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Using TMS to Identify Links between Human Visual Cortex and Deep Neural Networks

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Overview

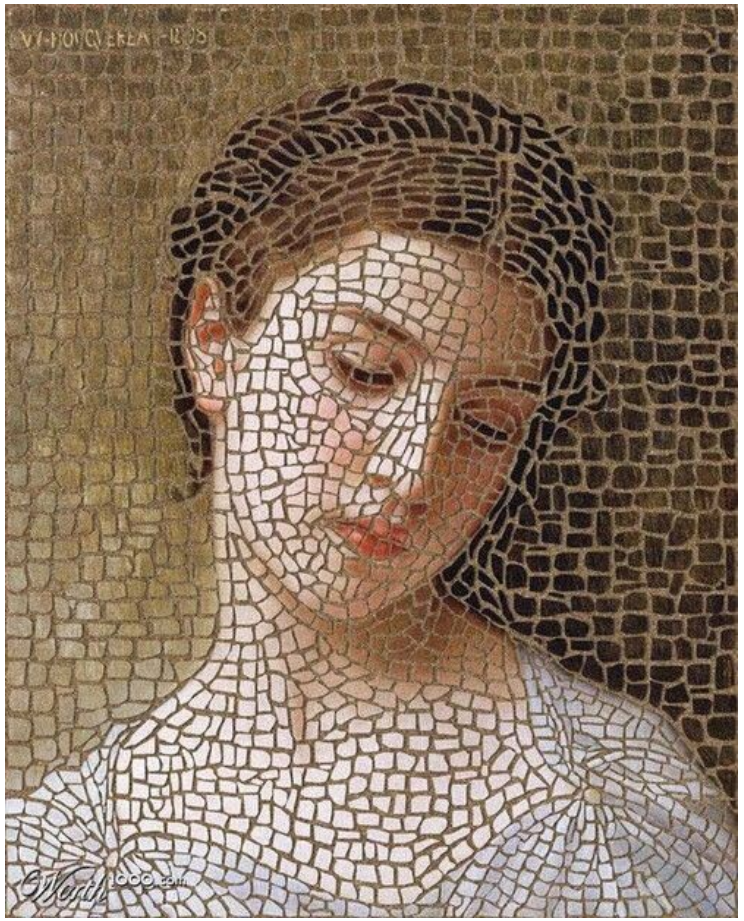
- Despite all the experimental data from fMRI, TMS and neurophysiology question how visual processing is performed in the brain still remains unclear
- Lately there were several assumptions that deep artificial neural networks might process information similarly to the human visual cortex
- In this study we will concentrate on early areas involved in face and object recognition in the occipital lobe
- We test this prediction by temporary disrupting this areas with online TMS in healthy participants during faces and objects classification task
- Then we introduce a DNN designed to predict (model) reaction times and accuracy for the same task

Holistic (configural) face processing

Numerous sources of evidence suggest that primate brains have special-purpose neural machinery that is selectively involved in the perception of faces.

That means that humans evolved brain regions that are reserved for face recognition and also that we look at faces differently as compared with another objects.

Holistic or configural strategy refers to our ability to see the face as a whole, taking into account the spacing between features as well as their shapes.



Face Inversion Effect (FIE)

Although most objects are more difficult to recognize upside down than right side up, face recognition is **disproportionately** impaired by inversion.

In many studies the effect has been used as a marker to indicate the involvement of specialized face recognition mechanisms.

