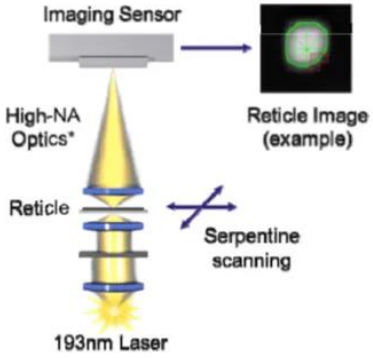
CENTER FOR DEEP LEARNING IN ELECTRONICS MANUFACTURING

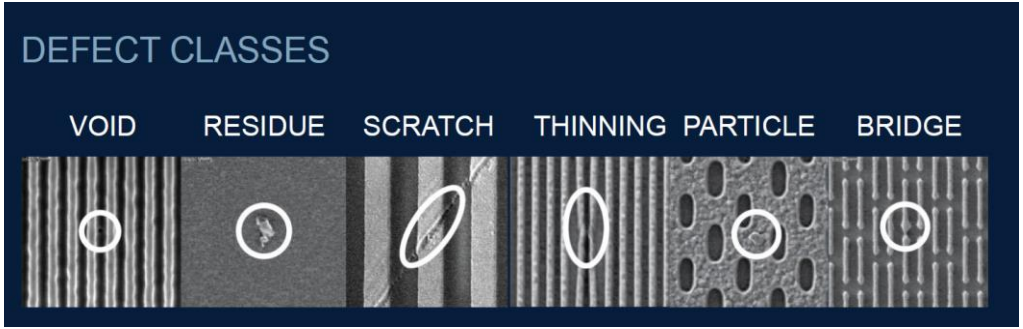
Five deep learning recipes for the mask making industry

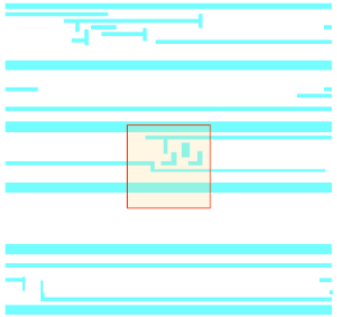
Ajay Baranwal et al (CDLe)
Noriaki Nakayamada et al (NuFlare)
Mikael Wahlsten et al (Mycronic)
Aki Fujimura et al (D2S)

A PARTNERSHIP OF NuFlare MYCRONIC D2S

DL can solve many mask industry problems







Mask inspection

Automatic defect categorization

Lithography hotspot detection

Fault detection and classification

Anomalous data synthesis

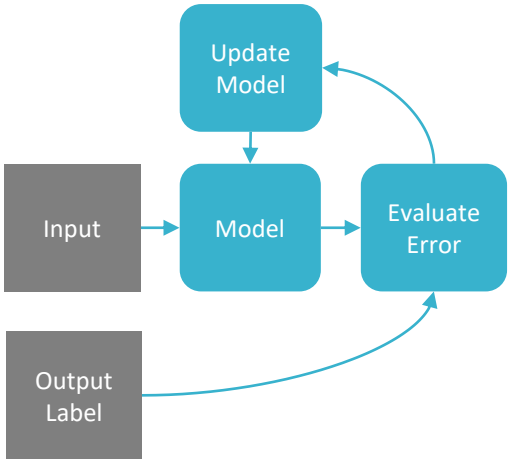
https://doi.org/10.1117/12.2282943
https://digital.hbs.edu/platform-digit/submission/applied-materials-when-machines-talk-to-each-othe/
https://semiengineering.com/searching-for-euv-mask-defects/

CDLe

Many DL techniques are used at CDLe

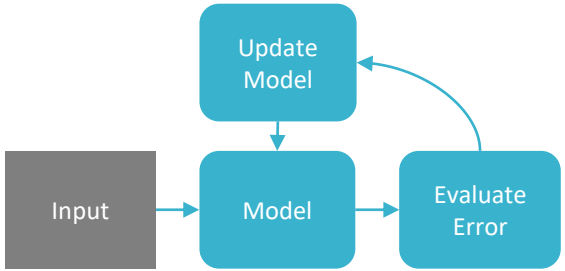
10 successful projects in past year

(Labeled data)



