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Transformers for Dark Matter with Strong Gravitational Lensing

Shashank Shekhar Shukla
IIT ISM DHANBAD
DHANBAD JHARKHAND
INDIA , 826004

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PERSONAL DETAILS

Name : Shashank Shekhar Shukla
Email : shuklashashankshekhar863@gmail.com
Mobile : 9569481813
Time Zone : UTC + 5:30
Github : https://github.com/Wodlfvllf
University : IIT ISM DHANBAD
Typical Working Hours : 1pm to 11:00 pm

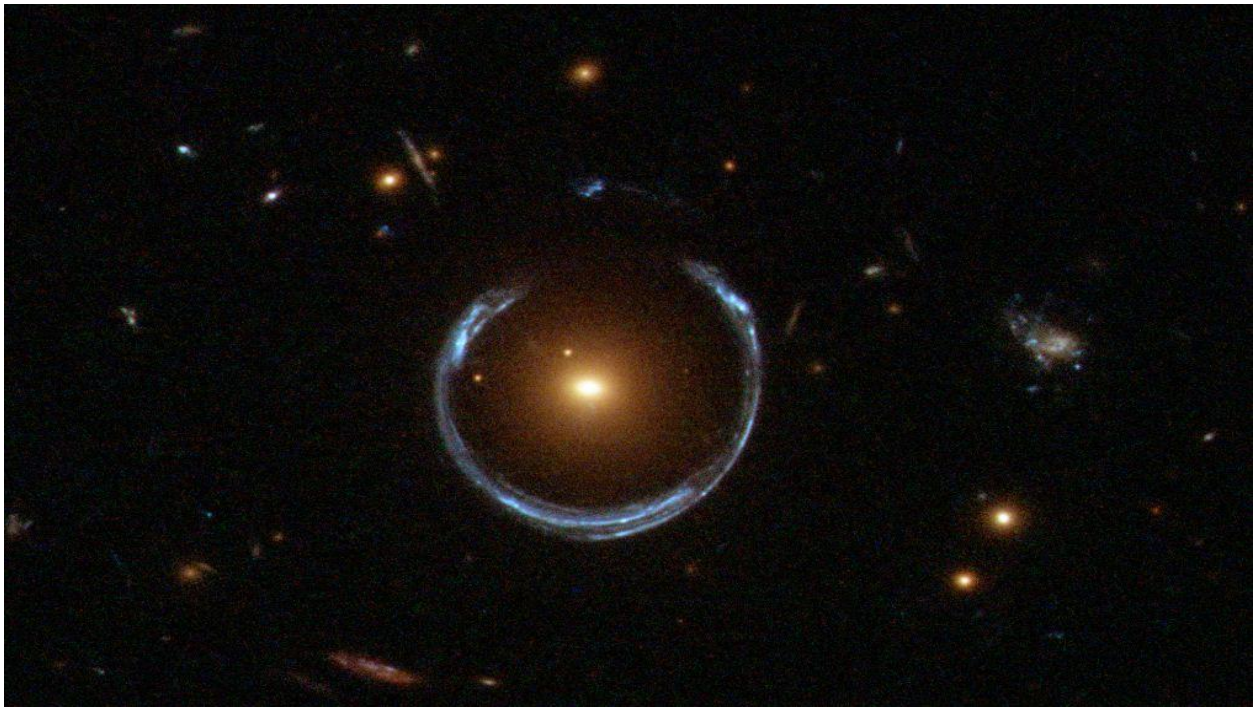
SYNOPSIS

About the Project

Gravitational lens images can be categorized into two groups based on their characteristics - either smooth or with substructure. While smooth lenses produce a singular image of the background source, lenses with substructure generate multiple images of the same source due to minute variations in the lens mass distribution, such as clumps of dark matter or stars. These additional lensed images provide valuable insights into the distribution of dark matter in galaxies and clusters of galaxies

To classify these images accurately, we propose the utilization of Vision Transformer (ViT) technology, a type of machine learning model that utilizes

transformer encoders and multi-head self-attention mechanisms to analyze image patches and learn contextual relationships between them. The use of ViT for gravitational lens image classification will help automate and optimize this process, resulting in more accurate classifications of images with and without substructure.



Why we need?

The classification of gravitational lens images is crucial for advancing our understanding of the properties and structure of the universe. Incorporating machine learning models such as ViT into this process will provide a more efficient and accurate classification method, allowing us to study and comprehend the complex properties of gravitational lens images with greater ease.

