Programming Assignments 3 and 4 – 601.455/655 Fall 2023

Score Sheet (hand in with report) Also, PLEASE INDICATE WHETHER YOU ARE IN 601.455 or 601.655

(one in each section is OK)

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Grade Factor		
Program (40)		
Design and overall program structure	20	
Reusability and modularity	10	
Clarity of documentation and programming	10	
Results (20)		
Correctness and completeness	20	
Report (40)		
Description of formulation and algorithmic approach	15	
Overview of program	10	
Discussion of validation approach	5	
Discussion of results	10	
TOTAL	100	

CIS PA 4 Report

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1 Mathematical Approach

1.1 Registration and d_k Calculation

We opted to implement a closed form solution for registration rather than an iterative method to have a quicker method. We used Arun's registration that we implemented in PA1, which we quickly describe below.

$$\bar{a} = \frac{1}{N}\sum_{i=1}^{N} \vec{a}_i \qquad \tilde{a}_i = \vec{a}_i - \bar{a}$$

$$\bar{b} = \frac{1}{N}\sum_{i=1}^{N} \vec{b}_i \qquad \tilde{b}_i = \vec{b}_i - \bar{b}$$

$$\mathbf{H} = \sum_i \begin{bmatrix} \tilde{a}_{i,x}\tilde{b}_{i,x} & \tilde{a}_{i,x}\tilde{b}_{i,y} & \tilde{a}_{i,x}\tilde{b}_{i,y} \\ \tilde{a}_{i,y}\tilde{b}_{i,x} & \tilde{a}_{i,y}\tilde{b}_{i,y} & \tilde{a}_{i,y}\tilde{b}_{i,z} \\ \tilde{a}_{i,z}\tilde{b}_{i,x} & \tilde{a}_{i,z}\tilde{b}_{i,y} & \tilde{a}_{i,z}\tilde{b}_{i,z} \end{bmatrix}$$

We then computed the singular value decomposition to get $\mathbf{H} = \mathbf{USV^t}$, where the rotation matrix $\mathbf{R} = \mathbf{VU^t}$. The translation was calculated using $T = \bar{b} - \mathbf{R}\bar{a}$. If the determinant of the rotation matrix is -1, the last columm of V was multiplied by -1 to make sure that the resulting rotation matrix has a determinant of 1. A determinant of -1 could be caused by having a very small rotation.

For each sample frame k of the marker bodies, the values $a_{i,k}$ and $b_{i,k}$, the positions of the LED markers with respect to the optical tracker, were registered using Arun's method with A_i and B_i, the positions of the LED markers, giving $F_{A,k}$ and $F_{B,k}$. The position of the pointer tip with respect to rigid body B was calculated using $d_k = F_{B,k}^{-1} F_{A,k} A_{tip}$.

1.2 Closest Point on Triangle

Since we are working with a surface mesh defined by triangles and we need to find the closest point on the surface to another point, we implemented a function that finds the closest point on a triangle to a given point.

If the vertices of a triangle are defined by p, q, and r, and the given point is a, the closest point on the triangle to a can be found by the following steps:

$$a - p = \lambda(q - p) + \mu(r - p)$$

$$\begin{bmatrix} q - p & r - p \end{bmatrix} \begin{bmatrix} \lambda \\ \mu \end{bmatrix} = \begin{bmatrix} a - p \end{bmatrix} \longrightarrow Ax = b \longrightarrow x = (A^T A)^{-1} A^T b$$

After calculating λ and μ,

if $\lambda \geq 0, \mu \geq 0, \lambda + \mu \leq 1:$ $\qquad c = p + \lambda(q - p) + \mu(r - p)$

if $\lambda < 0:$ $\qquad \text{ProjectOnSegment}(c, r, p)$

if $\mu < 0:$ $\qquad \text{ProjectOnSegment}(c, p, q)$

if $\lambda + \mu > 1:$ $\qquad \text{ProjectOnSegment}(c, q, r)$

To project on a segment given c, p, and q:

$$\lambda = \frac{(c - p) \cdot (q - p)}{(q - p) \cdot (q - p)}$$

$$\lambda^{(seg)} = Max(0, Min(\lambda, 1))$$

$$c* = p + \lambda^{(seg)} \times (q - p)$$

1.3 Iterative Closest Point

1.3.1 Optimized ("Binary") Search

We created a KD Tree* from Nodes that store point, triangle, index, right child, and left child information, which makes searching for the closest point on the mesh surface much faster compared to a linear search. We used starter code from Geeksforgeeks.com (contributed by Prajwal Kandekar) and modified it as necessary for this assignment. We kept only the insert and search functions but modified search so that it returns the nearest node rather than check the tree for if that specific point already exists in the tree. We used our own Euclidean distance function to calculate distances, and updated this with each recursive search throughout the tree. Each depth level in the KD tree is oriented with respect to a specific dimension, looping from 0 to 2 and back to 0 again. This allows for as close to a binary search as is possible with 3-dimensional information.

The tree is constructed with respect to the information stored at point, which is the centroid of the triangle's vertices. This was calculated as:

$$x_c = \frac{x_1 + x_2 + x_3}{3}$$

Where x_c is the x-coordinate of the centroid, and x_i is the x-coordinate of vertex i. The same calculations were used for the y and z coordinates. This was necessary because it seemed the easiest way to reference each individual triangle, since the alternative required Nodes for each individual vertex (3 times as many Nodes!) and storing the information of all triangles it contributes to. The search(...) function traverses these centroid points to find the closest Node to the given query point, and this returned Node's triangle information is used to calculate the correct c_k value using Euclidean distance.

* K = number of dimensions = 3

1.3.2 Iterative Refinement of Points

We first started with an initial guess of $F_{reg} = I$ such that $s_k = F_{reg}d_k$. We then found the closest point c_k on the mesh surface to s_k using the KD tree search algorithm and closest point on triangle. We then updated F_{reg} by registering the c_ks to d_ks. After calculating the distance from s_ks calculated using the new F_reg to the c_ks found, we compared the average distance between all the points to a d_max that we defined to determine if the iterative closest point algorithm converged.

2 Algorithms

2.1 Registration

Take in input vectors a (size: N x 3) and b (size: N x 3), where the registration algorithm will find a transform such that F*a = b. Transpose vectors. Calculate averages for a and b and detract from vectors a and b. Implement Arun's method by creating the H matrix using the calculated vectors. Calculate the registration frame using SVD least squares. The output of the registration function is a Frame object, with a rotation (3 x 3 matrix) and translation part (Point 3D object). After reading in $a_{i,k}$ and $b_{i,k}$, use a for loop for each k to find a transformation to A_i and B_i detailed in the Mathematical Approach section using Arun's method, and use those to calculate d_k.

