INL/MIS-22-69274-Revision-0

Automated Infrastructure & Dependency Detection via Satellite Imagery and Dependency Profiles Project Summary & Profession Background

July 2022

Shiloh N Elliott

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

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Data Scientist

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Idaho National Laboratory

Overview

- Professional Background
- Project Background
- Project Approaches
- Results

Making opportunities in overlooked spaces

2015 to 2019

- Critical Infrastructure Analyst (DHS)
- Technical Lead (DHS)
- Irrigation Modernization (WPTO)*
- Waterpower Resilience (WPTO)*

2020

- Automated Infrastructure & Dependency Detection via Satellite Imagery and Dependency Profiles (LDRD)*
- Assessment of U.S. Critical Infrastructure sites for Hydropower potential (WPTO)*

2021

- Marine Hydrokinetic Resource Assessment Framework for Microgrid Applications (WPTO)
- Military Operations Research Society 89th Symposium (LDRD) (Conference)
- IP & Copywrite Award: Irrigation Mod. Decision Support Engine (WPTO)
- IP: HydroGenerate (WPTO)

2022

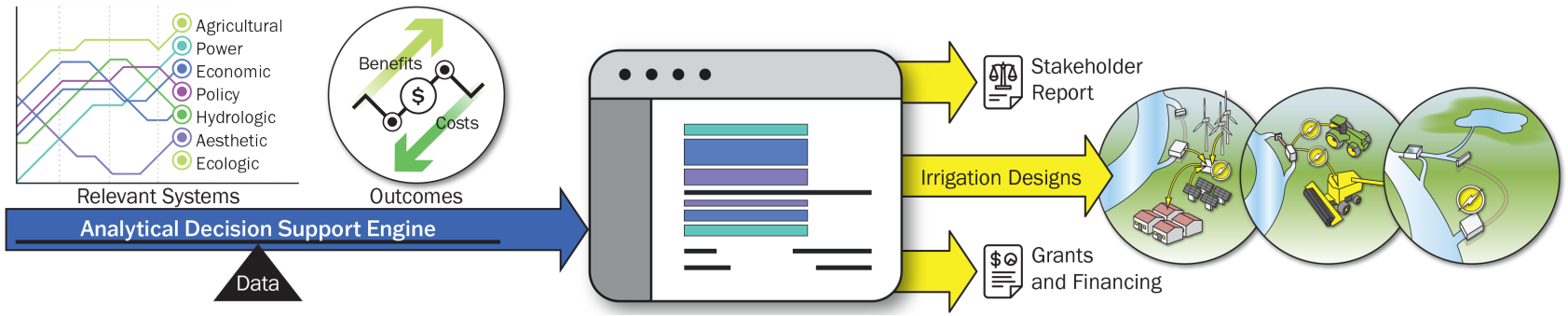
- ML and Satellite Imaging: NFC Dataset, Scene Change Detection, A Review of the State of the Art (NA24)*
- Enhancing Satellite Imagery & Geospatial Information Capabilities in Support of Nuclear Safeguards (NA24) (Workshop)
- A Review on the State of the Art of Machine Learning and Satellite Imaging: Detecting Scene Changes in Selected Nuclear Fuel Cycle Datasets (NA24) (Conference Paper)
- Identifying Critical Infrastructure in Aerial Imagery Data using Explainable Convolutional Neural Networks (Pre-Print)
- Unnamed Segmentation Paper One and Two (In Dev)
- IAEA's Symposium on International Safeguards: Reflecting on the Past and Anticipating the Future (FY23) (Presentation)
- IP: Scramble

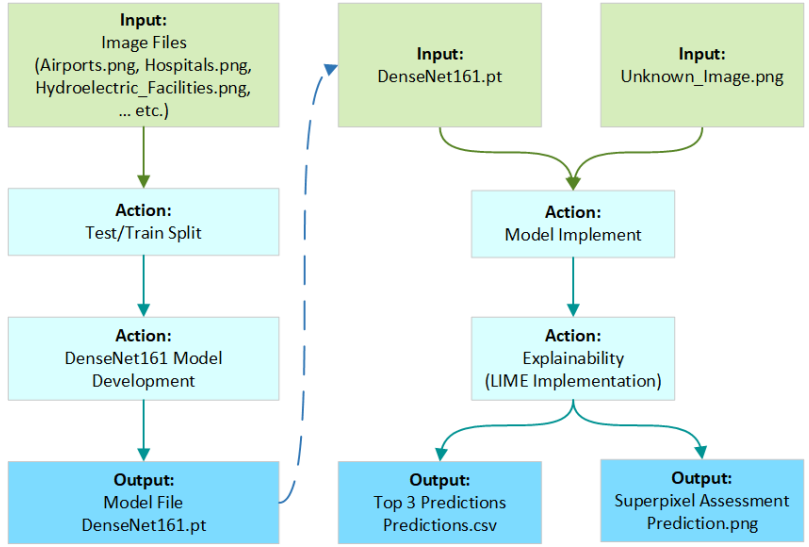
Research philosophy first principals

- We are not here to do what has been done before.
  - Pragmatism always wins the day.
    - Research in a vacuum doesn't make a sound.
- If the funder doesn't find you pretty, they should at least find you useful. Grow the pie.