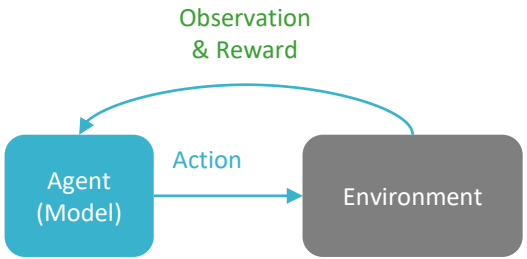
Supervised learning

(Unlabeled data)



Unsupervised learning

(“Games”)



Reinforcement learning

Recipe #1:
Mask rule error automatic categorization

Recommendation engines use deep learning

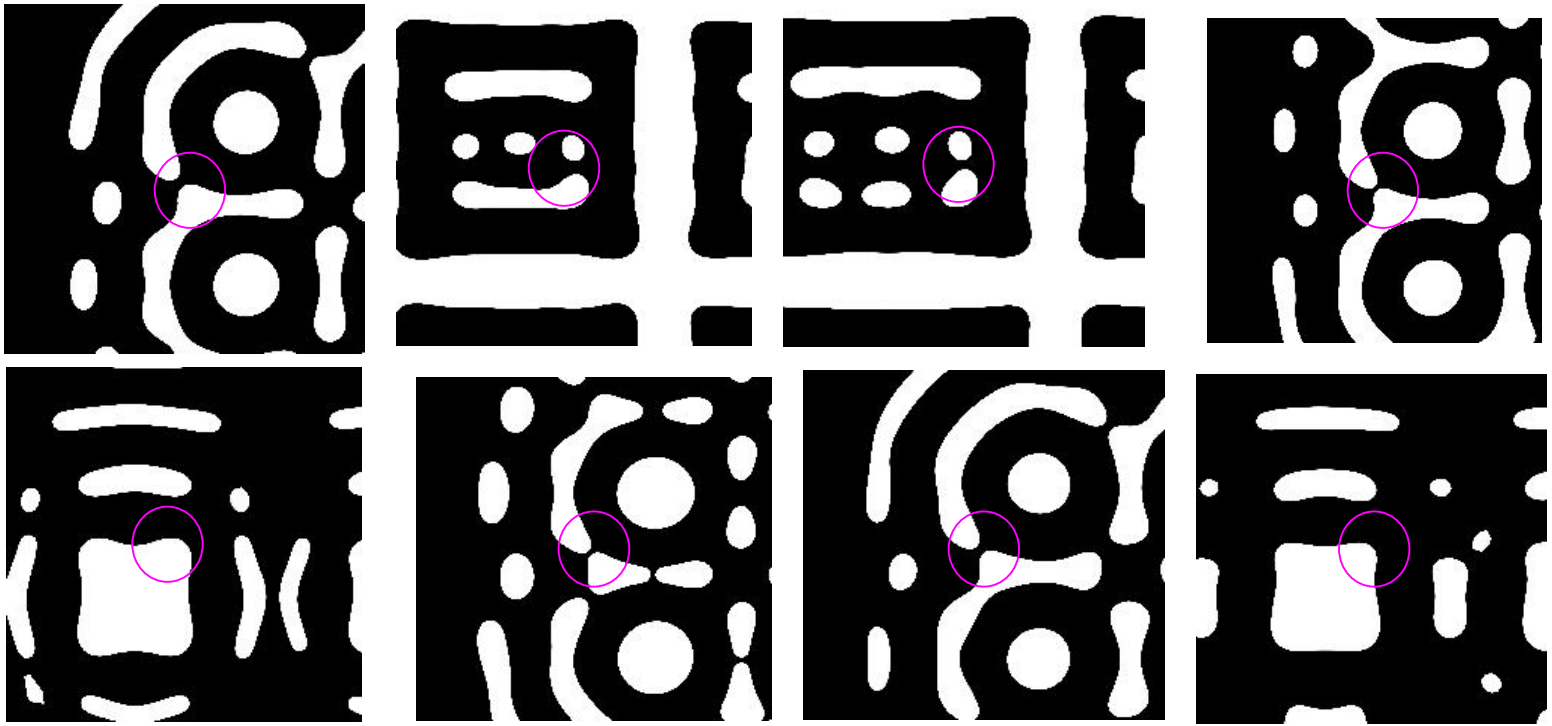
DL technique used: autoencoding (unsupervised DL)

