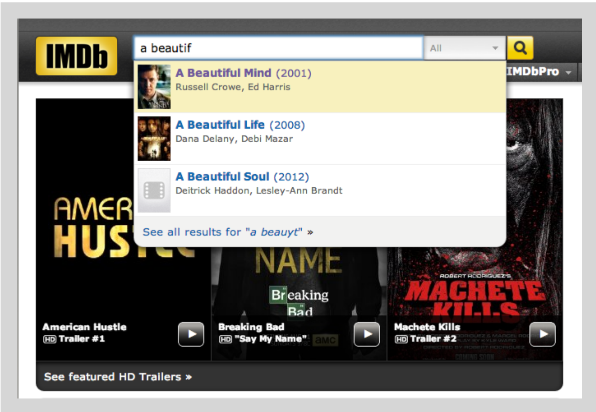
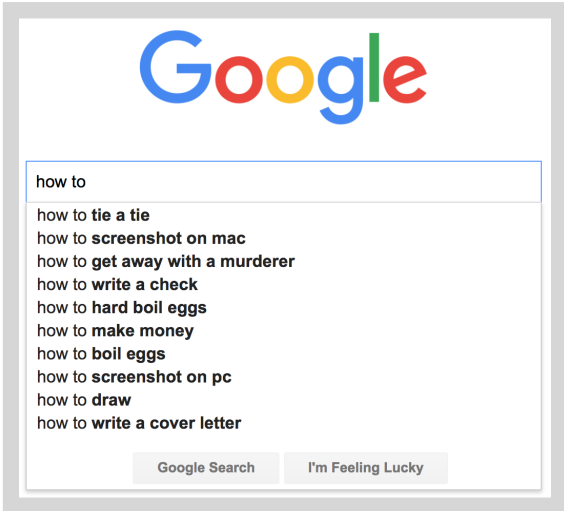
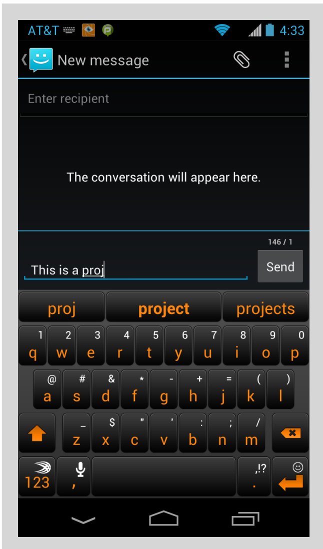
Programming Assignment: Autocomplete Me

Write a program to implement *autocomplete* for a given set of *N terms*, where a term is a query string and an associated nonnegative weight. That is, given a prefix, find all queries that start with the given prefix, in descending order of weight.

Autocomplete is pervasive in modern applications. As the user types, the program predicts the complete *query* (typically a word or phrase) that the user intends to type. Autocomplete is most effective when there are a limited number of likely queries. For example, the [Internet Movie Database]() uses it to display the names of movies as the user types; search engines use it to display suggestions as the user enters web search queries; cell phones use it to speed up text input.







In these examples, the application predicts how likely it is that the user is typing each query and presents to the user a list of the top-matching queries, in descending order of weight. These weights are determined by historical data, such as box office revenue for movies, frequencies of search queries from other Google users, or the typing history of a cell phone user. For the purposes of this assignment, you will have access to a set of all possible queries and associated weights (and these queries and weights will not change).

The performance of autocomplete functionality is critical in many systems. For example, consider a search engine which runs an autocomplete application on a server farm. According to one study, the application has only about 50*ms* to return a list of suggestions for it to be useful to the user. Moreover, in principle, it must perform this computation *for every keystroke typed into the search bar* and *for every user*!

In this assignment, you will implement autocomplete by *sorting* the terms by query string; (using the sorts introduced in lecture) *binary searching* to find all query strings that start with a given prefix; and *sorting* the matching terms by weight.