Pacific Northwest NATIONAL LABORATORY

FARMERS CONSERVATION ALLIANCE fca



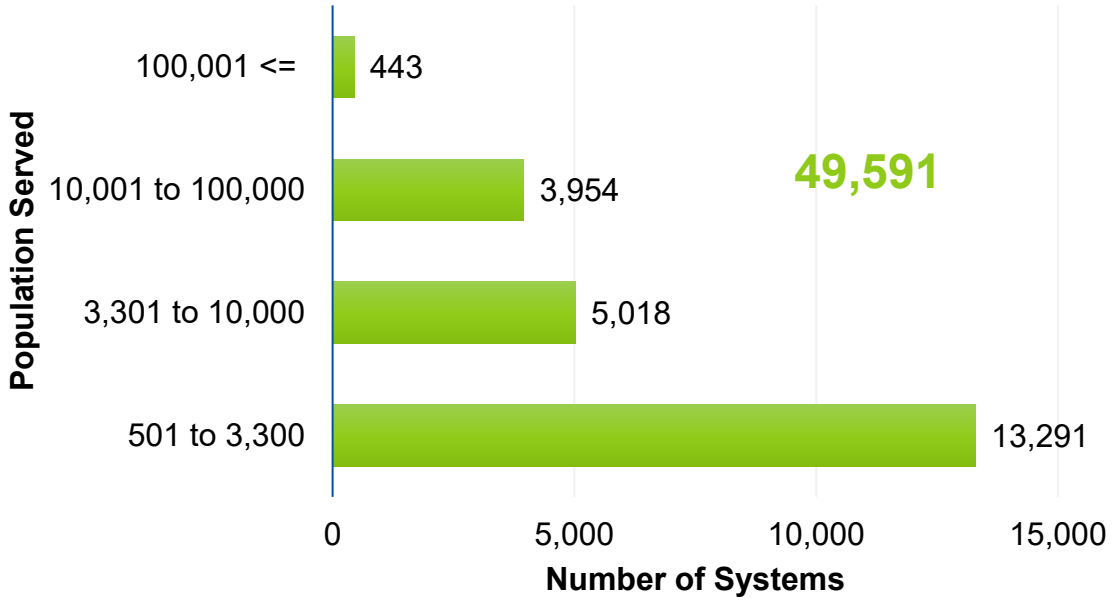


Professional Background | Project Background | Project Approaches | Results

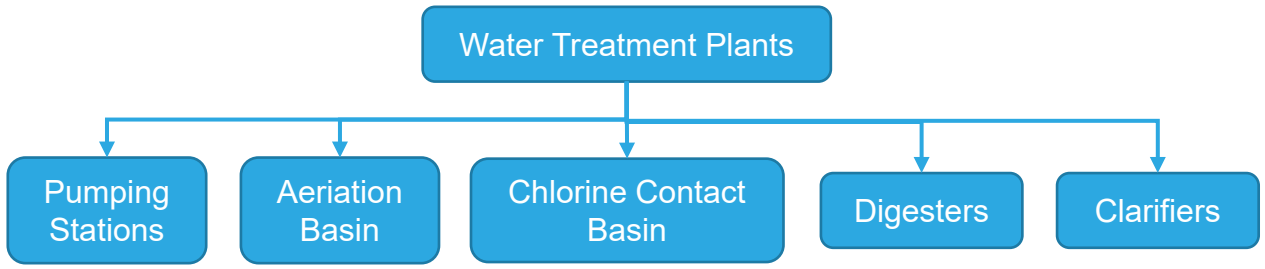
IDAHO NATIONAL LABORATORY

What are the goals of the LDRD and why are we conducting the work?

1. Develop a machine learning model capable of identifying critical infrastructure facilities (CI) with a high degree of accuracy from a satellite image
2. Develop the additional capability to identify sub-components of the chosen CI facilities
3. Provide a level of explainability to our 'black box' models



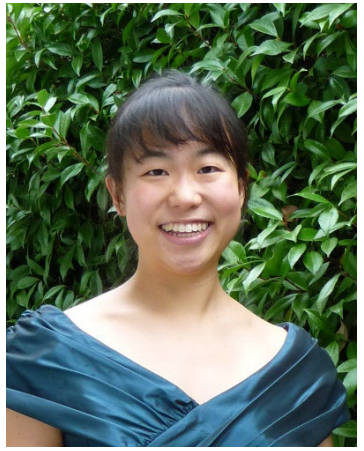
Airports	Potable Water Tanks	Hospitals
Hydroelectric Dams	Natural Gas Plants	Petrol Terminals
Substations	Water Treatment Plants	Solar Farms



Data and team composition are vital to project success

Data

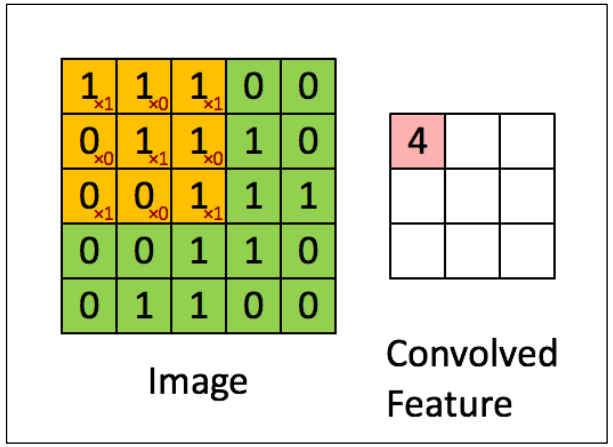
Team

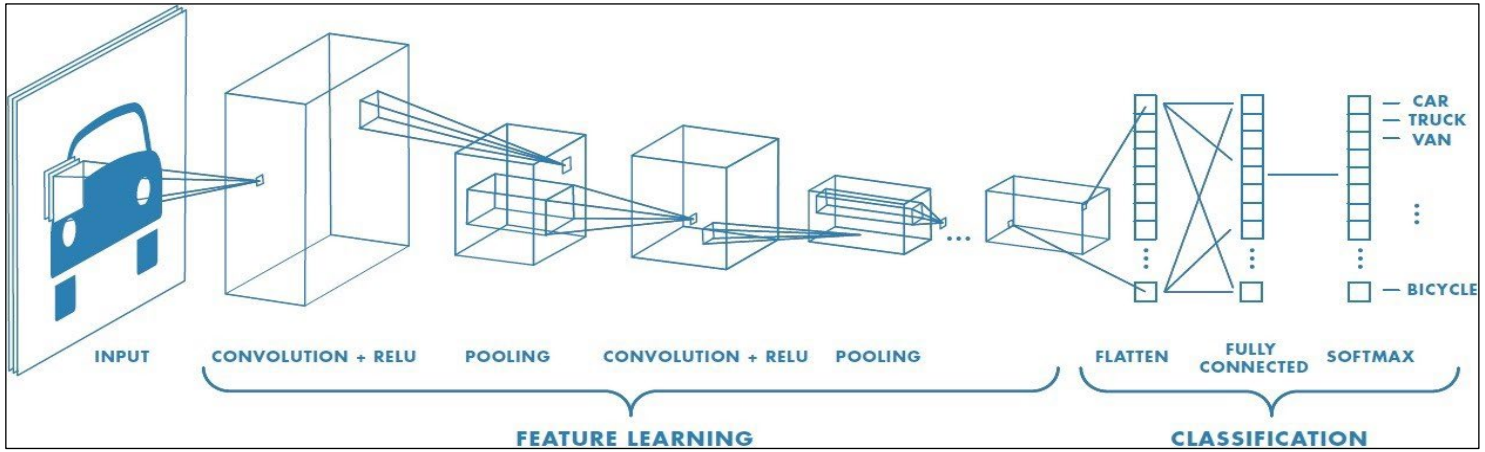


Professional Background | Project Background | Project Approaches | Results

Machine learning inspired by biological processes

- Components of CNNs
  - Convolutions (Kernels)
  - Pooling Layers
  - Fully Connected Layer

