

COSMIC: Content-based Onboard Summarization to Monitor Image Change

Detecting fresh impacts in HiRISE images with fully-convolutional networks

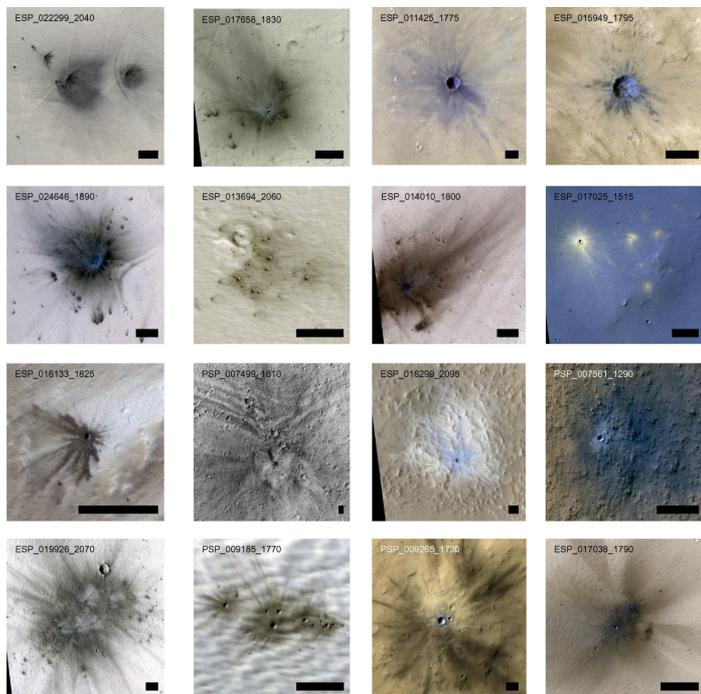
Asher Trockman

Mentor: Dr. Lukas Mandrake



Fresh impacts

The current martian cratering rate, Daubar et al. (2013)

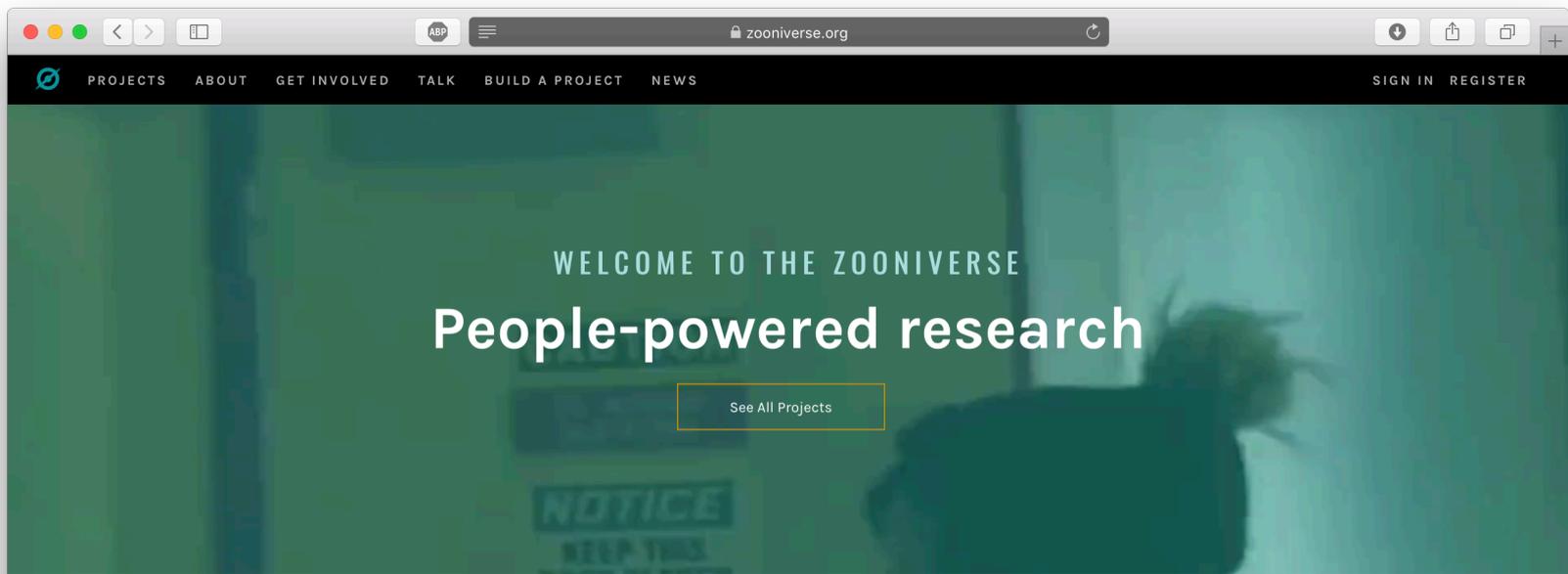


from Daubar et al. (2013)

- Found by looking at before/after CTX images (Daubar et al.)
- Crater diameters range from ~2.1—33.8 meters
- Craters > 3.9m occur at a rate of 1.65×10^{-6} craters/km²/year
 - (or about 240 per year)
- Often appear in clusters
- **Blast zones are 10-100x the diameter of the crater itself**
- Relatively rare event, little training data
 - We have **308 images** of confirmed impacts

Labeling fresh impacts

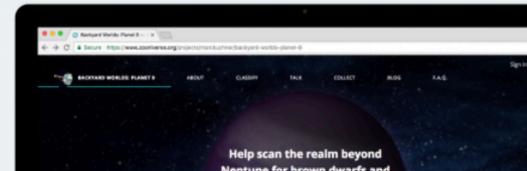
Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*



WHAT'S THIS?

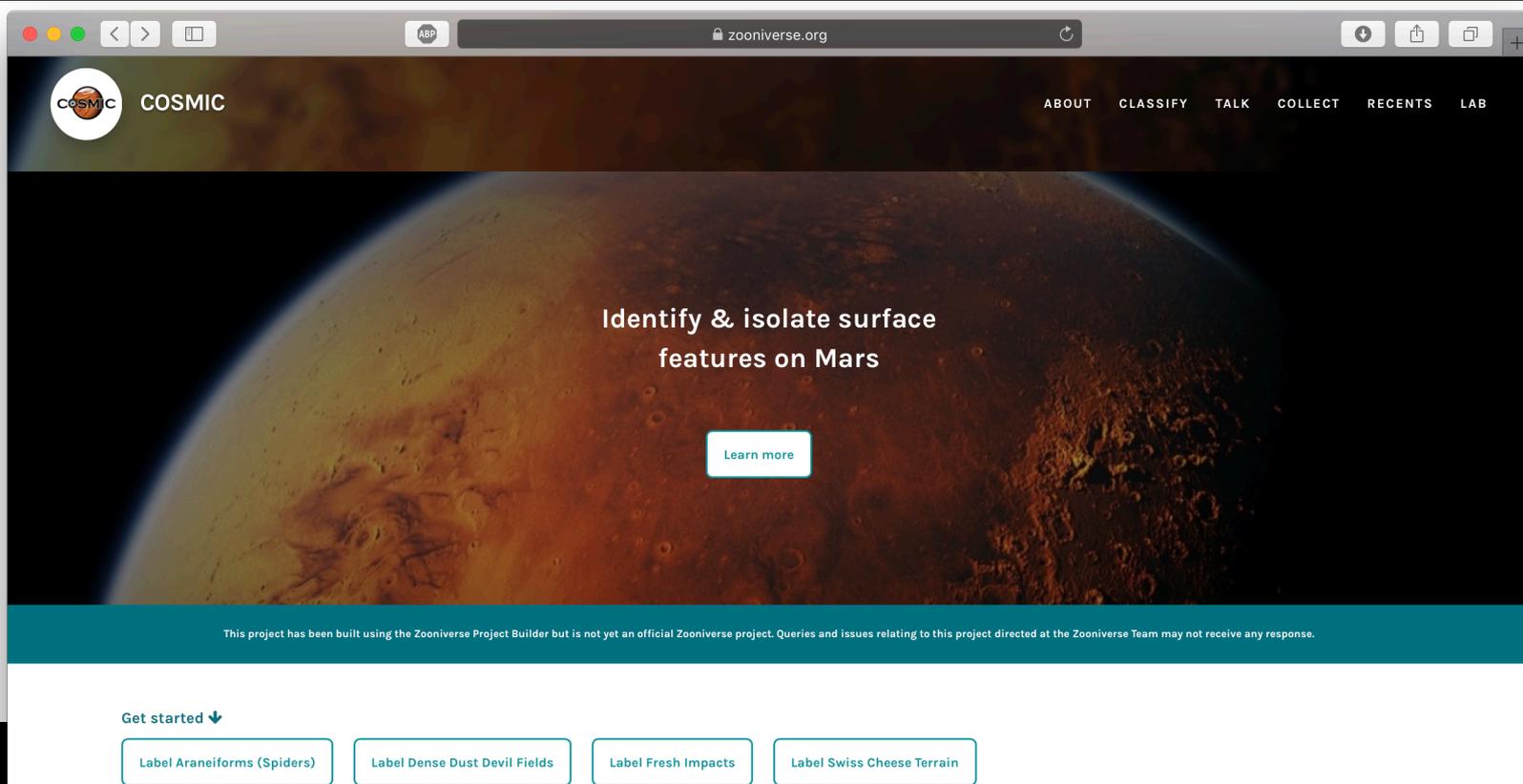
Discover, teach, and learn

The Zooniverse enables everyone to take part in real cutting edge research in many fields across the sciences, humanities, and more. The Zooniverse creates opportunities for you to unlock answers and contribute to real discoveries.



