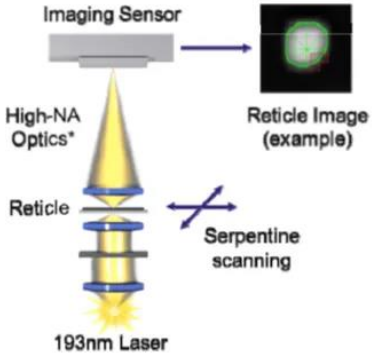
CENTER FOR DEEP LEARNING IN ELECTRONICS MANUFACTURING

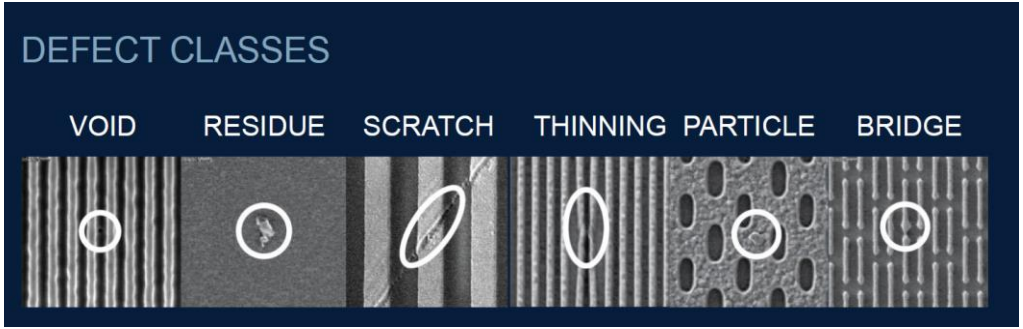
Accelerating semiconductor manufacturing with deep learning

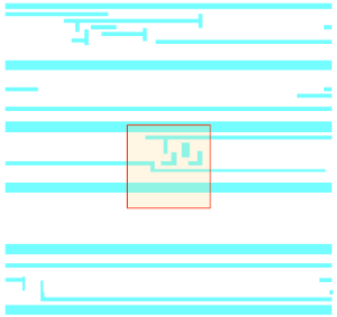
Ajay Baranwal (CDLe)

A PARTNERSHIP OF NuFLARE MYCRONIC D2S

DL can solve photomask industry problems







Mask inspection

Automatic defect categorization

Lithography hotspot detection

Fault detection and classification

Anomalous data synthesis

https://doi.org/10.1117/12.2282943
https://digital.hbs.edu/platform-digit/submission/applied-materials-when-machines-talk-to-each-othe/
https://semiengineering.com/searching-for-euv-mask-defects/

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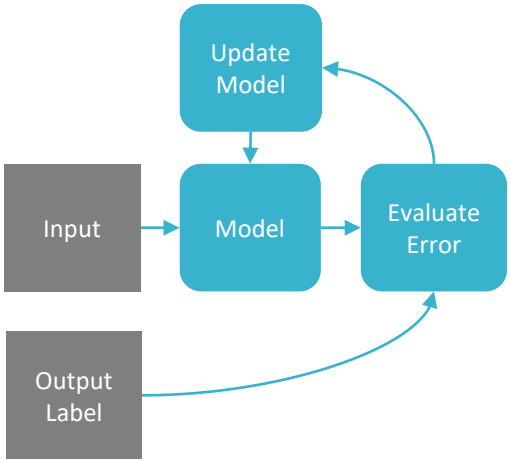
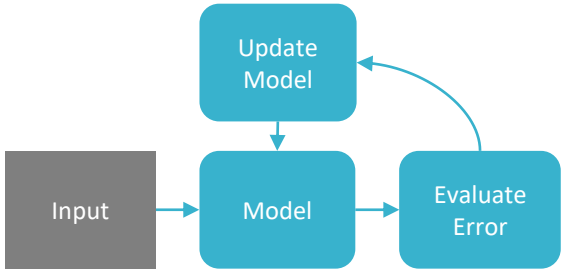
Many DL techniques are used at CDLe

(Labeled data)



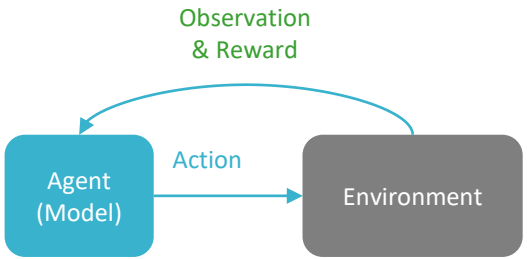
Supervised learning

(Unlabeled data)



Unsupervised learning

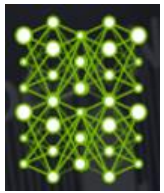
(“Games”)



Reinforcement learning

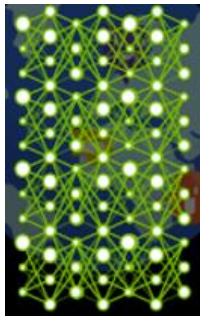
Deep learning scales infinitely - Automatically

7 ExaFLOPS
60 Million Parameters
8 Layers -> 150 Layers



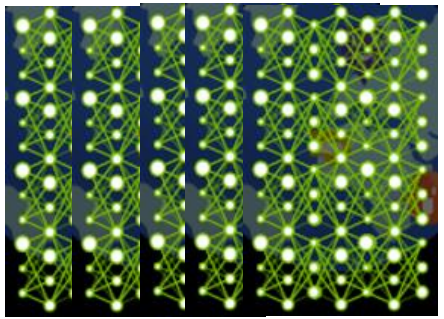
2015

20 ExaFLOPS
300 Million Parameters
Complex Architecture



2016

100 ExaFLOPS
8.7 Billion Parameters
Even More Complex Architecture



2017 / 2018

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Source: scaledml

Mask manufacturing problems are a bit different …

ImageNet:

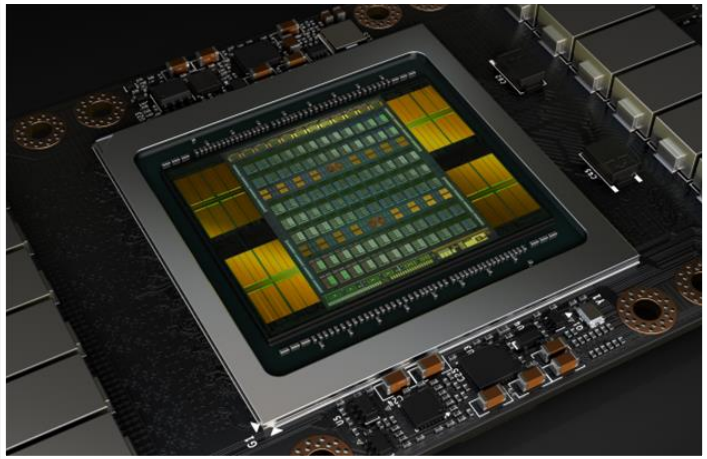
- 14.2M images
  - 1.2TB for complete dataset
- 3 σ accuracy is considered great
- Better than human is sufficient

x 450

=

Masks:

- 540TB in 10nm pixels to write a mask
  - One Mask > 450 x ImageNet dataset
- >7 σ accuracy required



