



Machine Intelligence

Beyond Neural Networks Alternative AIs for NDT

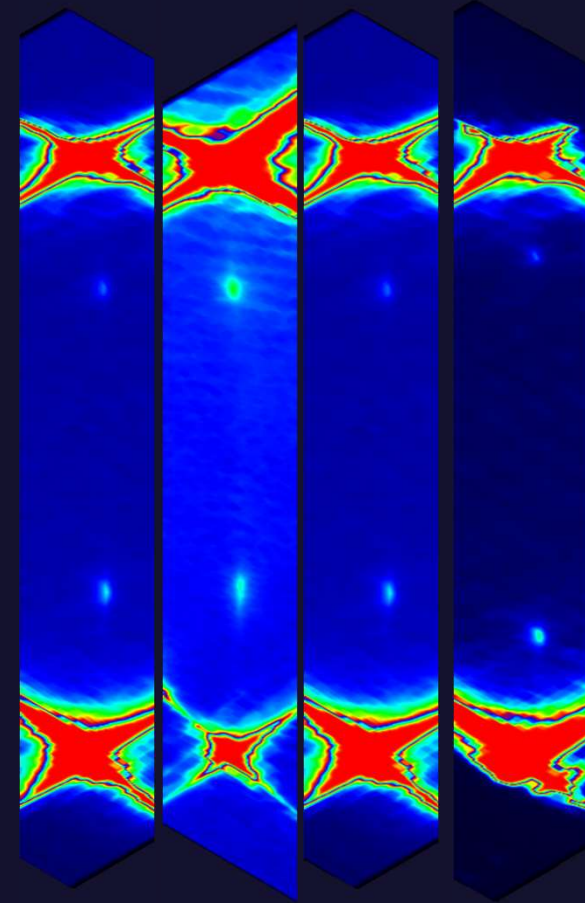
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(C) others

Introduction

- Started Machine Intelligence in 2012
- Developing AI technology
 - spin off from academic research
- Consultancy: control, vision, measurement, software
 - manufacturing and science sectors



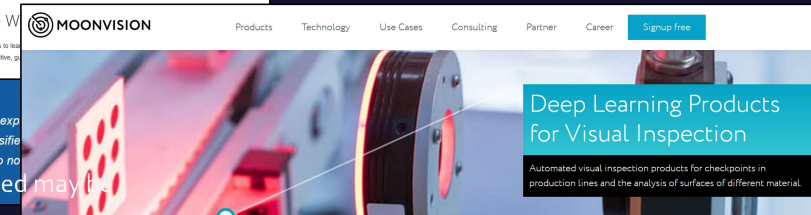
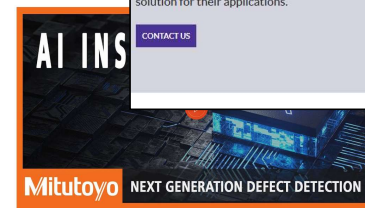
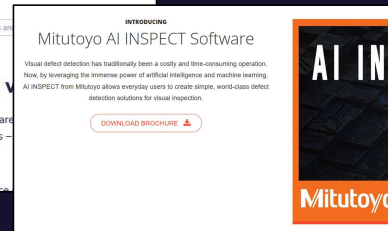
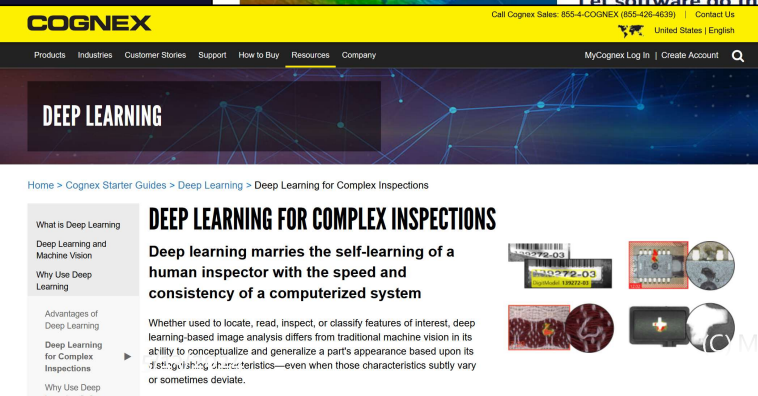
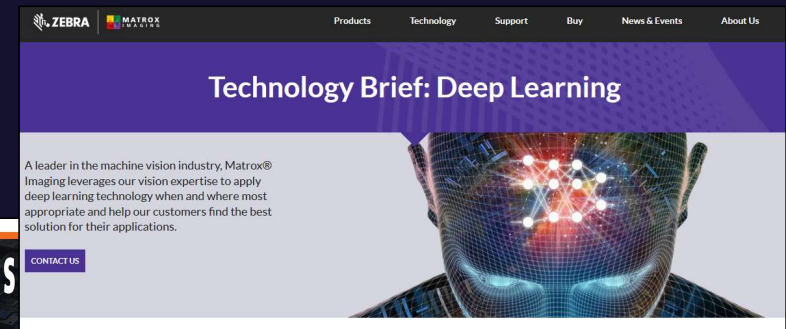
Why use AI in NDT?

- Automating (or augmenting) some task
 - When the data is complex, non-obvious or as a shortcut
- Use data
 - Detect: e.g. Is there a visible defect?
 - Classify: e.g. Is it a scratch or pitting?
- Make sense of data
 - Learn from: e.g. What parameters effect the product quality?
 - Understand: e.g. What is the relationship between temperature and porosity?

AI in NDT

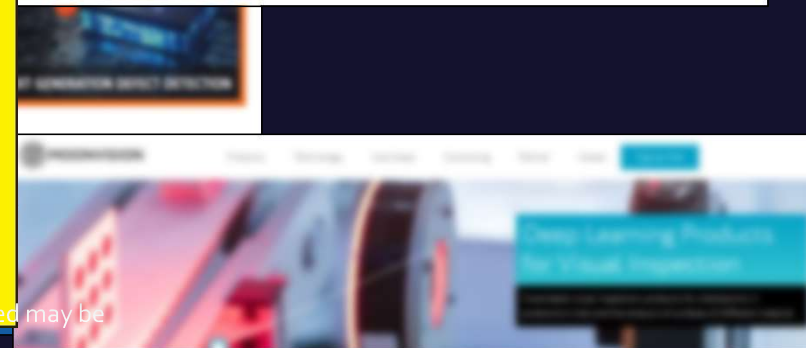
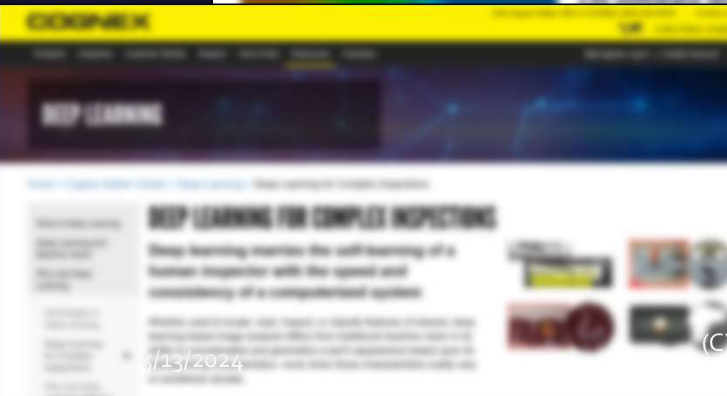
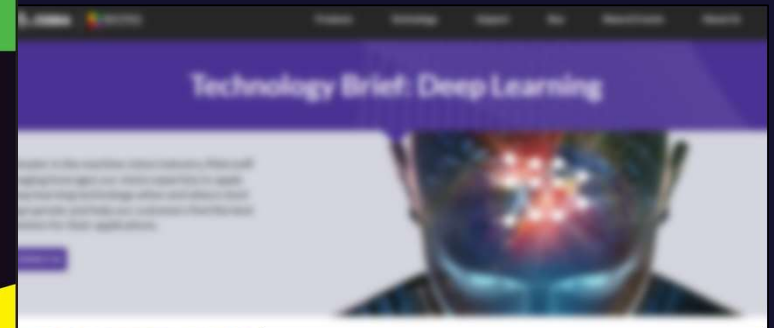
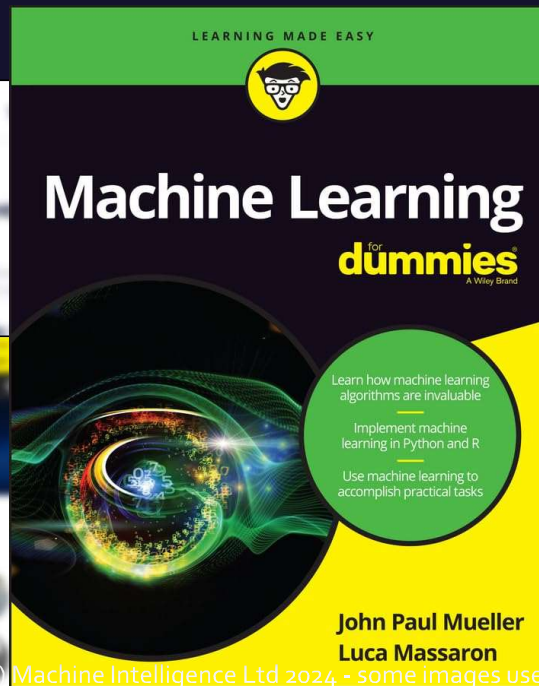
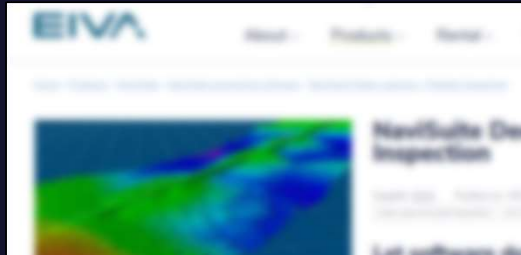


- Current state of the art is Deep Learning and Neural Networks
 - Majority of advertising seems to suggest that this is all there is...



AI in NDT

- Current state of the art is Deep Learning and Neural Networks
 - Majority of advertising seems to suggest that this is all there is...