2.2 Closest Point on Triangle

Take in an input consisting of a point (1 x 3) and an array of 3 point vectors that stored the vertex locations of a triangle. Transpose the point vectors as necessary to make sure that the matrices are the correct dimensions. Create the 2 known matrices shown in the mathematical approach and use least squares to find the unknowns. Using if-else statements on the calculated values to see if the closest point is on the edge of the triangle, calculate the final center point based on the conditions of the location. The output is c, the center point which is a 1 x 3 vector.

2.3 Iterative Closest Point

2.3.1 Optimized ("Binary") Search

Take in the point to find the closest point for, a 1 x 3 array, and a Node object that represents the root of the tree (which is found when creating and inserting nodes into the tree). Iterate over all triangle vertices in the mesh and calculate their centroids. Create Nodes from these centroids and store their corresponding triangle vertices and triangle indices. Add each Node to the same tree. The output of the search function returns a Node class object, that consists of the triangle index, vertex locations of the triangle, and its centroid.

2.3.2 Iterative Refinement of Points

Take in an input of d_ks (N x 3) and the mesh model triangles loaded into the KD tree. Start with $F_{reg} = I$. For each d_k, calculate $s_k = F_{reg} d_k$. Iterate over each s_k and search the tree for its nearest Node. Use the Node's triangle information to find the closest point on the triangle. Return this c_k for each point. Update F_{reg} by registering d_k and c_k for all points, and use this F_{reg} to update s_k. Calculate the average distance between s_ks and c_ks. If the average distance is less than d_{max} or the number of iterations has exceeded the max number of iterations, then the algorithm has converged. If the algorithm has not converged, repeat the process of finding c_ks and updating F_{reg} The output is the iteratively improved F_{reg}, a Frame object.

3 Overview of Program

Important Files for PA4:

File Directory	
File	Description
FileIO.py	functions to read input and output1 files
GenerateOutput4.py	functions to read the unknown dataset files and generate an output4 txt file
Point3d.py	class to create 3d point objects and perform cartesian math functions
Frame.py	class to do frame transformations, save frame data, and transform points.
Registration.py	an implementation of the Arun's registration method
ClosestPointOnTriangle.py	functions to find the closest location of a triangle to a given point
Mesh.py	class to store the surface mesh, and functions for KD-tree
ICP.py	function to run the ICP algorithm
testing.py	testing functions we used to test and debug our functions

3.1 Code Structure

GenerateOutput4.py is the main file that should be run on input data to get output 4 files.

> This file includes functions to read the unknown dataset files and generate the desired output files. The output includes our calculated s_k, c_k, and $||s_k - c_k||$ values.

testing.py is a script that takes an input debugging data set and outputs the error of our calculated variables compared to those given in out "-output1.txt" and "-output2.txt" files. It also includes a few component tests that we did in addition to the debugging tests.

> testKDTree() checks to make sure that the insert and search functions work correctly given a tree that we designed.
> testClosestPointToTriangle() checks to make sure that the correct closest point to a triangle is found given different conditions.
> printPA4OutputErrors() prints the average s_k error, c_k error, and magnitude error, and the number of iterations it takes to reach convergence.

FileIO.py includes functions to read the body, mesh, samplereadings, and output3 files.

> For each type of file, the exact dimensions of the output arrays are specified in the python file, so that users can look at the description and understand how the array is formatted.

Point3d.py and Frame.py include classes to create 3d point objects, do transformations, save frame data, and other Cartesian math functions.

> Each Point3d object stores the name of the frame it resides in in addition to its x, y, z coordinates. The base code for this class was taken off Github (cited in code) though we added several additional features (e.g., frame variable and error() function) as necessary for this scenario. Each Frame object

object stores its 3D rotation matrix $\mathbf{R}$ and 3D position vector $\vec{p}$, as well as its neighboring Frames so that the whole system may be traversed from one Frame object.

Registration.py has an implementation of the Arun's registration, following the algorithm detailed above.

registrationArunMethod() takes in 2 point clouds and finds a transformation $\mathbf{F}$ such that $\mathbf{F} \cdot a = b$

Mesh.py creates a mesh object given the points of the vertices, indices of the vertices for each triangles, and each triangles' neighbors, along with functions to easy get the centroid of triangles and the vertices of triangles in array form. This files also contains the implementation of the KD-tree.

insert() inserts new nodes into the KD-tree and search() returns the triangle closest to a point based on Euclidean distance.

ClosestPointOnTriangle.py includes functions that take in a point and a triangle's vertices points, and returns the closest point on the triangle to the given point.

findClosestPointOnTriangle() is the main function that is called.

ICP.py includes a function to run iterative closest point registration between a set of points and a surface, which is defined by a KD tree

ICP() takes in d_k, the root of the KD tree, d_{max}, max number of iterations, and the initial transformation prediction, and returns the point-to-surface transformation found using ICP.

3.2 Citations and Packages

Packages used:

- NumPy==1.26.0 (important functions include matrix functions and np.linalg.svd)
- Math (used math.comb, comes with python==3.11.0)
- Time (comes with python)

References:

- Point3D: https://github.com/SplinterFM/Point3d
- KD Tree: https://www.geeksforgeeks.org/search-and-insertion-in-k-dimensional-tree/

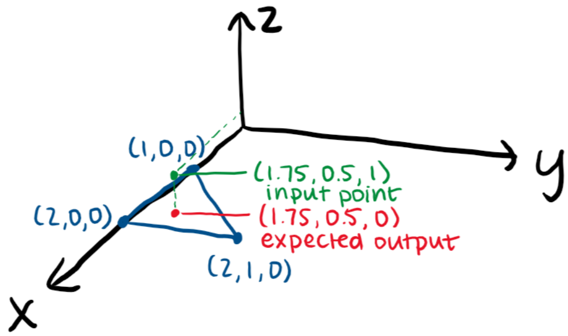
4 Verification of Code

4.1 Registration

We verified our Arun registration function by testing $\mathbf{F_D}$ against the first frame's D coordinates (using debugging file "a") and confirmed that $\mathbf{F_D^{-1}} \cdot \vec{D}_0 = \vec{d}_0$ on MATLAB.