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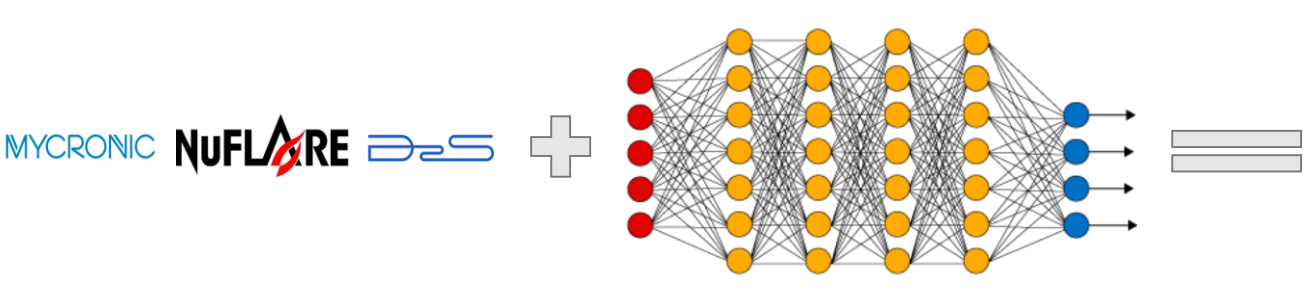
CDLe's mission is to succeed with DL breakthrough technology



CDLe is an alliance of industry leaders in electronic manufacturing

Deep learning is breakthrough technology

Success to speed up time-to-market of DL for electronic manufacturing

https://www.trissential.com/about-trissential/mission-values.php
https://dvl.in.tum.de/teaching/i2dl-ws18/
https://andrespira.com/th/blog/what-exactly-is-success/

CDLe has achieved 10 successful projects in past year

Semiconductor photomask industry

Flat Panel Displays (FPD) mask making industry

MYCRONIC

PCB assembly line

MYCRONIC

Two ways to be associated with CDLe

Send short terms assignees

Become partner company

Contact: Ajay Baranwal, ajay.baranwal@cdle.ai

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A PARTNERSHIP OF NuFLARE MYCRONIC D2S

D2S: Mask rule error automatic categorization

Recommendation engines use deep learning

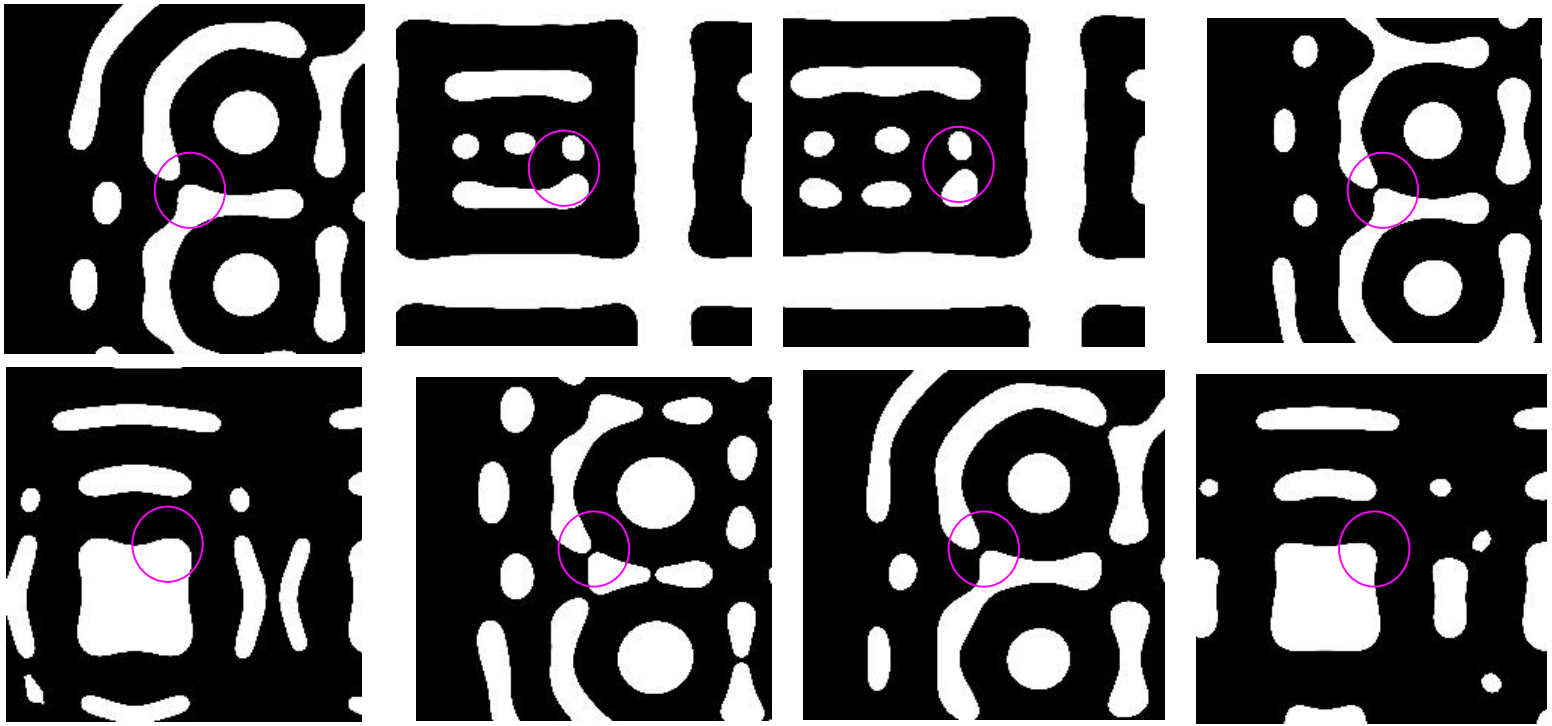
DL technique used: autoencoding (unsupervised DL)

