

INF 552 HW5

Teammates:

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Part 1.

Neural Network

Data Structure :

For convenience, we used 2 np.arrays to store image metadata and its label. And for the neural network structure, we used 2 np.arrays, W1 & W2, to represent the layers of the network, W1 is the weights of layer 1, the hidden layer, and W2 is the weights of layer 2, the output layer.

For generating initial random weights, we used np.random.uniform to generate the initial weights with values ranging from -0.01 to 0.01. And we followed the instructions to set the learning rate to 0.1.

For the training process, we used mini-batch stochastic gradient descent to update the weights. In this process, we used np.random.randint to decide the size of mini-batch, N and used np.random.choice to randomly choose N samples from the dataset for each epoch.

For the feed forward process, we used a np.array, X1, to denote the output of layer 1 and used X2, to denote the output of the network.

For the back propagation process, we would calculate the base case first, which is dW2, the derivative for the cost function with perspective to W2. $dW2 = X1.T * dZ2$.

And dZ2 is the derivative for cost function in perspective to Z2, Z2 is the input to layer 2.

$dZ2 = 2(Y_hat - Ys) * (Y_hat * (1 - Y_hat))$, Y_hat is the network output, Ys is the actual label.

We noticed that the sigmoid function in the HW instruction is different than the tanh function mentioned in the class, so the equation of dZ2 changed from $(1 - Y_hat * Y_hat)$ to $(Y_hat * (1 - Y_hat))$. Same as the dZ1.

Then we would calculate the dW1, the derivative for cost function with respect to W1, and W1 is the weights of layer 1.

$dW1 = dZ1 * X0.T$, where X0.T is the input data

$dZ1 = dZ2 * W2.T * (X1 * (1 - X1))$

After the calculation of $dW1$ & $dW2$, we now can update the $W1$ and $W2$. We used numpy to facilitate the above calculations.

$$W2 = W2 - \text{learn_rate} * dw2$$
$$W1 = W1 - \text{learn_rate} * dW1$$

After 1000 epochs, we can get our $W1$ and $W2$ to predict the test data.

Optimization:

When performing the matrix dot product and element-wise product, we use numpy functions to make the vector calculation faster instead of nested for-loops.

We added comments to describe how each variable is calculated making the program easy to understand.

Challenge:

1. In the initial couple of trials, we were stuck in getting accuracy of 77% where all the predicted values are very close to 0. Because about 77% of the testing data is not down, it gives the prediction by saying all pictures are not down, which is incorrect. After checking all the math and matrix calculation, we found an error where we updated $W2$ values before we calculated $dW1$ which requires old $W2$ values. This leads to the weird situation above.
2. We also fixed the initialized weights of the 2 neural network layers to be between -0.01 and 0.01, because we tried a lot of other methods to set up the initial weights and range (-0.01 to 0.01) gives the best.
3. It took us a lot of effort to find the best accuracy by running the program for many times, each of which was about 30s.
4. We spent some time learning how to correctly read and dissect the PGM picture files.

Result:

Prediction:

Case1:

```
gestures/A/A_down_1.pgm: is DOWN
gestures/A/A_down_2.pgm: is DOWN
gestures/A/A_hold_1.pgm: is Not DOWN
gestures/A/A_hold_10.pgm: is Not DOWN
gestures/A/A_stop_1.pgm: is Not DOWN
gestures/A/A_stop_4.pgm: is Not DOWN
gestures/A/A_up_1.pgm: is Not DOWN
```

