Automated Surface Feature Identification in Mars Orbital Images

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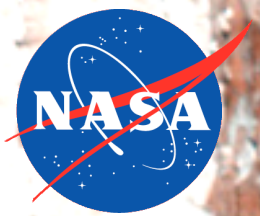
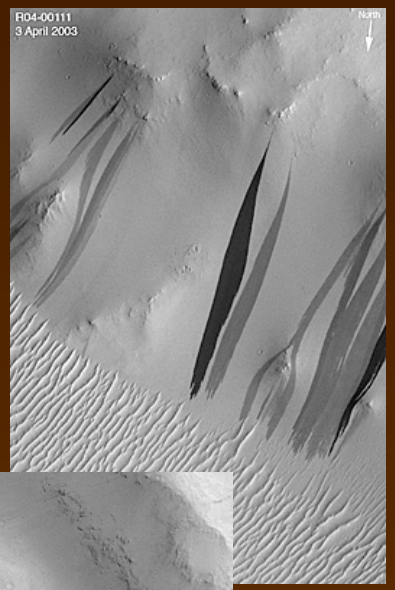
May 21, 2009



Funded by: NASA Applied Information Systems Research Program

Surface Features of Interest

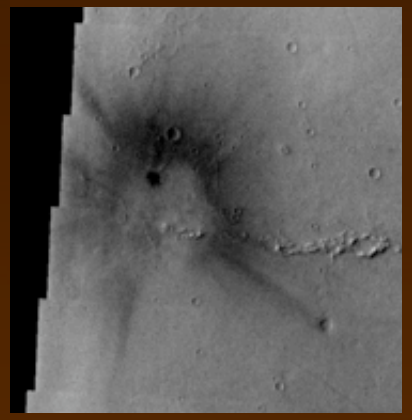
Dark slope streaks



MOC 12/2006

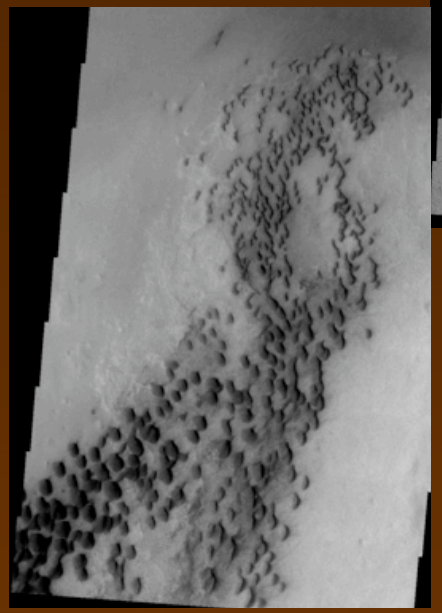
Dust devil tracks

MOC 6/2003



THEMIS 8/2008

THEMIS 10/2006



THEMIS 7/2007

> 50 Terabytes

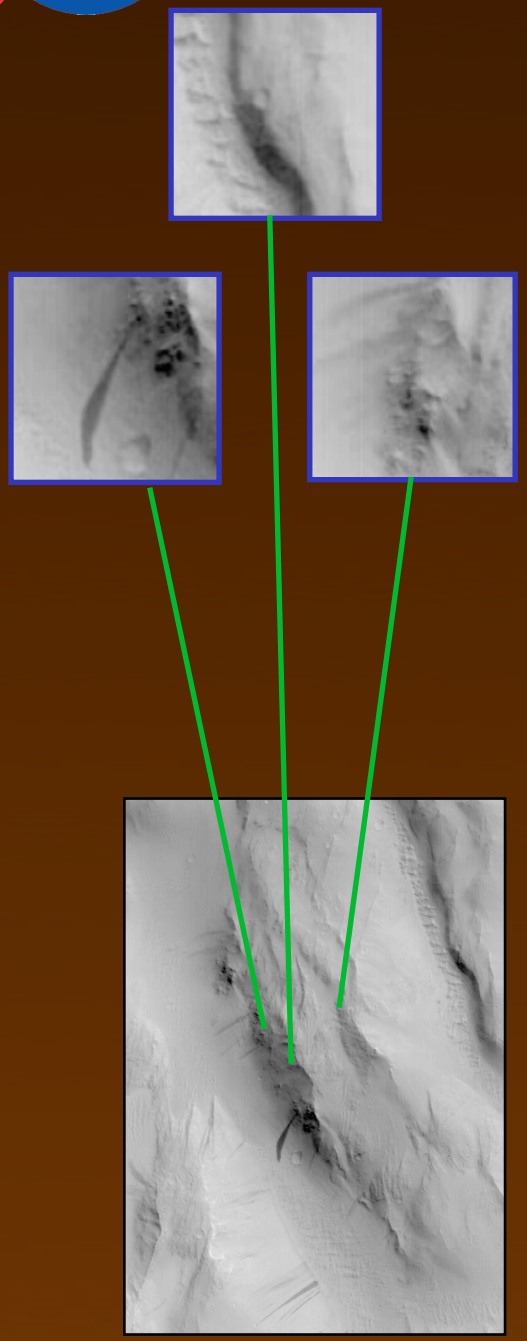
Dark Slope Streaks

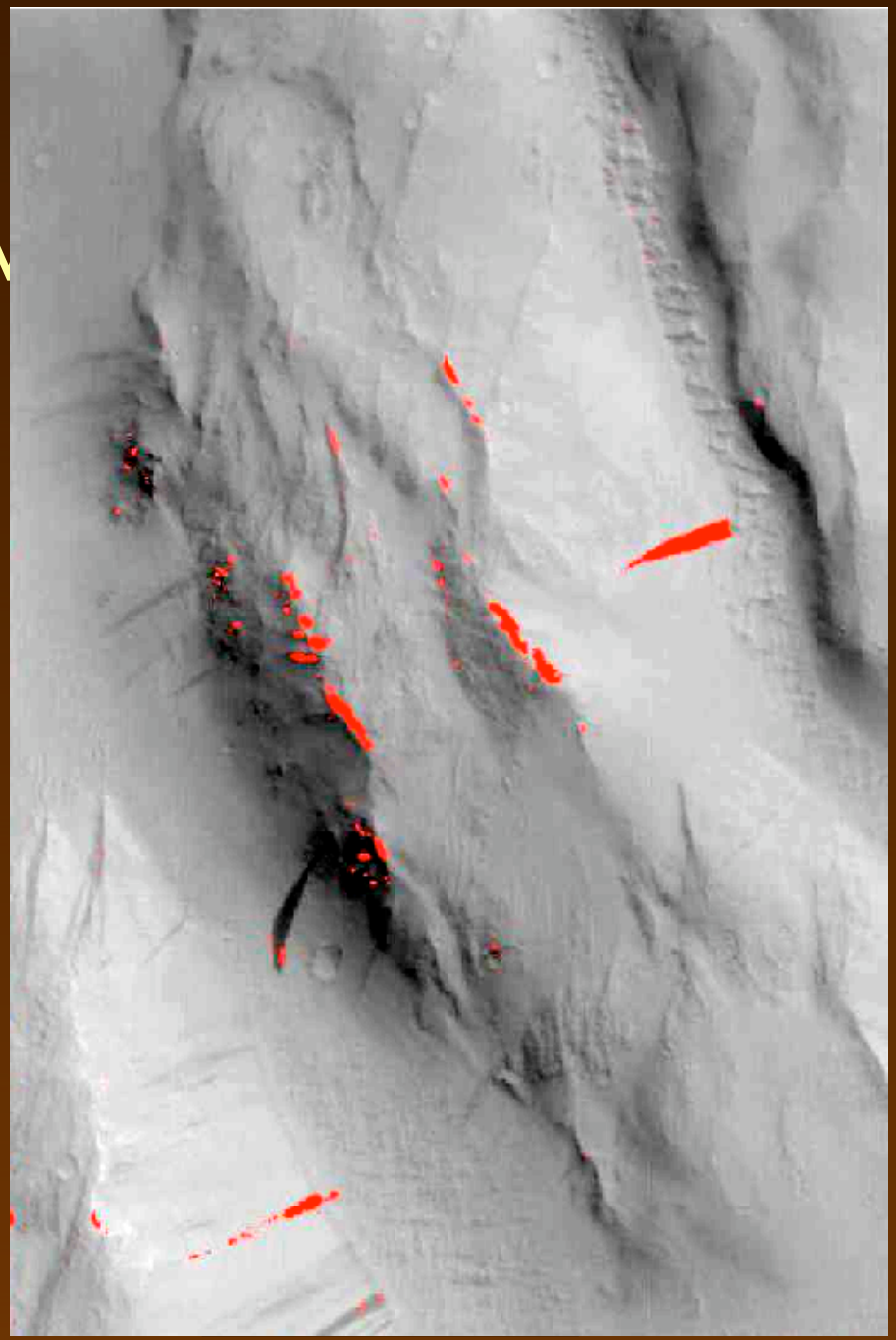
June 12, 2000

April 12, 2002

Image credit: MOC

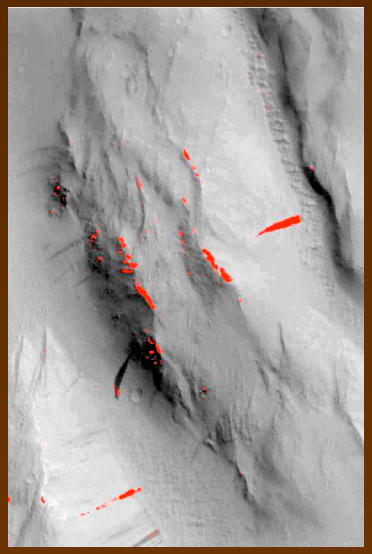
Landmark-Based vs. Pixel-Based





Dark slope streak

Dark slope streak



Landmark-Based Change Detection

Compute salience map

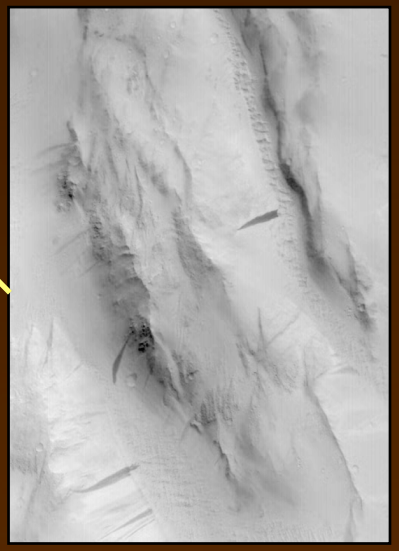
Detect landmarks

Extract attributes

Classify landmarks

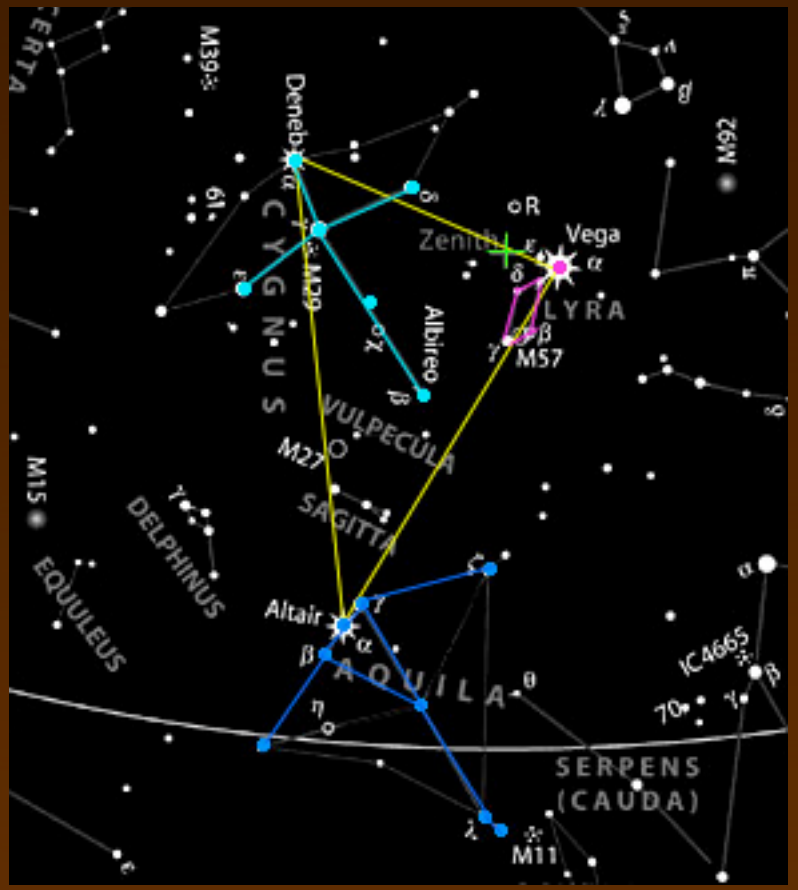
Compare landmark sets (change detection)

(in progress)

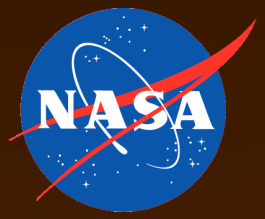


Salient Landmark Detection

- Compute salience of a region
  - How unusual is it?
  - Can we recognize it later?
- Benefits
  - Summarize a region with a few key landmarks
  - Recognize same region later without pixel-level registration
  - Not restricted to previously known types of features
  - Detect changes as new, vanished, or altered landmarks



