National Aeronautics and Space Administration

Enhancing JPL's Mission Science Planning & Data Discovery Capabilities with Machine Learning

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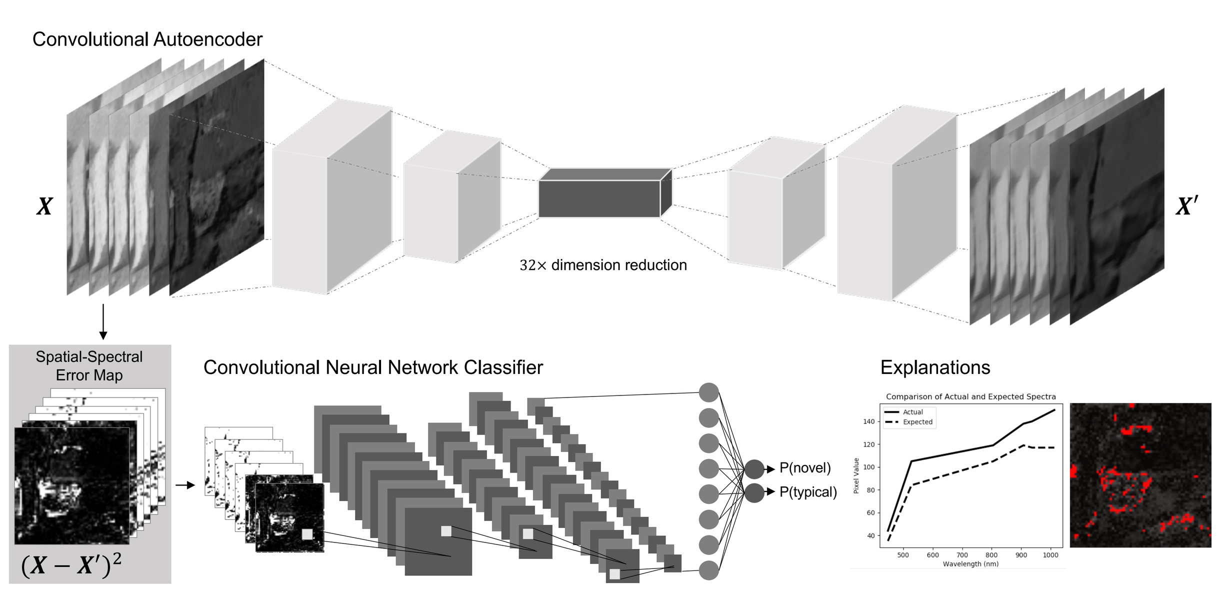
Program: SURP

Project Objective:

The objective of this task was to collaborate with Arizona State University to develop software technologies that leverage **machine learning** to enhance JPL's mission planning and data discovery capabilities. Specifically, we focused on methods for **novelty or anomaly detection** in data returned by planetary missions.

FY'19 Results: Supervised Novelty Detection



This figure shows the **Selections based on Autoencoder Modeling of Multispectral Image Expectations (SAMMIE)** system for novelty detection [4]. First, SAMMIE processes each 6-channel (multispectral) Mastcam image through a convolutional autoencoder and attempts to reconstruct it. The error map captures novel areas that could not be reconstructed. Next, a convolutional neural network is used to classify the error map content as "novel" or "typical". Finally, SAMMIE generates explanations that contrast the observed pixel spectra from what the model expected. Pixels with large deviation are marked in red.

SAMMIE performs well at detecting novel areas, but it requires both positive (novel) and negative (typical) examples to train the classifier. It can be difficult or impossible to provide examples in advance of all kinds of novelty that will be encountered, and a supervised method may be limited to detecting novelties seen during training. Therefore, we also investigated purely unsupervised methods that do not require any labels.

FY'19 Results: Unsupervised Novelty Detection

Data. We used 6-channel (multispectral) thumbnail images collected by the Mastcam imager on the Mars Science Laboratory rover. Thumbnails are available to inform tactical planning before the full products are downlinked and calibrated. This data set includes 156 images that were manually annotated (see red bounding boxes in Fig. 1) to highlight novel areas of interest, for evaluation purposes (not training). We further grouped these images into eight novelty categories (see Fig. 3).

Methods. We trained several novelty detection methods that require only a large collection of "typical" images (no novel examples are required). These include a convolutional autoencoder (CAE), generative adversarial network (GAN), principal component analysis (PCA), and Reed-Xiaoli (RX).