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Defining some terms

Artificial Intelligence

Machine Learning

Neural Networks

Deep Learning

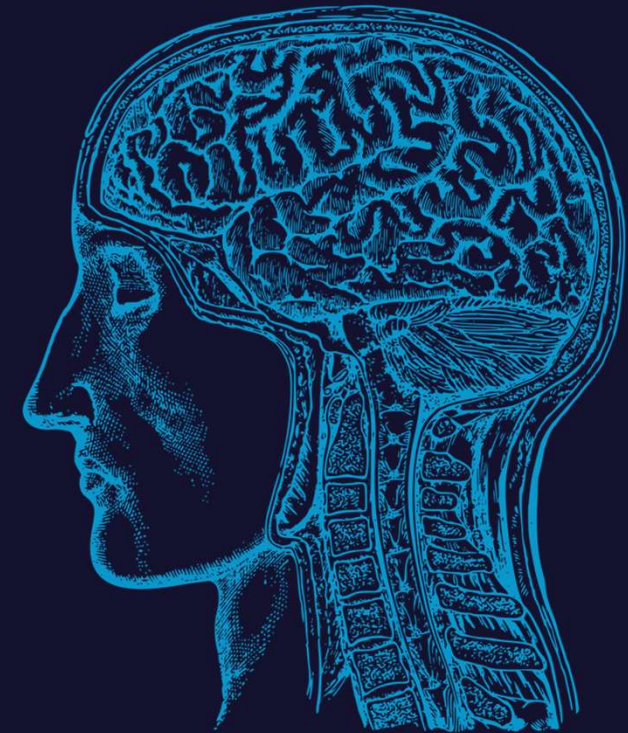
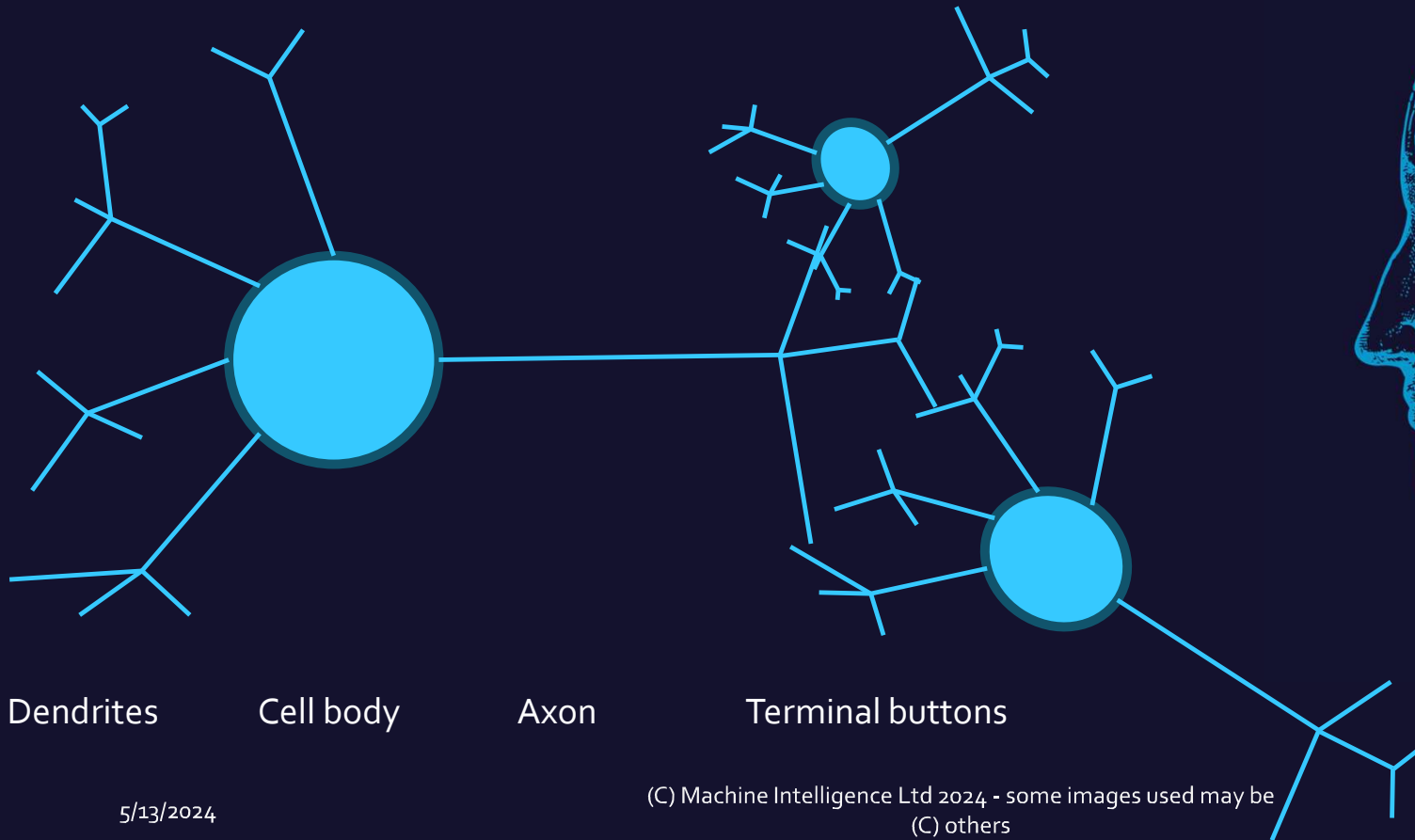
Other
techniques...

Robotics

Expert
systems

Natural
Language
Processing

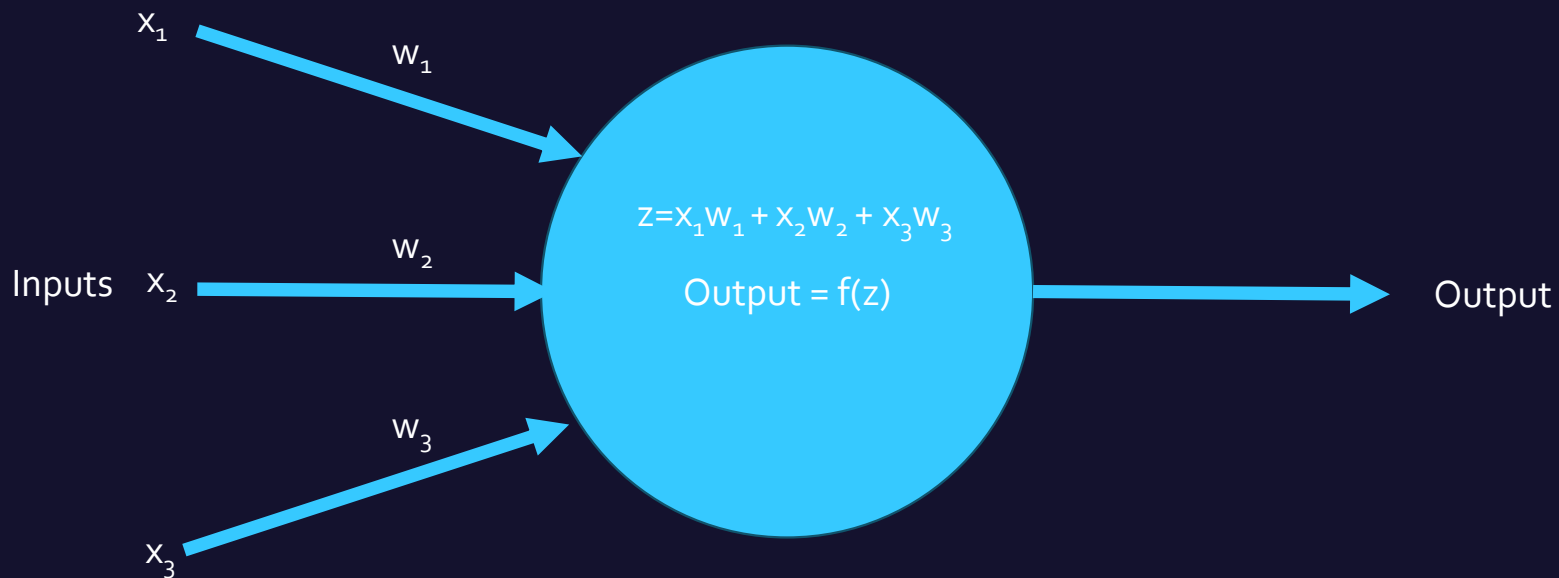
What is a Neural Network?



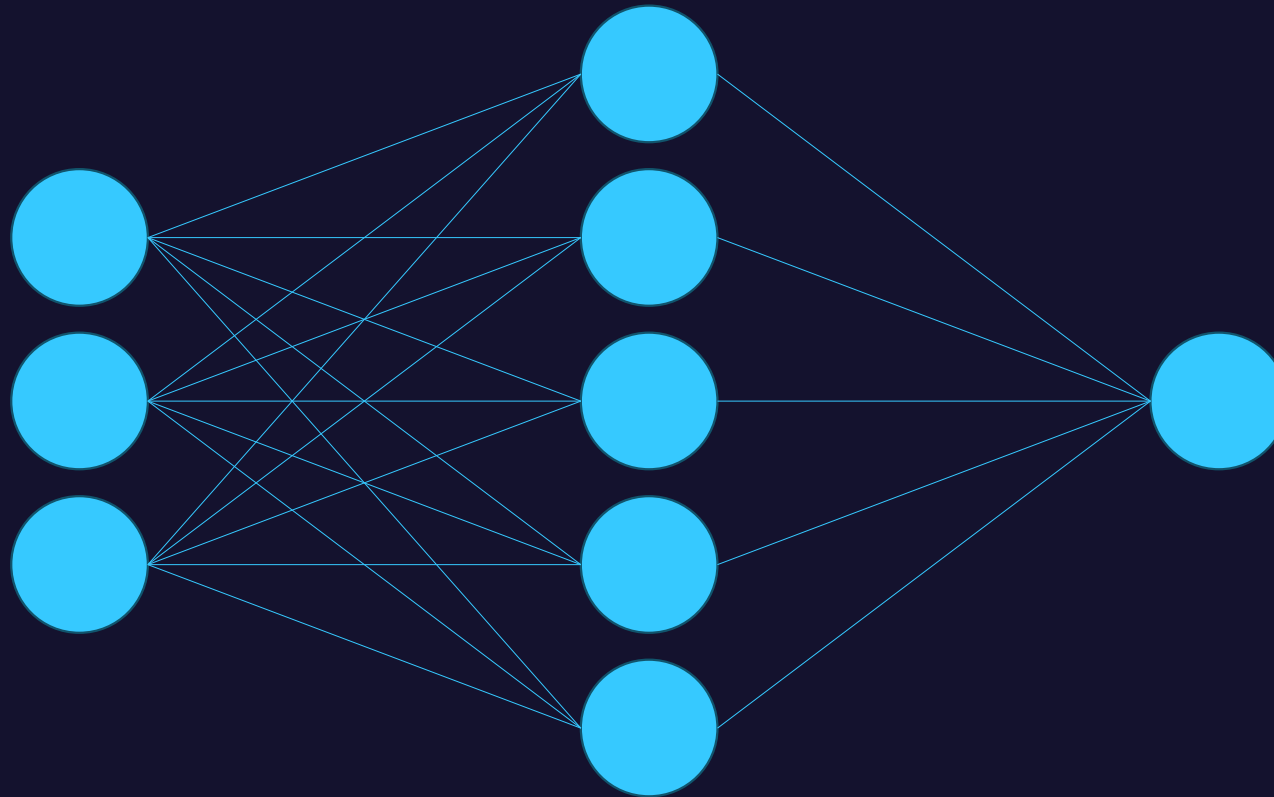
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What is a Neural Network?



What is a Neural Network?