Prosopagnosia

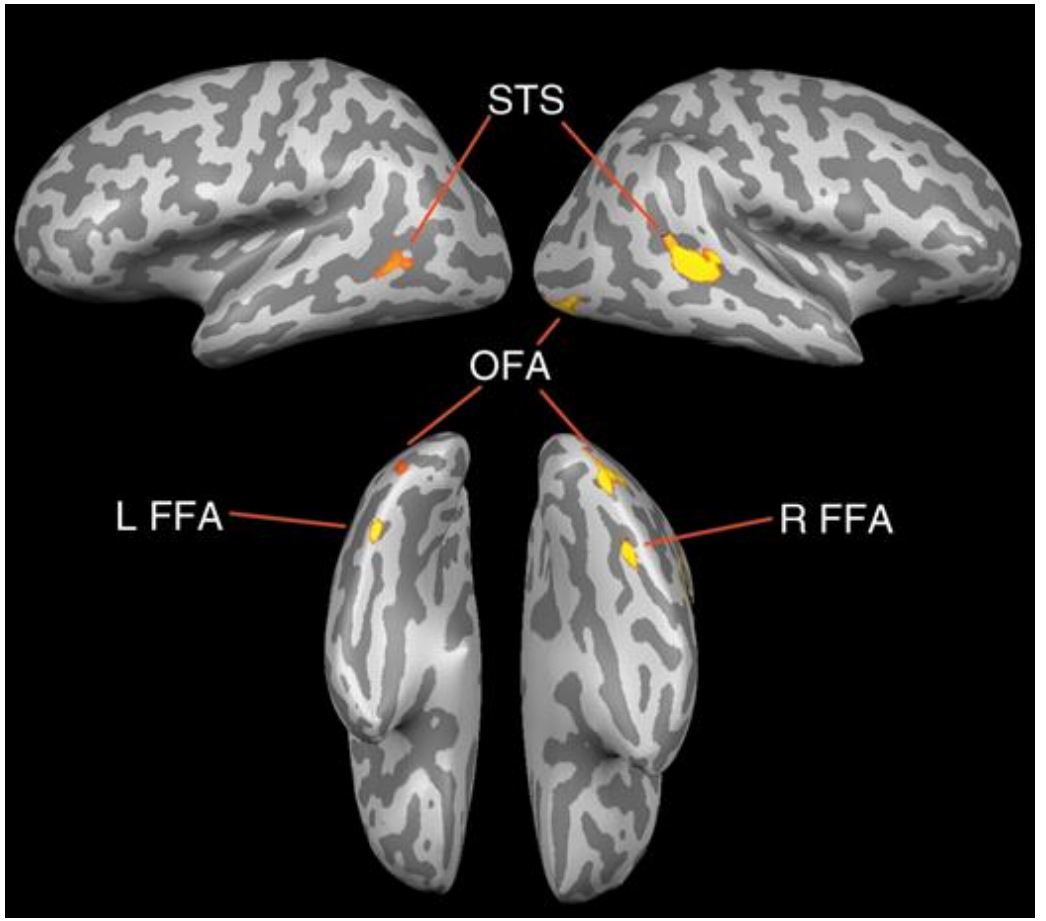
Prosopagnosia (face blindness) is a cognitive disorder that impairs face recognition

