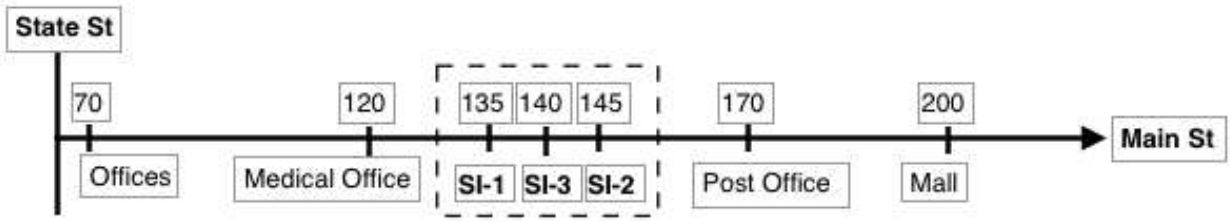
Computer Science I — CSCI-141
Illy caffé — Lab 6

10/12/2023

1 Problem

You have been hired to develop an application to help determine the placement for a new Illy caffé store. There are several store fronts available along Main Street. Developers are trying to determine the best placement of a store based on the distance to several large office buildings. They want to locate the store so that *it minimizes the sum of the distances from the store to offices on the street.* Additionally, they would like to use the application to determine the location of any new store. The diagram below shows locations chosen by several strategies. Numbers indicate distances to the intersection of Main and State. The "Sl-N" text means store locations identified by the numbered strategies.



optimal position: 135 (strategy 1), 140 (strategy 3), 145 (strategy 2)
sum of distances customers must travel: 180

You were asked to consider the following strategies to determine the best location of the new store (sometimes there might be more than one best location).

1. **Midpoint Distance Strategy**
   Let x be the distance of the business closest to State Street. Let y be the distance of the business farthest from State Street. Locate the new store at the mid-point between x and y; that is, at location $(x+y)/2$. For the above example, this strategy produces the location 135 and the sum of the distances to this location is
   $65 + 65 + 15 + 35 = 180$.
2. **Median Distance Strategy**
   Sort the distances and choose the location of the middle element. If the number of elements is even, choose the midpoint between the two middle elements. For the above example, this strategy produces 145, and the sum of the distances to this location is $75 + 55 + 25 + 25 = 180$.
3. **Average Distance Strategy**
   Locate the store at the average of the distances. For this example, this strategy produces 140, and the sum of the distances to this location is $70 + 60 + 20 + 30 = 180$.

The problem is that only one of these strategies *always* provides the *best* possible sum of distances.

2 Problem-solving Session (15%)

In a team of students, do the following:

1. Create a test case that has at least 3 and at most 5 business office locations that are between 0 and 10 *distance units* from State St. The test case should demonstrate that only one of the strategies is always optimal. Work through each strategy and indicate the calculated store location and the sum of the distances to each business, versus the optimal choice.
   Hint: If you think of the offices as distributed on a see-saw, how would you make it unbalanced?
   For each strategy your team should work in parallel to:
   (a) identify the optimal new store location;
   (b) compute the sum of the distances from this location to each office.
   Combine your answers, make a table of the results, and **identify the optimal strategy**. Team members should collect their answers, compare results, and list the results for each strategy.

2. Develop a Python function that implements the optimal strategy. Given a list of the unsorted locations, write a function that returns the best location. (Assume that there is an already-written list sort function, and call it.)

3. Write another Python function that, given a list of locations and the best location, calculates and returns the sum of the distances between the best location and each other location.

4. Study the **quick_select** algorithm on the next page.
   Run the algorithm for `k := 3` on the following list.

   ```
   [5, 2, 9, 22, 1, 3, 17, 12, 4, 13]
   ```

   Show all the intermediate steps and the final solution.

2.1 Quickselect Algorithm

This algorithm, known as quickselect, runs fast without sorting.

The quickselect approach is more efficient than sorting techniques seen so far. Quickselect finds the $\mathbf{k}^{th}$ **smallest number** in an *unsorted* list of numbers. Study the algorithm *pseudocode* below and consider how you could use quickselect to compute whatever location is necessary to solve the store location problem.

```
Function quick_select( a_list, k ):
    If a_list is not empty:
        pivot <- Choose the element at position ( len( a_list ) // 2 )
        smaller_list <- All elements of a_list smaller than pivot
        larger_list <- All elements of a_list larger than pivot
        count <- the number of occurrences of pivot value in a_list
        m <- the size of smaller_list
        If k >= m and k < m + count then:
            return pivot
        If m > k:
            return quick_select( smaller_list, k )
        Otherwise:
            return quick_select( larger_list, k - m - count )
```

It is a pre-condition that `k` is in the range `0` to `len(a_list)-1`.

3 In-lab Session (10%)

For in-lab, complete the first program that solves the problem. Work independently to complete the following tasks for upload to the In-lab MyCourses dropbox:

1. Create a project for this assignment. There will be multiple source files.

2. Extract and copy the `insertion.py` module from the lecture into your project, and rename the file to `insertion_sort.py`. This file will be the utility module for the `store_location.py` main program.

3. Modify the function `insertion_sort` to return the list.

4. Create a Python file named `tools.py`. This module will contain functions that will be shared by other main programs.

5. Implement these reusable functions in `tools.py`:
   - A function to read a file and return a list of business locations; and
   - The function from problem-solving that, given a list of locations and the best location, calculates and returns the sum of the distances between the best location and each other location. The `abs()` function can produce the absolute value of the distance between two locations.

   An example of input file content is shown below. Return only the list of numbers.

