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Deep Regression Techniques for Decoding Dark Matter with Strong Gravitational Lensing

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PERSONAL DETAILS

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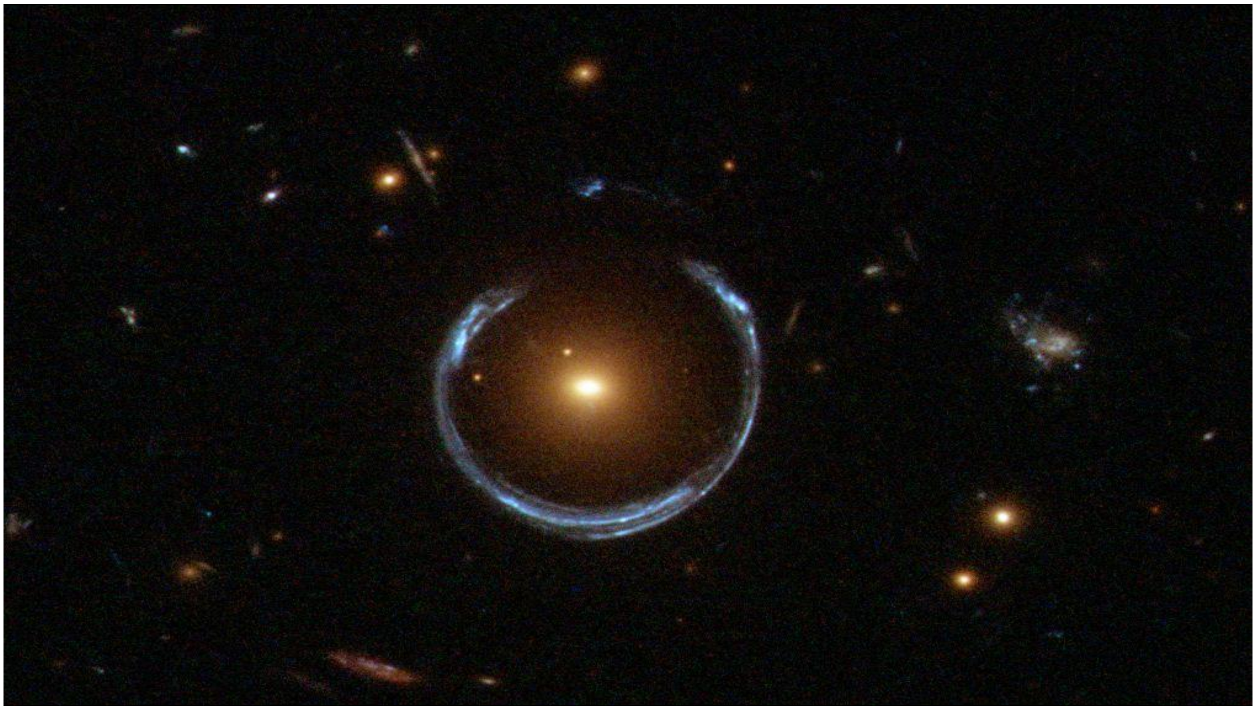
SYNOPSIS

About the Project

Strong gravitational lensing is a powerful technique to study dark matter in the universe. It allows us to map the distribution of dark matter by using the distorted shapes of background galaxies. However, the traditional methods of analyzing strong gravitational lensing data have limitations in terms of accuracy and speed. Deep learning has shown great promise in various fields of astrophysics and can potentially improve the analysis of strong gravitational lensing data. This proposal aims to develop deep regression techniques to decode the dark matter distribution from strong gravitational lensing data.



Why we need?

This project is important because understanding the distribution of dark matter in the universe is one of the most significant challenges in astrophysics. Dark matter does not emit, absorb, or reflect light, making it difficult to detect and study directly. However, its presence can be inferred from the gravitational effects it has on visible matter, such as stars and galaxies. Strong gravitational lensing is one of the most powerful techniques to map the distribution of dark matter. However, the traditional methods of analyzing strong gravitational lensing data have limitations in terms of accuracy and speed.