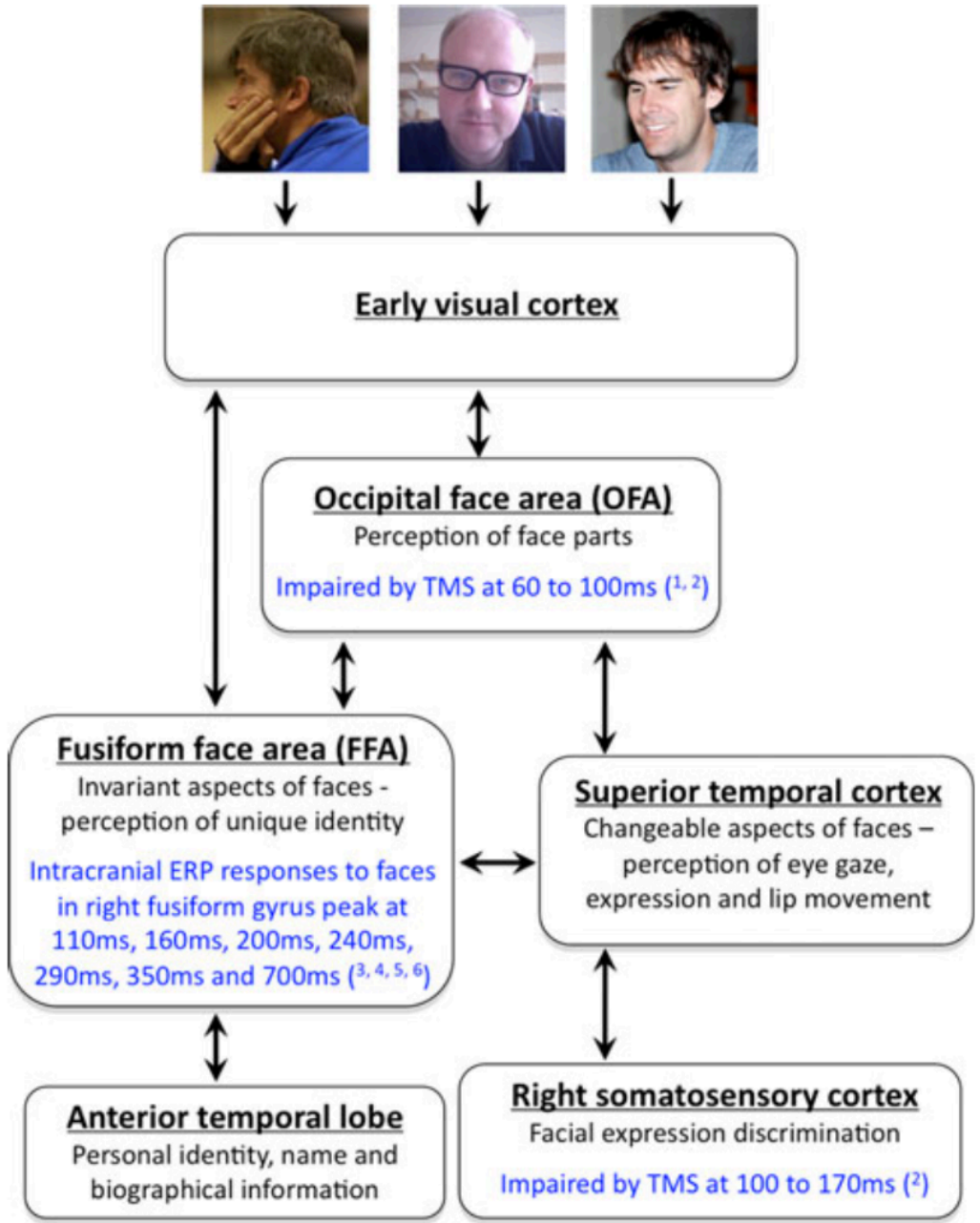
Prosopagnosic subjects paradoxically perform better at matching inverted faces than upright faces, the opposite of the normal "face inversion effect"

Face Perception Network

Visual processing in the brain is achieved hierarchically and face perception is not an exception.

Occipital Face Area is the first stage in a hierarchical face perception network in which it represents facial components prior to subsequent processing of increasingly complex facial features in higher face-selective cortical regions.