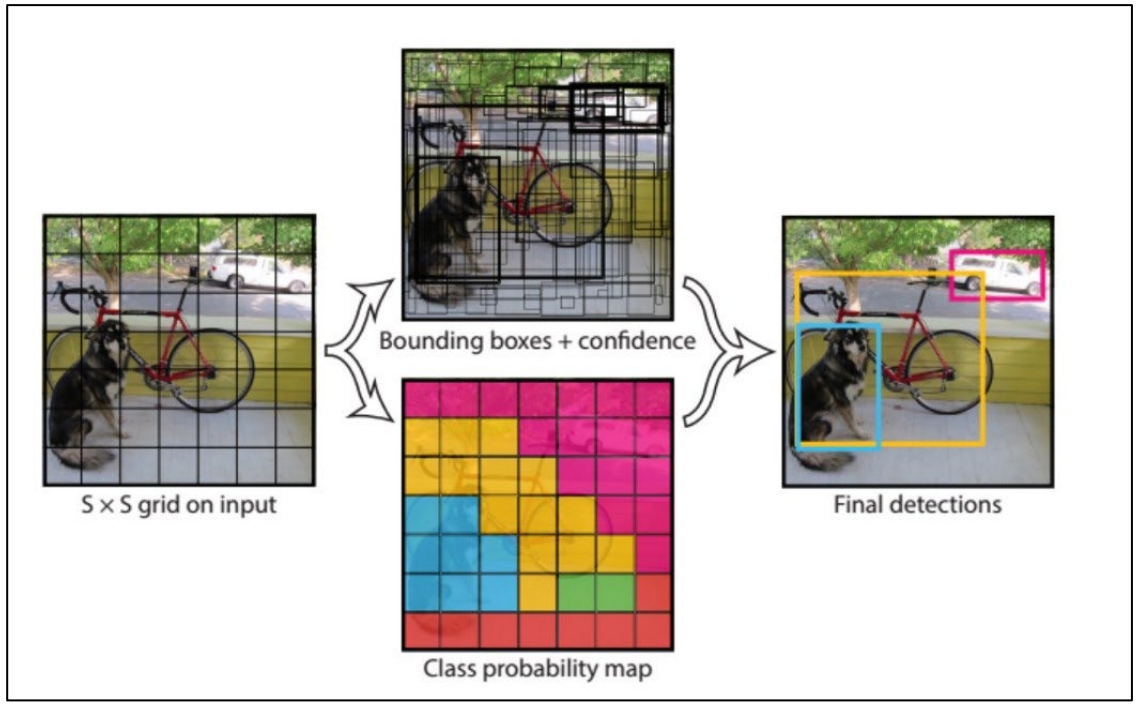




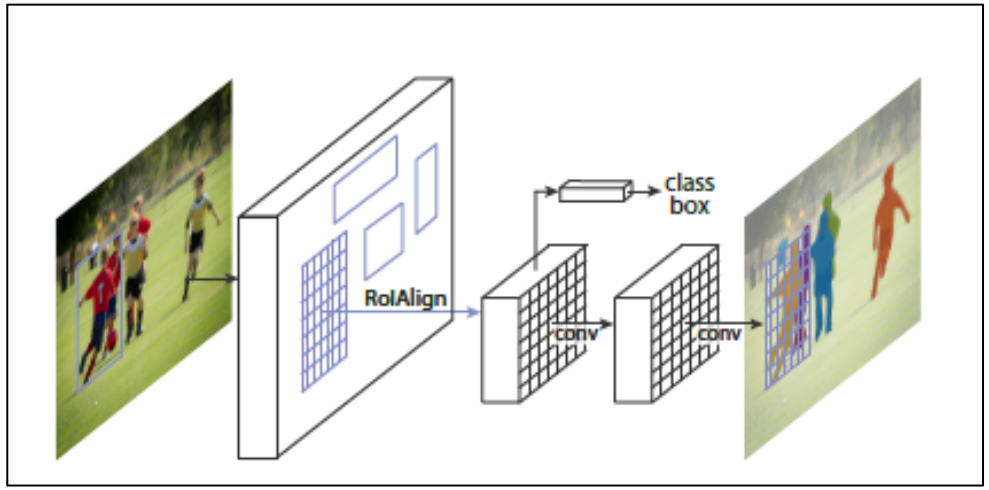
https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53

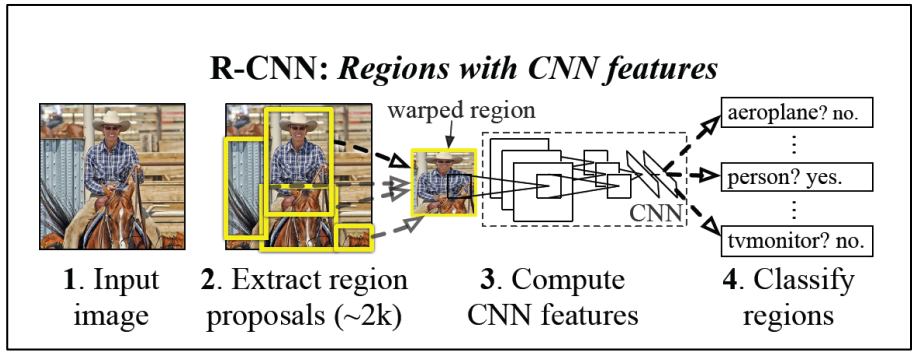
Image segmentation can be accomplished through several different modeling architectures

Yolo



Mask R-CNN





Data creation involved the merging of multiple data streams and processes

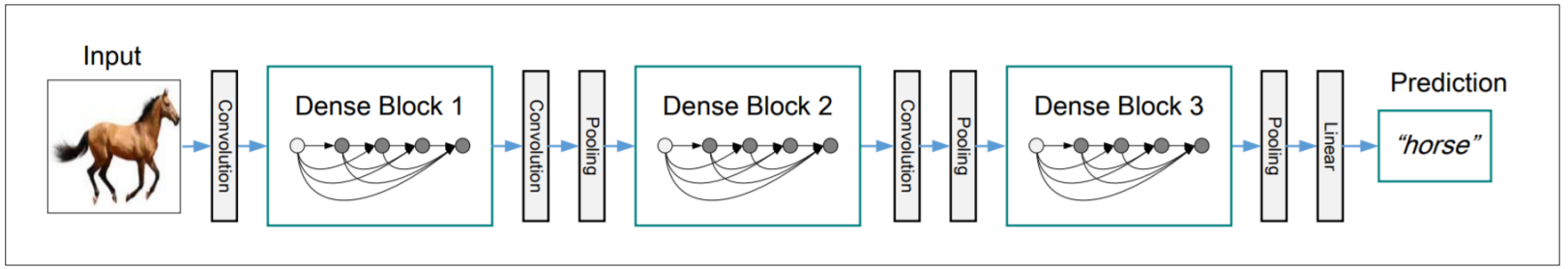
AHA

- Water Treatment Plants
- Airports
- Potable Water Tanks
- Hospitals
- Hydroelectric Dams
- Natural Gas Plants
- Petrol Terminals
- Substations
- Solar Farms

