Neutrino Detection Using Machine Learning

Malika Golshan and Adrian Bayer
Department of Physics and Astronomy, UC Berkeley, Berkeley, CA 94720

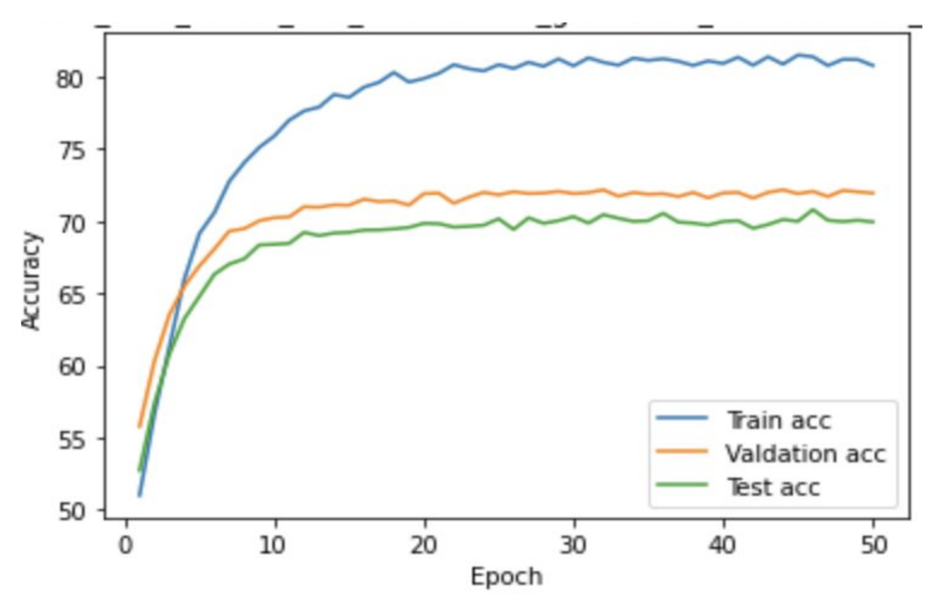
NSF Physics Frontier
Award number 2020275

