INL/CON-22-66395-Revision-0

Satellite Imagery Analysis for Critical Infrastructure

October 2022

Shiloh N Elliott

Changing the World's Energy Future

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

October 26, 2022

Shiloh Elliott, Ashley Shields, Eduardo Trevino, Mark Schanfein, and Gustavo Reyes

The Applicability of Explainable Convolutional Neural Networks to Detecting Facilities within the Nuclear Lifecycle

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Overview

- Motivation and Project Framing
- Data Generation
- Classification Approach
  - Modeling Pipeline
  - DenseNet 161
  - Explanability
- Change Detection Approach
- Future Efforts

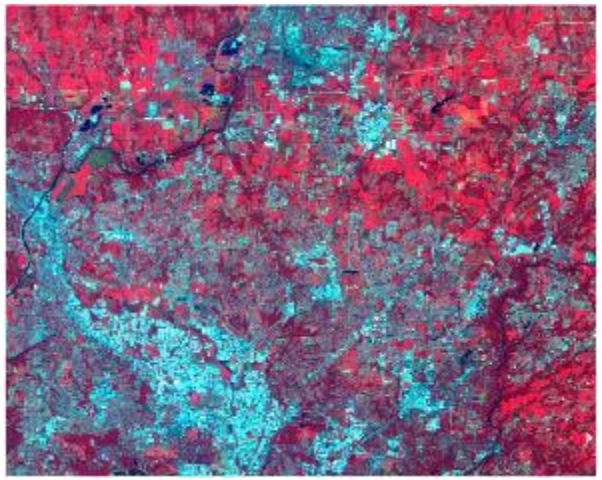
Can machine learning enable the human analyst?

*The detection of **undeclared** nuclear facilities and related nuclear material activities is one of the greatest challenges facing the international community under its nuclear non-proliferation mandate. Recent developments in machine learning algorithms and their merger with open-source satellite imagery provide an opportunity to assess the utilization of these methods in addressing this need . This initial ML study lays the groundwork for the autonomous detection of known nuclear powerplants (NPP) in the United States with initial findings working towards identifying **predecessor** and **successor** facilities at the front and back-end of operational NPPs. As this ML analytical coupling matures, its full potential can be realized going well beyond the basic identification of undeclared NPPs, to include the identification of predecessor and successor facilities within the entire nuclear fuel cycle and changes taking place at those sites.*

- Detection of undeclared nuclear facilities and related activities is challenging.
- Explainable CNNs may provide a capability to assist with the detection of these undeclared nuclear facilities and activities.
- If successful, this methodology could be utilized in the identification of predecessor and successor facilities.

Object detection and Classification in satellite imagery is an extensively studied but narrowly applied field

Object Detection



Classification

Noted Non-Proliferation Challenges

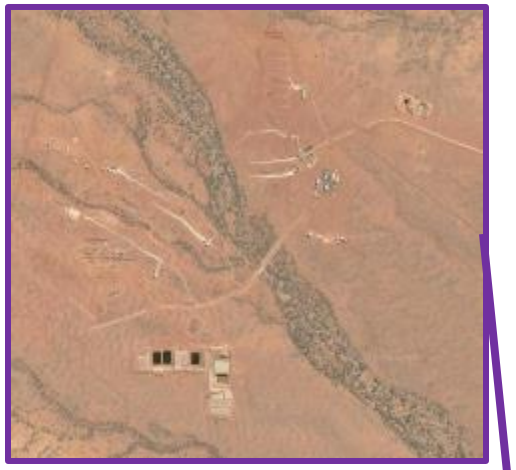
- "Looks can be deceiving"[1]
- Required SME knowledge[1,2]
- Data Scarcity[3]
- Proprietary Imagery (e.g., Thermal)[1]

1 https://www.annualreviews.org/doi/pdf/10.1146/annurev-earth-063016-015704
2 J.-J. Han and N. K. Kim, "Accuracy Assessment of Change Detection Algorithm for Satellite Imagery in Support of Interpretation of Nuclear Activities."
3 J.-J. Han and N. K. Kim, "What Experts Care About in Satellite Observation : A Quantitative Analysis for Countering Nuclear Proliferation."

