ROB 502 Fall 2022: Assignment 4

Due 10/26 at 11:59pm

Rules:

1. All homework must be done individually, but you are encouraged to post questions on Piazza
2. No late homework will be accepted (unless you use your late-day tokens)
3. Submit your code on autograder.io
4. Remember that copying-and-pasting code from other sources is not allowed

Code Download:

Download the template code zip here. Unzip the the contents of the zip file to your Dropbox directory. Make sure you have set up VScode before starting the assignment. Open the directory `hw4` in VScode. Do not run VScode from subdirectories of `hw4` .

Instructions:

Each problem will give you a file with some template code, and you need to fill in the rest. Make sure to only put your code in the areas that start with `// --- Your code here` and end with `// ---`. Do not edit code outside these blocks!

We use autograder.io, so if you're ever wondering "will I get full points for this?" just upload your code to the autograder to check. There is no limit to how many times you can upload to autograder. The autograder is set to ignore whitespace and blank lines, so there is some forgiveness on formatting. In most of these questions, the input/output and printing is handled for you in the template code, but in some you are asked to write it yourself. The autograder may test your problem with multiple different inputs to make sure it is correct. We will give you examples of some of these inputs, but the autograder will also try your code with some other inputs. The autograder will only show you if you got it right/wrong, so if you don't get full points, try to test some other inputs and make sure your program works.

Getting your program to successfully compile and correctly reproduce the sample output will get you some points, while the remaining points will be from hidden inputs that test some edge cases. Think about valid inputs that could break your logic.

In this assignment you will get practice using inheritance and polymorphism. Additionally you will practice using the Eigen C++ library.

1. Project Euler #4 [2 points]: Code a solution to the following problem: **Largest palindrome product**
   Template file: `euler4.cpp`

2. Fitting a Plane using RANSAC [14 points]: Your job is to take in point cloud data from a file and find the plane of the form $ax + by + cz + d = 0$ that best fits the data using RANSAC. The pointclouds are given as txt files (e.g. `pointcloud1.txt`), where the first line is the number of points, and the following lines are the (x,y,z) positions of the points. The point cloud data is noisy and has outlier points, meaning the points are not exactly on the same plane, and some points are very far.

   Recall that RANSAC iterative calls a problem-specific model-fitting algorithm on a random subset of the data. You will implement two different model-fitting algorithms for finding a plane given a set of points. To do this, edit the file `ransac.h` to create two subclasses of `BaseFitter`, one called `AnalyticFitter` and one called `LeastSquaresFitter`, each class should override the `fit` function and include an appropriate constructor. You should also implement RANSAC in the `ransac` function. You are given the file `ransac.cpp` which runs RANSAC with both `AnalyticFitter` and `LeastSquaresFitter`, and saves the outputs to `planes.txt`. You do not need to modify `ransac.cpp`, and the autograder will use our version, not yours. The fit methods should work as follows:

   - for `AnalyticFitter`: select three random points to fit the model of the plane using the equations of a plane derived from three points.
   - for `LeastSquaresFitter`: select 10 random points to fit the model of the plane, using least squares.

   For this problem, an inlier is a point whose distance to the plane is below some threshold (which you should pick). To compute distance from a point $[x, y, z]$to a plane $ax + by + cz + d = 0$ you can use the following formula (HINT: think about how to compute this distance for all points simultaneously, without a for-loop):

