Product Architecture and Design – Human Robot Interaction
H.E.A.R.T - Human Emotion Acquisition and Recognition Technology

For this exercise I propose the idea for a technology called as **H.E.A.R.T**. This is my attempt at an architecture for human emotion and state-of-mind detection by mapping brain waves.

Introduction: Human brain is a highly complex organ which on a higher level of explanation, is made up of billions of cells called neurons. These neurons form the communication system of the body as they send and receive information from all parts of the body. While communicating our neurons send out impulses in the form of waves. These waves tell us a bigger picture of what actions we are currently undertaking and what emotions we are currently feeling. Broadly there are four types of brain waves.

a. Delta - Sleeping, Dreaming
b. Theta - Drowsy, Meditative
c. Alpha - Relaxed
d. Beta - Alert and Working

For this project we will be focusing on the Beta waves emitted by the brain and map them onto emotions.

Traditional Brain Mapping: In a traditional setting, a skull cap embedded with sensors are placed on the head and electric impulses of the brain are captured. This process is called as Electroencephalogram, commonly called as an EEG. Once the EEG is done, the medical practitioners will generate a report of the signals and send it to an expert, usually a neurologist or a neurosurgeon who reads through the signals and interprets them.
While this is perfectly viable, we propose to make this more efficient and widely usable.

My proposed architecture:

Muse Headband >> maps brainwaves through EEG >> Send EEG signals into a Deep Learning algorithm for classification >> human emotion on screen.

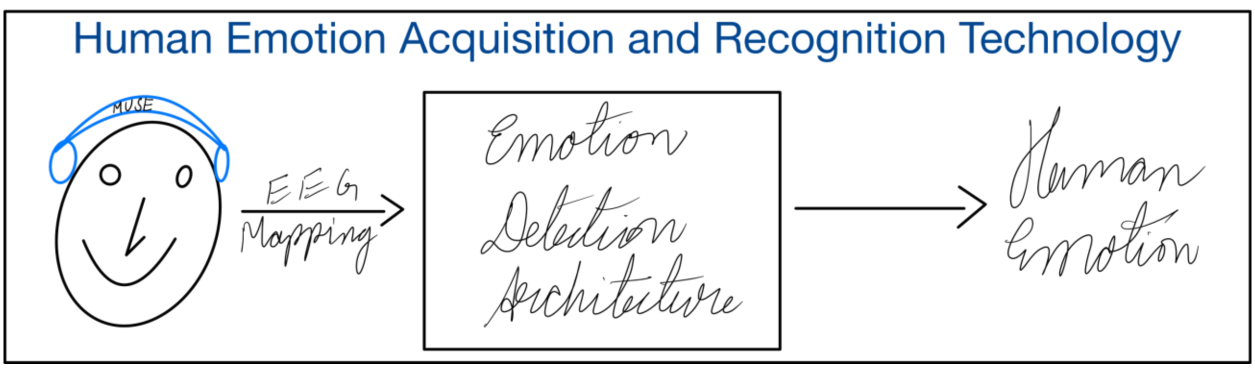

Fig. 1 H.E.A.R.T System Design

The heart of H.E.A.R.T is the Emotion Detection Architecture (EDA). For the EDA, we are going to be using a **Deep Learning Based Architecture**, consisting of Convolutional Neural Networks, Sparse Auto Encoders and Deep Neural Networks.