4.2 Closest Point on Triangle

Since there are multiple checks in the function that calculates the closest point on triangle, multiple tests that satisfy the different conditions were written. There are tests where the closest point should lie in the middle of the triangle, on the first edge, on the second edge, and on the third edge. These tests compared against expected results. An example of a test is shown below:



4.3 KD Tree

Following the example given on the Geeksforgeeks page, We changed it to include a third dimension since it was given for a 2D tree rather than a 3D one. testKDTree() in testing.py checks both the insert and search function by looking for the closest node to a given point. Comparison of the two outputs reveals that the correct answer is reached, validating our KD tree implementation. A more detailed analysis and testing of the KD tree as well as its comparison to linear search in terms of accuracy and runtime can be found in our PA3 report.

4.4 Iterative Closest Point

After coding the step of each iterations, we tested our algorithm to make sure that the ICP algorithm updates F_{reg} in each iteration. To verify our ICP algorithm works as expected, we calculated the squared error between c_k found in the last iteration and the expected c_k, and s_k calculated using our final F_{reg} and the expected s_k of the debugging datasets. The error of the magnitudes between the two were also found. These results are shown below:

Table 1: Comparison of Errors

Dataset	s_k **Error**	c_k **Error**	**Magnitude Error**
A	0.009555	0.008653	0.006690
B	0.422691	0.393646	0.145841
C	0.240907	0.271679	0.121285
D	0.338191	0.355969	0.129926
E	0.236451	0.214759	0.095905
F	0.852592	0.716775	0.332576

Table 2: Comparison of Number of Iterations

Dataset	A	B	C	D	E	F	
Iterations	1	4	6	10	7	100	$d_{max} = 0.3$
	1	9	11	13	11	100	$d_{max} = 0.15$

Looking at the error between our generated outputs and the expected outputs for the debug datasets shown in Table 1, our ICP algorithm performs well. The error increases as more noise is added to the datasets. In addition, the number of iterations for the first 5 datasets was pretty low, showcasing the efficiency of our algorithm. Dataset F hit the maximum number of iterations limit at 100, which makes sense as our convergence criteria was $d_{max} = 0.15$.

We picked d_{max} by looking at how much the number of iterations would increase if d_{max} in increased. We used $d_{max} = 0.15$ because the results from values just a bit higher, such as 0.2 or 0.3 had similar number of iterations (as seen in Table 2), but anything lower than 0.15 would cause multiple datasets to run until they reach the maximum number of iterations. The max number of iterations was picked by looking at how much the accuracy changes at the cutoff. For example, a max number of 100 vs 200 didn't have much of a difference in accuracy, but 100 is much more efficient. To summarize, d_{max} and maximum number of iterations were picked to balance accuracy and efficiency. However, we made sure that these numbers can be easily changed through the function parameters.

5 Results

5.1 Discussion

For all datasets A-F, the errors in s_k and c_k are greater than the errors associated with $||s_k - c_k||$, as shown in Table 1. This suggests that the their individual positional errors perhaps mitigate each other's when calculating the magnitude difference. The lowest error is seen in Dataset A, with an average error of 0.009 mm between s_k and c_k, implying this is likely a noise-free dataset. This assumption is further validated by dataset A's results in Table 2 as it did not need to iterate to reach convergence. From this, we conclude our code has high accuracy in ideal conditions.

Datasets B-E have similar error magnitudes for s_k and c_k, averaging at 0.3 mm across these 4 datasets. Assuming these datasets have similar noise additions to previous programming assignments, these likely have one type of additive noise each, such as varying amounts of Gaussian noise added to one marker (e.g., body A coordinates) or all markers. Our code is shown to be not very robust against these errors as there is a greater than 25x increase in the error magnitudes of s_k, c_k, and $||s_k - c_k||$. Even so, d_{max} is achieved as the numbers of iterations in Table 2 never reach the maximum threshold (100).

The opposite is seen in the large errors of dataset F, approximately 0.77 mm between s_k and c_k. I assume this dataset to be the noisiest of the six, likely containing multiple types and/or large amounts of noise. Our results for this dataset likely do not meet our d_{max} requirements, as the maximum number of iterations is reached for both values (shown in Table 2). Even so, our errors do not ever exceed 0.9 mm, meaning we achieved a reliable error of < 1 mm for noisy conditions.

The similarity in errors between s_k and c_k (largest difference is 0.14 mm in the very noisy dataset F) makes sense since s_k is calculated using frame $\mathbf{F_{reg}}$ that is registered between d_k and c_k. Overall, this code would need to be further refined to operate in noisy conditions as errors in the $0.5 - 1$ mm magnitude can make a large difference during surgery, especially when operating in areas with lots of important structures near the target region. Potential improvements to our code include switching to a different approach once a threshold number of iterations is reached (e.g., 50). The different approach could be switching to a convergence function that looks at the distance from previous iteration rather than a number (risks a long runtime), or improving the KD tree implementation to look at neighboring triangles if the closest point is in a neighboring triangle. Specific improvements to the KD tree include additional point variables that better represent its size or a bounding sphere implementation, since our code currently only utilizes the centroid of the triangle, which may be misleading if the centroid is far from the current point but the triangle has a large area.

