Special INNS Workshop: International Neural Network Society Workshop on Deep Learning Innovations and Applications

Morphological Classification of Radio Galaxies Using Semi-Supervised Group Equivariant CNNs

Authors

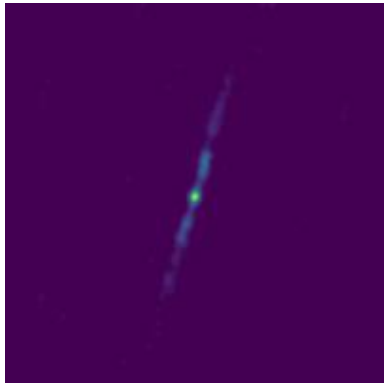
Mir Sazzat Hossain, Sugandha Roy, K. M. B. Asad, Arshad Momen, Amin Ahsan Ali, M Ashraful Amin, A. K. M. Mahbubur Rahman

Introduction

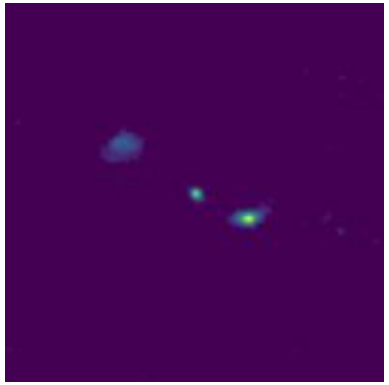
- The cosmos teems with a diverse array of galaxies, providing rich data for understanding the universe.
- Galaxy classification is crucial for understanding the formations and evolution of galaxies.
- Manual classification of galaxies is becoming impractical due to the sheer number of detected galaxies.
- The necessity of machine learning arises to handle the vast amount of data and automate the classification process.
- Current challenges include handling the diverse orientations of galaxies and efficiently using large amounts of unlabeled data.

Radio Galaxies: Types and Morphology

- Radio galaxies emit significant radiation at radio wavelengths.
- Two main types of radio galaxies based on morphology: Fanaroff-Riley Type I (FRI) and Type II (FRII).
