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Training CNN Architecture on Real Gravitational Lens Data

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Background

Gravitational lensing refers to the general relativistic effect where massive objects such as galaxies, stars, galaxy clusters or other quasi-stellar objects distort light emitted from a more distant light source with respect to the observer.

Strong lensing refers to when this effect is significant enough to produce multiple distorted and magnified images of the source. In recent years, the discovery of strong lensing systems in sky surveys has greatly benefitted from implementation of convolutional neural networks (CNNs).

This project aims to train the CNN architecture developed for the Lens Challenge (Metcalf 2019) using data of real lensed and non-lensed galaxies.

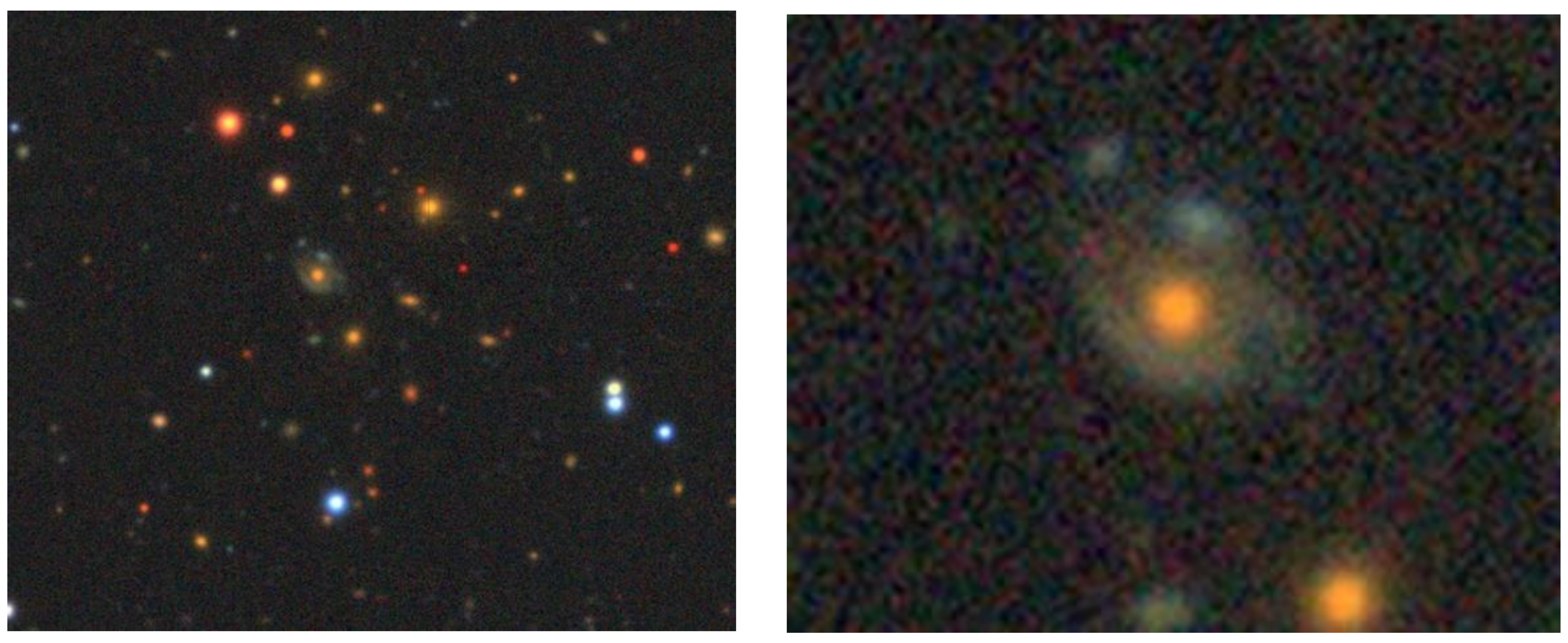

Figure 1. Depicts a snippet of DESI Legacy Survey Sky Viewer. Alongside it presents a zoomed in image of DESI-340.2304-00.0128 (Huang et al. 2021). Image of this Grade A lens was captured through the Dark Energy Spectroscopic Instrument (DESI) Survey.