Labeling fresh impacts

Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*



The screenshot shows a web browser window with the URL `zooniverse.org`. The page header includes the COSMIC logo and navigation links: ABOUT, CLASSIFY, TALK, COLLECT, RECENTS, and LAB. The main content area features a large image of Mars with the text "Identify & isolate surface features on Mars" and a "Learn more" button. A teal banner at the bottom of the main area contains a disclaimer: "This project has been built using the Zooniverse Project Builder but is not yet an official Zooniverse project. Queries and issues relating to this project directed at the Zooniverse Team may not receive any response." Below this banner is a "Get started" section with four buttons: "Label Araneiforms (Spiders)", "Label Dense Dust Devil Fields", "Label Fresh Impacts", and "Label Swiss Cheese Terrain".

COSMIC

ABOUT CLASSIFY TALK COLLECT RECENTS LAB

Identify & isolate surface features on Mars

Learn more

This project has been built using the Zooniverse Project Builder but is not yet an official Zooniverse project. Queries and issues relating to this project directed at the Zooniverse Team may not receive any response.

Get started ↓

Label Araneiforms (Spiders) Label Dense Dust Devil Fields Label Fresh Impacts Label Swiss Cheese Terrain

Labeling fresh impacts

Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*

The screenshot shows a web browser window displaying the Zooniverse website. The URL is zooniverse.org. The page features a dark navigation bar with links for PROJECTS, ABOUT, GET INVOLVED, TALK, BUILD A PROJECT, NEWS, NOTIFICATIONS, MESSAGES, and ATROCKMAN. Below this is a header for the COSMIC project, with sub-links for ABOUT, CLASSIFY, TALK, COLLECT, RECENTS, and LAB. The main content area is split into two columns. The left column shows a large grayscale image of a Martian surface with a red "ALREADY SEEN!" banner in the top left corner. The right column contains a task interface with a "TUTORIAL" tab selected. The task instructions read: "Label impact-modified and unmodified regions". There are two task options: "Label Fresh Impact" (0 of 0 required drawn) and "Label Non-Impact Regions" (0 of 1 required drawn). A "NEED SOME HELP WITH THIS TASK?" section includes a checkbox for "Hide previous marks" and a "Done" button with a settings gear icon. A vertical "FIELD GUIDE" sidebar is visible on the right edge of the task panel. Below the main text, there is a small inset image of a blue-tinted impact crater and a "Welcome to COSMIC: Fresh Impacts!" section with introductory text and a link to "More information on Martian impacts".

PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS NOTIFICATIONS MESSAGES ATROCKMAN

COSMIC ABOUT CLASSIFY TALK COLLECT RECENTS LAB

ALREADY SEEN!

WELCOME TO COSMIC:
Fresh Impacts!

Help us find **fresh impact craters** in images of Mars from the High Resolution Imaging Science Experiment (HiRISE) 🇺🇸🇩🇪

Scientists can learn more about Mars by studying fresh impacts, like the age of various regions on the surface.

Image: NASA/JPL/University of Arizona
[More information on Martian impacts](#)

TASK TUTORIAL

Label impact-modified and unmodified regions

Label Fresh Impact 0 of 0 required drawn

Label Non-Impact Regions 0 of 1 required drawn

NEED SOME HELP WITH THIS TASK?
 Hide previous marks

Done ⚙️

FIELD GUIDE

5 JPL

Labeling fresh impacts

Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*

The screenshot shows a web browser window with the URL `zooniverse.org`. The page header includes the COSMIC logo and navigation links: ABOUT, CLASSIFY, TALK, COLLECT, RECENTS, and LAB. The main content area features a large grayscale image of a planetary surface with a red banner in the top-left corner that reads "ALREADY SEEN!". To the right of the image is a vertical toolbar with icons for zooming (+, -), panning (C), and refreshing. The right-hand side of the interface contains a task panel with two tabs: "TASK" and "TUTORIAL". Under the "TASK" tab, the instruction is "Label impact-modified and unmodified regions". There are two task cards: a green one for "Label Fresh Impact" (0 of 0 required drawn) and a grey one for "Label Non-Impact Regions" (0 of 1 required drawn). Below these is a section titled "NEED SOME HELP WITH THIS TASK?" with a checkbox for "Hide previous marks" and a green "Done" button with a settings gear icon. A vertical "FIELD GUIDE" button is located on the far right edge of the task panel.

Labeling fresh impacts

Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*

The screenshot shows a web browser window with the URL `zooniverse.org`. The page header includes the COSMIC logo and navigation links: ABOUT, CLASSIFY, TALK, COLLECT, RECENTS, and LAB. The main content area features a large grayscale image of a lunar surface. A red banner in the top-left corner of the image reads "ALREADY SEEN!". A green, irregular polygon is drawn around a dark impact crater in the lower-center of the image. To the right of the image is a control panel with a vertical toolbar containing icons for zooming (+, -), panning (C), and refreshing. The main task panel has two tabs: "TASK" and "TUTORIAL". Under the "TASK" tab, the instruction is "Label impact-modified and unmodified regions". There are two task cards: a green one for "Label Fresh Impact" (1 of 0 required drawn) and a grey one for "Label Non-Impact Regions" (0 of 1 required drawn). Below these is a section titled "NEED SOME HELP WITH THIS TASK?" with a checkbox for "Hide previous marks (1)". A green "Done" button with a settings gear icon is at the bottom of the task panel. A vertical "FIELD GUIDE" button is on the far right.

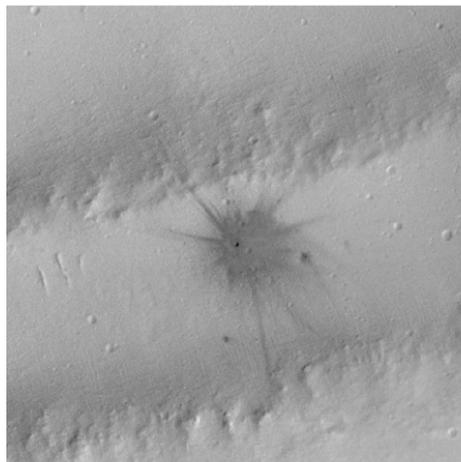
Labeling fresh impacts

Enlisting the help of citizen scientists to generate labels en masse with *Zooniverse*

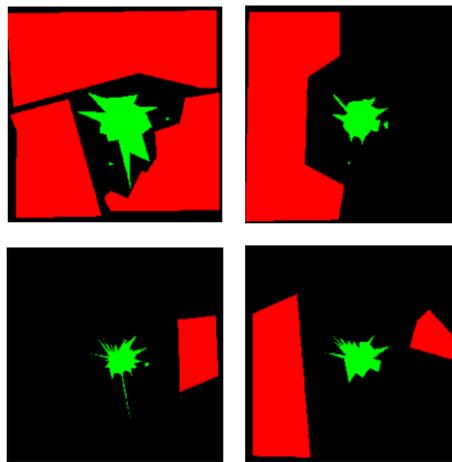
The screenshot shows a web browser window with the URL `zooniverse.org`. The page header includes the COSMIC logo and navigation links: ABOUT, CLASSIFY, TALK, COLLECT, RECENTS, and LAB. The main content area displays a grayscale image of a planetary surface with several red rectangular bounding boxes. One box in the top-left corner is labeled "ALREADY SEEN!". A central impact crater is outlined in green. On the right side, there is a control panel with two tabs: "TASK" and "TUTORIAL". Under the "TASK" tab, the instruction reads "Label impact-modified and unmodified regions". There are two task buttons: "Label Fresh Impact" (1 of 0 required drawn) and "Label Non-Impact Regions" (1 of 1 required drawn). Below these is a section titled "NEED SOME HELP WITH THIS TASK?" with a checkbox for "Hide previous marks (2)". A green "Done" button is at the bottom of the task panel. A vertical "FIELD GUIDE" button is on the far right edge of the interface.