Summer Triangle: Deneb, Vega, and Altair

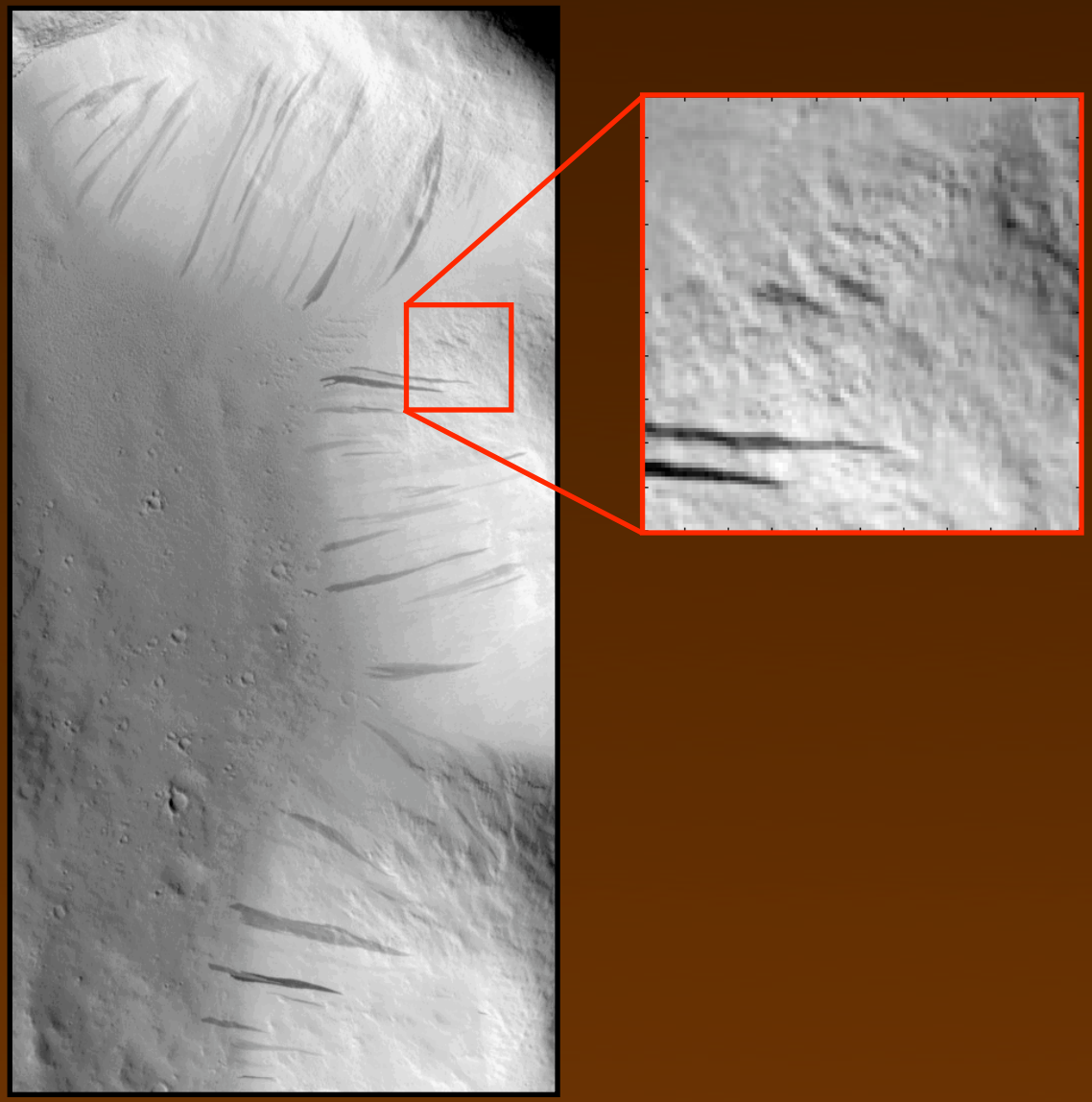


Salience

- Ideal: salience(region) = how interesting the region is
- Proxies
  - Intensity histogram: analyze distribution of pixel values
  - Covariance matrix: analyze spatial properties of region
- Salience = interest with respect to a reference (larger region, full image)

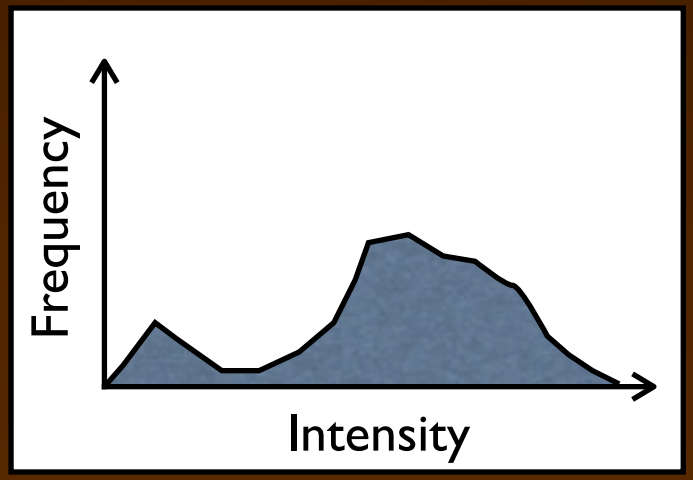
1. Intensity Histograms

- Region = vector of intensity histogram counts (no spatial)

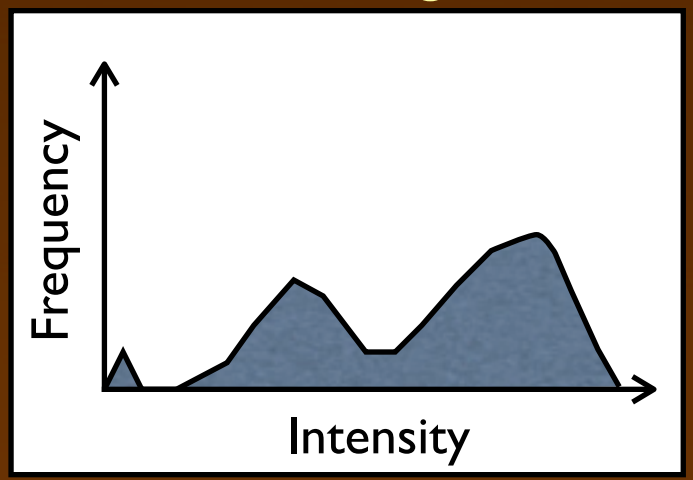


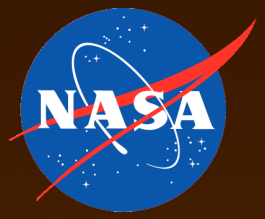
HiRISE PSP_003570_1915

Window



Full image





Histogram Salience Computation

- Entropy: How heterogeneous is the window?

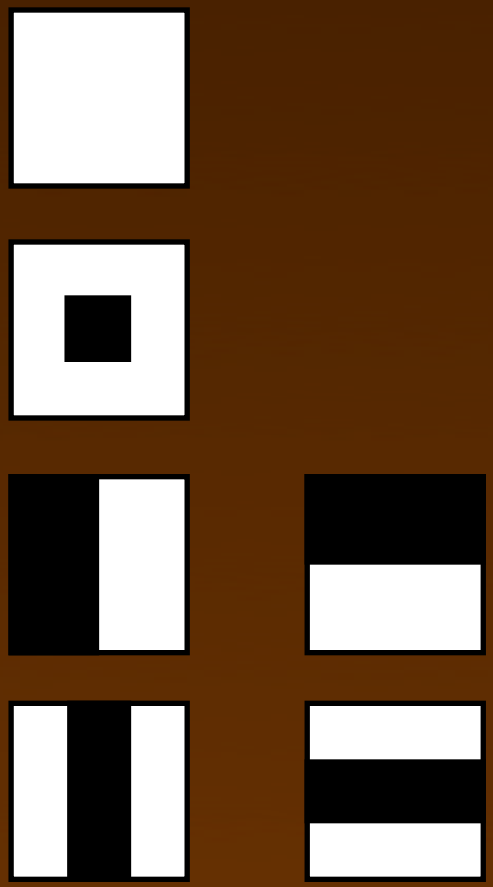
$$salience(w) = H(w) = -\sum_i w(i) \log w(i)$$

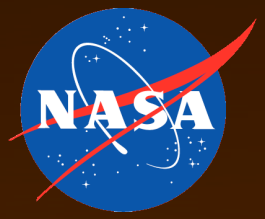
- KL-divergence: How much does a window stand out from the full image, or from a context window?

$$salience(w_1) = D_{KL}(w_1||w_2) \sum_i w_1(i) \log \frac{w_1(i)}{w_2(i)}$$

2. Covariance Descriptors

- How are image attributes related? (no intensity)
- Attributes: Haar filter values over 3x3 areas
  - Boxcar average
  - Center-surround
  - Horizontal and vertical gradient
  - Horizontal and vertical bar