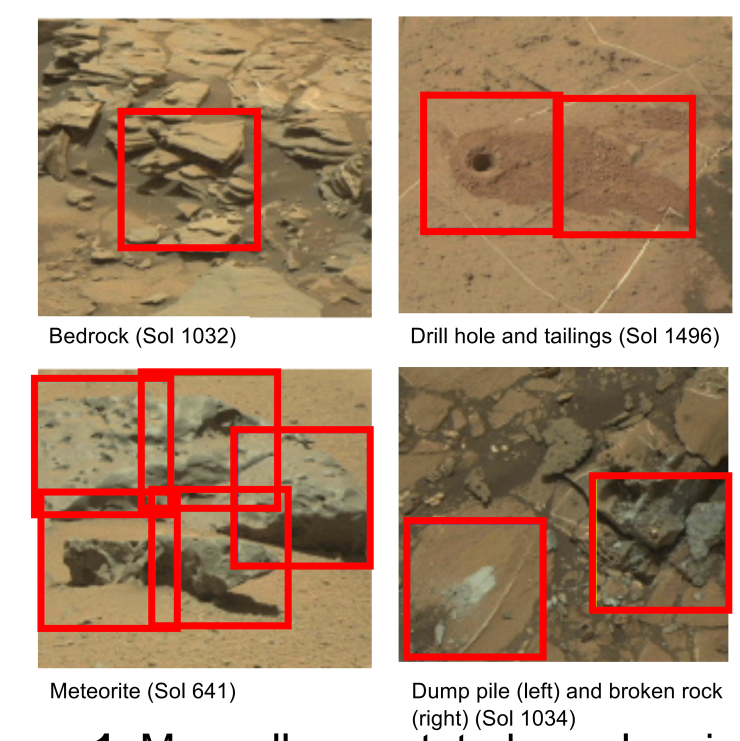
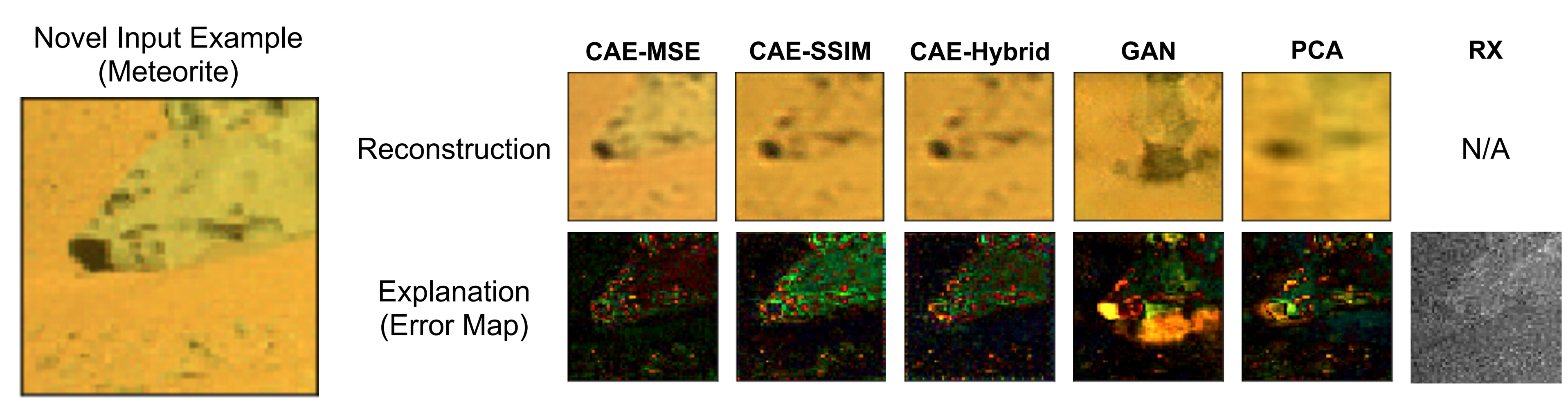


Figure 1. Manually annotated novel regions.



Results. Shown above (Fig. 2) is the novel region highlighted by each method on an image of a meteorite, which we expect to be considered "novel". Autoencoder methods most clearly indicate the meteorite as the novel part of the image, whereas other methods are less obvious.

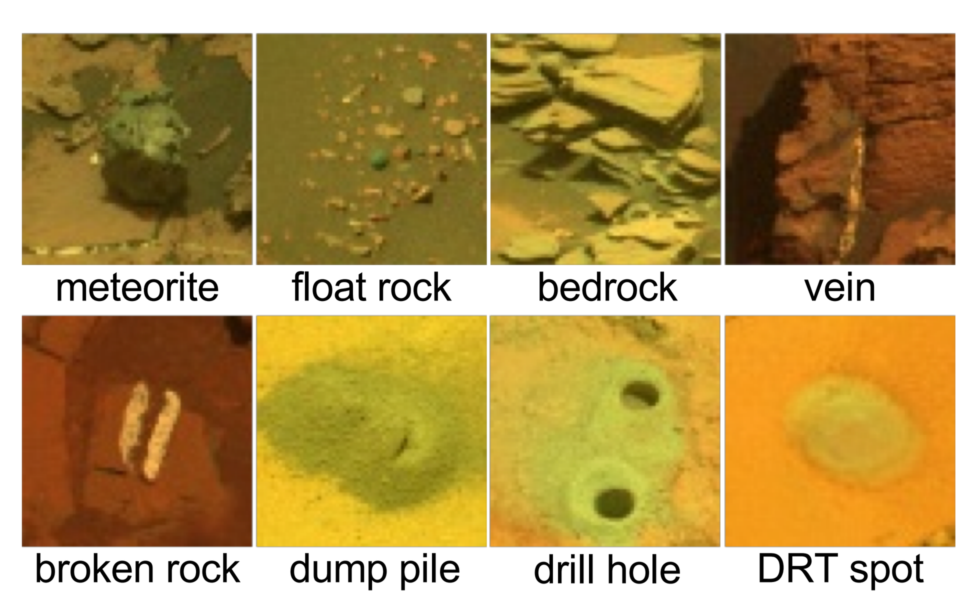


Figure 3. Eight categories of novel geology in the Mastcam multispectral image data set.