5.2 Unknown outputs

5.2.1 Dataset G

```
200 PA4-G-Unknown-Output.txt
-4.51 -18.59 -39.31 -4.49 -18.59 -39.39 0.082
-6.95 7.05 51.03 -6.95 7.05 51.00 0.026
12.56 21.68 49.28 12.58 21.69 49.26 0.036
-11.94 -13.57 -47.16 -11.99 -13.53 -47.12 0.080
7.37 25.11 10.36 7.35 25.25 10.34 0.138
-5.02 20.38 13.28 -4.93 20.28 13.36 0.156
-41.48 -15.70 -30.79 -41.21 -15.73 -30.59 0.343
-19.04 -31.80 -21.57 -19.06 -32.03 -21.58 0.230
17.29 -10.42 -20.77 17.35 -10.19 -20.52 0.352
30.39 7.25 -28.66 30.37 7.39 -28.44 0.268
-6.59 -6.32 -43.47 -6.52 -6.40 -43.42 0.116
37.57 10.31 -8.92 37.65 10.30 -8.96 0.090
18.53 -1.28 58.89 18.56 -1.34 58.86 0.074
-6.94 7.28 58.83 -6.99 7.28 58.80 0.053
0.40 -14.79 -3.47 0.38 -14.84 -3.48 0.060
38.30 5.00 -11.95 38.37 4.99 -12.03 0.109
-9.26 7.22 28.57 -9.45 7.15 28.61 0.207
5.45 23.09 26.72 5.47 23.10 26.70 0.035
18.78 -8.55 10.38 18.73 -8.46 10.32 0.123
-4.81 24.51 28.92 -4.81 24.36 28.86 0.160
21.18 3.44 56.35 21.18 3.40 56.31 0.051
22.24 9.99 51.71 22.19 9.94 51.67 0.082
28.08 -3.46 16.89 27.99 -3.42 16.83 0.115
35.55 -1.89 -18.99 35.43 -1.91 -18.99 0.116
16.73 -4.70 45.30 16.73 -4.74 45.27 0.053
11.81 -6.29 42.05 11.80 -6.33 42.02 0.046
-29.38 -26.51 -39.81 -29.44 -26.48 -39.86 0.084
-10.05 7.59 4.00 -9.99 7.53 3.99 0.090
19.67 -8.97 7.97 19.62 -8.87 7.90 0.135
-13.41 -5.15 5.50 -13.49 -5.17 5.51 0.080
-2.20 15.79 57.77 -2.17 15.74 57.76 0.056
-13.55 10.93 23.14 -13.72 10.80 23.09 0.217
21.68 25.34 2.88 21.77 25.49 2.87 0.174
2.85 -18.06 -12.43 2.87 -18.16 -12.42 0.096
-33.75 -28.00 -21.54 -33.85 -28.02 -21.55 0.103
19.12 -15.07 -17.07 19.13 -14.82 -16.83 0.345
-31.09 -11.49 -47.06 -31.05 -11.41 -46.89 0.185
```

-4.19 -13.60 -0.67 -4.23 -13.67 -0.67 0.085
21.11 1.89 53.38 21.11 1.85 53.35 0.054
0.21 -17.07 -28.76 0.37 -17.10 -28.87 0.191
-13.85 -29.47 -35.61 -13.87 -29.54 -35.70 0.120
-26.72 -29.66 -16.33 -26.90 -29.76 -16.27 0.208
0.39 -1.88 -26.00 0.38 -1.87 -26.04 0.041
22.38 -6.46 15.03 22.32 -6.30 14.96 0.179
10.06 20.82 56.22 10.09 20.72 56.20 0.106
26.83 10.47 26.40 26.87 10.44 26.37 0.059
-29.64 -29.63 -34.21 -29.71 -29.60 -34.25 0.083
-15.57 20.14 23.66 -15.61 20.22 23.63 0.096
-0.27 -12.68 -33.32 -0.12 -12.58 -33.42 0.206
-23.06 9.44 -18.14 -23.06 9.50 -18.12 0.064
1.30 8.52 -15.17 1.30 8.50 -15.19 0.024
-11.59 -4.13 9.79 -11.68 -4.16 9.81 0.098
6.51 -8.40 19.59 6.51 -8.49 19.58 0.086
-3.63 9.05 -11.12 -3.63 9.04 -11.14 0.028
-41.63 -7.24 -16.47 -41.49 -7.21 -16.57 0.177
-42.39 -17.37 -24.01 -42.50 -16.91 -24.26 0.532
33.05 17.21 -4.70 33.20 17.28 -4.72 0.169
18.65 16.13 55.92 18.57 16.02 55.89 0.143
-19.37 -4.07 -48.05 -19.45 -4.09 -47.95 0.130
16.39 -6.70 21.66 16.36 -6.61 21.61 0.103
18.09 -6.08 24.99 18.05 -6.03 24.94 0.075
9.52 26.04 3.97 9.51 26.22 3.95 0.175
-39.30 -17.77 -37.46 -39.12 -17.65 -37.44 0.218
-36.44 -26.48 -26.67 -36.51 -26.44 -26.70 0.086
-21.56 -17.97 -47.75 -21.59 -17.90 -47.66 0.117
-16.72 12.14 -27.13 -16.67 12.04 -27.16 0.114
-5.99 -2.41 36.35 -6.02 -2.55 36.32 0.141
4.98 -17.05 -12.28 4.95 -17.06 -12.31 0.050
5.59 -6.87 49.67 5.60 -7.03 49.64 0.161
16.53 24.72 -15.62 16.37 25.02 -15.68 0.347
-6.23 -1.31 36.37 -6.26 -1.31 36.35 0.037
-8.36 8.26 -23.51 -8.40 8.20 -23.52 0.071
29.70 16.12 13.73 29.85 16.19 13.80 0.185
0.60 -19.13 -19.35 0.70 -19.25 -19.35 0.160
7.48 16.00 62.95 7.50 15.98 63.20 0.256
20.73 0.32 -25.65 20.93 0.38 -25.51 0.248
-40.04 -15.38 -35.91 -39.82 -15.29 -35.91 0.234
-25.67 -31.20 -19.22 -25.77 -31.33 -19.23 0.155
-25.92 -5.61 -7.57 -25.89 -5.63 -7.67 0.105
-31.09 -15.12 -46.46 -30.95 -15.06 -46.27 0.247
-0.49 -7.22 31.63 -0.54 -7.31 31.60 0.101
-31.11 -26.94 -15.55 -31.20 -26.98 -15.51 0.107
26.64 13.12 24.16 26.73 13.12 24.16 0.085
20.51 20.52 -27.99 20.45 20.43 -27.87 0.164
12.02 20.64 57.85 12.04 20.55 57.82 0.101
32.40 -2.63 13.17 32.34 -2.63 13.10 0.090
-0.38 -7.23 32.15 -0.43 -7.32 32.13 0.103
11.77 24.03 -8.43 11.62 24.18 -8.52 0.227
35.50 11.65 -15.23 35.40 11.59 -15.22 0.118
14.40 -13.66 -17.43 14.43 -13.40 -17.24 0.323
-11.21 8.20 11.91 -11.14 8.17 11.90 0.073
6.90 11.10 -10.92 6.90 11.09 -10.94 0.027
-13.33 5.19 -41.35 -13.39 5.12 -41.29 0.118
-23.11 2.93 -44.43 -23.13 2.83 -44.25 0.206
1.39 -6.12 -26.92 1.40 -6.11 -26.98 0.063
-15.75 -11.06 -2.12 -15.87 -11.23 -2.22 0.234
9.61 22.77 -6.67 9.53 22.84 -6.76 0.138
-8.07 -23.02 -39.85 -8.03 -23.09 -39.97 0.141
-6.63 8.67 47.42 -6.69 8.68 47.40 0.069
-35.16 6.99 -29.53 -34.99 6.81 -29.50 0.251
11.74 -6.47 -22.09 11.73 -6.44 -21.88 0.212
14.88 25.57 -8.27 14.84 25.77 -8.34 0.224
-35.54 -19.16 -41.61 -35.50 -19.03 -41.55 0.142
35.45 15.27 2.41 35.56 15.29 2.37 0.115
-24.32 12.18 -26.39 -24.29 12.04 -26.43 0.154
14.88 18.37 -31.24 14.96 18.41 -31.00 0.258
-6.45 11.63 44.72 -6.54 11.64 44.71 0.101
8.29 20.50 55.90 8.32 20.47 55.88 0.047
9.60 -14.49 -17.21 9.53 -14.32 -17.16 0.194
-38.68 2.97 -31.83 -38.45 2.79 -31.74 0.303
-28.41 -1.56 -11.22 -28.58 -1.27 -11.41 0.383
28.42 -7.81 -24.31 28.31 -7.66 -24.04 0.331
-9.42 7.14 28.02 -9.61 7.07 28.06 0.205
27.32 22.85 -5.95 27.35 23.02 -6.05 0.201
18.40 0.64 62.19 18.48 0.53 62.26 0.152
21.40 -13.80 -19.84 21.56 -13.45 -19.93 0.400
-37.04 -2.30 -41.12 -36.83 -2.35 -40.96 0.263
34.47 -2.85 -20.76 34.29 -2.83 -20.72 0.189
-28.42 -3.20 -10.14 -28.44 -3.17 -10.19 0.058
15.48 8.60 62.94 15.48 8.57 63.17 0.228
28.20 21.67 6.77 28.31 21.86 6.76 0.220
-28.65 3.54 -42.16 -28.56 3.40 -41.98 0.249
39.90 6.63 -0.35 40.16 6.24 -0.31 0.472
-2.24 -7.40 -36.64 -2.13 -7.35 -36.71 0.133
22.43 24.84 -11.25 22.53 25.06 -11.27 0.241
-41.01 0.70 -24.22 -40.81 0.64 -24.28 0.214
32.38 -5.22 10.59 32.27 -5.06 10.48 0.228
-19.21 -31.62 -19.89 -19.23 -31.86 -19.90 0.234
-6.76 -25.15 -35.25 -6.66 -25.29 -35.35 0.193
3.53 -12.19 7.78 3.51 -12.16 7.75 0.053
16.56 17.99 57.57 16.54 17.89 57.53 0.107
-5.39 11.97 58.89 -5.35 11.95 58.87 0.044
-6.78 9.66 44.33 -6.87 9.67 44.32 0.087
-14.63 3.80 -2.15 -14.55 3.72 -2.18 0.119
-31.71 -18.83 -8.51 -31.76 -18.79 -8.52 0.066
17.94 22.19 -27.75 17.95 22.19 -27.79 0.044
6.05 -12.10 -22.41 5.97 -12.05 -22.34 0.115
-40.55 -21.29 -28.45 -40.58 -21.13 -28.34 0.197
-27.09 7.11 -15.77 -27.10 7.15 -15.79 0.049
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21.20 -11.38 -21.70 21.21 -11.26 -21.45 0.277
-3.44 18.63 10.49 -3.39 18.60 10.50 0.067
33.29 -5.50 -21.61 33.07 -5.41 -21.59 0.242
-5.08 -5.59 28.83 -5.13 -5.62 28.80 0.068
31.78 7.93 -26.80 31.65 7.89 -26.74 0.150
-3.04 -11.88 4.37 -3.08 -11.92 4.35 0.060
7.23 24.33 3.11 7.14 24.45 3.05 0.161
31.01 -9.89 -14.41 30.87 -9.85 -14.46 0.151
28.44 20.58 9.59 28.60 20.75 9.64 0.235