gestures/A/A_up_10.pgm: is Not DOWN
gestures/B/B_down_1.pgm: is DOWN
gestures/B/B_down_2.pgm: is Not DOWN
gestures/B/B_hold_1.pgm: is Not DOWN
gestures/B/B_hold_2.pgm: is Not DOWN
gestures/B/B_stop_1.pgm: is Not DOWN
gestures/B/B_stop_2.pgm: is Not DOWN
gestures/B/B_up_1.pgm: is Not DOWN
gestures/B/B_up_4.pgm: is Not DOWN
gestures/C/C_down_1.pgm: is DOWN
gestures/C/C_down_2.pgm: is DOWN
gestures/C/C_hold_1.pgm: is Not DOWN
gestures/C/C_hold_2.pgm: is Not DOWN
gestures/C/C_stop_2.pgm: is Not DOWN
gestures/C/C_stop_3.pgm: is Not DOWN
gestures/C/C_up_1.pgm: is Not DOWN
gestures/D/D_down_1.pgm: is Not DOWN
gestures/D/D_down_2.pgm: is Not DOWN
gestures/D/D_hold_1.pgm: is Not DOWN
gestures/D/D_hold_2.pgm: is Not DOWN
gestures/D/D_hold_6.pgm: is Not DOWN
gestures/D/D_stop_1.pgm: is Not DOWN
gestures/D/D_stop_2.pgm: is Not DOWN
gestures/D/D_up_1.pgm: is Not DOWN
gestures/D/D_up_3.pgm: is Not DOWN
gestures/E/E_down_1.pgm: is DOWN
gestures/E/E_hold_1.pgm: is Not DOWN
gestures/E/E_hold_5.pgm: is Not DOWN
gestures/E/E_stop_1.pgm: is Not DOWN
gestures/E/E_stop_2.pgm: is Not DOWN
gestures/E/E_up_1.pgm: is Not DOWN
gestures/E/E_up_2.pgm: is DOWN
gestures/F/F_down_1.pgm: is Not DOWN
gestures/F/F_down_4.pgm: is DOWN
gestures/F/F_hold_1.pgm: is Not DOWN
gestures/F/F_hold_2.pgm: is Not DOWN
gestures/F/F_stop_2.pgm: is Not DOWN
gestures/F/F_stop_5.pgm: is Not DOWN
gestures/G/G_down_2.pgm: is DOWN
gestures/G/G_down_3.pgm: is DOWN
gestures/G/G_hold_4.pgm: is Not DOWN
gestures/G/G_stop_2.pgm: is Not DOWN
gestures/G/G_stop_5.pgm: is Not DOWN
gestures/G/G_up_2.pgm: is DOWN

gestures/G/G_up_5.pgm: is Not DOWN
gestures/H/H_down_2.pgm: is Not DOWN
gestures/H/H_hold_10.pgm: is Not DOWN
gestures/H/H_hold_2.pgm: is Not DOWN
gestures/H/H_hold_5.pgm: is Not DOWN
gestures/H/H_stop_5.pgm: is Not DOWN
gestures/H/H_stop_6.pgm: is Not DOWN
gestures/H/H_up_5.pgm: is Not DOWN
gestures/I/I_hold_2.pgm: is Not DOWN
gestures/I/I_hold_5.pgm: is Not DOWN
gestures/I/I_down_3.pgm: is DOWN
gestures/I/I_stop_5.pgm: is Not DOWN
gestures/I/I_stop_6.pgm: is Not DOWN
gestures/I/I_up_2.pgm: is Not DOWN
gestures/I/I_up_3.pgm: is DOWN
gestures/J/J_down_5.pgm: is DOWN
gestures/J/J_down_6.pgm: is Not DOWN
gestures/J/J_hold_2.pgm: is Not DOWN
gestures/J/J_hold_3.pgm: is Not DOWN
gestures/J/J_stop_7.pgm: is Not DOWN
gestures/J/J_stop_8.pgm: is Not DOWN
gestures/J/J_up_1.pgm: is Not DOWN
gestures/J/J_up_2.pgm: is Not DOWN
gestures/K/K_down_2.pgm: is DOWN
gestures/K/K_down_3.pgm: is DOWN
gestures/K/K_hold_1.pgm: is Not DOWN
gestures/K/K_hold_2.pgm: is Not DOWN
gestures/K/K_hold_3.pgm: is Not DOWN
gestures/K/K_stop_1.pgm: is Not DOWN
gestures/K/K_stop_2.pgm: is Not DOWN
gestures/K/K_stop_1.pgm: is Not DOWN
gestures/K/K_stop_2.pgm: is Not DOWN