amazon

NETFLIX

Mask rule check can generate thousands of errors

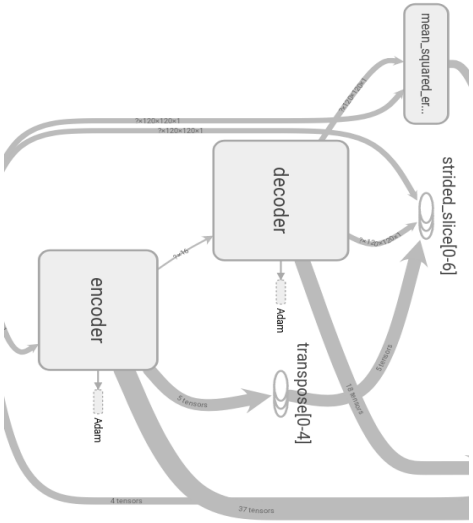
Best to report similar errors together



Unsupervised deep autoencoder captures similarity

After training, encoding abstracts out similar features

Mask image clip

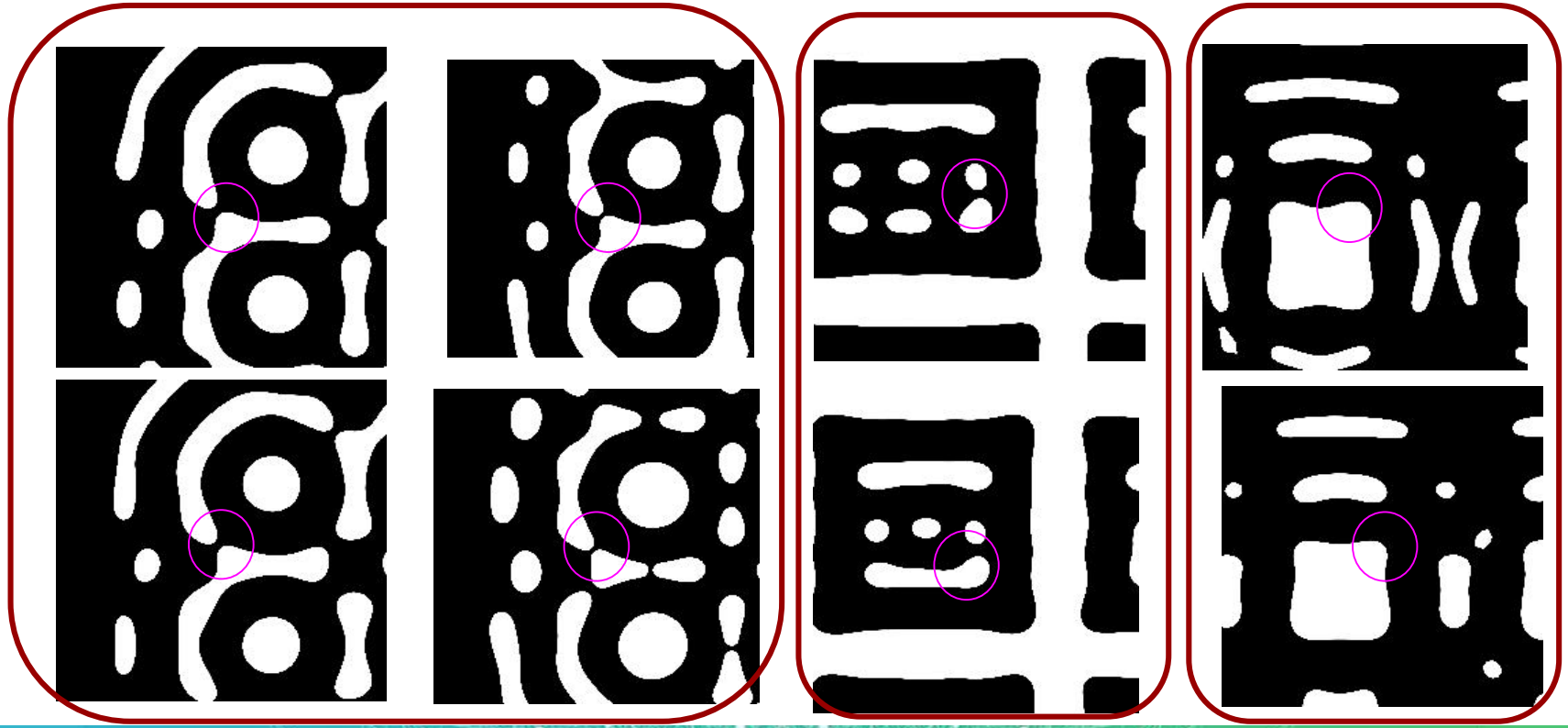


Autoencoder

5.8539410e+01,
2.1572763e+02,
1.4674566e+02,
6.1346753e+01,
…

Series of numbers (Also called encoding)