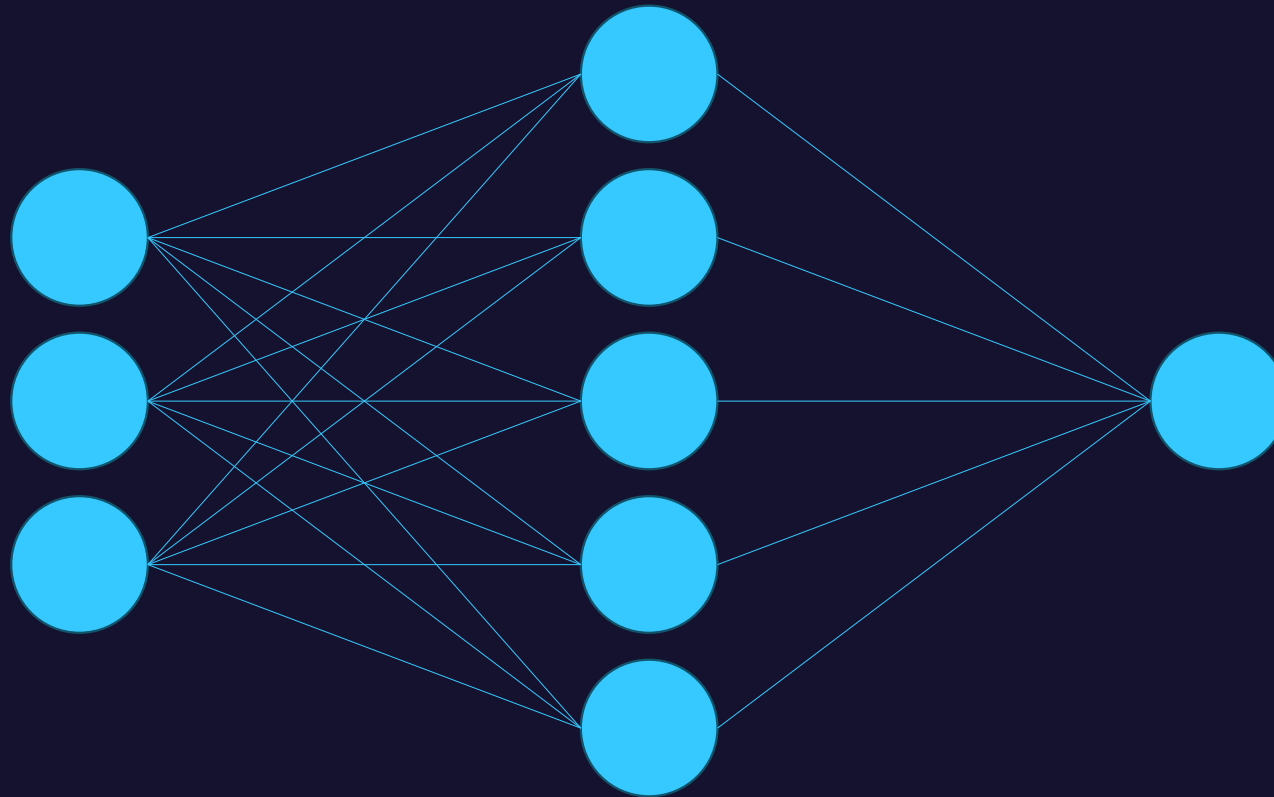
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Input layer

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Hidden layer

Output layer

What is a Neural Network?



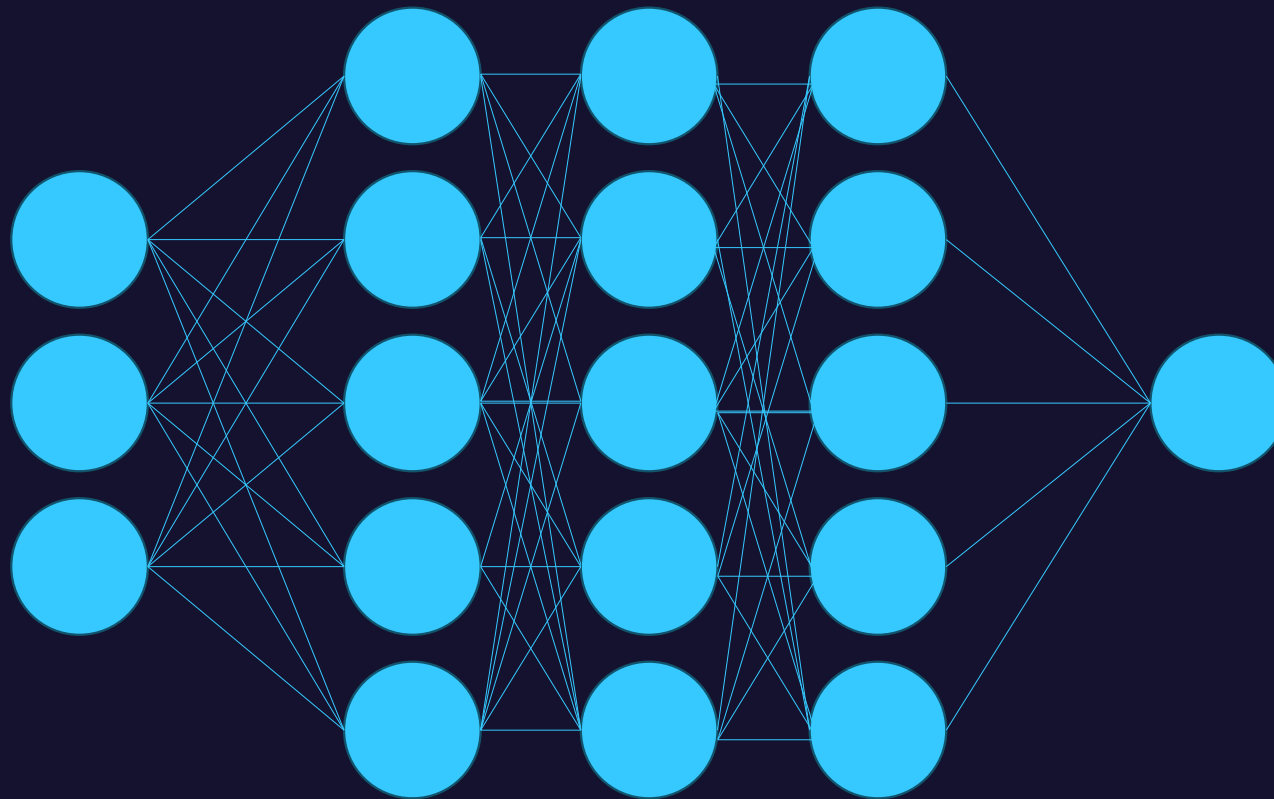
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Input layer

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Hidden layer

Output layer

What is a Deep Neural Network?



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Input layer

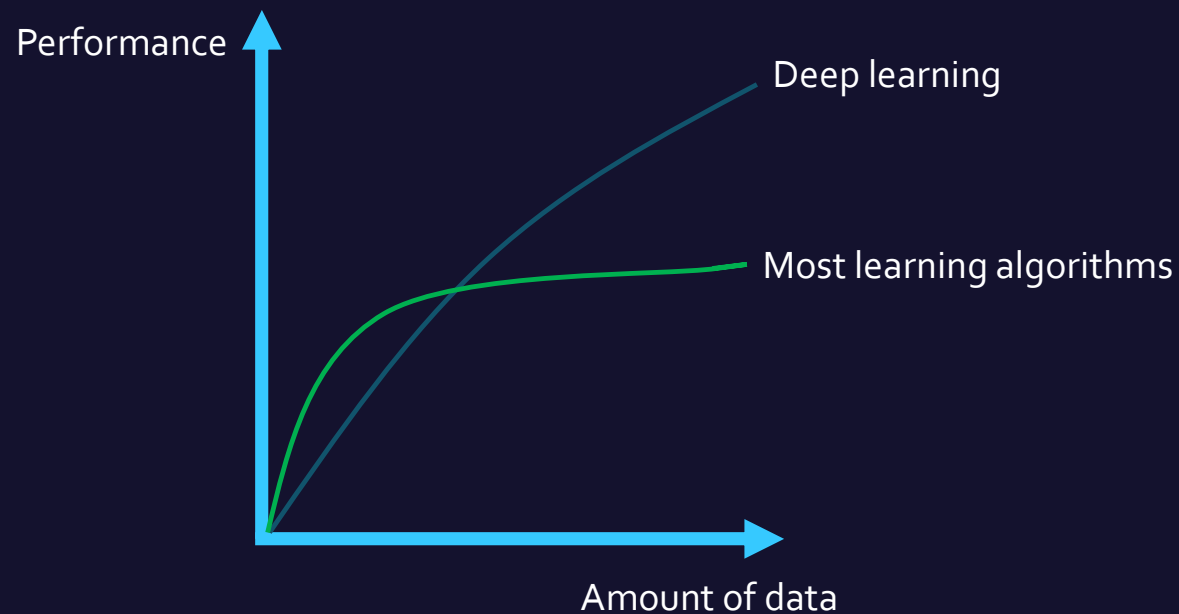
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Hidden layer

Output layer

Pros and cons of NNs

- Pros:
 - Well understood methods for training
 - Massive user base
 - Provable that they can solve any task
 - Scalable
- Cons
 - Black boxes
 - Hard to know how they work
 - Hard to add domain knowledge efficiently
 - Also can be hard to work with odd data-types
 - Hardware inefficient
 - Typically need large amounts of training data

Pros and cons of NNs



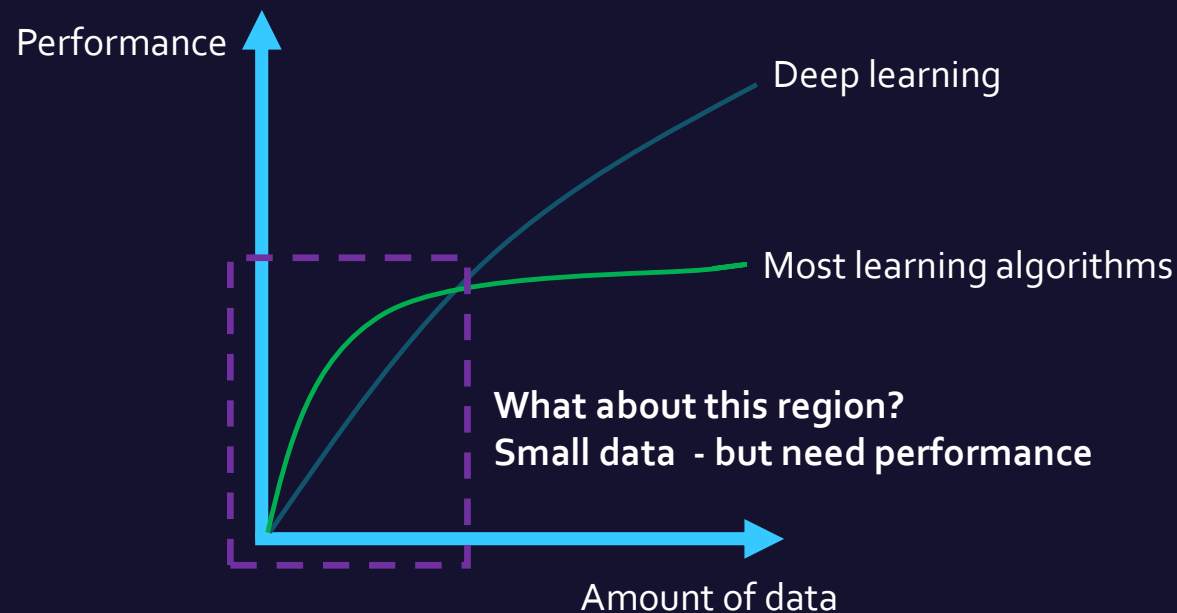
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Sarker, I.H. Deep Learning: A Comprehensive Overview on Techniques, Taxonomy, Applications and Research Directions. *SN COMPUT. SCI.* 2, 420 (2021).

Pros and cons of NNs



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Sarker, I.H. Deep Learning: A Comprehensive Overview on Techniques, Taxonomy, Applications and Research Directions. *SN COMPUT. SCI.* 2, 420 (2021).

