Computational perception

Homework 3

Neural Code of V1 neurons

Due date: November 2. 11.59 p.m. Credit: 13 points

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Overview

In the last sixty years, V1 neurons have traditionally been characterized to exhibit orientation tuning and mathematically modeled by Gabor filters. According to Hubel and Wiesel, there are three types of cells: simple, complex, and hypercomplex cells. While simple and complex cells are bar and edge detectors, hypercomplex cells are more complex in nature, but over the years, hypercomplex cells have been caricatured into neurons simply with end-stopping properties, i.e., the neuron's responses will decrease when the bar in the stimulus is larger than the receptive field of the neuron. However, the representations and processing of the V1 neurons remain controversial even today.

Deep learning (convolutional neural network) provides a state-of-the-art approach for characterizing the neurons. In this assignment, you are given a CNN model of 302 V1 neurons learned from the 2-photon calcium imaging data obtained by our Peking University collaborators. This model can potentially be considered an in-silico model of V1 neurons allowing us to perform experiments on them to understand their codes based on individual and population levels. In this assignment, we will investigate (1) to what extent the CNN models characterize the neurons well, (2) the features that the neurons are tuned to at the individual level, (3) what these neurons actually detect in images. There are many questions we can ask and are still asking. That is something you can explore in the Free Exploration part of the assignment.

Notations

1. Please read the "Notations" part in the Notebook carefully.
2. Model input size should be an image with width 50 and height 50.
3. Model is trained by images with pixel values ranging from 0 to 1. Be sure to normalize the pixel value of your input image from 0 to 1. Here, we offer a code that can simply normalize an image's pixel range from 0 to 1 by using (x-x.min)/(x.max-x.min). Also, you can try other method to see what the result will be. See the function: GF.norm_to_1() in the "Notations" part of Notebook.
4. In the version of Colab that is free of charge notebooks can run for <u>at most 12 hours per day.</u> Please make full use of it. Turn off the page if you are not running any script.
5. For getting the response of a set of images, we offer you a function called: GF.get_model_rsp; Please study how to use the function in the "Notations" part of the notebook.
6. Selected cells with good performance or visualization: 2,3,11,26,37,39,55,57,77,82,121,235. This is the index you can directly define in the cell_num variable in the notebook.
7. For part 3, to run a new image and save response to the path, be sure to change the save name(which has the annotation after the line with "!! be sure to change this ").

Requirements

1. Start your homework early, please check all the stuff before you submit the homework. Submitting the writeup late will use your late days.
2. please read the notations in the notebook, also, you should read the <u>notations in the code block (start with #, this is very important for you to find the answers).</u>
3. Please save <u>all your results in the folder 'Results',</u> it is specified in the "import" block of the notebook, with the variable name of <u>"main_savepath"</u>; E.g. If you have a result, and you need to save to a folder name calls: "your_prefer_name"; Here is what you should do: <u>New_save_path=GF.mkdir(main_savepath,"your_prefer_name"),</u> then, you will have a directory path variable #New_save_path#, you can save all your results there.
4. Submit format: ①Please upload PDF writeup to Gradescope(don't need to assign pages); ②PDF writeup+code, pack in 1 zip file, with name Lastname_Firstname_HW#.zip, to Canvas; Also, in writeup and Jupyter notebook, you need to show: your name, your andrew ID, homework#.
5. Please create a new page for each Part of questions (do not need to create new pages for subpart questions).
6. For the code part, you have to start your code below the text "Your code starts here" in the notebook. Also, please specify Part 1, Part 2, etc.
7. Please use 11 font size for your normal text, and 1.15 paragraph spacing in your report.

Part 1. Tuning curves (3 points)

The CNN model is trained using the shared core model approach described in a 2017 NeurIPS paper.
http://bethgelab.org/media/publications/6942-neural-system-identification-for-large-populations-separating-what-and-where.pdf.

This model, instead of training one CNN for each neuron, trains all the neurons simultaneously using a "shared core," and the output of the shared core is then fully connected to each individual neuron's representation. This uses all the neurons' data to train the shared core, effectively multiplying the amount of data for training the neural network. On the other hand, it is possible that the neural network, in using the shared core, has to make a compromise among all the neurons and might not be able to tailor the network for an individual neuron.

The real V1 neurons were further tested with 1000 test images. This allows us to compare the tuning curve of each neuron with the predicted tuning curve of the neuron. Your first task is to evaluate how well the model can predict the responses of a set of 10 neurons to these 1000 images (Please do not use the sample neurons we gave you in the notebook, for the 10 neurons index, please see the **Notations** part).