Nie, S., Jiang, Z., Zhang, H., Cai, B., & Yao, Y. (2018). Inshore ship detection based on mask r-cnn. *International Geoscience and Remote Sensing Symposium (IGARSS)*, *2018-July*, 693–696. https://doi.org/10.1109/IGARSS.2018.8519123

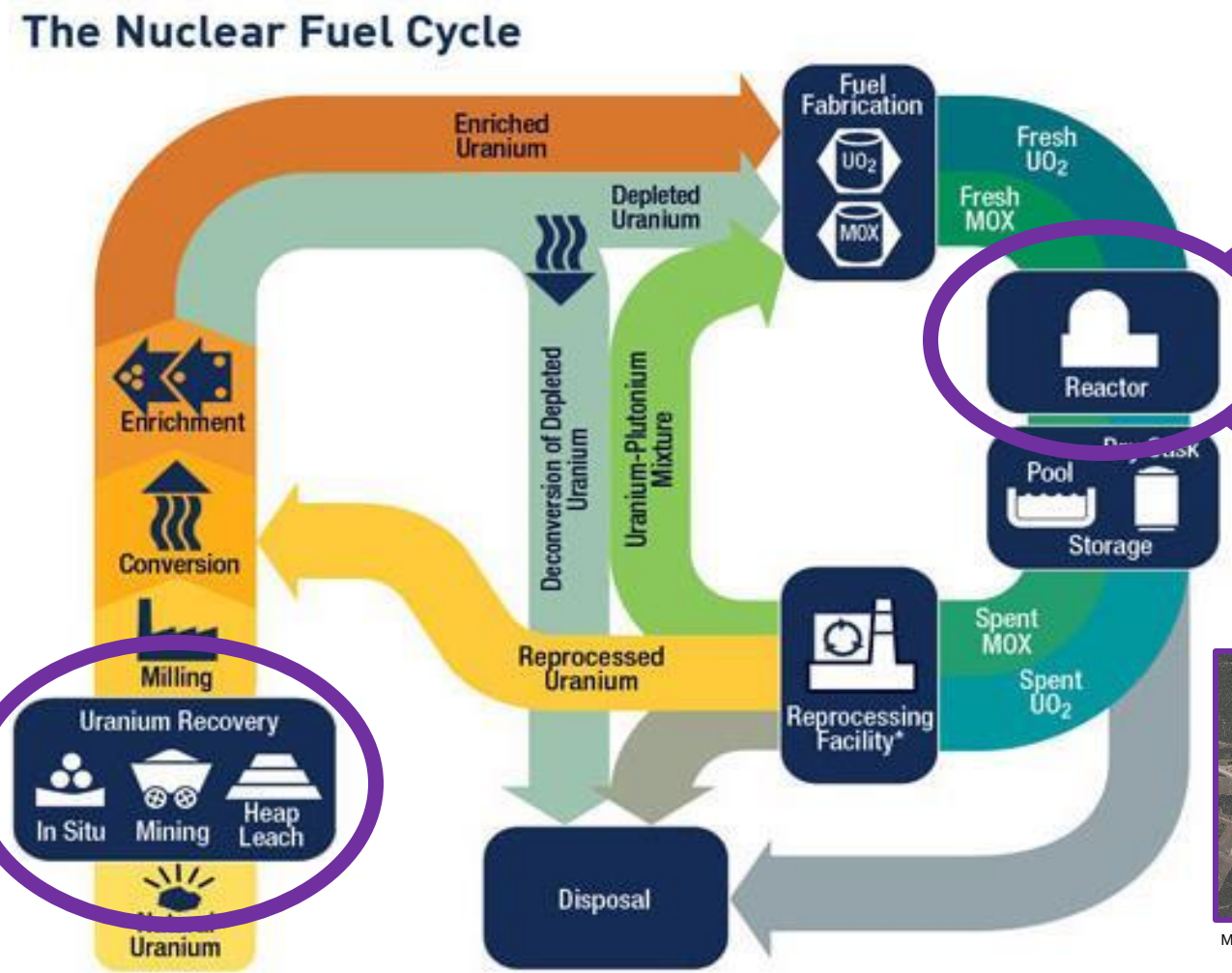
https://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/image-classification/what-is-image-classification-.htm

Where can remote sensing techniques be applied in the Nuclear Fuel Cycle?