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-34.89 3.51 -15.24 -34.83 3.45 -15.37 0.151
15.74 -8.09 14.14 15.70 -8.02 14.09 0.099
-18.00 -32.20 -29.80 -18.02 -32.37 -29.87 0.180
33.19 -5.51 -22.00 32.96 -5.41 -21.95 0.246
-35.02 -16.90 -43.74 -34.98 -16.78 -43.68 0.142
-9.72 23.52 19.48 -9.63 23.34 19.59 0.235
-43.66 -10.13 -22.14 -43.55 -10.05 -22.19 0.142
26.36 23.00 -16.92 26.50 23.23 -16.95 0.271
-5.64 -10.84 6.18 -5.69 -10.91 6.18 0.085
19.11 20.39 35.78 19.10 20.33 35.74 0.075
12.67 18.60 -29.96 12.74 18.61 -29.93 0.078
21.59 14.13 45.33 21.56 14.07 45.29 0.082
-15.02 -31.52 -24.54 -15.02 -31.73 -24.56 0.209
-36.46 -25.76 -31.45 -36.49 -25.67 -31.48 0.095
-1.99 16.02 56.87 -1.93 15.95 56.84 0.094
-0.69 21.57 36.86 -0.67 21.46 36.81 0.124
15.47 -11.15 6.36 15.43 -11.11 6.29 0.085
-13.84 -31.03 -29.83 -13.83 -31.20 -29.89 0.188
9.50 25.42 0.99 9.41 25.56 0.92 0.182
20.13 -1.23 49.49 20.11 -1.25 49.46 0.045
-15.17 -19.79 -7.95 -15.13 -19.91 -7.76 0.234
35.79 7.53 -18.59 35.73 7.48 -18.61 0.080
13.04 -5.68 59.54 13.08 -5.78 59.51 0.117
-15.35 -7.56 1.23 -15.43 -7.58 1.24 0.086
-32.49 8.13 -20.67 -32.38 8.02 -20.74 0.171
-18.83 -10.22 -49.26 -18.89 -10.23 -49.16 0.112
-6.85 4.10 56.64 -6.90 4.09 56.61 0.058
-36.98 -24.45 -33.67 -36.97 -24.33 -33.67 0.115
-7.31 8.47 39.46 -7.46 8.46 39.46 0.148
-30.15 6.59 -38.29 -30.03 6.43 -38.18 0.229
-17.70 6.19 -13.62 -17.71 6.24 -13.63 0.050
20.35 -10.01 4.34 20.29 -9.98 4.28 0.090
28.12 21.96 -15.94 28.27 22.14 -15.96 0.236
7.62 -9.41 -23.15 7.53 -9.32 -23.03 0.174
-6.84 4.56 53.28 -6.92 4.55 53.26 0.082
14.04 -3.91 62.44 14.14 -4.29 62.44 0.393
6.58 19.68 60.63 6.56 19.73 60.58 0.080
-12.33 -28.17 -16.99 -12.38 -28.27 -16.95 0.117
-22.40 12.39 -26.44 -22.38 12.26 -26.48 0.140
39.86 6.93 -0.97 39.99 6.92 -0.99 0.130
34.14 -1.20 12.49 34.22 -1.04 12.57 0.199
-21.37 -12.68 -47.85 -21.41 -12.73 -47.88 0.075
-0.35 -6.06 44.55 -0.41 -6.19 44.52 0.149
28.81 -5.61 12.69 28.74 -5.50 12.57 0.179
24.30 3.25 37.36 24.29 3.21 37.32 0.052
22.59 10.29 49.08 22.55 10.24 49.04 0.071
-24.29 -31.58 -19.83 -24.39 -31.72 -19.84 0.167
-6.71 20.07 14.01 -6.62 19.96 14.12 0.185
34.39 -4.88 8.13 34.24 -4.77 8.04 0.201
-3.74 24.24 29.23 -3.74 24.10 29.18 0.148