Multi-label problem

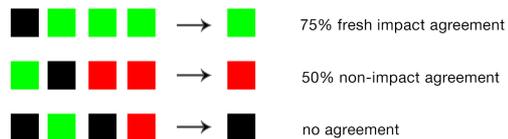
Merging labels by 50% inter-rater agreement (voting)



Fresh Impact Example



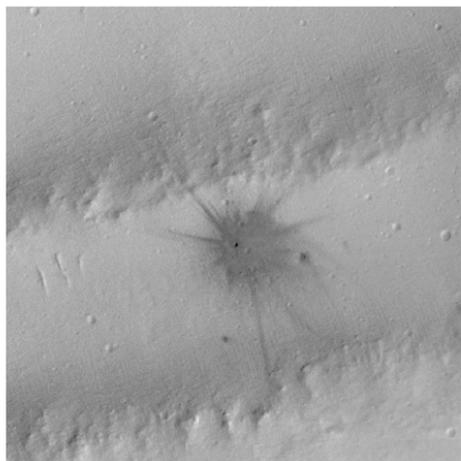
Labels from 4 Users



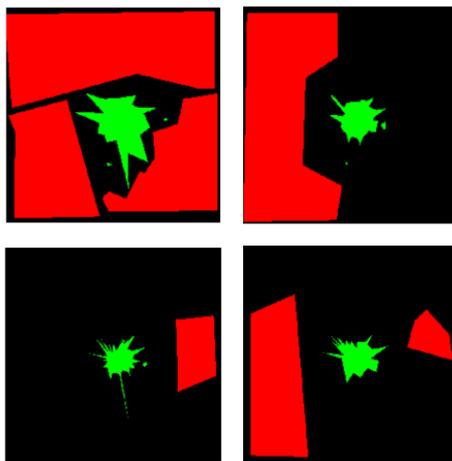
Merged Label
(Voting)

Multi-label problem

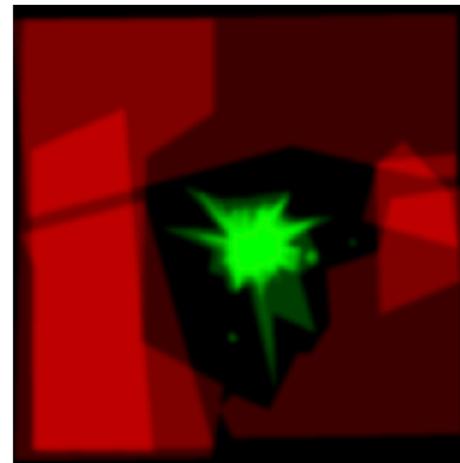
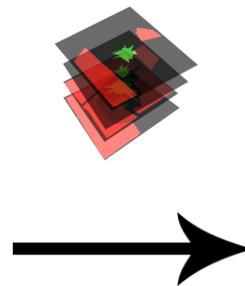
Extracting labeler confidence: real-valued labels



Fresh Impact Example



Labels from 4 Users

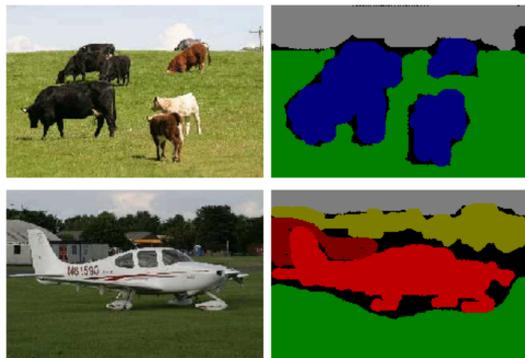


Merged Label
(Frequency)

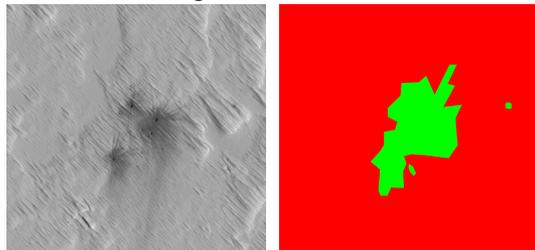
Semantic Segmentation

Labeling image regions at the pixel-level. Example: MSRC dataset.

Example segmented images:



The goal of this work:



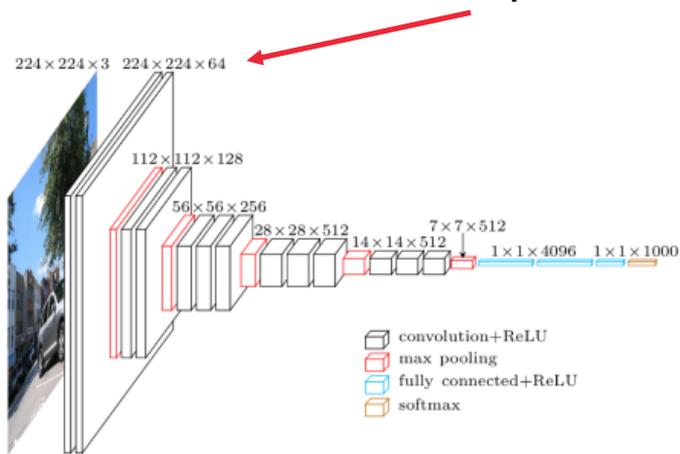
Some approaches:

- TextureCam (Semantic Texton Forests, Shotton et al.)
- Region-based CNNs (R-CNNs, Girshick et al.)
- **Fully-convolutional networks** (FCNs, Long et al.)

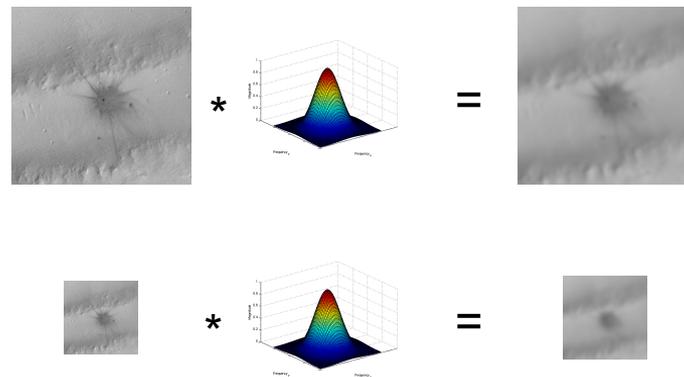
Fully Convolutional Networks (*Deep Filters*)

CNNs that work on input of *any size*

Most CNNs: Fixed size input



Convolution: Any size input



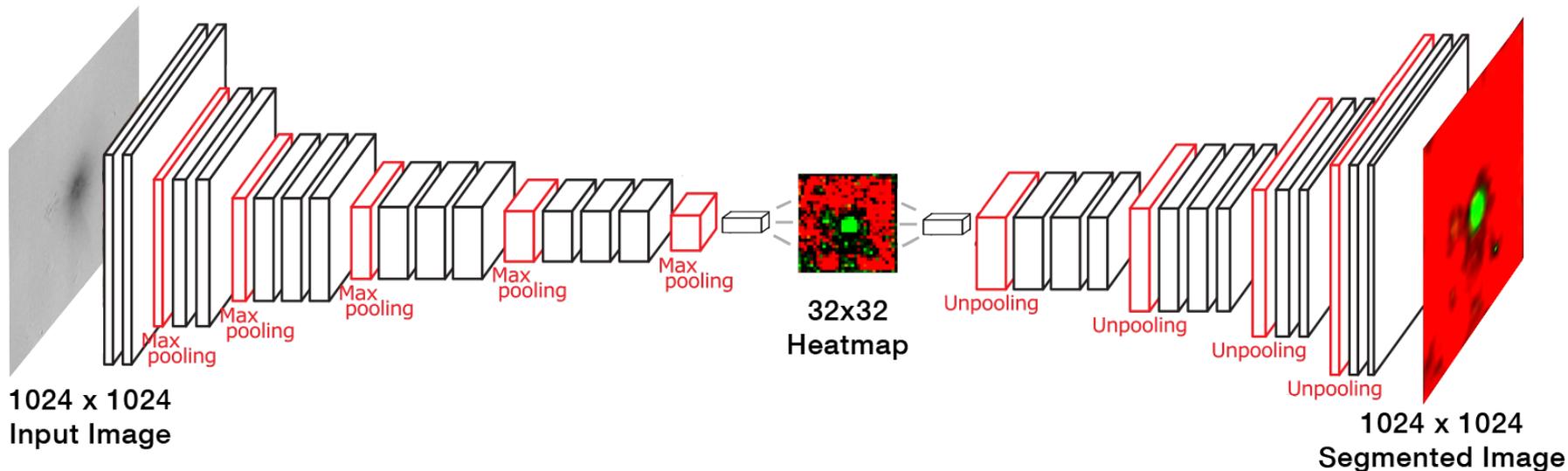
Problem: Fully connected (FC) layers



Solution: Convert FC to conv layers.