amazon

NETFLIX

Mask rule check can generate thousands of errors

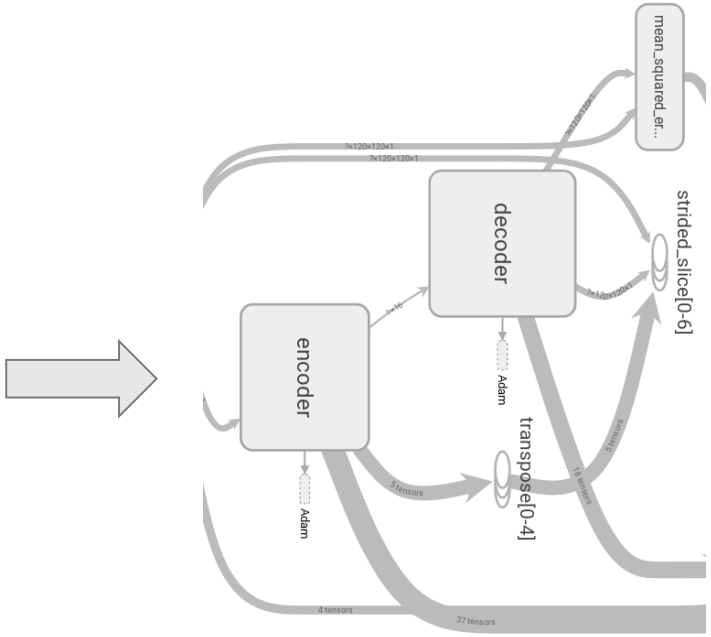
Best to report similar errors together



Unsupervised Autoencoder captures similarity

Uses same data as input and output for training

Mask image clip

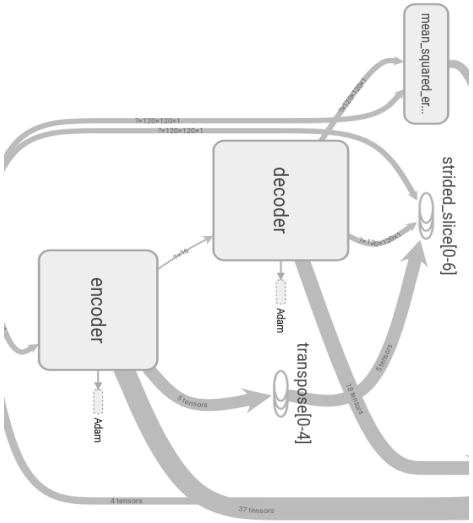


Same mask image clip

Unsupervised deep autoencoder captures similarity

After training, creates encoding for every mask image clip

Mask image clip



Autoencoder

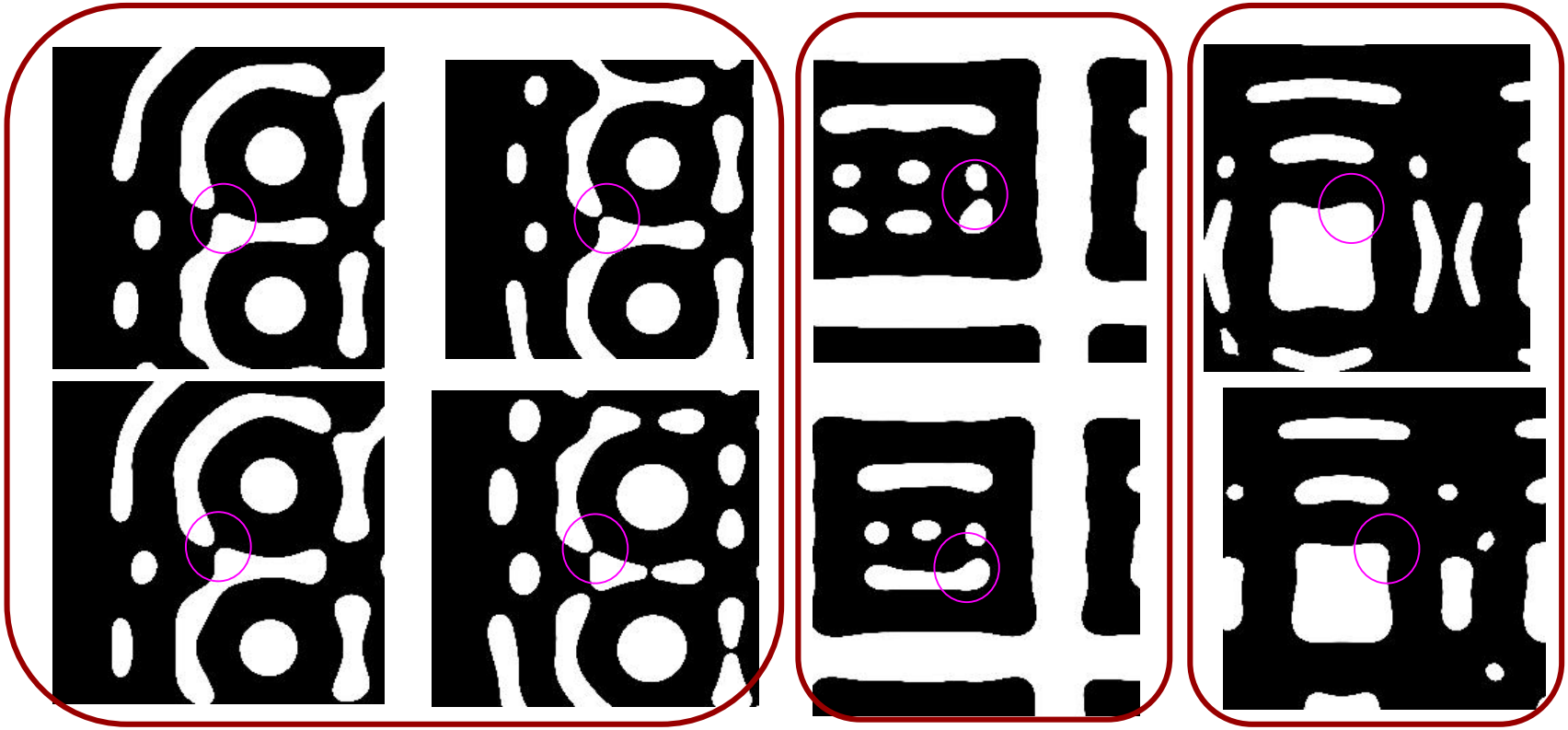
...

```
-6.90551400e-01, -4.18511915e+00,
 2.06112623e+00, -1.51410028e-01,
-2.68224931e+00,  7.21601295e+00,
-5.43296051e+00, -3.20511770e+00,
 2.15347147e+00,  8.18617404e-01,
 2.95589471e+00, -9.31145012e-01,
-6.62960470e-01, -1.27928896e+01,
 1.86616671e+00,  1.90052949e-02,
-2.27907753e+00, -8.11386645e-01,
-3.20432723e-01,  6.76728106e+00,
-2.45643973e+00,  7.35447228e-01,
 1.30219030e+00, -3.21892333e+00,
```

...

Series of numbers (Also called encoding)

Mask rule check groups similar errors together automatically



Mycronic: PCB component pick-and-place (PnP) error classification

Amazon Go automatic checkout uses deep learning

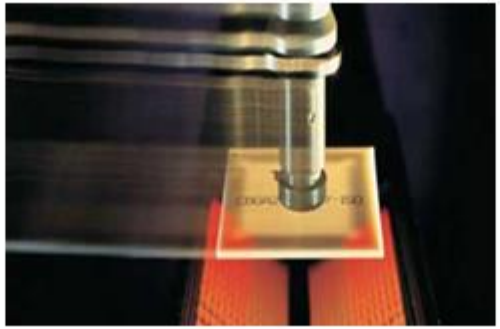
DL technique used: object classification, others (supervised DL)

https://www.cnet.com/pictures/photos-inside-amazon-go-store-no-cashiers-seattle/7/

