MATLAB EXPO

Automated Optical Inspection and Defect Detection with Deep Learning

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MathWorks®

What is Automated Optical Inspection?

*“ Automated optical inspection is the **image-based** or **visual inspection** of manufacturing parts where a camera scans the device under test for both **failures** and **quality defects**"*

Automated Defect Detection

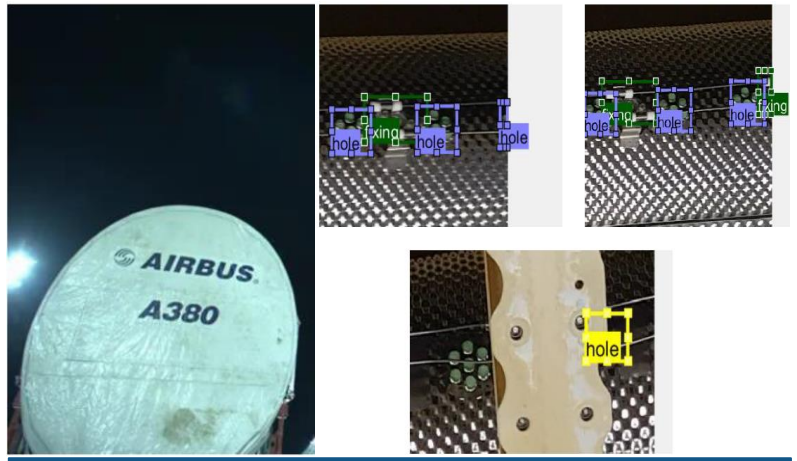
Machine Vision

Visual Inspection

Automated Inspection

Customer References

AIRBUS



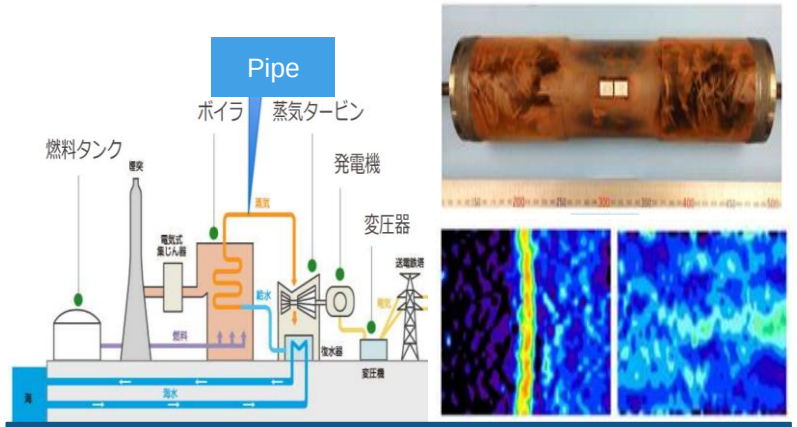
Automatic Defect Detection

Visual Inspection of Automotive Parts

MUSASHI

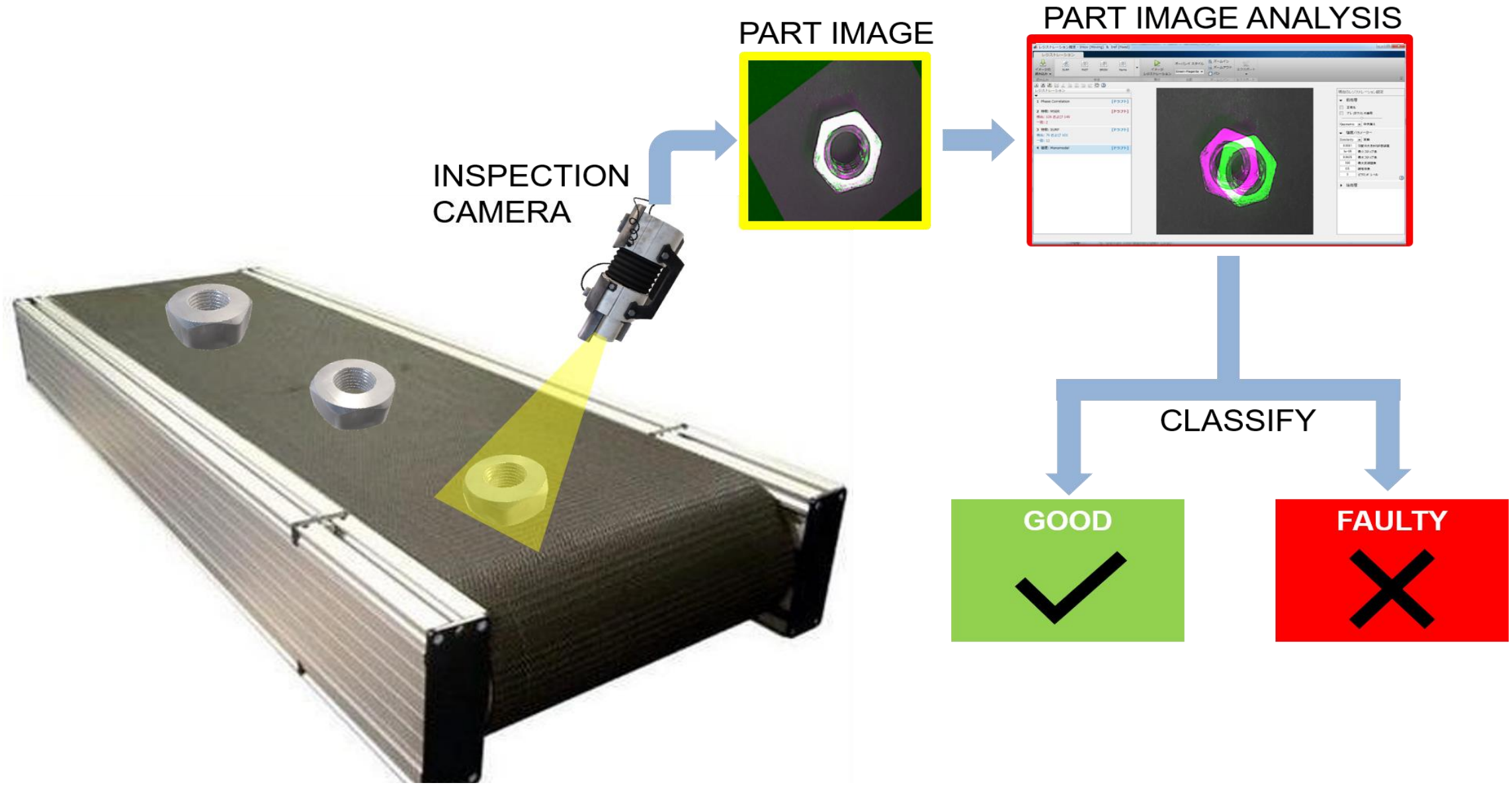
KRRI

Defect Detection in Railway Components

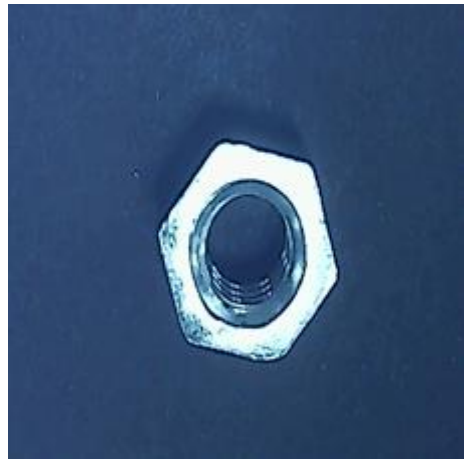


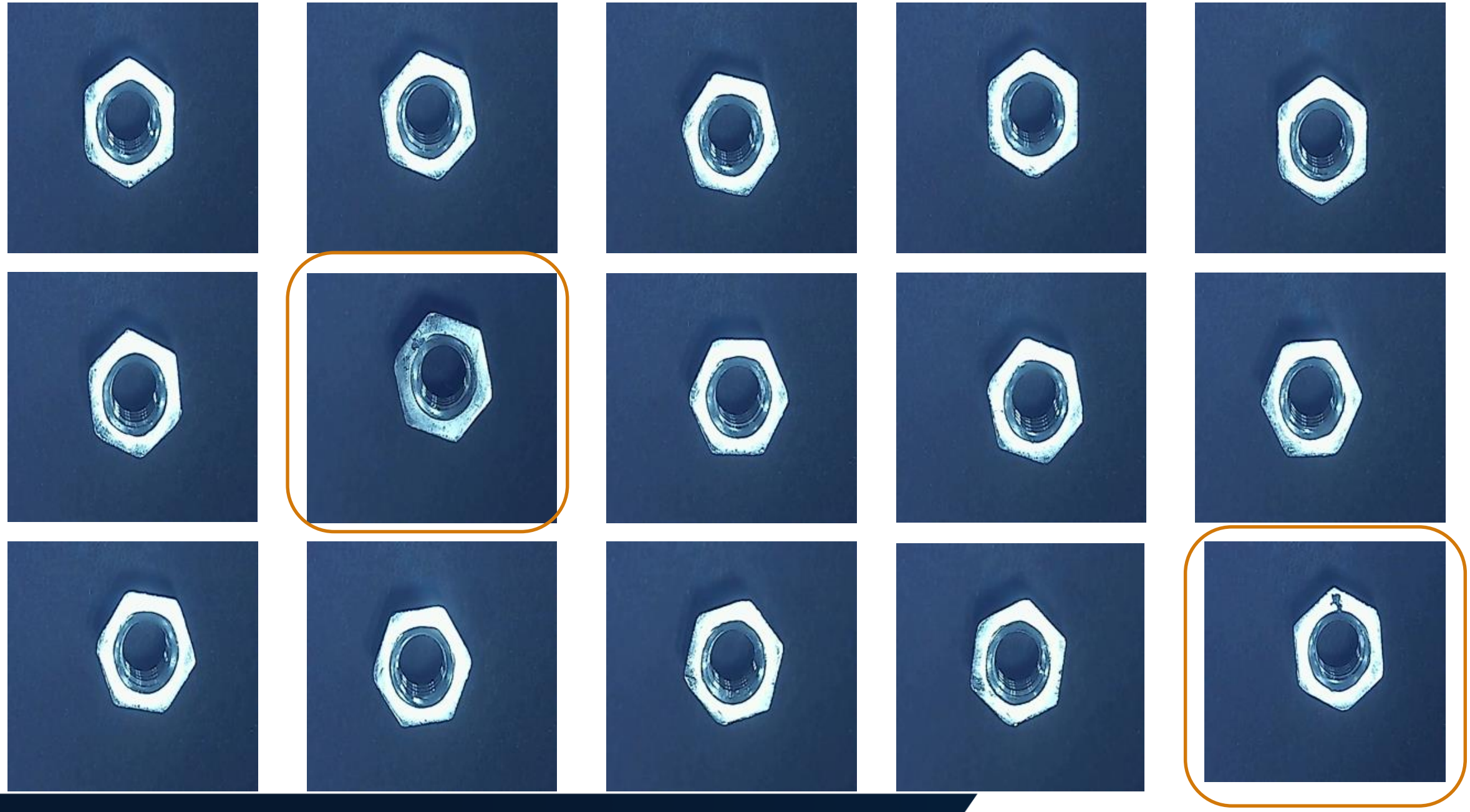
Assess Pipe Weld Damage at Power Plants

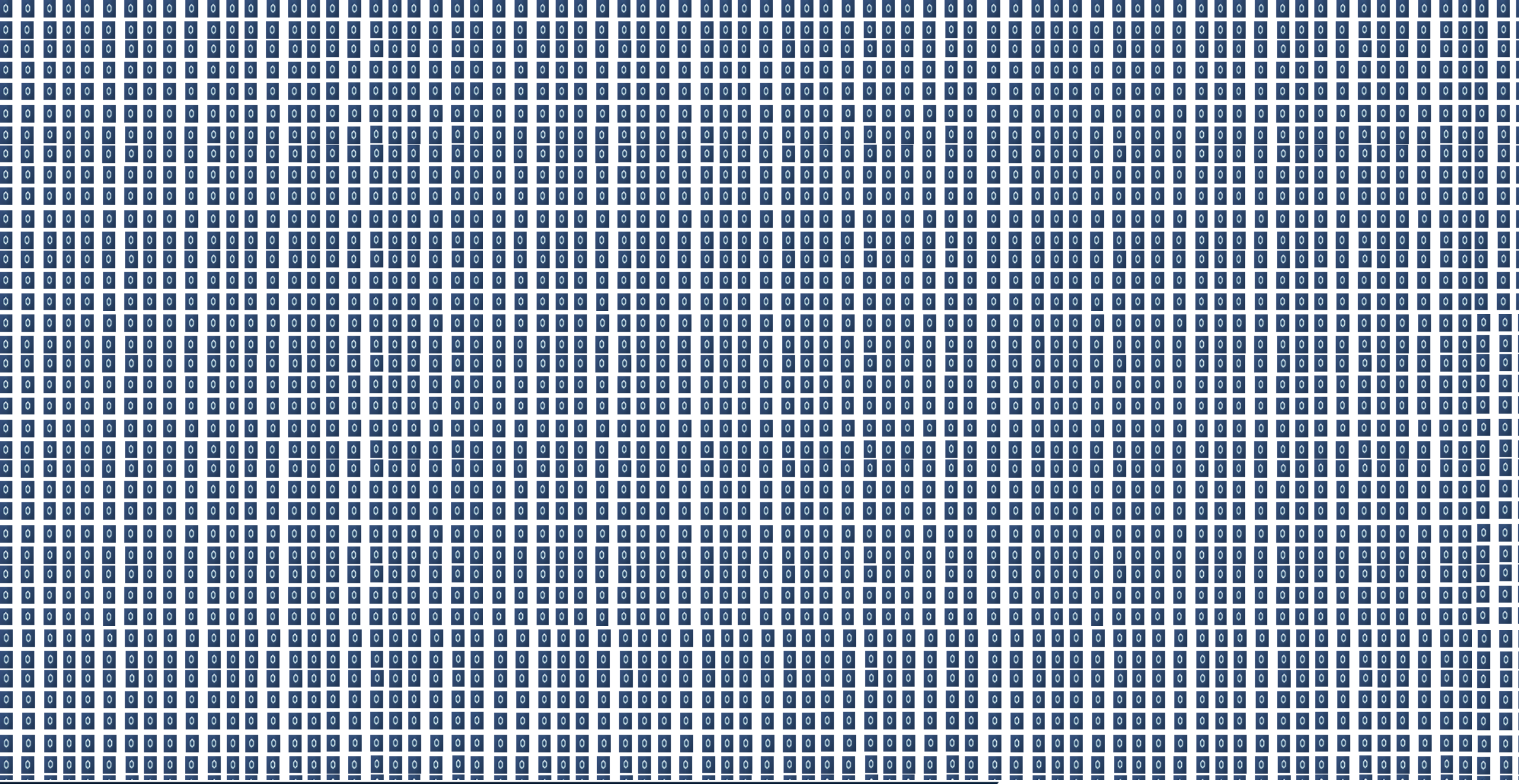
Kansai Electric Power
power with heart


PART IMAGE
PART IMAGE ANALYSIS
INSPECTION
CAMERA
CLASSIFY
GOOD
FAULTY

Can you find the defective hex nut?