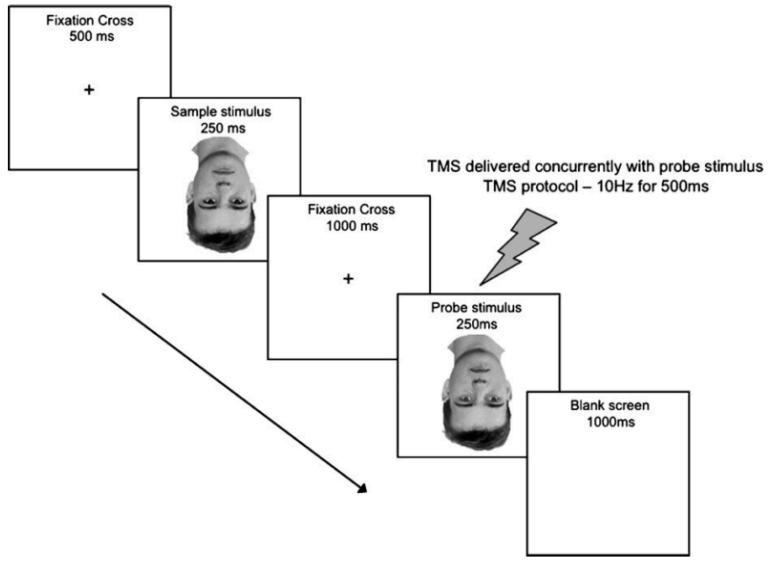

Early visual cortex
Occipital face area (OFA)
Perception of face parts
Impaired by TMS at 60 to 100ms (1, 2)
Fusiform face area (FFA)
Invariant aspects of faces - perception of unique identity
Intracranial ERP responses to faces in right fusiform gyrus peak at 110ms, 160ms, 200ms, 240ms, 290ms, 350ms and 700ms (3, 4, 5, 6)
Superior temporal cortex
Changeable aspects of faces – perception of eye gaze, expression and lip movement
Anterior temporal lobe
Personal identity, name and biographical information
Right somatosensory cortex
Facial expression discrimination
Impaired by TMS at 100 to 170ms (2)

Experiment Design

The experiment will use within-subject 4 x 3 design in which participants are going to discriminate between upright and inverted faces and houses while double pulse online TMS would be delivered over OFA, over object recognition area in the lateral occipital cortex (LO) or no TMS would be delivered

The task of the participant is to determine if the probe stimulus is different from sample stimulus

Fig. 1. Face stimuli were generated from an image of a male face. The two eyes and the mouth were replaced in each of the four faces by eyes and mouths from different faces but the rest of the face was constant.



