

## Lab 4

*April 1, 2003**Due Date: Tuesday April 15*

This lab will bring together several of the topics we have studied this semester to find the route (i.e. sequence of flights) from a given airport at a desired arrival time to a desired destination airport in the shortest amount of time. Here's a some sample output of the last part (Part 3). I hope almost everyone is able to complete Part 3.

```
Options: Compute Shortest Routes(1), Show Route (2), Exit(3): 1
Source Airport Code: BOS
Arrival Time at Airport: 1100
AM or PM (A or P):A
```

```
Options: Compute Shortest Routes(1), Show Route (2), Exit(3): 2
Destination Airport Code: HOU
Elapsed time since BOS airport arrival to HOU arrival is 7 hours and 45 minutes.
Itinerary:
    TW 53 (BOS 1203 PM --> STL 223 PM)
    WN 759 (STL 400 PM --> HOU 545 PM)
```

```
Options: Compute Shortest Routes(1), Show Route (2), Exit(3): 2
Destination Airport Code: SFO
Elapsed time since BOS airport arrival to SFO arrival is 9 hours and 36 minutes.
Itinerary:
    TW 53 (BOS 1203 PM --> STL 223 PM)
    TW 183 (STL 325 PM --> SFO 536 PM)
```

```
Options: Compute Shortest Routes(1), Show Route (2), Exit(3): 2
Destination Airport Code: JFK
Elapsed time since BOS airport arrival to JFK arrival is 5 hours and 13 minutes.
Itinerary:
    DL 1865 (BOS 245 PM --> JFK 413 PM)
```

Since this lab has several components in it, I'm providing some guidance to keep everyone on track. I strongly recommend that everyone complete the first two parts (or at least the first part) by the early submission deadline on April 8. Remember that you receive a 10% bonus for whatever portions you hand in by April 8 at the start of class.

## Part 1: Binary Heap (40 pts)

**Design and implement a General BinaryHeap Class** that supports the methods described below. As part of your binary heap you must have a `Handle` class (ideally, as an inner class). My recommendation is that each `Handle` object will have a single instance variable that is an integer holding the index in the array representation of the binary heap where the given item is held.

Here are the methods that you are to implement. The methods `size` and `isEmpty` should run in constant time. All other methods should run in  $O(\log n)$  time where  $n$  is the size of the heap.

- `BinaryHeap.Handle insert(double key, Object data)` takes as input a key (a `double`) and a reference to the associated data that could be an object of any type (of type `Object` in Java or using a `Template` in C++). It should insert the given item in the binary heap returning a `Handle` to it.
- `int size()` returns the number of items in the heap.
- `boolean isEmpty()` returns true iff the heap is holding no items.
- `double minimumKey()` returns the value of the minimum key.
- `Object extractMin()` removes the minimum item returning its data.
- `boolean decreaseKey(BinaryHeap.Handle h, double newKey)` takes as input a handle and a new key. Let  $x$  be the binary heap item specified by the `h`. If  $x$ 's key is smaller than `newKey` then it does nothing and returns `false` (indicating the key was not changed). Otherwise, it decreases the value of  $x$ 's key to `newKey` (fixing the binary heap and handles as appropriate) and returns `true`. As an alternate, and really better option, you can have the `decreaseKey` method be part of the `BinaryHeap.Handle` class in which case it will just take the new key as its single parameter.
- `toString` (or in C++ overload the `<<` operator) which takes no parameters and returns a string (or `ostream` in C++). So that we can tell the structure of the binary heap, please output the key and associated data for the array elements of your binary heap representation in the order they appear in the array. You do not need your program to show the binary heap as a tree but you may find this helpful to do by hand so you can check your output.

A driver called `BinaryHeapTester (.java and .cc)` is provided. *You must turn in your output from this when you submit Part 1.* Note that in `BinaryHeapTester` the associated data is just a string. You may modify `BinaryHeapTester` if your interface is slightly different than above – just describe the modifications made in your write-up.

I strongly recommend that you write a `private swap` method that swaps two elements in the binary heap (and only move elements using this method). By doing this all of the maintenance required to keep the instance variable within the `Handle` correct can be done within this method. In fact, you may want to just implement the binary heap without the `Handle` and then add it. If you implement your binary heap methods using a swap method then it will be very easy to incorporate the `Handle`.

## Part 2: Weighted Directed Graph (30 pts)

Design and implement a **Weighted Directed Graph Class** that allows multiple edges between vertices (which in the application in Part 3 will be airline flights between cities). I

strongly recommend that you also implement a `Vertex` class that will hold the information associated with each vertex and an `Edge` class that will hold the information associated with each Edge. Here are the basic methods that I recommend you have for each class – add others as needed. I think their names are self explanatory. If you have any questions, please ask. (For those using C++ replace the `toString` methods by overloading the `<<` operator.)