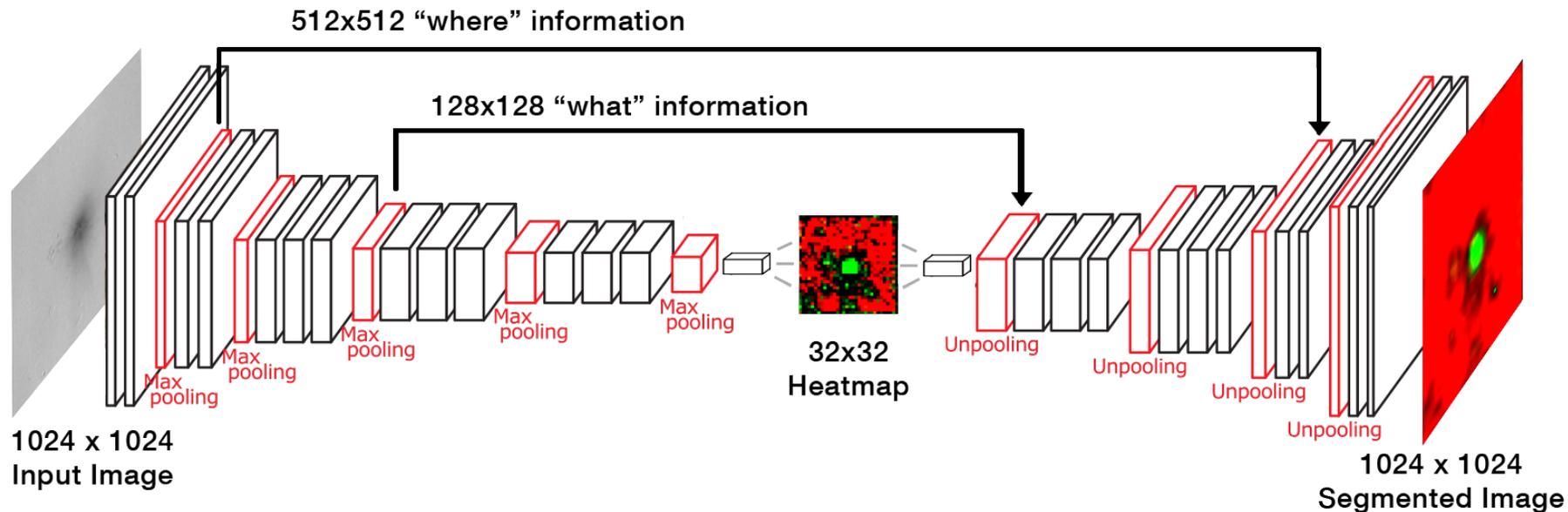
Fully Convolutional Networks for Semantic Segmentation

Long et al., 2015



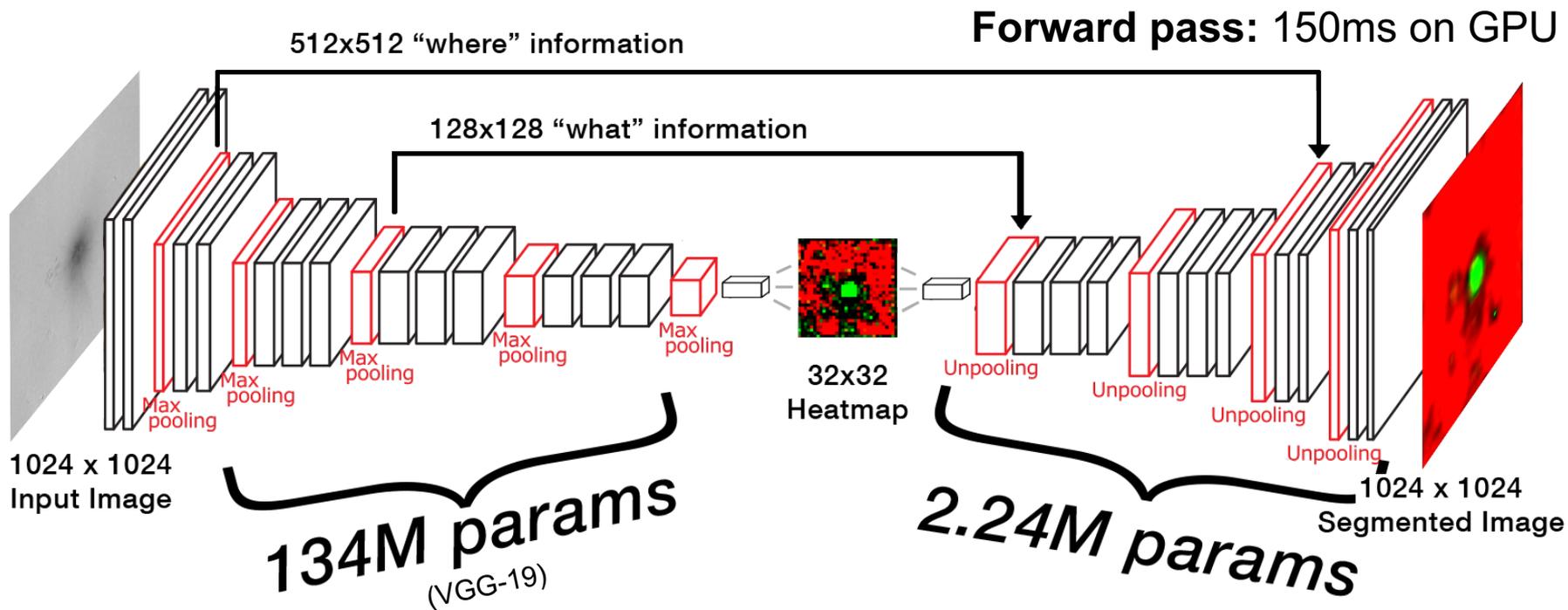
Fully Convolutional Networks for Semantic Segmentation

Long et al., 2015



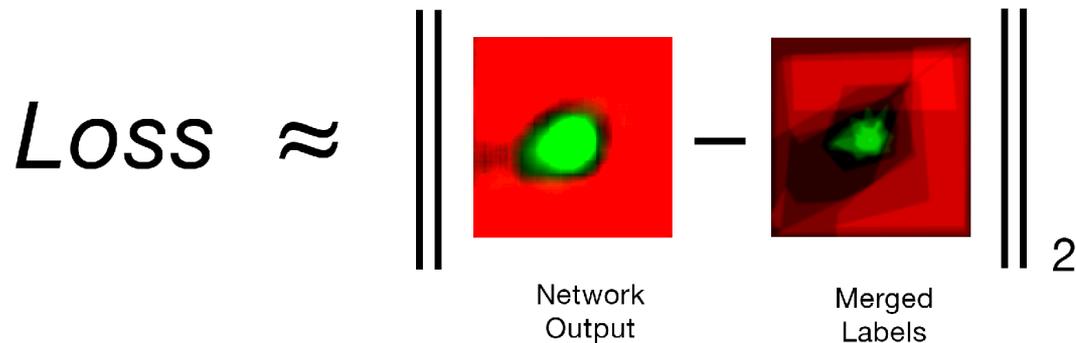
Fully Convolutional Networks for Semantic Segmentation

Long et al., 2015

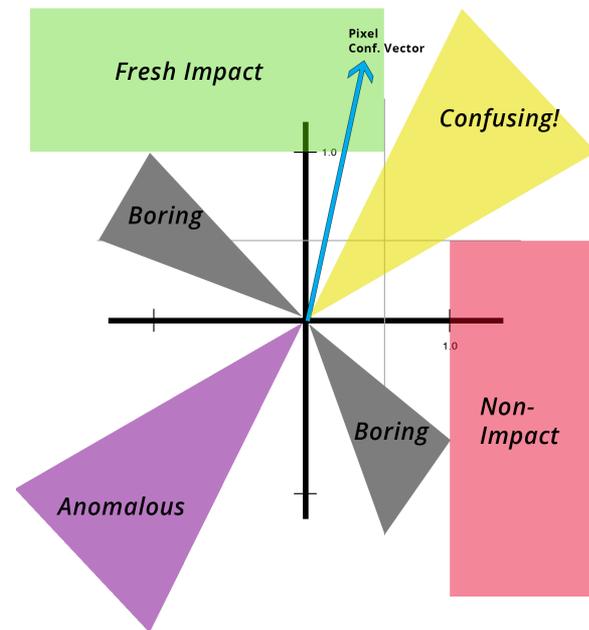


Training with real-valued labels

Instead of pixel classification, do regression and choose confidence thresholds



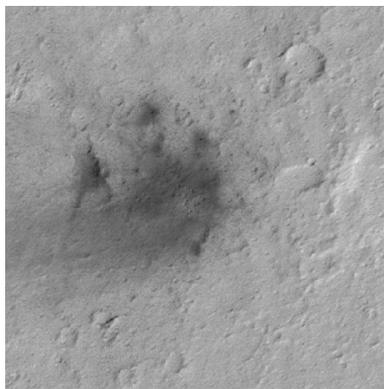
Per-pixel loss is the mean-squared error of the network's pixel and the label's pixel



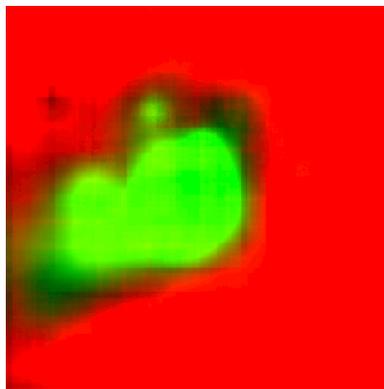
Each pixel is a 2-vector

Training with real-valued labels

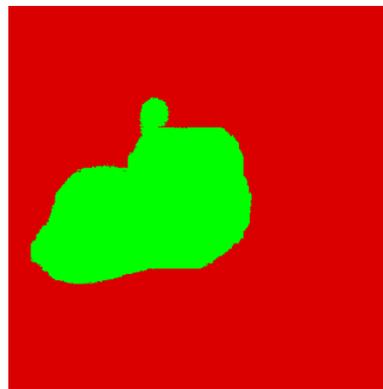
Instead of pixel classification, do regression and choose **confidence thresholds**