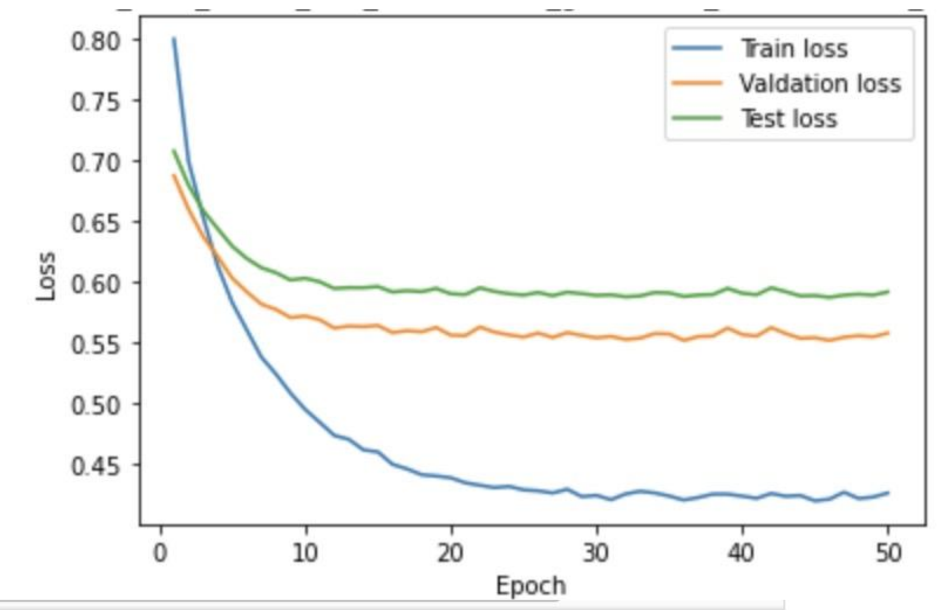
Introduction

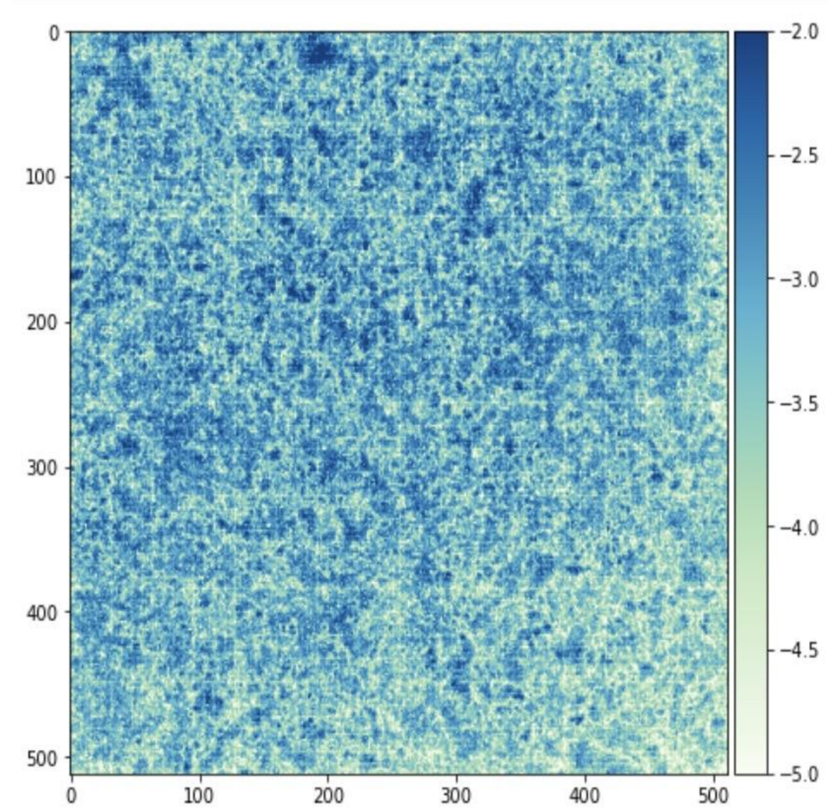
The neutrino is an elementary subatomic particle with no electric charge and spin of ½. The neutrino also has very little mass. In the standard model of particle physics they are even expected to be massless, but the observed flavor oscillations would not be possible without the neutrino having some mass.

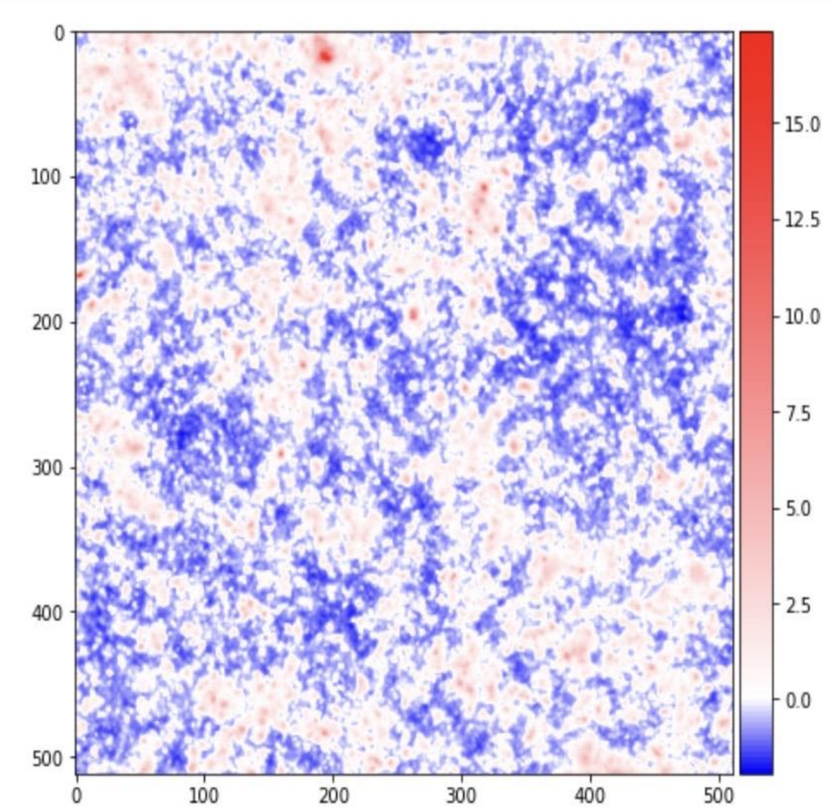
Due to the nature of neutrinos, particle physics experiments have a hard time accurately measuring neutrino mass. Currently the upper bound of the neutrino mass in particle experiments is $M < 0.8$eV and the lower bound is $M > 0.06$eV. On the other hand using cosmological methods has allowed the upper bound mass to be measured at 0.12 eV and it is believed that we can go even lower.