Incorrectly picked components need to be identified

Monitored using images of picked components

Magazine with components

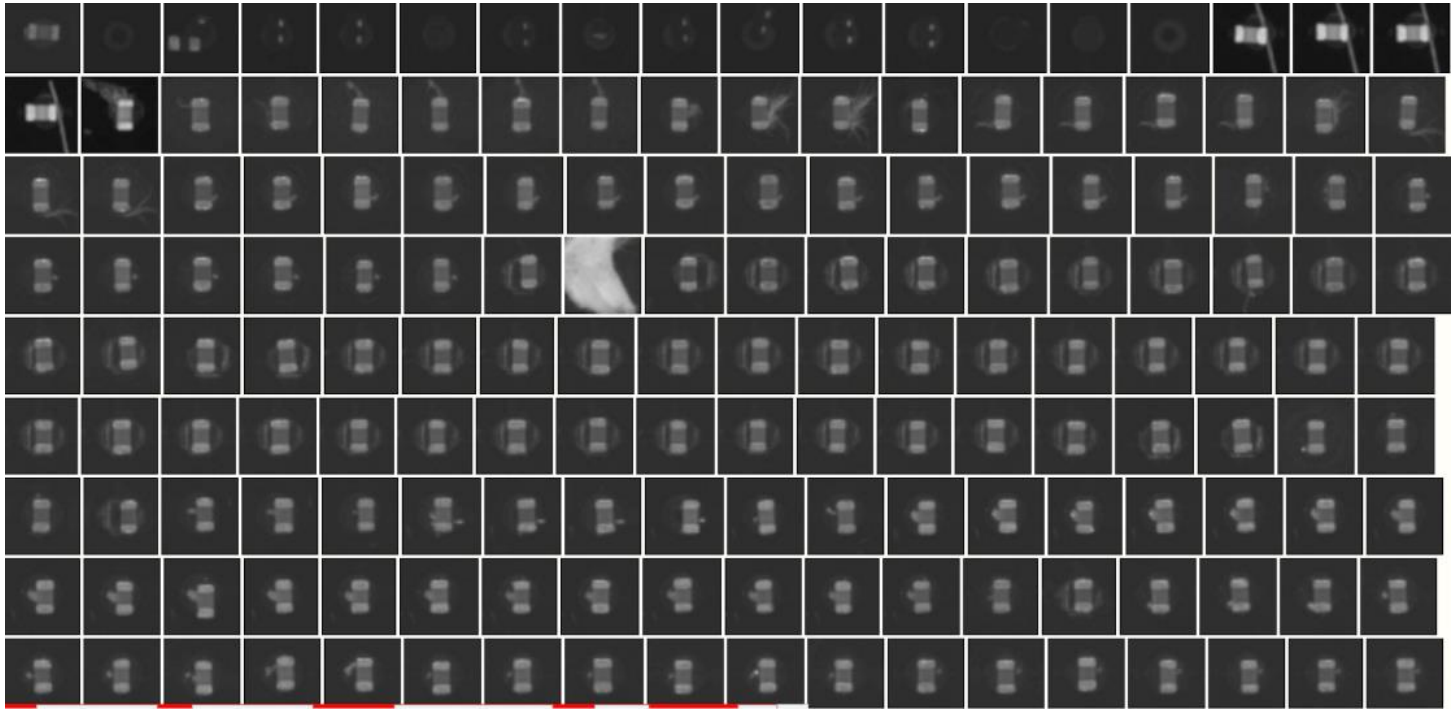


Robot arm picked a component (Image taken)

Component Mounted on PCB

This problem is difficult

Classical computer vision is not sufficient

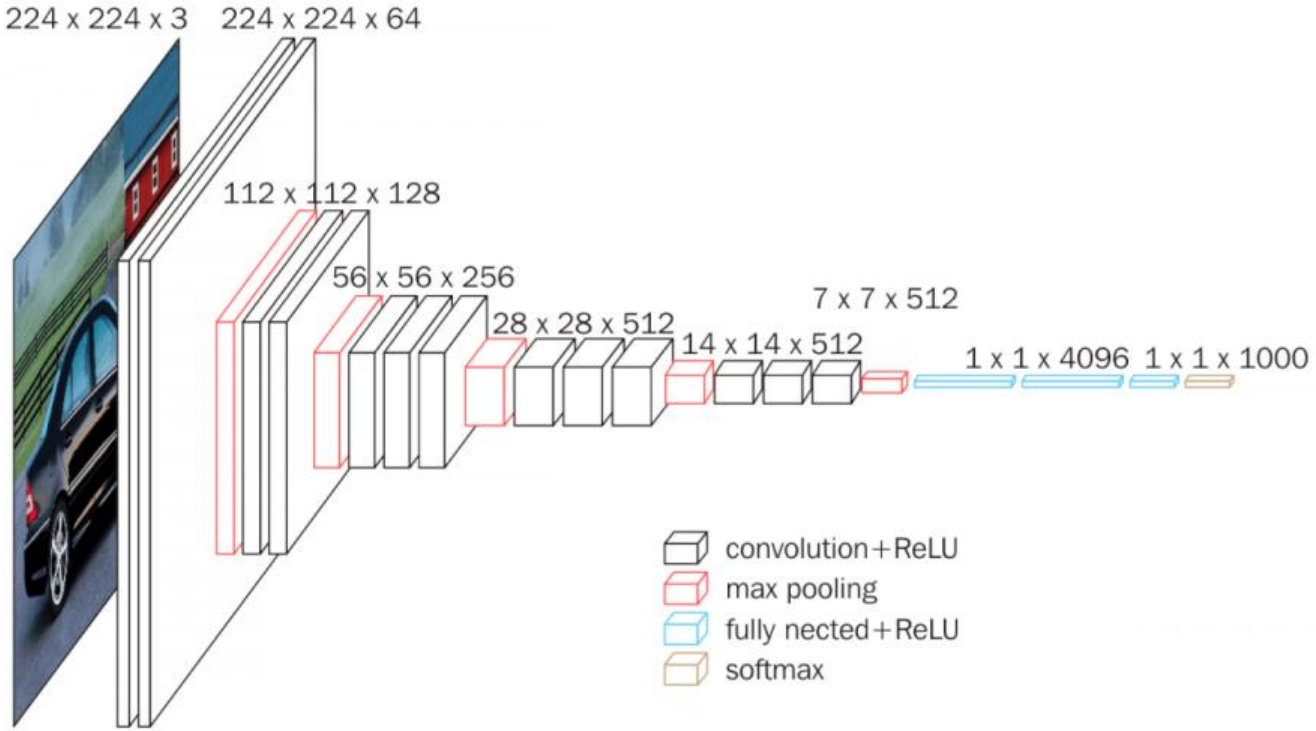


Historical & manual labels for supervised learning

Table 1 Quick Reference to all the Image Classes

Example	Errortag/pickErr?	Productiontag/ToolErr?			
	OK	UNDEF		NOT PICKED	UNDEF
	BILLBOARDED	UNDEF		STOP PRODUCTION	SOLDER PASTE NOT PICKED
	TOMBSTONED	UNDEF		STOP PRODUCTION	SOLDER PASTE DPMO
	CORNED PICK	UNDEF		STOP PRODUCTION	SOLDER PASTE
	WRONG PICK ANGLE	UNDEF		STOP PRODUCTION	ATTACHED
	UPSIDE DOWN	UNDEF		STOP PRODUCTION	WRONG PACKAGE
	DAMAGED	UNDEF		STOP PRODUCTION	CORRUPTED IMAGE

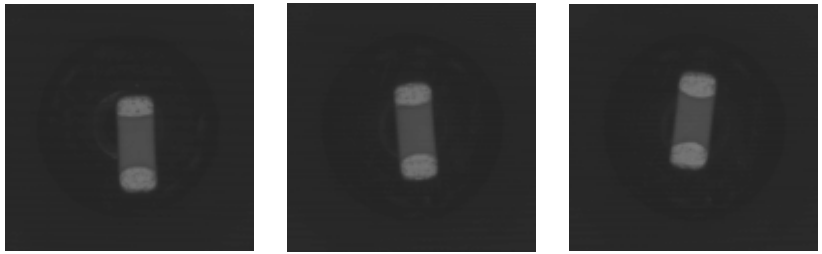
Object classification uses deep CNN



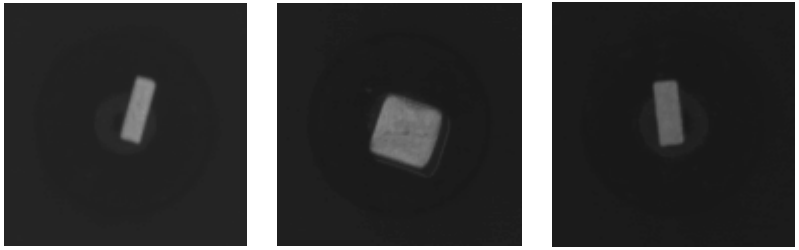
https://neurohive.io/en/popular-networks/vgg16/

CNN based classifier was used to identify “Bad” PnP

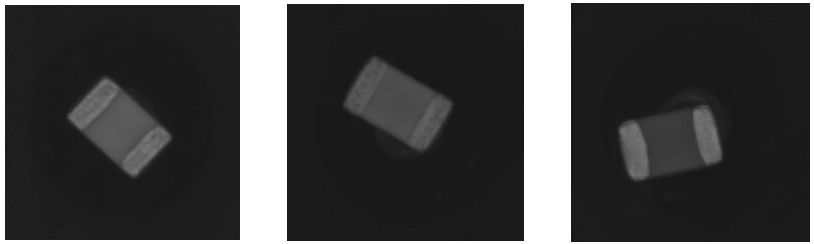
Accuracy 99.76%, even on different machines