5.2.2 Dataset H

200 PA4-H-Unknown-Output.txt
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24.05 14.10 32.36 24.03 14.00 32.38 0.105
-8.07 -3.04 24.11 -8.10 -3.05 24.13 0.038
13.78 20.00 -29.88 13.80 20.09 -30.04 0.184
-36.50 -19.67 -12.33 -36.50 -19.58 -12.33 0.088
2.46 5.98 -18.63 2.50 6.01 -18.64 0.054
-39.36 0.74 -34.09 -39.19 0.72 -34.00 0.192
22.58 1.65 44.54 22.46 1.63 44.55 0.129
-35.53 -9.33 -44.64 -35.50 -9.26 -44.57 0.101
-42.94 -3.21 -23.79 -42.72 -3.22 -23.80 0.216
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30.17 16.57 12.94 30.22 16.50 12.98 0.098
-41.61 -15.62 -30.31 -41.46 -15.58 -30.17 0.211
-4.18 -10.92 7.27 -4.19 -10.91 7.29 0.027
-4.66 -18.83 -39.17 -4.45 -18.83 -39.22 0.216
-6.04 0.48 51.04 -6.12 0.53 51.16 0.149
35.33 14.89 -0.87 35.51 14.94 -0.87 0.185
22.00 -16.39 -9.13 21.89 -16.31 -9.11 0.135
-2.15 9.01 -12.00 -2.20 9.03 -12.02 0.058
5.03 -6.17 -23.97 5.10 -6.17 -24.04 0.094
33.02 6.87 14.36 33.00 6.77 14.36 0.103
11.38 -6.73 27.84 11.35 -6.63 27.87 0.107
-26.45 -27.56 -39.41 -26.53 -27.68 -39.57 0.216
-5.02 24.15 20.11 -4.96 24.08 20.16 0.109
18.74 -16.56 -4.70 18.67 -16.43 -4.84 0.211
-40.42 -20.12 -19.46 -40.45 -20.03 -19.45 0.091
26.27 20.37 -23.02 26.45 20.34 -22.98 0.186
3.97 16.43 -2.04 3.82 16.52 -2.14 0.199
17.25 -16.14 -14.74 17.28 -15.95 -14.60 0.233
-3.98 13.96 57.61 -4.02 13.99 57.64 0.062
-37.40 -8.43 -9.62 -37.26 -8.38 -9.71 0.175
-4.72 -15.49 -3.72 -4.75 -15.48 -3.71 0.034
3.44 3.24 -20.76 3.48 3.28 -20.79 0.065
11.78 17.83 -23.66 11.66 17.73 -23.60 0.168
26.16 14.68 -27.91 26.25 14.68 -27.99 0.114
4.29 -0.63 -22.75 4.34 -0.61 -22.81 0.080
-2.41 24.15 20.28 -2.36 24.09 20.31 0.095
28.33 7.17 23.71 28.27 7.08 23.71 0.109
7.95 21.82 -4.69 7.76 21.95 -4.95 0.344
-35.38 -20.84 -12.29 -35.41 -20.77 -12.27 0.081
-12.93 -4.30 7.25 -12.94 -4.29 7.27 0.035
4.11 -2.89 -23.79 4.16 -2.85 -23.86 0.093
19.81 -0.15 -23.97 19.82 -0.19 -23.93 0.062
-6.51 22.37 17.01 -6.46 22.38 17.03 0.057
35.00 4.15 -21.19 34.99 4.06 -21.14 0.100
39.57 8.25 -0.91 39.59 8.15 -0.88 0.107
-11.88 23.71 21.57 -11.81 23.65 21.63 0.110
-6.17 0.08 39.62 -6.20 0.07 39.65 0.043
18.85 9.03 -28.08 18.93 9.04 -28.01 0.104
-32.38 -5.62 -45.58 -32.35 -5.57 -45.51 0.094
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10.78 -16.73 -6.08 10.84 -16.54 -6.04 0.200
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28.81 20.20 10.21 28.94 20.24 10.29 0.158
19.30 -12.10 1.40 19.19 -11.98 1.35 0.179
-11.14 -3.36 11.92 -11.16 -3.37 11.96 0.046
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-30.34 -26.62 -14.18 -30.39 -26.56 -14.16 0.079
36.16 9.56 -15.02 36.25 9.50 -15.00 0.113
-6.93 9.12 -1.33 -6.92 9.16 -1.30 0.043
-5.71 3.14 62.90 -5.70 3.12 62.92 0.029
7.34 21.16 39.30 7.36 21.25 39.33 0.096
-13.27 -27.58 -38.64 -13.14 -27.74 -38.73 0.225
33.05 -6.42 -0.80 32.86 -6.36 -0.74 0.217
-30.36 -17.91 -46.11 -30.41 -17.86 -46.11 0.074
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27.79 7.80 25.28 27.70 7.71 25.28 0.127
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-13.82 -26.55 -13.43 -13.82 -26.69 -13.34 0.167
32.74 12.24 12.74 32.74 12.14 12.73 0.102
-28.48 -0.63 -45.16 -28.43 -0.61 -45.06 0.105
-17.97 -26.53 -11.70 -17.99 -26.61 -11.59 0.144
6.08 -7.64 26.05 6.06 -7.62 26.06 0.036
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3.60 21.03 3.85 3.40 21.15 3.78 0.245
16.55 26.88 0.77 16.66 27.13 0.82 0.288
13.27 -6.48 28.27 13.25 -6.37 28.29 0.113
-42.13 -16.18 -20.58 -42.17 -16.10 -20.56 0.092
31.13 18.61 -17.60 31.19 18.54 -17.56 0.098
19.96 25.83 -8.24 20.11 25.98 -8.22 0.214
37.56 3.15 -13.92 37.62 3.14 -13.91 0.063
-6.71 2.64 58.57 -6.78 2.62 58.57 0.072
25.24 -11.01 -0.44 25.18 -10.72 -0.57 0.324
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27.66 -12.74 -13.64 27.45 -12.55 -13.64 0.285
25.71 8.76 32.38 25.60 8.68 32.38 0.133
22.70 -7.45 11.12 22.60 -7.23 11.07 0.251
-15.75 -12.24 -48.41 -15.78 -12.21 -48.48 0.074
16.59 26.92 1.90 16.79 27.05 1.87 0.248
-29.23 -22.56 -43.65 -29.31 -22.65 -43.79 0.191
19.44 -6.82 -23.69 19.51 -7.02 -23.80 0.232
12.76 15.70 -23.14 12.68 15.60 -23.09 0.138
-4.56 13.78 7.16 -4.63 13.86 7.14 0.102
-8.05 -26.69 -34.55 -7.89 -26.87 -34.62 0.243
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7.46 10.76 -11.30 7.47 10.89 -11.37 0.144
14.59 -5.79 38.99 14.54 -5.73 39.03 0.088
-22.19 11.45 -32.88 -22.12 11.34 -32.80 0.150
21.57 10.15 57.52 21.46 10.06 57.62 0.176
27.14 10.35 25.80 27.09 10.25 25.81 0.110
9.50 6.25 -15.80 9.54 6.29 -15.89 0.109
0.94 10.60 -8.55 0.93 10.69 -8.57 0.093
-10.35 9.83 31.59 -10.47 9.68 31.67 0.210
27.83 22.61 -2.23 27.94 22.60 -2.20 0.113
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0.06 -16.78 -7.07 0.02 -16.76 -7.06 0.045
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18.10 -14.03 -0.97 18.00 -13.90 -1.06 0.186
8.34 4.37 63.09 8.34 4.32 63.04 0.069
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-6.96 -23.75 -14.97 -6.96 -23.82 -14.90 0.101
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20.52 -9.07 -22.98 20.58 -9.00 -22.82 0.183
18.13 14.35 62.40 18.12 14.25 62.36 0.104
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8.28 20.16 -6.87 8.05 20.27 -7.00 0.282
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13.91 22.07 38.81 13.98 22.09 38.84 0.079
-22.78 -10.59 -49.63 -22.88 -10.40 -49.31 0.384
-14.85 10.55 -32.45 -14.91 10.40 -32.38 0.178
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5.85 0.03 -21.81 5.89 0.07 -21.90 0.100
-16.45 7.70 -15.02 -16.42 7.56 -15.10 0.158
-39.11 2.41 -20.98 -38.91 2.34 -21.02 0.213
32.84 -0.47 -24.32 32.86 -0.55 -24.30 0.084
30.62 5.31 18.71 30.50 5.24 18.67 0.146
33.10 -8.02 -13.95 32.86 -7.86 -13.96 0.285
7.88 22.03 -4.10 7.64 22.21 -4.19 0.313
31.70 10.56 15.05 31.71 10.47 15.07 0.096
-8.49 -6.42 14.19 -8.51 -6.43 14.21 0.035
40.16 6.37 -1.64 40.24 6.29 -1.60 0.119
-20.04 12.27 -30.38 -20.03 12.11 -30.34 0.169
36.43 13.13 -9.72 36.52 13.07 -9.70 0.112
2.06 -18.09 -20.80 2.43 -18.00 -21.58 0.862
-15.30 20.92 26.07 -15.42 21.01 26.10 0.157
-38.43 -18.71 -14.60 -38.48 -18.64 -14.57 0.086
37.27 12.67 4.37 37.31 12.76 4.37 0.104
-15.93 -31.75 -24.39 -15.92 -31.97 -24.36 0.223
-8.80 8.23 -14.20 -8.77 8.15 -14.18 0.083
4.27 23.67 22.77 4.32 23.67 22.80 0.066
-28.51 1.32 -12.63 -28.47 1.31 -12.77 0.146
-11.00 -28.79 -34.09 -10.94 -28.98 -34.18 0.220
-4.50 -11.90 3.70 -4.52 -11.91 3.72 0.035
-42.41 -12.86 -18.68 -42.40 -12.77 -18.67 0.096
36.16 13.33 7.26 36.30 13.34 7.34 0.165
-16.29 16.77 23.02 -16.41 16.87 23.03 0.159