Goals and Deliverables

Goals

The proposed project aims to achieve the following goals:

- The proposed project aims to develop a deep learning model for accurately classifying gravitational lensing data.
- The goal is to surpass the current state-of-the-art techniques to provide more precise measurements of lensing effects and a deeper understanding of the matter distribution in the lensing system.
- A comprehensive analysis of the proposed model will be conducted to evaluate its strengths and weaknesses, identify areas for improvement, and ensure its suitability for scientifc research.
- The code and trained models will be released as open source to enable wider adoption and beneft the scientifc community.
- The code will be designed to be easily extensible, allowing for future enhancements based on community feedback and advancements in the feld.
- The project has the potential to signifcantly advance the feld of astrophysics and cosmology by providing more accurate and reliable methods for analyzing gravitational lensing data.

Deliverables

- Develop deep learning models for image classifcation of gravitational lensing data with exceptional performance using transfer learning with pretrained vision transfers on imagenet.
- Train a ViT model using Iterative Erasing and Distilling Vision Transformer technique capable of accurately classifying gravitational lens images with and without substructure.
- Use ROC curve and AUC score as evaluation metrics to assess the performance of the developed models.
- Fine-tune the models to optimize their performance and compare their efcacy.
- Provide open-source code and trained models to the scientifc community for further research and development.
- Enhance our understanding of the matter distribution in the lensing system and contribute to scientifc research in the field.

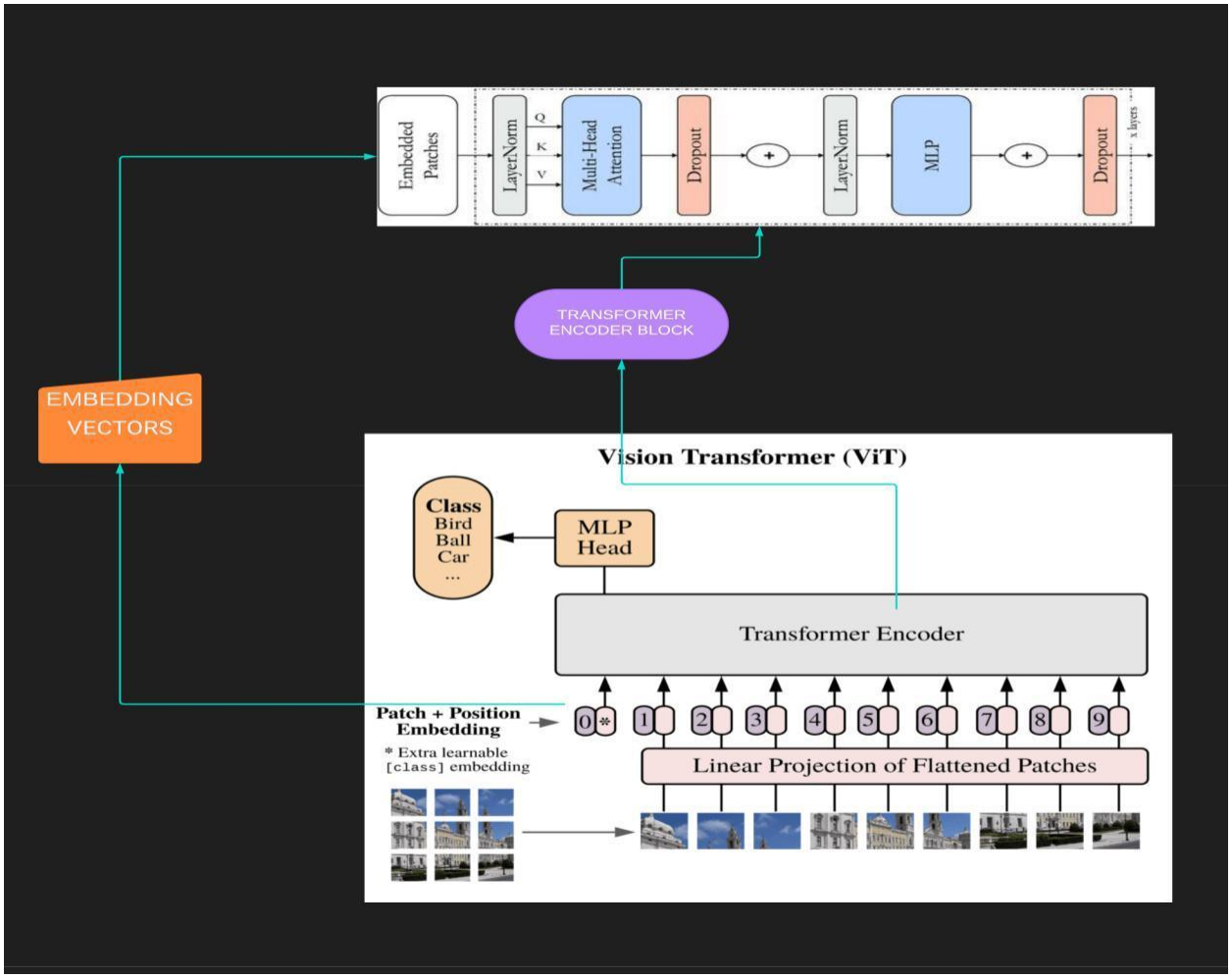
Related Tasks

Dataset

As per the description page, dataset to be used is not specified. So I assume it will be similar to that provided for evaluation test task V under DeepLense Project.The frst goal is to prepare a dataset of simulated gravitational lens images with and without substructure. The dataset will be preprocessed, and image patches will be extracted, and augmented to include variations such as rotation and scaling.