   ```
   Offices 70
   MedicalOffice 120
   PostOffice 170
   Mall 200
   ```

6. Create the main program file named `store_location.py` to contain a main and a function to compute the optimal location using insertion sort. (`store_location.py` is the first of two 'main modules'.) **You may not use either the builtin `list.sort()` function or the `sorted()` function**. Import the `insertion_sort.py` module into the `store_location.py` module. (Do NOT copy the content, and do not forget to modify the function `insertion_sort` to return the list.) Import the `tools.py` module into `store_location.py`, and write the function to compute the optimal location using insertion sort. Finally, write the main function so that it reads the file, computes the optimal location, calculates the sum of differences, and prints the results as shown in the example below. The `store_location.py` must use the functions you wrote in the `tools.py` file and the insertion sort function in `insertion_sort.py`. Here is example of `store_location.py` output for the in-lab:

   ```
   Enter data file: test_data_writeup.txt
   Optimum new store location:  145.0
   Sum of distances to the new store:  180.0
   ```

For the In-lab, zip `store_location.py` module and `tools.py` to a file named lab06.zip and upload it to mycourses. Do this before the In-lab deadline.

4 Implementation (75%)

Read the rest of this assignment carefully to understand and then implement the remaining requirements. The assignment involves two programs that solve the problem different ways. The *two programs* implement the same strategy and are instrumented so that they measure and report their time performance.

First, add instrumentation to the `store_location.py` program that you wrote in the post-PSS. The instrumentation will measure time of execution.

The operations to measure are the calculation of the optimal location, plus the sum of distances. Do not include the time to read the file and make the data list.

After completing instrumentation of the `store_location.py` program, copy that file to a new file named `select_median.py`. In this module, you will implement the **quick_select** algorithm to solve the problem, and replace the sorted approach.

Here is a summary of *what you will complete and deliver* for this assignment:

1. `tools.py`: the module you wrote in post-PSS containing the functions that are reusable by both main program modules.

2. `store_location.py`: the application you wrote in the post-PSS implementing the sorted approach, to which you added instrumentation;

3. `select_median.py`: an instrumented program implementing the *quickselect* algorithm; and

4. `report.txt`: a file containing *your name* and answers to the questions at the end of this section.

4.1 Program Operation and Instrumentation

Each program has similar structure, processes the same input files, and produces the same kind of results. Both implementations prompt for the input file name. Each program calculates and prints the optimal location of the store and the sum of the distances that people would have to travel to reach the store from each given location.

Each implementation must have instrumentation that reports the elapsed time used to sort and select the location. The Python `time` module has a `time.perf_counter()` function that returns the current number of fractions of a second used by the process as it runs. Use this time module function to capture a start time and a finish time; the difference is the elapsed time.

To test performance, download the set of large test cases and unzip to get and use the cases:

`http://www.cs.rit.edu/~csci141/Labs/06/TestData.zip`

Run each implementation several times with this data file. Measure how much time it takes to find the median *after* reading the file and *before* printing results. List your time comparisons for each implementation. Be patient; these runs may take some time.

Remember that, when a data set has an even number of elements, the optimal location is midway between the two middle numbers. Computing the midpoint requires identifying both middle values of the collection, as the strategy stated in the beginning.

You may not use either the builtin `list.sort()` function or the `sorted()` function.

4.2 A Small Example

Below is an example of running the sorted dataset program that solves a small version of this problem. This example is really too small to reveal much.

```
Enter data file: test_data_writeup.txt
Optimum new store location:  145.0
Sum of distances to the new store:  180.0

elapsed time :  3.845399999979904e-05
```

Running the programs using 10,000 to 25,000 elements provides a better comparison.

4.3 Larger Examples

This example uses a 100,000 element data set.

```
Enter data file: test_dataset100K.txt
Optimum new store location:  50100.5
Sum of distances to the new store:  2508114488.0

elapsed time :  0.29255081399999994
```

And this example uses the `test_dataset1M.txt` data set of 1 million business locations.

```
Enter data file: test_dataset1M.txt
Optimum new store location:  50128.5
Sum of distances to the new store:  25020348525.0

elapsed time :  3.2213172912597656
```

Do not try to run these large examples with the `store_location.py` program. Insertion sort is too slow!

4.4 Questions

Answer the following questions on quickselect and program performance as you design, implement and test your programs. This will show that you understand how quickselect works and how to measure execution time in a program. (hint: to analyze the algorithm, apply it by hand to a small, unsorted data sequence.)

1. What is the purpose of the `pivot`? Do you really need to choose the middle item as the pivot? Would the algorithm have behaved differently if you had selected the first item as the pivot each time?
2. Specify at least 4 test cases varying the size of the list of distances and considering an empty list. Does providing a sorted list impacts the efficiency of quickselect? Remember: *a test case identifies specific input values and expected outputs.*
3. What is the elapsed time performance of your median program using insertion sort when it processes a large data set? What is the elapsed time performance of your median program using quickselect when it processes the same large data set? Enter the elapsed times of *several runs* of each program in your report.

5 Grading

Your grade will be based on the following *individually-developed work*:

1. 15%: The utility module, `tools.py`;

2. 20%: The sorting median program, `store_location.py`;

3. 20%: The quickselect median program, `select_median.py`; and

4. 20%: The `report.txt` file containing *your name* and answers to the questions reporting each program's performance.

6 Submission

Submit all four required components in a zip file called `lab06.zip` and submit the zip file to the MyCourses dropbox for this assignment. **Use zip only. Do not use another compression mechanism.**