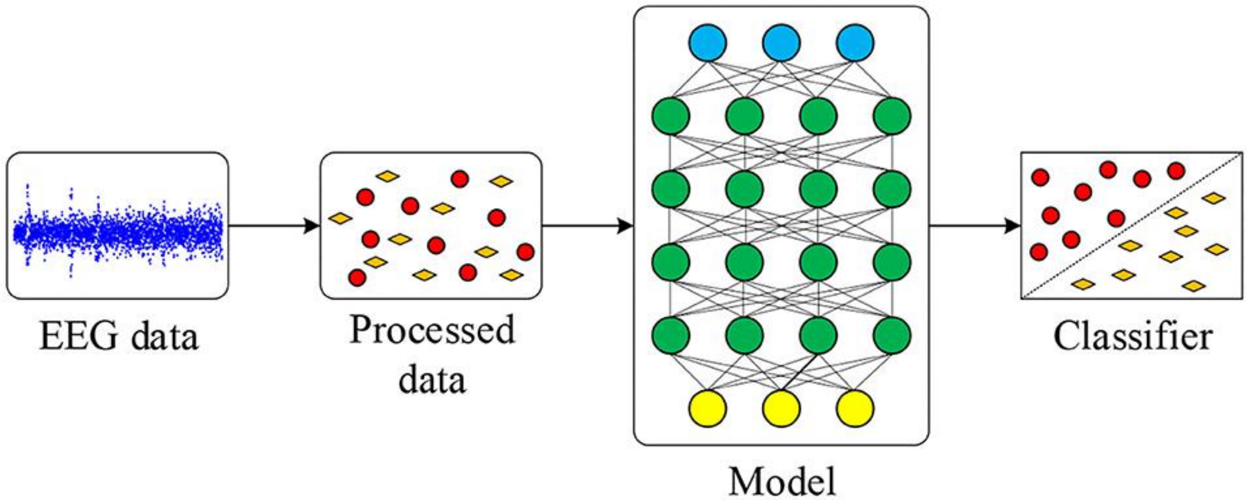

Fig. 2 Internal Architecture of H.E.A.R.T

There are several approaches in the literature for Brain wave classification. I am choosing one with Deep Learning so as to improve the accuracy of the predictions.

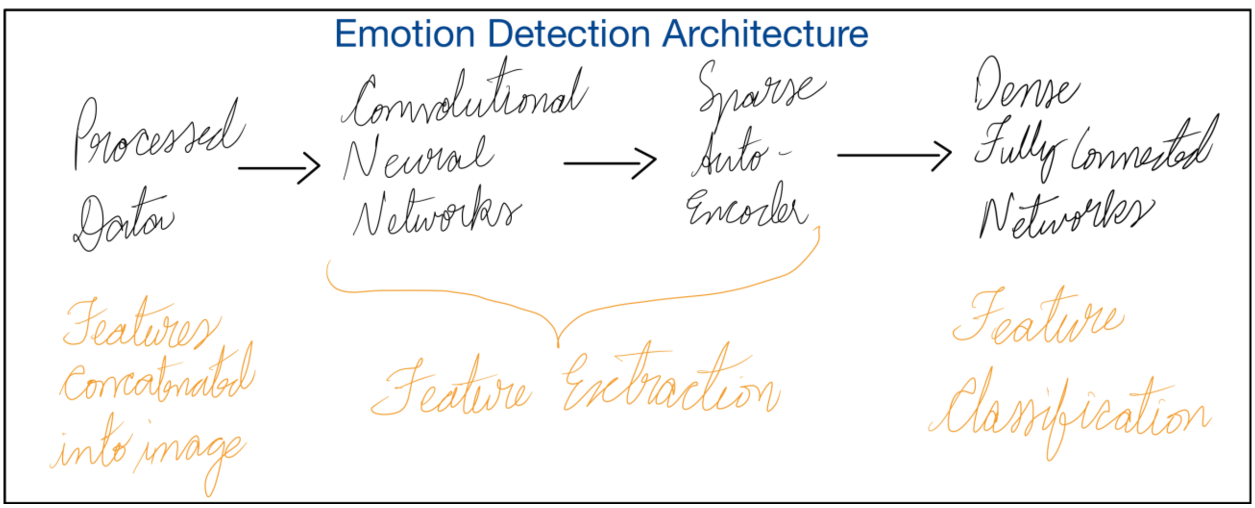

Fig. 3 Emotion Detection Architecture

This robust Emotion Detection Architecture presents a really accurate prediction tool for the emotions mapped out by the Muse headband. While such a heavy architecture can get computationally expensive and would require huge resources, we can **train it on our local system** which has such resources and then deploy only the trained model onto the user's device. The training is done using the **DEAP Dataset**. This is a dataset for emotion analysis using EEG, physiological and video signals. Now I present the User Interface Design for the Teach Pendant.