Covariance Salience Computation

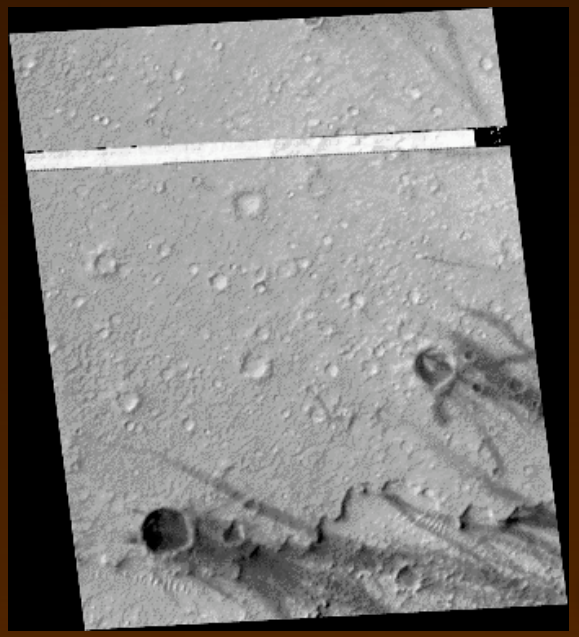
- Region = matrix of covariance values

- Covariance matrix: each attrib. vs. each other attrib.
- Distance between two covariance matrices (Tuzel et al., 2006):

$$salience(w_1) = \rho(C_1, C_2) = \sqrt{\sum_i \ln^2 \lambda_i(C_1, C_2)}$$

- Salience of a region:
  - Distance between region and full image
  - Distance between region and context window