Deep learning has shown great potential in various fields of astrophysics, including cosmology and gravitational lensing. Deep regression techniques can potentially improve the accuracy and speed of analyzing strong gravitational lensing data. This project aims to develop a deep regression model that can accurately map the dark matter distribution from strong gravitational lensing data. The implementation of the model in a user-friendly software package will make it accessible to the wider astrophysics community, enabling them to make new discoveries in the field of dark matter research. Therefore, this project is essential for advancing our understanding of dark matter and the structure of the universe.

Goals and Deliverables

Goals

The proposed project aims to achieve the following goals:

- Develop a deep regression model for accurately mapping the distribution of dark matter from strong gravitational lensing data.
- Compare the performance of the deep regression model with traditional methods of analyzing strong gravitational lensing data.
- Investigate the robustness of the deep regression model through testing on simulated and real strong gravitational lensing datasets.
- Implement the deep regression model in a user-friendly software package for broader use in the astrophysics community.
- Design the software code to be easily extendable for future improvements based on community feedback and advancements in the field.
- Contribute to advancing the field of astrophysics and cosmology by providing more accurate and reliable methods for analyzing gravitational lensing data.

Deliverables

- Develop deep learning models using deep regression techniques for estimating dark matter properties, including population-level quantities and properties of dark matter particle candidates (e.g. CDM, WDM, axions, SIDM) with exceptional performance using transfer learning with pretrained models on imagenet such as Resnet 50 and Inceptionv2.
- Train a Artificial Neural Network using Convolution Neural Network and Vision Transformer for accurately mapping gravitational lens images to the mass of corresponding dark matter.
- Use mean squared error(MSE) as evaluation metrics to assess the performance of the developed models.
- Fine-tune the models to optimize their performance and compare their efficacy.

- Provide open-source code and trained models to the scientific community for further research and development.
- Enhance our understanding of the matter distribution in the lensing system and contribute to scientific research in the field.

Related Tasks

Dataset

As per the description page, dataset to be used is not specified. So I assume it will be similar to that of provided for evaluation test task III under DeepLense Project.The first goal is to prepare a dataset of simulated gravitational lens images with masses. The dataset will be preprocessed, and image patches will be extracted, and augmented to include variations such as rotation and scaling.

Architectures

We are goint to use Artificial Neural Network regression techniques which consists of two types, Convolution Neural Network and Attention based Networks.

- **State-of-the-art Convolution Neural Networks(Resnet50)**
    - We first load the pre-trained ResNet50 model without its classification head using the ResNet50() function from Keras.
    - We then freeze all the layers of the pre-trained model so that they are not updated during training.
    - We add a regression head on top of the pre-trained model by passing the output of the pre-trained model through a Flatten() layer and two Dense() layers.
    - The last dense layer has a single output node for the final regression task.
    - We then compile the model using the mean squared error loss and Adam optimizer, and train the model on the training data.
    - Finally, we evaluate the model on the test data using the mean squared error loss and mean absolute error metric.
- **Vision Transformer(Pretrained On Imagenet)**
    - We first load the pre-trained ViT model without its classification head using the vit.ViT() function from the vit_keras package.
    - We then freeze all the layers of the pre-trained model so that they are not updated during training.

- We add a regression head on top of the pre-trained model by passing the output of the pre-trained model through a Flatten() layer and two Dense() layers.
- The last dense layer has a single output node for the final regression task.
- We then compile the model using the mean squared error loss and Adam optimizer, and train the model on the training data.
- Finally, we evaluate the model on the test data using the mean squared error loss and mean absolute error metric.

TIMELINE

- **COMMUNITY BONDING PERIOD(4 MAY - 29 JUNE)**
    - Get familiarized with the project and the team
    - Discuss the project requirements and goals with the mentor
    - Explore the dataset and collect additional data if needed
    - Set up the development environment and tools
    - Discuss the project timeline with the mentor and identify potential risks and challenges.
- **PHASE - 1 (29 May - 11 June)**
    - Implement a data preprocessing pipeline for strong gravitational lensing images.
    - Familiarize with the dataset and pre-process it, including data cleaning and normalization.
    - Develop a baseline model using traditional methods for analyzing strong gravitational lensing data, such as maximum likelihood estimation and Bayesian methods.
    - Evaluate the baseline model and set a benchmark for comparison.
- **PHASE - 2 (12 June - 10 july)**
    - Explore different deep learning architectures, including Vision Transformers and Pretrained ResNet50 models, for developing a deep regression model that can accurately map the dark matter distribution from strong gravitational lensing data.
    - Train and evaluate the deep regression models and compare their performance with the baseline model.