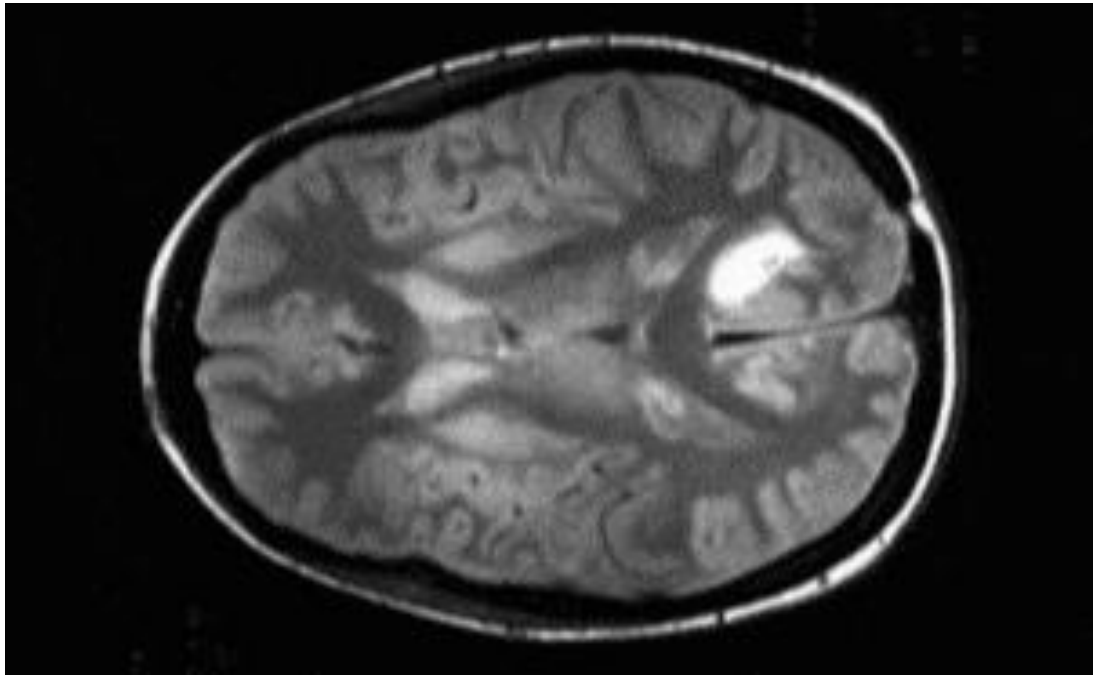
Mask rule check groups similar errors together automatically



Recipe #2:
Fast mask design construction

Medical diagnosis uses deep learning

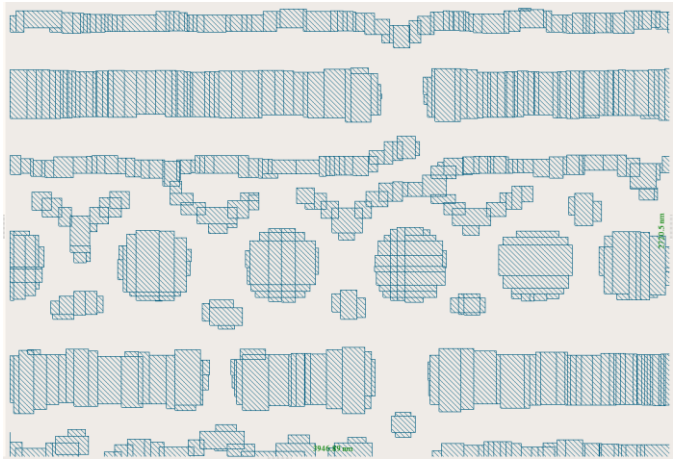
DL technique used: U-net architecture (supervised learning)