Pros and cons of NNs

- Black box
 - What can we, as a human, do with the weight matrix?
- Validation
 - Models are often only as good as the training data
 - They can often only be validated as well as the testing data permits
 - How do we check for issues?
 - Overfitting
 - Underfitting
 - Bias

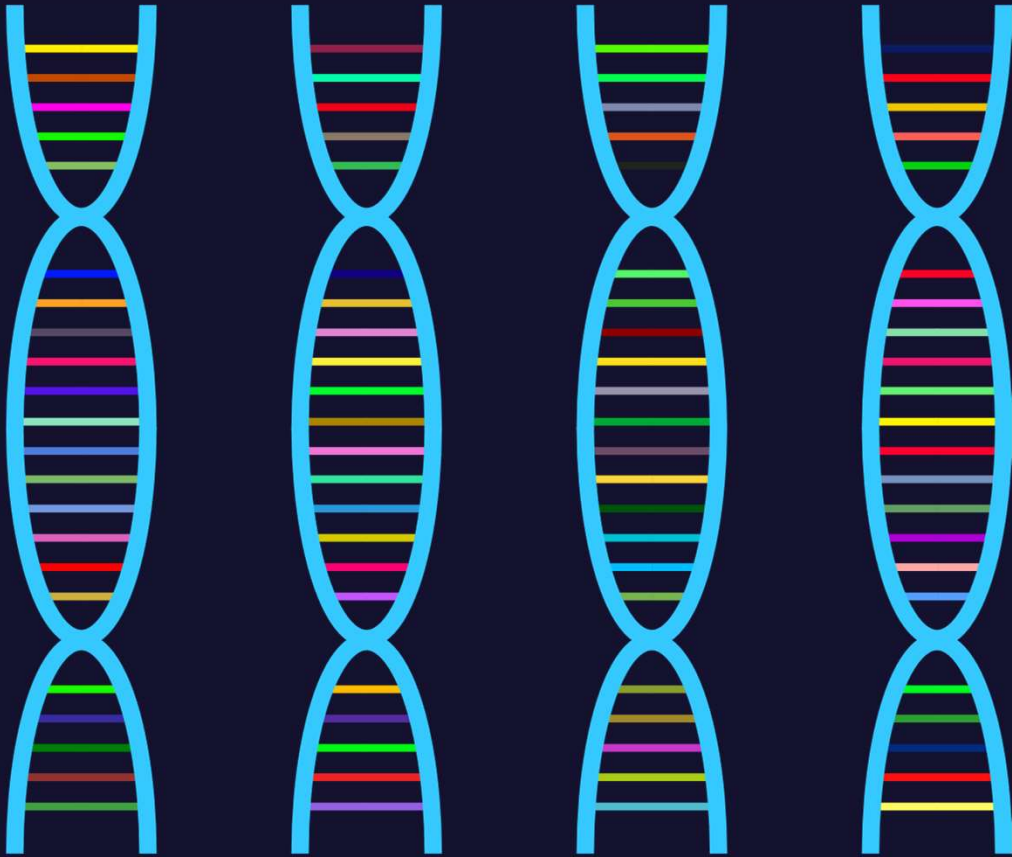
Other types of ML

- Regression
- Principle Component Analysis (PCA)
- K-Nearest Neighbour (KNN)
- Support Vector Machines (SVM)
- Bayesian Inference
- Decision trees / forests
- Evolutionary algorithms
- Many, many others...

Other types of ML

- Pros:
 - Lots of choice
 - Different models for classification, regression, detection etc.
 - Many have explanatory power
 - Some are unsupervised learners
 - Predictable behaviour
- Cons:
 - Not all are suitable for all data types
 - Not all scale well
 - In complexity
 - Number of inputs

Our Technology

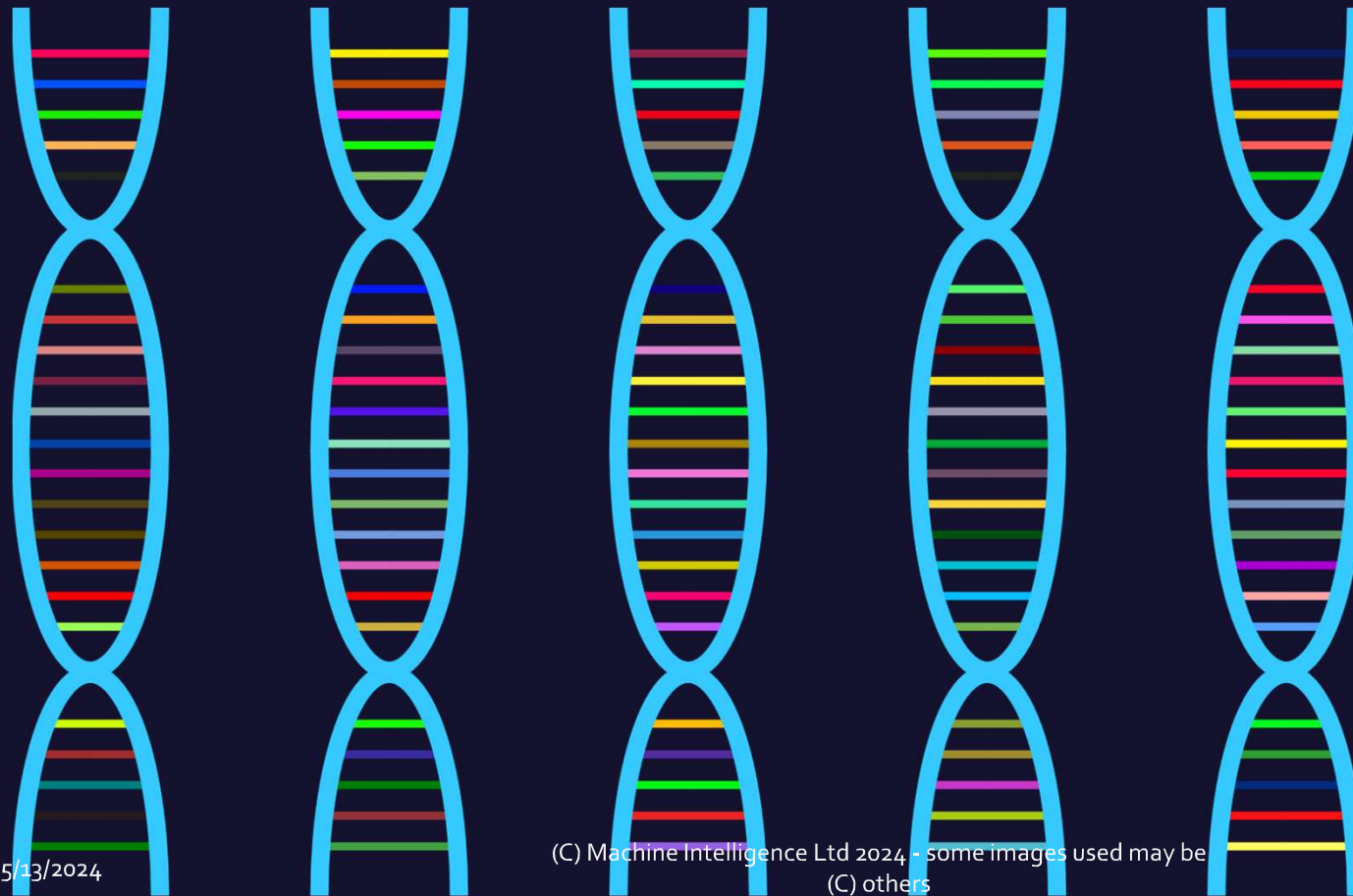


- Bio-inspired
- Genetic programming
 - Outputs computer programs
 - Application agnostic
 - Easy to add domain knowledge
 - Scalable

