Project : Face and Digit Classification

Deadline: May 5^{th}, 11:55pm.
Perfect score: 100.

Project Instructions:

Teams: Assignments should be completed by teams of up to four students. You can work on this assignment individually if you prefer. No additional credit will be given for students that complete an assignment individually. Make sure to write the name and RUID of every member of your group on your submitted report.

Submission Rules: Submit your reports electronically as a PDF document through Canvas (`canvas.rutgers.edu`). For programming questions, you need to also submit a compressed file via Canvas, which contains your code. Do not submit Word documents, raw text, or hardcopies etc. Make sure to generate and submit a PDF instead. Each team of students should submit only a single copy of their solutions and indicate all team members on their submission. Failure to follow these rules will result in lower grade for this assignment.

Program Demonstrations: You will need to demonstrate your program to the TAs on a date after the deadline. The schedule will be coordinated by the TAs. During the demonstration you have to use the file submitted on Canvas and execute it on your personal computer. You will also be asked to describe the architecture of your implementation and key algorithmic aspects of the project. You need to make sure that you are able to complete the demonstration and answer the TAs' questions within the allotted 10 minutes of time for each team. If your program is not directly running on the computer you are using and you have to spend time to configure your computer, this counts against your allotted time.

Late Submissions: No late submission is allowed. 0 points for late assignments.

Precision: Try to be precise. Have in mind that you are trying to convince a very skeptical reader (and computer scientists are the worst kind...) that your answers are correct.

Collusion, Plagiarism, etc.: Each team must prepare its solutions independently from other teams, i.e., without using common notes, code or worksheets with other students or trying to solve problems in collaboration with other teams. You must indicate any external sources you have used in the preparation of your solution. Do not plagiarize online sources and in general make sure you do not violate any of the academic standards of the department or the university. Failure to follow these rules may result in failure in the course.

Project Description:

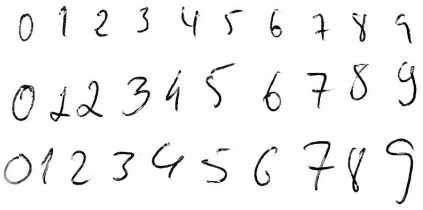
Acknowledgement: This project is based on the one created by Dan Klein and John DeNero that was given as part of the programming assignments of Berkeley's CS188 course.

In this project, you will design two classifiers: a three-layer neural network and a perceptron. You will test your classifiers on two image data sets: a set of scanned handwritten digit images and a set of face images in which edges have already been detected. Even with simple features, your classifiers will be able to do quite well on these tasks when given enough training data.

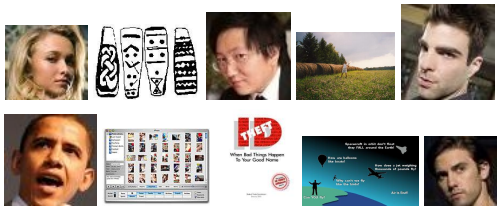
Optical character recognition (OCR) is the task of extracting text from image sources. The first data set on which you will run your classifiers is a collection of handwritten numerical digits (0-9). This is a very commercially useful technology, similar to the technique used by the US post office to route mail by zip codes. There are systems that can perform with over 99% classification accuracy (see LeNet-5 for an example system in action).

Face detection is the task of localizing faces within video or still images. The faces can be at any location and vary in size. There are many applications for face detection, including human computer interaction and surveillance. You will attempt a simplified face detection task in which your system is presented with an image that has been pre-processed by an edge detection algorithm. The task is to determine whether the edge image is a face or not.

Please refer to
`https://ai.berkeley.edu/classification.html` for basic functions in Python that you can borrow for this project.
Data: http://rl.cs.rutgers.edu/fall2019/data.zip



Which Digit?



Which are Faces?

Which Digit?

Face or not face?

Figure 1: Examples of the data points in the data set.

What you should do:

1. Implement the following for detecting faces and classifying digits:
   (a) The Perceptron algorithm
   (b) A three-layer Neural Network (input layer, hidden layer 1, hidden layer 2, output) using your own implementation of the forward pass, back-propagation, and weight update (check the slides)
   (c) A three-layer Neural Network (input layer, hidden layer 1, hidden layer 2, output) using the PyTorch library
2. Train the algorithms on the part of the data set that is reserved for training. First, use only 10% of the data points that are reserved for training, then 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and finally 100%. All the results should a function of the number of data points used for training.
3. Compare the performances of the two algorithms using the part of the data set that is reserved for testing, and report:
   - The time needed for training as a function of the number of data points used for training.
   - The prediction error (and standard deviation) as a function of the number of data points used for training.
4. Write a report describing the implemented algorithms and discussing the results and the learned lessons.

Please keep in mind that:

- You can use existing libraries (for loading files, low-level vector-matrix operations, etc.), but not for the training and prediction algorithms. You should implement these algorithms yourself, from scratch. The only exception is for the third part (c), where you are asked to use PyTorch.
- It's OK to share ideas, but not code or writing.
- Part of your score will depend on the accuracy of the predictions made by your program.
- Your algorithm should not look at the testing data before the training is over. If you use any testing data point for training, that would be considered as cheating.

Additional information:

- You are allowed to use any external resources you like, including the code on the Berkeley page. The only things I want you to implement by yourselves are the core operations of neural networks and Perceptron (forward pass for prediction, error gradient back-propagation, and weight update).

- How will you be graded? a) Show the TAs that you correctly implemented and understood neural network and Perceptron, b) Show that the code runs without issues (reads an image from the test data file, and returns a predicted label), c) Write a short report describing what you did, how the different algorithms performed (time and accuracy), and how did they improve as you used more and more of the training data (10%, 20%, ..., 100%).

- There is no standard definition of "good enough" here. Typically, if you have less than 70% accuracy even when you use 100% of your training data then that means that you could do a better job on the features or that something was wrong. Once you hit that barrier of 70%, don't spend more time on the algorithm.

- Regarding the features, don't spend too much time on designing complicated features that require a lot of coding. You would be surprised that the simplest features could be great predictors. For instance, you could just use the pixels directly as features (i.e. one binary feature per pixel in the image).

- I am not a big fun of rigid structure, because it kills creativity and the spirit of taking initiatives. So, anything I didn't say or specify is open to your own interpretation and I wouldn't tell you that you did it wrong. For instance, I didn't tell you how to write the report (except for the learning curves I expect to see), so write whatever you think is a decent report that you would be proud of. I didn't say how to read the text files into images, but you could easily figure out the size of each image in the files and parse the files accordingly.

- How to compute the average prediction error (or accuracy) and its standard deviation? What we want is a metric for how consistent our prediction accuracy will be if we use a certain number of training points. Thus, we need to vary which training points are used and see the spread of results. The following pseudocode would accomplish this:
  For i=1:5 (you can use more iterations, if time permits)
  Train on 10% of randomly selected data points
  Test on test data and save the accuracy in acc[i]
  End
  Return mean(acc) and std(acc).
  Repeat the same for 20%, 30%, etc.
  You may find the random module in Python to be especially convenient in choosing your random samples. Please let us know if you have any questions.

Have fun!