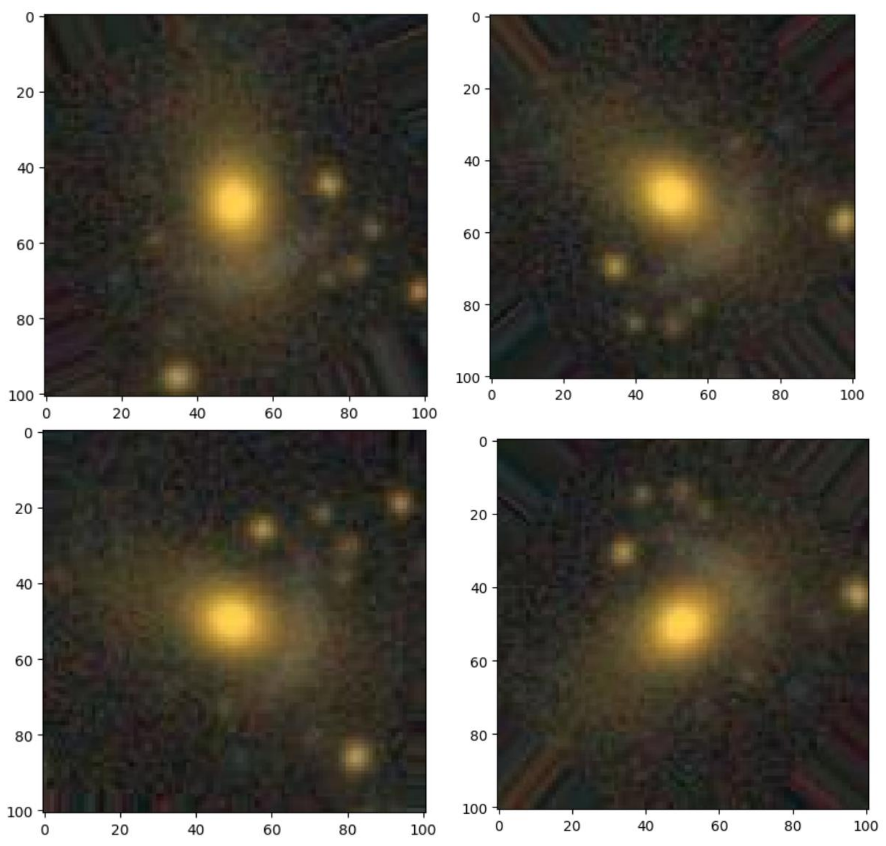

Figure 2. Depicts the original image, a horizontal flip, a vertical flip and a vertical flip with a 90-degree rotation of the lens candidate DESI-049.3327-30.1661

Lens Paper Reference	Data Augmented Lens Sample	Size of Images	No. of magnitude bands
Huang (2020)	3,051	101x101	4
Huang (2021)	10,000	101x101	4
Diehl (2017)	3,699	101x101	4
Dawes (2022)	3,924	101x101	4
Rojas (2022)	3,645	101x101	4
Stein (2022)	10,692	101x101	4
Storfer (2022)	5,761	101x101	4
O'Donnell (2022)	2,331	101x101	4
Jacobs (2019)	4,599	101x101	4
Zaborowski (2022)	1,629	101x101	4

Table 1. Presents information on the augmented lens datasets. Cutouts were standardized to 101x101 images and were captured in the g, r, i and z photometric bands.

Methods and Data

This project utilized the Legacy Viewer, developed for the DESI Legacy Survey, to gather approximately 6000 strong lens candidates from previous literature.

Candidate data was retrieved via a Python program, based on their right ascension and declination. Approximately 4225 non-lensed galaxies were collected from Astro Data Lab.

Data augmentation was performed on each lens and non-lens candidates' FITS image to increase the size of the training sets.

Eight unique augmentations were applied through 90-degree rotations as well as horizontal and vertical flips.

Augmented lens candidates were then split into 10 separate datasets (Table 1) based on their original papers and formatted into hdf5 file types.

All datasets were used to train the Lens Challenge CNN alongside a comparative non-lens sample. This CNN architecture is comprised of four convolutional blocks and fully connected layers.

Results and Discussion

When evaluating the ten datasets, we look for the mix of results that have the smoothest decreasing training and validation loss curve along with the Receiver Operating Characteristic (ROC) that contains the highest true positive rate and lowest false positive rate. On this criteria, Diehl (2017), Dawes (2022), Huang (2021) and Stein (2022) performed the best. This may be likely attributed to the larger sample sizes of Huang and Stein and a more diverse set of lenses in Diehl and Dawes. The model showed signs of overfitting in many of the other datasets.