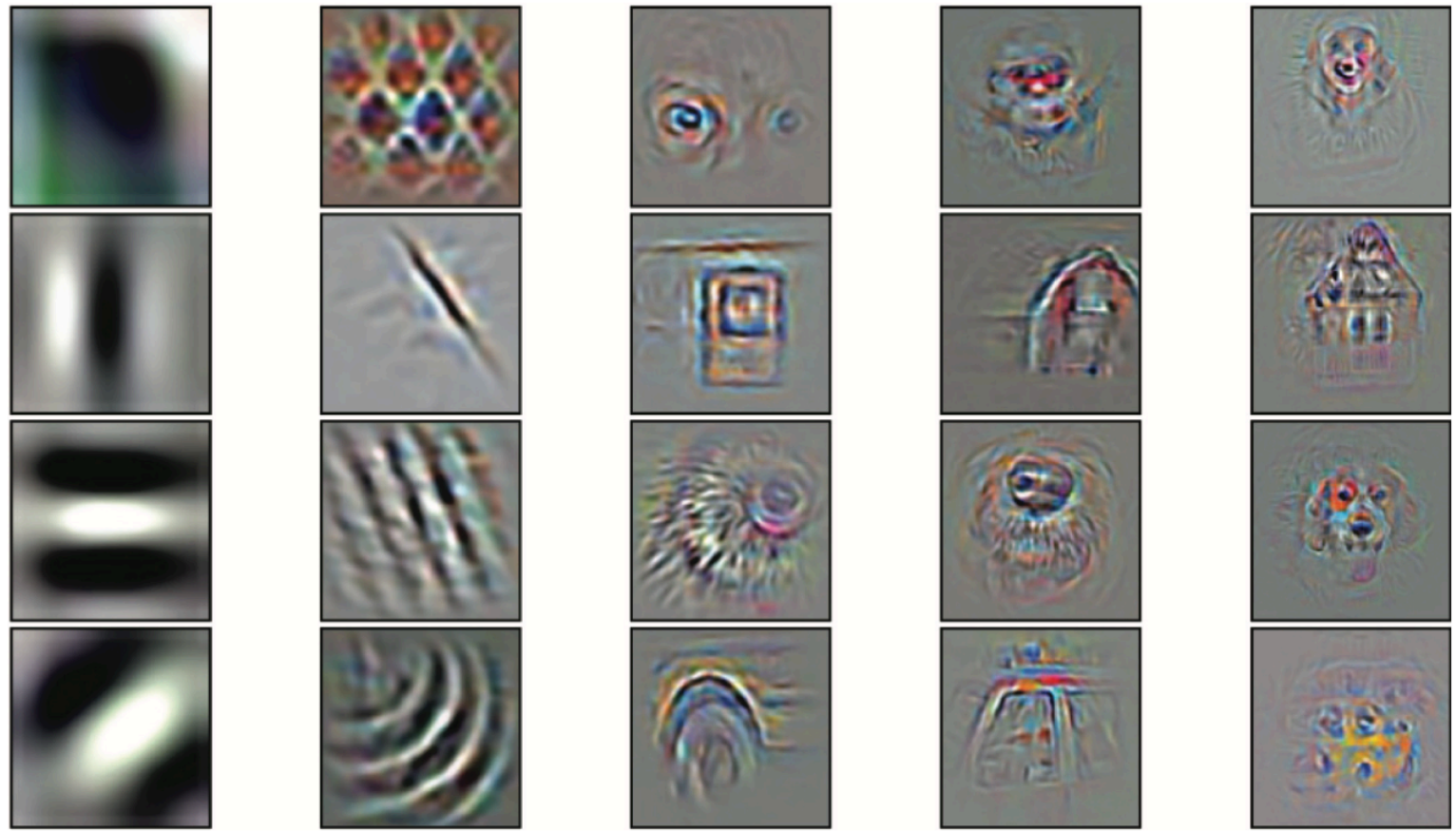
Expectations and further analysis

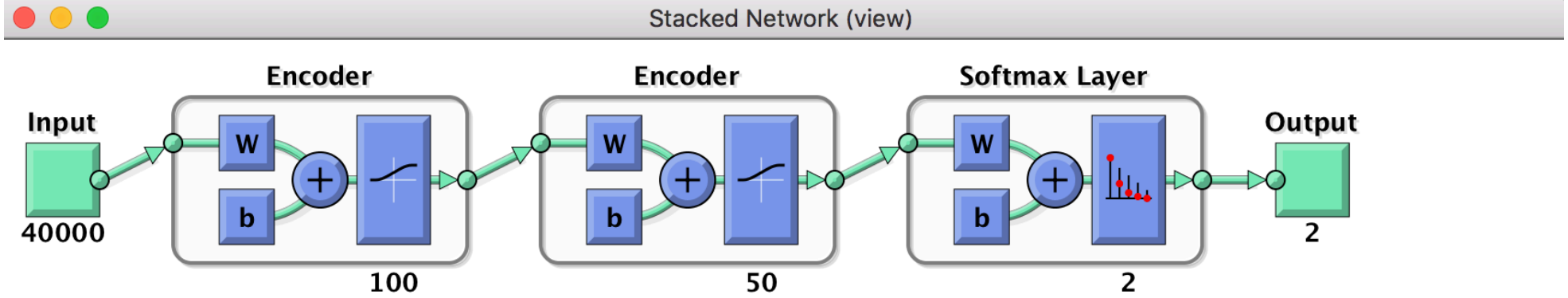
- Consisting with the results of previous studies we expect TMS over OFA to disrupt classification of both upright and inverted faces, but have no effect on either upright or inverted houses. In contrast, TMS over LO would disrupt performance of inverted faces, inverted and upright houses, but would have no effect on upright faces.
- Accuracy would be measured with d', an unbiased measure of discrimination performance, and reaction times would be measured with ms.
- A four-by-three repeated measures analysis of variance (ANOVA) with stimulus (face or house), orientation (upright or inverted) and TMS site (OFA, LO, no TMS) is going to be conducted.