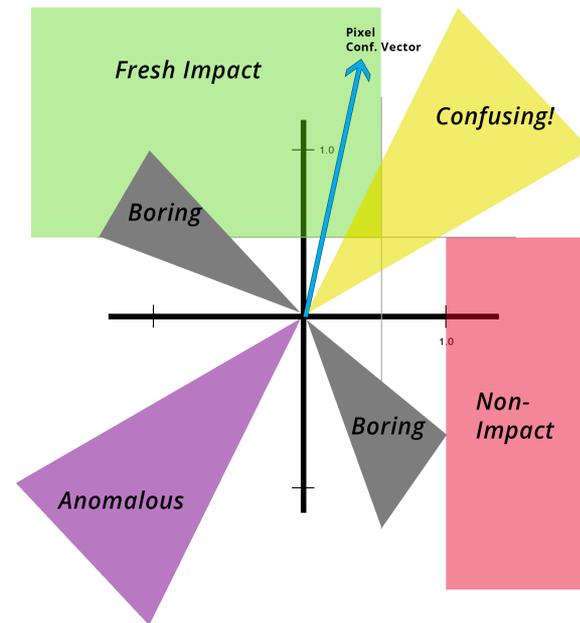
Fresh Impacts



Network Heatmap



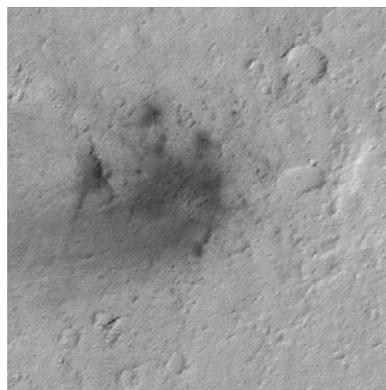
Binary Segmentation



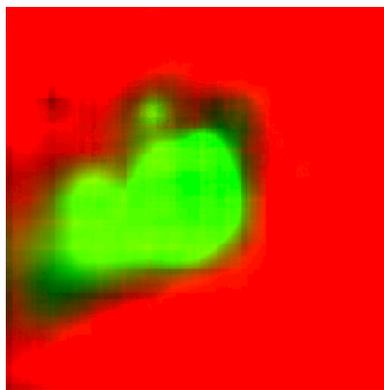
Each pixel is a 2-vector

Training with real-valued labels

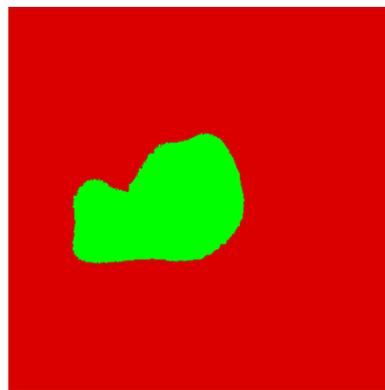
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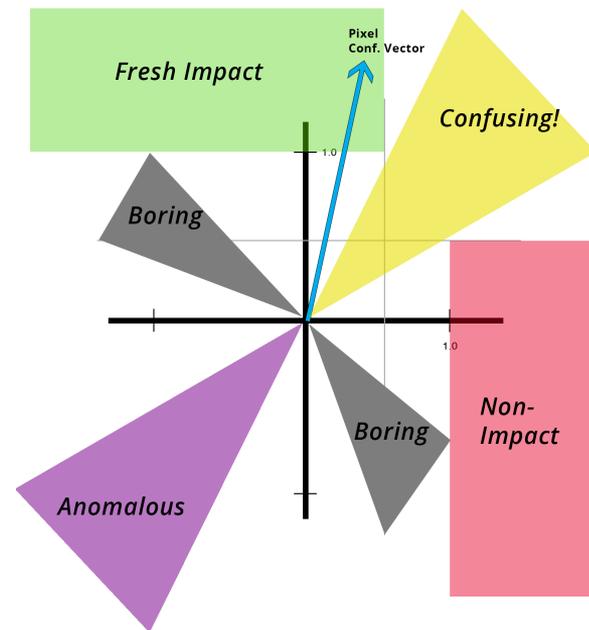
Fresh Impacts



Network Heatmap



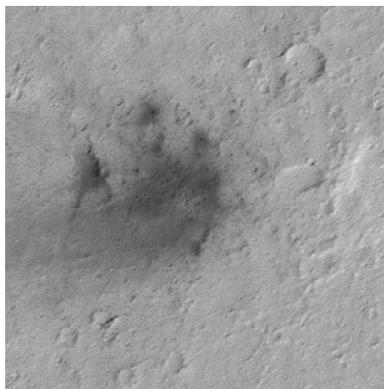
Binary Segmentation



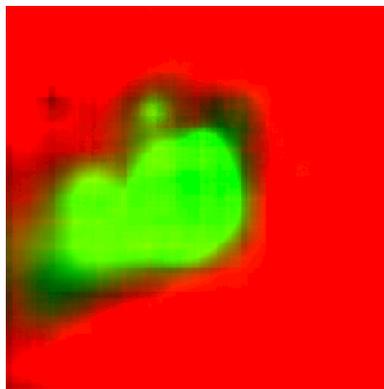
Each pixel is a 2-vector

Training with real-valued labels

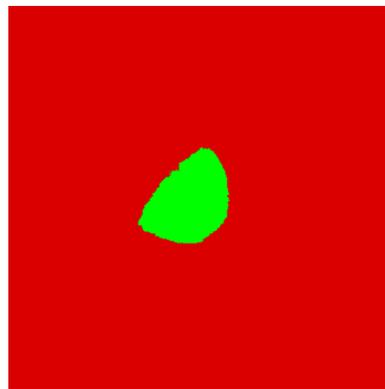
Instead of pixel classification, do regression and choose **confidence thresholds**



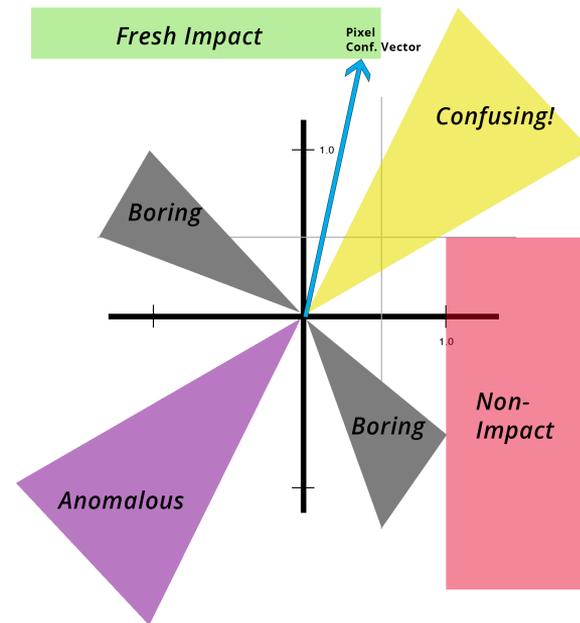
Fresh Impacts



Network Heatmap



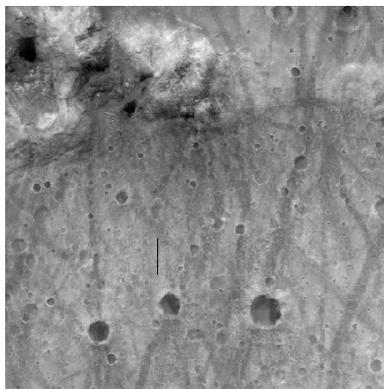
Binary Segmentation



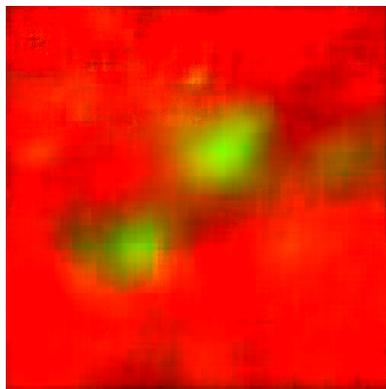
Each pixel is a 2-vector

Training with real-valued labels

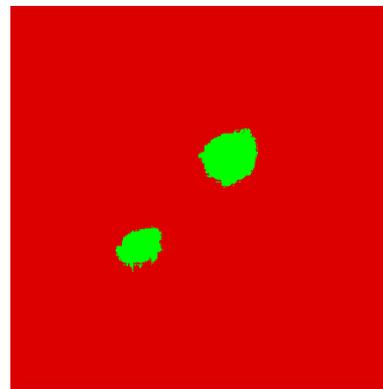
Instead of pixel classification, do regression and choose **confidence thresholds**