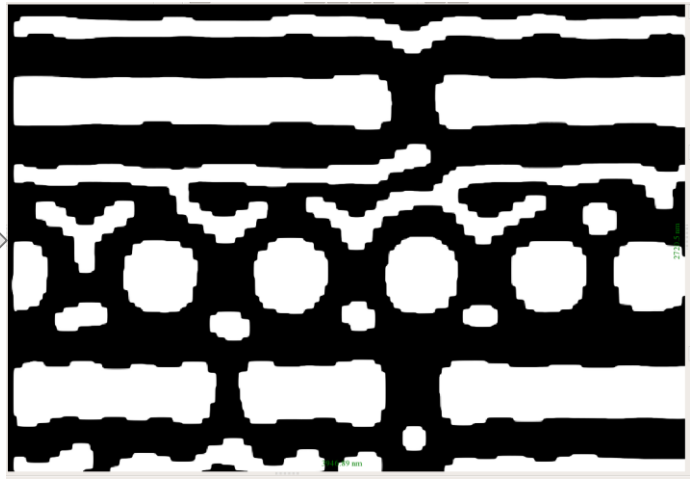
https://github.com/jantic/DeOldify

Faster but less accurate simulation is useful for evaluation

Quickly estimate downstream impact



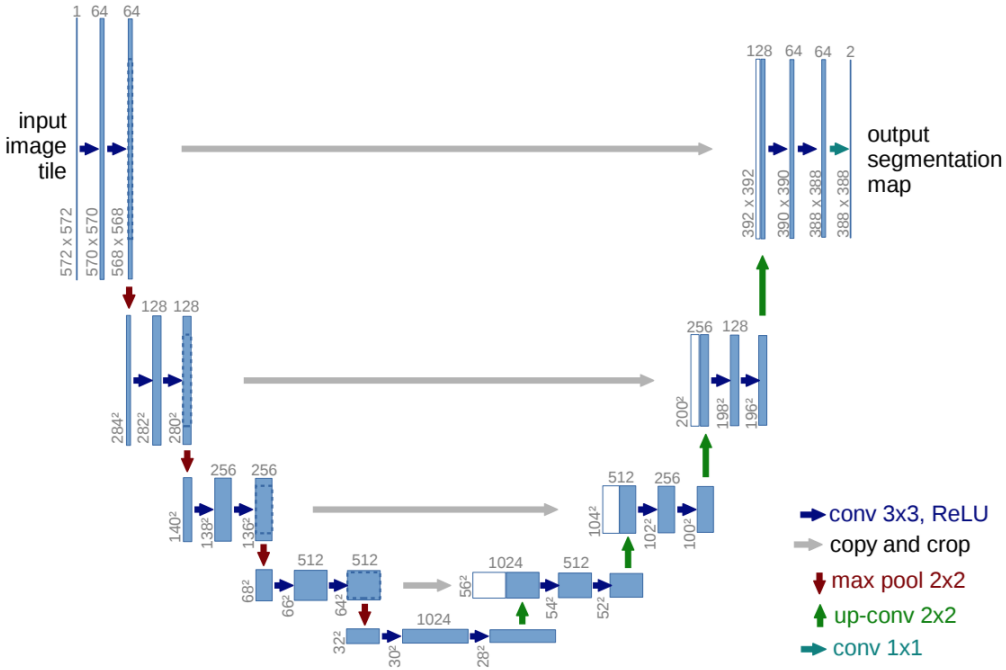
TrueModel(R) Simulation



Overlapping shots list

Simulated dose map

U-Net architecture translates images using pixel values

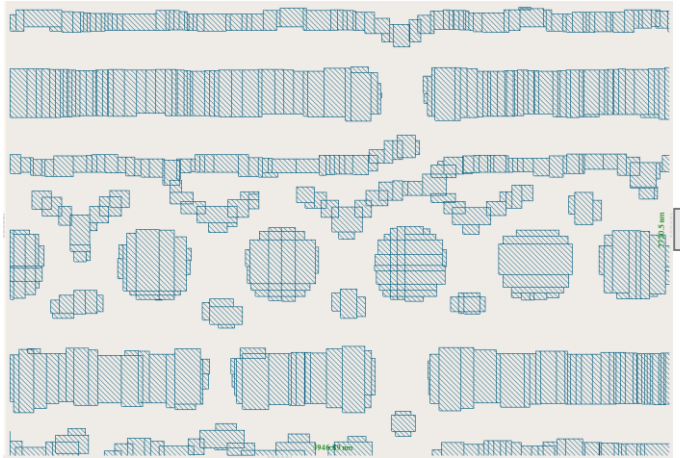


We customized architecture and loss function

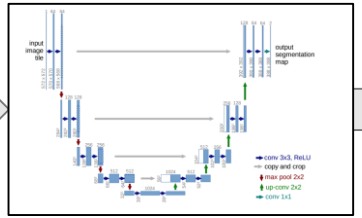