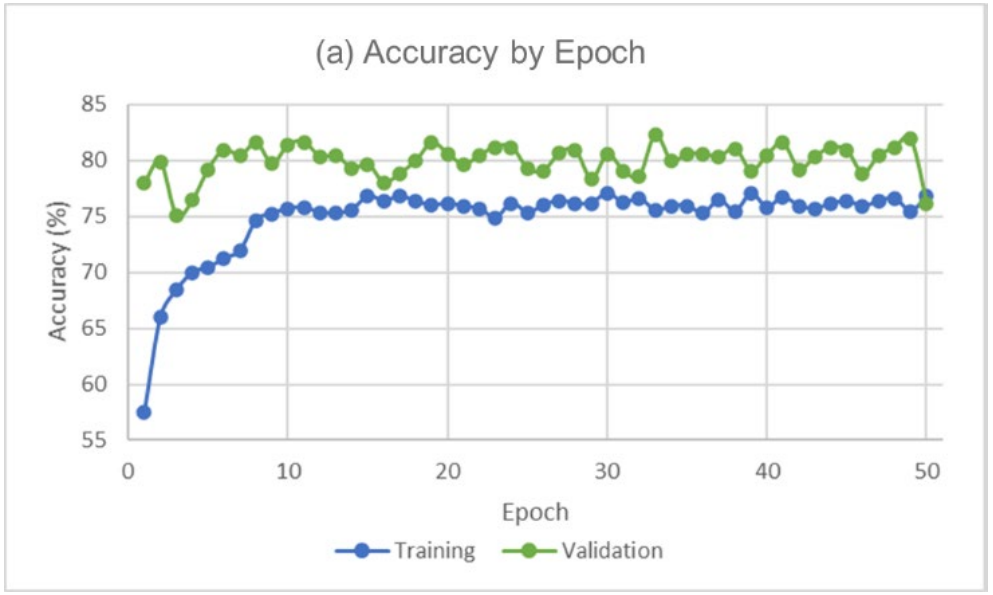
Interns

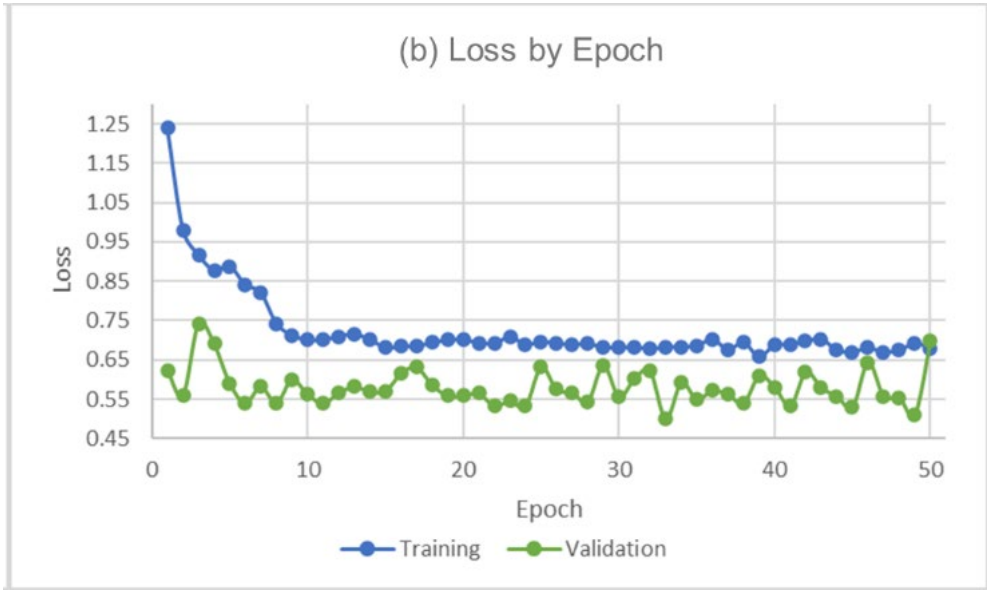
Professional Background → Project Background → Project Approaches → Results