Part 1: autocomplete term. Write an immutable data type `Term.java` that represents an autocomplete term: a query string and an associated integer weight. You must implement the following API, which supports comparing terms by three different orders: lexicographic order by query string (the natural order); in descending order by weight (an alternate order); and lexicographic order by query string but using only the first *r* characters (a family of alternate orderings). The last order may seem a bit odd, but you will use it in *Part 3* to find all query strings that start with a given prefix (of length *r*).

```
public class Term implements Comparable<Term> {

    // Initializes a term with the given query string and weight.
    public Term(String query, long weight)

    // Compares the two terms in descending order by weight.
    public static Comparator<Term> byReverseWeightOrder()

    // Compares the two terms in lexicographic order but using only the first r characters of each query.
    public static Comparator<Term> byPrefixOrder(int r)

    // Compares the two terms in lexicographic order by query.
    public int compareTo(Term that)

    // Returns a string representation of this term in the following format:
    // the weight, followed by a tab, followed by the query.
    public String toString()

    // unit testing (required)
    public static void main(String[] args)
}
```

Corner cases. The constructor should throw a `java.lang.NullPointerException` if `query` is `null` and a `java.lang.IllegalArgumentException` if `weight` is negative. The `byPrefixOrder()` method should throw a `java.lang.IllegalArgumentException` if `r` is negative.

Performance requirements. The string comparison functions should take time proportional to the number of characters needed to resolve the comparison.

Part 2: binary search. When binary searching a sorted array that contains more than one key equal to the search key, the client may want to know the index of either the *first* or the *last* such key. Accordingly, implement the following API:

```
public class BinarySearchDeluxe {

    // Returns the index of the first key in a[] that equals the search key, or -1 if no such key.
    public static <Key> int firstIndexOf(Key[] a, Key key, Comparator<Key> comparator)

    // Returns the index of the last key in a[] that equals the search key, or -1 if no such key.
    public static <Key> int lastIndexOf(Key[] a, Key key, Comparator<Key> comparator)

    // unit testing (required)
    public static void main(String[] args)
}
```

Corner cases. Each static method should throw a `java.lang.NullPointerException` if any of its arguments is `null`. You should assume that the argument array is in sorted order (with respect to the supplied comparator).

Performance requirements. The `firstIndexOf()` and `lastIndexOf()` methods should make at most $1 + \lceil \log_2 N \rceil$ compares in the worst case, where N is the length of the array. In this context, a *compare* is one call to `comparator.compare()`.

Part 3: autocomplete. In this part, you will implement a data type that provides autocomplete functionality for a given set of string and weights, using `Term` and `BinarySearchDeluxe`. To do so, *sort* the terms in lexicographic order; use *binary search* to find the all query strings that start with a given prefix; and *sort* the matching terms in descending order by weight. Organize your program by creating an immutable data type `Autocomplete` with the following API:

```
public class Autocomplete {

    // Initializes the data structure from the given array of terms.
    public Autocomplete(Term[] terms)
```

```
    // Returns all terms that start with the given prefix, in descending order of weight.
    public Term[] allMatches(String prefix)

    // Returns the number of terms that start with the given prefix.
    public int numberOfMatches(String prefix)

    // unit testing (required)
    public static void main(String[] args)
}
```

Corner cases. The constructor should throw a `java.lang.NullPointerException` if its argument is `null` or if any of the entries in its argument array are `null`. Each method should throw a `java.lang.NullPointerException` if its argument is `null`.

Performance requirements. The constructor should make proportional to $N \log N$ compares (or better) in the worst case, where N is the number of terms. The `allMatches()` method should make proportional to $\log N + M \log M$ compares (or better) in the worst case, where M is the number of matching terms. The `numberOfMatches()` method should make proportional to $\log N$ compares (or better) in the worst case. In this context, a *compare* is one call to any of the `compare()` or `compareTo()` methods defined in `Term`. Any sort must be linearithmic.

Input format. We provide a number of sample input files for testing. Each file consists of an integer N followed by N pairs of query strings and nonnegative weights. There is one pair per line, with the weight and string separated by a tab. A weight can be any integer between 0 and 2^63 — 1. A query string can be an arbitrary sequence of Unicode characters, including spaces (but not newlines).