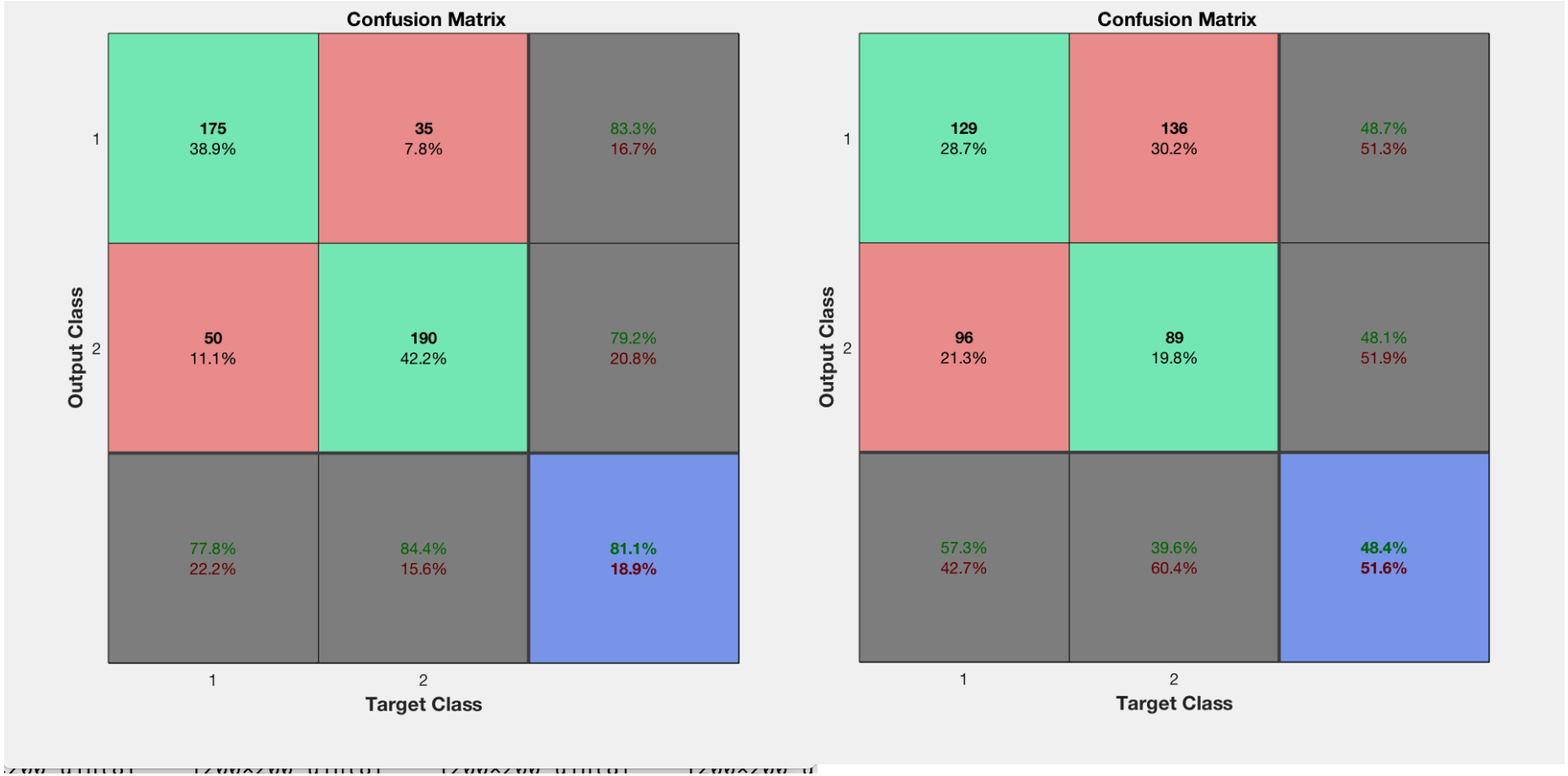
Deep Neural Network

- Artificial neural networks are inspired by the brain, and their computations could be implemented in biological neurons.
- Deep feedforward networks, which now dominate computer vision, take further inspiration from the architecture of the primate visual hierarchy. However, the current models are designed with engineering goals, not to model brain computations.
- Initial studies comparing internal representations between these models and primate brains find surprisingly similar representational spaces.