$$\frac{|ax + by + cz + d|}{\sqrt{a^2 + b^2 + c^2}}$$

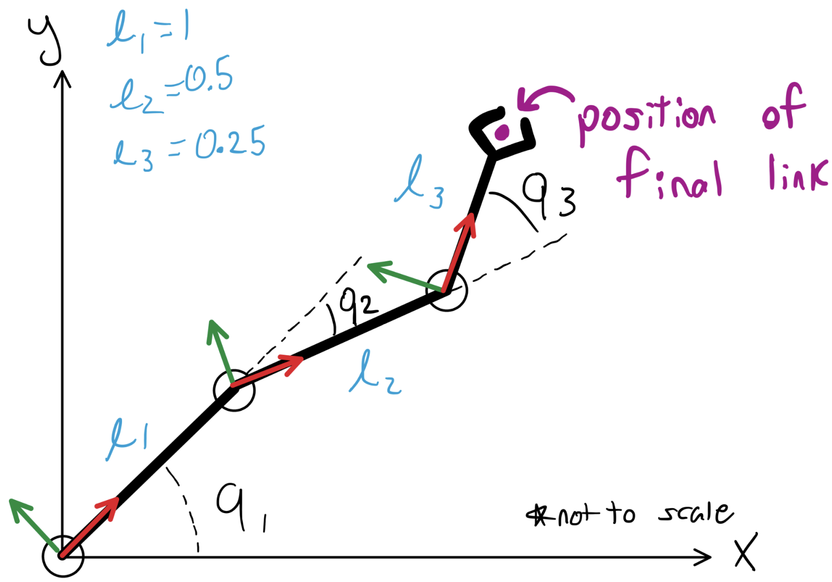
Make sure you tune the number of iterations and inlier threshold parameters to get good fits on the example data. The autograder will check whether the angle between your output `[a, b, c, d]` and the true coefficients is within 10 degrees. The true coefficients for the two given examples are:

`pointcloud1.txt`	[1, -1, -0.4, -1.0]
`pointcloud2.txt`	[-0.4, 1.0, -0.4, 1.0]

You can use the script `viz_plane.py` to visualize the data. If you run it with no arguments, it will visualize the point cloud in `pointcloud.txt` and a plane with (incorrect) default parameters. If you give it four numbers (a,b,c,d) as arguments, it will visualize that plane. See `python viz_plane.py -h` for help info.

Template file: `ransac.h`

3. Forward Kinematics [9 points]: Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters (wikipedia). In this problem you will write down the kinematic equations of a 3-link robot arm in C++. Your program will read in a text file where each line is the joint positions θ_1 θ_2 θ_3 separated by spaces, and may have multiple lines. You should then compute and print to `std::cout` the corresponding position for the $(x\ y)$ position of the final link. For printing, use `std::setprecision(3)` and the `operator<<` defined for `Eigen::Vector2d`. The diagram below describes the kinematics of the robot. The counter-clockwise rotations are positive (right-handed system)



The forward kinematics are computed using a series of matrix multiplications, where each T matrix below is a homogeneous transformation matrix. You should use the "current axis" semantics from the lecture slides. Since we're working in 2D, these transformation matrices are 3x3, and have the following format, where `q` is a joint angle in radians (see diagram):

$$T = \begin{bmatrix} \mathrm{Rot}(q) & \mathrm{t} \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos(q) & -\sin(q) & t_x \\ \sin(q) & \cos(q) & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

First, implement a function `transform_mat`, which takes in the joint angle `q` and the length of the link `l` and returns the transform `T`. Use the diagram above to figure out how to use `l` to set `tx` and `ty`. The values for `l1,l2,l3` are given in the diagram above. (HINT: draw the arm in the configuration where all the q's are 0!)