For the `Edge` class you really just need to store the head, tail and the edge weight.

- constructor `Edge(Vertex head, Vertex tail, double weight)`
- accessor public methods: `Vertex getTail()`, `Vertex getHead()`, `double getWeight()`
- `String toString()`

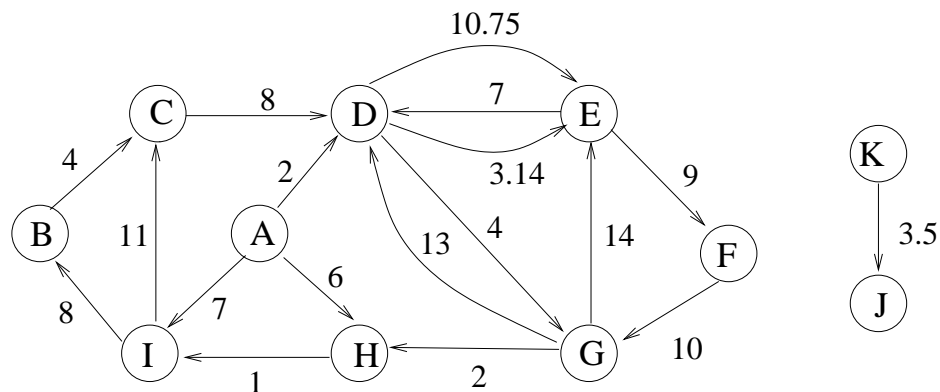
For the `Vertex` class I recommend that you use an adjacency list of `Edges`. A little more will need to be added for Part 3, but do that after you get Part 2 working.

- constructor `Vertex(String name)` where `name` is what will be used by the `toString` method.
- `String toString()`

Finally for the graph class you most likely will want instance variables for the number of vertices, number of edges, and then the adjacency list. I recommend the following methods:

- constructor `Graph()` that initializes the graph to have no vertices and no edges (i.e. an empty graph).
- `void addVertex(Vertex v)`
- `void addEdge(Edge e)`
- `int numberOfVertices()`
- `int numberOfEdges()`
- `Iterator outEdges(Vertex v)` - return an iterator that goes through all of the outgoing edges from `v` (in an arbitrary order). If you use a Java `ArrayList` for your list of adjacent vertices then you can just use the provided `iterator()` method of an `ArrayList` to create this iterator. The two methods of the `Iterator` class you would then use are `hasNext()` and `next()`.
- `Iterator vertexIterator()` - returns an iterator over all of the vertices in the graph (in an arbitrary order).
- `String toString()` - To be sure that both of your above iterators work. For the `toString` method you should use `vertexIterator` to iterate over all of the vertices. Then for each vertex `v` use `outEdges(v)` to iterator over `v`'s outgoing edges printing out each one (giving the head, tail, and weight in some easy to read form).

A driver called `GraphTester (.java and .cc)` is provided. *You must turn in your output from this when you submit Part 2.* You may modify this driver if your interface is slightly different than above. Here is the graph that is created by the graph tester.



### Part 3: Fastest Route Application (30 pts)

**Design and Implement a Variant of Dijkstra’s Shortest Path Algorithm** for the application described on the first page. Believe it or not, you are really almost done – your graph and binary heap classes do all the work. You just need to make the right calls to them :-). I’d like everyone to spend some time thinking about how you modify Dijkstra’s algorithm for this problem and so won’t give the details here. I will go over it in class on Tuesday April 8 (and in the help sessions if desired) so if you prefer just save Part 3 for the second week of the assignment.

Let me state the problem once again. You are given an list of all flights between a set of airports. The user gives a departure airport and a time when he/she would like to arrive at the airport. The user will also gives a destination airport. The task is to find a sequence of flights that will get the user to the destination airport at the earliest time *with the restriction of a minimum layover of one hour at any intermediate airports and also the flight out of the departure airport must be at least one hour after the stated arrival time.* Your output should include all of the information given in the sample output on page 1 but can format it differently if you desired. There are two data files: `airport-data.txt` and `flight-data.txt` both of which contain actual airline schedules (with over 3500 flights) from 1992 collected by Roberto Tamassia from EasySABRE.

The file `airport-data.txt` first contains the number of cities (an integer). Then for each city there is a line with two items (separated by a tab). The first is a 3 letter airport code. The second is an offset from GMT. The data from which I constructed these two data files also contained the  $x$  and  $y$  coordinate of the airport and the name of the city/airport but I removed those. If anyone would like to see the original data, it is `full-airplane-data.txt`. However, you don’t need to use this for your lab. I recommend that you create an `Airport` class that extends `Vertex`. This can hold the GMT conversion that is provided in the data file and in general could hold the other data associated with an airport.