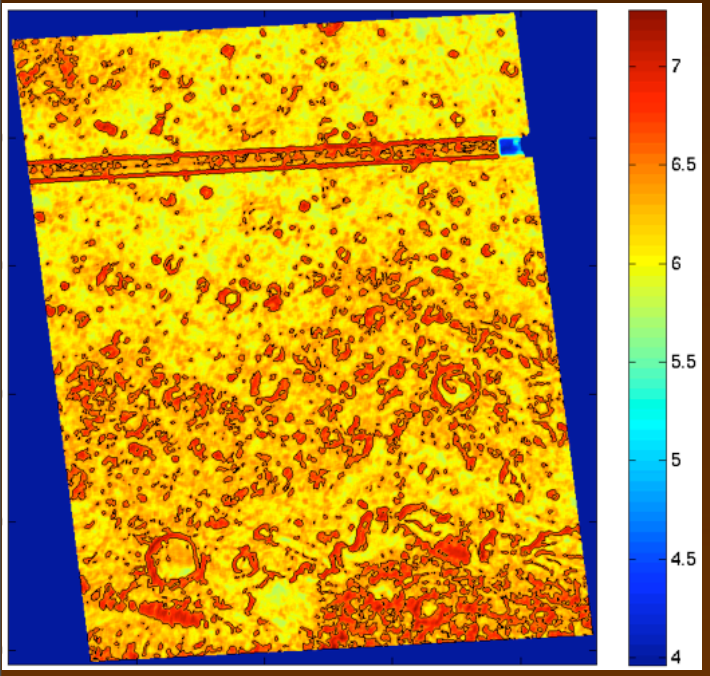
Salience Maps



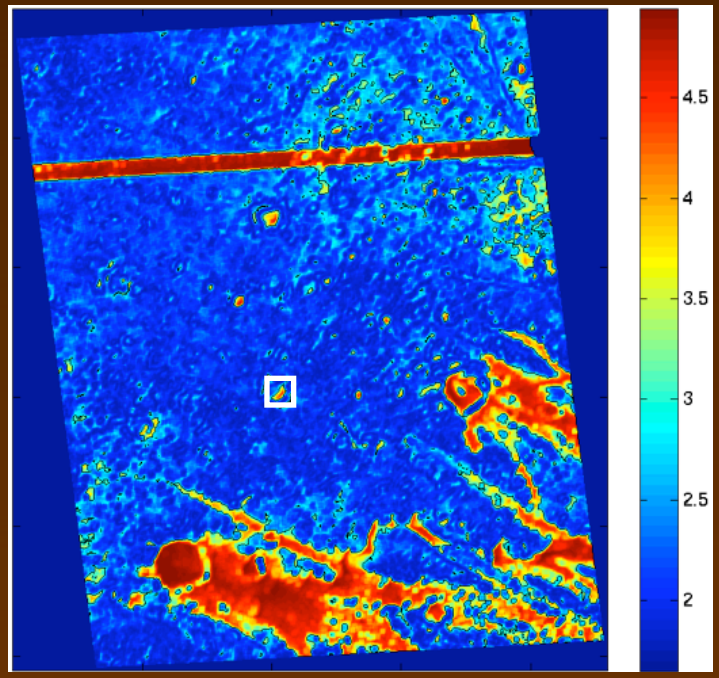
MOC R0201153

Compute salience map

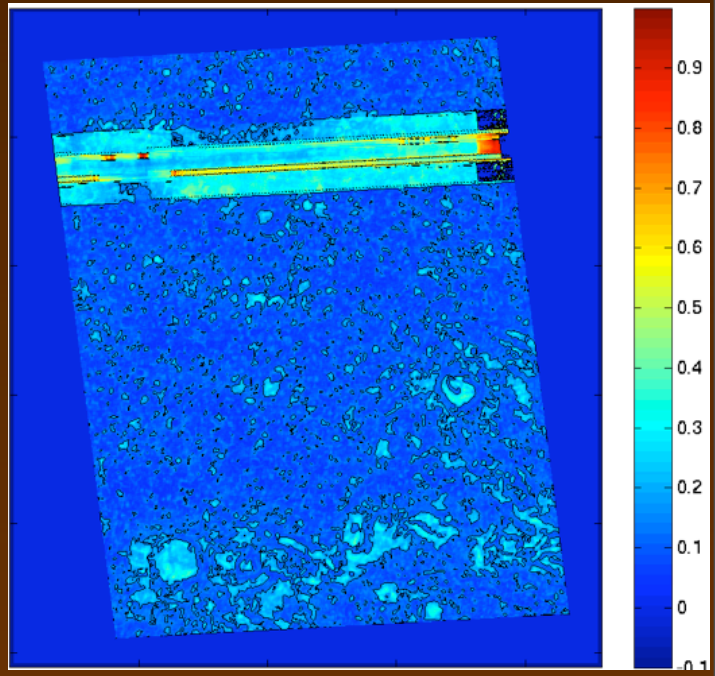
Entropy



KL-divergence



Covariance

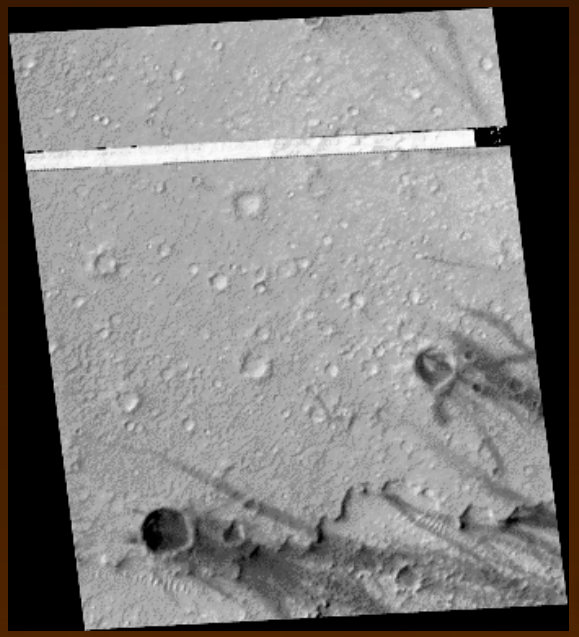


Window size = 20 x 20 pixels

Salience Maps

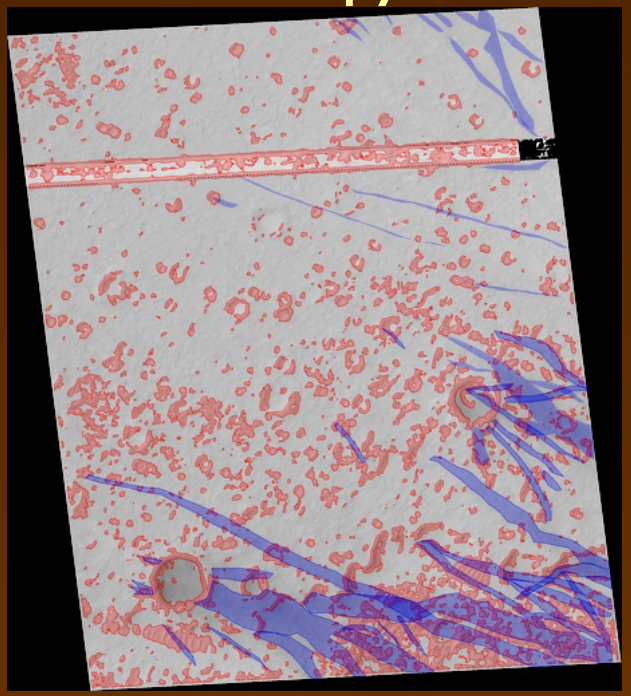
Detect landmarks

- Use a threshold to identify landmarks