DenseNet161 proved to be the most accurate of architectures trained and tested

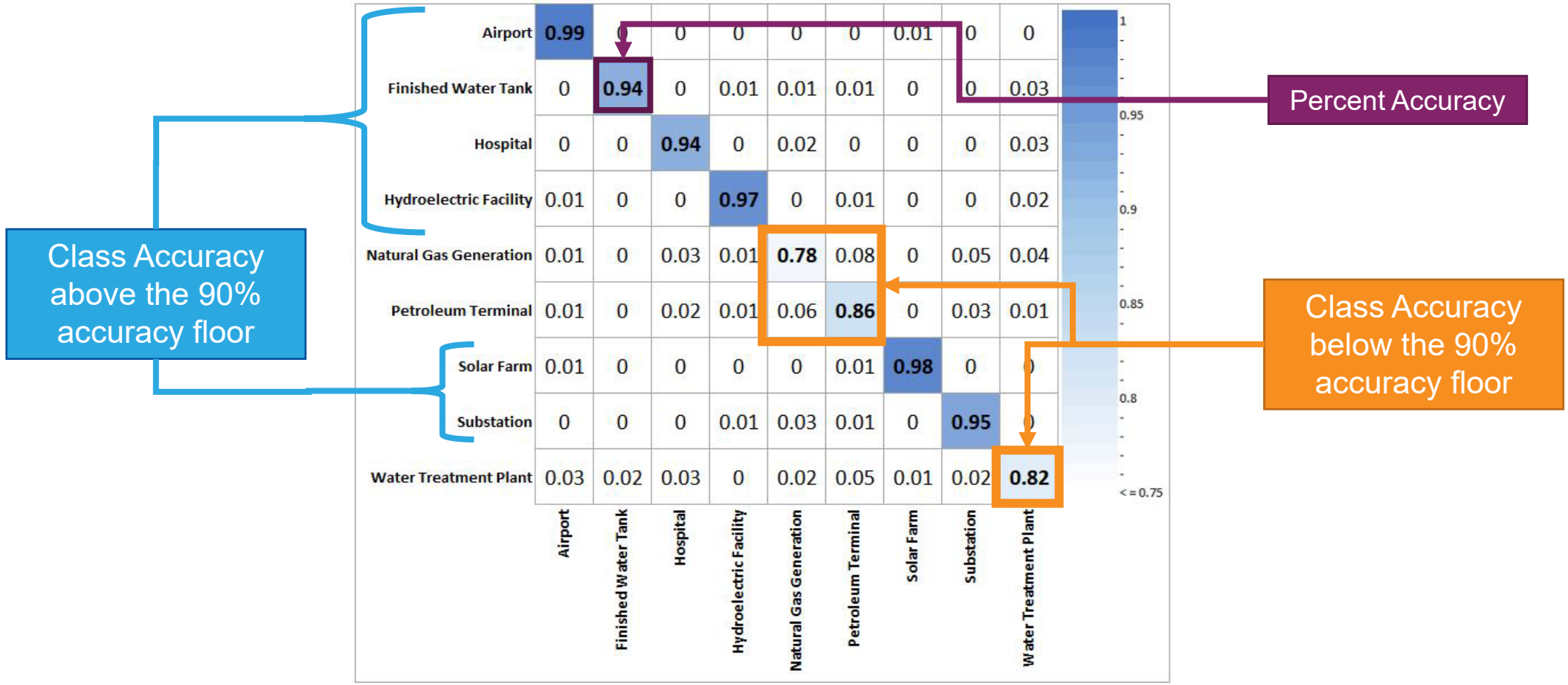


https://arxiv.org/pdf/1608.06993.pdf



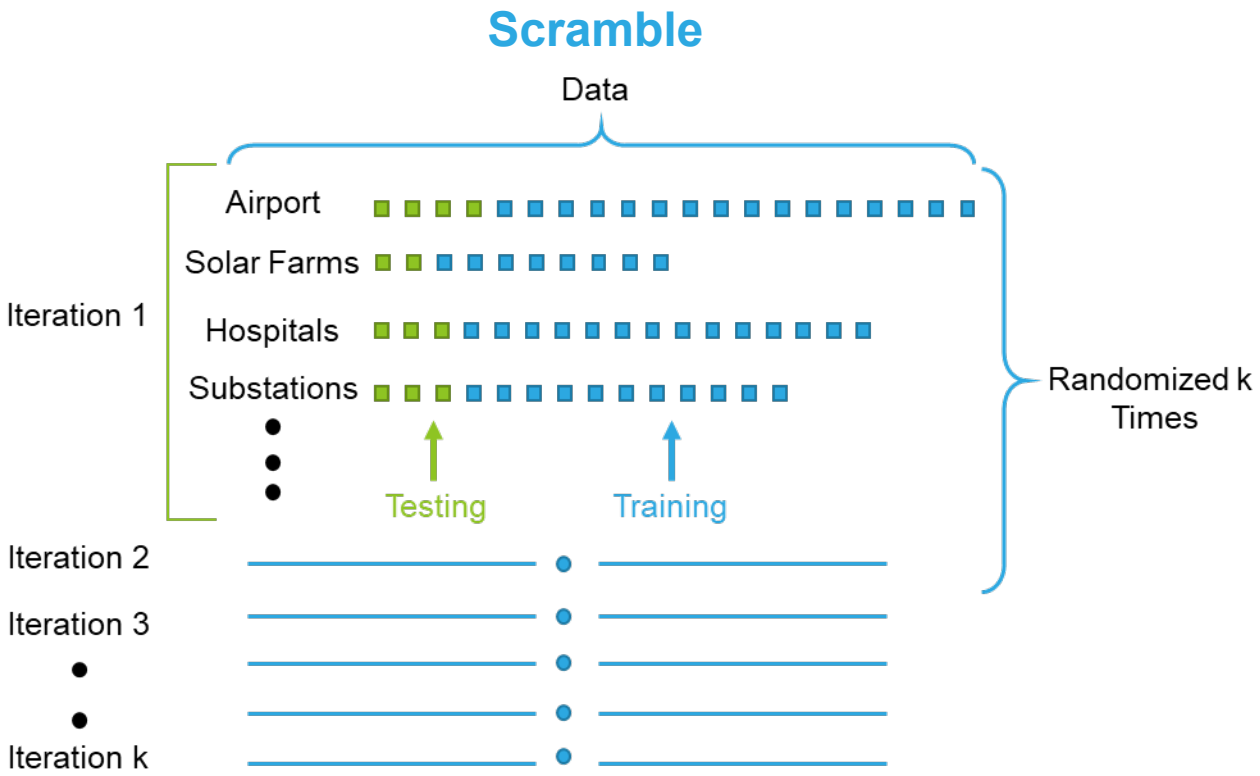


The team established a 90 percent accuracy class floor and developed a hyperparametrized model



Professional Background | Project Background | Project Approaches | Results

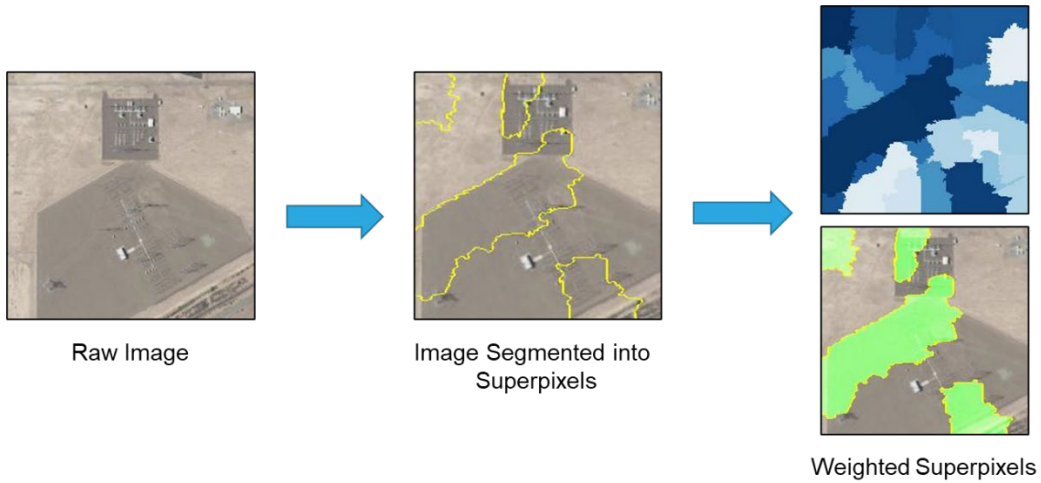
Models in a high consequence, low likelihood ecosystems need validation