The file `flight-data.txt` contains one line per flight that is tab delimited with the following 8 items: airline, flight number, code for source airport, local departure time, A or

P (for am or pm) for departure time, code for destination airport, local arrival time, A or P for arrival time. The original data set also had fields related to the fare class, number of stops, and more. I recommend that you create a `Flight` class that extends `Edge` that can hold the above information and will have the needed accessors.

The only further change is that you might want to add some methods to your `Vertex/Airport` class or you may prefer to keep this in your driver. The variables you need to store for each vertex/airport are: the handle for calling `decreaseKey`, a boolean indicating whether or not it is still in the binary heap, the edge from its parent (set when it is removed from the binary heap), and the cost to reaching it from the source (also set when it is removed from the binary heap). Also, you will need a way to access an `Airport` when given its three letter code since that is what the user will input. Just use a `hashTable` for this (either from Lab 2 or simply use the Java provided `HashMap` – the key is the three letter code and the associated data is the `Airport`).

For testing this part, you should make a simple driver that provides the following two options (plus whatever others you want for helping debug). First the user should be able to give a source airport and a desired arrival time at the airport and have the best route (i.e. sequence of flights) computed between that airport and all others. The second option should allow the user to provide a destination airport and give the best route computed from the source airport (based on the last call made to the first option). The driver will also need to read in the data. To help reduce the time you spend here, code fragments to read each of the data files and store the fields in local variables (that you can then decide how to use) are provided on the course home page under labs. You will be given (in the “What to Submit” section) some specific routes to compute. Your output should include all of the information show on page 1. For debugging purposes you might want to make a small version of the data set so that you can trace what is happening.

To help reduce the time you need to spend on converting times into the same time zone and computing flight lengths and layover lengths, on the course page under labs, I’m providing a class `GMTtime` with the following methods:

- constructor `GMTtime(int localTime, int gmtOffset, boolean am)`
- `int minutesSince(GMTtime time)` which returns the number of minutes (which could be greater than 60) that have elapsed from the `this` to `time`. This will properly deal with times going across AM and PM.
- `String toString()` returns a string with the times in the form they were in the data file except it uses “AM” and “PM” versus just “A” and “P”.

For your convenience the constructor computes the value of several instance variables that you can use in other methods if needed. These include the local time, the local time in a 24 hour clock (called `localMilitaryTime`), the GMT offset, local hours, minutes (between 0 and 59), the GMT time, and final the GMT time converted completely to minutes. For example 2:30AM would be 150 minutes into the day.

## What to Submit

For this lab you are expected to submit the following. Please include these items in the given order so that the TAs can find everything easily.

- A completed and signed cover sheet with your name written legibly on the top.
- A write-up that describes your basic design with the focus being on variations/additions from what is described above. **If there were any problems with your implementation (e.g. wrong output was obtained, a run-time error occurred) then clearly indicate that in your write-up and give as much information as you can as to what you think is causing the problem.**
- Part 1 when submitted should be clearly labeled and include: your binary heap code and the output from `BinaryHeapTester`. It is your job to check that the output is correct and if it is not to clearly mark any problems you noticed. You do NOT need to submit `BinaryHeapTester` – if you made any changes to it just summarize those in your write-up.
- Part 2 when submitted should be clearly labeled and include: all code that is used for your graph representation (e.g. the `Graph`, `Vertex`, and `Edge` classes) as well as your output from `GraphTester`. It is your job to check that the output is correct and if it is not to clearly mark any problems you noticed. You do NOT need to submit `GraphTester` – if you made any changes to it just summarize those in your write-up.
- Part 3 when submitted should be clearly labeled and include: any code you wrote that was not included in either Part 1 or Part2. This includes your driver. Finally, you should provide the output from the following:
  - With a source city of STL and desired airport arrival of 7AM show the fastest route to ABQ and PVD.
  - With a source city of PHX and desired airport arrival of 6PM show the fastest route to PVD, DEN and STL.

Although you should not submit the output for the queries shown on page 1 of this assignment, I would recommend you use them to help test that your program is working. If your output does not match that shown on page 1 (and lands in the desired city later than what is shown) then there is a problem. If you cannot fix the problem then submit this output to help illustrate what is happening. Finally, for all of your submitted output you should check that the elapsed time given from the arrival at the source airport to the arrival at the destination airport is correct. Don't forget to account for different time zones. You can tell from the GMT offset which time zone each airport is in.