Google Earth

https://world-nuclear.org/information-library/country-profiles/others/uranium-in-africa.aspx



Maxar

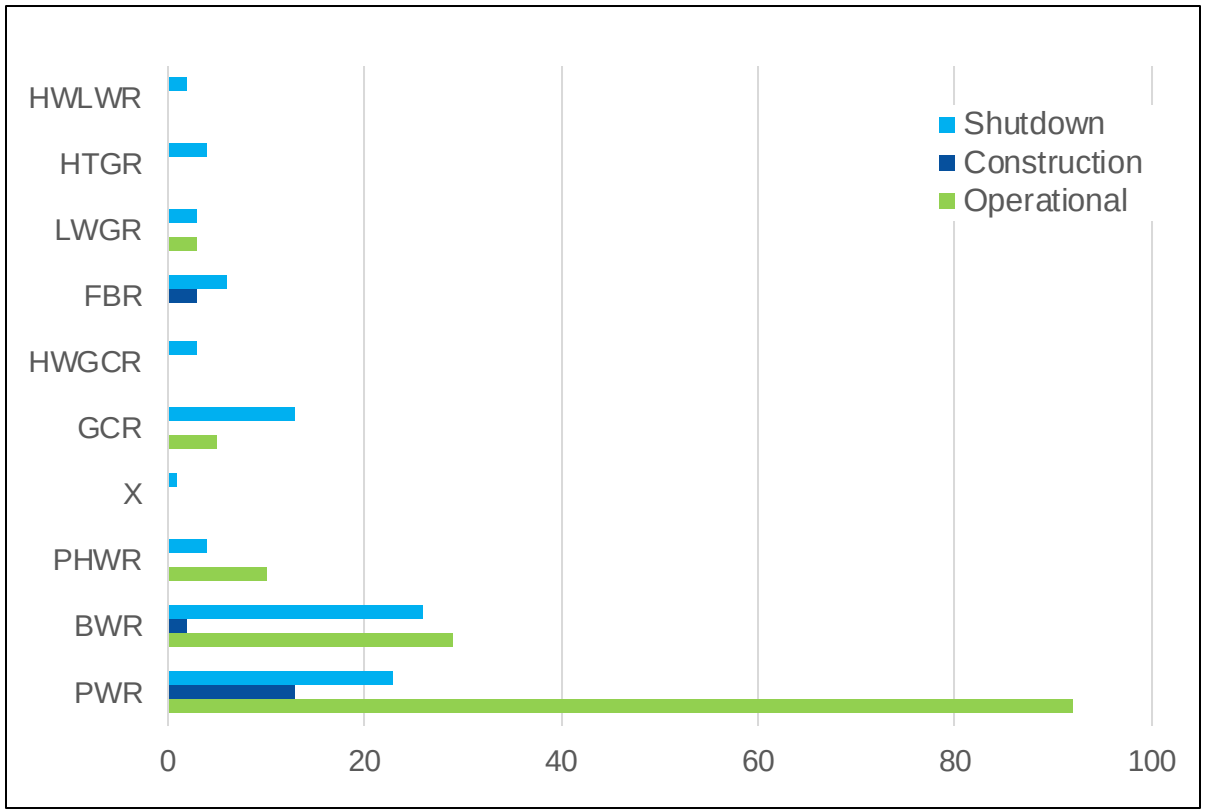
Maxar

* Reprocessing of spent nuclear fuel, including mixed-oxide (MOX) fuel, is not practiced in the United States.
Note: The NRC has no regulatory role in mining uranium.

As of January 2019

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Data generation is the key component to a successful ML process