- Analyze the results and identify areas for improvement.

- **PHASE - 3 (14 july - 21 August)**
  - Implement additional features to improve the model's performance and usability.
  - Conduct experiments to evaluate the performance of the model on different subsets of the dataset.
  - Analyze the model's predictions and assess the model's robustness and generalization ability.
  - Conduct extensive testing and debugging of the code.
  - Document the project progress and update the project wiki page.

- **Final WEEK (21 august - 28 august)**
  - Finalize the project and submit the code and pre-trained models.
  - Submit the final report, including a summary of the project, key findings, and the project's impact
  - Prepare for the final evaluation by the mentor and the GSoC program.
  - Disseminate our findings and software package to the astrophysics community through publications and presentations at relevant conferences

CONCLUSION

This proposal aims to develop deep regression techniques for decoding dark matter with strong gravitational lensing. The proposed work has the potential to revolutionize the field of dark matter research by providing a more accurate and efficient way of analyzing strong gravitational lensing data. The implementation of the model in a user-friendly software package will make it accessible to the wider astrophysics community, enabling them to make new discoveries in the field.

ABOUT ME

Personal Background

As a sophomore undergraduate student specializing in Mining Machinery Engineering at the prestigious Indian Institute of Technology (ISM) Dhanbad, I have been captivated by the power of deep learning to revolutionize the landscape of modern technology. With an unwavering passion for delving into the latest research and experimenting with various algorithms and architectures, I am constantly astounded by the breakthroughs and advancements that emerge within this field.

Of particular fascination to me is how deep learning has become a game-changer in solving complex problems that have confounded traditional methods. From surpassing human-level performance in image recognition to driving groundbreaking advancements in natural language processing, the transformative potential of deep learning is truly awe-inspiring.

As a highly motivated and curious individual, I am eager to connect with other like-minded experts in the field and actively engage in the exchange of ideas and insights. By expanding my knowledge and skillset in deep learning, I aspire to contribute to the pioneering developments in this exciting and rapidly evolving field, which holds the promise of shaping the technological landscape of our future.

How did I hear about this programme?

I heard about Google Summer Of Codes in class 12th while I was preparing for jee advanced. I am an open source enthusiast from past 1 year and I always wanted to take part in Google Summer Of Codes.

Time during Summers

This year is an internship season for us so I'll be working for about 40 hours per week before 1 july. Online tests will start from 1 july for internships which will end in first week of august. So in that period I 'll be working for around 30 hours a week.

What excites me about the Project?

- The project involves using cutting-edge machine learning techniques to solve a real-world problem in the field of astrophysics and cosmology.
- The project has the potential to significantly advance our understanding of dark matter, a fundamental yet elusive component of the universe.
- The project offers an opportunity to develop new software tools that can be used by the wider astrophysics community to analyze gravitational lensing data, potentially leading to new discoveries and insights.
- The project involves collaboration with experts in the field of astrophysics and machine learning, providing a valuable opportunity to learn from and work with top researchers.
- The project offers a chance to make a meaningful contribution to the scientific community and potentially impact our understanding of the universe.

Why should I be selected for the Project?

I believe that I would be an excellent candidate for this project because of the following reasons:

- Firstly, I have a strong background in deep learning and computer vision. I have completed several courses and worked on various projects related to deep learning, including image classification, object detection, and segmentation.
- Secondly, I have a keen interest in astronomy and astrophysics. The project's focus on studying the gravitational lensing phenomenon to uncover dark matter structures in the universe is fascinating to me. This project provides an opportunity to work on a project that not only advances my skills but also contributes to scientific research.
- Lastly, I am a highly motivated and dedicated individual who enjoys working in a team environment. I am eager to collaborate with fellow researchers to develop and improve the proposed model's performance. I am confident that I possess the necessary skills and attitude required to deliver high-quality results for the project.
- In conclusion, I believe that my expertise in deep learning and computer vision, interest in astrophysics, and motivation to excel make me a strong candidate for the Deep Regression Techniques for Decoding Dark matter with Strong Gravitational lensing. Thank you for considering my application.