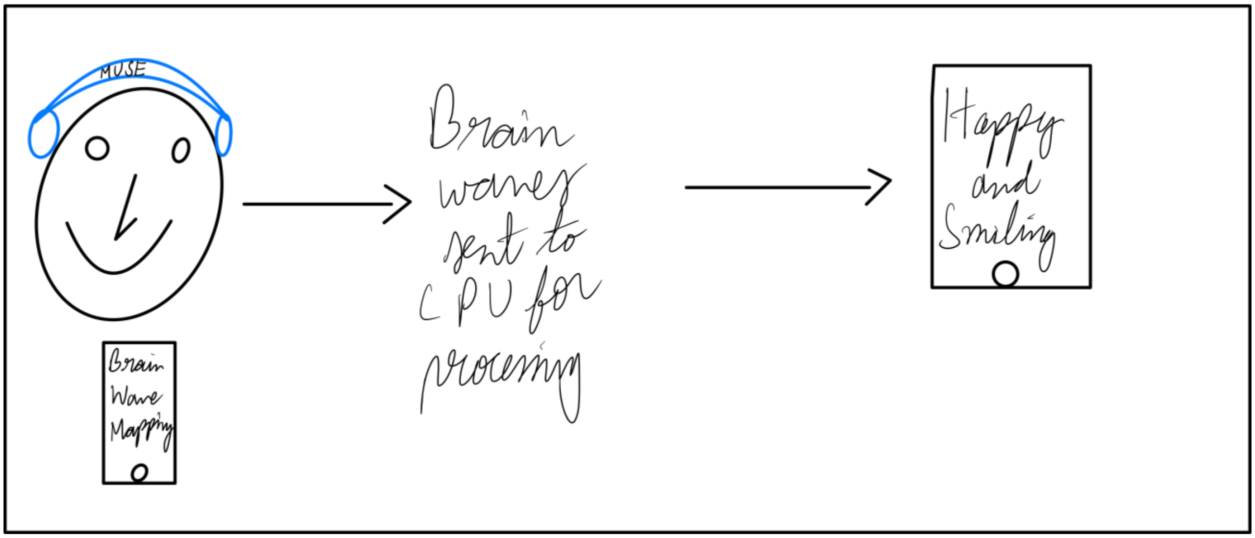

Fig. 4 User Interface design

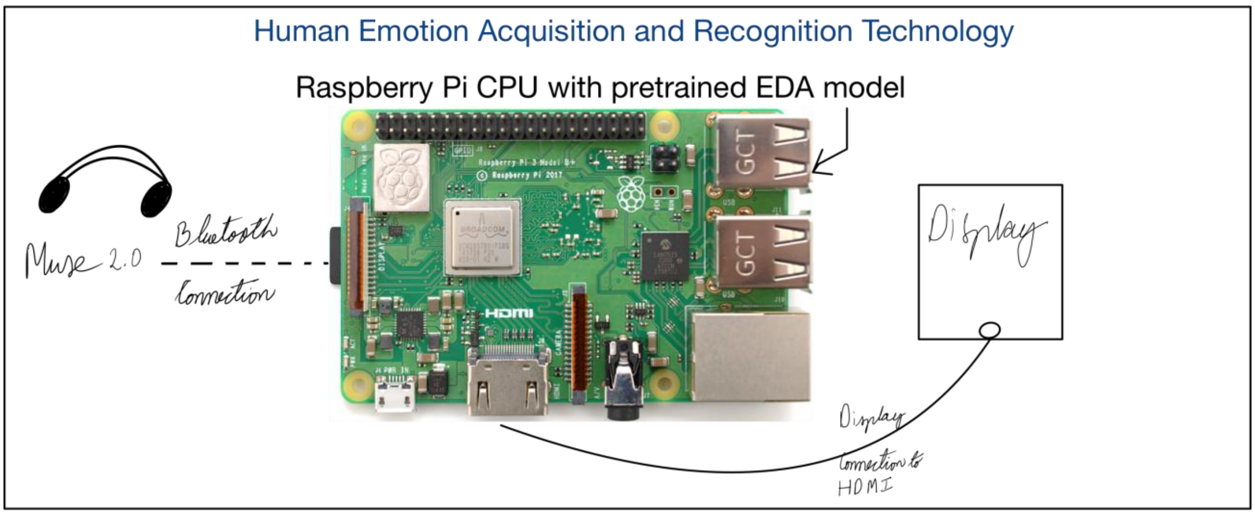

Fig. 5 Physical H.E.A.R.T Architecture

Hardwares used for the System Design

1. Muse 2.0 headband to detect brainwaves
2. Raspberry Pi 3 CPU
3. 4.0-inch LCD HDMI Display
4. HDMI cable
5. Nvidia Dgx™ A100 - GPU server for model training

Softwares/libraries used for the System Design

1. Raspberry Pi OS (For running Raspberry Pi)
2. Keras (For Deep Leaning)
3. Tensorflow (For Deep Learning)
4. DEAP Dataset
5. Python 3

Part 2: Integrating the teach pendant with Jetson Nano and to a Social Robot

I have integrated the earlier design for a Human Emotion Detection architecture called as H.E.A.R.T with a pre-designed robot with a humanoid for factor. In this case it designed to take in the emotion detected by the H.E.A.R.T and process it for performing related activities.