Accuracy: 0.891566265060241

Case 2:

gestures/A/A_down_1.pgm: is DOWN
gestures/A/A_down_2.pgm: is DOWN
gestures/A/A_hold_1.pgm: is Not DOWN
gestures/A/A_hold_10.pgm: is Not DOWN
gestures/A/A_stop_1.pgm: is Not DOWN
gestures/A/A_stop_4.pgm: is Not DOWN
gestures/A/A_up_1.pgm: is Not DOWN
gestures/A/A_up_10.pgm: is Not DOWN

gestures/B/B_down_1.pgm: is DOWN
gestures/B/B_down_2.pgm: is Not DOWN
gestures/B/B_hold_1.pgm: is Not DOWN
gestures/B/B_hold_2.pgm: is Not DOWN
gestures/B/B_stop_1.pgm: is Not DOWN
gestures/B/B_stop_2.pgm: is Not DOWN
gestures/B/B_up_1.pgm: is Not DOWN
gestures/B/B_up_4.pgm: is Not DOWN
gestures/C/C_down_1.pgm: is DOWN
gestures/C/C_down_2.pgm: is DOWN
gestures/C/C_hold_1.pgm: is Not DOWN
gestures/C/C_hold_2.pgm: is Not DOWN
gestures/C/C_stop_2.pgm: is Not DOWN
gestures/C/C_stop_3.pgm: is Not DOWN
gestures/C/C_up_1.pgm: is Not DOWN
gestures/D/D_down_1.pgm: is Not DOWN
gestures/D/D_down_2.pgm: is Not DOWN
gestures/D/D_hold_1.pgm: is Not DOWN
gestures/D/D_hold_2.pgm: is Not DOWN
gestures/D/D_hold_6.pgm: is Not DOWN
gestures/D/D_stop_1.pgm: is Not DOWN
gestures/D/D_stop_2.pgm: is Not DOWN
gestures/D/D_up_1.pgm: is Not DOWN
gestures/D/D_up_3.pgm: is Not DOWN
gestures/E/E_down_1.pgm: is DOWN
gestures/E/E_hold_1.pgm: is Not DOWN
gestures/E/E_hold_5.pgm: is Not DOWN
gestures/E/E_stop_1.pgm: is Not DOWN
gestures/E/E_stop_2.pgm: is Not DOWN
gestures/E/E_up_1.pgm: is Not DOWN
gestures/E/E_up_2.pgm: is DOWN
gestures/F/F_down_1.pgm: is Not DOWN
gestures/F/F_down_4.pgm: is DOWN
gestures/F/F_hold_1.pgm: is Not DOWN
gestures/F/F_hold_2.pgm: is Not DOWN
gestures/F/F_stop_2.pgm: is Not DOWN
gestures/F/F_stop_5.pgm: is Not DOWN
gestures/G/G_down_2.pgm: is DOWN
gestures/G/G_down_3.pgm: is DOWN
gestures/G/G_hold_4.pgm: is Not DOWN
gestures/G/G_stop_2.pgm: is Not DOWN
gestures/G/G_stop_5.pgm: is Not DOWN
gestures/G/G_up_2.pgm: is DOWN
gestures/G/G_up_5.pgm: is Not DOWN

gestures/H/H_down_2.pgm: is DOWN
gestures/H/H_hold_10.pgm: is Not DOWN
gestures/H/H_hold_2.pgm: is Not DOWN
gestures/H/H_hold_5.pgm: is Not DOWN
gestures/H/H_stop_5.pgm: is Not DOWN
gestures/H/H_stop_6.pgm: is Not DOWN
gestures/H/H_up_5.pgm: is Not DOWN
gestures/I/I_hold_2.pgm: is Not DOWN
gestures/I/I_hold_5.pgm: is Not DOWN
gestures/I/I_down_3.pgm: is DOWN
gestures/I/I_stop_5.pgm: is Not DOWN
gestures/I/I_stop_6.pgm: is Not DOWN
gestures/I/I_up_2.pgm: is Not DOWN
gestures/I/I_up_3.pgm: is Not DOWN
gestures/J/J_down_5.pgm: is DOWN
gestures/J/J_down_6.pgm: is Not DOWN
gestures/J/J_hold_2.pgm: is Not DOWN
gestures/J/J_hold_3.pgm: is Not DOWN
gestures/J/J_stop_7.pgm: is Not DOWN
gestures/J/J_stop_8.pgm: is Not DOWN
gestures/J/J_up_1.pgm: is Not DOWN
gestures/J/J_up_2.pgm: is Not DOWN
gestures/K/K_down_2.pgm: is DOWN
gestures/K/K_down_3.pgm: is DOWN
gestures/K/K_hold_1.pgm: is Not DOWN
gestures/K/K_hold_2.pgm: is Not DOWN
gestures/K/K_hold_3.pgm: is Not DOWN
gestures/K/K_stop_1.pgm: is Not DOWN
gestures/K/K_stop_2.pgm: is Not DOWN
gestures/K/K_stop_1.pgm: is Not DOWN
gestures/K/K_stop_2.pgm: is Not DOWN

Accuracy: 0.9156626506024096

Part 2.