https://arxiv.org/abs/1505.04597

DL can construct mask shapes from shots faster

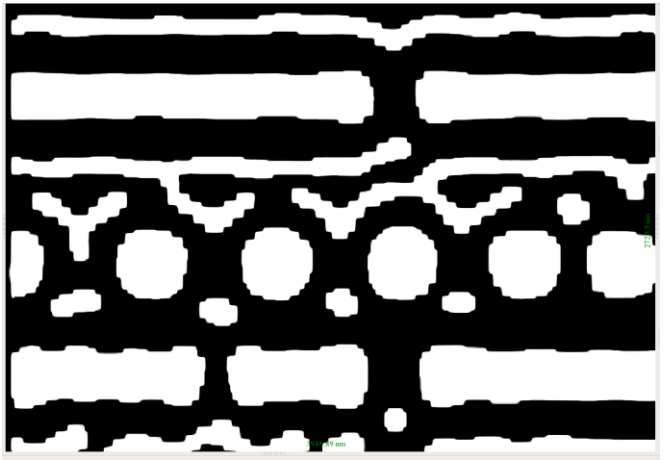
Current implementation reduces run time by 2.5x



Overlapping shots list



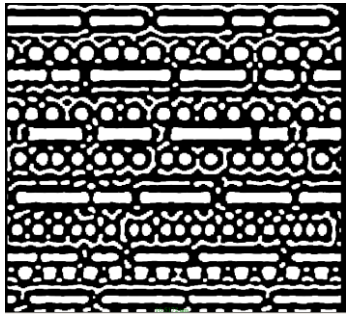
DL



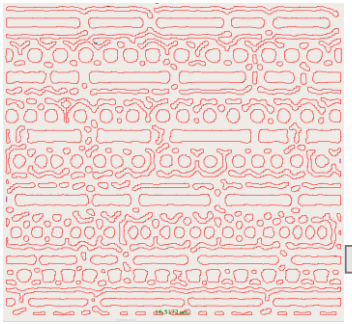
Constructed dosemap

Max EPE error is below 3 nm even with overlapping shots

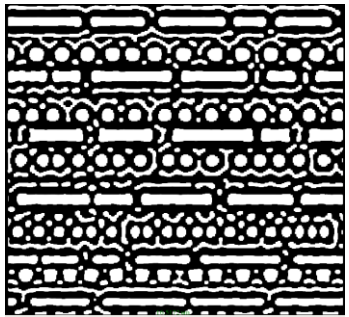
Not to replace simulation but useful for evaluation function