- FRI radio galaxies have a large, bright core and diffuse, extended lobes. The lobes are elongated, connected to the core, and exhibit a fainter radio emission away from the core.
- FRII radio galaxies have brightened lobes and a fainter core. They are typically more luminous than FRI radio galaxies, with observed hotspots at the ends of the lobes.



FRI Galaxy



FRII Galaxy

Current Methods for Galaxy Classification and Drawbacks

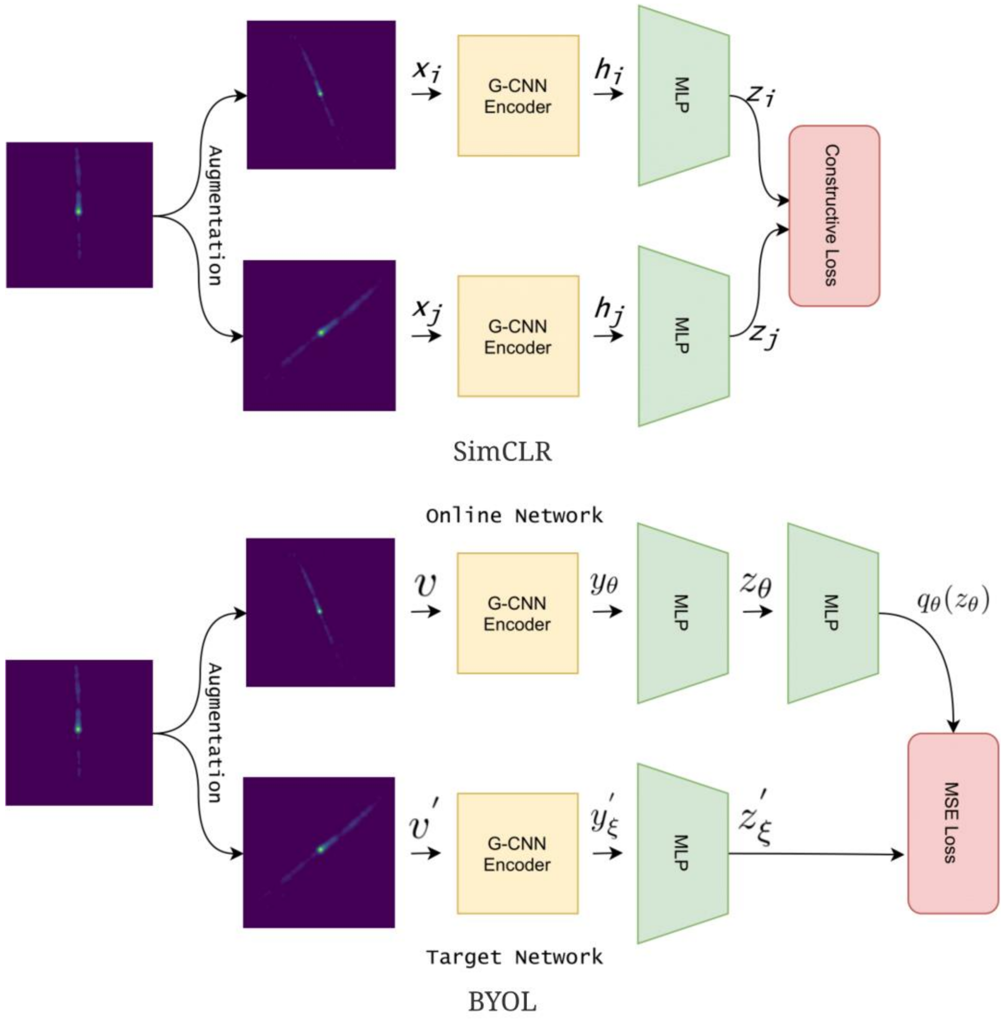
- Various machine-learning techniques, including CNNs and Region-based CNNs, are used for classifying radio galaxies.
- Challenges include handling different galaxy orientations and isometries like translation, rotation, and mirror reflection.
- Augmenting data with rotated images has limitations in improving classification accuracy.
- Effective utilization of a large amount of unlabeled galaxy data remains a challenge in the classification process.
- Semi-supervised learning holds promise in extracting meaningful information from unlabeled data, but further advancements are needed to fully exploit its potential