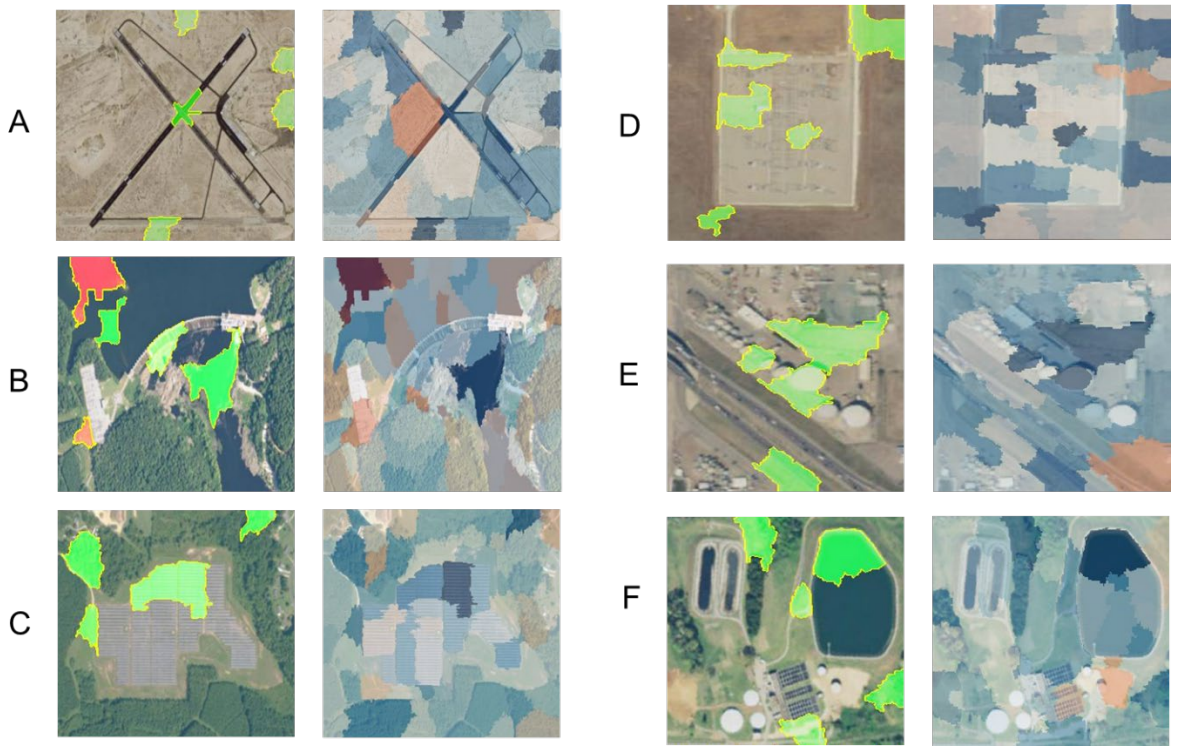


Facilities	Average Accuracy (k=10)
Airports	97
Hydroelectric Dams	96
Solar Farms	94
Hospitals	93
Potable Water Tanks	93
Substations	91
Petrol Terminals	86
Natural Gas Generation Plants	78
Water Treatment Plants	78
Overall Model Average	90