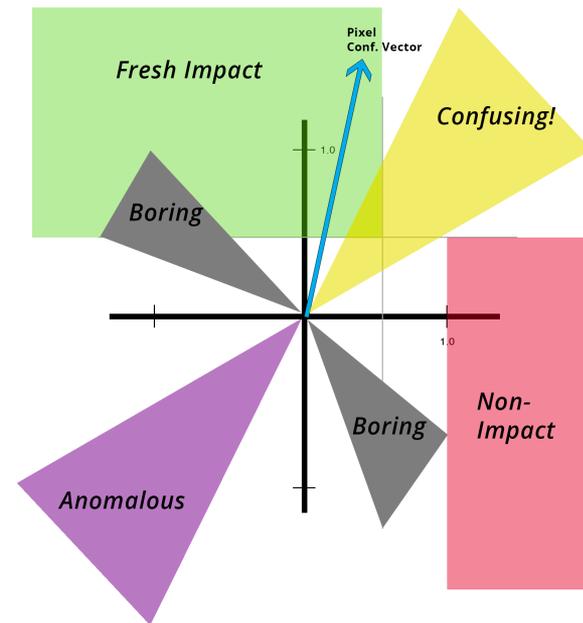
Old Impacts



Network Heatmap



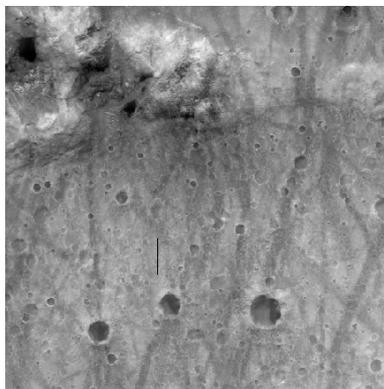
Binary Segmentation



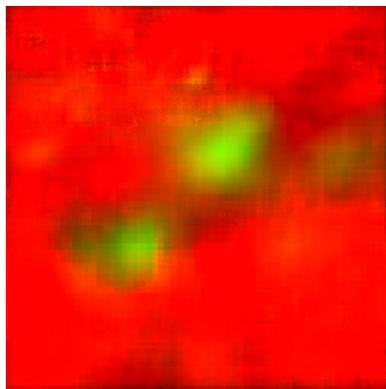
Each pixel is a 2-vector

Training with real-valued labels

Instead of pixel classification, do regression and choose **confidence thresholds**



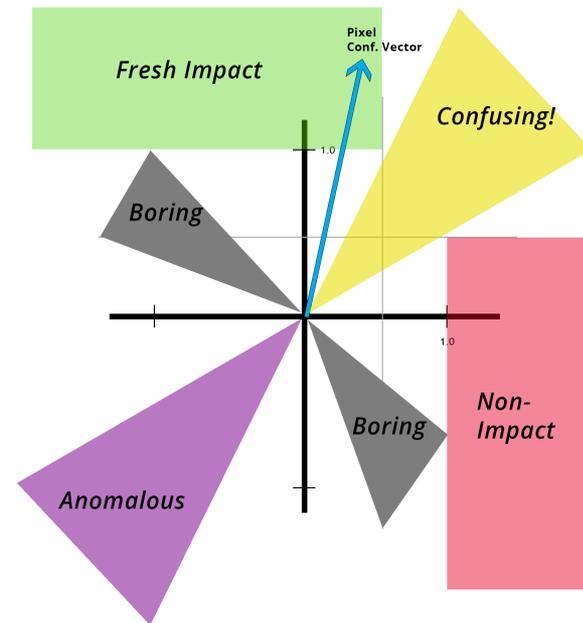
Old Impacts



Network Heatmap



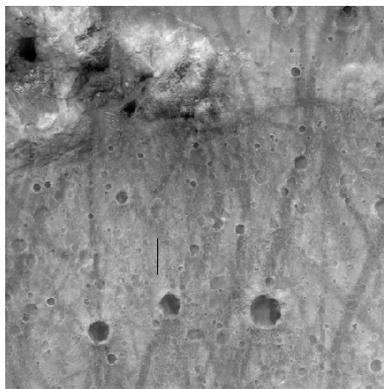
Binary Segmentation



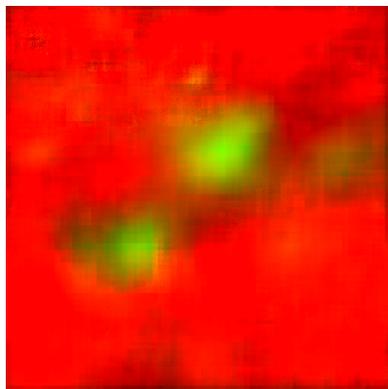
Each pixel is a 2-vector

Training with real-valued labels

Instead of pixel classification, do regression and choose **confidence thresholds**



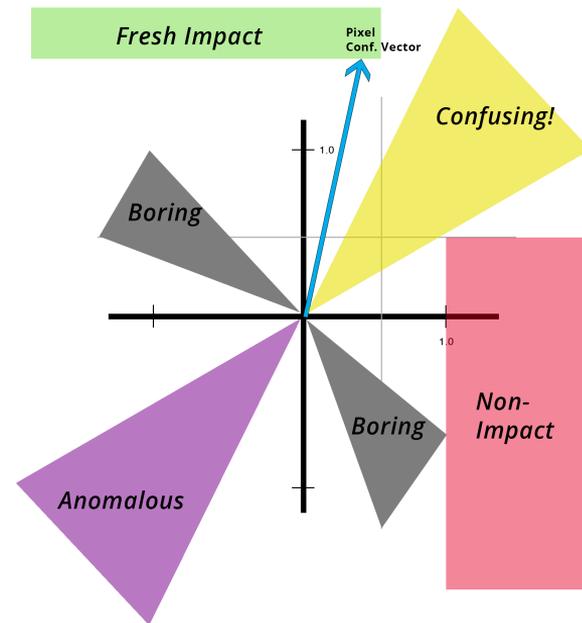
Old Impacts



Network Heatmap



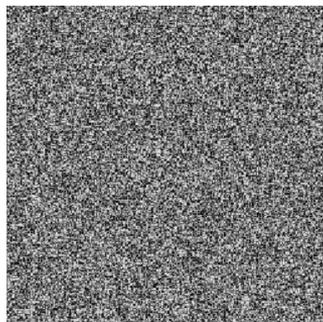
Binary Segmentation



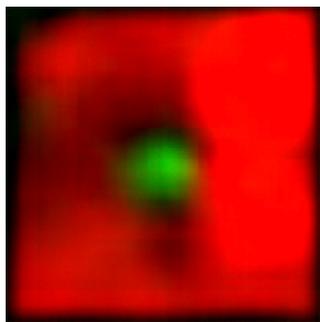
Each pixel is a 2-vector

Early difficulty: troublesome priors

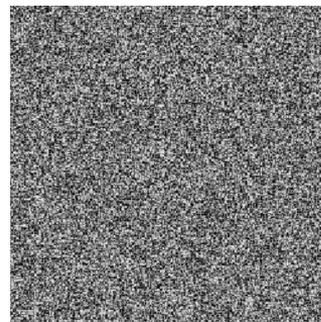
Does the fully-convolutional network really know what a fresh impact looks like?



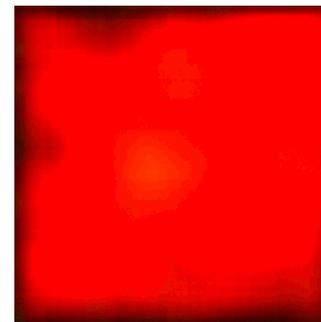
Uniform Noise



Network Heatmap



Uniform Noise



Network Heatmap

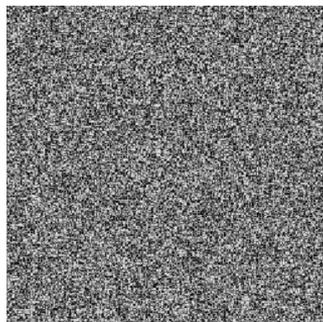
Every image the network saw had a fresh impact somewhere.



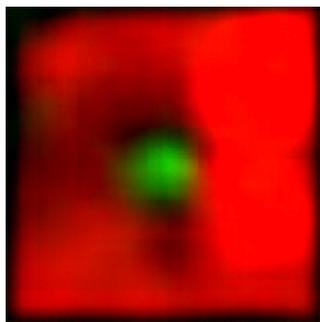
Solution: Add images *without* fresh impacts to the dataset.

Early difficulty: troublesome priors

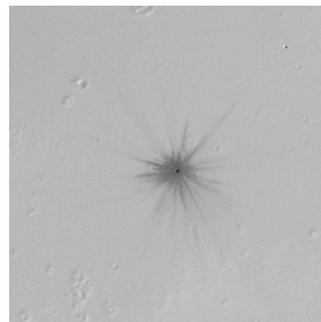
Does the fully-convolutional network really know what a fresh impact looks like?



