Jet Propulsion Laboratory
California Institute of Technology

PDS Cartography and Imaging Sciences Node
Jet Propulsion Laboratory U.S. Geological Survey

Deep Ensemble MERNet: Recent Advances for the Content-Based Classification of MER Pancam Images

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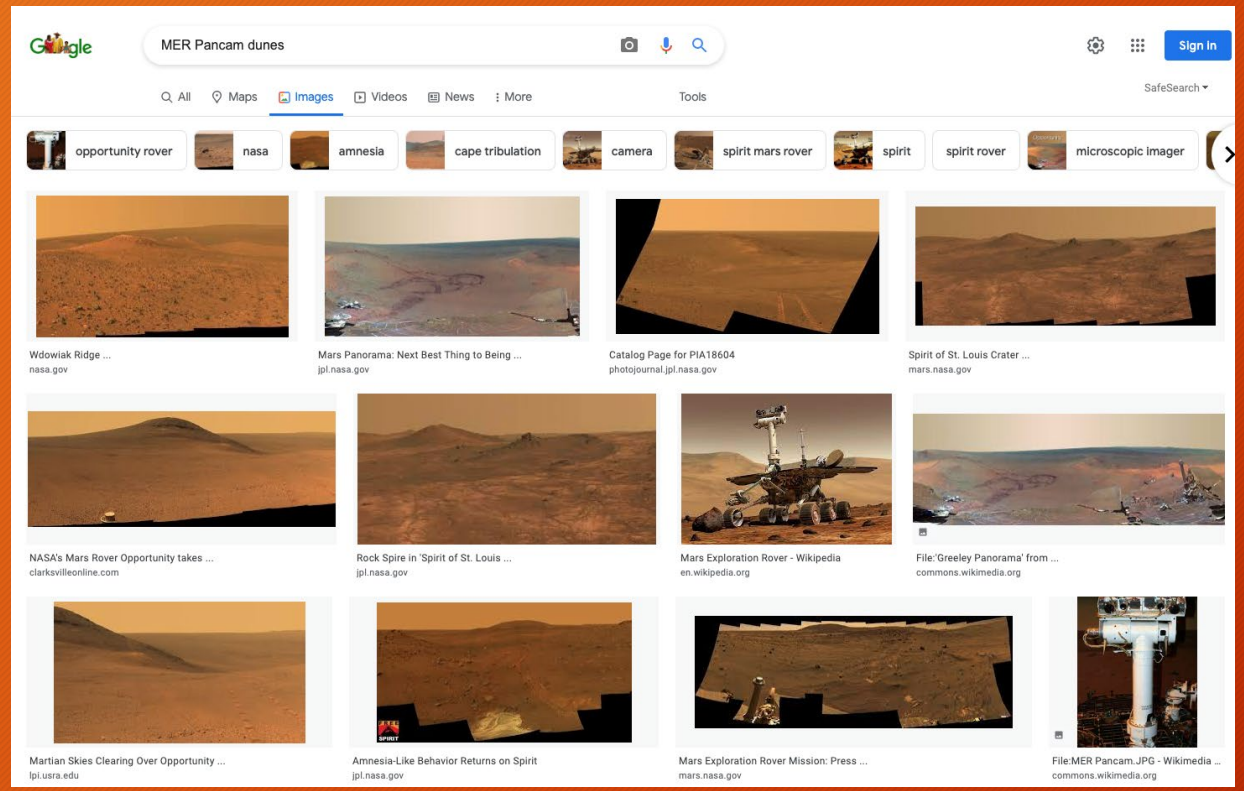
Current PDS Data Set Collections

- 7.1M - Mars Exploration Rover (MER)
- 17M - Mars Science Laboratory (MSL)
- 4.1M – Lunar Reconnaissance Orbiter (LRO)
- 2.2M - Mars Reconnaissance Orbiter (MRO)
- More …

How to Find What You Want?