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Evolutionary Algorithms

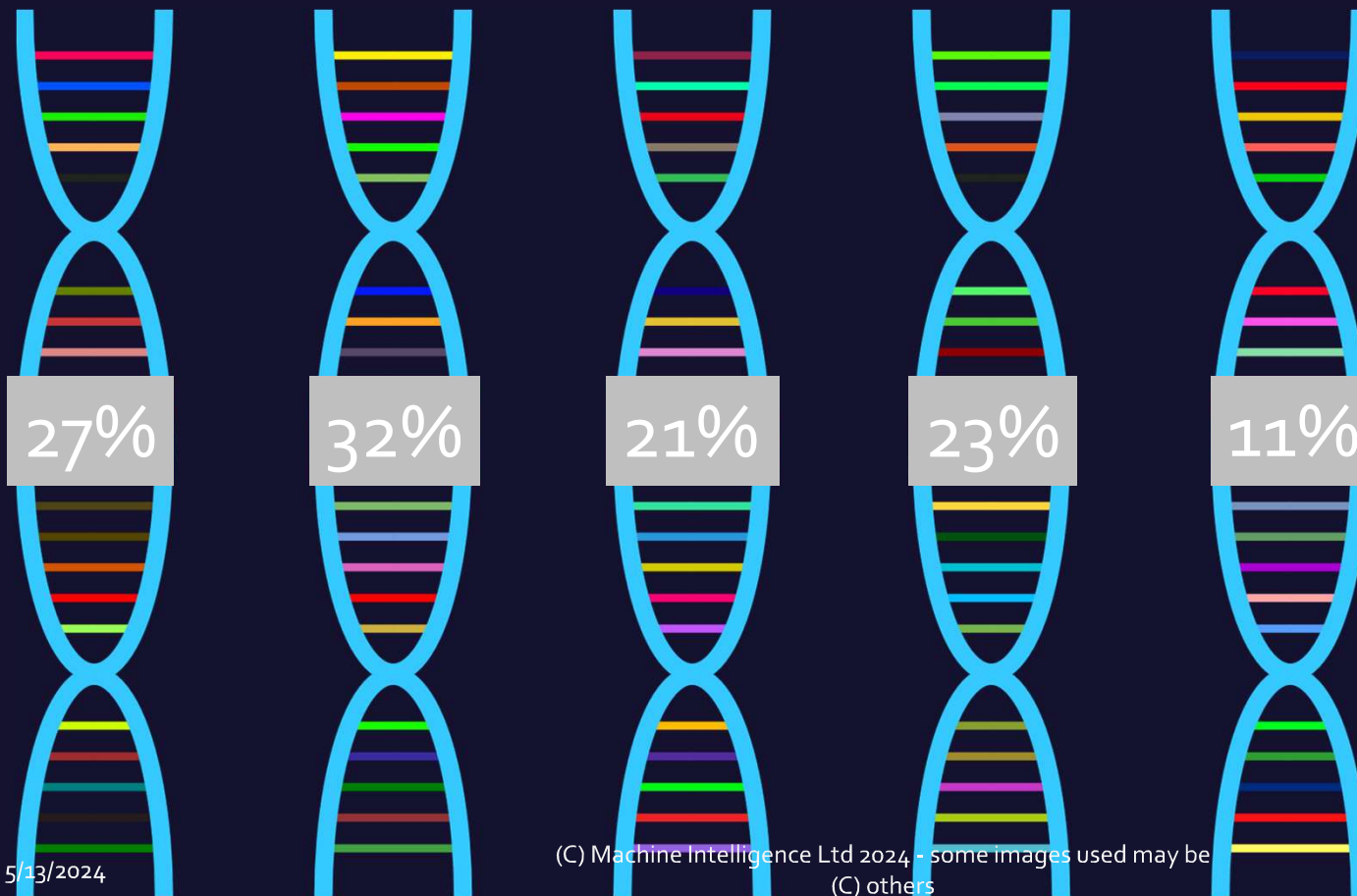


Random
Generated
Population

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(C) others

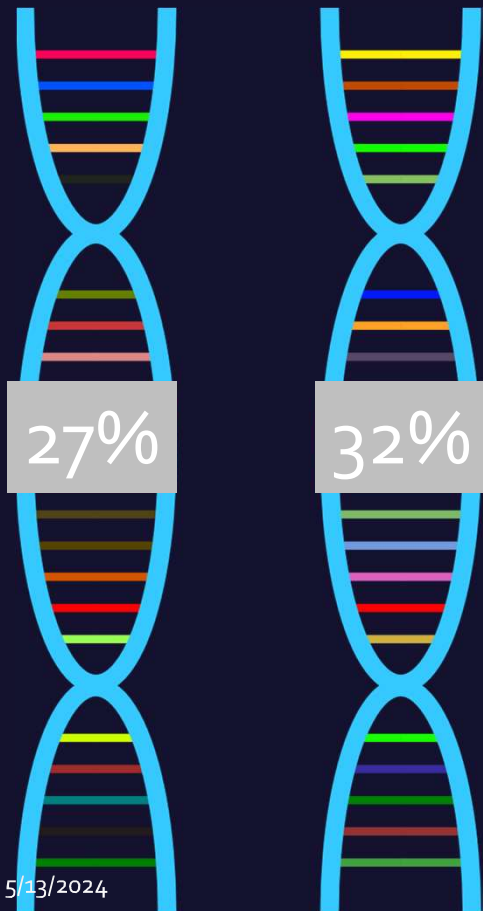
Evolutionary Algorithms



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Evolutionary Algorithms

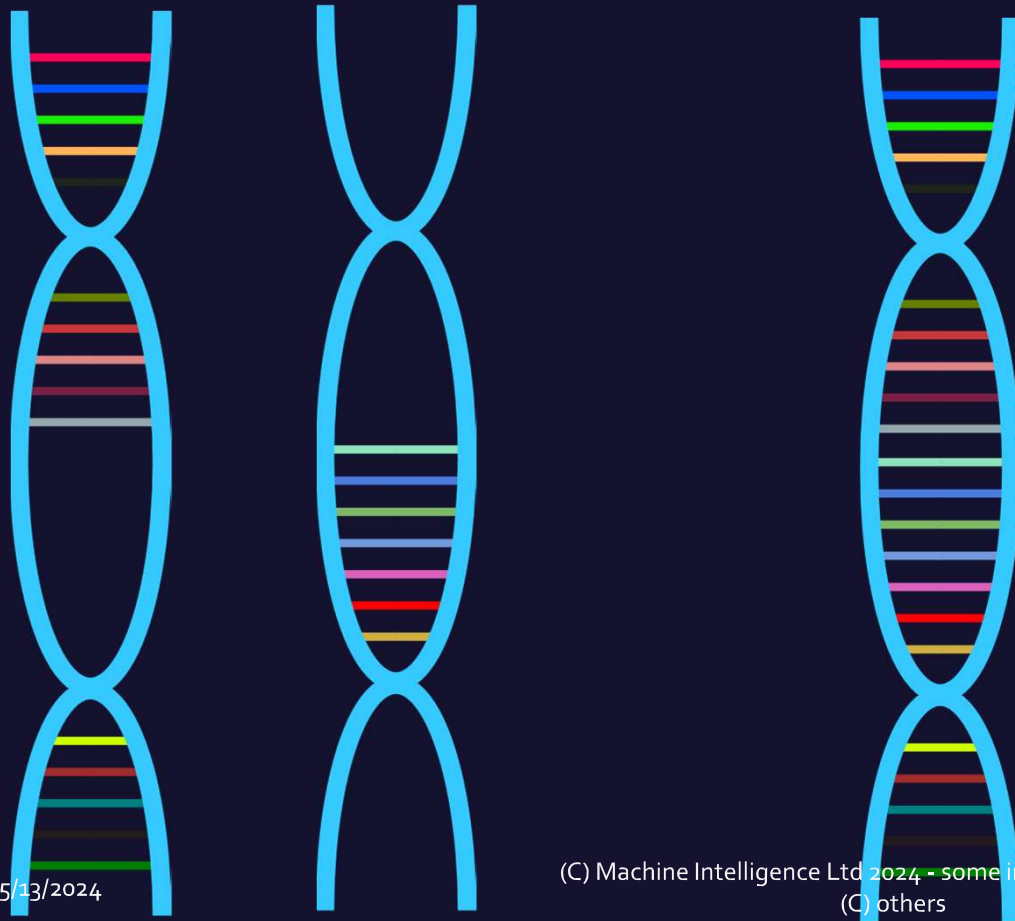


Build next
population:
Select
Parents

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Evolutionary Algorithms

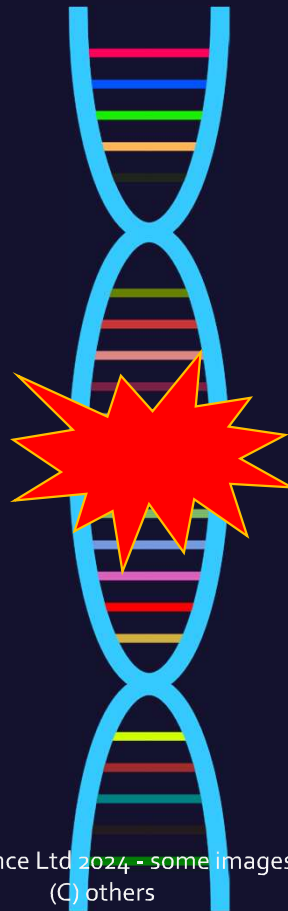


Build next
population:
Generate child by
crossover

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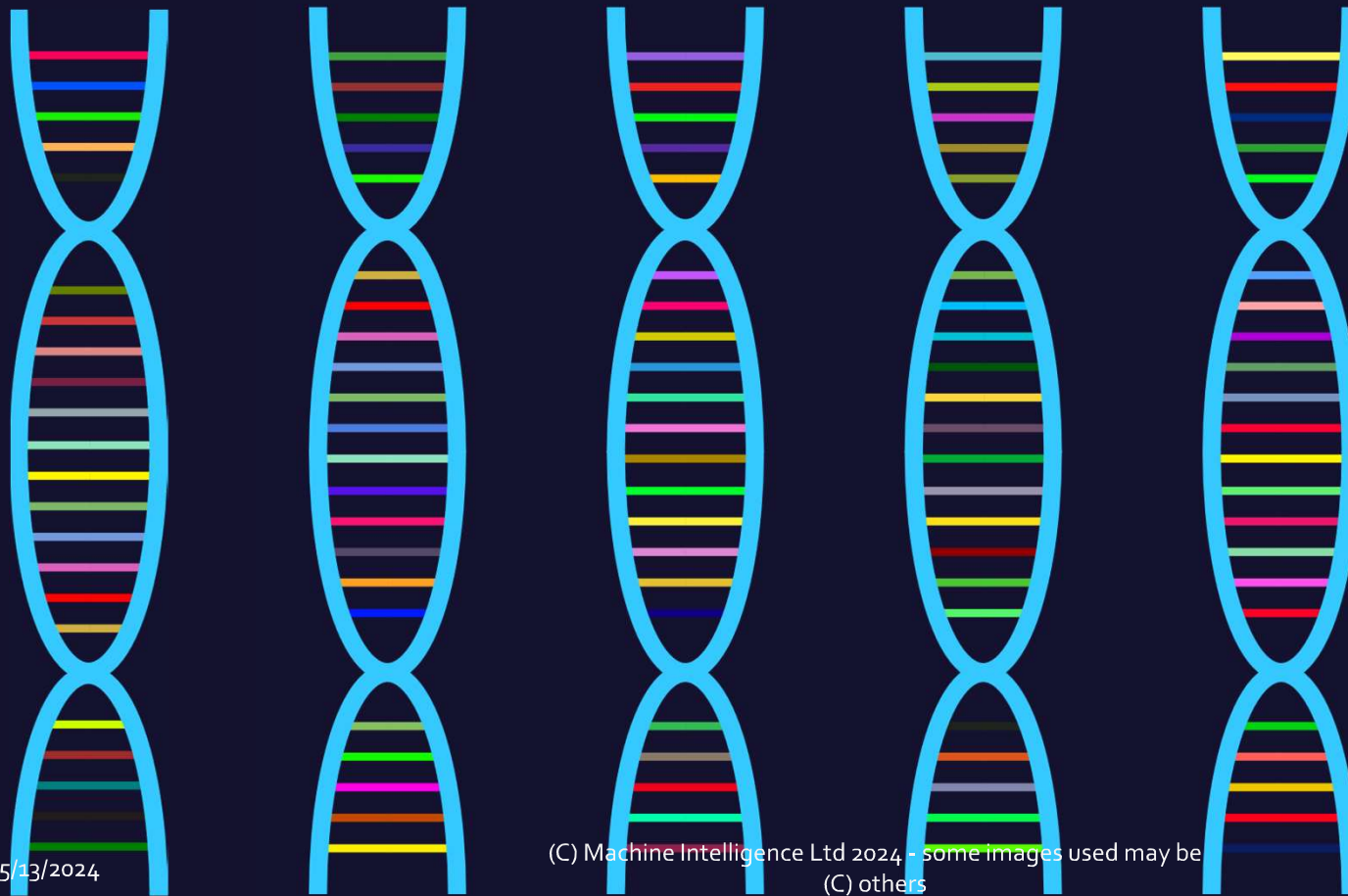
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(C) others