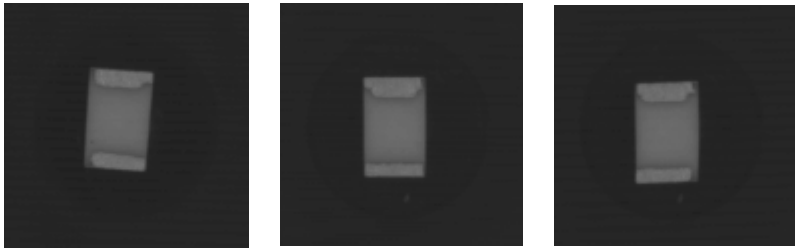
Bad-”Billboarded”



Bad-”Tombstone”



Bad - “Wrong pick angle”



OK

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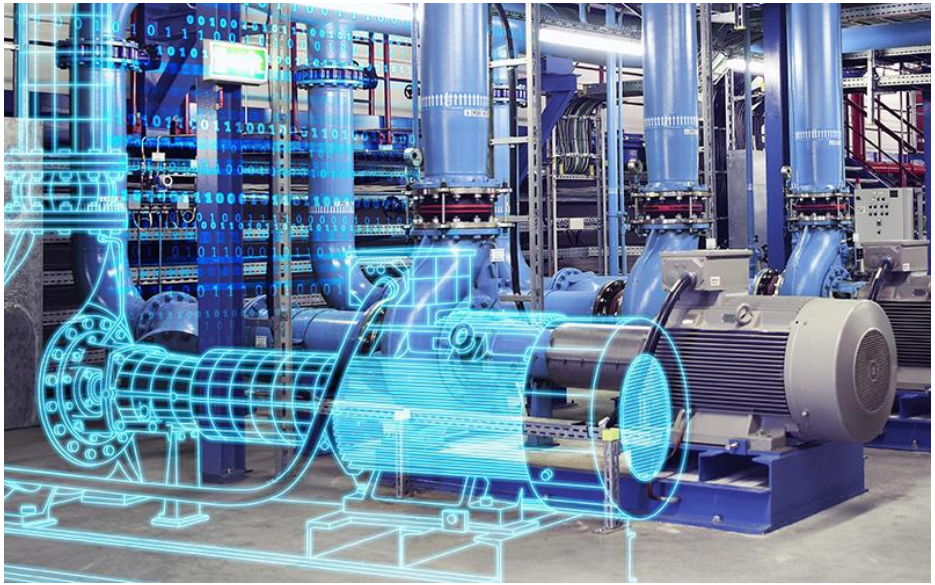
MYCRONIC

D2S: Digital twins creation with TrueMask(R) DLK Deep Learning Toolkit

Digital twins can benefit from deep learning

DL technique used: mixture models, GANs (semi-supervised DL)

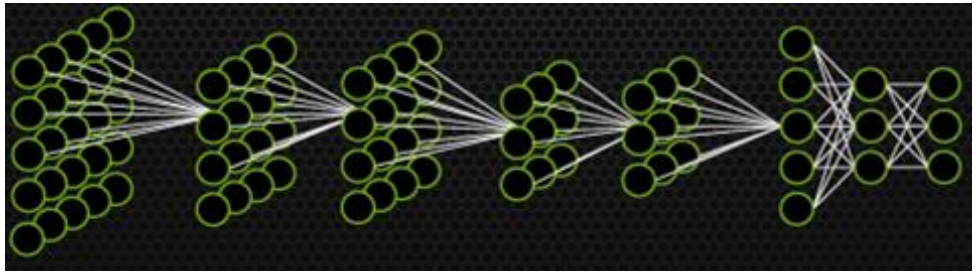


https://www.attendmia.com/blog/2019/02/27/explore-the-latest-manufacturing-technology/

DLK: GPU-accelerated platform for DL to generate digital twins

Digital Twins for Training Data Generation

Pre-trained Deep Learning Neural Networks

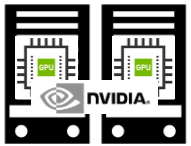


Verification

Mask Simulation

Wafer Simulation

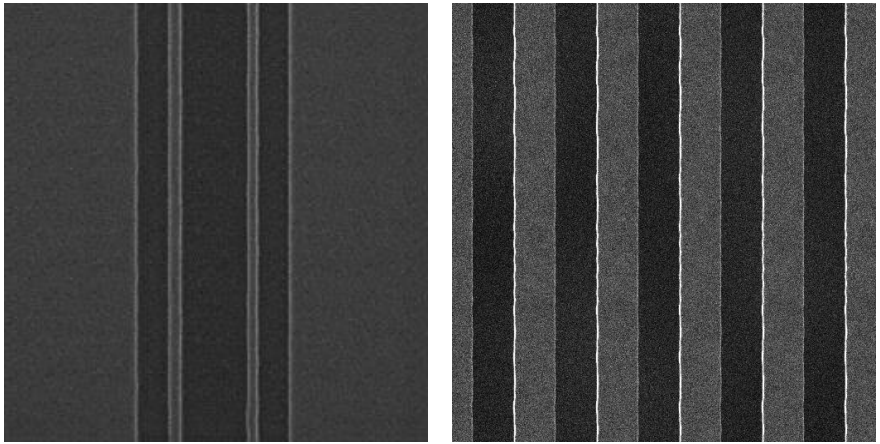
Computational Design Platform (CDP)



Distributed TensorFlow™

SEM digital twin is a must for all data analysis in mask shops and wafer fabs

- Almost all mask and wafer analysis is based on SEM images
- Getting mask and wafer SEM from mask shops and wafer fabs are difficult



Neural style transfer was seed idea for SEM digital twin

Picture of Dog

Style: Starry Night of Vincent van Gogh

New Artwork

https://towardsdatascience.com/artistic-style-transfer-b7966a216431

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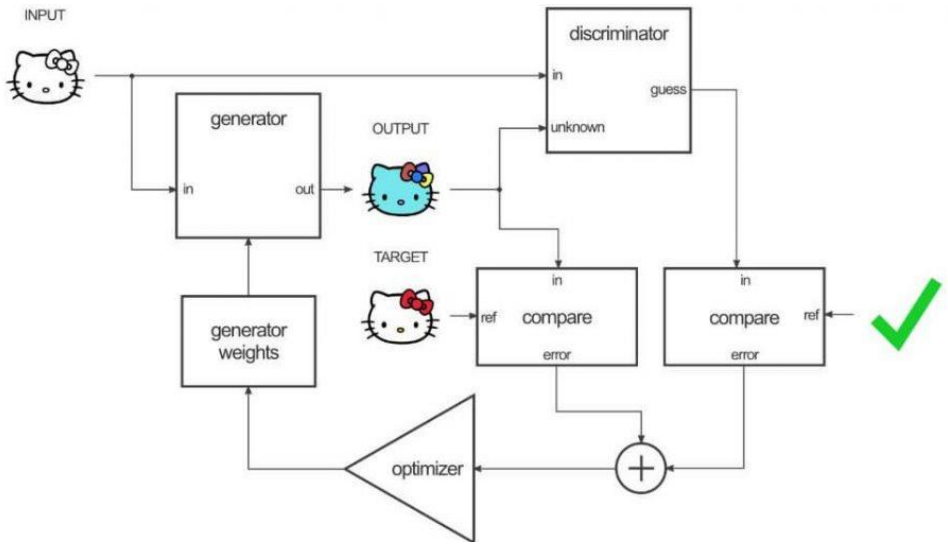
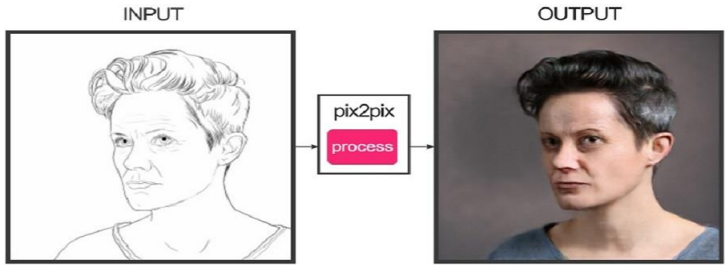
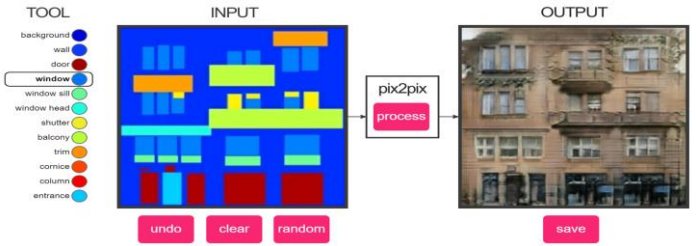
Generative Adversarial Networks (GANs) based Pix2Pix architecture was used finally