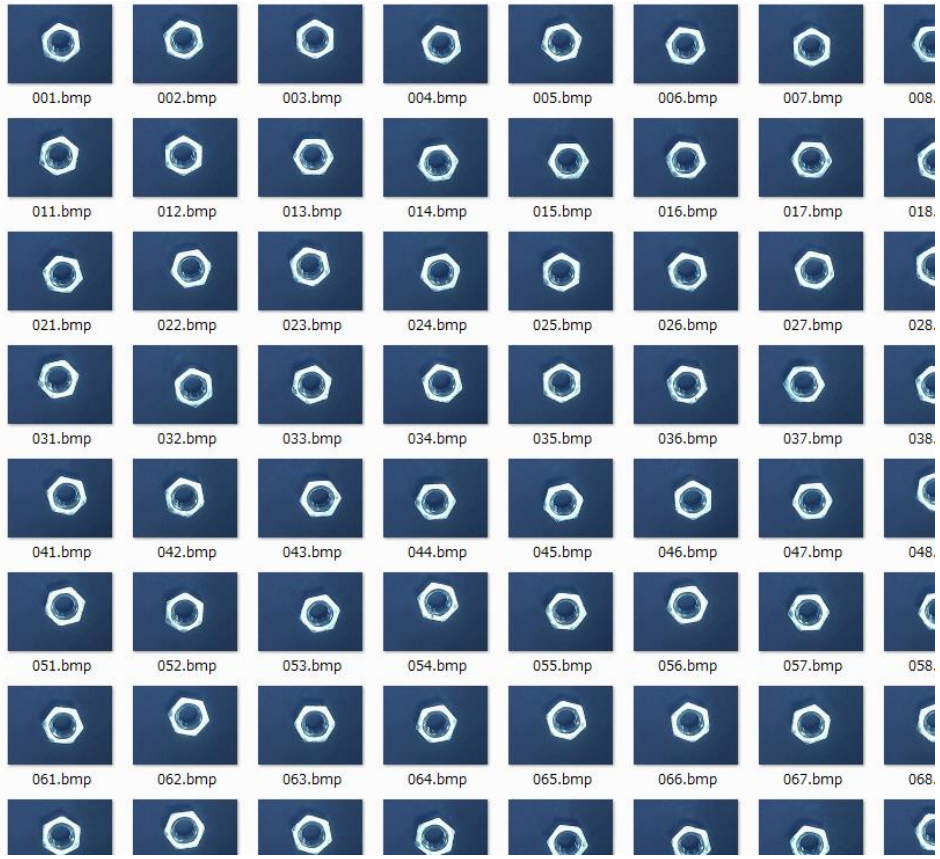




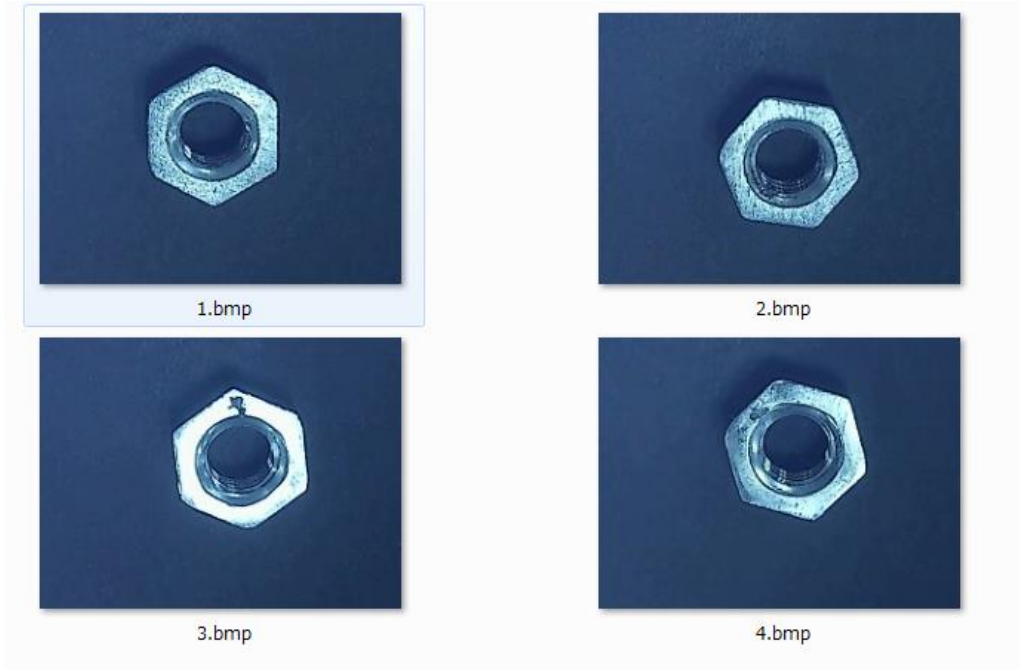


Finding Defective Hex Nuts

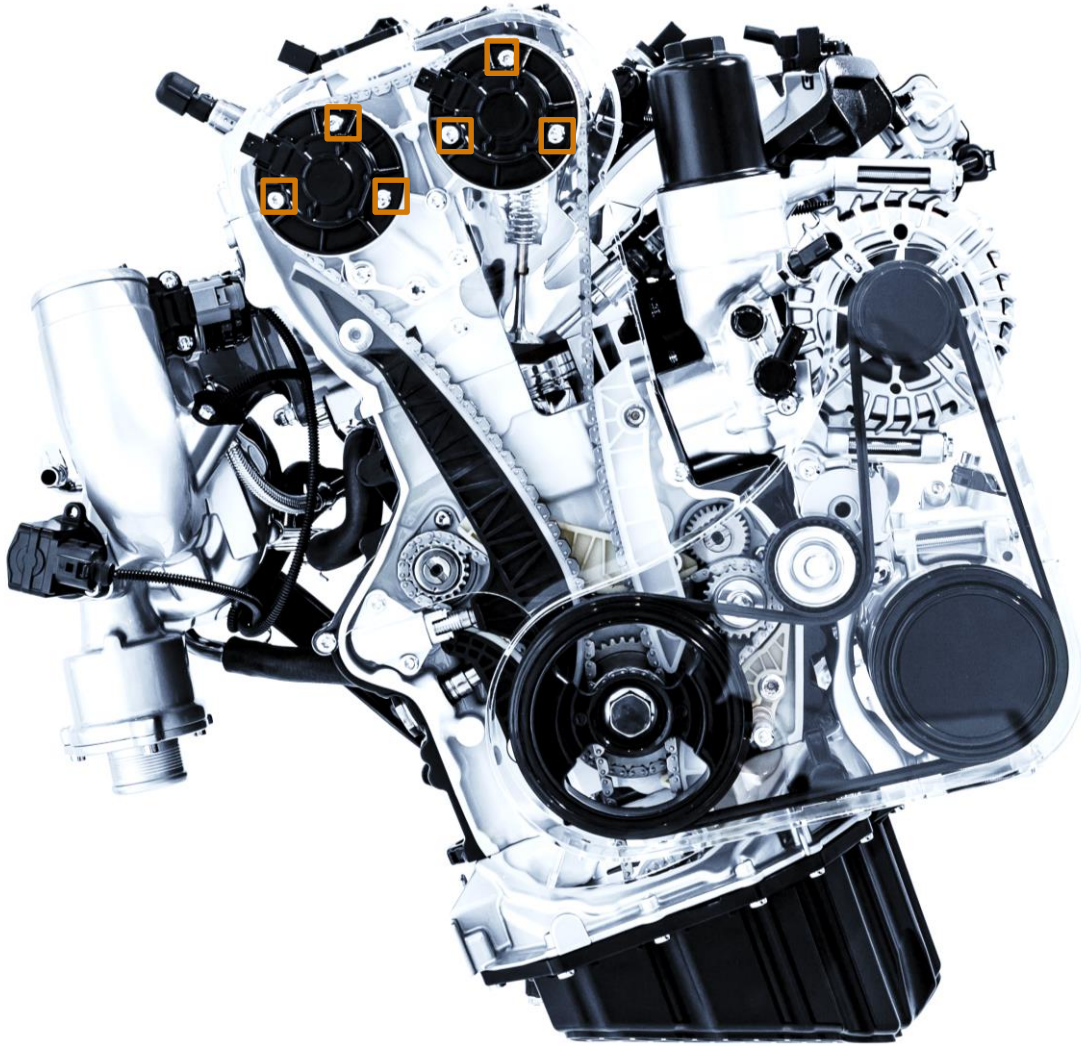
Good



Defective



Detecting Parts



Defect Detection Workflow

DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Ground truth labeling

AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

Iteration and Refinement

Defect Detection Workflow

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Iteration and Refinement

Data Access and Preprocessing – Common Challenges

- How do I access large data that might not fit in memory?
- How do I preprocess data and get the right features?
- How do I label my data faster?
- What if I have an imbalanced dataset or don’t have enough data?

Data Access and Preprocessing – Common Challenges

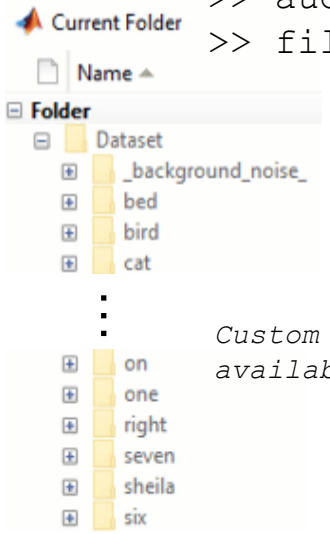
How do I access large data that might not fit in memory?

How do I load and access large amounts of data?

Datastores

Loads image/signal data into memory as and when needed

```
>> imageDatastore
>> audioDatastore
>> fileDatastore
```

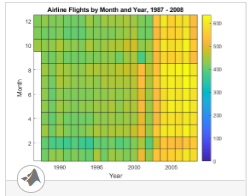


Custom Datastores also available

Tall Arrays

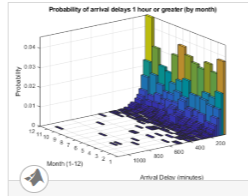
Work with out-of-memory numeric data

- Train deep neural networks for numeric arrays



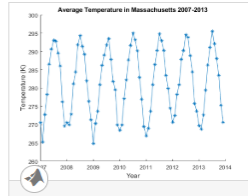
Analyze Big Data in MATLAB Using Tall Arrays

Use tall arrays to work with big data in MATLAB®. You can use tall arrays to perform a variety of calculations on different types of



Histograms of Tall Arrays

Use histogram and histogram2 to analyze and visualize data contained in a tall array.

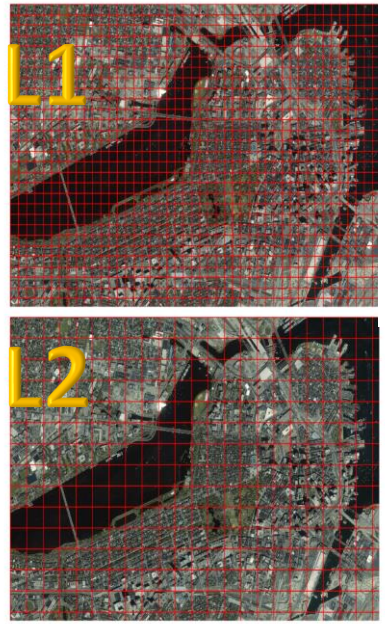


Process Big Data in the Cloud

Access a large data set in the cloud and process it in a cloud cluster using MATLAB capabilities for big data.

BigImage

Work with very large, tiled and multi-resolution images



Each red box is a 1024-by-1024 tile in the file.
L1's dimensions = 29,600 x 46,000
L2's dimensions = 14,800 x 23,000
L3's dimensions = 7,500 x 12,000

```
Rows = 29600
Columns = 46000
TileSizeIntrinsic = [1024 1024]
ResolutionLevelSizes = [29600 46000
                        14800 23000
                         7500
12000]
CoarsestLevel = 3
FinestLevel = 1
PixelSpacings = [1 1; 2 2; 3.947
3.833]
```

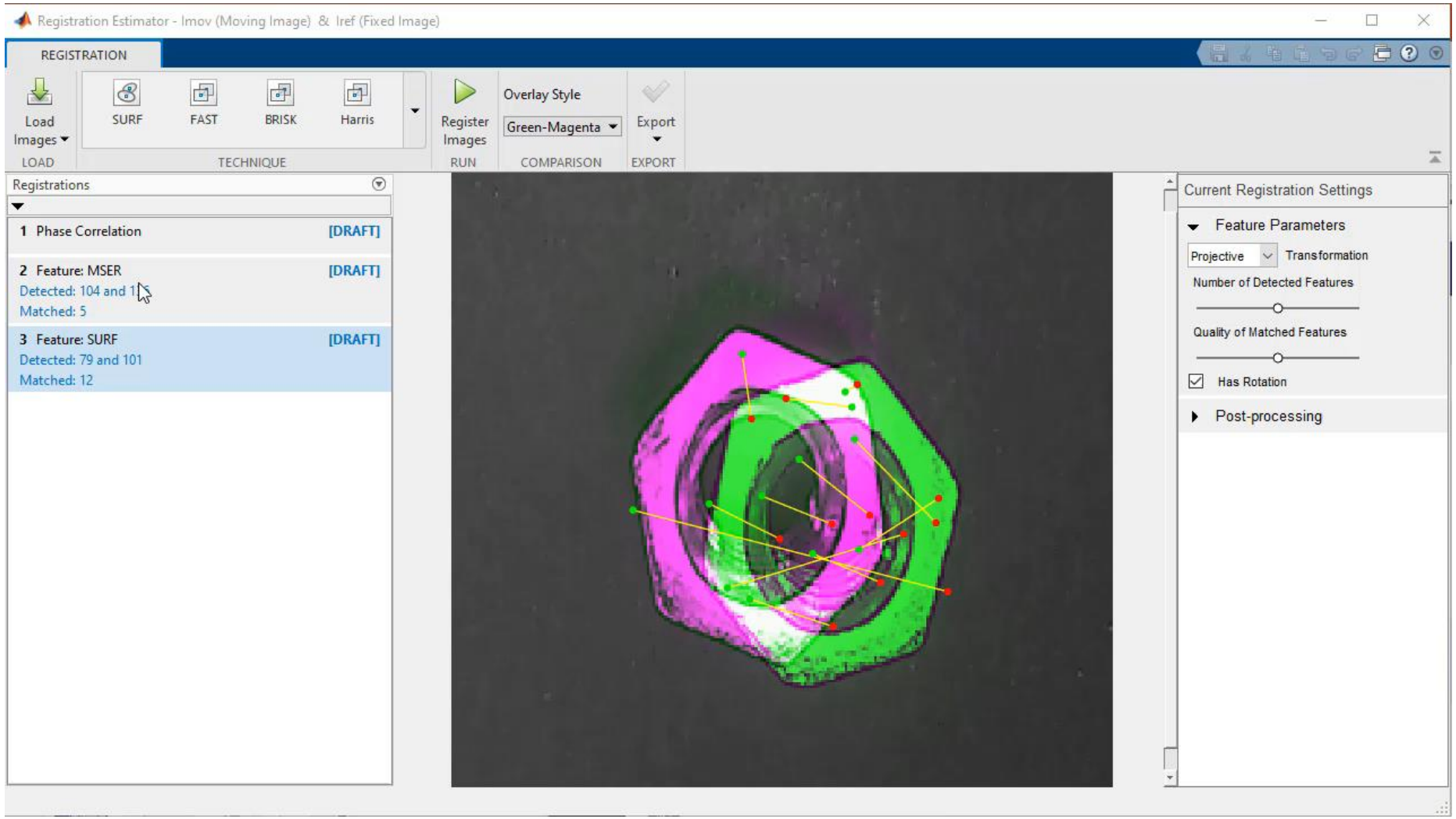
Data Access and Preprocessing – Common Challenges

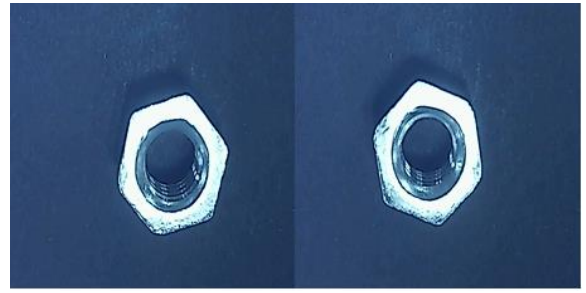
How do I preprocess data and get the right features?