- The file wiktionary.txt contains the 10,000 most common words in Project Gutenberg, with weights proportional to their frequencies.
- The file cities.txt contains over 90,000 cities, with weights equal to their populations.

```
% more wiktionary.txt           % more cities.txt
10000                           93827
   5627187200   the                   14608512  Shanghai, China
   3395006400   of                    13076300  Buenos Aires, Argentina
   2994418400   and                   12691836  Mumbai, India
   2595609600   to                    12294193  Mexico City, Distrito Federal, Mexico
   1742063600   in                    11624219  Karachi, Pakistan
   1176479700   i                     11174257  İstanbul, Turkey
   1107331800   that                  10927986  Delhi, India
   1007824500   was                   10444527  Manila, Philippines
    879975500   his                   10381222  Moscow, Russia
                ...                             ...
       392323   calves                       2  Al Khāniq, Yemen
```

Below is a sample client that takes the name of an input file and an integer *k* as command-line arguments. It reads the data from the file; then it repeatedly reads autocomplete queries from standard input, and prints out the top *k* matching terms in descending order of weight.

```
public static void main(String[] args) {

    // read in the terms from a file
    String filename = args[0];
    In in = new In(filename);
    int N = in.readInt();
    Term[] terms = new Term[N];
    for (int i = 0; i < N; i++) {
        long weight = in.readLong();           // read the next weight
        in.readChar();                         // scan past the tab
        String query = in.readLine();          // read the next query
        terms[i] = new Term(query, weight);    // construct the term
    }

    // read in queries from standard input and print out the top k matching terms
    int k = Integer.parseInt(args[1]);
    Autocomplete autocomplete = new Autocomplete(terms);
    while (StdIn.hasNextLine()) {
        String prefix = StdIn.readLine();
        Term[] results = autocomplete.allMatches(prefix);
        for (int i = 0; i < Math.min(k, results.length); i++)
            StdOut.println(results[i]);
    }
}
```

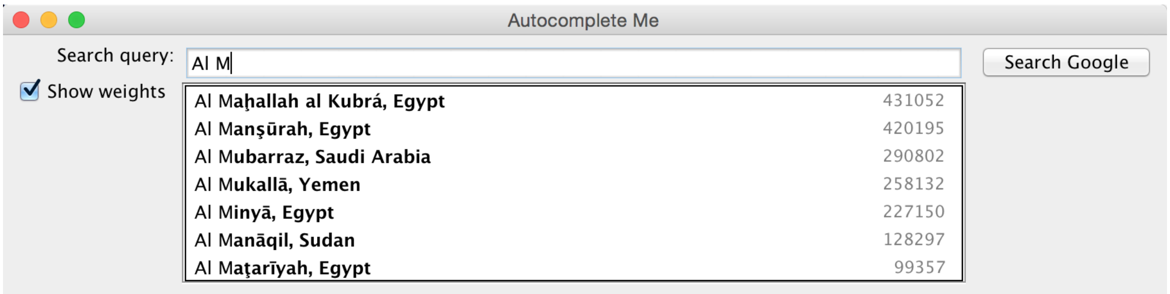
Here are a few sample executions:

```
% java-algs4 Autocomplete wiktionary.txt 5
auto
          619695   automobile
          424997   automatic
comp
        13315900   company
         7803980   complete
         6038490   companion
         5205030   completely
         4481770   comply
the
      5627187200   the
       334039800   they
       282026500   their
       250991700   them
       196120000   there
```

```
% java-algs4 Autocomplete cities.txt 7
M
    12691836   Mumbai, India
    12294193   Mexico City, Distrito Federal, Mexico
    10444527   Manila, Philippines
    10381222   Moscow, Russia
     3730206   Melbourne, Victoria, Australia
     3268513   Montréal, Quebec, Canada
     3255944   Madrid, Spain
Al M
      431052   Al Maḩallah al Kubrá, Egypt
      420195   Al Manşūrah, Egypt
      290802   Al Mubarraz, Saudi Arabia
      258132   Al Mukallā, Yemen
      227150   Al Minyā, Egypt
      128297   Al Manāqil, Sudan
       99357   Al Maţarīyah, Egypt
```

Interactive GUI (optional, but fun and no extra work). Download and compile [AutocompleteGUI.java](). The program takes the name of a file and an integer *k* as command-line arguments and provides a GUI for the user to enter queries. It presents the top *k* matching terms in real time. When the user selects a term, the GUI opens up the results from a Google search for that term in a browser.

```
% java-algs4 AutocompleteGUI cities.txt 7
```



Deliverables. Submit `Autocomplete.java`, `BinarySearchDeluxe.java`, and `Term.java`. You may not call any library functions other than those in `java.lang`, `java.util`, and `algs4.jar`. Finally, submit a [readme.txt]() file and answer the questions.

This assignment was developed by Matthew Drabick and Kevin Wayne.