Convolutional neural networks, trained on simulations, can discover strong lenses in survey image data.

An extended catalog of galaxy-galaxy strong gravitational lenses discovered in DES using convolutional neural networks

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INTRO

- Strong lensing is driving much discovery in astronomy, including galaxy evolution, cosmology and dark matter[1].
- Thousands of lenses are discoverable in current imaging; tens of thousands to come in LSST and Euclid[2].
- Deep Learning techniques from computer vision can make lens discovery in large image sets efficient.

METHOD

1. Simulate galaxy-galaxy strong lenses with the seeing and other characteristics of Dark Energy Survey (DES) co-add images.
2. Train CNNs, using simulated lenses, non-lenses and real galaxies.
3. Score ~8 million postage stamps, chosen to match the colors of simulated lenses in survey photometry[3] (Fig. 2).

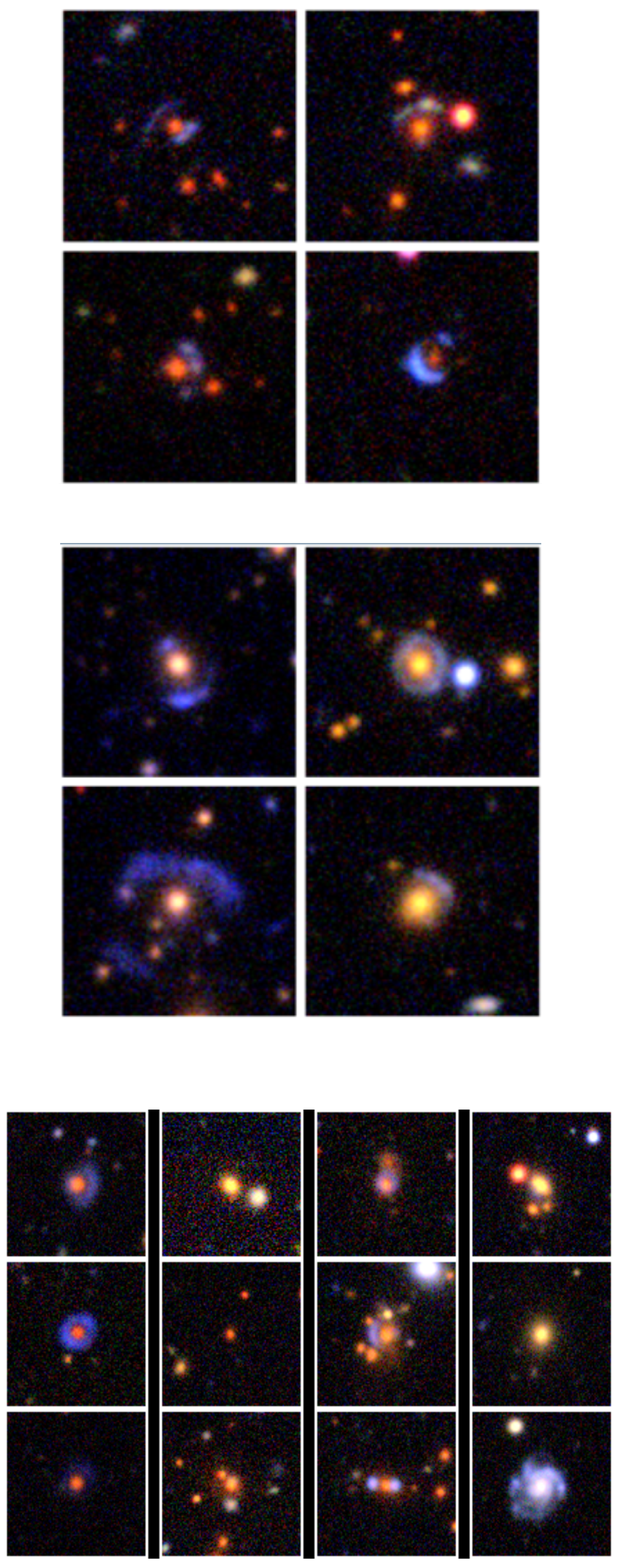

Figure 1. Top: Four of 84 high-redshift ($z > 0.8$) lens candidates from Jacobs et al 2019a[4]. **Middle**: Four bright arcs detected in the DES search of Jacobs et al 2019b. **Bottom**: Images used in training the neural networks. *Left column*: Simulated lenses and lensed sources. *Second from left*: Simulated lens galaxies without a lensed source. *Third from left*: Real ellptical galaxies and simulated lensed sources. *Right column*: Real field galaxies, used as negative examples.

RESULTS

- Total of 511 high-quality strong lens candidates discovered.
- 84 high-redshift (lens at $z > 0.8$) discovered (see Jacobs et al 2019a)[4].

DISCUSSION

- Discovery of candidates involved manual inspection of ~20,000 images. False positives are still an issue.
- Improvements in simulations (better PSF matching, a greater variety of lens colors, greater use of real sources) likely to bring gains in accuracy.

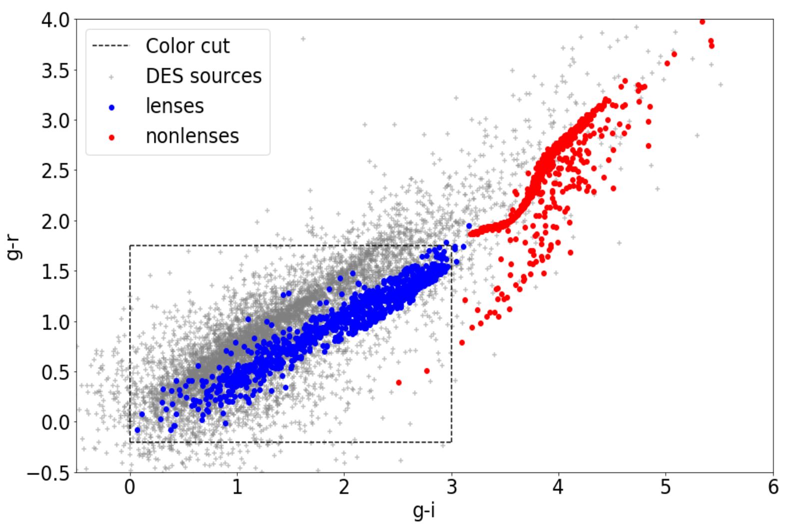

Figure 2. *g-i* vs *g-r* colors of simulated lenses and non-lenses, with sources from the DES catalog shown in grey. The box indicates the color-cut used to select a catalog of 7.9 million sources for scoring by CNNs.

Deployment in the cloud

This methodology was tested both on local HPC resources and in the Microsoft Azure Cloud (the author received sponsored credit from Microsoft[5]).

The trained TensorFlow model was deployed onto a GPU-enabled virtual machine. This has the advantage of bringing the code closer to the data – the model can be deployed on an instance in a region as close to the data as possible.

This reduced data transfer times, a significant bottleneck, by a factor of 5, without requiring GPU access co-located with the survey data.

Both the training process and the trained model can be deployed on demand in a container in the cloud (using AzureML or the equivalent from another provider). This way, **a trained model can be easily shared with the astronomical community as as web service.**

5 **Disclosure**: Jacobs was awarded a Cloud Research Software Fellowship by Microsoft Asia in May 2019 which includes $3000 of Azure credits and $2000 travel support.

References

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