22.17 -2.24 34.69 22.02 -2.17 34.67 0.165
-34.40 3.81 -15.09 -34.27 3.78 -15.26 0.220
36.91 5.69 -15.46 36.88 5.61 -15.42 0.096
-4.13 2.67 -27.75 -4.12 2.67 -27.72 0.034
-15.64 8.93 -37.84 -15.63 8.88 -37.74 0.108
-0.11 -10.73 -30.20 0.01 -10.71 -30.20 0.118
-12.01 -18.06 -7.17 -12.04 -18.06 -7.13 0.053
-39.89 -15.60 -14.59 -39.81 -15.51 -14.65 0.136
22.45 3.46 48.15 22.35 3.41 48.17 0.116
18.97 -6.64 18.98 18.91 -6.45 18.98 0.201
-2.45 23.78 18.54 -2.39 23.74 18.58 0.079
21.16 13.18 52.15 21.08 13.07 52.16 0.138
-34.36 5.35 -35.59 -34.21 5.27 -35.49 0.192
15.09 23.11 23.25 15.17 23.21 23.30 0.130
-37.93 -10.03 -10.60 -37.88 -9.94 -10.63 0.100
-7.26 5.73 -29.49 -7.30 5.66 -29.45 0.088
-6.84 16.96 41.00 -6.95 16.98 41.09 0.151
-26.66 -25.79 -10.77 -26.71 -25.84 -10.63 0.154
-23.01 -32.48 -24.89 -23.05 -32.74 -24.87 0.267
-2.81 15.23 6.30 -2.89 15.33 6.27 0.135
3.93 -7.01 50.09 3.91 -7.02 50.12 0.034
25.68 8.43 32.58 25.58 8.35 32.58 0.135
-30.23 3.92 -40.81 -30.17 3.91 -40.68 0.145
16.94 -3.47 56.74 16.87 -3.47 56.77 0.078
38.05 -0.66 -12.73 37.82 -0.61 -12.62 0.268
-0.12 -15.67 -4.92 -0.15 -15.64 -4.92 0.045
21.67 -11.10 -21.59 21.66 -11.14 -21.53 0.075
-6.18 -23.38 -15.16 -6.15 -23.48 -15.09 0.122
0.50 -8.44 -28.49 0.59 -8.42 -28.54 0.112
-35.94 5.37 -20.61 -35.74 5.26 -20.67 0.232
-20.79 5.71 -41.63 -20.77 5.66 -41.52 0.120
6.64 -12.66 5.56 6.63 -12.54 5.55 0.118
13.42 11.53 -13.63 13.22 11.57 -13.71 0.227
9.93 3.04 -18.54 9.91 3.15 -18.65 0.160
8.18 16.16 63.23 8.21 16.12 63.21 0.059