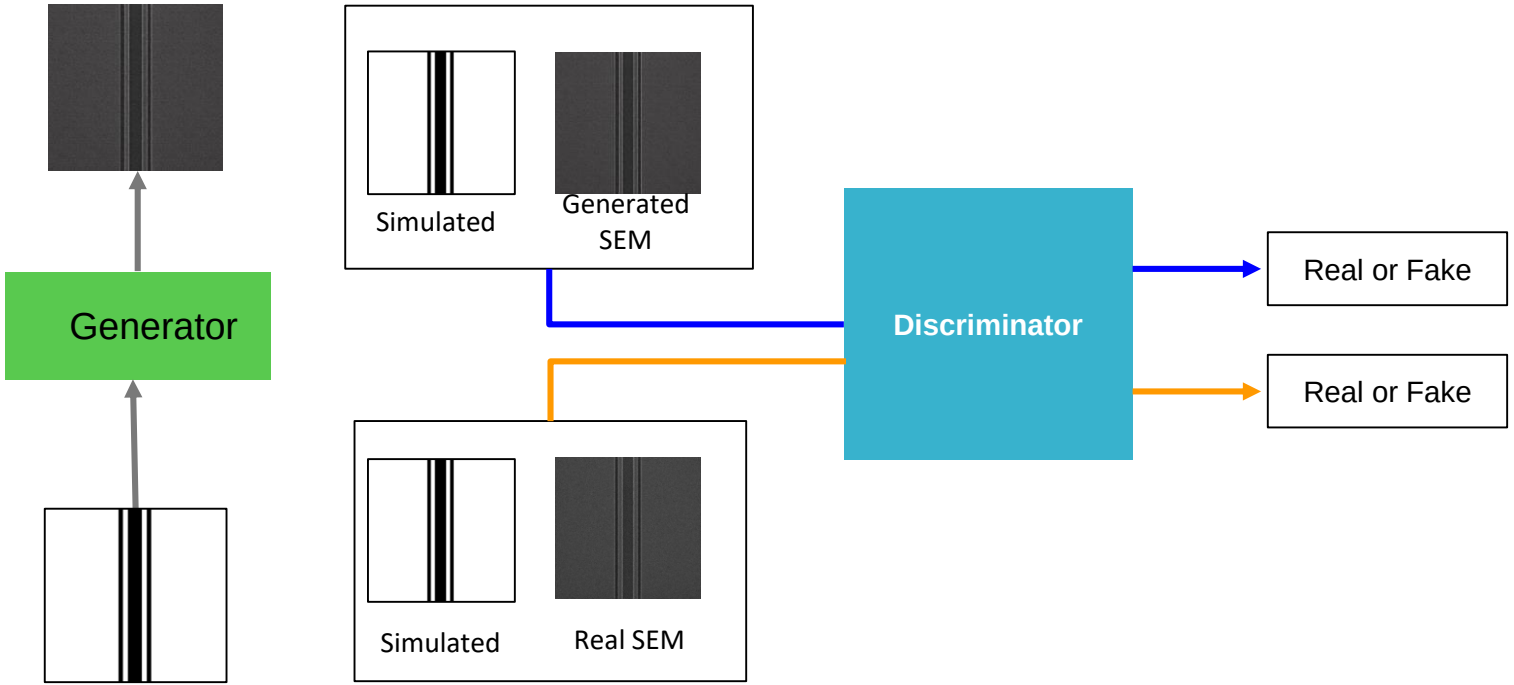




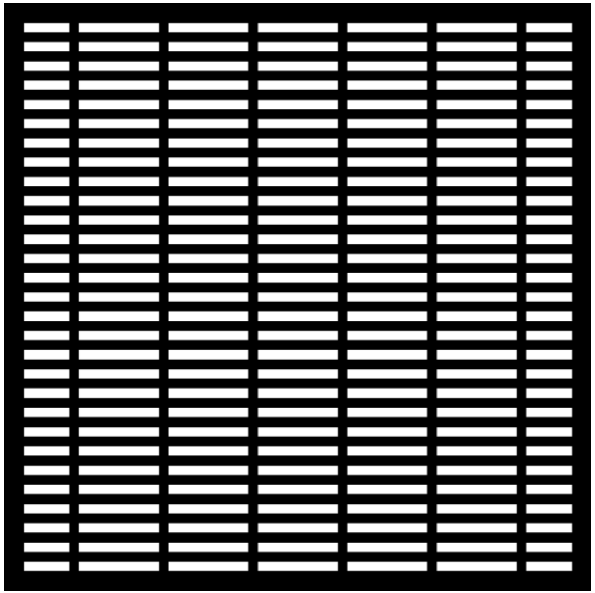


https://neurohive.io/en/popular-networks/pix2pix-image-to-image-translation/
https://affinelayer.com/pixsrv

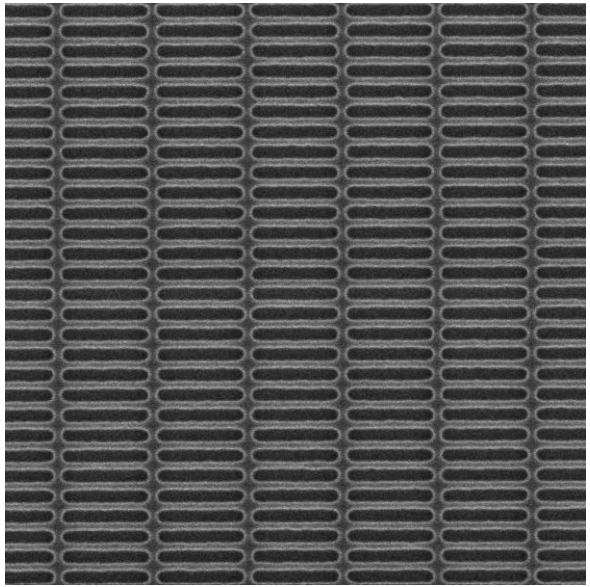
Generative Adversarial Networks (GANs) based Pix2Pix architecture was used finally



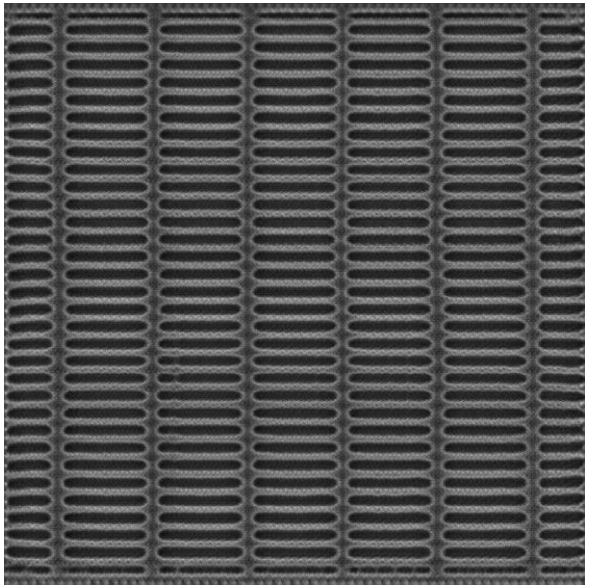
SEM images from TrueMask(R) DLK SEM digital twin