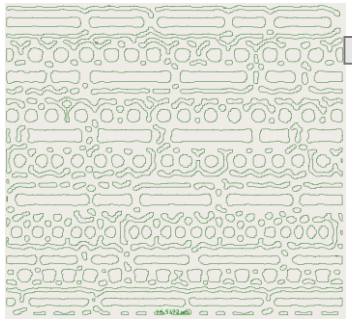
Simulated dose map



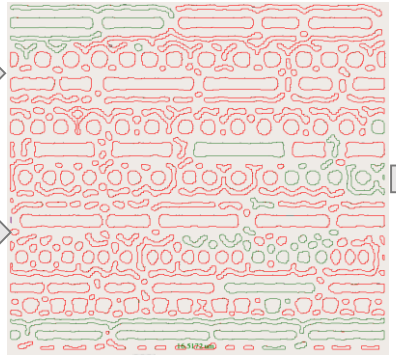
Simulated contours



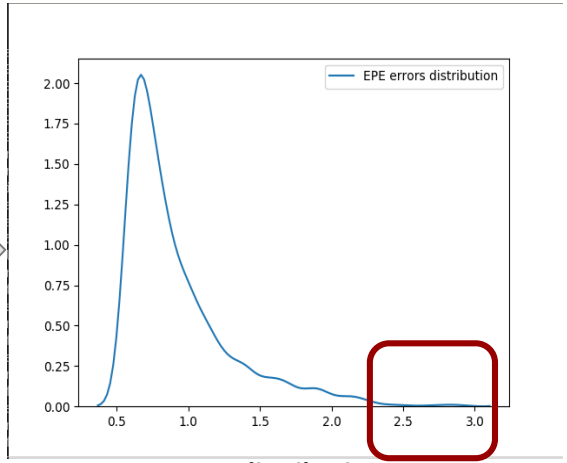
Constructed dose map



Constructed contours



EPE of two contours



EPE distribution
x-axis: EPE error
y-axis: distribution

Recipe #3:
PCB component pick-and-place (PnP) error classification

Amazon Go automatic checkout uses deep learning

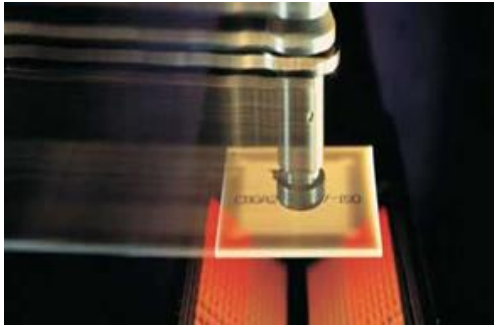
DL technique used: object classification, others (supervised DL)

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



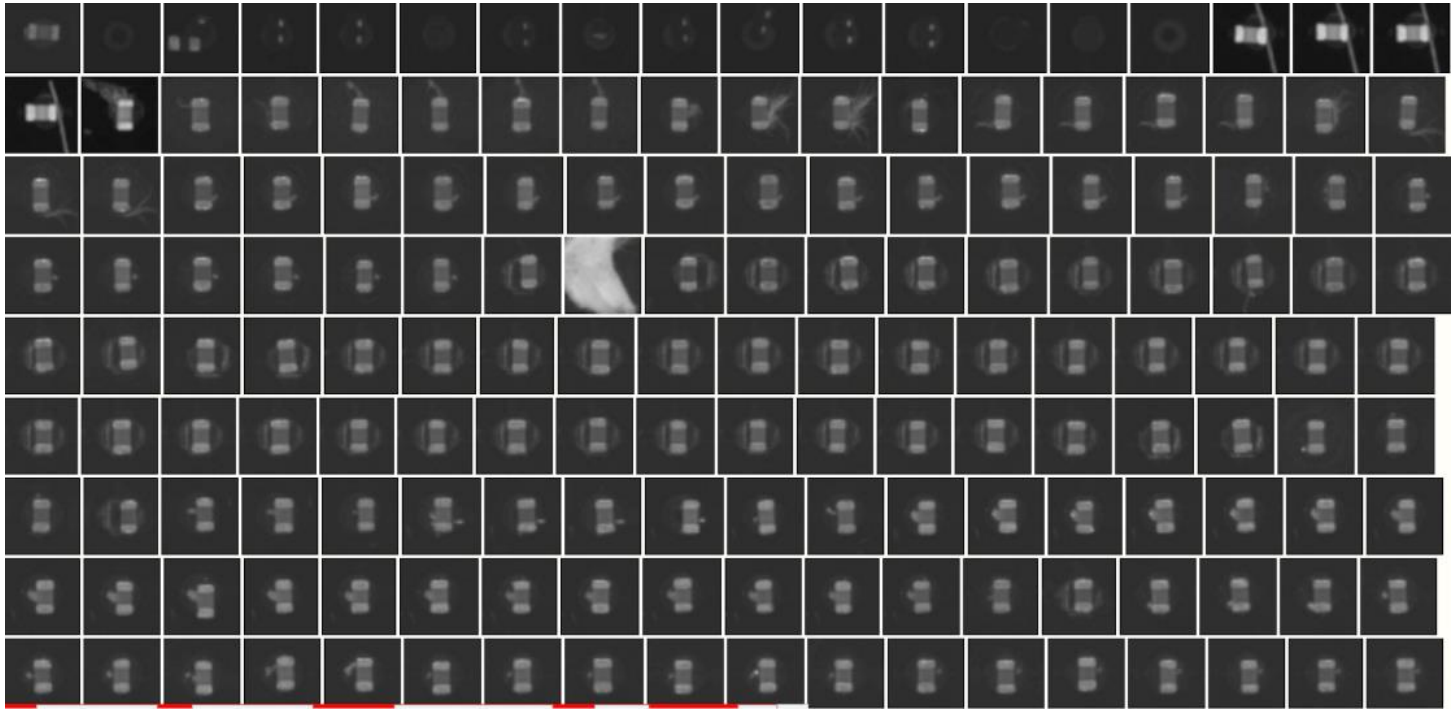
Robot arm picked a component (Image taken)