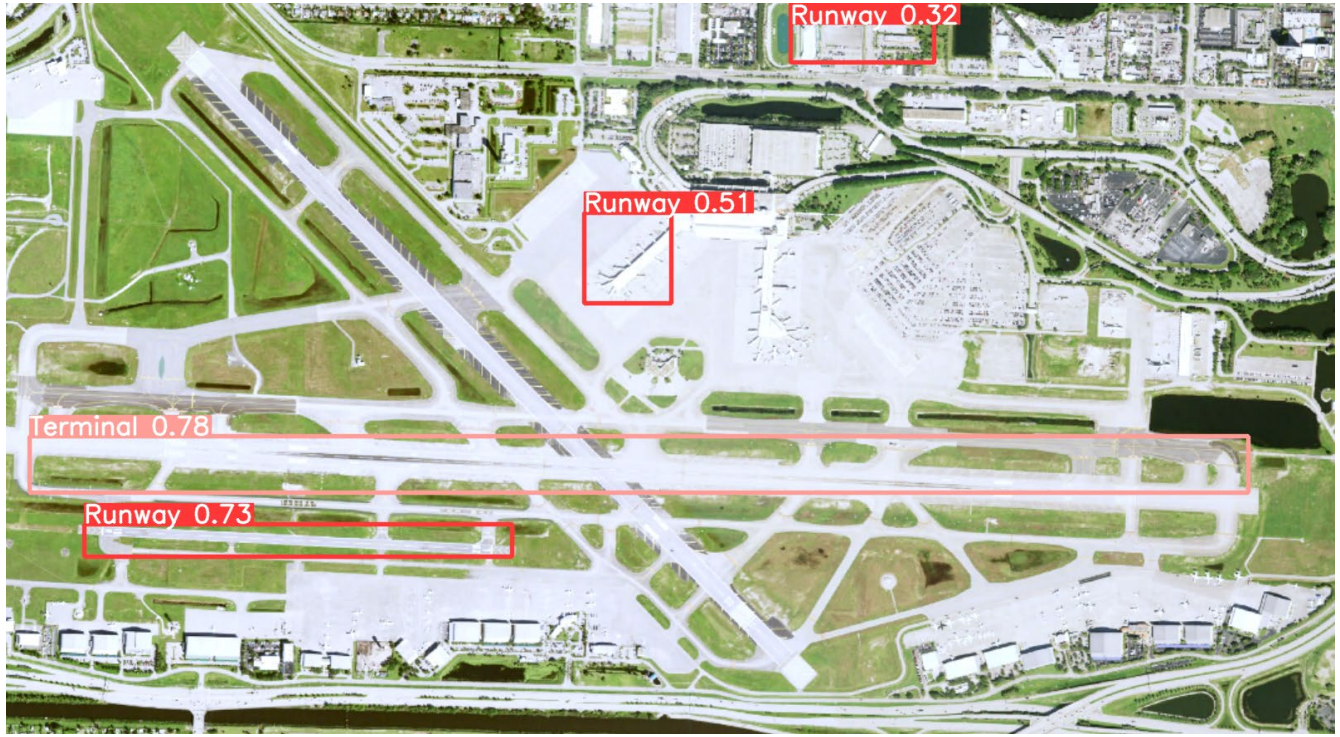
https://www.osti.gov/biblio/1861032

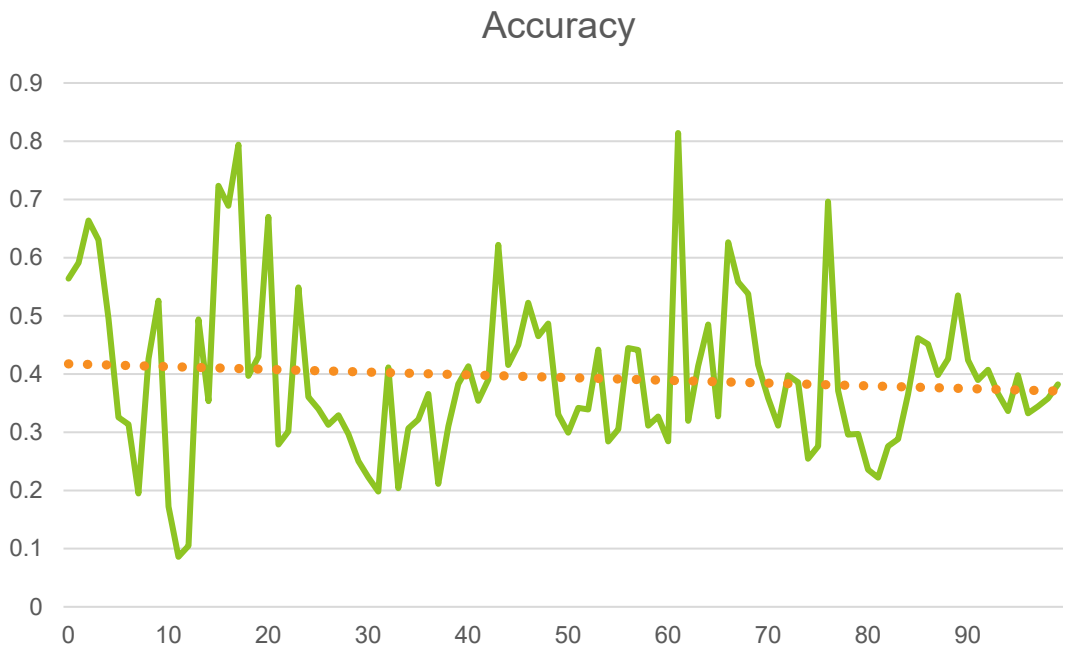
LIME provides insight into how DenseNet161 made its classifications





Object detection with YoloV5 proves to be challenging



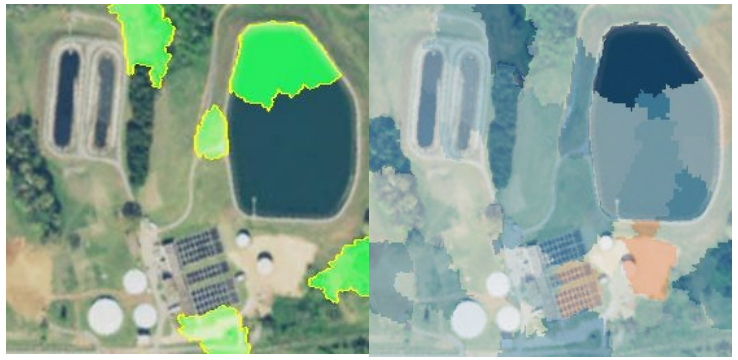


Total Framework

DenseNet161.pt

Facility Classification

LIME



Segmentation Model

- Water Treatment Plants
- Airports
- Hospitals
- Substations

Professional Background | Project Background | Project Approaches | Results

Tangible outcomes of LDRD investment

Conference Attendance
- MORS 86th Symbolism

Papers
- Identifying Critical Infrastructure in Aerial Imagery Data using Explainable Convolutional Neural Networks
- Unnamed Segmentation Paper One and Two

Modeling Capability
- DenseNet161 Configuration (facility detection)
- Segmentation Configuration (in dev, facility component detection)

Workforce Conversion and Education Outreach
- Eight interns (3 graduates, 6 undergraduates)
- One conversion to FTE

IP
- Scramble

Potential Follow-On Work Gov.
- NA24
- EERE's WPTO
- DHS S&T

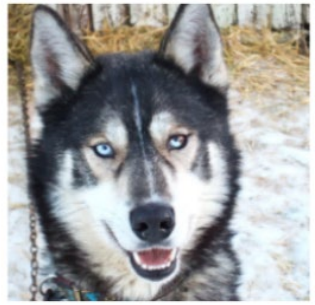
Academic and Private Partnerships
- Georgia Tech.
- NSL

Questions

Extra Slides

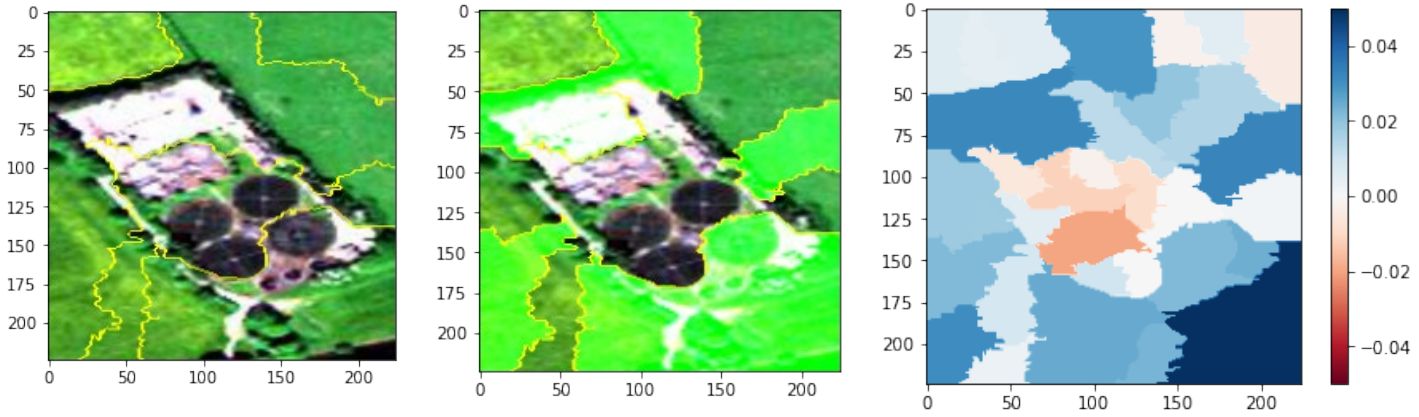
Extra Slides

- Local Interpretable Model-Agnostic Explanations (LIME)