Simulated mask pattern



Real SEM images



SEM image by Digital Twin

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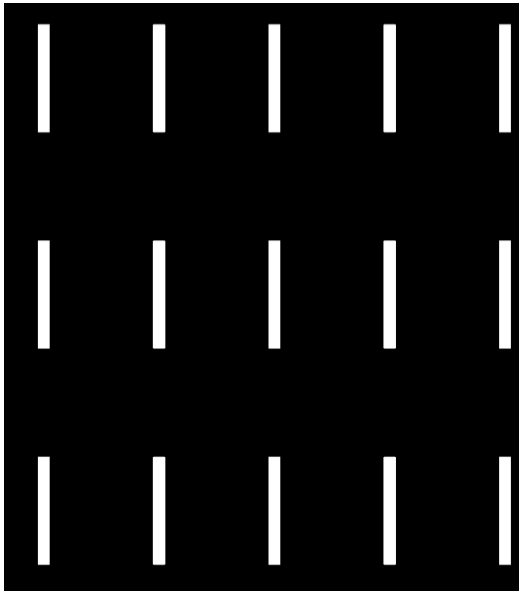
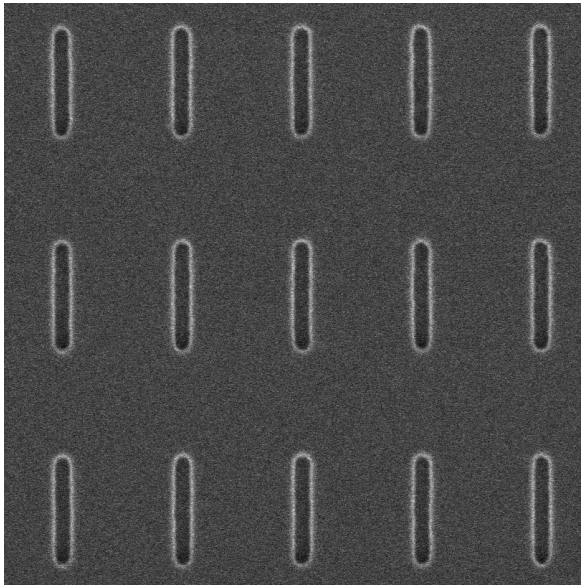
SEM images from TrueMask(R) DLK SEM digital twin



Simulated mask pattern



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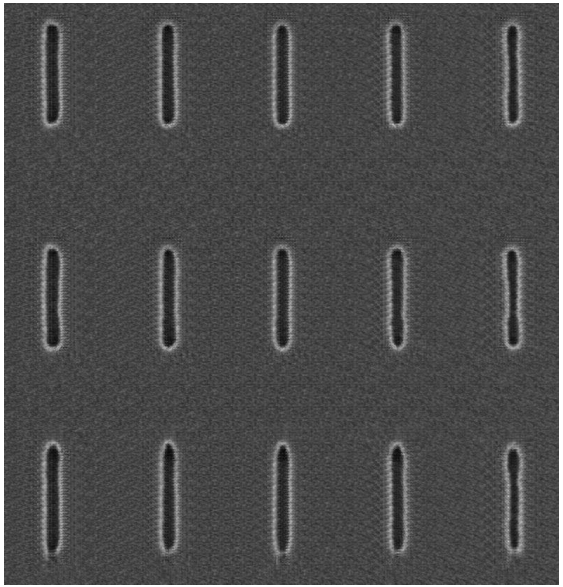

SEM image by Digital Twin

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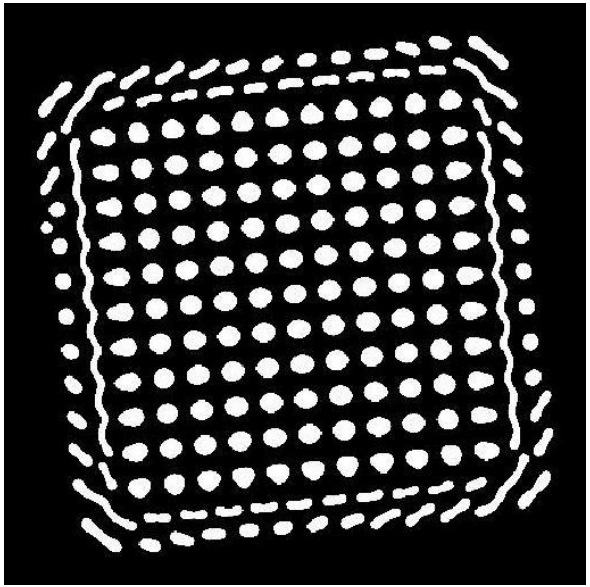
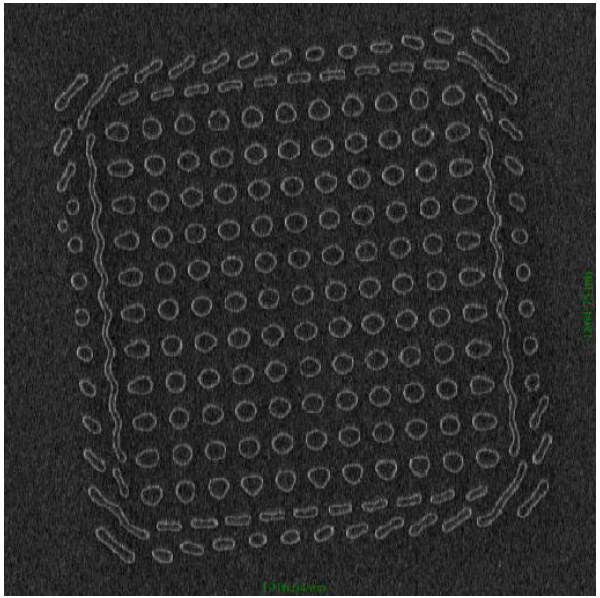
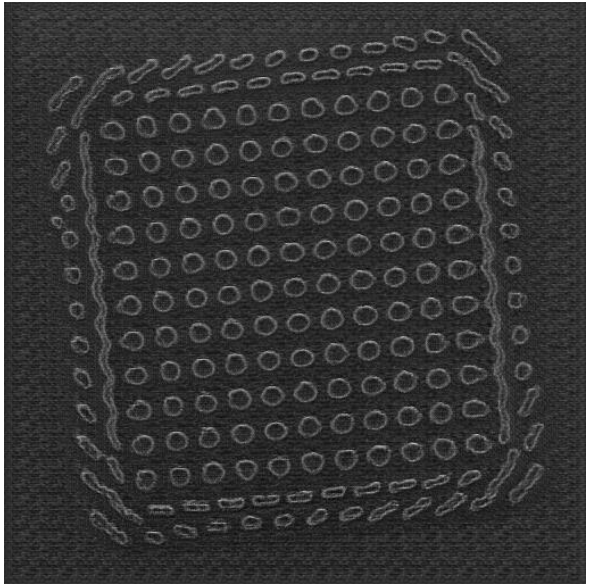
SEM images from TrueMask(R) DLK SEM digital twin