5.2.3 Dataset J

200 PA4-J-Unknown-Output.txt
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-21.48 11.24 -35.30 -21.42 10.80 -35.13 0.474
-5.45 -19.87 -11.16 -5.27 -20.27 -10.89 0.515
-2.79 3.33 -24.74 -2.65 3.46 -24.84 0.220
33.36 15.93 -10.21 34.10 16.66 -10.39 1.059
-23.86 -13.14 -5.60 -23.81 -13.05 -5.76 0.193
0.52 -4.21 50.88 -0.28 -6.11 50.90 2.063
-16.71 2.58 -2.55 -16.38 2.18 -2.57 0.518
16.73 -3.86 51.21 16.90 -4.05 51.23 0.260
22.57 -15.59 -4.11 22.14 -14.56 -4.88 1.353
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26.88 14.97 23.42 26.25 14.63 23.19 0.750
-17.31 -1.55 -47.05 -17.32 -1.51 -47.15 0.103
-42.74 -14.02 -18.16 -42.05 -13.86 -18.37 0.741
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5.2.4 Dataset K

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36.41 7.70 -16.77 36.40 7.76 -16.80 0.061
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1.92 -7.02 53.71 1.97 -6.99 53.71 0.060
16.54 -10.54 -20.19 16.62 -10.41 -20.08 0.190
-13.06 15.47 17.57 -13.13 15.43 17.49 0.115
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38.34 11.05 -3.84 38.23 11.04 -3.85 0.111
-20.59 -24.41 -9.07 -20.57 -24.39 -9.14 0.072
18.41 21.83 29.50 18.37 21.76 29.49 0.078
-0.17 -6.53 38.75 -0.14 -6.55 38.74 0.044
13.53 22.75 -27.80 13.71 22.54 -27.90 0.293
-7.60 6.29 35.27 -7.63 6.25 35.28 0.055
-6.47 5.77 -26.37 -5.93 5.64 -26.07 0.635
29.52 17.22 12.91 29.61 17.32 12.95 0.146
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-5.61 8.98 -4.76 -5.68 9.09 -4.78 0.131
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20.51 -6.94 -23.94 20.51 -6.87 -23.88 0.094
13.56 22.63 -24.59 13.81 22.40 -24.48 0.362
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13.40 24.08 19.74 13.39 24.08 19.74 0.013
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-36.19 1.73 -38.30 -36.22 1.72 -38.28 0.039
39.23 9.49 -0.70 39.22 9.53 -0.72 0.054
-29.09 9.57 -20.33 -29.16 9.65 -20.28 0.113
-35.82 1.27 -39.20 -35.77 1.25 -39.34 0.156
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-19.22 3.59 -10.64 -19.18 3.50 -10.69 0.109
-4.88 3.08 -27.99 -4.84 3.15 -28.05 0.101
6.74 -9.09 17.53 6.75 -9.06 17.50 0.038
1.00 -6.53 46.57 0.97 -6.72 46.56 0.199
-19.75 -0.41 -6.27 -19.86 -0.35 -6.18 0.153
26.18 23.56 -10.93 26.10 23.49 -10.93 0.101
-5.85 0.01 46.45 -5.97 -0.08 46.45 0.153
-7.33 3.28 -36.07 -7.25 3.39 -36.13 0.143
24.05 16.14 27.36 24.08 16.17 27.35 0.035
16.43 9.47 -24.42 16.69 9.56 -24.38 0.272
-8.05 -20.67 -10.01 -8.00 -20.72 -9.95 0.097
8.67 -6.87 47.81 8.71 -6.76 47.80 0.116
20.44 18.35 35.49 20.59 18.44 35.51 0.178
13.75 23.63 -20.20 13.89 23.36 -20.19 0.305
33.04 -2.33 12.01 33.37 -2.57 11.98 0.408
-22.58 -4.03 -47.50 -22.67 -3.97 -47.34 0.196
23.16 15.92 31.93 23.09 15.89 31.91 0.077
-18.39 -16.45 -47.92 -18.41 -16.43 -47.89 0.035
-11.70 2.67 14.86 -11.82 2.64 14.89 0.132
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-17.46 -28.64 -14.35 -17.45 -28.62 -14.38 0.047
21.38 -5.63 20.71 21.42 -5.69 20.69 0.070
4.09 -0.07 -22.75 4.05 -0.07 -22.71 0.054
19.49 6.61 -27.45 19.67 6.71 -27.36 0.228
-15.10 -11.86 -48.47 -15.21 -11.88 -48.57 0.150
-12.66 9.18 -33.20 -12.72 9.14 -33.17 0.070
-4.33 12.83 55.10 -4.70 12.97 55.16 0.403
-6.66 6.65 53.98 -7.01 6.69 53.99 0.348
14.15 -16.12 -2.23 14.18 -16.27 -2.20 0.162
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-19.73 0.13 -6.14 -19.62 0.04 -6.21 0.153
34.67 11.82 -17.89 34.64 11.87 -17.91 0.062
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-14.79 14.56 31.75 -14.77 14.53 31.76 0.039
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-39.42 -22.07 -21.36 -39.47 -22.14 -21.34 0.091
22.27 7.87 53.24 22.14 7.86 53.20 0.131

-36.53 -3.29 -41.66 -36.77 -3.04 -41.45 0.402 -31.88 7.96 -19.62 -31.93 7.97 -19.58 0.062 30.43 20.90 0.68 30.30 20.79 0.67 0.175

6 Partner Work

Both Kiana and Keerthana worked on all the python files as well as the report.