does the recommendation algorithm make a difference for Facebook?

Considering only those 63 Facebook users with an id that is a multiple of 1000, compute and print the **number** of Facebook users who have the same first 10 friend recommendations under both recommendation systems, and the **number** of Facebook users who have different first 10 friend recommendations under the two recommendation systems. For example, in the data above, user 29000 has the same first ten recommendations under both recommendation systems, while user 28000 and user 30000 both have different recommendations under the two recommendation systems. This program will take some time to compute (at least a couple of minutes).

The format of this problem's printed output is given near the beginning of the assignment.

Submit your work