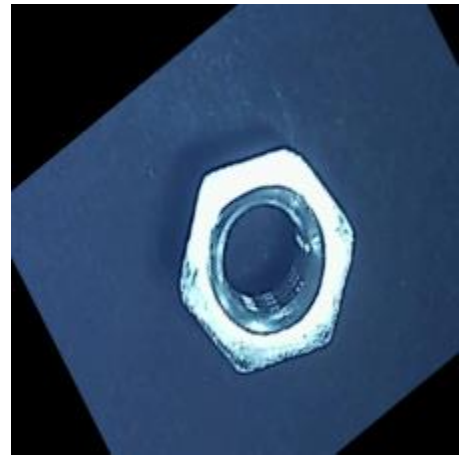
Data Access and Preprocessing – Common Challenges

How do I preprocess data and get the right features?

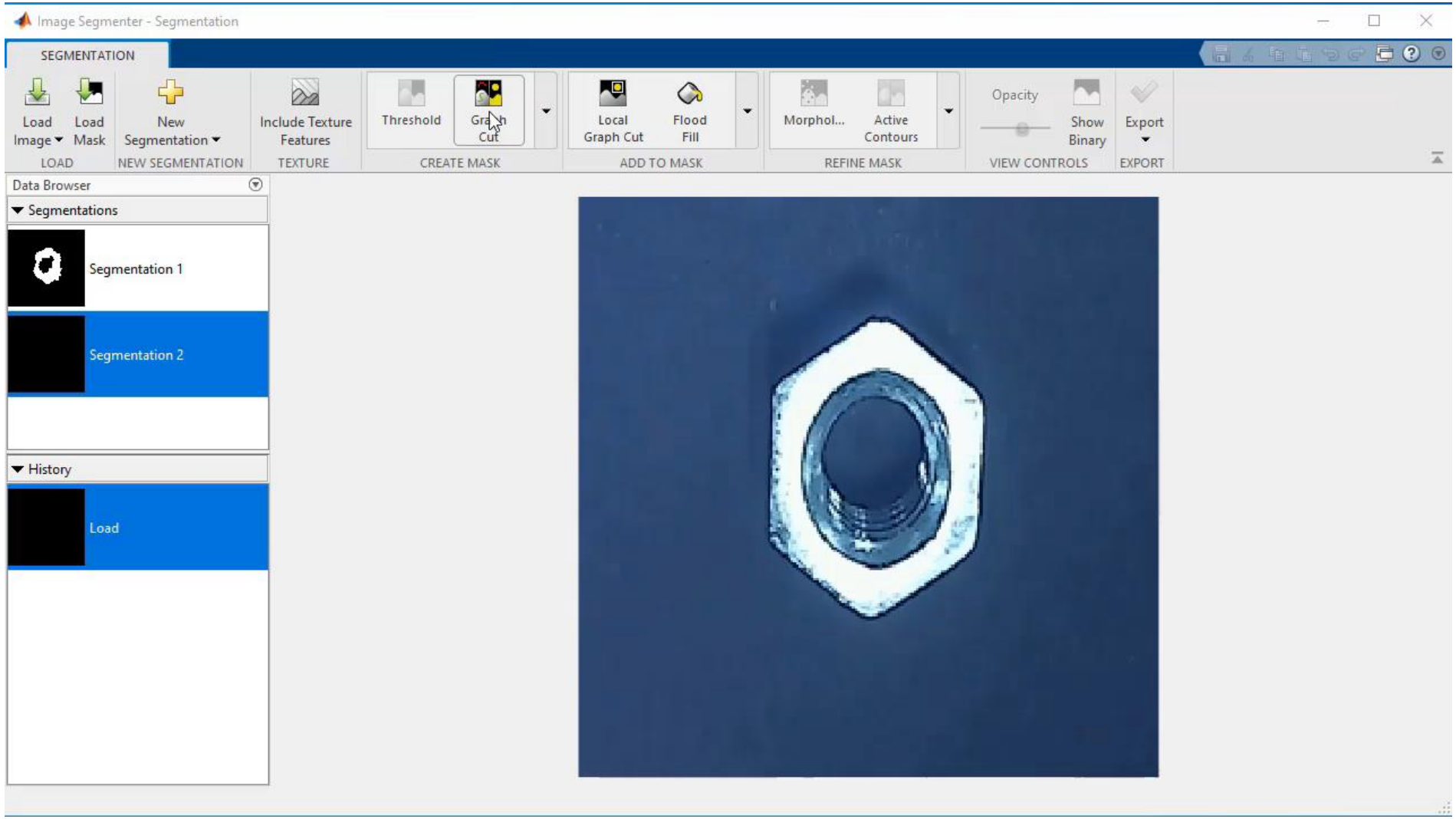
Pre-processing Data – Registration Estimator App

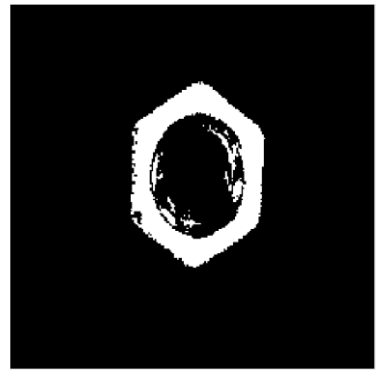




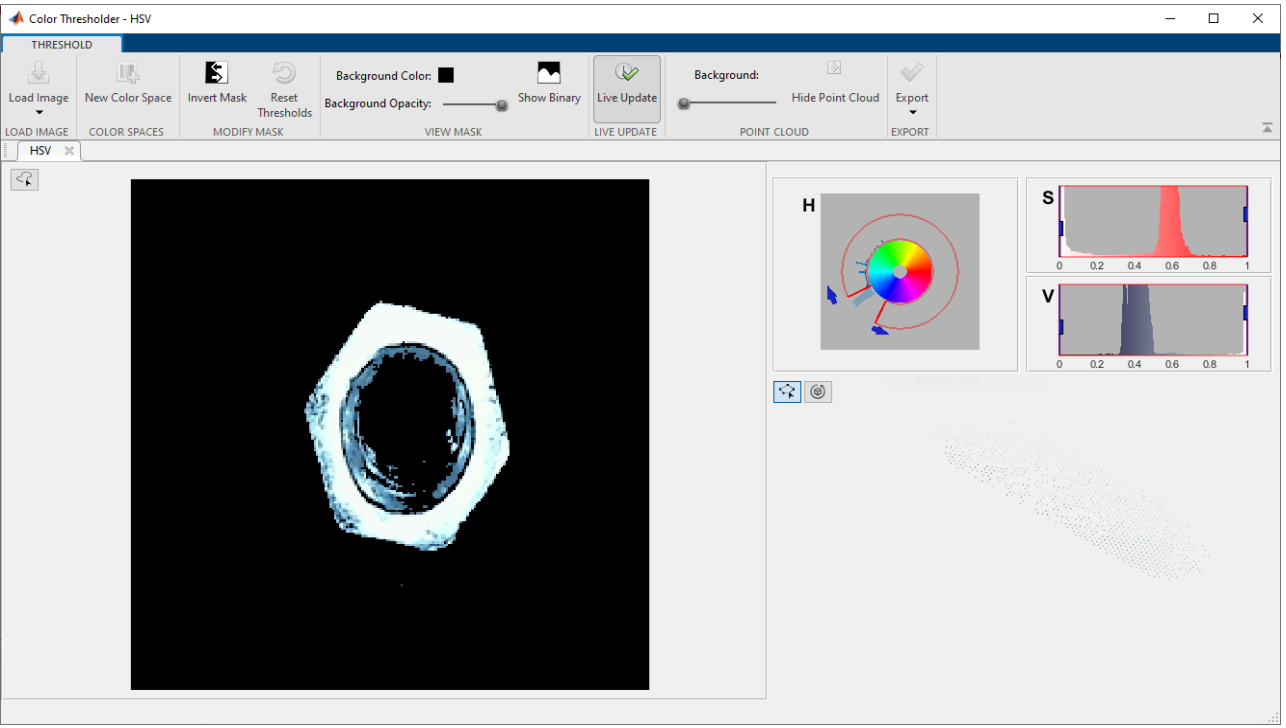


Pre-processing Data – Image Segmenter App





Preprocessing Data - Apps



Color Thresholder

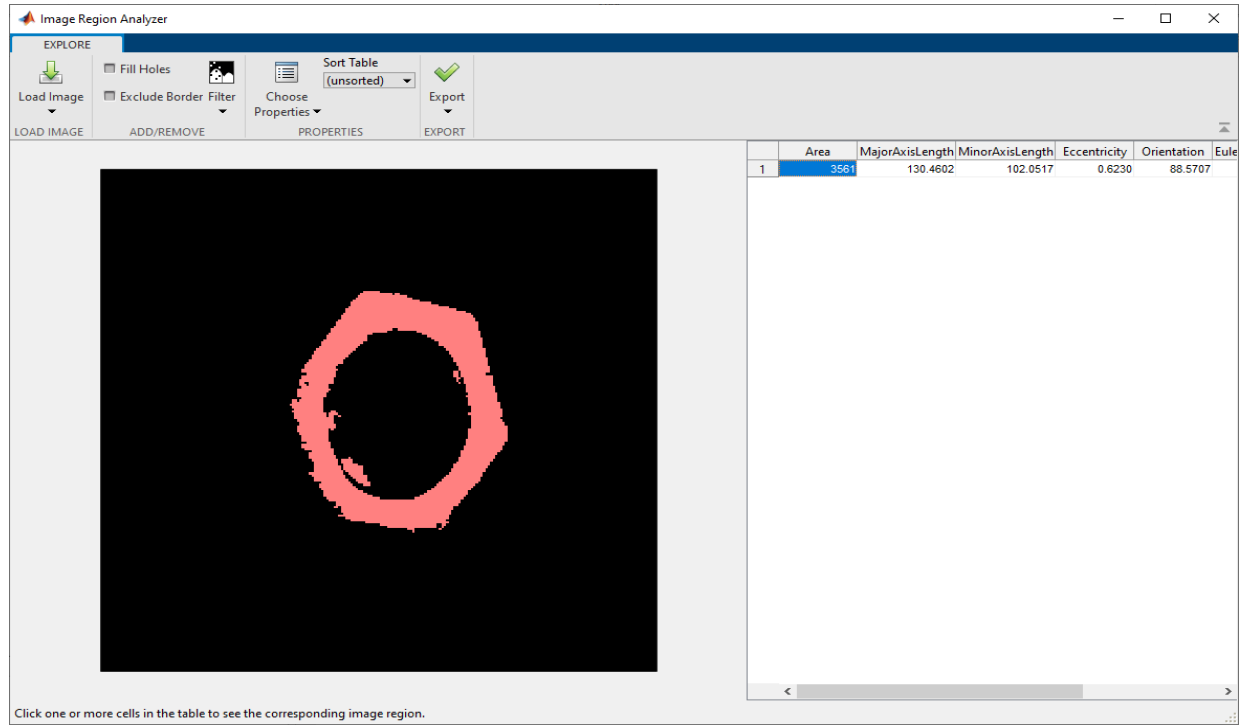
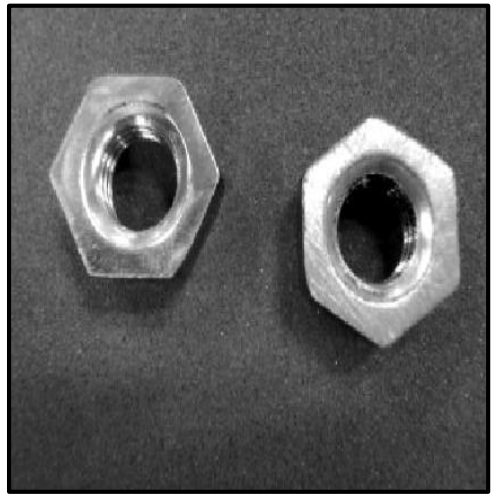