338 Unique Reactors

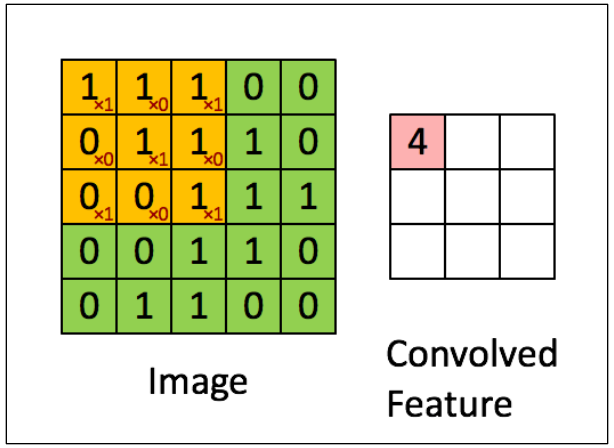
242 Usable Facility Sites

MAXAR

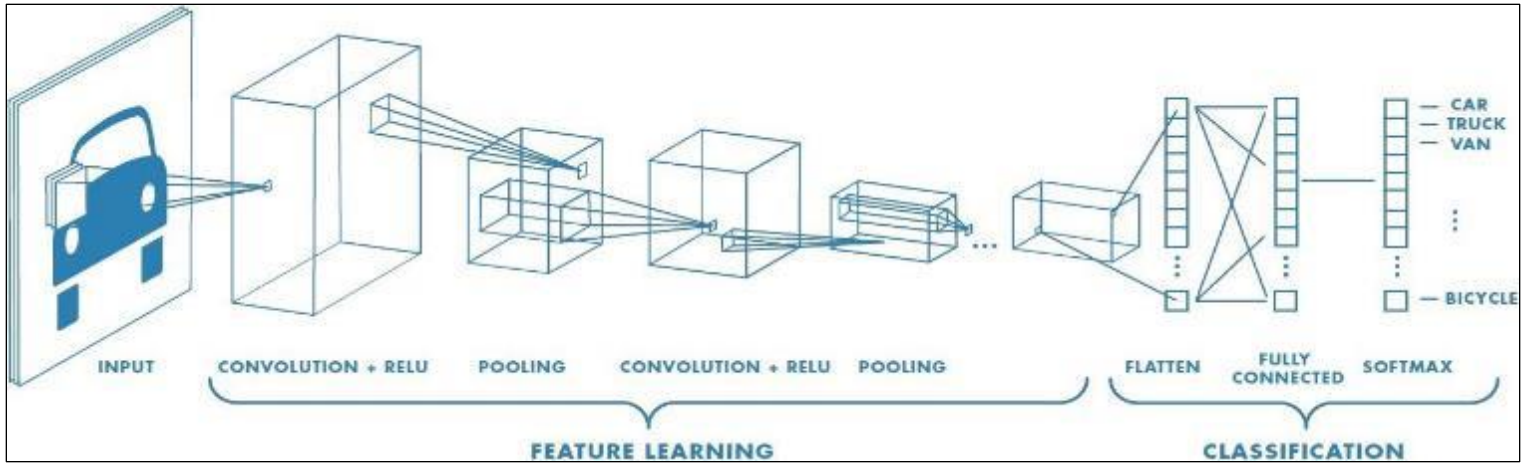
Maxar

What are the key components of CNNs and why are they used in satellite imagery analysis?