1. We show you how to plot the "tuning curve" of a neuron, which is the sorted response of the neuron to the 1000 images, as well as the prediction of that neuron by the model. Use that to understand the data structure of the real neuron's response and the model neuron's response. Plot the tuning curves as well as the predictions of 10 neurons as a 2x5 plots array. Include it in your report. Remember to read the "Notations" part carefully in the notebook, we offer you a function called GF.get_model_rsp to help you to find the predicted response. (1 point)
2. Plot a 2D scatter plot with the x-axis indicating the responses of a true neuron to the different stimuli and the y-axis indicating the responses of the neuron's model to the corresponding stimuli. Figure out how to plot a scatter plot. Your task now is to compute the Pearson correlation between the model and the neuron, which provides a measure of the performance of the neuron. Print out a 2x5 array of these scatterplots of the 10 cells with the Pearson correlation inside each plot's title, or just include them with the plots in your writeup. (1 point)
3. Make some observations and discuss the above plots on the tuning curves, scatter plots, and Pearson correlation measures in your report. (1 point)

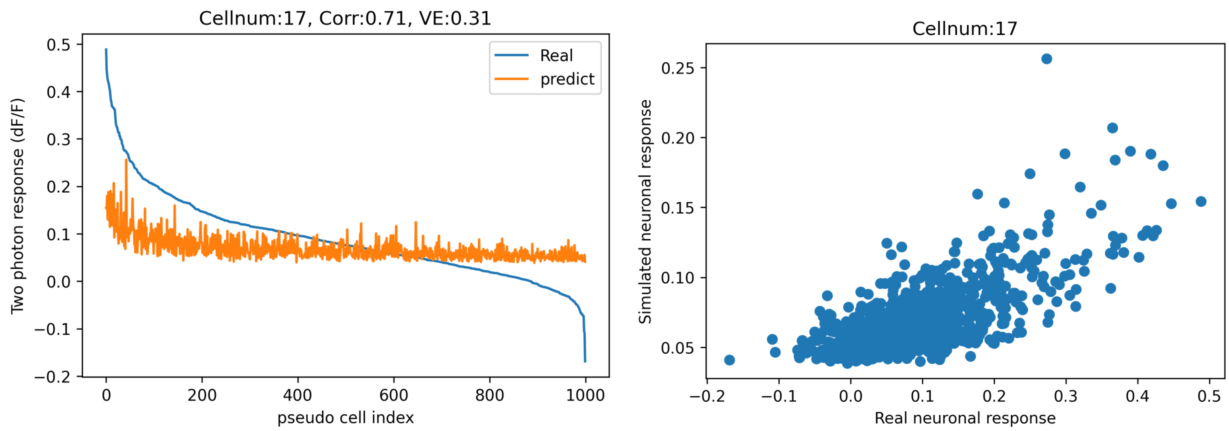

Figure 1. Left panel: tuning curve (blue) and its prediction (red) of neuron #17; Right panel. A scatter plot of the neuron's true response and the model's predicted response.

Part 2. Feature preferences (5 points)

1. Use the visualization code provided to visualize the stimulus that optimizes the response of each neuron of the 10 neurons. For each of the 10 neurons, identify the top 10 images that excite the neuron the most according to its tuning curve. Include only the top 10 images of three of these neurons of your choice in the report, indicating the index (number) of these neurons with these images. Explain why you choose these neurons – e.g., why their top stimuli or visualization are interesting. Are the 10 top images of each neuron consistent with the visualization? Include at least three observations with the figures in the report. For your convenience, you can save the top images into your defined folder, remember, you have to put all your results within the "Results" directory, you can use GF.mkdir with the "main_savepath" to do that. (1 point)