Primate visual system uses sequence of processing stages: detection of edges, primitive shapes, and moving up to gradually more complex visual shapes




Stacked Network (view)
Input
40000
Encoder
W
b
100
Encoder
W
b
50
Softmax Layer
W
b
2
Output
2


Confusion Matrix
Output Class
Target Class
1
2
175
38.9%
35
7.8%
83.3%
16.7%
50
11.1%
190
42.2%
79.2%
20.8%
77.8%
22.2%
84.4%
15.6%
81.1%
18.9%
Confusion Matrix
Output Class
Target Class
1
2
129
28.7%
136
30.2%
48.7%
51.3%
96
21.3%
89
19.8%
48.1%
51.9%
57.3%
42.7%
39.6%
60.4%
48.4%
51.6%

Next Steps

- Use Restricted Boltzmann Machines instead of Autoencoders to acquire Deep Belief Network and improve overall accuracy
- Substitute Softmax Layer for Leaky-Integrate-And-Fire Layer to achieve biological plausibility
- Perform an Experiment with TMS
- Feed accuracy and reaction times data into Neural Network
- Manually switch off connections in the network to adjust it with our experimental data

Sources

- Pitcher, D., Walsh, V., & Duchaine, B. (2011). The role of the occipital face area in the cortical face perception network. *Experimental Brain Research*, *209*(4), 481–493. https://doi.org/10.1007/s00221-011-2579-1
- Chao, L. L., Martin, A., & Haxby, J. V. (1999). Are face-responsive regions selective only for faces? *Neuroreport*, *10*(14), 2945–2950. https://doi.org/10.1097/00001756-199909290-00013
- Farah, M. J., Tanaka, J. W., & Drain, H. M. (1995). What causes the face inversion effect? *Journal of Experimental Psychology. Human Perception and Performance*, *21*(August), 628–634. https://doi.org/10.1037/0096-1523.21.3.628
- Farah, M. J., Wilson, K. D., Maxwell Drain, H., & Tanaka, J. R. (1995). The inverted face inversion effect in prosopagnosia: Evidence for mandatory, face-specific perceptual mechanisms. *Vision Research*, *35*(14), 2089–2093. https://doi.org/10.1016/0042-6989(94)00273-O
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *17*(11), 4302–11. https://doi.org/10.1098/Rstb.2006.1934
- Kriegeskorte, N. (n.d.). Deep Neural Networks : A New Framework for Modeling Biological Vision and Brain Information Processing. https://doi.org/10.1146/annurev-vision-082114-035447
- Pitcher, D., Duchaine, B., Walsh, V., Yovel, G., & Kanwisher, N. (2011). The role of lateral occipital face and object areas in the face inversion effect. *Neuropsychologia*, *49*(12), 3448–3453. https://doi.org/10.1016/j.neuropsychologia.2011.08.020
- Pitcher, D., Walsh, V., Yovel, G., & Duchaine, B. (2007). TMS Evidence for the Involvement of the Right Occipital Face Area in Early Face Processing. *Current Biology*, *17*(18), 1568–1573. https://doi.org/10.1016/j.cub.2007.07.063Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral face-inversion effect. *Current Biology*, *15*(24), 2256–2262. https://doi.org/10.1016/j.cub.2005.10.072
- Lee, H., & Ng, A. Y. (n.d.). Sparse deep belief net model for visual area V2, 1–8.
- Damasio, A. R., Damasio, H., Hoesen, G. W. Van, Ph, D., & Cecil, L. D. (1982). Prosopagnosia : Anatomic basis and behavioral mechanisms, (April), 331–342.
- Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(Pt 3), 305–327. https://doi.org/10.1111/j.2044-8295.1986.tb02199.x
- Fatahi, M., Ahmadi, M., Ahmadi, A., Shahsavari, M., & Devienne, P. (n.d.). Towards an Spiking Deep Belief Network for Face Recognition Application.
- Puce, A., Allison, T., Gore, J. C., & McCarthy, G. (1995). Face-Sensitive Regions in Human Extrastriate Cortex Studied By Functional Mri. *Journal of Neurophysiology*, *74*(3), 1192–1199.

Thank you for your attention!