Objective of the study

- Develop an effective classification approach for radio galaxies using a semi-supervised learning framework.
- Utilize self-supervised learning techniques to learn robust representations from unlabeled data.
- Fine-tune the learned representations using a labeled dataset for accurate galaxy classification.
- Address the challenge of diverse galaxy orientations using Group Equivariant Convolutional Neural Networks (G-CNNs).

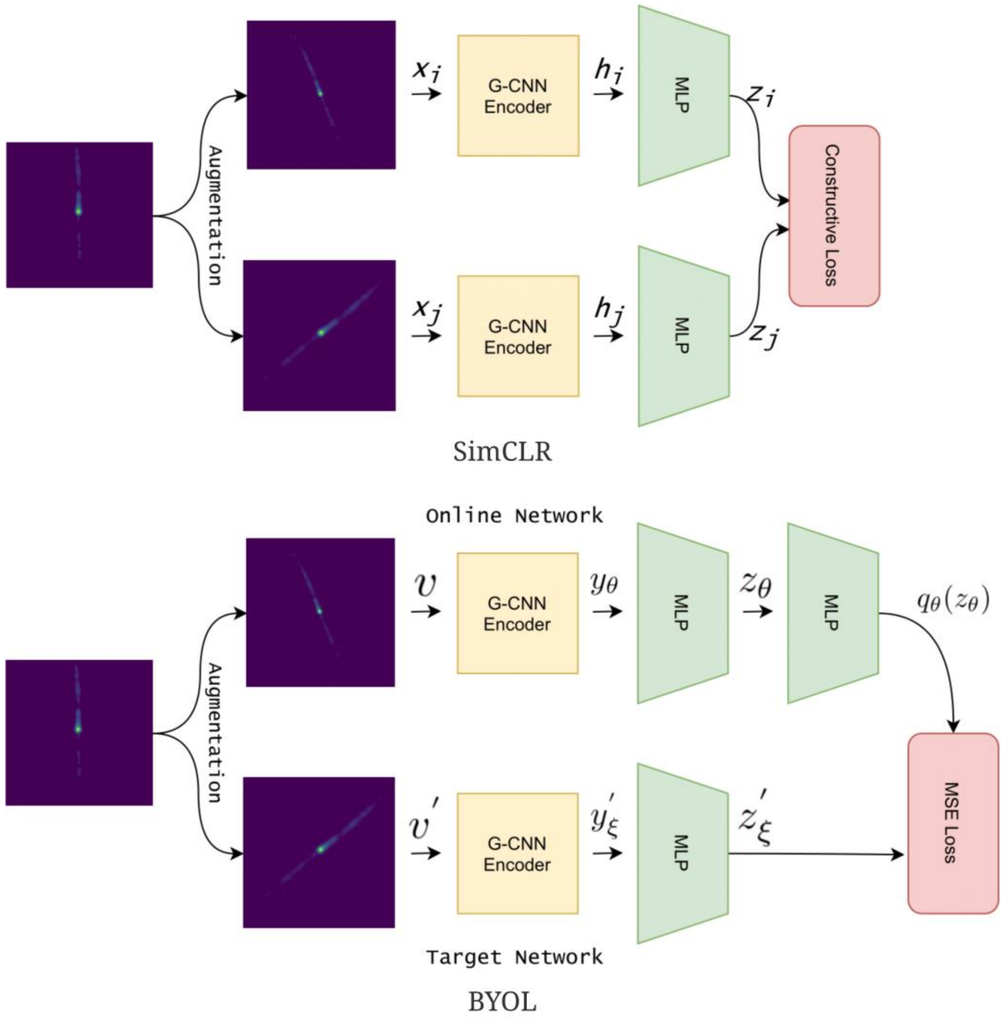
Proposed Method

- Utilize self-supervised learning techniques, such as SimCLR and BYOL, to learn representations from a large unlabeled dataset.
- Extract meaningful features from the data through self-supervised learning.
- Apply contrastive learning frameworks to enhance the model's ability to capture important patterns and structures.



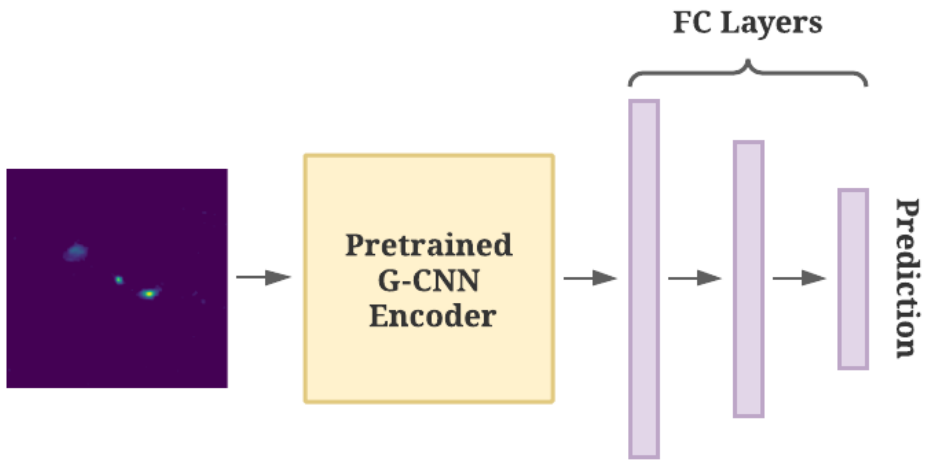
Proposed Method

- Modify the encoders of self-supervised models to handle diverse galaxy orientations.
- Employ Group Equivariant Convolutional Neural Networks (G-CNNs) as feature extractors.
- Ensure the model remains invariant to different isometries, such as translation, rotation, and mirror reflection.