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

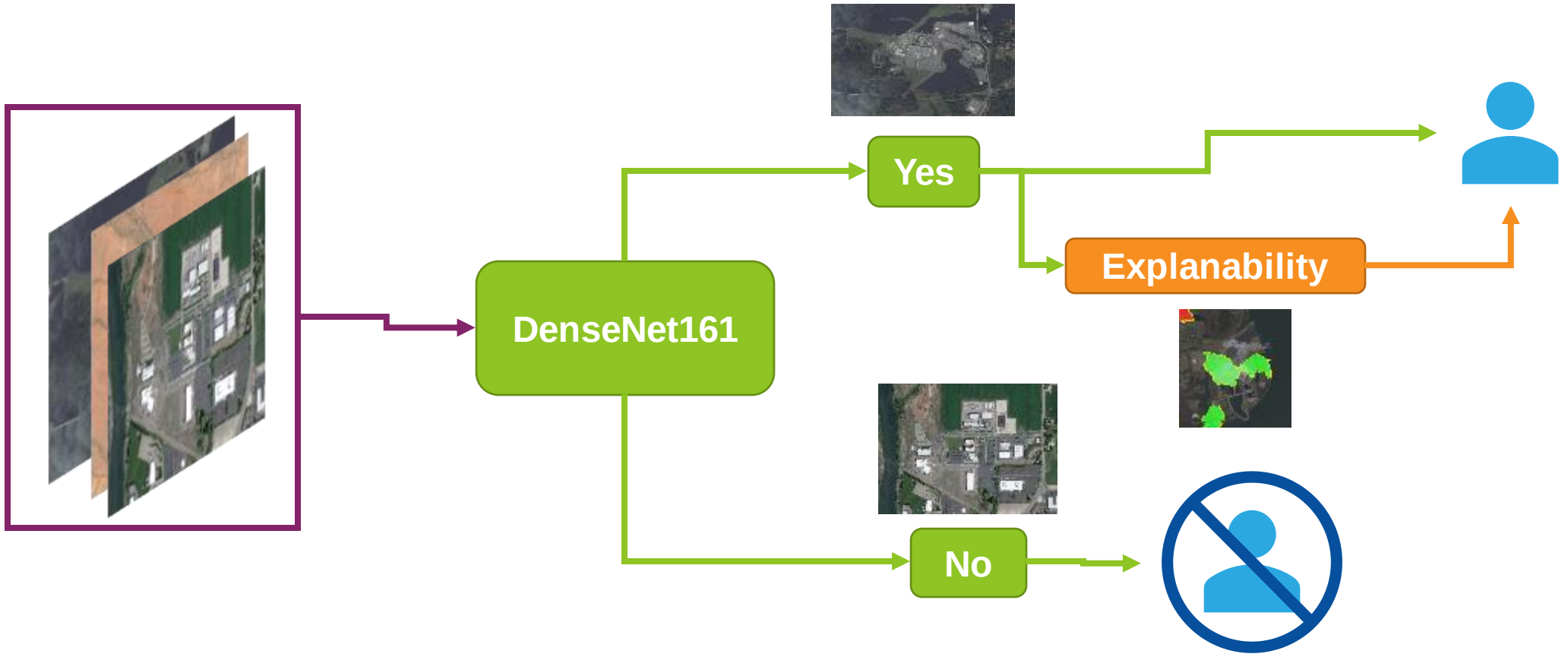


https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53

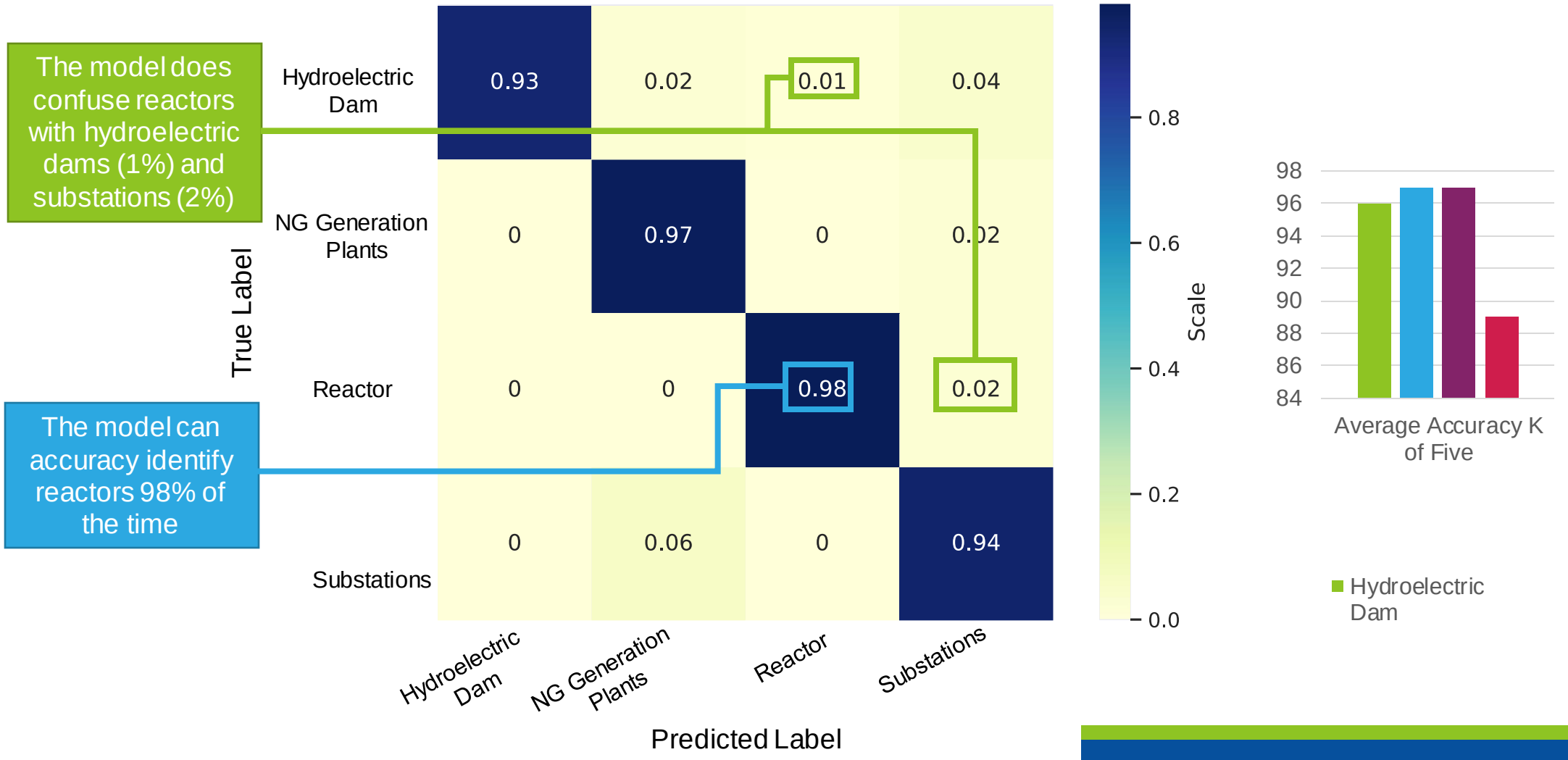


https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53

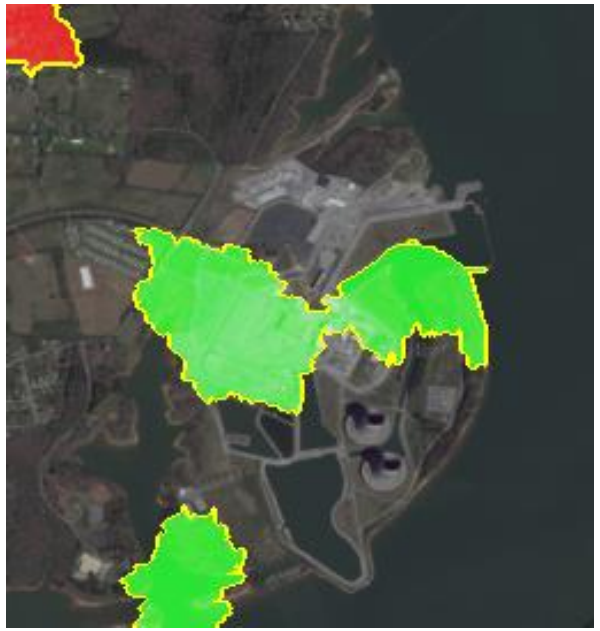
What does our current modeling process look like?



DenseNet-161 results are encouraging, but rigorous verification and validation testing is needed.