Image Region Analyzer

Pre-processing Data – Built-in Algorithms

`imadjust`



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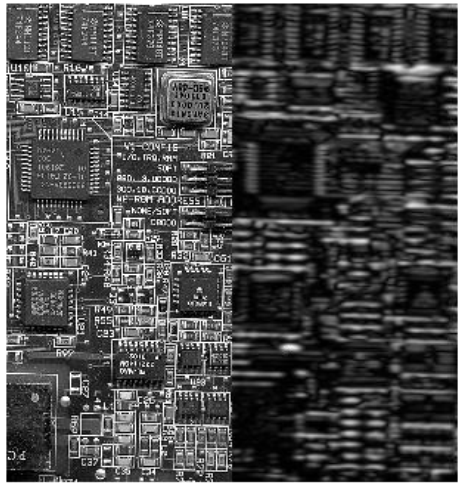
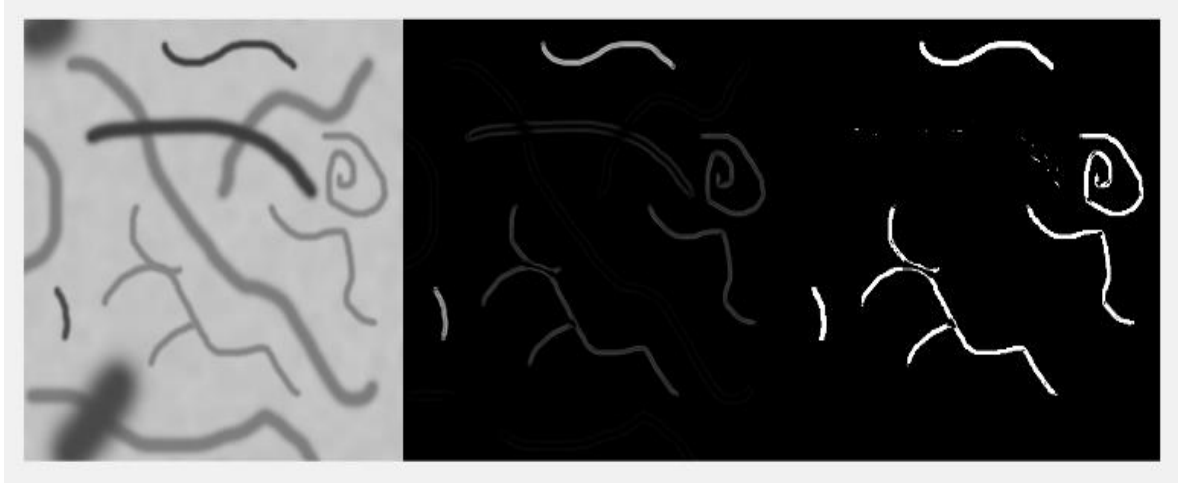


`fibermetric`

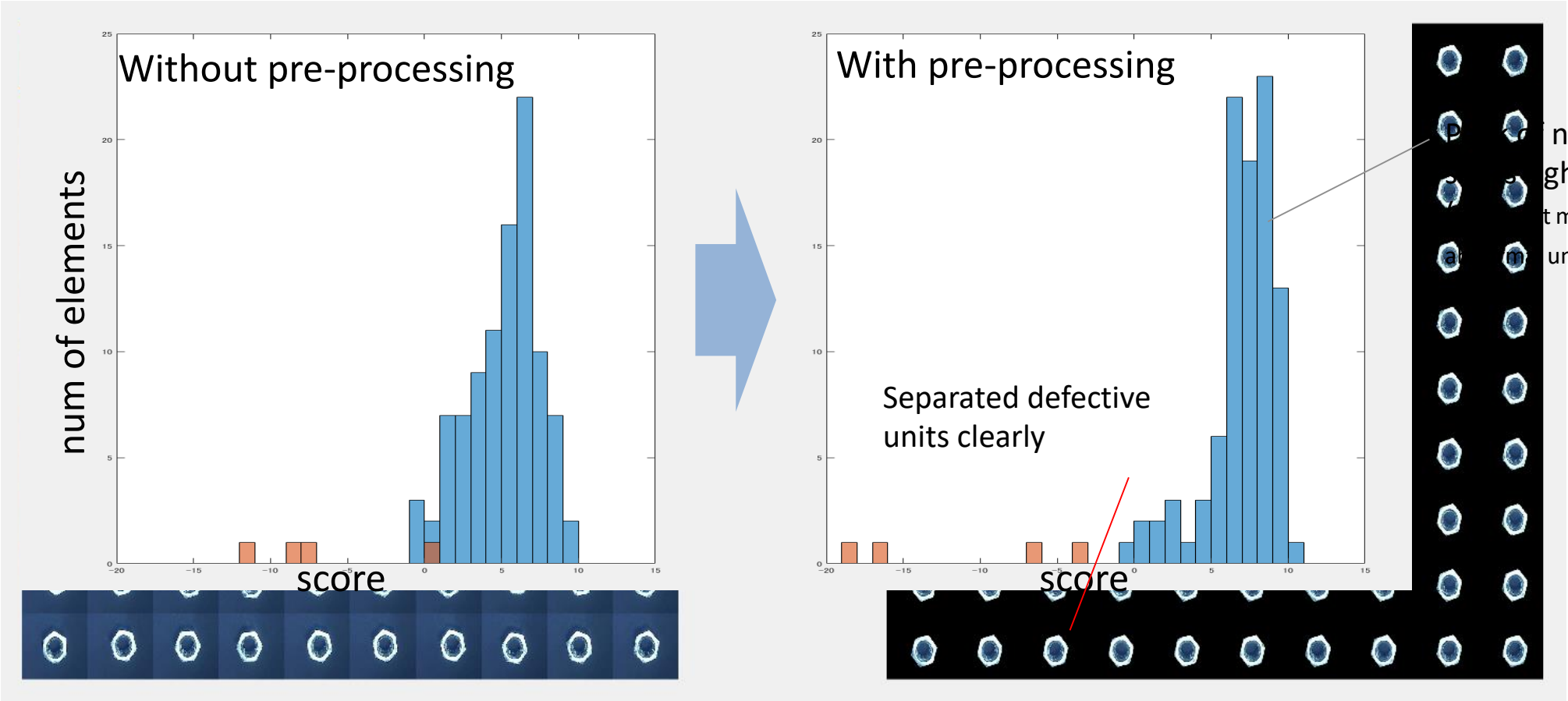


Defect detection using AlexNet: Results with preprocessing

Without pre-processing

Histogram of predicted scores

With pre-processing



Data Access and Preprocessing – Common Challenges

How do I label my data faster?

Data Preprocessing - Labeling

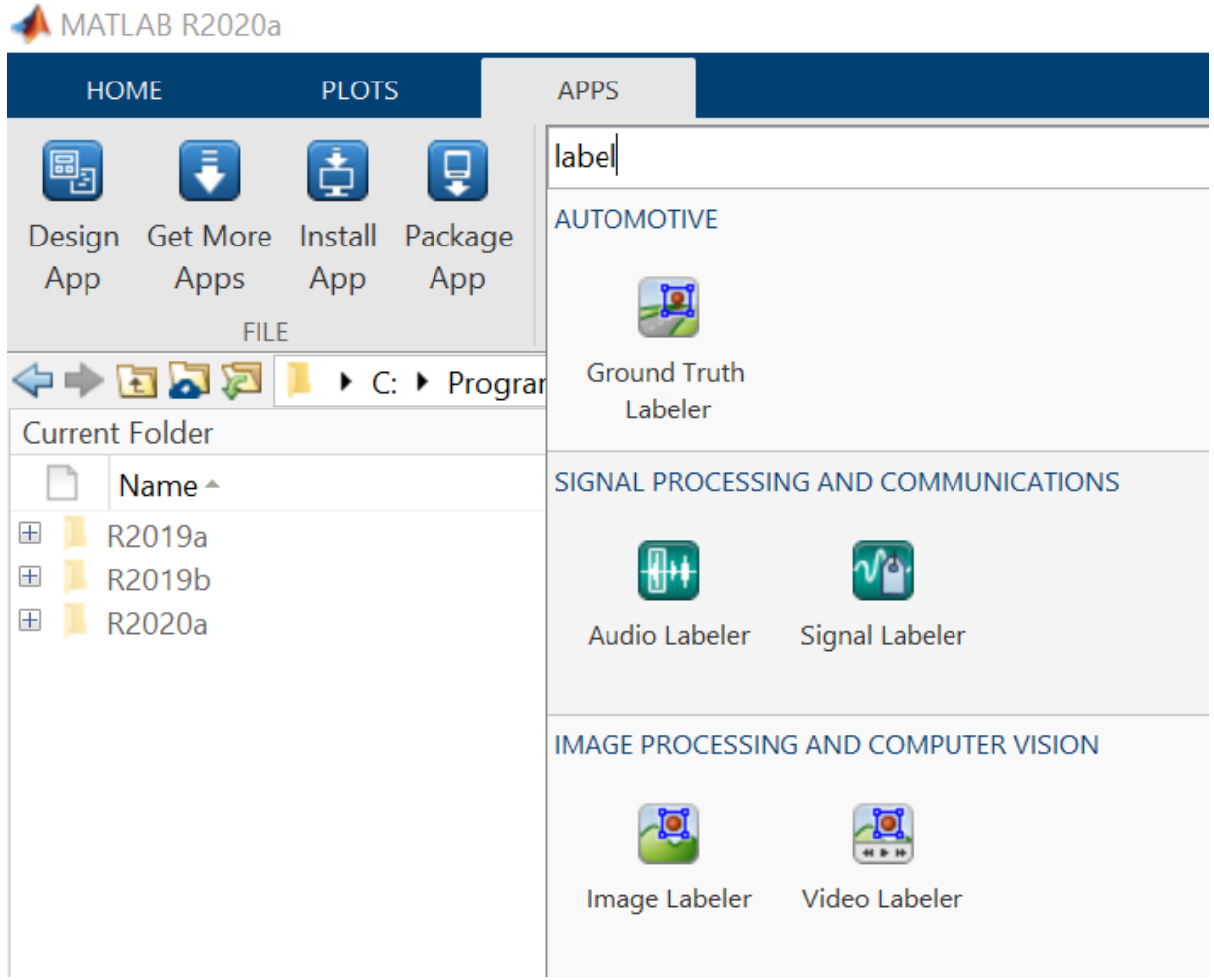
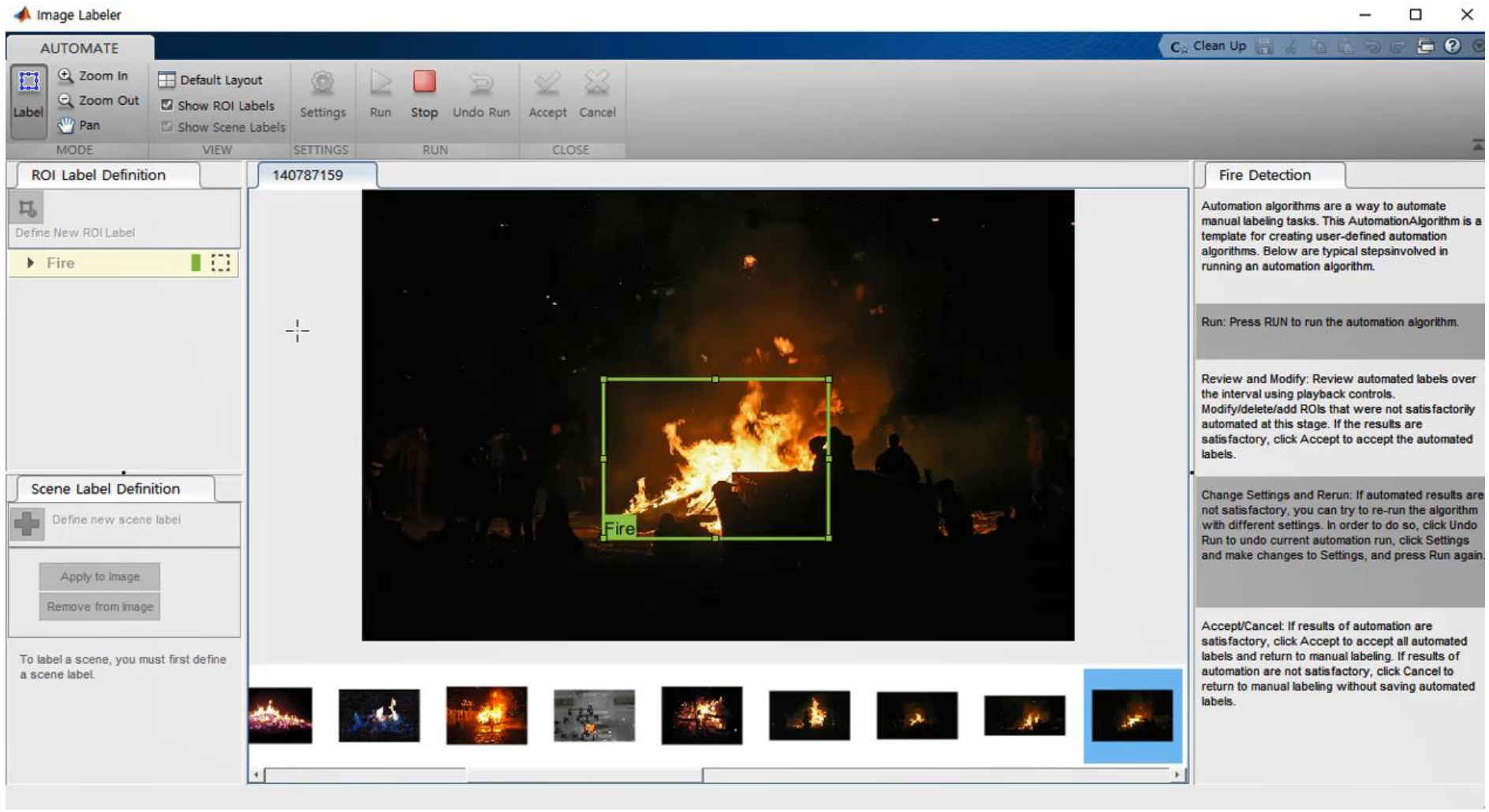