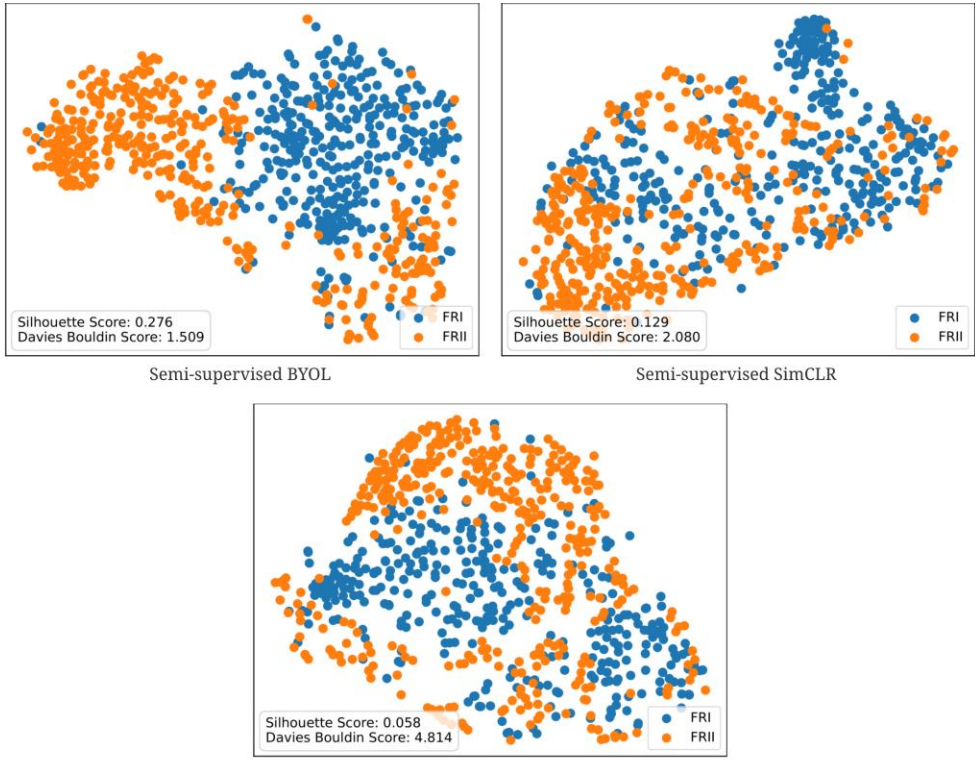
Proposed Method

- Modify the pre-trained encoder obtained from self-supervised learning.
- Replace the last fully connected layer of the encoder with a new architecture of three fully connected linear layers.
- Adapt the model to the specific task of FR classification.
- Employ a supervised learning approach with cross-entropy loss for fine-tuning.



Results - Cluster Quality Analysis

- Visualizations of representations obtained from fine-tuned encoders show distinct clustering of FRI and FRII classes
- Semi-supervised models (BYOL and SimCLR) exhibit significantly improved cluster quality compared to the supervised model
- Silhouette Score and Davies Bouldin Score confirm the effectiveness of the semi-supervised models in capturing meaningful patterns and structures



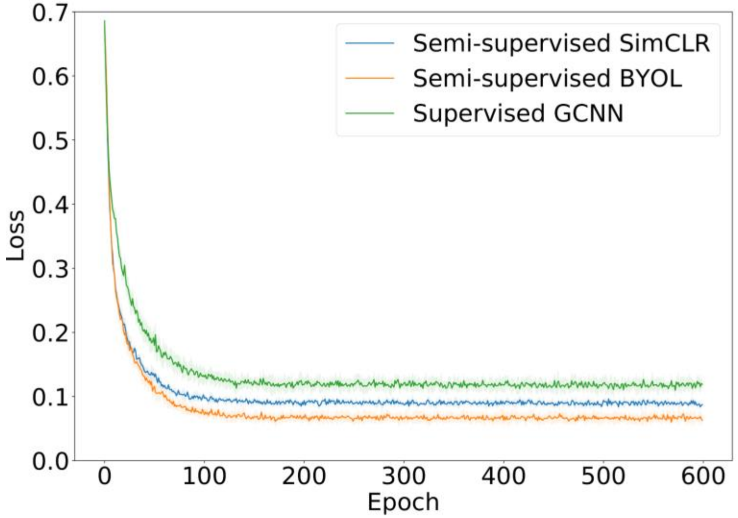
Semi-supervised BYOL

Semi-supervised SimCLR

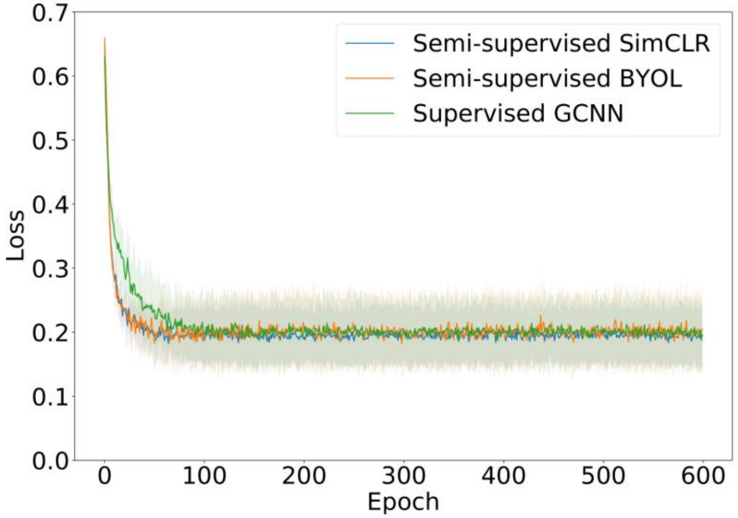
Supervised G-CNN

Results - Convergence Analysis

- Evaluated convergence during fine-tuning using 5-fold cross-validation on Dataset-F.
- Rapid convergence observed in training and validation loss plots.
- Fine-tuned encoders converged faster than the supervised G-CNN approach.
- Demonstrates efficiency and effectiveness of our semi-supervised learning approach for FR classification.