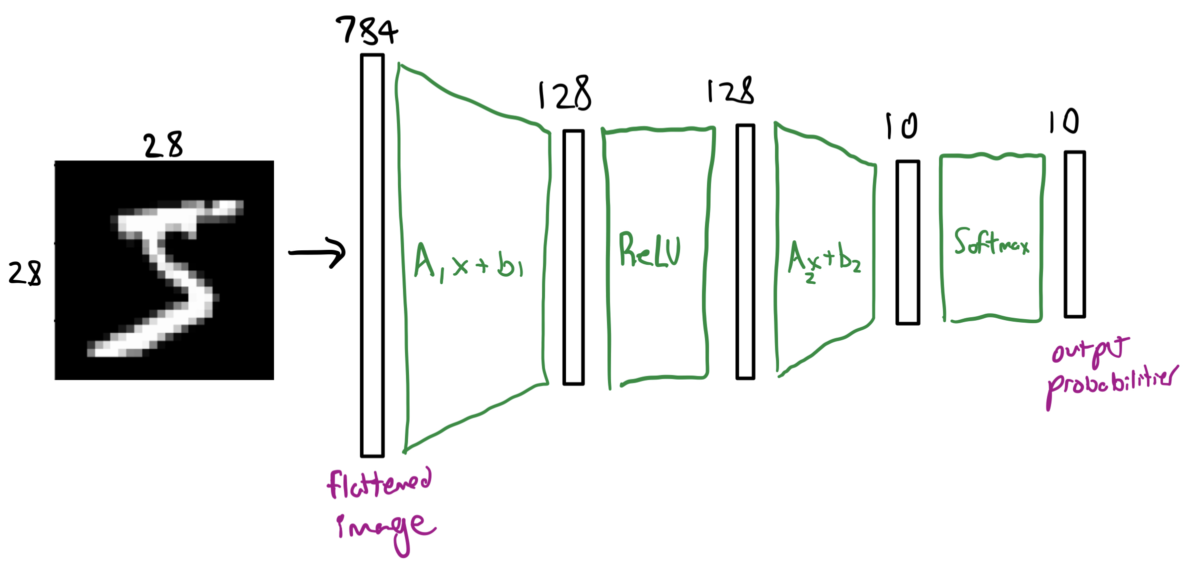
Next, use `transform_mat` inside `main` to compute the xy position of the final link, reading each line in the input file `joint_angles.txt` and printing the 2D position of the end-effector. Use a newline between each output. For example, if the input is `0 1.5707 0`, then the output should be

```
1
0.75
```

You can test your code with different inputs by editing the input file, or by running it in the terminal and supplying the name of another input file as an argument, for example: `./fk joint_angles1.txt`

Template file: `fk.cpp`

4. Neural Networks [8 points]: Many common neural networks can be represented as a series of simple matrix operations, such as matrix multiplication or element-wise maximum. Each of these individual operations is called a *layer*. In this problem you will implement a simple neural network for image classification. The input data is an image of handwritten digits (example below), flattened to a vector of size 784, and the output is 10 numbers which are the class probabilities. For example, if `probabilities[3]=0.2`, that would mean 20% confidence the input is the number `3`.



The architecture consists of four layers (green shapes in the diagram)

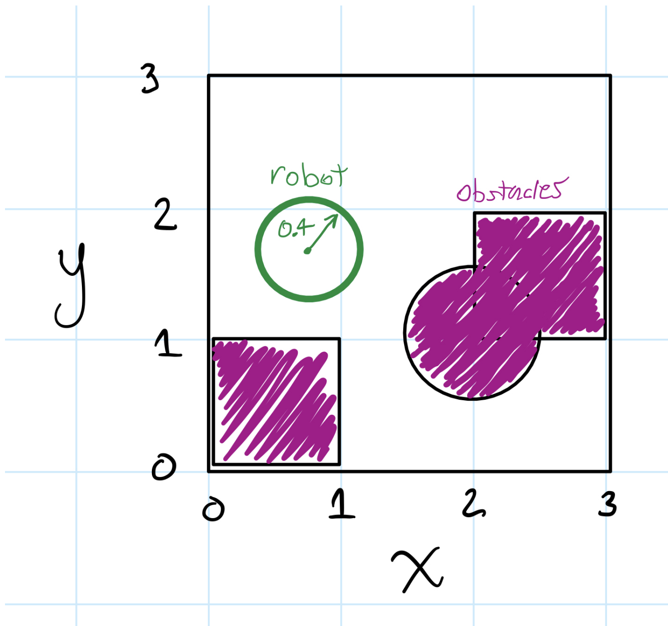
1. Linear layer, which computes `y=Ax+b`
2. ReLU, which computes the element-wise max with 0: `y= max (x,0)`
3. Linear layer
4. Softmax, which converts a vector x to a vector of class probabilities y, using the formula ($y_i = e^{x_i} / \sum_i e^{x_i}$). This ensures the class probabilities sum to 1.