Explanability provides a critical level of transparency to a usually opaque modeling process.



Change detection the next step in the modeling pipeline.

	1	2	…	$n-1$	n
1	0	75	…	100	50
2	10	25	…	60	30
…	…	…	…	…	…
$m-1$	35	50	…	150	130
m	255	0	…	1	200

−

1	2	…	$n-1$	n
10	90	…	70	30
40	25	…	30	50
…	…	…	…	…
35	50	…	120	160
255	0	…	5	255

=

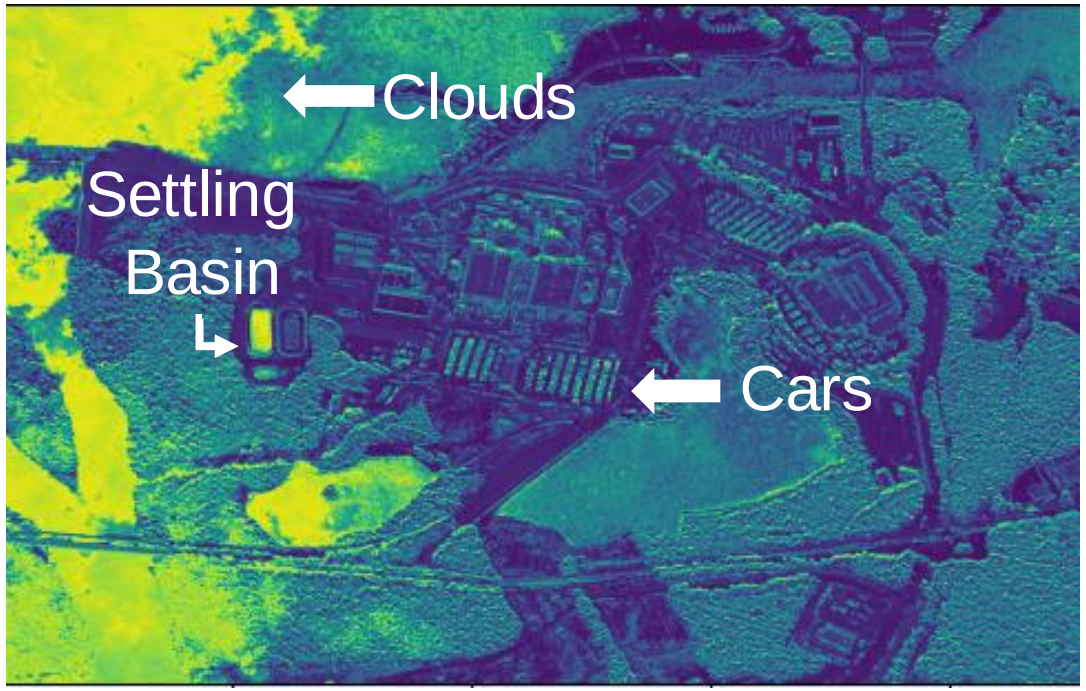
-10	-15	…	30	20
-30	0	…	30	-20
…	…	…	…	…
0	0	…	30	-30
0	0	…	-4	0