Architectures

The Vision Transformer (ViT) is a state-of-the-art deep learning architecture for image classifcation that is based on the Transformer architecture used in natural language processing. The ViT model is designed to handle variable-sized inputs and to learn spatial relationships between image patches using self-attention mechanisms.



Architectures

- **Vision Transformer using Iterative Erasing**
- **Distilling Vision Transformer**

Architecture of Vision Transformer using Iterative Erasing using Visual Attention:

- Input image is passed through a sequence of learnable embeddings to convert it into a sequence of fxed-size feature vectors.
- These feature vectors are passed through a stack of Transformer encoder layers, which perform attention-based computations on the input sequence to extract relevant visual features.
- During training, the Iterative Erasing technique is applied, where a portion of the input image is randomly erased and the remaining partial image is used as input to the model.
- The model is trained to predict the missing part of the image based on the remaining information and the context learned from previous Transformer layers.
- The iterative erasing process is repeated multiple times with different portions of the image being erased each time, enabling the model to learn from different perspectives and become more robust to variations in the input.
- The final output of the model is a vector representing the probability distribution over the different classes or labels for the input image.
- The performance of the model is evaluated using metrics such as Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC) rather than accuracy alone.
- The attention mechanism in the model enables it to selectively focus on relevant parts of the image and understand their relevance to the overall context, improving the model's ability to detect patterns and make accurate predictions.
- The use of the Iterative Erasing technique further improves the model's ability to learn from different perspectives and become more robust to variations in the input, leading to more accurate and robust computer vision model.

Architecture of Drilling Vision Transformer

- Technique for compressing large vision transformers into smaller, more efficient models.
- Involves training a smaller student model to mimic the behavior of a larger teacher model.
- Uses various techniques such as attention distillation, feature distillation, and knowledge distillation to transfer information from teacher to student.
- Can significantly reduce the computational and memory requirements of vision transformers while maintaining high accuracy

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.
  - Develop several Vision Transformer model architecture and train it on a subset of the dataset.
  - Evaluate the model using standard metrics such as ROC curve and AUC.
  - Evaluate the baseline model and set a benchmark for comparison.
- **PHASE - 2 (12 June - 10 july)**
  - Further train and fne-tune the model(by applying Distilling Vision Transformer Technique and Iterative Erasing technique) using various hyperparameter tuning techniques.
  - Conduct experiments to evaluate the performance of the model on different subsets of the dataset.
  - Anaalyze the model's predictions and assess the model's robustness and generalization ability.

- **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

The proposed project seeks to develop an innovative deep learning model for classifying Dark Matter Morphology using strong gravitational lensing images. We propose utilizing the Vision Transformer architecture, a state-of-the-art technique that has demonstrated exceptional results across various computer vision tasks. Our model will be trained on a large dataset of strong gravitational lensing images and evaluated using robust metrics such as Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC) rather than relying solely on accuracy. By improving the accuracy of Dark Matter Morphology classifcation, we can gain further insight into the nature of dark matter and its role in the formation of the universe's structure. Successful completion of this project would provide valuable contributions to the feld of astrophysics and cosmology while also offering a signifcant boost to the open-source community through the release of code and pre-trained models. Additionally, this project can pave the way for further research on deep learning in astrophysics and

image classifcation, including applications in galaxy classifcation and star identifcation.

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 have been 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 proposed project is exciting because it involves the development of a novel deep learning model for Dark Matter Morphology classification using strong gravitational lensing images, which can provide us with a better understanding of the universe's structure and the role of dark matter. The use of Vision Transformer architecture for this task is also exciting as it has shown promising results in various computer vision tasks. The project's potential impact in the feld of astrophysics and cosmology and its potential to pave the way for further research in the feld of deep learning and astrophysics is also a signifcant factor that can generate excitement. Moreover, the opportunity to work with a mentor and a team of experienced developers and contribute to an open-source project can also be exciting for students and developers who are passionate about AI and astrophysics.

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 classifcation, 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 scientifc 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 confdent 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 Transformers for Dark Matter Morphology with Strong Gravitational Lensing. Thank you for considering my application