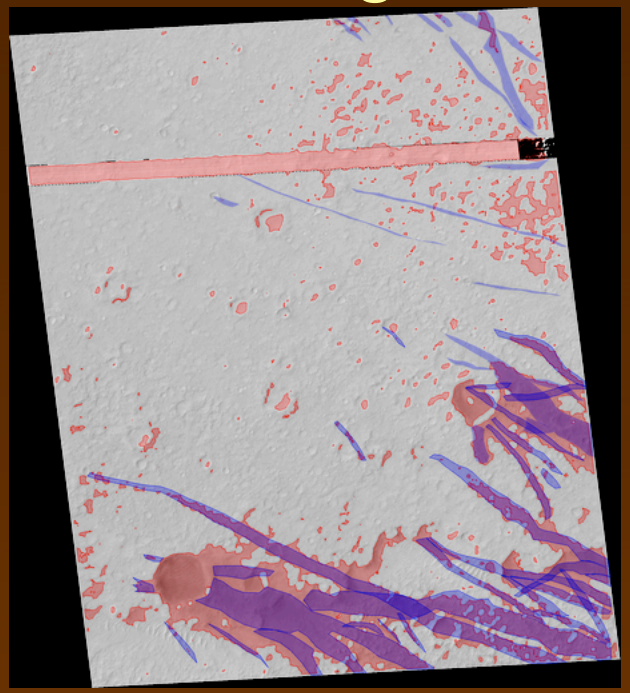


MOC R0201153

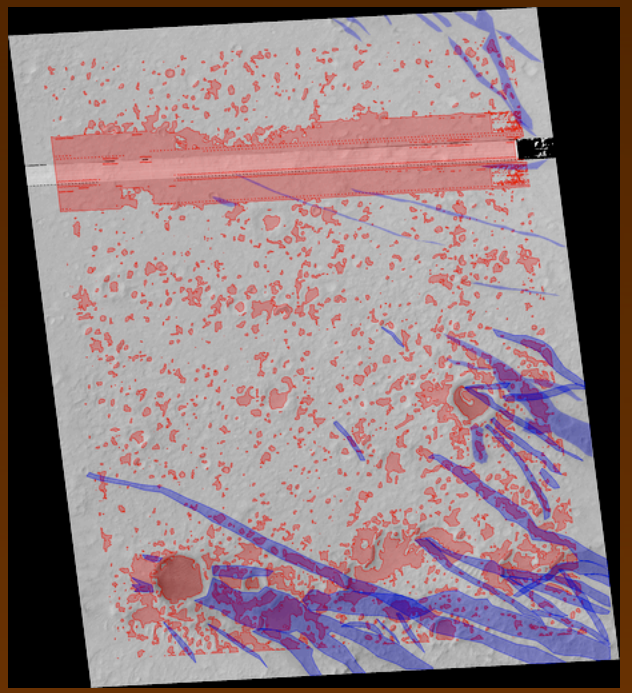
Entropy



KL-divergence



Covariance

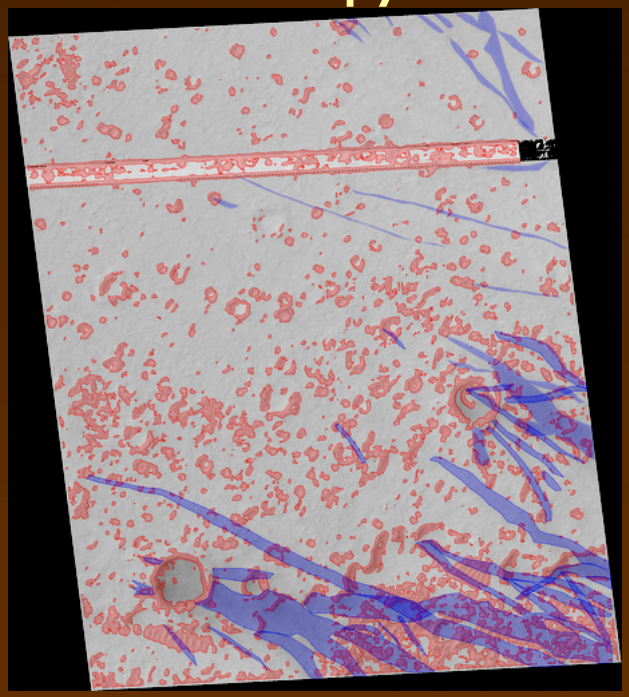


Window size = 20 x 20 pixels

Evaluating Landmark Detection

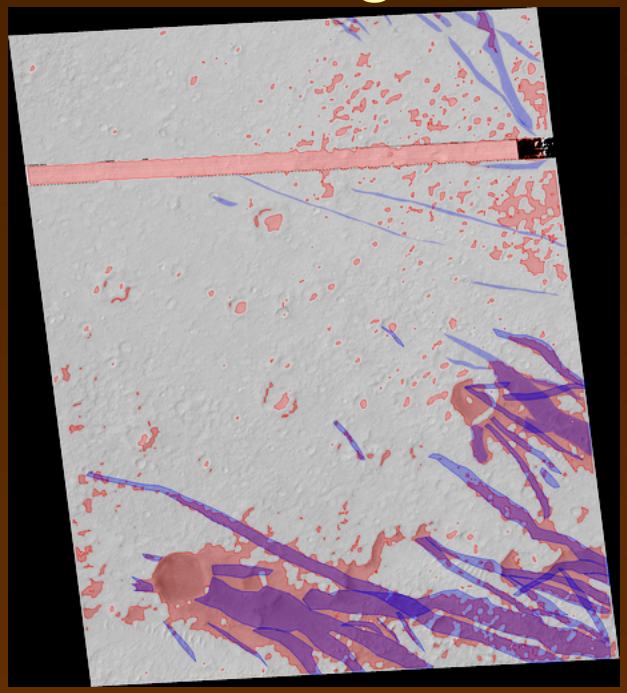
- True positives: pixels in manual and detected landmarks
- False positives: pixels in detected but not manual landmarks