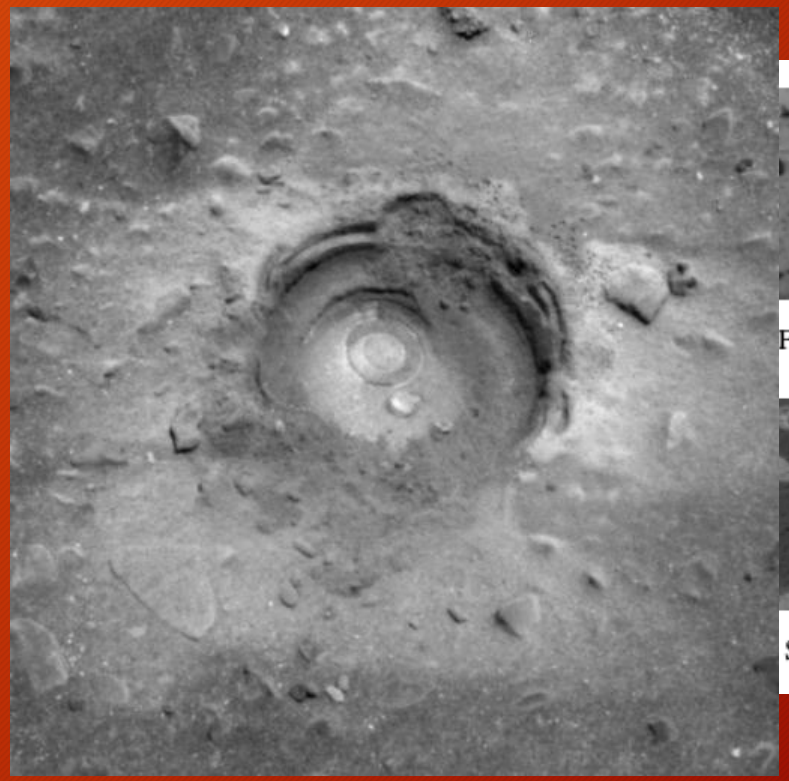
Google search

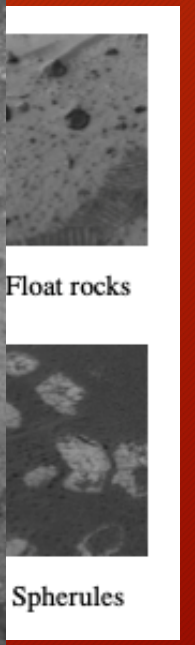


Manual examination

Machine Learning Solution

Transfer learning





MERNet

The amount of labeled images required to train machine learning classifier is significantly reduced

Data Set

MERNet data: http://doi.org/10.5281/zenodo.4302760

- MER Pancam data set
  - 3,004 Pancam images
  - 26 classes – imbalanced representations
  - Multi-label classifier
  - Image resolution:
    - 512x512 pixels
    - 1024x1024 pixels
  - Train/validation/test split (60%/15%/25%)
  - Augmentation methods
    - Rotation
    - Skewing
    - Shearing
  - Images were labeled using Zooniverse.org
  - Labeled data set was published on Zenodo

Classes:
- Rover Tracks
- Soil Trench
- Clasts
- Bright Soil
- Spherules
- Nearby Surface