Image & Video Labeler

Image Labeler
+ Video labeler

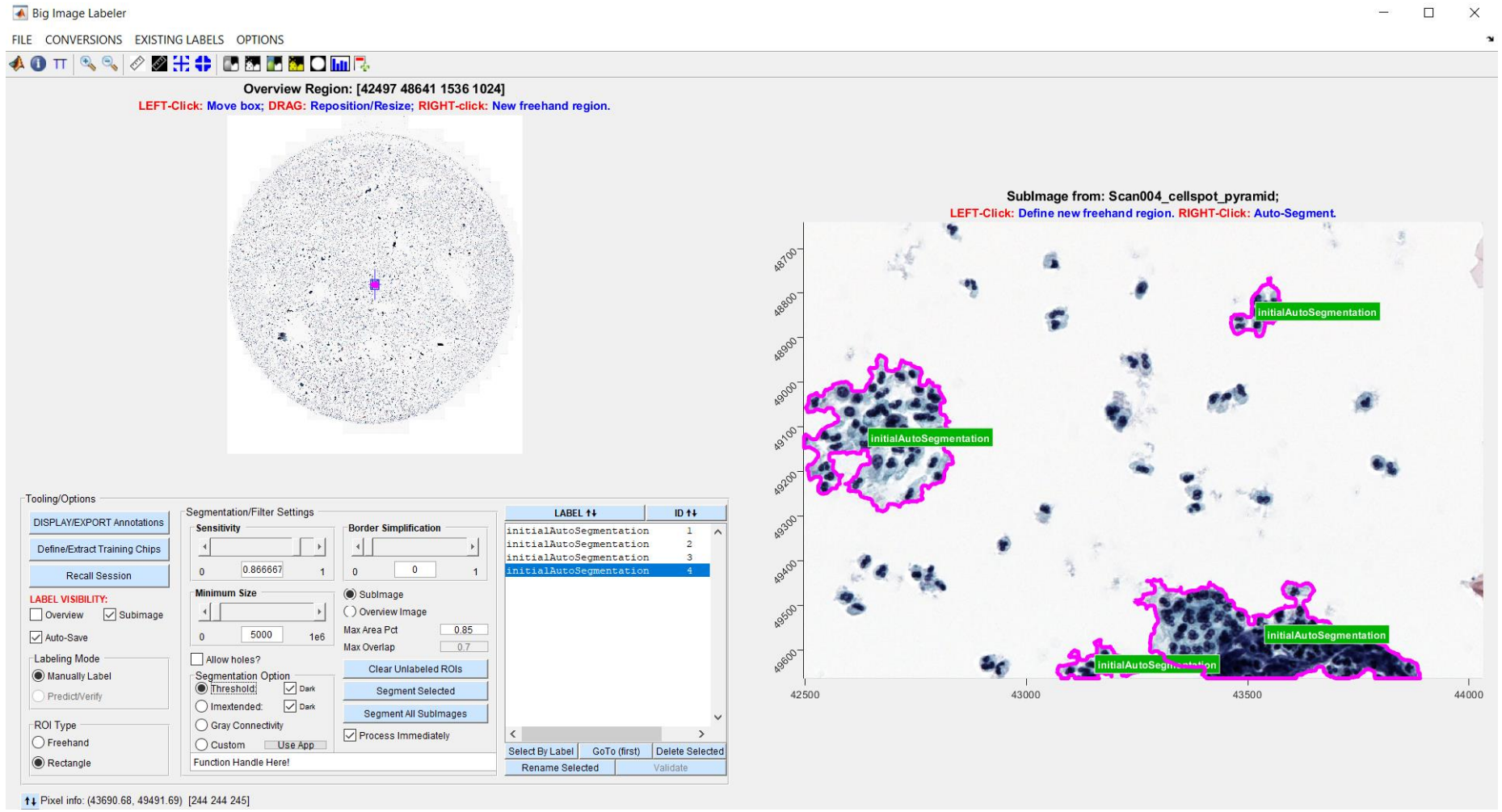
Big-Image
Labeler



Big Image Labeler

Image Labeler
+ Video labeler

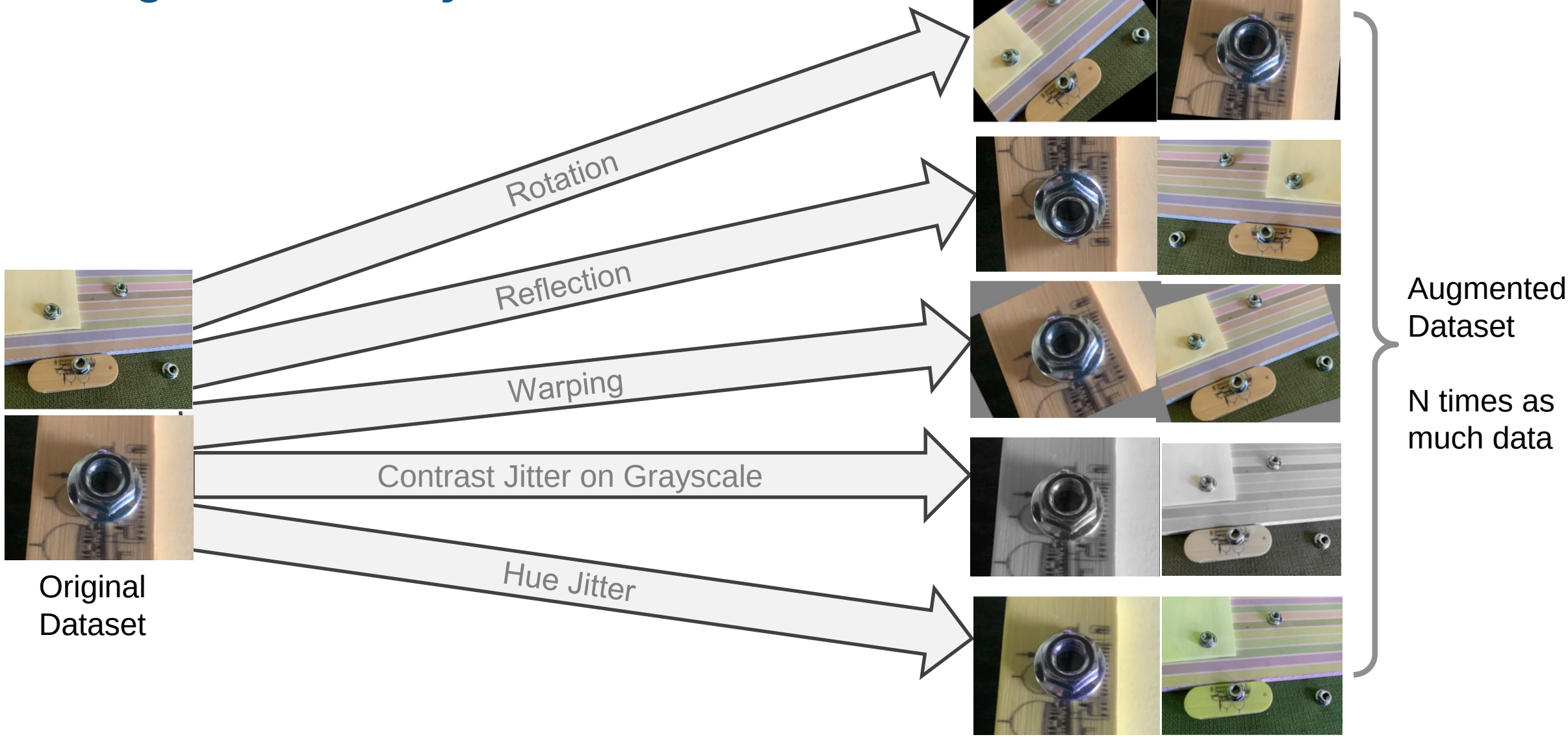
Big-Image
Labeler



Data Access and Preprocessing – Common Challenges

What if I have an imbalanced dataset or don’t have enough data?

Data Augmentation by Transformation



Data Augmentation : Generative Adversarial Networks (GANs)

Defect Detection Workflow

DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Ground truth labeling

AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

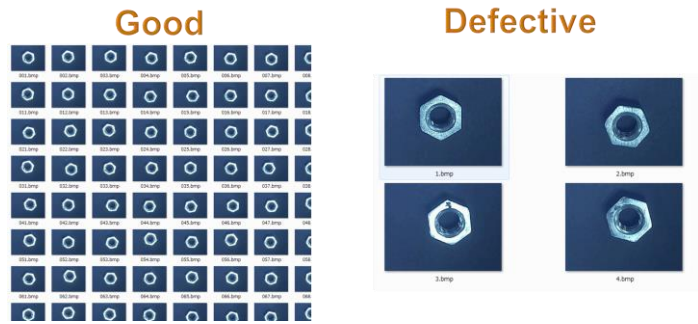
DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

Iteration and Refinement

Deep Learning for Defect Detection

Deep learning for Classification



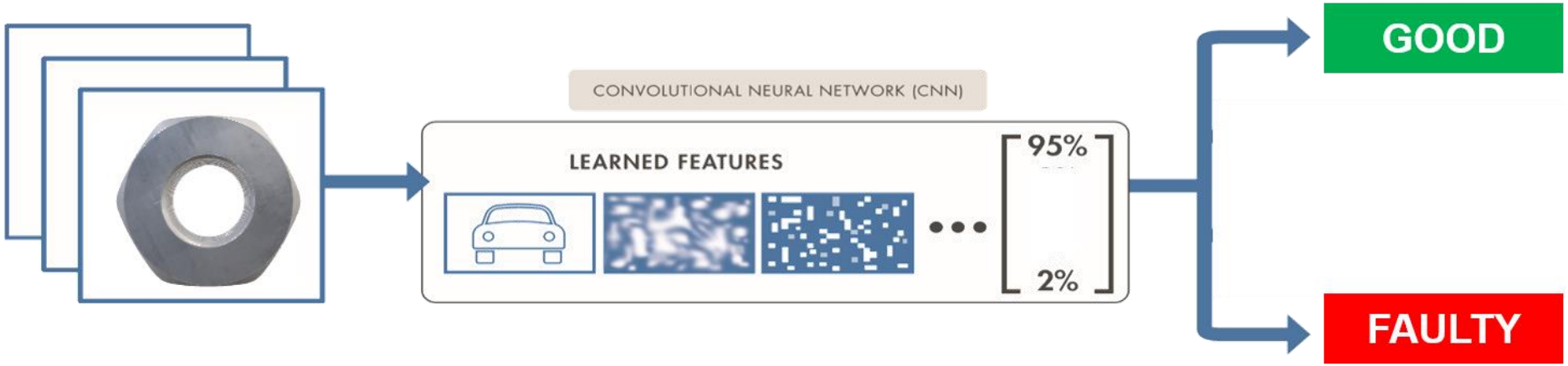
Deep Learning for Object Detection

Deep Learning for Defect Detection – Multiple techniques

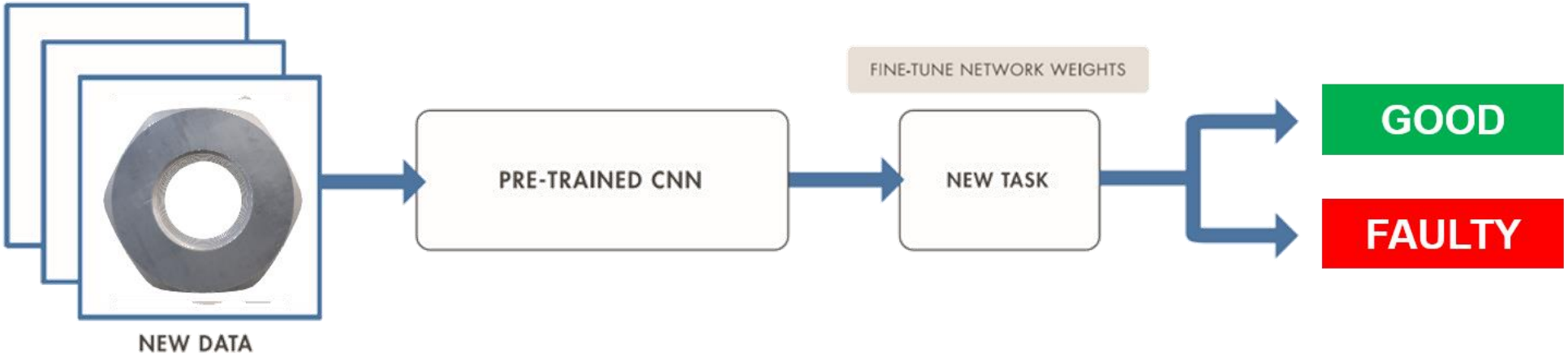
Deep learning for Classification

Two Approaches for Deep Learning

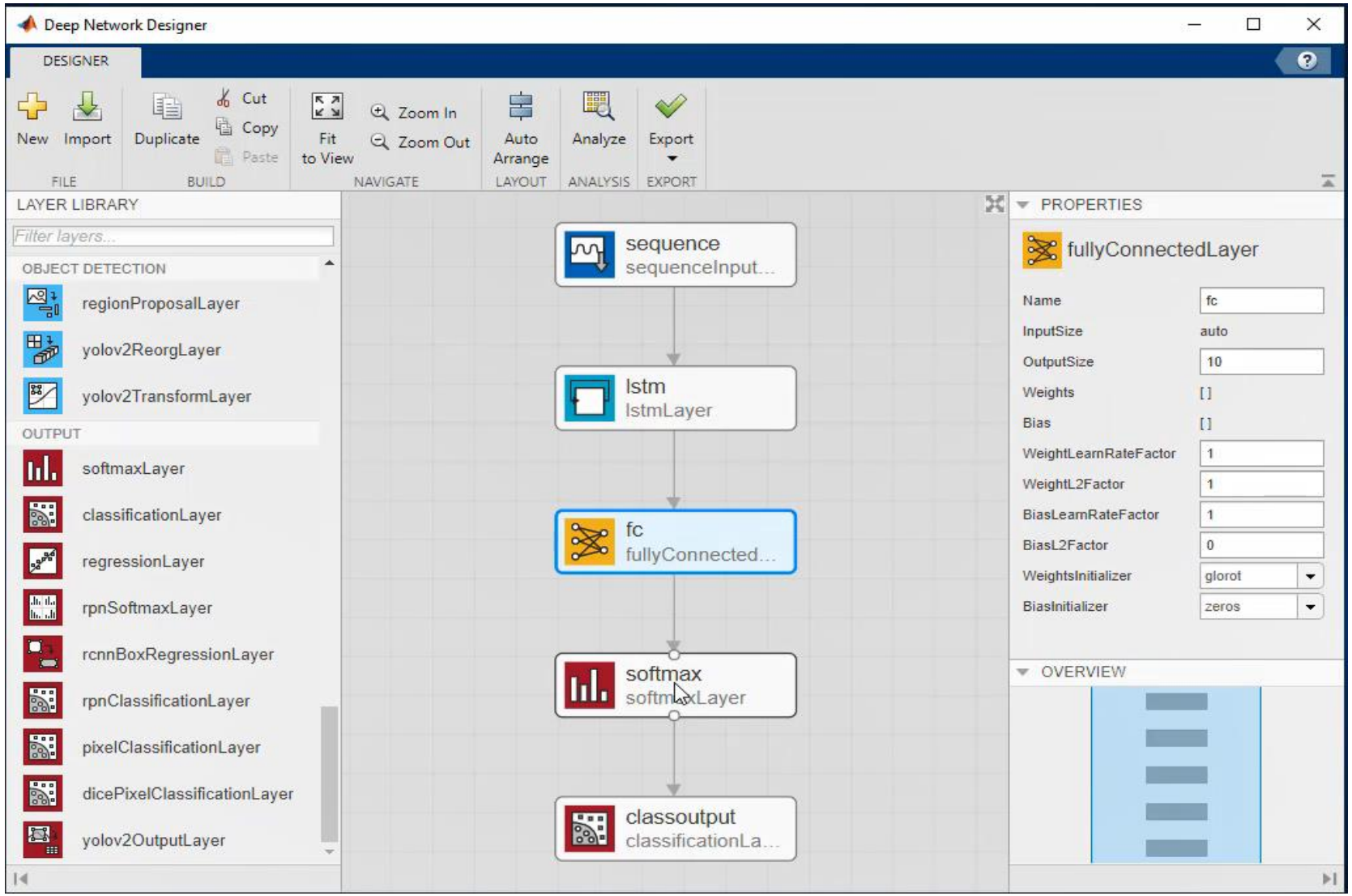
1. Train a deep neural network from scratch