Library used: From sklearn.neural_network import MLPClassifier

Result:

gestures/A/A_down_1.pgm: is DOWN check

gestures/A/A_down_2.pgm: is DOWN check
gestures/A/A_hold_1.pgm: is Not DOWN check
gestures/A/A_hold_10.pgm: is Not DOWN check
gestures/A/A_stop_1.pgm: is Not DOWN check
gestures/A/A_stop_4.pgm: is Not DOWN check
gestures/A/A_up_1.pgm: is Not DOWN check
gestures/A/A_up_10.pgm: is Not DOWN check
gestures/B/B_down_1.pgm: is DOWN check
gestures/B/B_down_2.pgm: is Not DOWN
gestures/B/B_hold_1.pgm: is Not DOWN check
gestures/B/B_hold_2.pgm: is Not DOWN check
gestures/B/B_stop_1.pgm: is Not DOWN check
gestures/B/B_stop_2.pgm: is Not DOWN check
gestures/B/B_up_1.pgm: is Not DOWN check
gestures/B/B_up_4.pgm: is DOWN
gestures/C/C_down_1.pgm: is DOWN check
gestures/C/C_down_2.pgm: is DOWN check
gestures/C/C_hold_1.pgm: is Not DOWN check
gestures/C/C_hold_2.pgm: is Not DOWN check
gestures/C/C_stop_2.pgm: is Not DOWN check
gestures/C/C_stop_3.pgm: is Not DOWN check
gestures/C/C_up_1.pgm: is Not DOWN check
gestures/D/D_down_1.pgm: is Not DOWN
gestures/D/D_down_2.pgm: is Not DOWN
gestures/D/D_hold_1.pgm: is Not DOWN check
gestures/D/D_hold_2.pgm: is Not DOWN check
gestures/D/D_hold_6.pgm: is Not DOWN check
gestures/D/D_stop_1.pgm: is Not DOWN check
gestures/D/D_stop_2.pgm: is Not DOWN check
gestures/D/D_up_1.pgm: is Not DOWN check
gestures/D/D_up_3.pgm: is DOWN
gestures/E/E_down_1.pgm: is DOWN check
gestures/E/E_hold_1.pgm: is Not DOWN check
gestures/E/E_hold_5.pgm: is Not DOWN check
gestures/E/E_stop_1.pgm: is Not DOWN check
gestures/E/E_stop_2.pgm: is Not DOWN check
gestures/E/E_up_1.pgm: is Not DOWN check
gestures/E/E_up_2.pgm: is DOWN
gestures/F/F_down_1.pgm: is DOWN check
gestures/F/F_down_4.pgm: is DOWN check
gestures/F/F_hold_1.pgm: is Not DOWN check
gestures/F/F_hold_2.pgm: is Not DOWN check
gestures/F/F_stop_2.pgm: is Not DOWN check
gestures/F/F_stop_5.pgm: is Not DOWN check