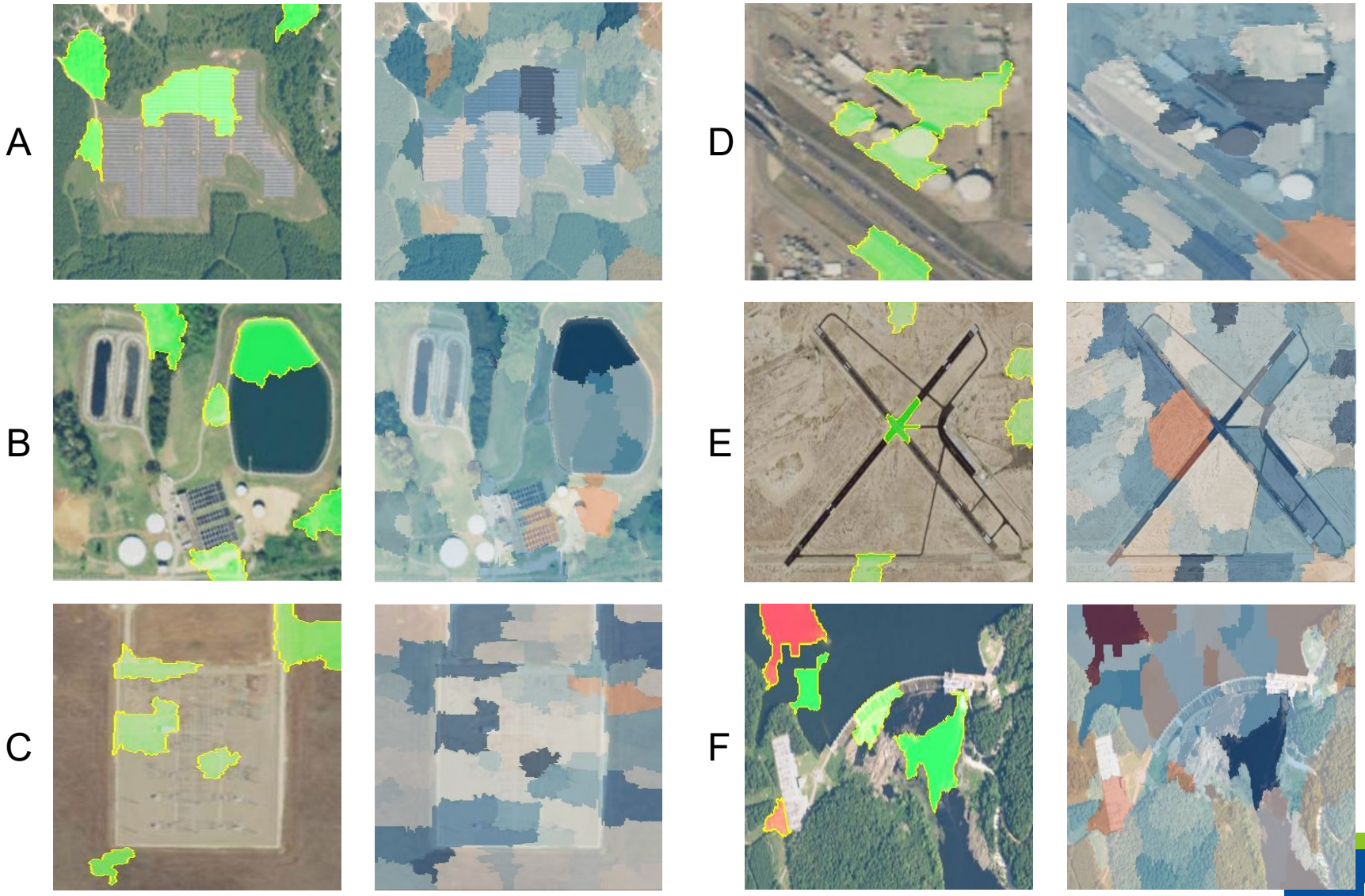


(a) Husky classified as wolf

(b) Explanation



Extra Slides



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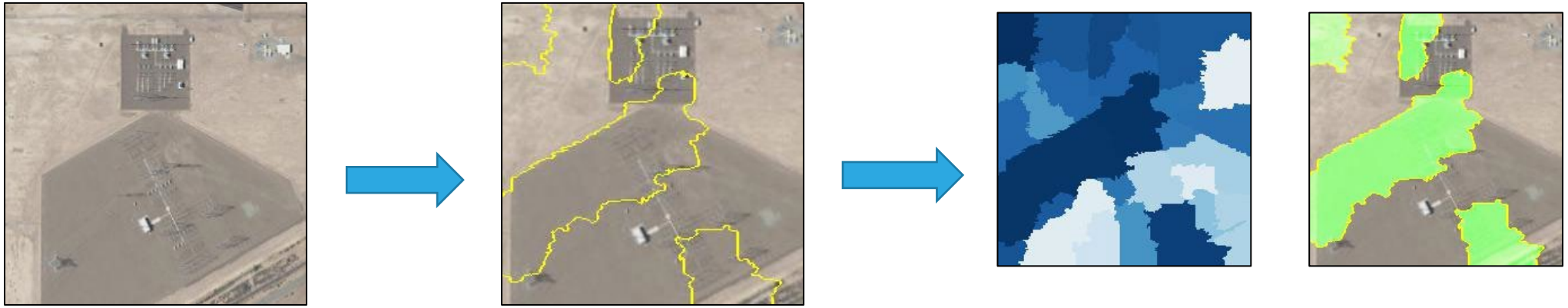

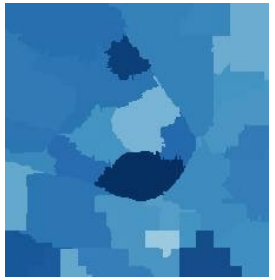

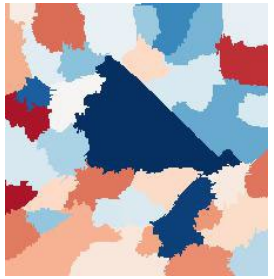

SHAP		
	First Guess	Overall
Airports	95	100
Hydroelectric Dams	98	100
Solar Farms	1	54
Hospitals	64	85
Potable Water Tanks	14	68
Substation	0	**2**
Petrol Terminals	75	98
Natural Gas Generation Plants	54	92
Water Treatment Plants	1	4

LIME		
	First Guess	Overall
Airports	99	100
Hydroelectric Dams	93	99
Solar Farms	95	99
Hospitals	68	80
Potable Water Tanks	11	41-78
Substation	88	98
Petrol Terminals	80	100
Natural Gas Generation Plants	40	90
Water Treatment Plants	60	96