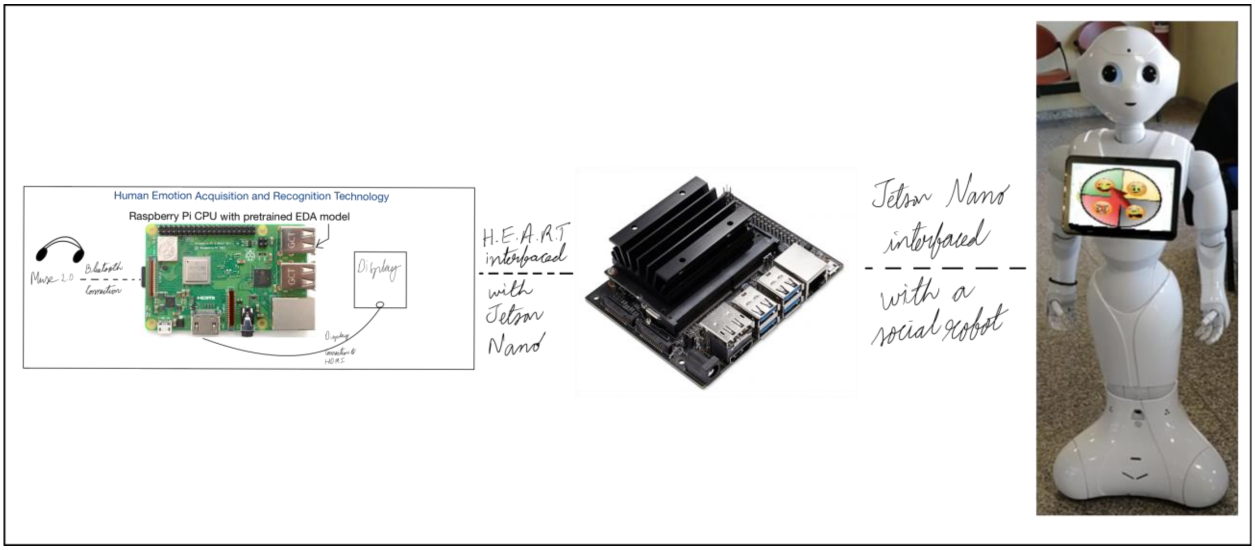

Fig. 6 H.E.A.R.T - Jetson Nano - Robot Interfaced Architecture

2.a) Cyber-resilient architecture for this robot

Since the main portion of this design is the H.E.A.R.T technology, we must focus our efforts on making this aspect of the robot cyber resilient. Since there is no direct connection to the internet between the Raspberry Pi board in the test and usage phase, the design is more or less effective against most cyber-threats. But to make the entire robot cyber-resilient we must do more. The robot needs to have the following components.