Figure: multi-label example for MERNet

MERNet V1 Classifier

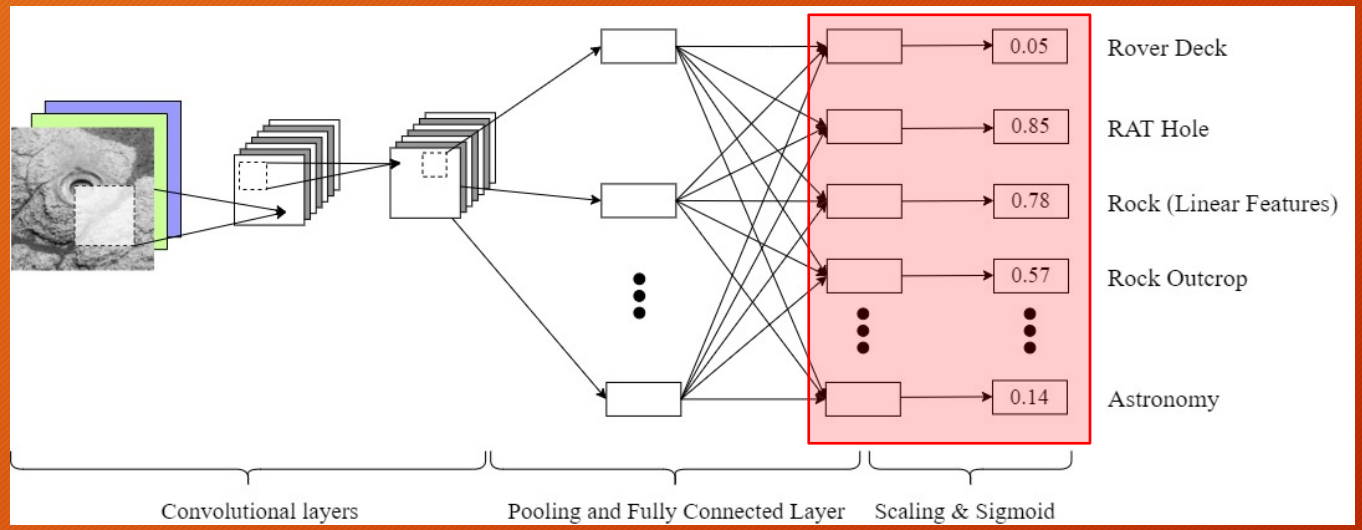
- Steven Lu, et al., Content-based Classification of Mars Exploration Rover Pancam Images, LPSC, 2021

- Methods
  - Finetuned VGG-16 Convolution Neural Network (CNN) architecture
  - Classifier chain approach: explicitly model the dependencies between classes
  - Classifier calibration approach: calibrate the classifier's self-reported posterior probabilities

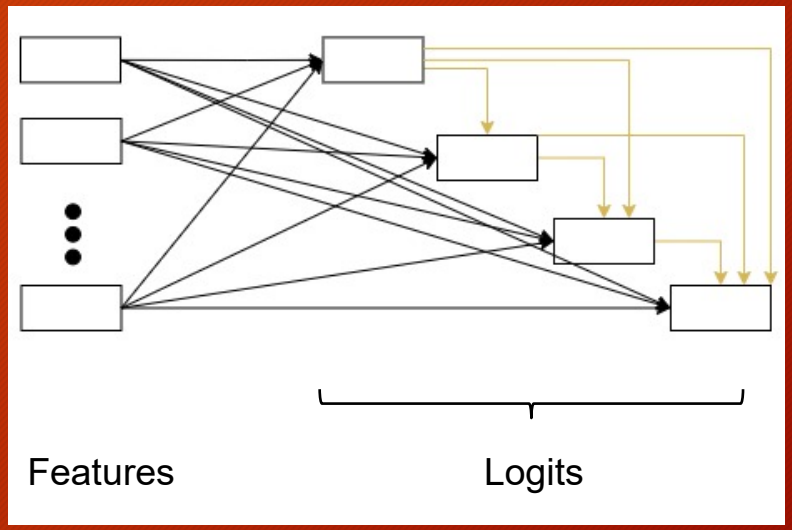
- Results
  - Majority classes (> 10%): good performance
  - Minority classes (5 – 10%): acceptable performance, but lower than majority classes
  - Extreme minority classes (< 5%): low performance

Classifier Chain

VGG-16 Model Architecture[1]



Classifier Chain[2]



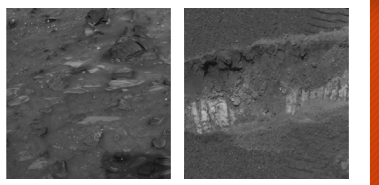
The classes placed later in the chain tend to benefit more

[1]Simonyan, Karen, and Andrew Zisserman. "Very deep convolutional networks for large-scale image recognition." *arXiv preprint arXiv:1409.1556* (2014).