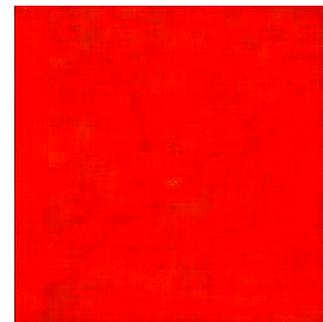
Uniform Noise



Network Heatmap



Uniform Noise



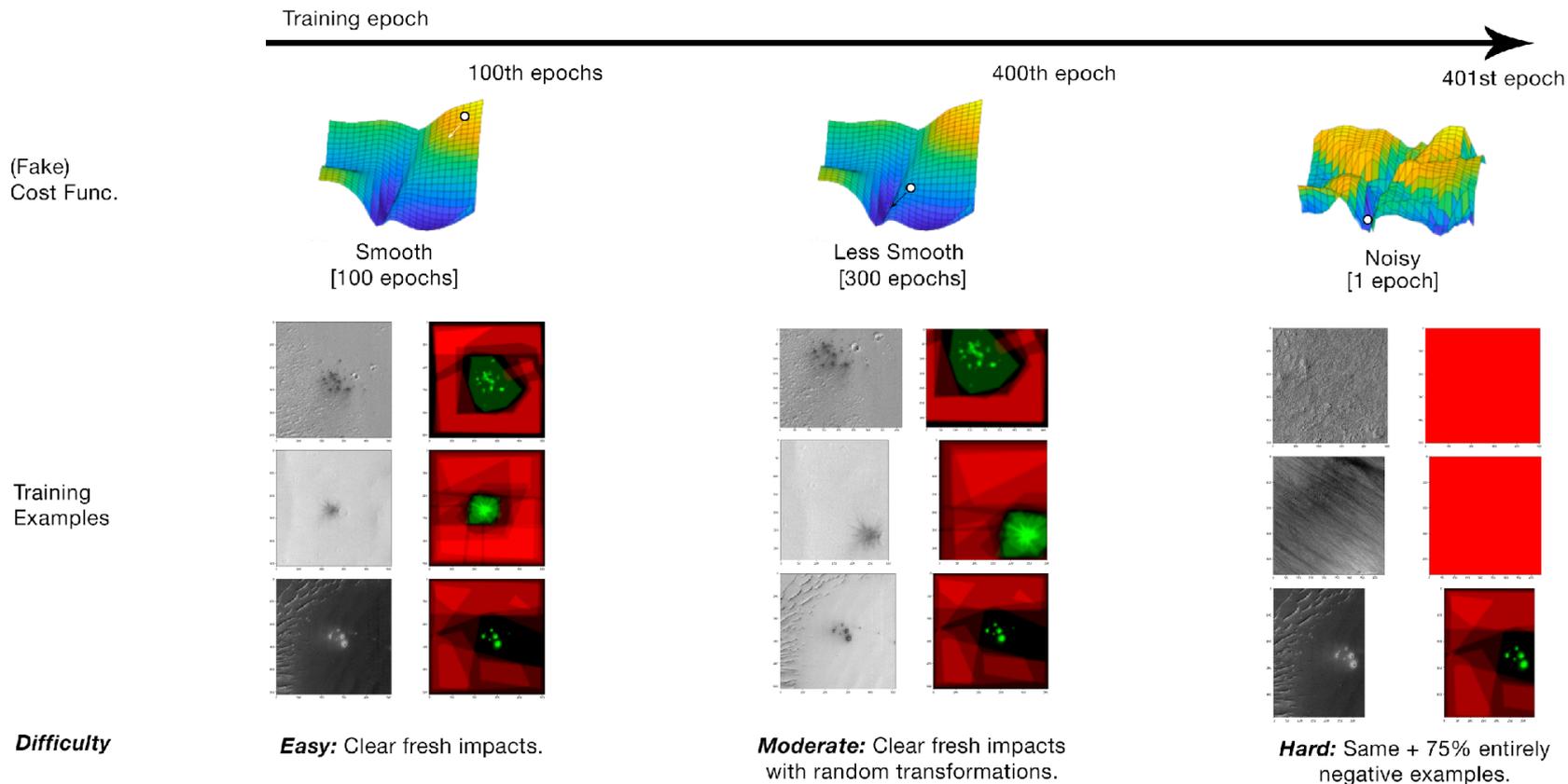
Network Heatmap

Every image the network saw had a fresh impact somewhere.



New problem: Unbalanced data biased towards non-impacts.

Real solution: Curriculum Learning (Bengio et al., 2009)

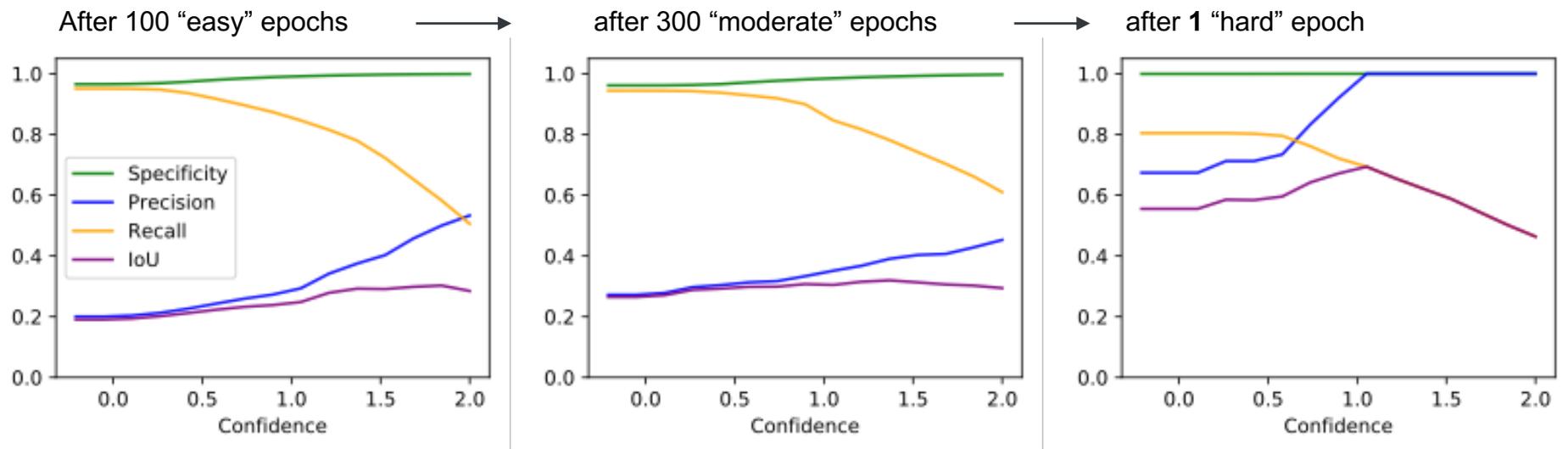


Evaluation in terms of precision and recall

Model trained with *real-valued* merged labels, tested on *discrete* merged labels

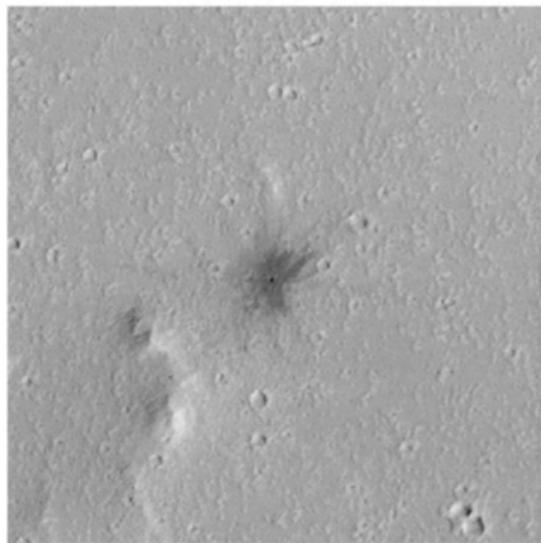
Training set: 280 fresh impact images + 1020 impact-free images