Entropy



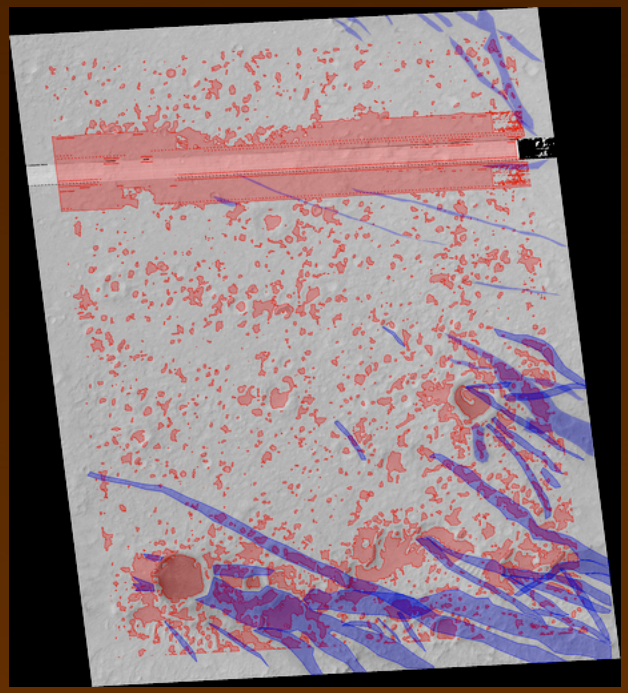
TP	21%
FP	8%

KL-divergence



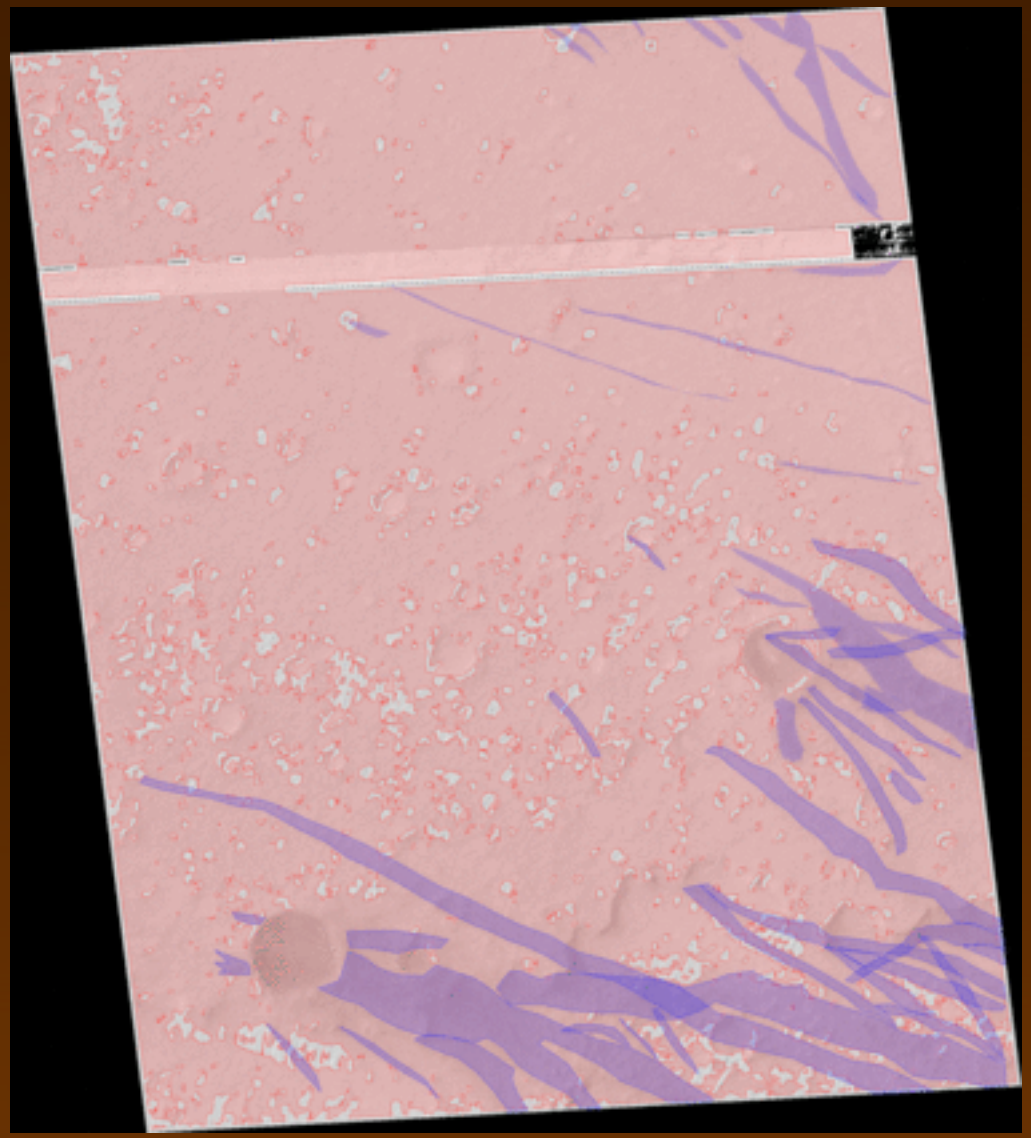
TP	71%
FP	6%

Covariance



TP	25%
FP	14%

Increasing the Salience Threshold



(Animation)

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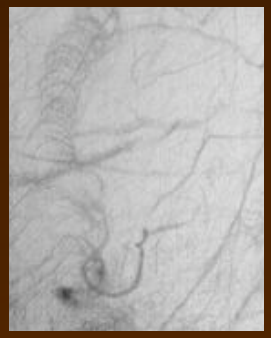
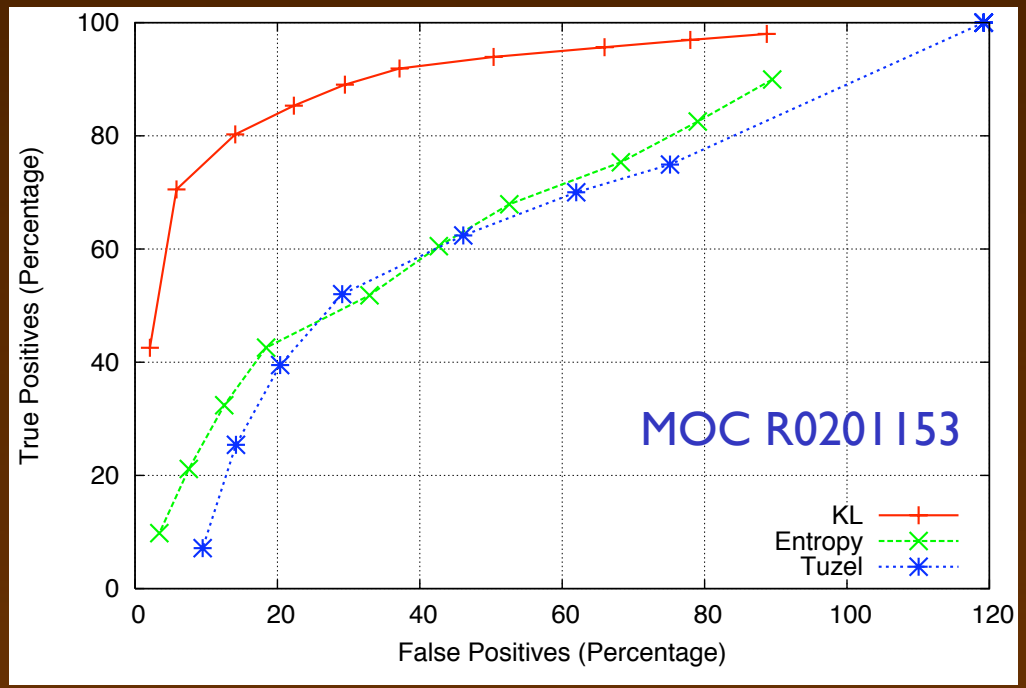
ROC Curves