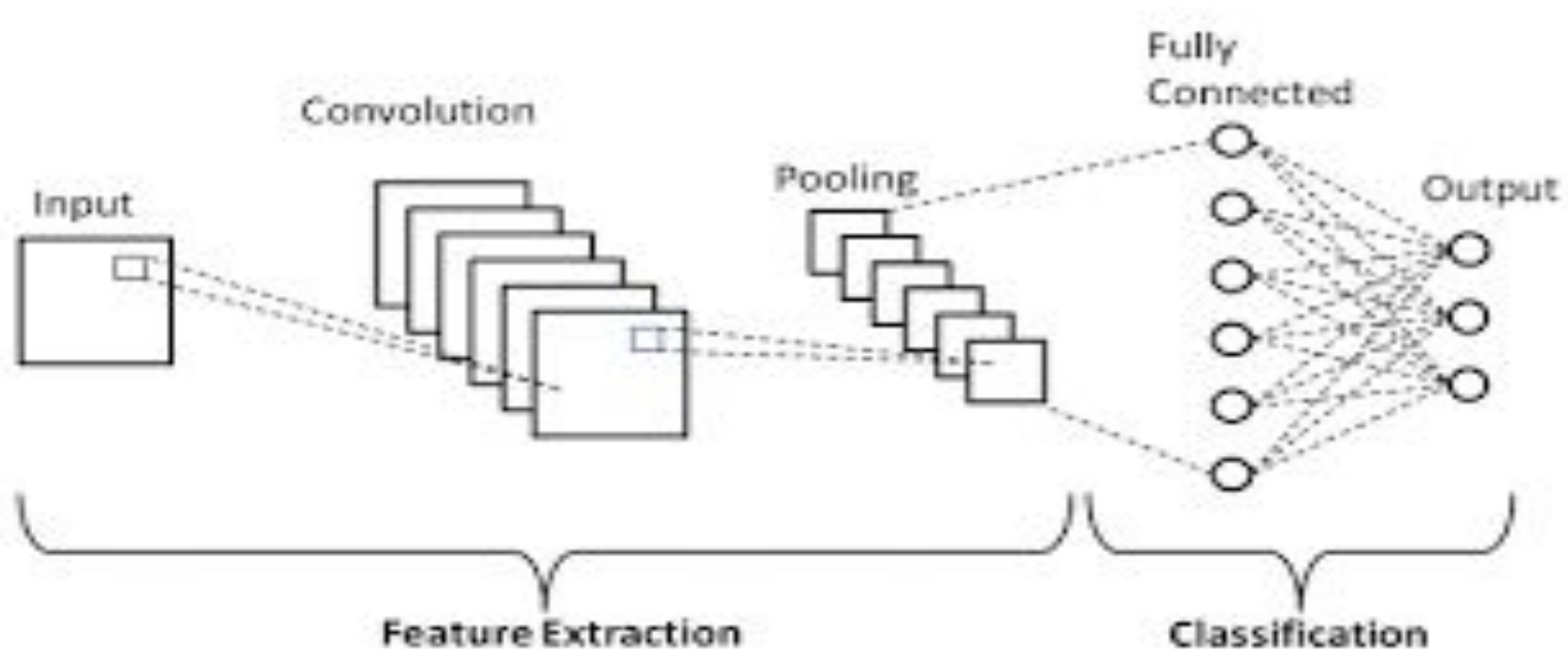
Currently what we are hoping to do is to see whether machine learning can be used to accurately classify between massive and non-massive neutrino cosmologies, in the hope that we can demonstrate that machine learning techniques can be used to aid in better measuring neutrino mass.











Results

So far we have constantly been able to get an accuracy in the mid 80s for our model. These results have been possible through exponentially scheduling the learning rate.

We have also produced integrated-gradient saliency maps to understand where the information is coming from.

Future Plans

We would like to use other methods in addition to saliency maps to interpret what the model is learning – whether information is gathered from voids or clusters.

In the future we would also like to see if we can increase the accuracy by using different parameters such as the redshift and looking at other loss functions.

Further into the future we would like to use regression instead of classification to measure the masses of neutrinos but this is most likely when we are certain that we have obtained the highest accuracy for our model currently

Method

Firstly, data is simulated that resembles weak lensing maps. After we have attained our maps we create a machine learning model, specifically a Convolutional Neural Network (CNN), which is a type of classification model. To better fine tune our model we use a package called optuna that allows the user to run many trials with different parameters from a range specified by the user.

References

[1] Dvorkin, C., Gerbino, M., Alonso, D., Battaglia, N., Bird, S., Rivero, A. D., Fuller, G., Lattanzi, M., Loverde, M., Muñoz, J. B., Sherwin, B., & Slosar, A. (2019). Neutrino Mass from Cosmology: Probing Physics Beyond the Standard Model. *arXiv*. https://doi.org/10.48550/arXiv.1903.03689

[2]The KATRIN Collaboration. Direct neutrino-mass measurement with sub-electronvolt sensitivity. *Nat. Phys.* 18, 160–166 (2022). https://doi.org/10.1038/s41567-021-01463-1

[3] Balaji, S. (2020, August 29). *Binary image classifier CNN using tensorflow*. Medium. Retrieved March 7, 2023, from https://medium.com/techiepedia/binary-image-classifier-cnn-using-tensorflow-a3f5d6746697