Evolutionary Algorithms



Build next
population:
Mutation

Evolutionary Algorithms

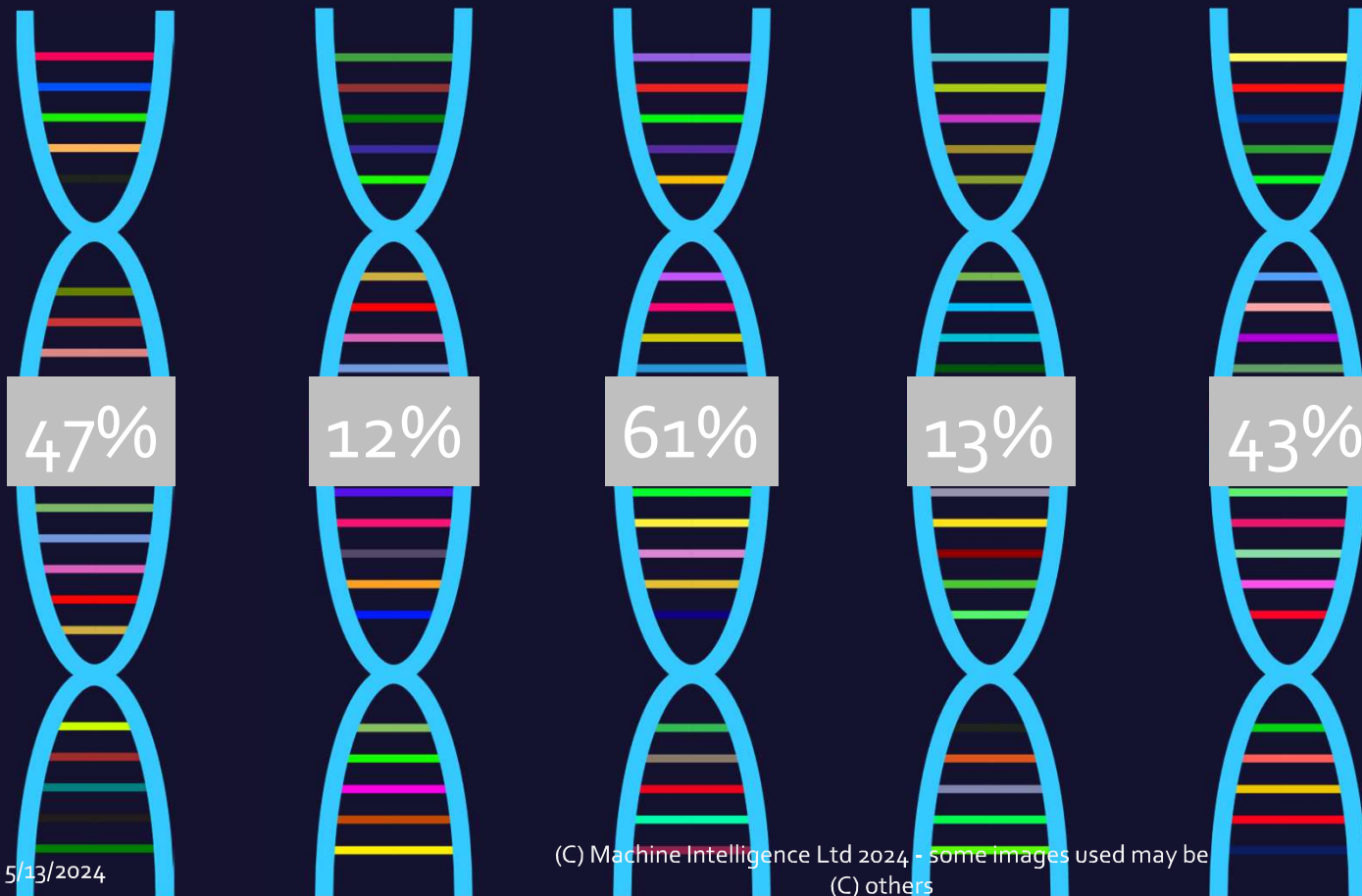


Build next
population:
Repeat until new
population
complete

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Evolutionary Algorithms



Test
New
Population

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Evolutionary Algorithms

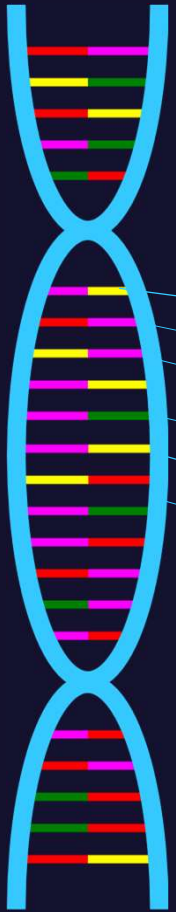


Repeat until
success

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Our technology



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Digital DNA

→ Node1 = Laplace(Inputs[0], 13)
→ Node2 = LocalNormalize(Node1, 12, 1)
→ Node3 = LocalNormalizeWithGauss(Node2, 6, 7)
→ Node4 = LocalStats(Node3, 8, 5, Range)
→ Node5 = SmoothGaussian(Node4, 1, 18)
→ Output = Threshold(Node5, 12.3)

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Represents computer programs (6) others



Allows for introspection

Technology



Labelling software

Tools for letting the user view images in a conventional way and mark up areas of interest

Image processing library

Software library providing algorithms for image manipulation. MI library is combination of OpenCV and custom/closed source algorithms.
End user may want to extend this.

Machine learning

The evolutionary algorithm, distributed learning and visualisation tools for the ML.

Run time

Three ways to use the generated models:
1) Via API
2) Use generated code + image processing library
3) Command line application

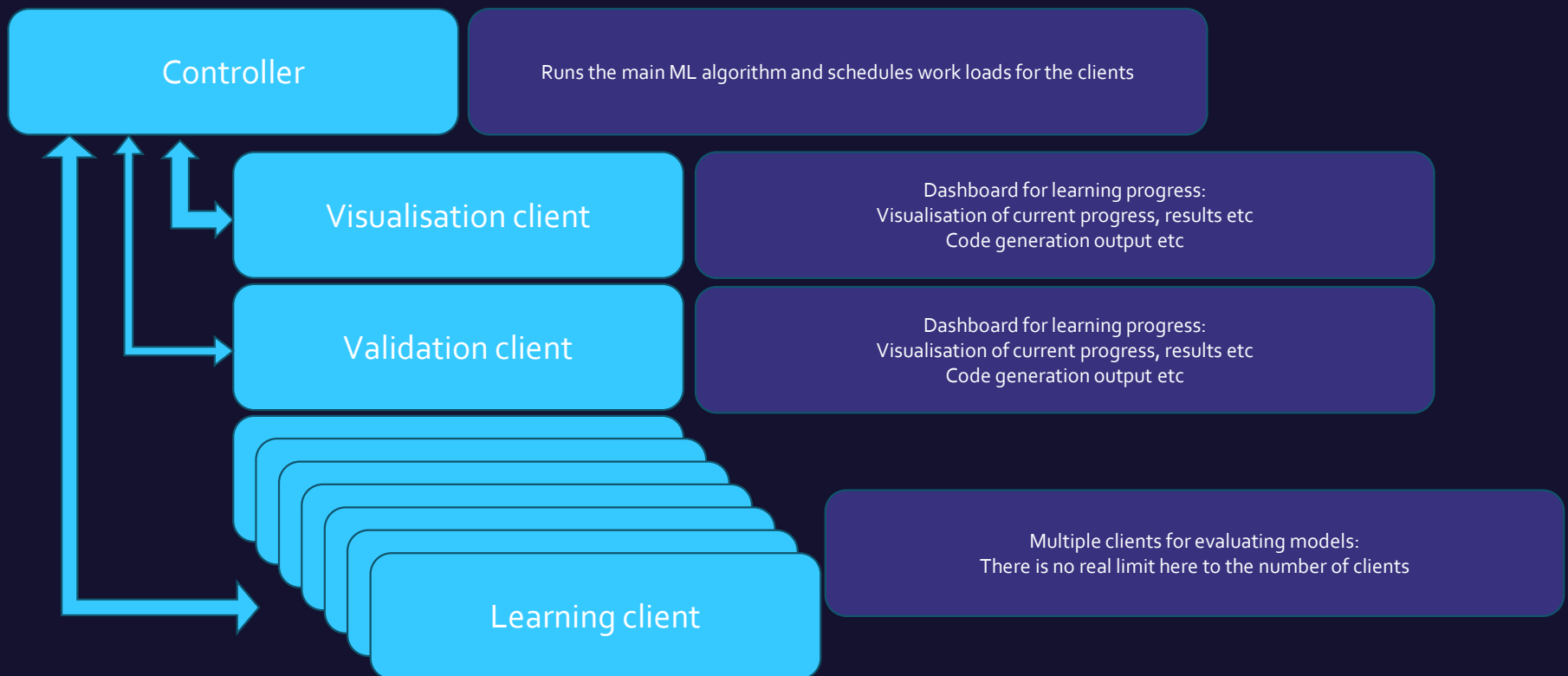
Top-end application

End user application. Most likely 3rd party software

There are 5 software levels to consider:

Technology

Overview of ML architecture:



Technology



Current development status:

Labelling software

Desktop application:
C#, WPF, optimised for digitising tablet.
Image processing for human operators and other actions targeted for digital X-ray.

Image processing library

.net library:
Commercial OpenCV license

Machine learning

.net applications:
C# 4.8, WCF for IPC

Run time

.net applications

Top-end application

Proof-of-concept complete for BAE. Also integrated into RR project.

Technology



Future development:
(With focus on Programmable collab)

Labelling software

Move to web application:
Would need expertise outside of MI to develop

Image processing library

Update:
MI to update this to latest versions of all platforms
Check cross-platform and GPU support

Machine learning

Re-develop:
MI would need to update this to use new infrastructure from Programmable etc

Run time

Re-develop:
1) Programmable interface
2) Library API
3) Code generator export

Top-end application

Connect to Siemens apps etc

Use case: X-ray inspection



- Finalist for Digital Catapult's "Made Smarter Technology Accelerator"

<https://accelerator.madesmarter.uk/>



- Developing AI based system for visual inspection of airplane components: x-ray weld assessment
- Working with BAE Systems in Samelsbury

Use case: X-ray inspection

MVP target problem: Image Based Defect Detection

- Visual inspection of digital images
- Time consuming, laborious, skilled
- Critical importance for defence and aerospace
- Integrated decision making for the operator



Our Solution

- Our machine learning system
 - ✓ Unique technique
 - ✓ **Small training set**
 - ✓ Rapid set up time
 - ✓ Generates computer programs
 - ✓ **Understandable output**
- New software to integrate deeply with inspection process



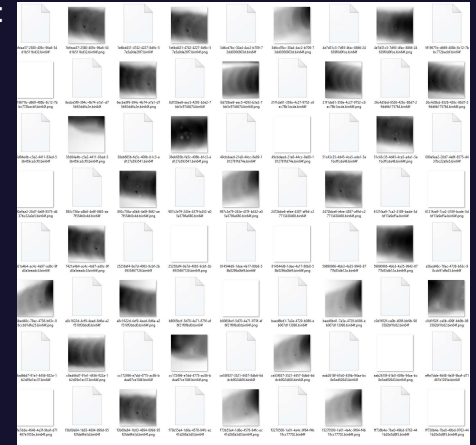
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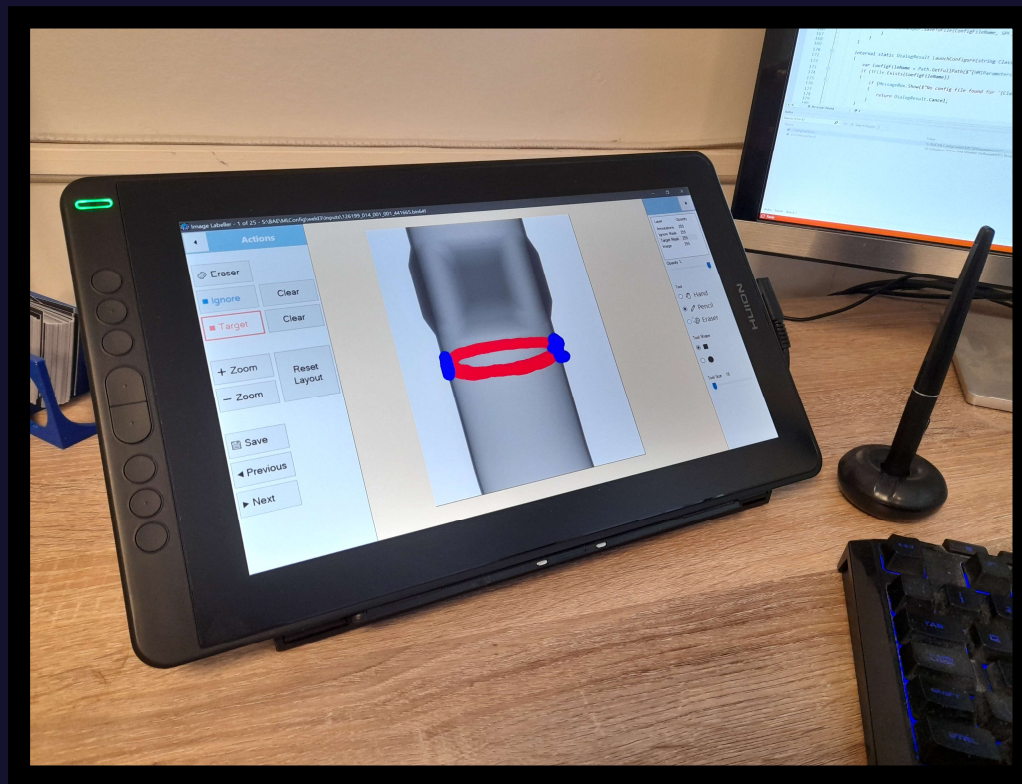
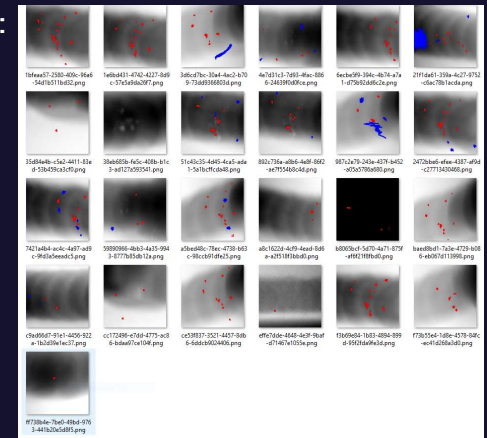
Making the training set