2. Fine-tune a pre-trained model (transfer learning)

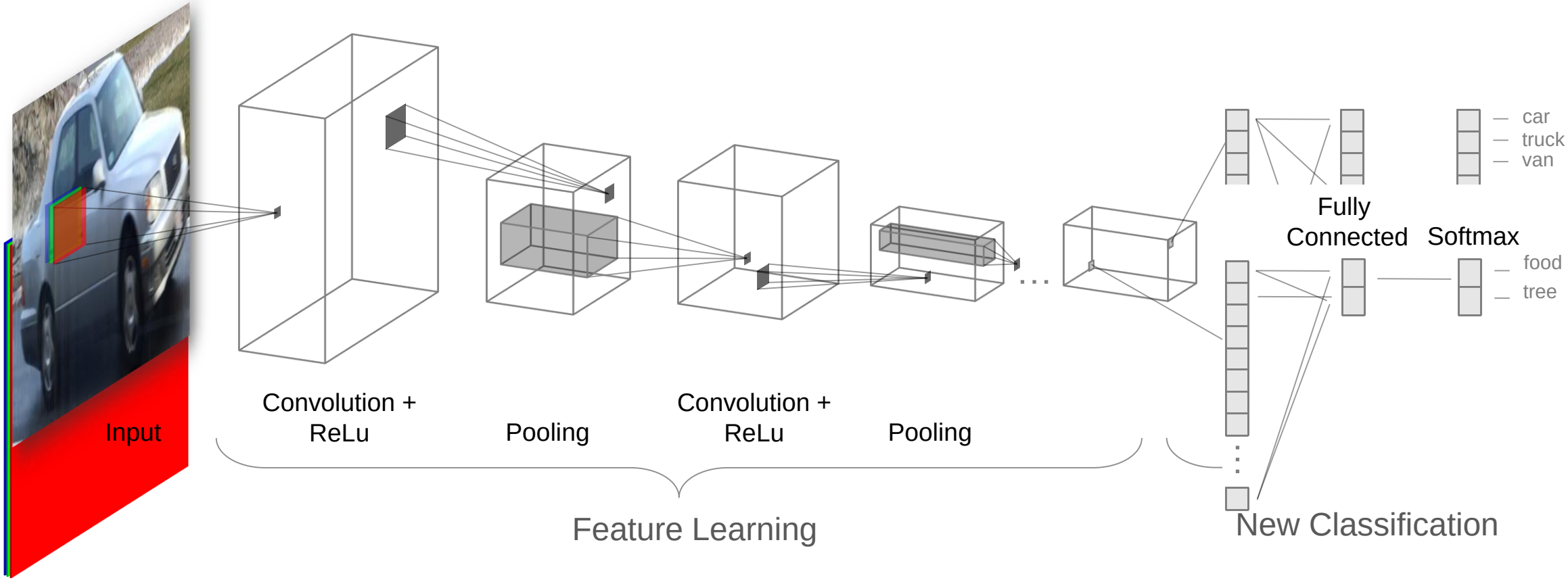


Train a Deep Neural Network from Scratch

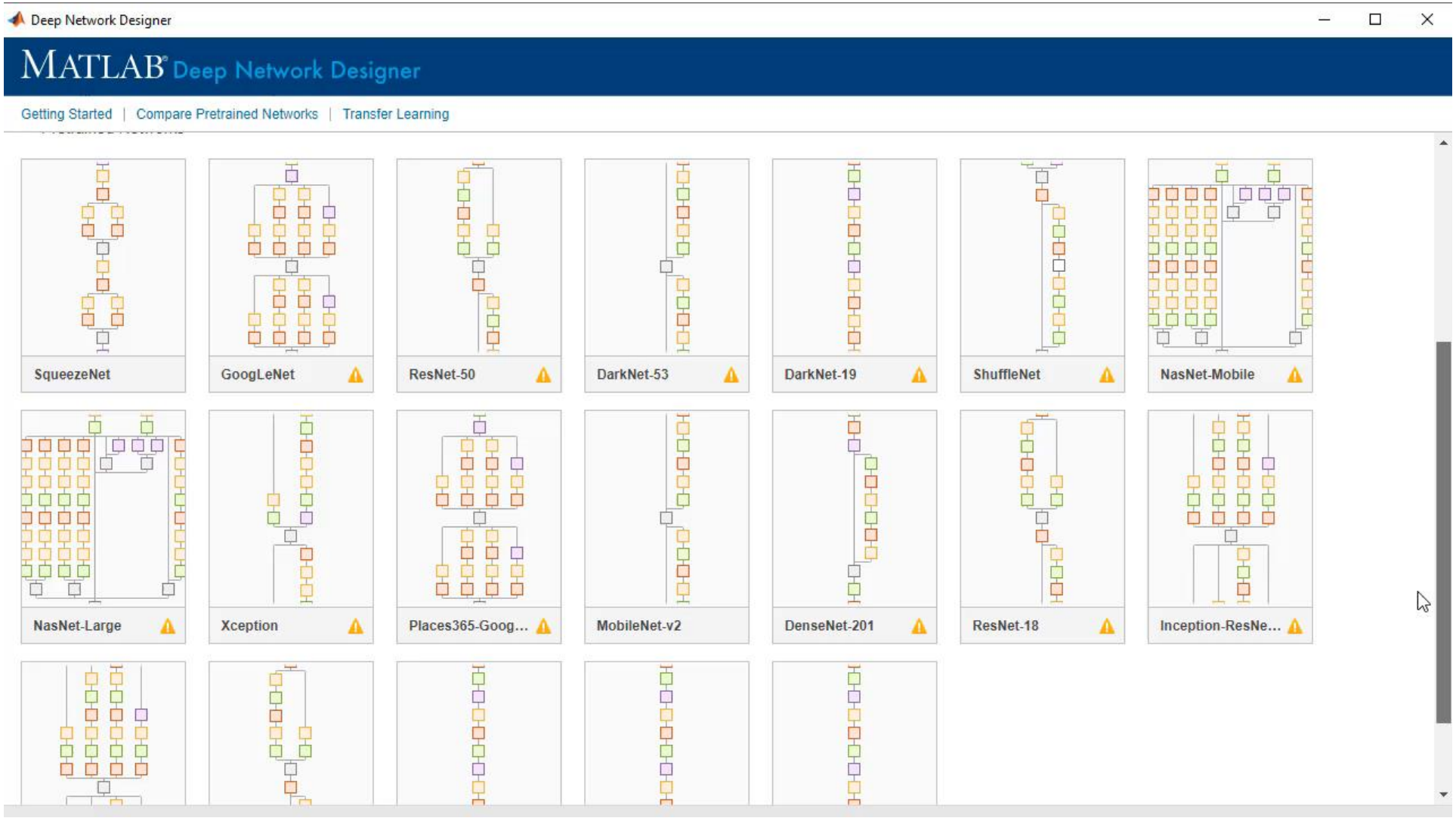


Two approaches for Deep learning

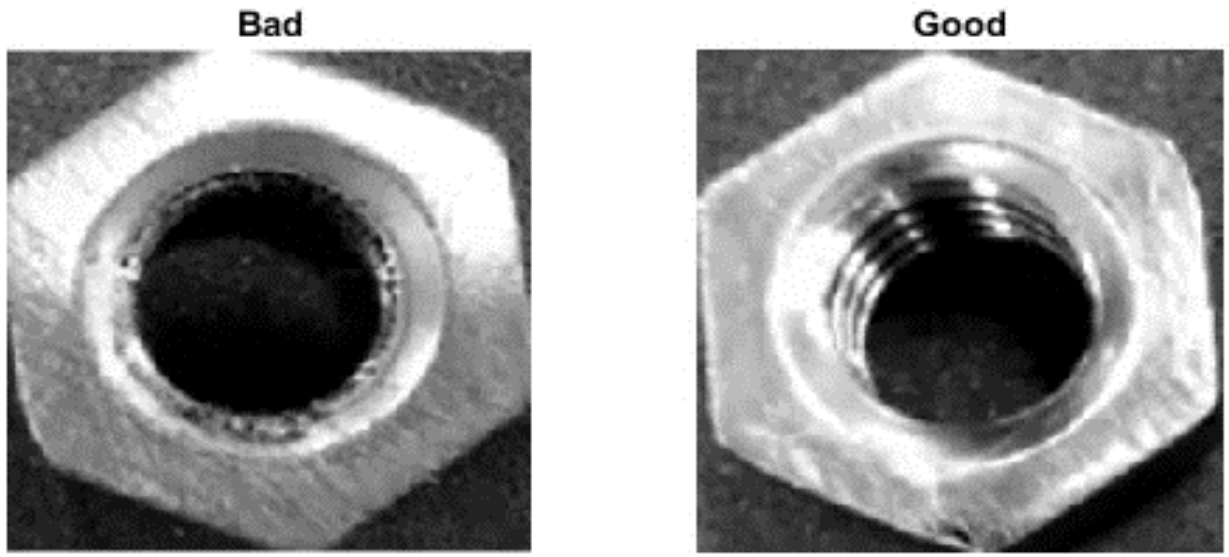
Approach 2. Fine-tune a pre-trained model (Transfer learning)



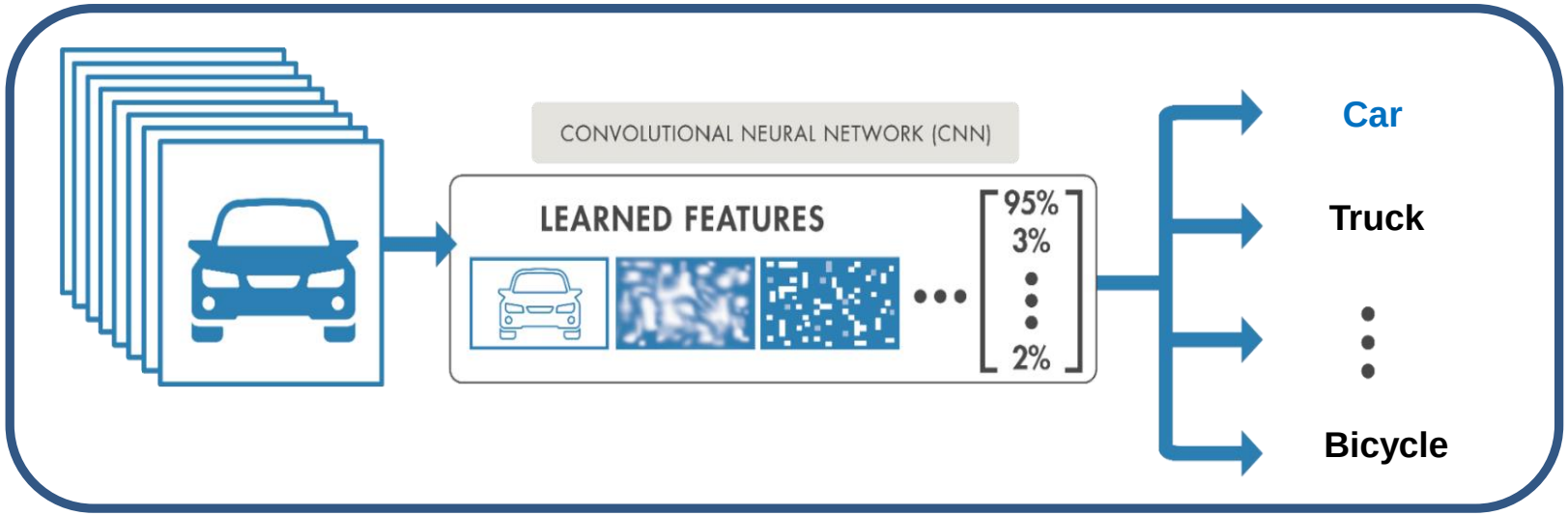
Fine-tune a Pre-trained Model (Transfer Learning)