Testing set: 15 fresh impact images + 132 impact-free images

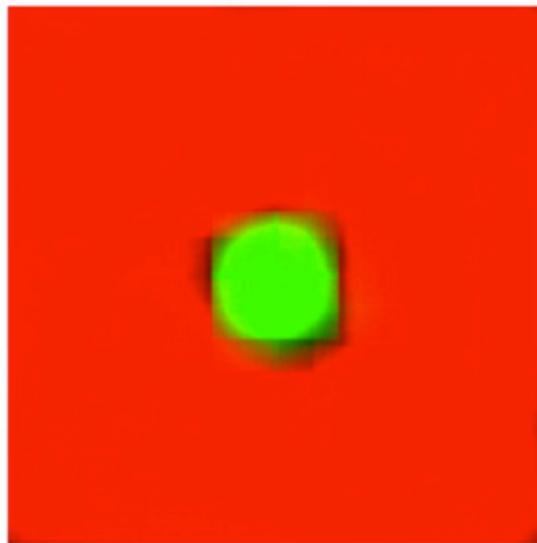


Robustness checks

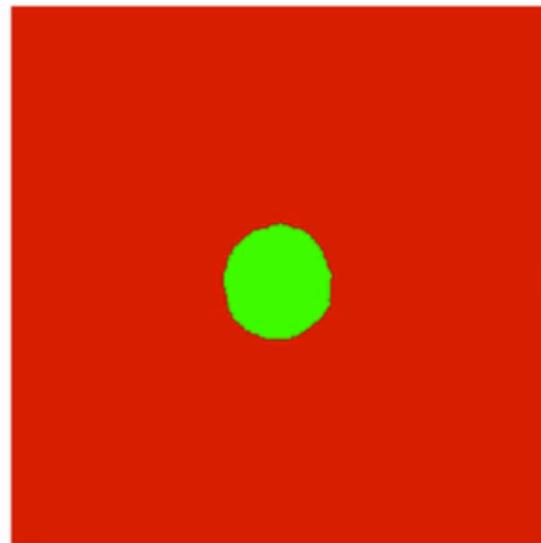
1. Sensitivity to noise



Input Image
Increasingly Strong Noise



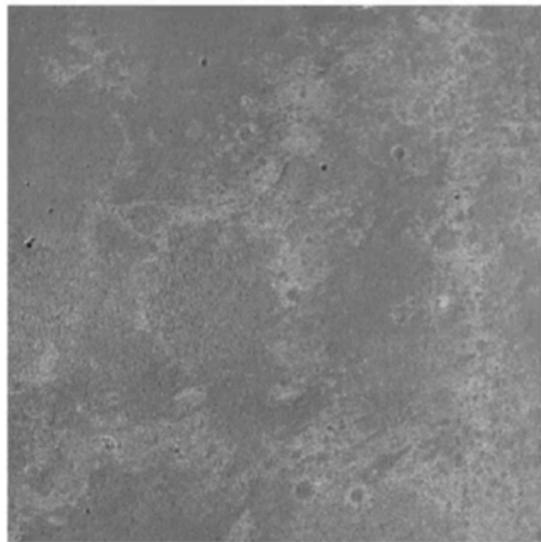
Network Heatmap



Binary Segmentation

Robustness checks

2. Sensitivity to translation



Input Image Stream



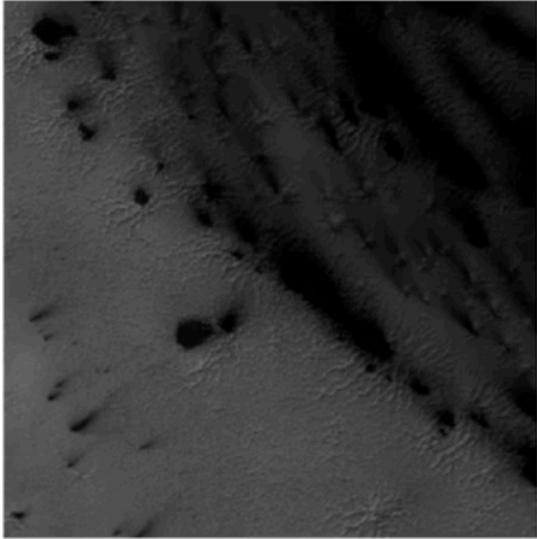
Network Heatmap



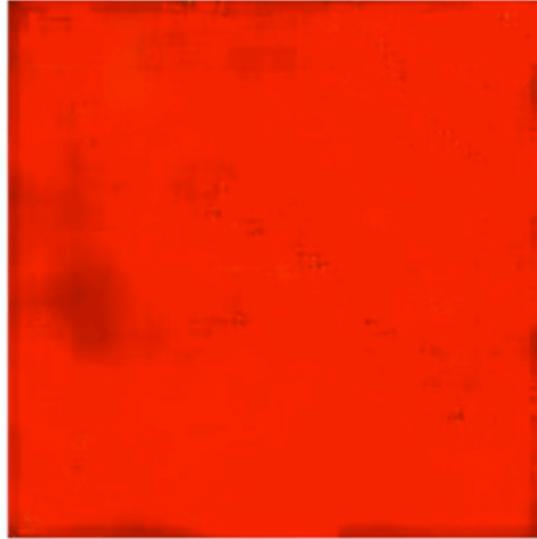
Binary Segmentation

Robustness checks

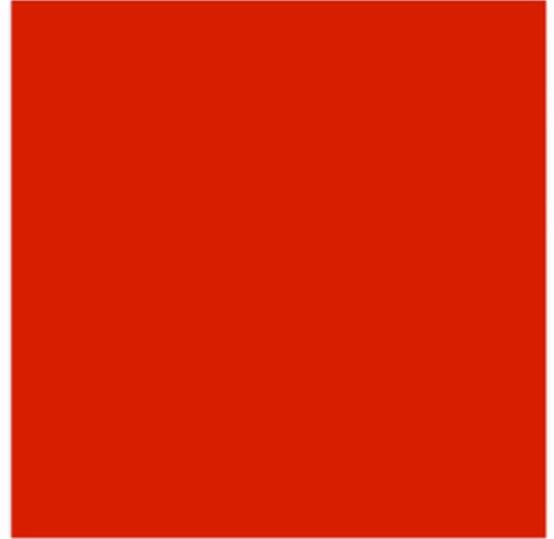
2. Sensitivity to similar landforms (araneiforms)



Input Image Stream



Network Heatmap

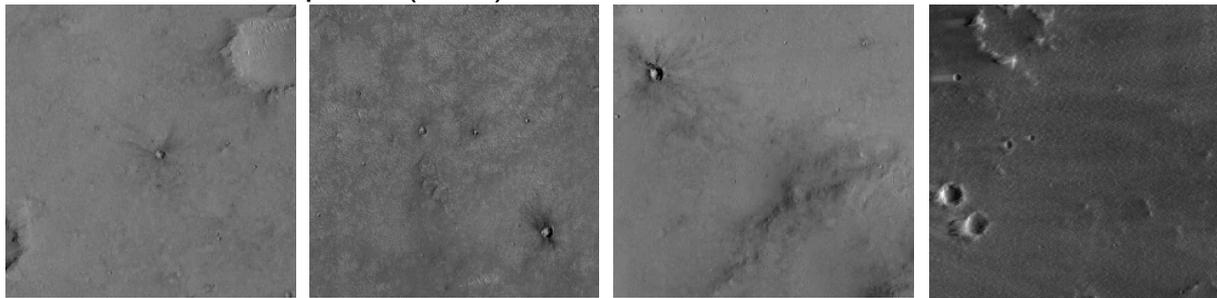


Binary Segmentation

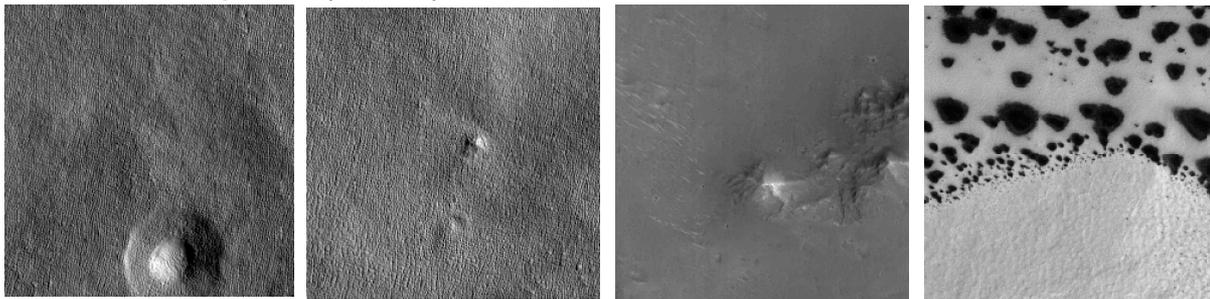
HiRISE image exploration with the FCN

Found small, potentially fresh impacts (from 10 HiRISE browse images)

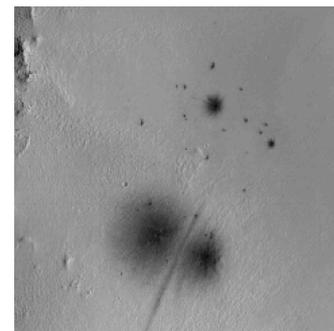
Possible fresh impacts (~5%):



Not fresh impacts (~95%):



FCN selected ~5%
of considered patches.



“Re-discovered” fresh impact
from training set

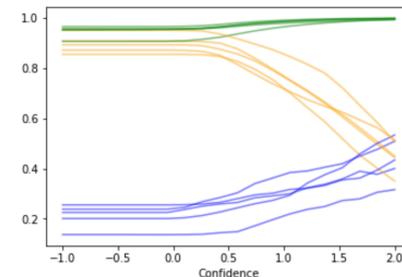
Next steps

Working on COSMIC in the coming semester

- Cross validation (running now!)
- Comparison of other FCN architectures, e.g. AlexNet, GoogLeNet, VGG-16
 - VGG-16 already implemented
- Cleaning up code (constantly working on this)
- Model compression

Thanks!

First step of the curriculum
for cross validation (5 folds pictured)
before I ran out of memory



The logo consists of the letters 'JPL' in a bold, red, sans-serif font. The 'J' and 'L' have a distinctive shape with a horizontal base that tapers slightly towards the ends. The 'P' is also bold and red, with a vertical stem and a curved top.

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