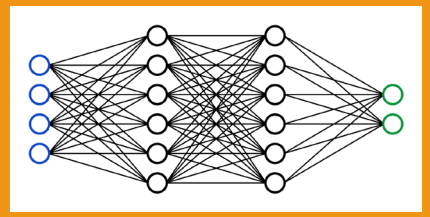
[2]Read, Jesse, et al. "Classifier chains for multi-label classification." Machine learning 85.3 (2011): 333.

Deep Ensemble MERNet

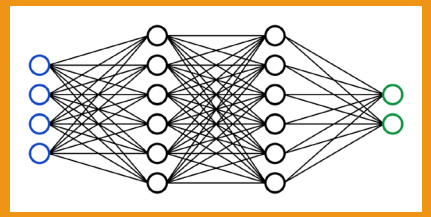
Training images



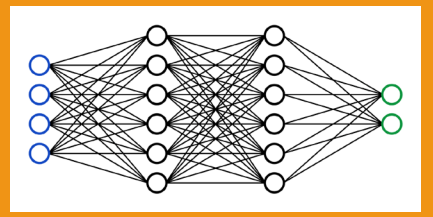
CNN classifier 1



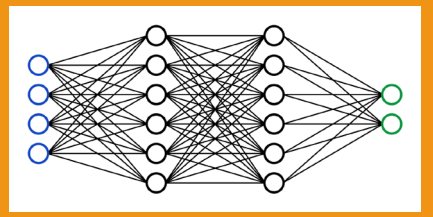
CNN classifier 2



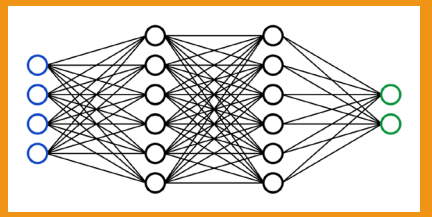
CNN classifier 3



CNN classifier 4



CNN classifier 5



Combine outputs from individual classifiers

Final classification results

Deep Ensemble MERNet

Deep Ensemble MERNet

Individual classifiers

- Classifier 1
  - Single classifier chain (specific to general order)
  - Binary cross entropy loss with mean reducing method
- Classifiers 2 - 4
  - Single classifier chain (general to specific order)
  - Binary cross entropy loss with mean/sum reducing method
  - Dropout operation
- Classifier 5
  - 10 classifier chains (using hierarchical clustering algorithm)