Classification with Trained MobileNetV2



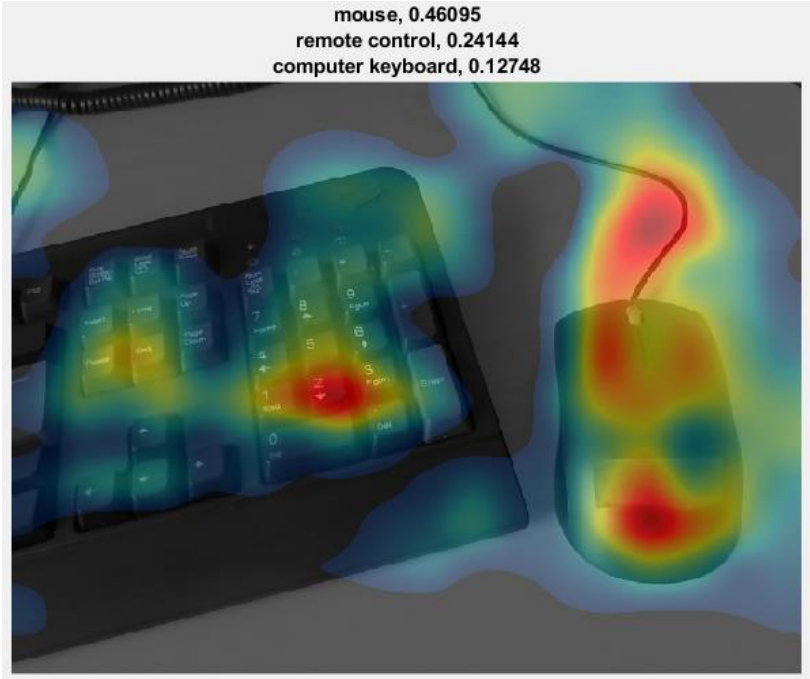
Challenges with Deep Learning Models



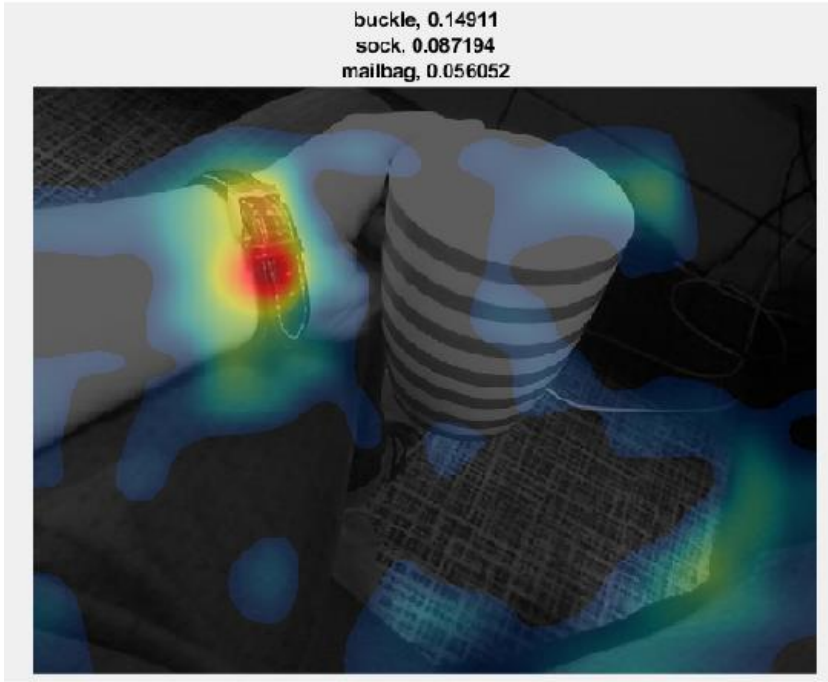
Explainable AI is required

- Class Activation Mapping（CAM）
- Grad-CAM

Class Activation Mapping to Investigate Network Predictions



Classified as “keyboard” due to the presence of the mouse

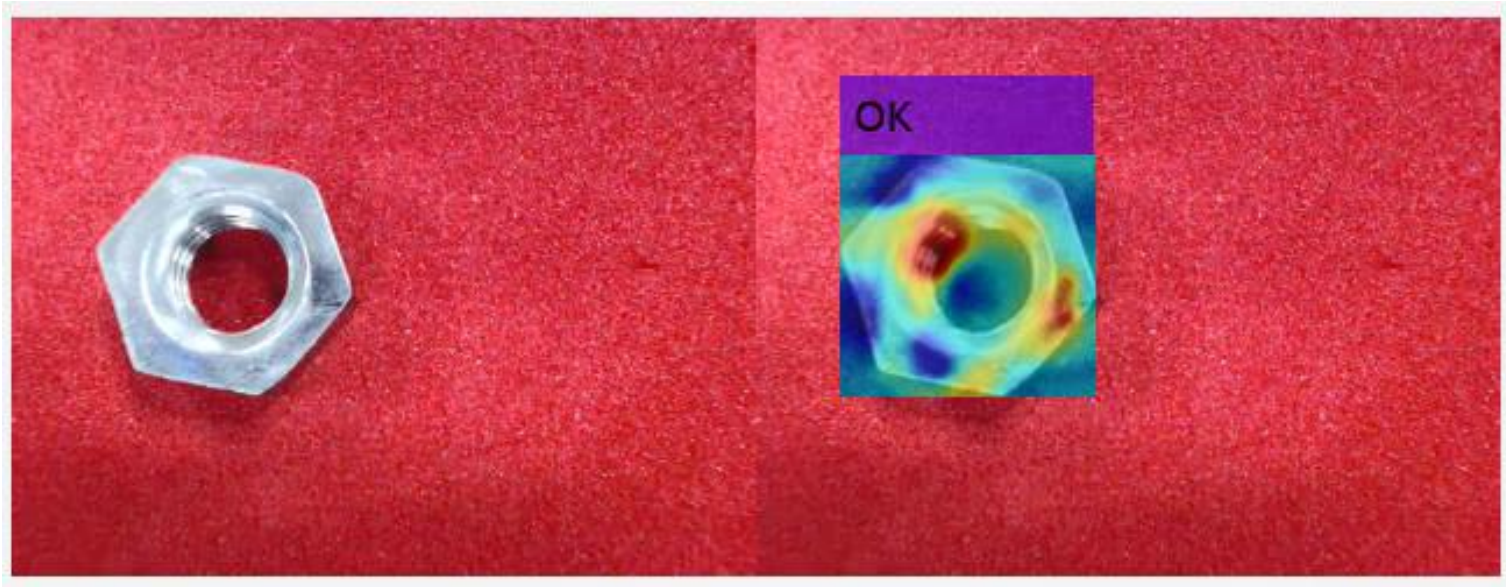


Incorrectly classified “coffee mug” as “buckle” due to the watch

Visualization of Features with CAM

Captured Image

Classification and CAM

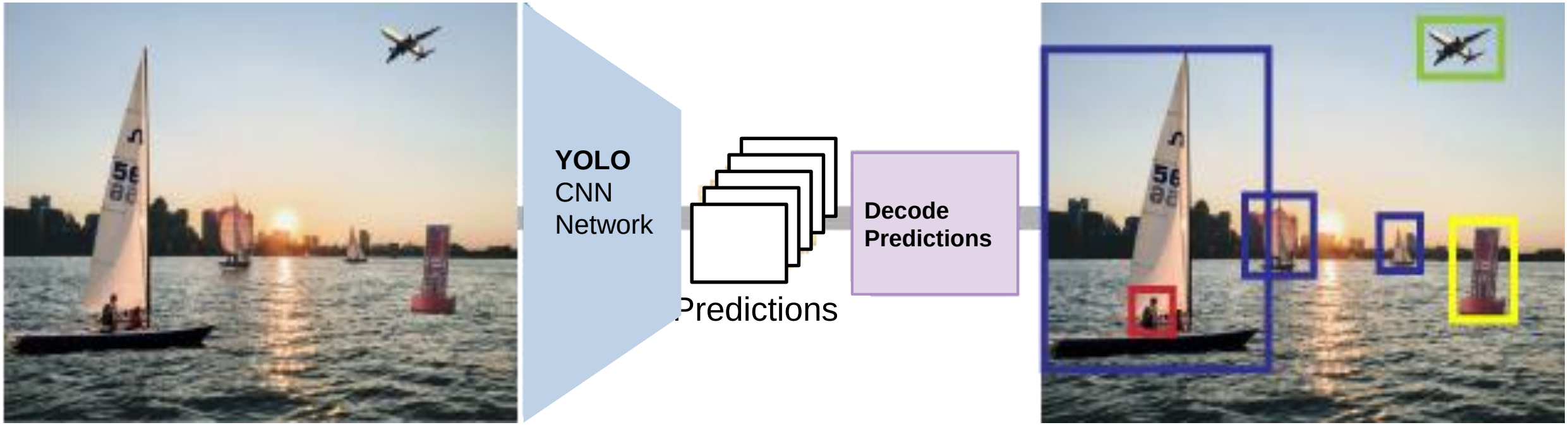


OK → Reacts to whole surface

Bad→ Reacts to the scratch

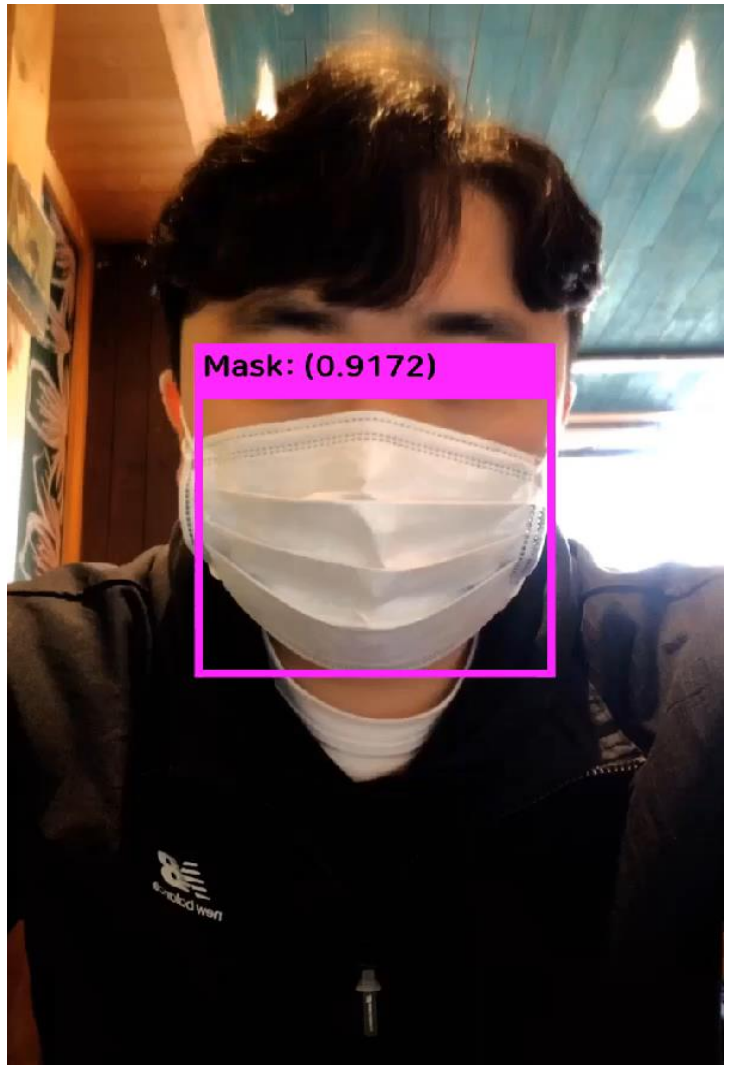
Deep Learning for Object Detection

Detecting Objects with You Only Look Once (YOLO) v2

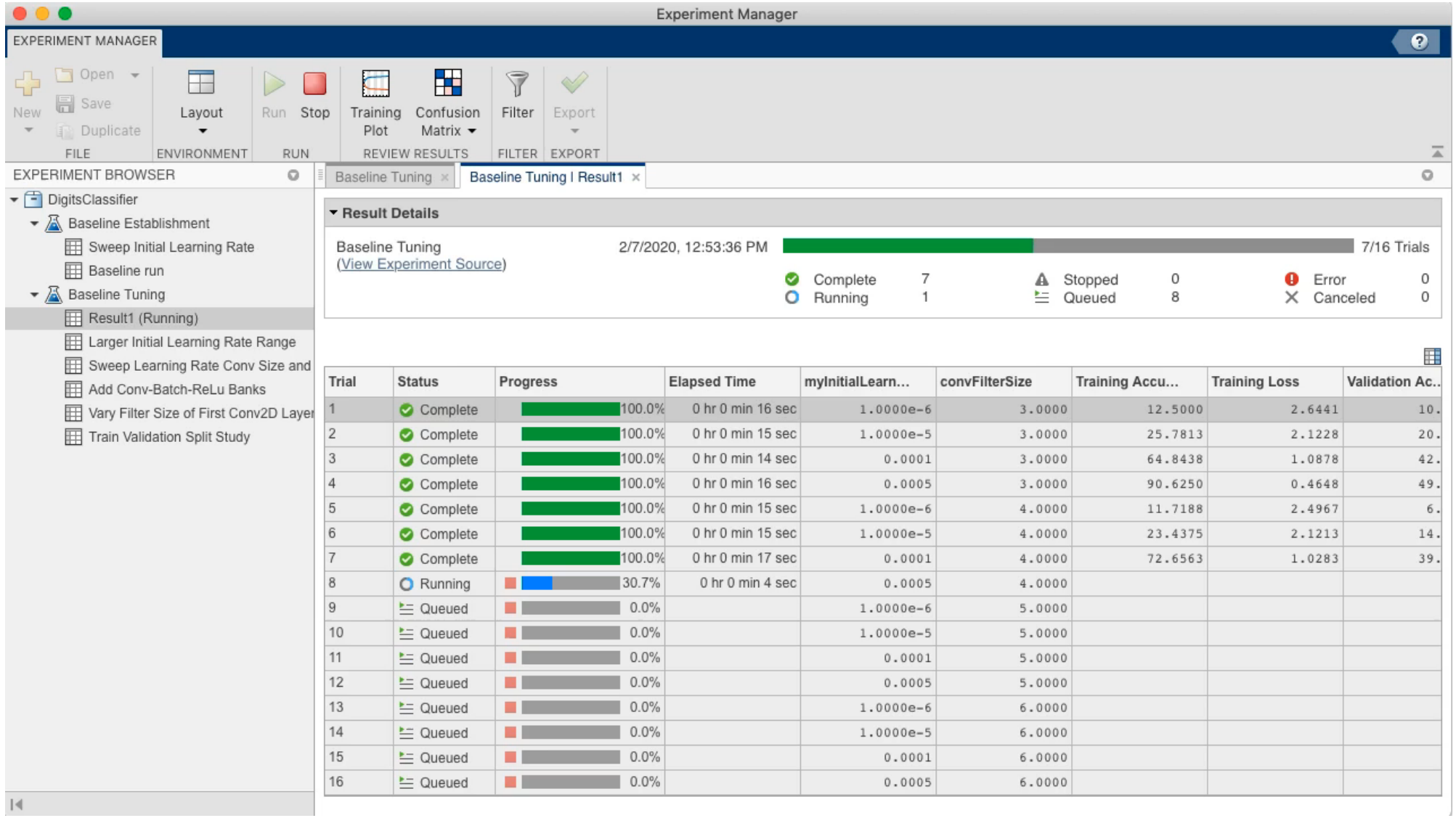


Build, test, and deploy a deep learning solution that can detect objects in images and video

Mask Detection with YOLO v2



Experiment Manager



Trial	Status	Progress	Elapsed Time	myInitialLearn...	convFilterSize	Training Accu...	Training Loss	Validation Ac..
1	Complete	100.0%	0 hr 0 min 16 sec	1.0000e-6	3.0000	12.5000	2.6441	10.
2	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-5	3.0000	25.7813	2.1228	20.
3	Complete	100.0%	0 hr 0 min 14 sec	0.0001	3.0000	64.8438	1.0878	42.
4	Complete	100.0%	0 hr 0 min 16 sec	0.0005	3.0000	90.6250	0.4648	49.
5	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-6	4.0000	11.7188	2.4967	6.
6	Complete	100.0%	0 hr 0 min 15 sec	1.0000e-5	4.0000	23.4375	2.1213	14.
7	Complete	100.0%	0 hr 0 min 17 sec	0.0001	4.0000	72.6563	1.0283	39.
8	Running	30.7%	0 hr 0 min 4 sec	0.0005	4.0000			
9	Queued	0.0%		1.0000e-6	5.0000			
10	Queued	0.0%		1.0000e-5	5.0000			
11	Queued	0.0%		0.0001	5.0000			
12	Queued	0.0%		0.0005	5.0000			
13	Queued	0.0%		1.0000e-6	6.0000			
14	Queued	0.0%		1.0000e-5	6.0000			
15	Queued	0.0%		0.0001	6.0000			
16	Queued	0.0%		0.0005	6.0000			