Inputs:



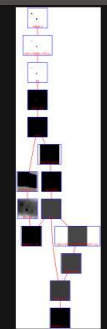
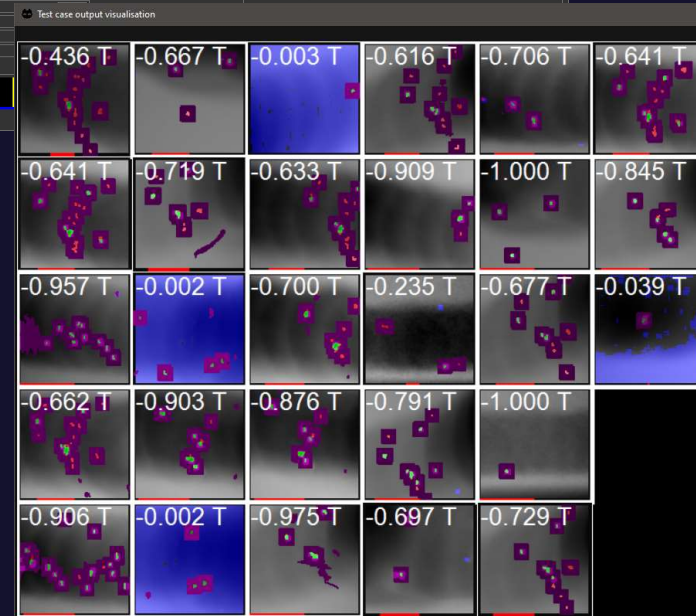
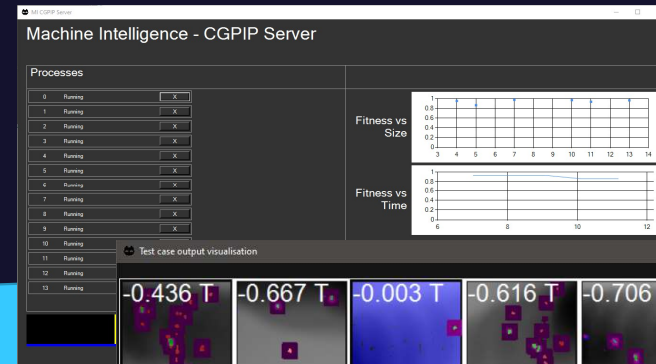
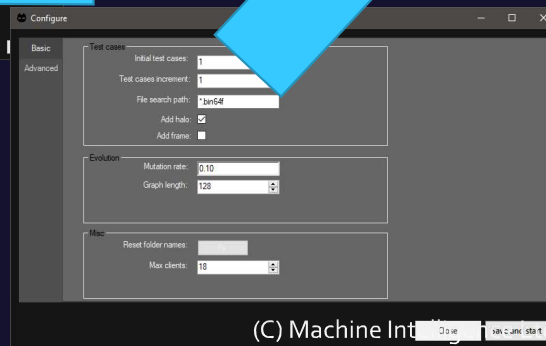
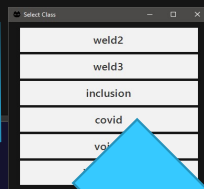
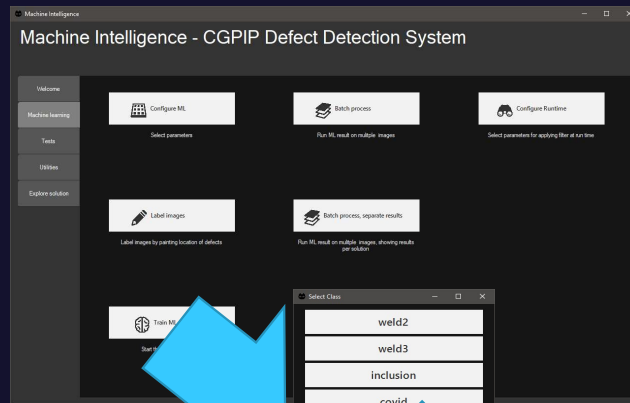
Targets:



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Machine Learning



```
CGPImage Node_0_000 =  
CGPImageFunctions.Laplace(Inputs  
[0][01], 5);  
CGPImage Node_0_002 =  
CGPImageFunctions.Unsharpen  
(Node_0_000, 4,32);  
CGPImage Node_0_003 =  
CGPImageFunctions.SmoothGaussian  
(Node_0_002, 24,14);  
CGPImage Node_0_006 =  
CGPImageFunctions.Add(Node_0_003,  
Inputs[0][00], Node_0_000);  
CGPImage Node_0_009 =  
CGPImageFunctions.Erode(Inputs[0]  
[00], 5);  
CGPImage Node_0_012 =  
CGPImageFunctions.LocalNormalizeWi  
thGauss(Node_0_009, 19, 9);
```

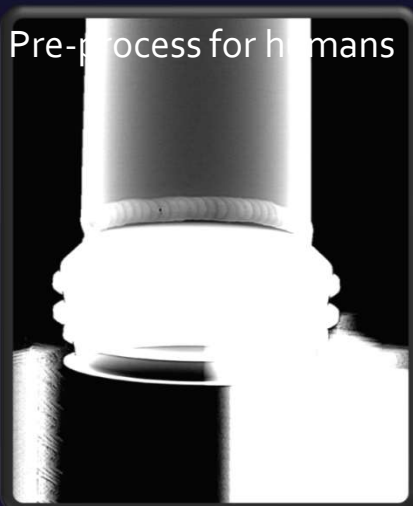
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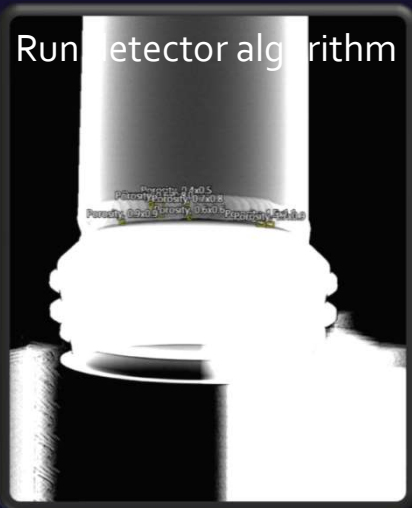
Original image



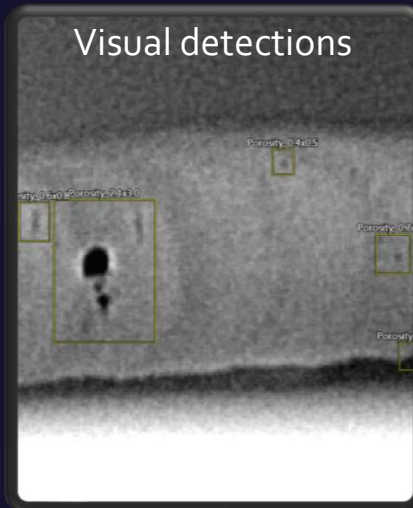
Pre-process for humans



Run detector algorithm



Visual detections


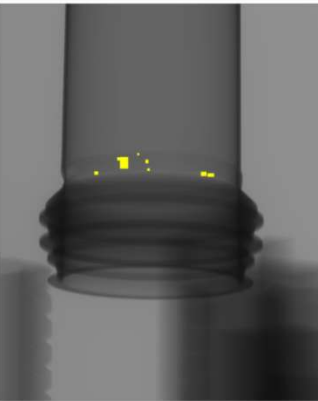


Images

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NDT Number: 15665 - 2 Items						
Unreviewed, Processed	28500247-405	15665	NO DO	SP9006415	B	A
Unreviewed, Processing	28500247-405	15665	NO DO	SP9006415	E	A
NDT Number: 152871 - 3 Items						
Unreviewed, Processed	28500208-405	152871	NO DO	SP900627	C	1
Unreviewed, Processed	28500208-405	152871	NO DO	SP900627	D	1
Unreviewed, Processed	28500208-405	152871	NO DO	SP900627	E	1
NDT Number: 148771 - 1 Item						
Unreviewed, Processed	28500208-405	148771	NO DO	SP900627	E	1
NDT Number: 131049 - 6 Items						
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	A	2
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	Z	2
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	2	Measurement Calibration
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	2	Measurement Calibration
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	A	3
Unreviewed, Processed	28500248-401	131049	NO DO	12775870	E	3
NDT Number: 126201 - 4 Items						
Unreviewed, Processed	28500247-405	126201	NO DO	12699821	B	2
Unreviewed, Processed	28500247-405	126201	NO DO	12699821	A	2
Unreviewed, Processed	28500247-405	126201	NO DO	12699821	C	4
Unreviewed, Processed	28500247-405	126201	NO DO	12699821	F	7
NDT Number: 126199 - 9 Items						
Unreviewed, Processed	28500247-405	126199	NO DO	12699821	E	2
User ACCEPT, Processed	28500247-405	126199	NO DO	12699821	B	3
Unreviewed, Processed	28500247-405	126199	NO DO	12699821	B	3
Unreviewed, Processed	28500247-405	126199	NO D1	12699821	B	3
User ACCEPT, Processed	28500247-405	126199	NO DO	12699821	B	3
Unreviewed, Processed	28500247-405	126199	NO DO	12699821	B	4
Unreviewed, Processed	28500247-405	126199	NO DO	12699821	C	4
Unreviewed, Processed	28500247-405	126199	NO DO	12699821	E	7
User ACCEPT, Processed	28500247-405	126199	NO D2	12699821	E	7

Images

Image Data

Visualise detection results on dashboard

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X-ray Software for BAE



Images

Close

User: admin

	Status	Drawing Number	NDT Number	Rework Status	Order Number	Shot	Weld
NDT Number: 156685 - 2 Items							
+	Unviewed, Processed	J28500247-405	156685	RD D0	SFP006415	B	4
+	Unviewed, Processed	J28500247-405	156685	RD D0	SFP006415	E	4
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+	Unviewed, Processed	J28500059-403	152871	RD D0	SFP003827	D	1
+	Unviewed, Processed	J28500059-403	152871	RD D0	SFP003827	E	1
NDT Number: 146771 - 1 Items							
+	Unviewed, Processed	J28500059-403	146771	RD D0	SFP001355	E	1
NDT Number: 131049 - 6 Items							
+	Unviewed, Processed	J28500248-401	131049	R2 D0	12775970	A	2
+	IQI: Unviewed	J28500248-401	131049	RD D0	12775970	2	Measurement Calibration
+	IQI: Unviewed	J28500248-401	131049	RD D0	12775970	2	Measurement Calibration
+	IQI: Unviewed	J28500248-401	131049	RD D0	12775970	2	Measurement Calibration
+	Unviewed, Processed	J28500248-401	131049	R2 D0	12775970	A	3
+	Unviewed, Processed	J28500248-401	131049	RD D0	12775970	E	3
NDT Number: 126201 - 4 Items							
NDT Number: 126199 - 9 Items							
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+	Unviewed, Processed	J28500247-405	126199	RD D0	12699831	B	4
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+	Unviewed, Processed	J28500247-405	126199	RD D0	12699831	E	7
+	Unviewed, Processed	J28500247-405	126199	RD D2	12699831	E	7