Simulated mask pattern



Real SEM images



SEM image by Digital Twin

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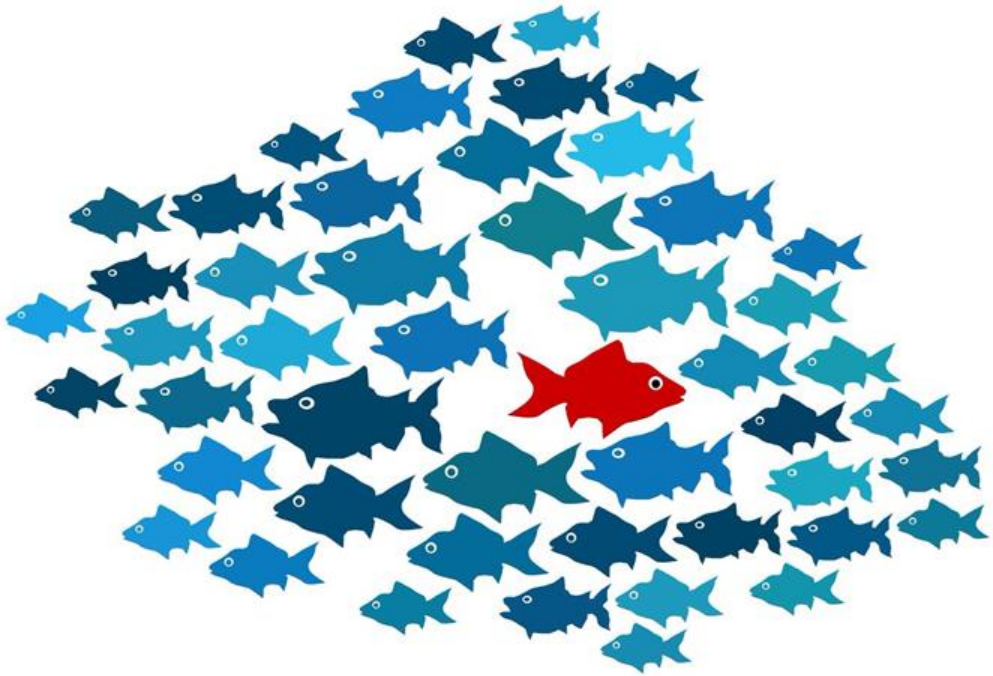
Humans can find an anomaly easily



https://www.pinterest.co.uk/pin/849421179688401557/

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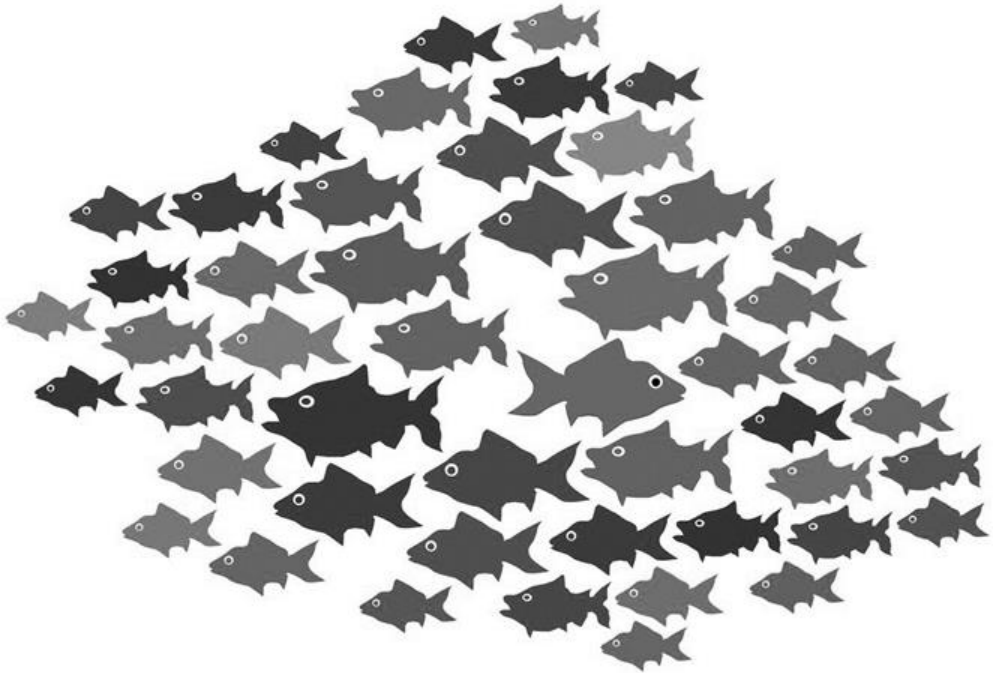
How about now?

Still find anomaly?



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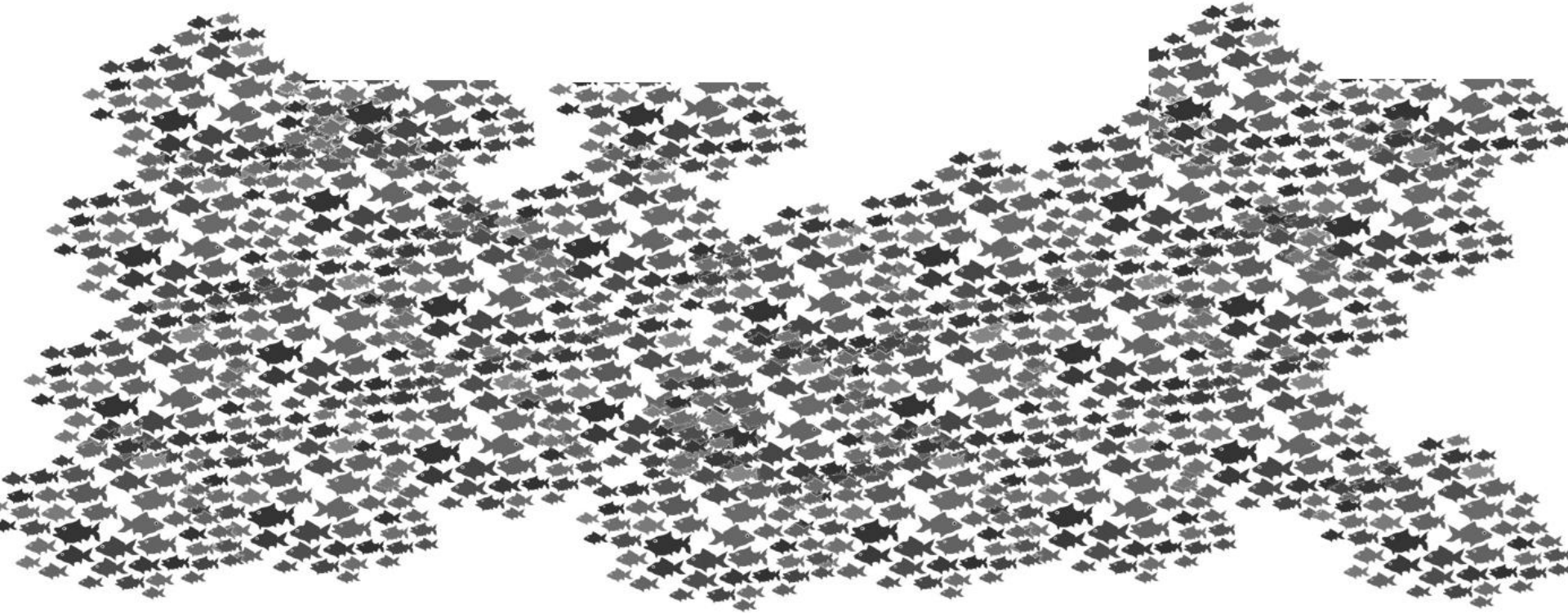
And now?

DL performs great to find anomaly for huge data



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