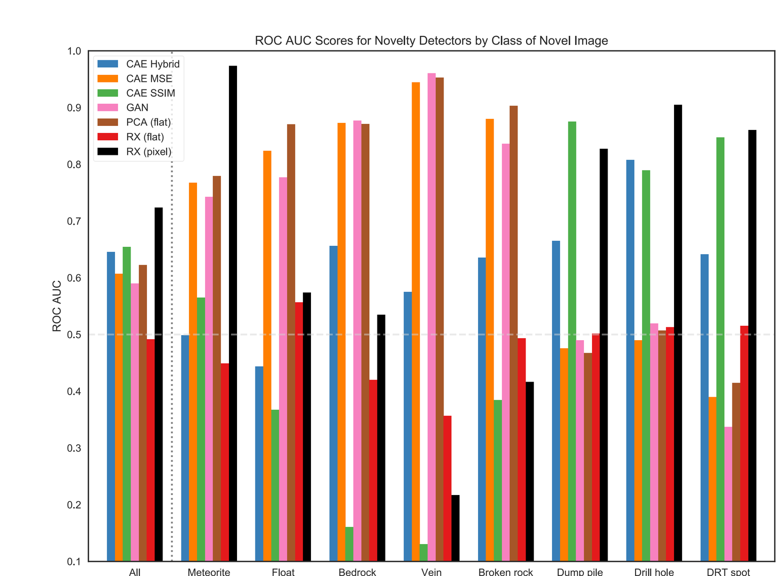


Figure 4. RX and CAE trained with structural similarity (SSIM) loss were best for detecting dump piles, drill holes, and DRT spots as novel (*morphological* novelties) while the GAN, CAE with MSE loss, and PCA methods were best for detecting the remaining classes (*spectral* novelties).

Benefits to NASA and JPL (or significance of results):

- Enables application of cutting-edge data analysis methods to image data sets from rovers and orbiters for novelty and change detection
- Provides tools to help decrease mission planning time/effort and meet shorter timelines
- Direct application to MSL and Mars 2020 rover missions
- Future potential use by Mars Sample Return, Europa Lander

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Publications:

[1] Hannah R. Kerner, Danika F. Wellington, Kiri L. Wagstaff, Samantha Jacob, James F. Bell III, and Heni Ben Amor, "Novelty detection for multispectral planetary images," *Fall Meeting of the American Geophysical Union*, 2018.

[2] Hannah Kerner, Kiri Wagstaff, Brian Bue, and Heni Ben Amor, "Change detection on Mars: A deep learning approach," *NeurIPS Women in Machine Learning Workshop*, 2018.

[3] Hannah Kerner, Danika Wellington, Kiri Wagstaff, Jim Bell, and Heni Ben Amor, "Novelty detection for multispectral images with application to planetary exploration," *IMA Workshop on Recent Advances in Machine Learning and Computational Methods for Geoscience*, 2018.

[4] Hannah R. Kerner, Danika F. Wellington, Kiri L. Wagstaff, James F. Bell, and Heni Ben Amor, "Novelty detection for multispectral images with application to planetary exploration," *Innovative Applications of Artificial Intelligence*, 2019.

[5] Hannah Kerner, Kiri Wagstaff, Brian Bue, Danika Wellington, Sammie Jacob, Jim Bell, and Heni Ben Amor, "Comparison of novelty detection methods for multispectral images from the Mastcam instrument onboard Mars Science Laboratory," *4th Planetary Data Workshop*, 2019.

[6] Hannah R. Kerner, Kiri L. Wagstaff, Brian D. Bue, Patrick C. Gray, James F. Bell III, and Heni Ben Amor, "Toward generalized change detection on planetary surfaces with convolutional autoencoders and transfer learning," *Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, in press, 2019.

[7] Hannah R. Kerner, Kiri L. Wagstaff, Brian D. Bue, Danika F. Wellington, Samantha Jacob, James F. Bell III, Chiman Kwan, and Heni Ben Amor, "Comparison of novelty detection methods for multispectral images in rover-based planetary exploration missions," under review.

[8] Hannah R. Kerner, Kiri L. Wagstaff, Brian D. Bue, Patrick Gray, James F. Bell III, and Heni Ben Amor, "Toward generalized change detection on planetary surfaces with deep learning," *Fall Meeting of the American Geophysical Union*, December 2019 (to appear).

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