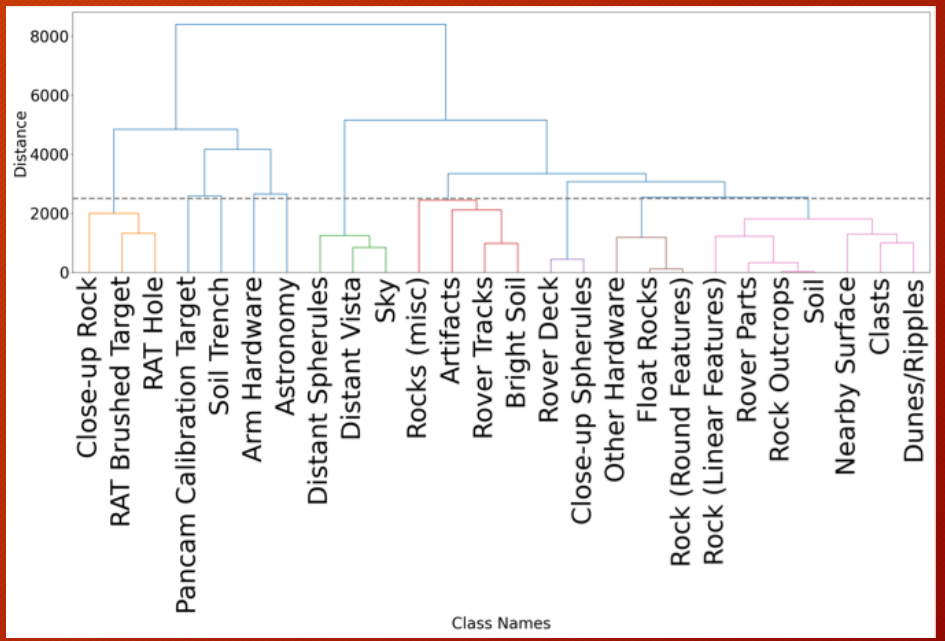


Figure: Dendrogram of 10 classifier chains

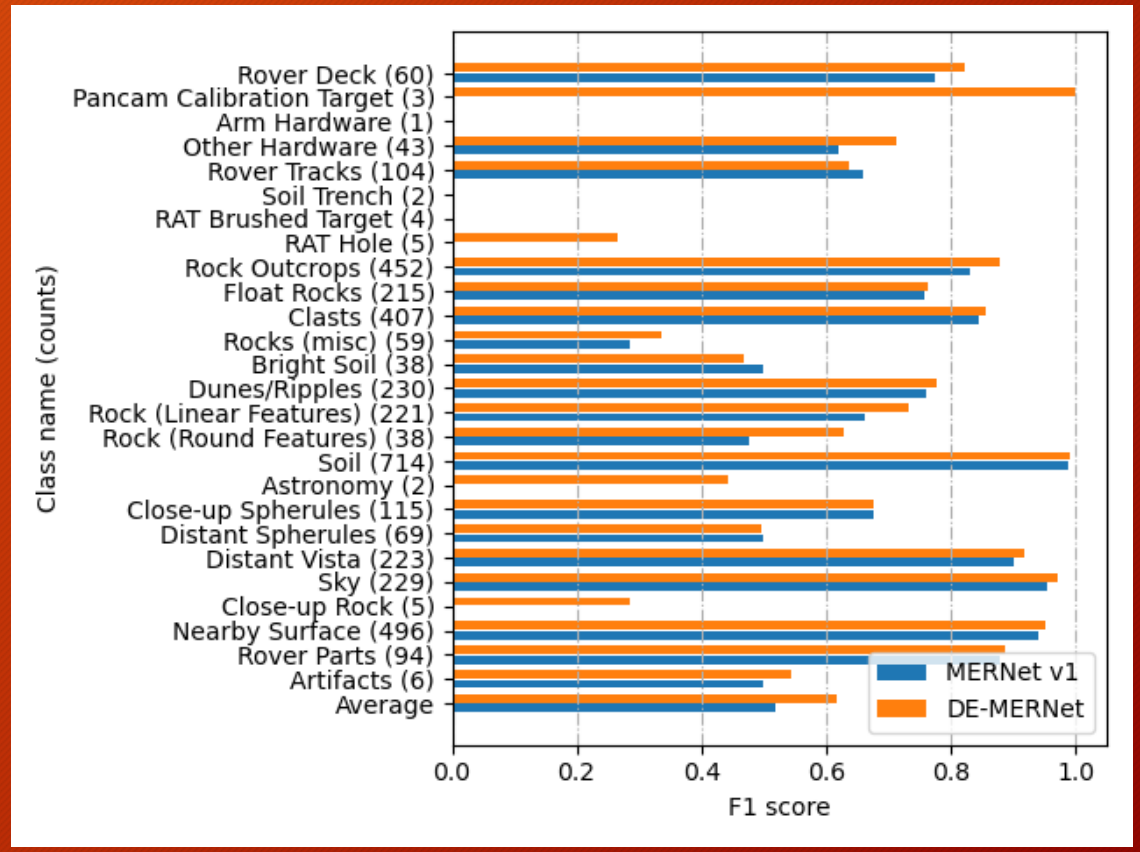
Deep Ensemble MERNet

Combine Outputs from Individual Classifiers

- Average
- Majority vote
- Weight by F1 score
- Weight by best performance

DE-MERNet Classifier Evaluation

- Evaluation metrics: precision, recall, and F1 score
- Average F1 score is 61.7% (9.7% improvement comparing to MERNet v1 classifier)
- Zero F1 score classes were reduced from 7 to 3