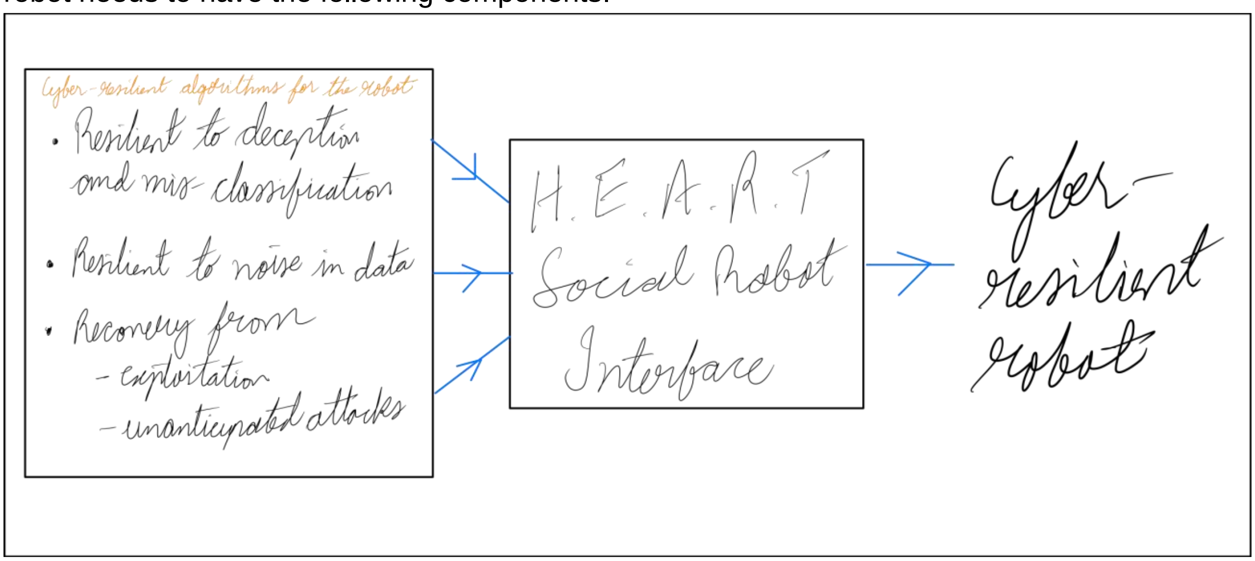

Fig. 7 Cyber-resilient H.E.A.R.T Robot Architecture

2.b) As we can see in Fig. 6, our robot has a humanoid form factor. It has a movable base with wheels. Two articulated arm which can do the tasks of shaking-hands, brings whatever is required by the user. If needed it can even move its arms to dance. Like the ones done by Boston Dynamics. These functional aspects are described in the image below. These functional aspects go a long way in providing care-giver services for people who need it like children, the elderly, people with disabilities etc.

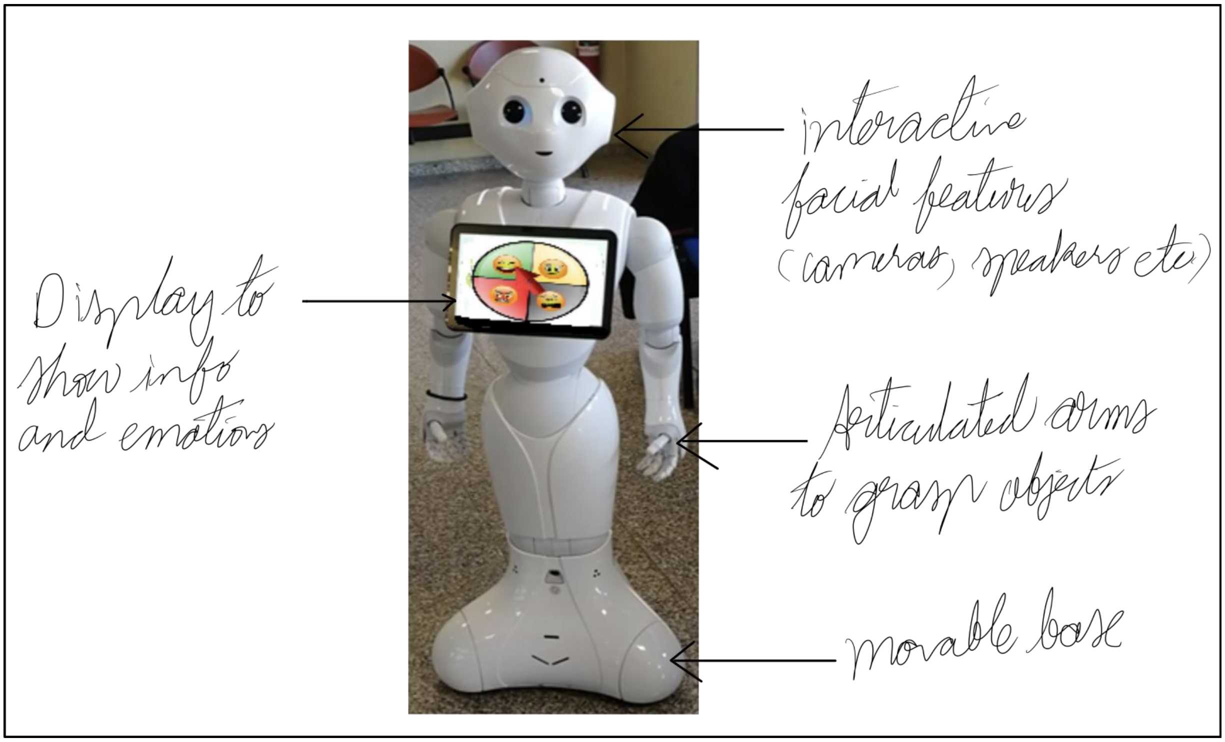

Fig. 8 Functional aspects of the selected robot

Robot learning during run time and usage of Deep Learning:

Since the robot is interfaced with the Raspberry Pi which has the pretrained Emotion Detection Architecture, the robot can just run during runtime without the need for training. In fact, it wouldn't need any training examples at runtime. This makes the H.E.A.R.T based robot work even faster during runtime. Now, to extend the capabilities to include getting your favorite food / beverage, or comforting / humoring you, we can add further **Deep Learning Capabilities**, this time to the **Jetson Nano board** since it has a better GPU capability than the Raspberry Pi. For this part of the robot's capabilities, we can use simple look-up table to map emotion to a particular task. We can also make different combinations of emotions to be mapped into different tasks as well. Once the task is identified, we can use a **Reinforcement Learning algorithm to make the robot better at said task**. An architecture for the same can be seen in fig. 9 below.

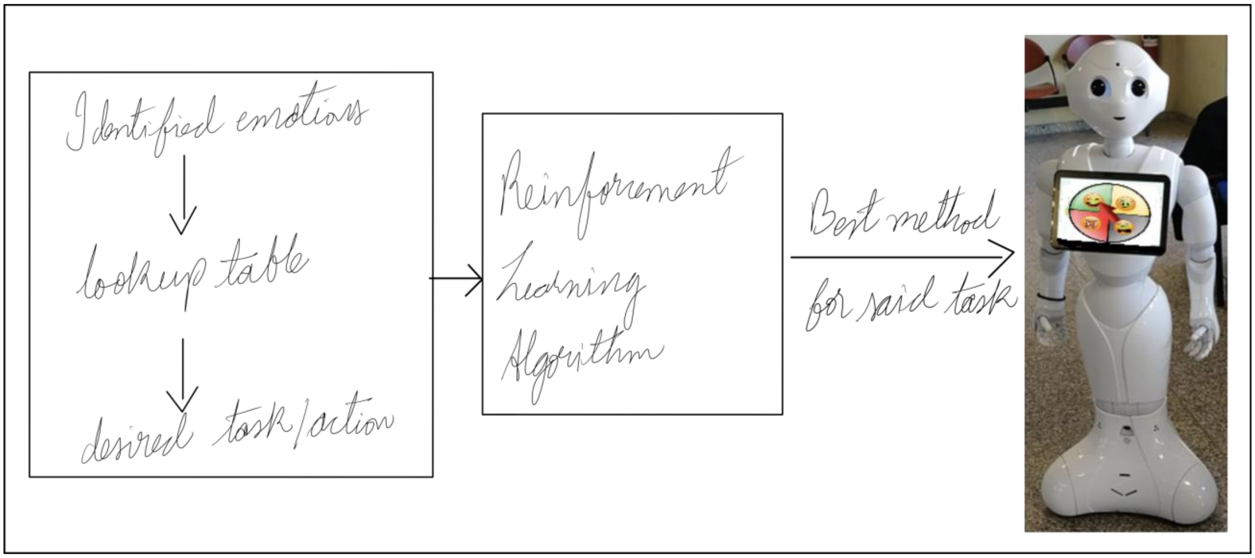

Fig. 9 Emotion-driven robot architecture

Resources:

1. Houssein, E.H., Hammad, A. & Ali, A.A. Human emotion recognition from EEG-based brain–computer interface using machine learning: a comprehensive review. Neural Comput & Applic 34, 12527–12557 (2022). https://doi.org/10.1007/s00521-022-07292-4
2. Liu, J., Wu, G., Luo, Y., Qiu, S., Yang, S., Li, W., & Bi, Y. (2019). EEG-Based Emotion Classification Using a Deep Neural Network and Sparse Autoencoder. *Frontiers in Systems Neuroscience*. https://doi.org/10.3389/fnsys.2020.00043