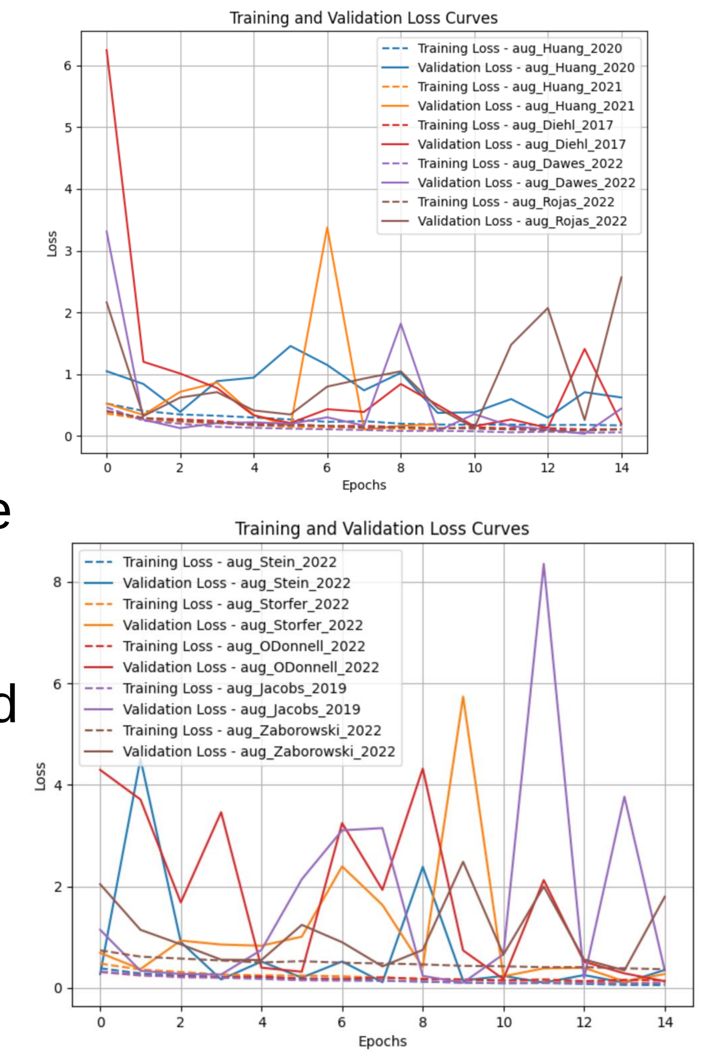

Figure 3. Training and Validation loss curves of the ten datasets on "Lens Challenge" CNN

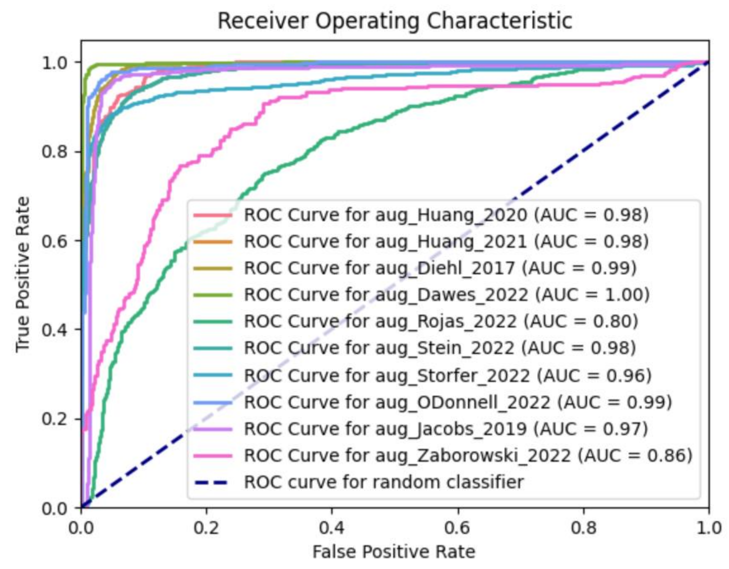

Figure 5. ROC Curves depicting the true positive rates and false positive rates for the ten datasets.

Conclusions and Future Work

To improve upon this work, more lens candidates and non-lens samples may be collected to produce broader and more representative training datasets.

Advanced machine learning techniques such as regularization to account for overfitting and adjustment of hyperparameters may be explored to achieve better performance on validation sets for the model.

Acknowledgements

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