The sizes are shown in the table below, and all matrices are already loaded for you in the template. You job is to finish implementing the class `Linear` and create and implement the classes for the `ReLU` and `Softmax` layers. Then in `main`, you then need to construct the layers and call them in the right order to produce the output `y` given the input `x`. The code should write the class probabilities to `output.csv` (already in the template for you). You can then run `python network/viz_outputs.py` to visualize the 4 test images and their associated class labels. The predicted and actual class labels should match, and the confidences should be >0.99.

x	(784, 1)
A1	(128, 784)
A2	(10, 128)
b1	(128, 1)
b2	(10, 1)
y (your output!)	(10, 1)

Template file: `network.cpp`

5. Collision Checking [14 points]: You will write a collision checker for a disc-shaped robot in a world made up of axis-aligned rectangles and disc-shaped obstacles (see image below for an example). Your job is to implement the `check_collision` and `contains` methods which override the methods in the base class, the `check_intersection_with_edge` function, and the `check_collisions` function. The provided `main` function in `collision.cpp` will then construct a world using these shapes, and check whether a disc-shaped robot is in collision at various positions and with various radii. The position and radius are read from the input text file (e.g. `robot_positions.txt`), where each line is the `x y radius` separated by spaces.



While it is possible to define a more general collision check between arbitrary shapes, it is much faster to define more specific collision checks for certain simple shapes. This is a common pattern used in physics engines and collision checkers. The shape-specific `check_collision` routines should work as follows:

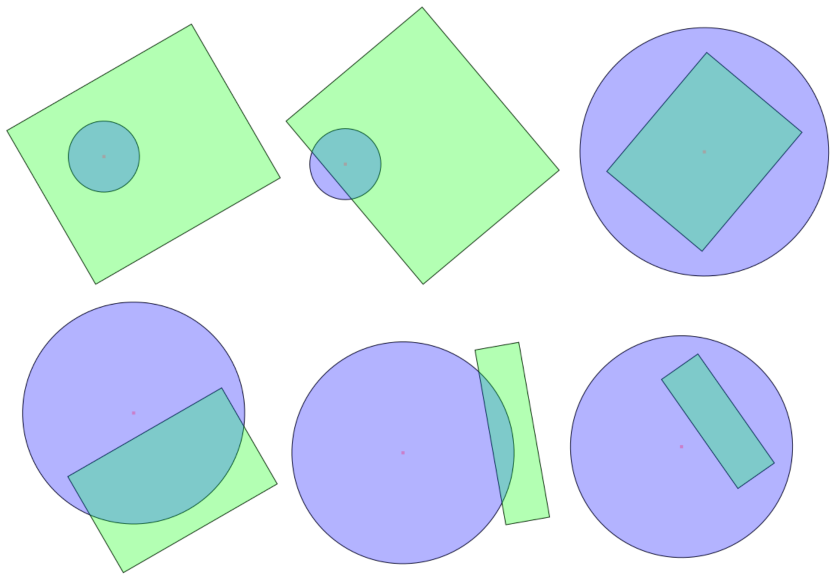
For `Disc` versus `Disc`:

- Compute the distance between the centers of the discs. If that distance is less than or equal to the sum of their radii, then return collision = true

For `Rectangle` versus `Disc`:

- Check whether the center of the disc is contained inside the rectangle. If so, return collision = true
- Otherwise, check whether any of the corner points of the rectangle are contained inside the disc, if so return collision = true
- Finally, check whether any of the rectangles edges intersect the disc by checking each edge for intersection with the disc. To check whether an edge (line segment) intersects a disc (circle), we attempt to find a point on the segment which also lies on the circle. If we can find such a point, then the circle and segment intersect. Please refer to the Lab 13 document for information on how to do this.

See the diagram below for some examples of how circles and rectangles may or may not intersect.



Credit: https://stackoverflow.com/a/402019

You can test your code with different inputs by running it in the terminal and supply the name of the input file as an argument, for example: `./collision robot_positions2.txt`. You can add more test cases by adding more lines to the text file, specifically positions where the robot is just barely touching or not touching the obstacles. This will help you pass the hidden test cases in the autograder. You can use the `viz_world.py` script to help you visualize the different test cases.

Input filename	Expected outputs
`robot_positions.txt`	1
`robot_positions2.txt`	1
`robot_positions3.txt`	0

Template File: `collision.h`