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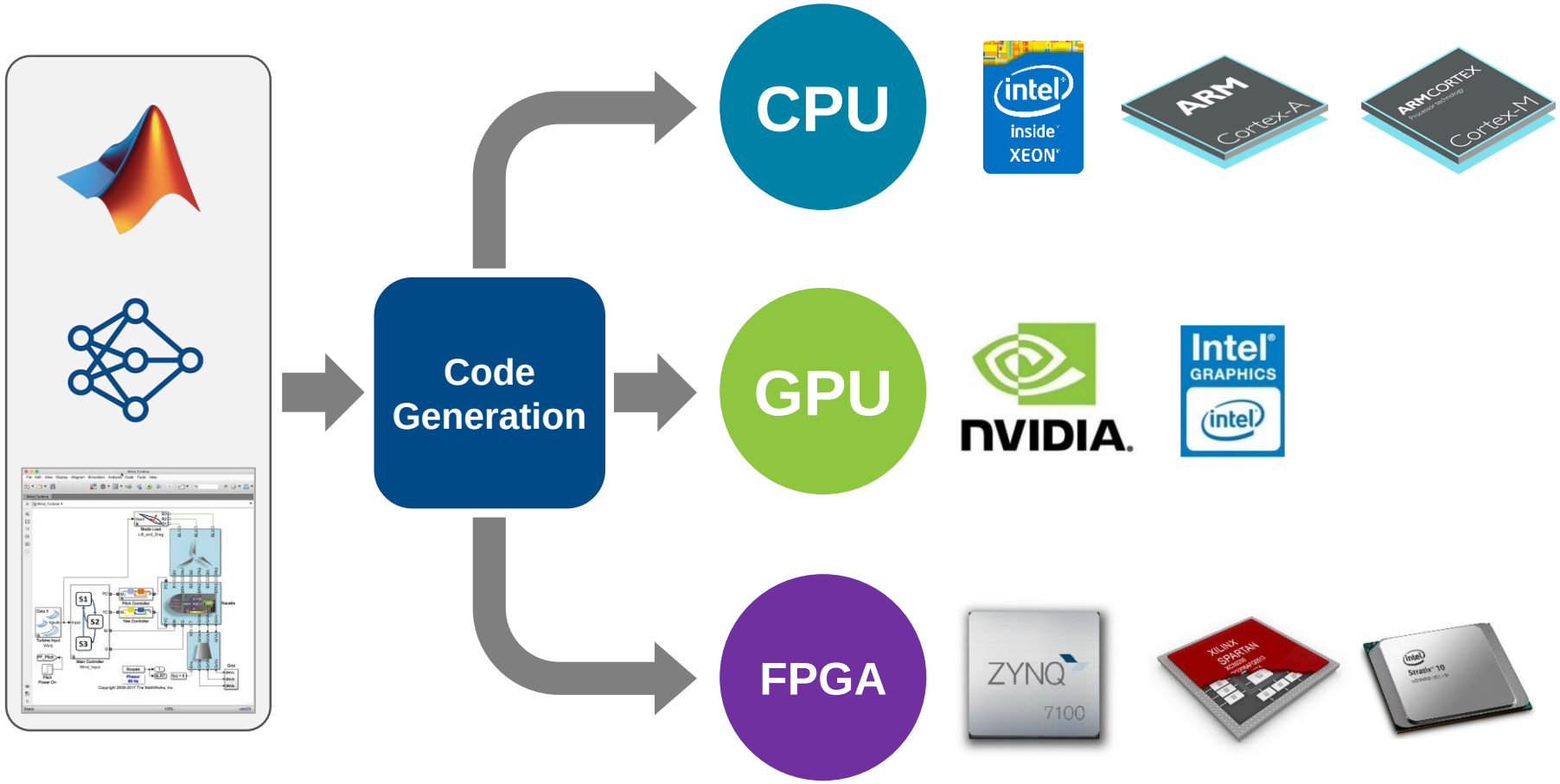
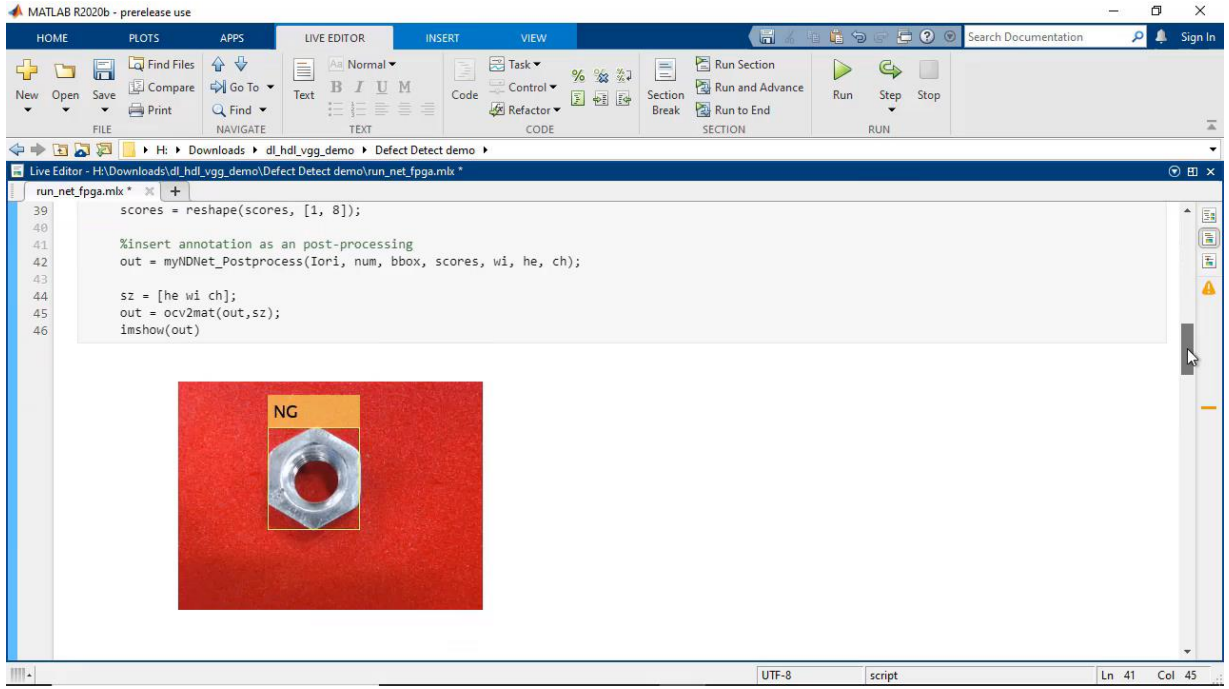
Iteration and Refinement

Deploy to Any Processor with Best-in-class Performance



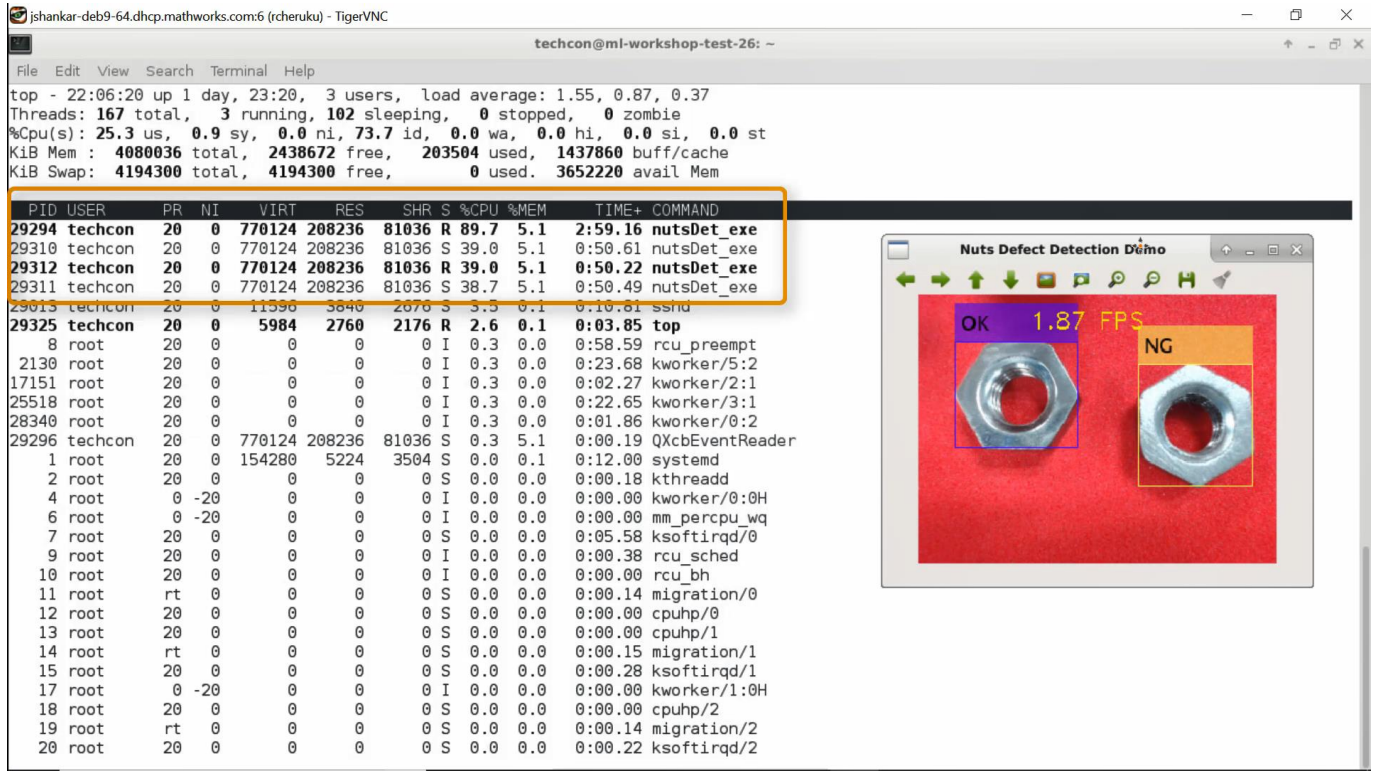
Deploy to Hardware



Deploy defect detection algorithms from MATLAB to ZCU102 board from Xilinx

Deploy defect detection algorithms from MATLAB to Jetson AGX Xavier

Deploy to Hardware

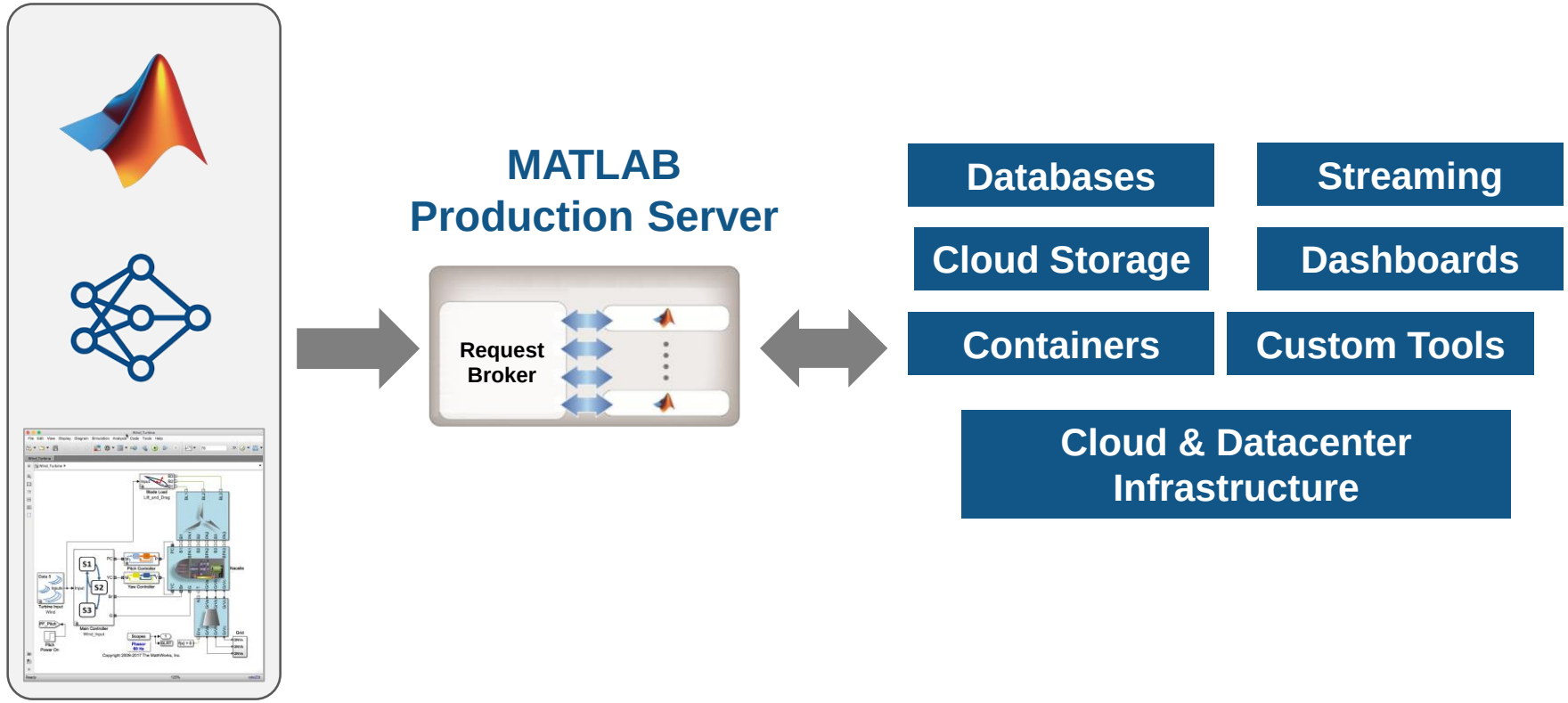


Defect detection deployed on ARM Cortex-A microprocessor

Resources:

- Deploying Deep Neural Networks to GPUs and CPUs Using MATLAB Coder and GPU Coder
- Using GPU Coder to Prototype and Deploy on NVIDIA Drive, Jetson
- Real-Time Object Detection with YOLO v2 Using GPU Coder
- Image Classification on ARM CPU: SqueezeNet on Raspberry Pi
- Deep Learning on an Intel Processor with MKL-DNN

Deploy to Enterprise IT Infrastructure



Defect Detection Workflow

DATA PREPARATION

- Data access and preprocessing
- Simulation-based data generation
- Ground truth labeling

AI MODELING

- Model design and tuning
- Hardware-accelerated training
- Model exchange across frameworks

DEPLOYMENT

- Embedded Devices
- Enterprise Systems
- Edge, cloud, desktop

Iteration and Refinement

Key Takeaways

- Interactive and easy to use apps help explore, iterate and automate workflows
- Flexibility and options to choose networks and optimizations based on data and requirements
- MATLAB provides an easy and extensible framework for defect detection from data access to deployment

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Computer Vision Toolbox

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Deep Learning Toolbox

Design, train, and analyze deep learning networks

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THANK YOU!