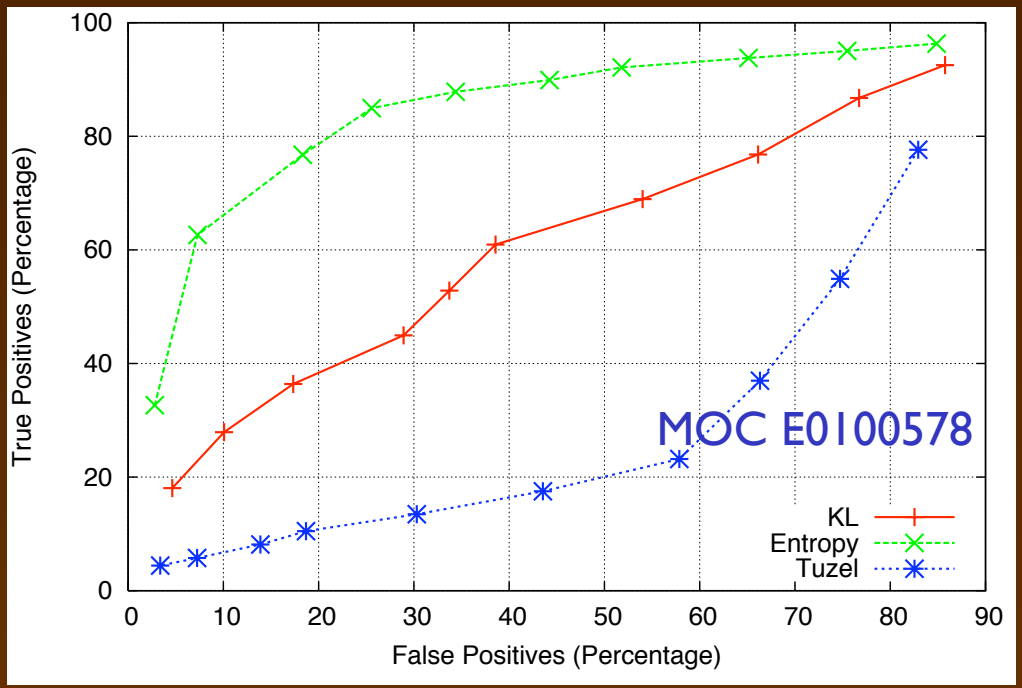
Best performance at upper left corner
(100% TP, 0% FP)



Dust Devil Tracks



Dark Slope Streaks

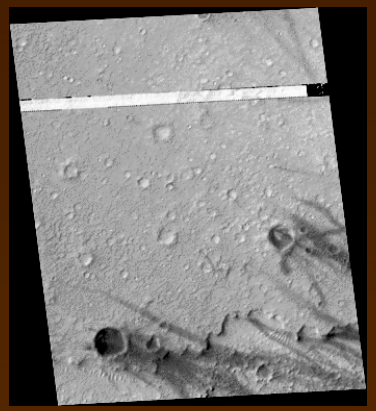


Landmark Classification

Extract attributes

Classify landmarks

Annotated Images



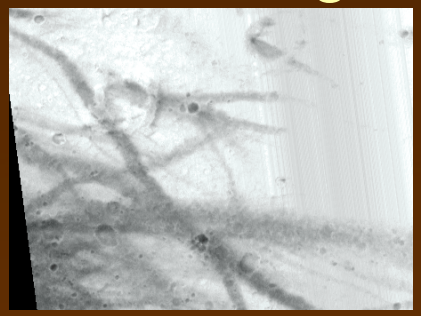
Training Examples
(114, 33, 1.2) Streak
(839, 87, 5.3) Devil
(206, 110, 15.7) Crater
...

Machine Learning

Classifier

- Dark Slope Streak
- Dust Devil Track
- Crater

New Image



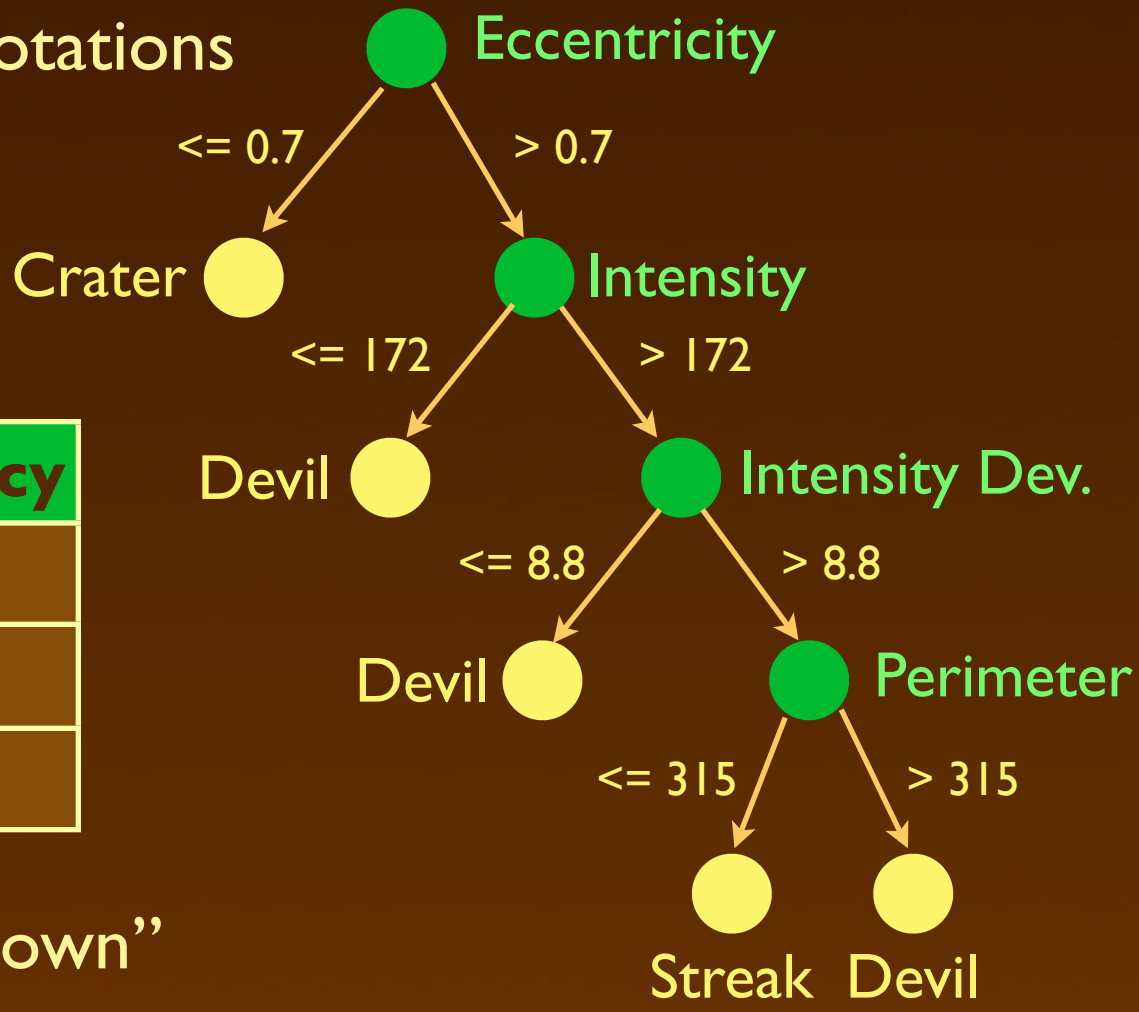
New Examples
(627, 122, 7.3) ?
(922, 80, 8.9) ?
(739, 154, 8.8) ?
...