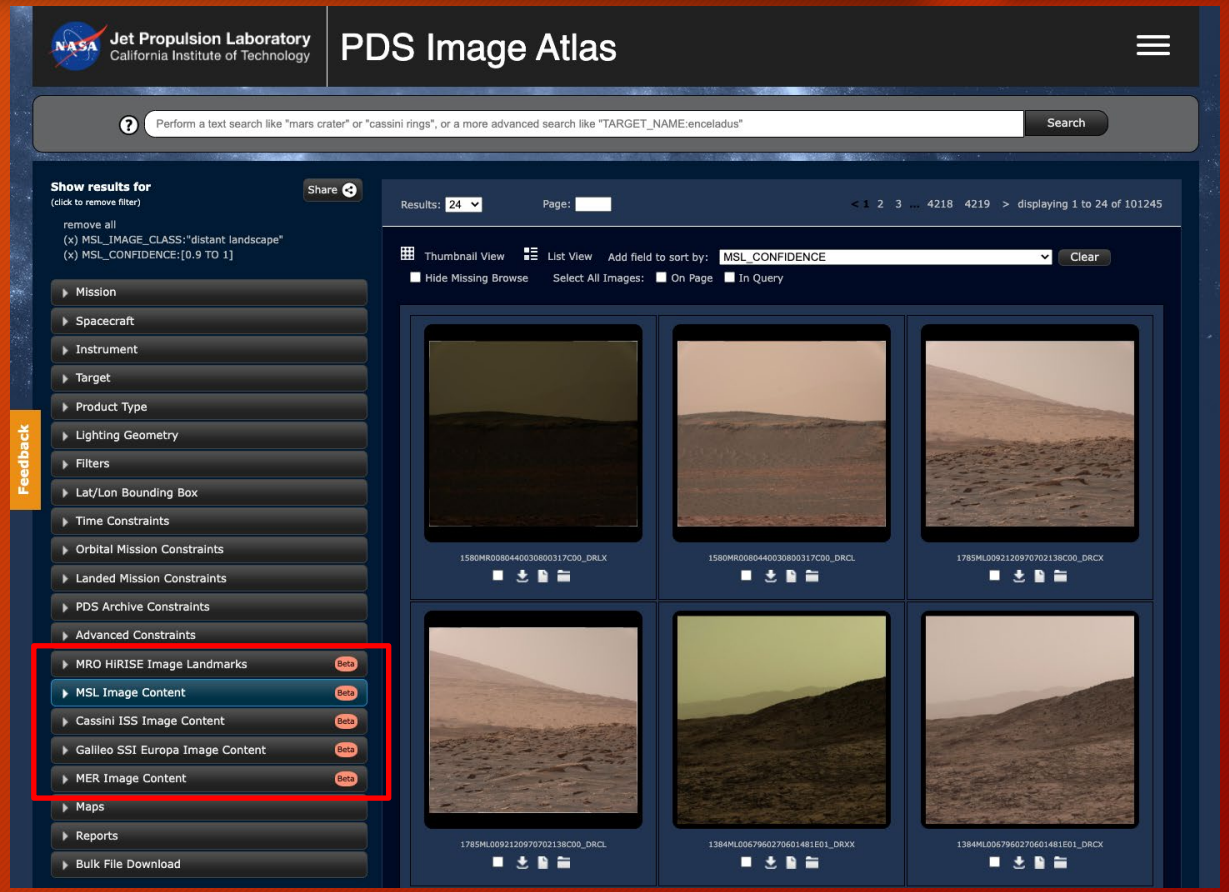
PDS Image Atlas[1]

Existing image content-based search capability:

- MRO HiRISE images
- MSL Mastcam and MAHLI images
- MER Pancam images
- Cassini ISS images
- Galileo SSI Europa images

Will be added in the near future:

- LRO LROC images
- Mars 2020 images



[1]http://pds-imaging.jpl.nasa.gov/search/

Summary

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- Transfer learning can be used when the labeled data set is small
- Classifier chain and ensemble approaches can be used to improve the performance of minority classes when the labeled data set is severely imbalanced
- DE-MERNet results were deployed on PDS Image Atlas
  - PDS Image Atlas: http://pds-imaging.jpl.nasa.gov/search/
- Future work
  - Incorporate ML interpretability methods in our workflow
  - LRO LROC classifier; Mars 2020 classifier

Thank you: PDS Cartography and Imaging Sciences Node