gestures/G/G_down_2.pgm: is DOWN check
gestures/G/G_down_3.pgm: is DOWN check
gestures/G/G_hold_4.pgm: is Not DOWN check
gestures/G/G_stop_2.pgm: is Not DOWN check
gestures/G/G_stop_5.pgm: is Not DOWN check
gestures/G/G_up_2.pgm: is DOWN
gestures/G/G_up_5.pgm: is Not DOWN check
gestures/H/H_down_2.pgm: is Not DOWN
gestures/H/H_hold_10.pgm: is Not DOWN check
gestures/H/H_hold_2.pgm: is Not DOWN check
gestures/H/H_hold_5.pgm: is Not DOWN check
gestures/H/H_stop_5.pgm: is Not DOWN check
gestures/H/H_stop_6.pgm: is Not DOWN check
gestures/H/H_up_5.pgm: is Not DOWN check
gestures/I/I_hold_2.pgm: is Not DOWN check
gestures/I/I_hold_5.pgm: is Not DOWN check
gestures/I/I_down_3.pgm: is DOWN check
gestures/I/I_stop_5.pgm: is Not DOWN check
gestures/I/I_stop_6.pgm: is Not DOWN check
gestures/I/I_up_2.pgm: is Not DOWN check
gestures/I/I_up_3.pgm: is Not DOWN check
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gestures/J/J_down_6.pgm: is Not DOWN
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gestures/J/J_hold_3.pgm: is Not DOWN check
gestures/J/J_stop_7.pgm: is Not DOWN check
gestures/J/J_stop_8.pgm: is Not DOWN check
gestures/J/J_up_1.pgm: is Not DOWN check
gestures/J/J_up_2.pgm: is Not DOWN check
gestures/K/K_down_2.pgm: is DOWN check
gestures/K/K_down_3.pgm: is DOWN check
gestures/K/K_hold_1.pgm: is Not DOWN check
gestures/K/K_hold_2.pgm: is Not DOWN check
gestures/K/K_hold_3.pgm: is Not DOWN check
gestures/K/K_stop_1.pgm: is Not DOWN check
gestures/K/K_stop_2.pgm: is Not DOWN check
gestures/K/K_stop_1.pgm: is Not DOWN check
gestures/K/K_stop_2.pgm: is Not DOWN check

Accuracy for test:
0.891566265060241

Result of using **Limited-memory BFGS** for MLPClassifier:

gestures/A/A_down_1.pgm: is DOWN check
gestures/A/A_down_2.pgm: is DOWN check
gestures/A/A_hold_1.pgm: is Not DOWN check
gestures/A/A_hold_10.pgm: is Not DOWN check
gestures/A/A_stop_1.pgm: is Not DOWN check
gestures/A/A_stop_4.pgm: is Not DOWN check
gestures/A/A_up_1.pgm: is Not DOWN check
gestures/A/A_up_10.pgm: is Not DOWN check
gestures/B/B_down_1.pgm: is DOWN check
gestures/B/B_down_2.pgm: is Not DOWN
gestures/B/B_hold_1.pgm: is Not DOWN check
gestures/B/B_hold_2.pgm: is Not DOWN check
gestures/B/B_stop_1.pgm: is Not DOWN check
gestures/B/B_stop_2.pgm: is Not DOWN check
gestures/B/B_up_1.pgm: is Not DOWN check
gestures/B/B_up_4.pgm: is Not DOWN check
gestures/C/C_down_1.pgm: is DOWN check
gestures/C/C_down_2.pgm: is DOWN check
gestures/C/C_hold_1.pgm: is Not DOWN check
gestures/C/C_hold_2.pgm: is Not DOWN check
gestures/C/C_stop_2.pgm: is Not DOWN check
gestures/C/C_stop_3.pgm: is Not DOWN check
gestures/C/C_up_1.pgm: is Not DOWN check
gestures/D/D_down_1.pgm: is Not DOWN
gestures/D/D_down_2.pgm: is Not DOWN
gestures/D/D_hold_1.pgm: is Not DOWN check
gestures/D/D_hold_2.pgm: is Not DOWN check
gestures/D/D_hold_6.pgm: is Not DOWN check
gestures/D/D_stop_1.pgm: is Not DOWN check
gestures/D/D_stop_2.pgm: is Not DOWN check
gestures/D/D_up_1.pgm: is Not DOWN check
gestures/D/D_up_3.pgm: is Not DOWN check
gestures/E/E_down_1.pgm: is DOWN check
gestures/E/E_hold_1.pgm: is Not DOWN check
gestures/E/E_hold_5.pgm: is Not DOWN check
gestures/E/E_stop_1.pgm: is Not DOWN check
gestures/E/E_stop_2.pgm: is Not DOWN check
gestures/E/E_up_1.pgm: is Not DOWN check
gestures/E/E_up_2.pgm: is DOWN
gestures/F/F_down_1.pgm: is DOWN check
gestures/F/F_down_4.pgm: is DOWN check
gestures/F/F_hold_1.pgm: is Not DOWN check
gestures/F/F_hold_2.pgm: is Not DOWN check
gestures/F/F_stop_2.pgm: is Not DOWN check