Landmark Attributes
Area (size)
Perimeter
Mean intensity (0-255)
Std dev. of intensity
Ellipse-fit
Eccentricity
Orientation
Fit error
Roughness

Landmark Classification Models

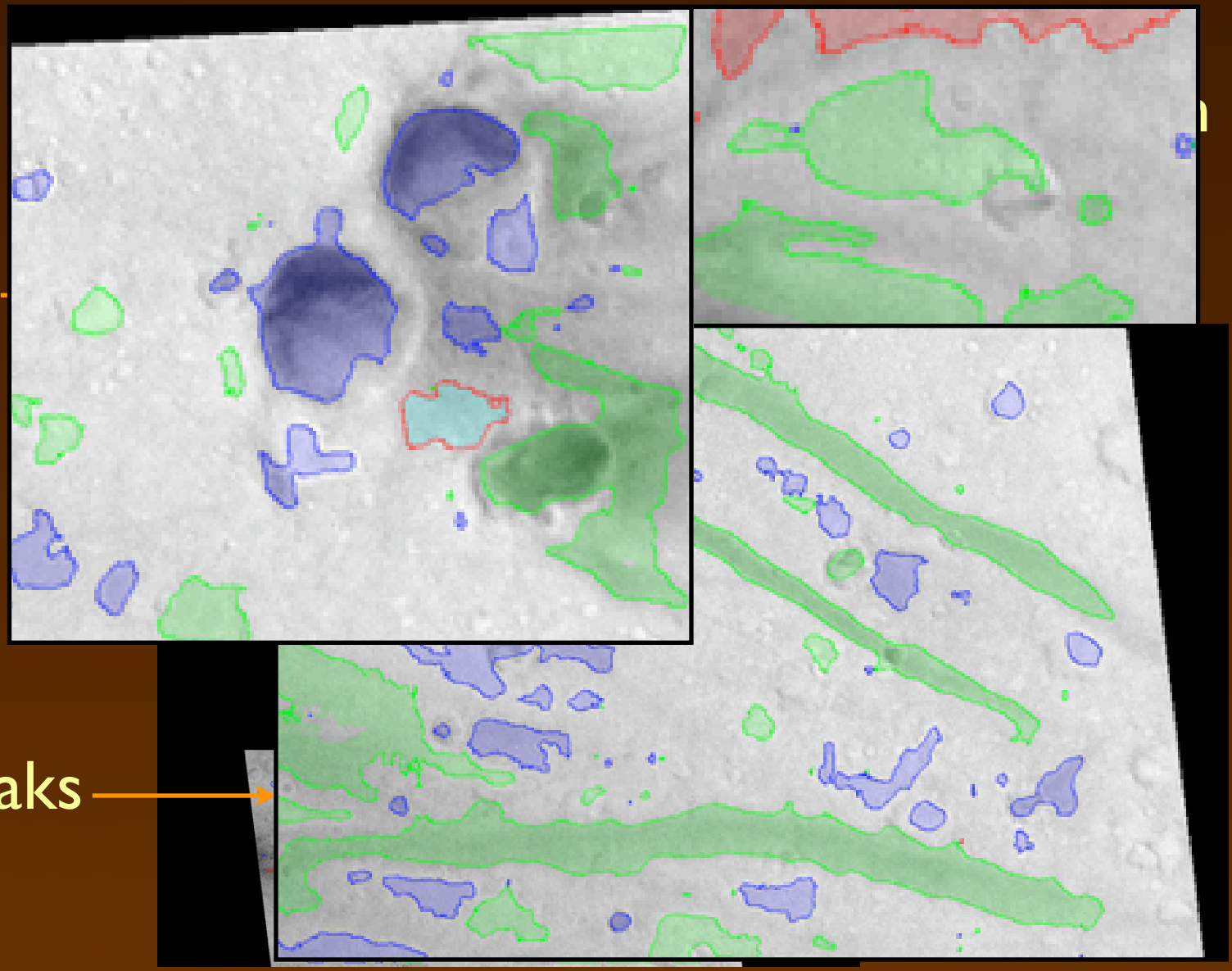
- Based on 767 manual annotations
  - Dark slope streaks (70)
  - Dust devil tracks (656)
  - Craters (41)

Classifier	Accuracy
Neural Network	95%
Decision Tree	94%
Support Vector Machine	91%



- If conf < 0.98, mark "unknown"
- Most useful feature: eccentricity

Landmark Classification Results



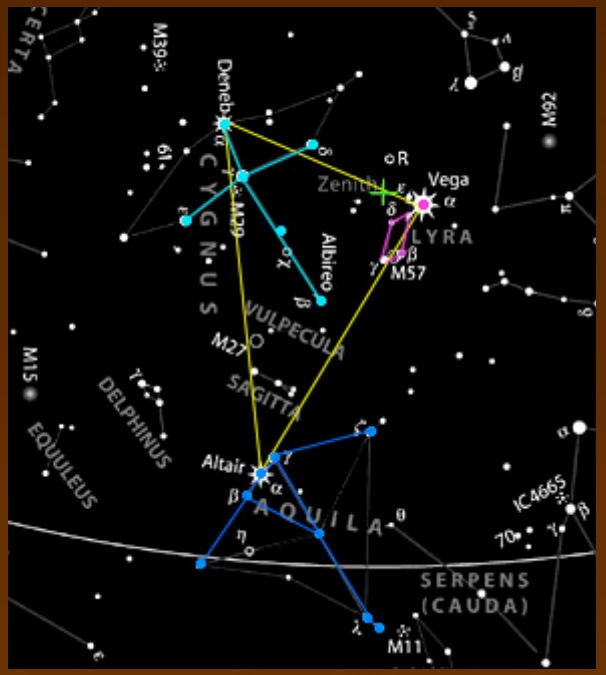
MOC R0701606

Salience: KL-divergence in 20x20 window, from 200x200 window

Next: Change Detection

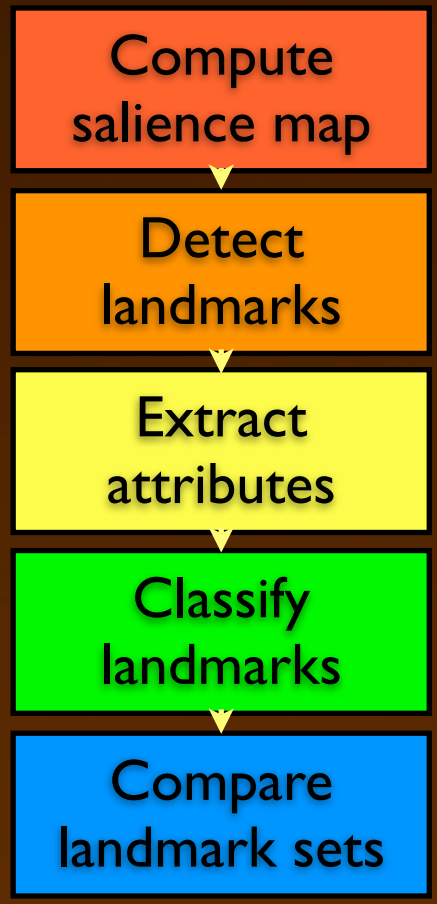
Compare landmark sets (change detection)

- State of the art: pixel-based registration and differencing
- Regional landmark graphs:
  landmarks (with class and features) plus relative position
- Ellipse-fit projections can enable recognition even between images from different instruments
- Expect reduction in runtime and in false detections



Summary

- Landmark-based image analysis
  - Characterize semantic content of image (gullies, streaks, etc.)
  - Use histograms or covariance descriptors, statistical measures of distance/salience
- Benefits
  - Support content-based archive searches
  - Enable faster change detection
- Thank you! Any questions?



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