What does basic change detection look like when applied to the existing data set?

McGuire Nuclear Station

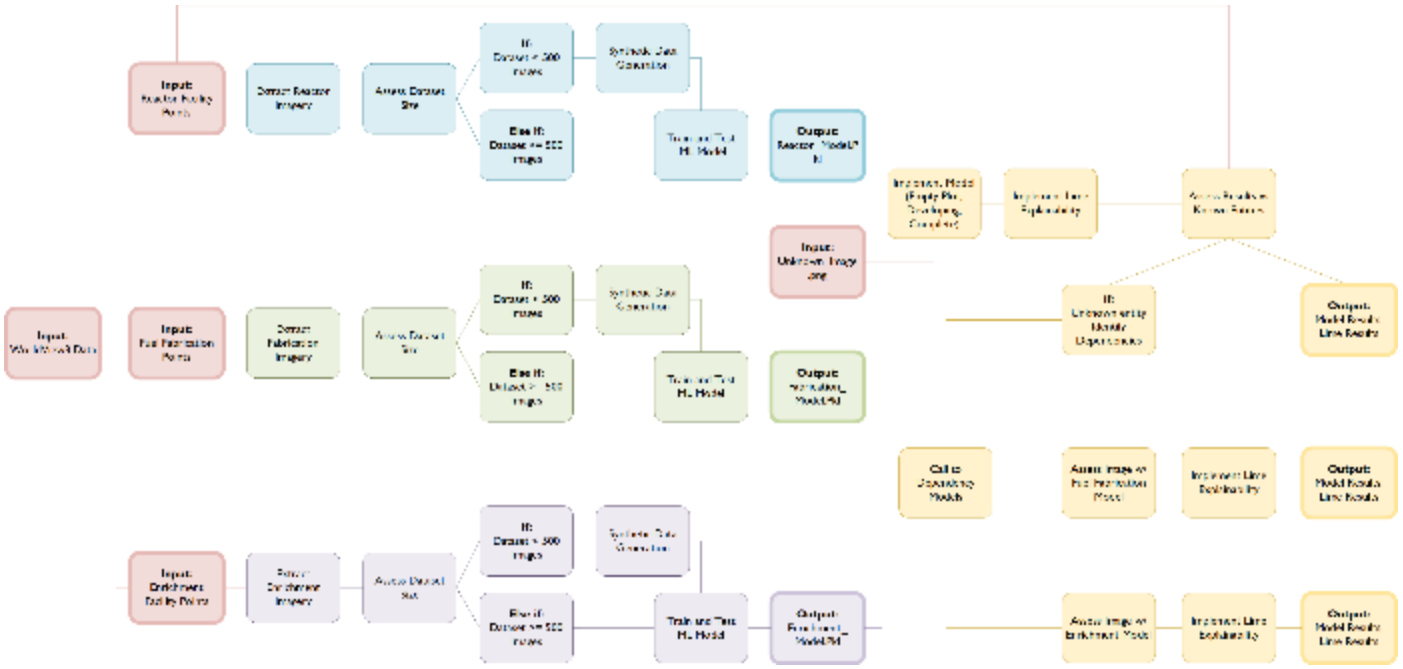
17/9/2017
(Sunday)

28/9/2017
(Thursday)



Future activities and modeling efforts.

- Verifying of the classification pipeline
- Change detection
- Object detection
- Predecessor and Successor facility detection



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Questions?