gestures/F/F_stop_5.pgm: is Not DOWN check
gestures/G/G_down_2.pgm: is DOWN check
gestures/G/G_down_3.pgm: is DOWN check
gestures/G/G_hold_4.pgm: is Not DOWN check
gestures/G/G_stop_2.pgm: is Not DOWN check
gestures/G/G_stop_5.pgm: is Not DOWN check
gestures/G/G_up_2.pgm: is Not DOWN check
gestures/G/G_up_5.pgm: is Not DOWN check
gestures/H/H_down_2.pgm: is Not DOWN
gestures/H/H_hold_10.pgm: is Not DOWN check
gestures/H/H_hold_2.pgm: is Not DOWN check
gestures/H/H_hold_5.pgm: is Not DOWN check
gestures/H/H_stop_5.pgm: is Not DOWN check
gestures/H/H_stop_6.pgm: is Not DOWN check
gestures/H/H_up_5.pgm: is Not DOWN check
gestures/I/I_hold_2.pgm: is Not DOWN check
gestures/I/I_hold_5.pgm: is Not DOWN check
gestures/I/I_down_3.pgm: is DOWN check
gestures/I/I_stop_5.pgm: is Not DOWN check
gestures/I/I_stop_6.pgm: is Not DOWN check
gestures/I/I_up_2.pgm: is Not DOWN check
gestures/I/I_up_3.pgm: is Not DOWN check
gestures/J/J_down_5.pgm: is DOWN check
gestures/J/J_down_6.pgm: is DOWN check
gestures/J/J_hold_2.pgm: is Not DOWN check
gestures/J/J_hold_3.pgm: is Not DOWN check
gestures/J/J_stop_7.pgm: is Not DOWN check
gestures/J/J_stop_8.pgm: is Not DOWN check
gestures/J/J_up_1.pgm: is Not DOWN check
gestures/J/J_up_2.pgm: is Not DOWN check
gestures/K/K_down_2.pgm: is DOWN check
gestures/K/K_down_3.pgm: is DOWN check
gestures/K/K_hold_1.pgm: is Not DOWN check
gestures/K/K_hold_2.pgm: is Not DOWN check
gestures/K/K_hold_3.pgm: is Not DOWN check
gestures/K/K_stop_1.pgm: is Not DOWN check
gestures/K/K_stop_2.pgm: is Not DOWN check
gestures/K/K_stop_1.pgm: is Not DOWN check
gestures/K/K_stop_2.pgm: is Not DOWN check

Accuracy for test:
0.9397590361445783

Summary:

The MLPClassifier is fairly simple to implement and it produces similar prediction accuracy under the same constraints as our self-implemented Neural Network.

Although most of the time the accuracy is around 89%, both the sklearn library and our own Neural Network will sometimes give different prediction accuracy. We believe the reason is that we run into local optimal solutions and it depends on our initial weights setup condition.

Interestingly, the sklearn document for MLPClassifier shows an optimizer for the relatively small scale of data size, like our homework. Instead of stochastic gradient descent, it suggests using **Limited-memory BFGS** in the family of quasi-Newton methods. As we tried using it, the result boosted up to be around 93%.

Part 3. Application of Neural Network

Neural Network has many branches, like GNN, CNN, RNN. We are very interested in GNN. So, we searched for the application of Graph Neural Network. Traffic jams are a big problem now. Accurately predicting traffic speed, traffic volume and road density in the transportation network is essential in route planning and flow control. A graph-based spatio-temporal neural network method is used to solve these problems. The input of the model is a spatiotemporal graph. In this spatiotemporal graph, nodes are represented by sensors placed on the road, edges are represented by the distance of pairs of nodes above the threshold. Each node contains a time series as a feature. The goal is to predict the average speed of a road in a time interval.

[1] Zhonghan Wu, Shirui Pan etc, "A Comprehensive Survey on Graph Neural Networks", IEEE, 24 March 2020

Individual contribution:

Ziqiao Gao: Optimize, implement and debug the Neural Network algorithm for part 1

He Chang: Optimize, implement and debug the Neural Network algorithm for part 1

Fanlin Qin: Research online and use the open source python library to implement Neural Network algorithm applications and complete part 2&3.