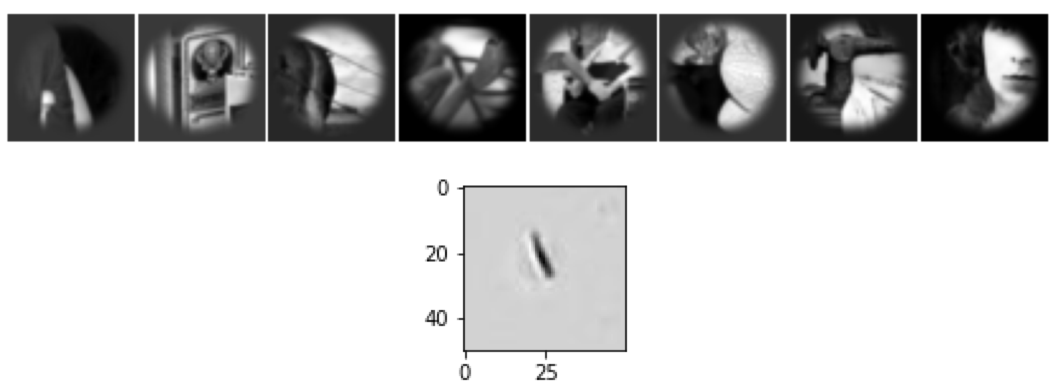

Figure 2. Example: Top 8 images of neuron #17 and its visualization

2. One approach to characterize the stimulus preference or tuning of the neurons is to compute the weighted sum of some top images, where the weight is the response of the neuron to that image. We provide the codes for computing the weighted sum of the top 10 images using the real neuron's responses as weights. Your task is to compute the weighted sum of the top 10 images using the model neuron's responses as weights. For three of your

chosen neurons, compare the models' weighted-sum images and the real neurons' weighted-sum images thus obtained. Include both results of your three chosen neurons in the writeup with some observations. Also, you need to see what is the simulated-neuron response for both visualization and the weighted sum image. Specify which one is larger and make some conclusions. (1 point)

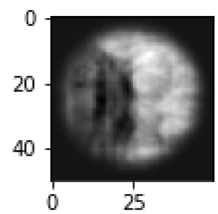

Figure 3. Example: Weighted sum of top 10 images.

3. Is this weighted sum method dependent on the number of top stimuli we used? Compare the weighted sum of the top 10 images, top 50 images, top 200 images, 500 images, and top 1000 images for the three neurons. Include your observations in the report. (1 point).
4. Another approach to characterize the stimulus preference is by presenting the neuron with a set of simple artificial stimuli. Pattern stimuli is a set of stimuli containing a set of parametric stimuli, including corners, angles, crosses, curves, rings, grating etc. Identify the top 10 stimuli for three of your chosen neurons. Compute the weighted sum of the top 10 or 20 pattern stimuli for three of your chosen neurons. What do you observe? Include at least three observations in the report with supporting evidence (1 point)
5. Compare and contrast the feature preference characterization using the weighted sum methods on natural images and pattern stimuli, as well as visualization. Include some supporting evidence, such as figures in your observations and discussion in the report. (1 point).

Part 3. Responses to Images (3 points)

1. Select at least three neurons that have good prediction performance from the designated ten neurons, as well as at least two other neurons (with good prediction performance) of your choice from the rest of the dataset. It is reasonable to assume the high-performance models reasonably capture the transfer function or receptive field properties of the neurons. Hence, it is reasonable to treat the models as neurons in-silico and investigate how these "neurons" respond to images. We show you an example of obtaining a neuron response to the Kanizsa triangle by "convolving" this neuron's CNN to the image (Please refer to the code how we did that). Investigate how these three chosen "neurons" respond to the Kanizsa triangle. Include at least three interesting observations with relevant figures in your report. (1 point)
2. Explore the artificial neurons in the data set and see how they respond to the Kanizsa triangle. Identify and discuss at least five distinct types of interesting responses you can observe and include figures on each of the five examples in the report. Remember, the

models chosen should have high prediction performance to be considered trustworthy (1 point).

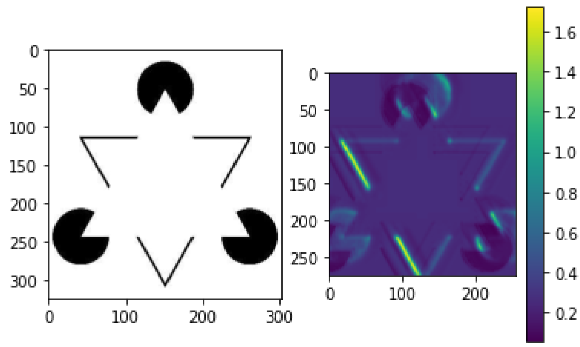

Figure 4. Example: Neuronal model “convolve” response to Kanizsa triangle

3. Select a real (natural) image of your choice and convolve it with the five representative neurons in Part 3.2. Do these neurons behave the way you expect based on their behaviors in Part 3.2? Include supporting figures in your discussion in the report. (1 point)

Part 4: Free Exploration (2 points, with up to 2 additional bonus points for the top 5 answers)

As in other problem sets, you are free to come up with your own question and spend at least two hours performing some free exploration. 2 points will be awarded for reasonable answers. You should ask a clear question with a hypothesis and describe your method for answering that question, as well as to provide the results and discussion. We expect your contents to be at least 1 page including supporting figures. Outstanding answers will be awarded up to 2 bonus points beyond the two standard points.