Train Loss



Validation Loss

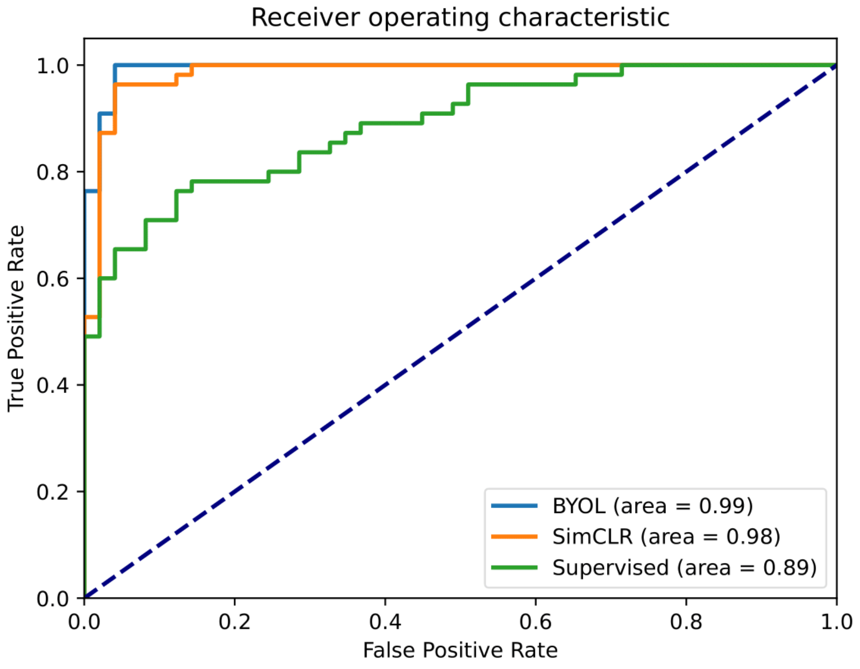
Results - Performance Comparison

Table 3. Performance comparison between Semi-supervised and Supervised methods; The table illustrates the superiority of our Semi-supervised models over the state-of-the-art supervised method across various classification metrics

		FRI			FRII		
	Accuracy[%]	Precision	Recall	f1-score	Precision	Recall	f1-score
Semi-supervised SimCLR	95.77 ± 0.90	**0.98 ± 0.061**	0.93 ± 0.018	0.95 ± 0.011	0.94 ± 0.013	**0.98 ± 0.014**	0.96 ± 0.009
Semi-supervised BYOL	**97.12 ± 0.40**	0.97 ± 0.008	0.96 ± 0.009	**0.97 ± 0.005**	0.96 ± 0.007	0.98 ± 0.008	**0.97 ± 0.004**
Supervised G-CNN	94.80 ± 0.90	0.93 ± 0.012	**0.96 ± 0.010**	0.94 ± 0.009	**0.96 ± 0.009**	0.94 ± 0.012	0.95 ± 0.009

Results - ROC Analysis and Statistical Significance

- Utilized ROC curves and AUC scores for performance evaluation.
- AUC scores of 0.99 (BYOL) and 0.98 (SimCLR) indicate accurate distinction between radio galaxy classes.
- Minimal false positives ensure correct identification of radio galaxies.
- Statistical t-test shows significant improvement in performance compared to supervised G-CNN.
- t-test for semi-supervised BYOL: t-value of approximately -3.47, p-value of approximately 0.0038.



Conclusion

- Our novel approach for classifying radio galaxies demonstrated significant effectiveness.
- Fine-tuning the pre-trained encoder with limited labeled data improved performance over traditional supervised methods.
- Our semi-supervised models outperformed the supervised model in accuracy, convergence, and ability to distinguish between classes.
- Our work highlights the potential of semi-supervised learning in radio galaxy classification and encourages further research in the field.

Thank You