Image

Meta Data

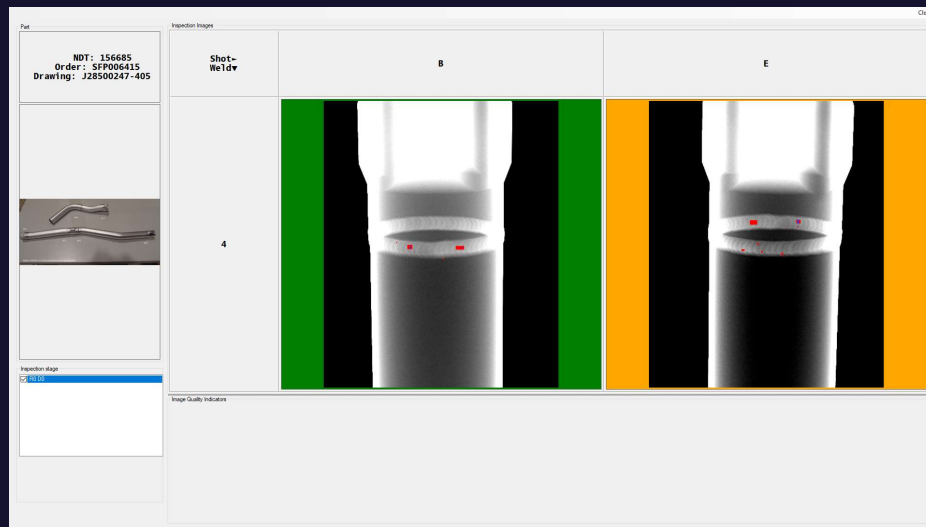
S:\testmon\156685_023_001_001_608660.dcm

Tags

History

Time	Type	User	Message	Result
24/03/2022 11:09	SYSTEM		No user logged in	Seen by ML software
24/03/2022 11:11	ML	admin	Detector running	PROCESSING
24/03/2022 11:11	ML	admin	Detector Personality: Signed: a748857576	PROCESSING
24/03/2022 11:11	ML	admin	Detector inclusion: Signed: 94277967b	PROCESSING
24/03/2022 11:11	ML	admin	Detector run: 7 detections	PROCESSED

X-ray Software for BAE



User can explore images with viewing software and make final Pass/Fail decisions

Use case: Visual defects for RR



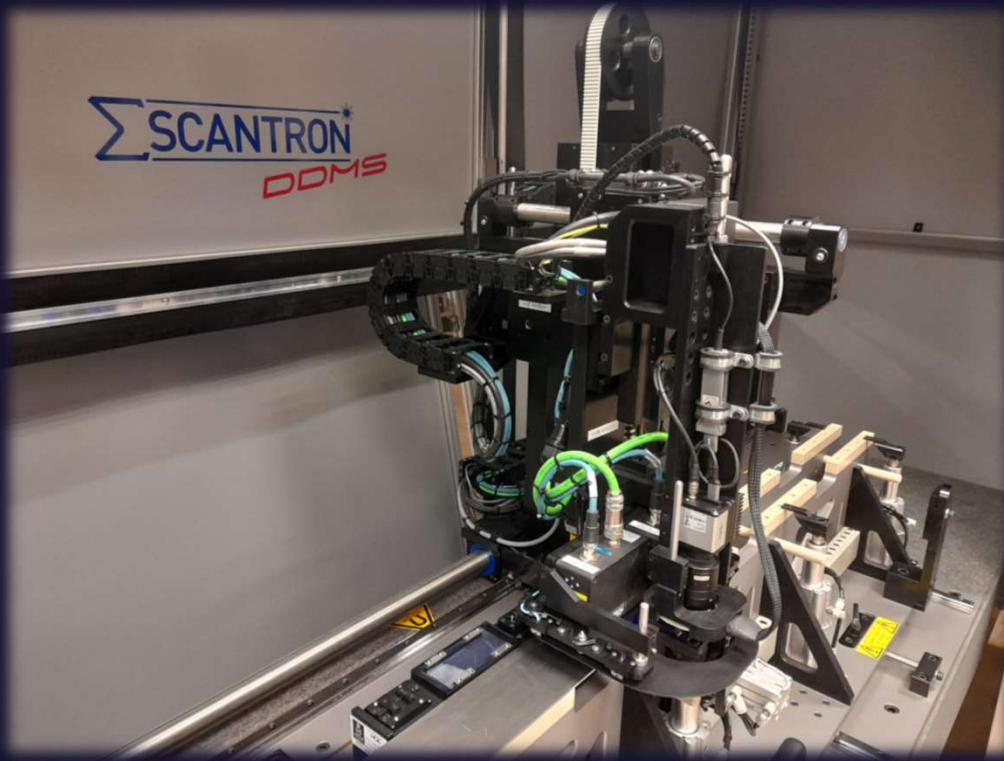
- Defect Detection and Measurement System
- AI powered defect detector
- Multi-modal measurement + sentencing of components
- Full automation
- 1 system deployed and used in production
- 1 system nearing completion



Automated inspection system :
3D scanning, metrology and vision



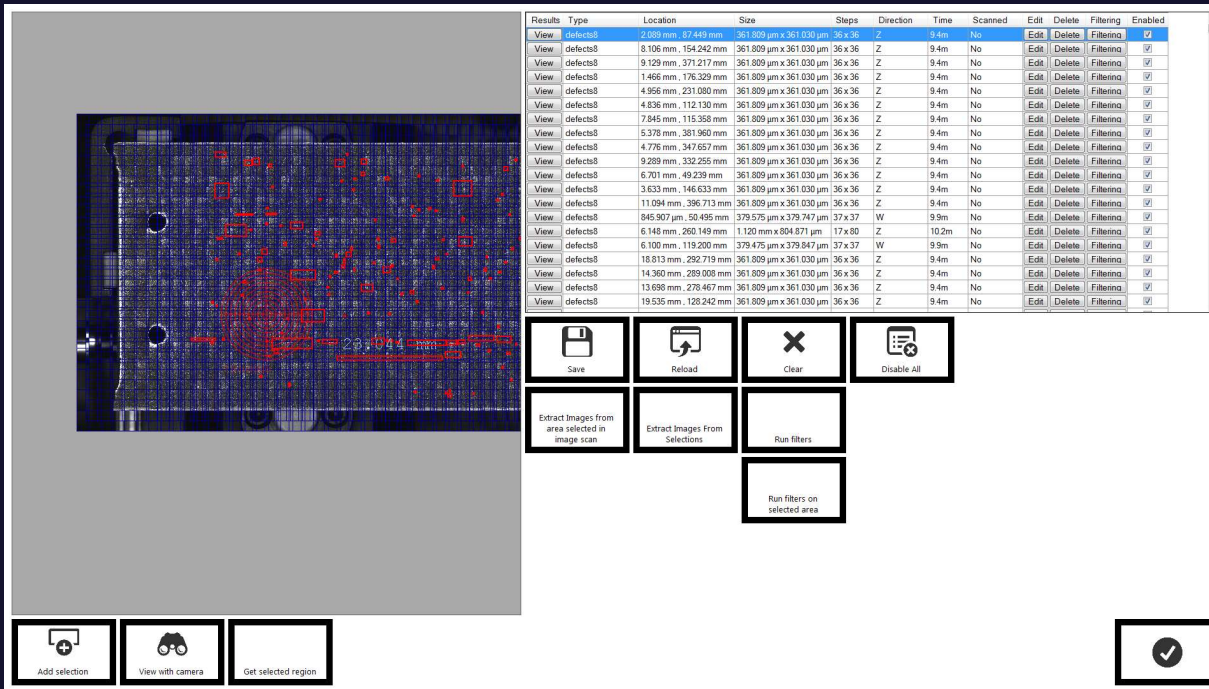
Use case: Visual defects for RR



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Use case: Visual defects

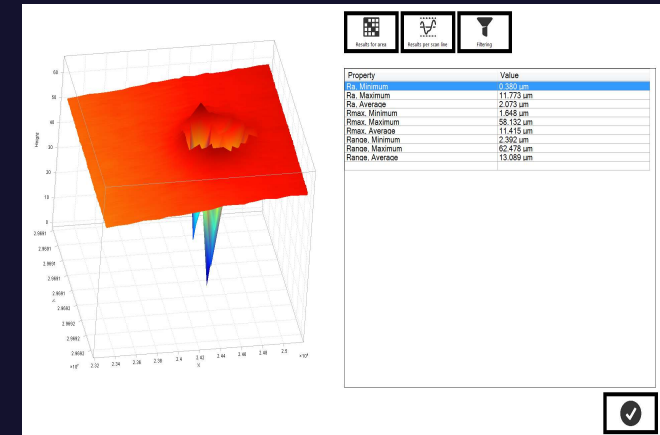


Results	Type	Location	Size	Steps	Direction	Time	Scanned	Edit	Delete	Filtering	Enabled
View	defects0	2.089 mm, 87.449 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	8.106 mm, 154.242 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	9.129 mm, 371.217 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	1.466 mm, 176.329 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	4.956 mm, 231.080 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	4.836 mm, 112.130 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	7.845 mm, 115.358 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	5.378 mm, 381.960 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	4.776 mm, 347.657 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	9.289 mm, 332.255 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	6.701 mm, 49.239 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	3.633 mm, 146.633 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	11.094 mm, 396.713 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	945.907 µm, 50.498 mm	379.575 µm x 379.747 µm	37 x 37	W	9.9m	No	Edit	Delete	Filtering	✓
View	defects0	6.148 mm, 260.149 mm	1.120 mm x 804.871 µm	17 x 10	Z	10.2m	No	Edit	Delete	Filtering	✓
View	defects0	6.100 mm, 119.200 mm	379.475 µm x 379.847 µm	37 x 37	W	9.9m	No	Edit	Delete	Filtering	✓
View	defects0	18.813 mm, 292.719 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	14.360 mm, 289.008 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	13.698 mm, 276.467 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓
View	defects0	19.535 mm, 128.242 mm	361.809 µm x 361.030 µm	36 x 36	Z	9.4m	No	Edit	Delete	Filtering	✓

Save Reload Clear Disable All

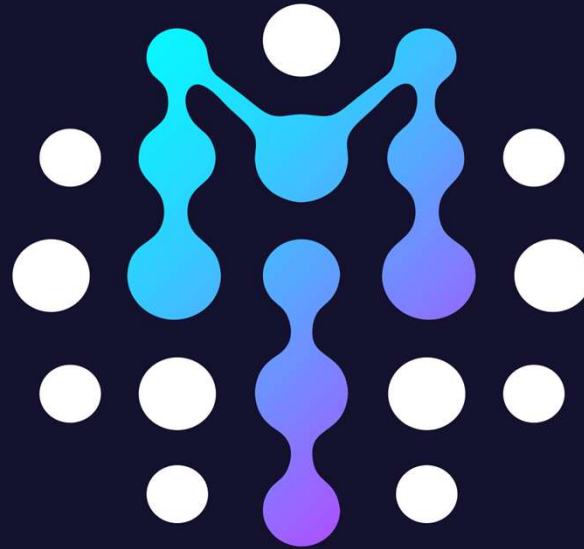
Extract Images from area selected in image scan Extract Images From Selections Run filters Run filters on selected area

Add selection View with camera Get selected region



Final thoughts

- AI extremely important and useful in NDT
- Many different types of ML out there to use
 - Pros and cons for each
- Selecting the right ML algorithm may be important for your application
 - Meet regulatory issues
 - Be confident in the solution
 - Learn something about your problem



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5/13/2024 Thank you for listening - any questions?

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