Component Mounted on PCB

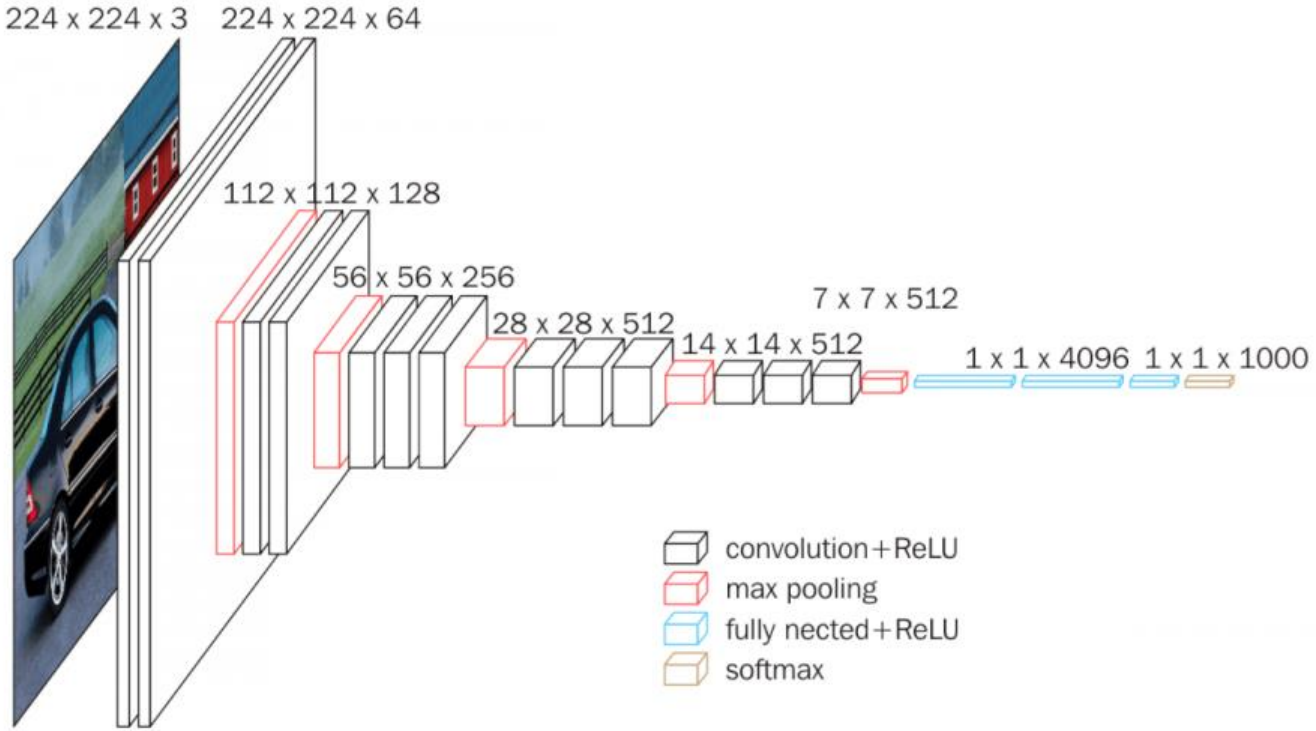
https://www.alibaba.com/product-detail/pick-and-place-robot-arm_62008663790.html

This problem is difficult

Classical computer vision is not sufficient



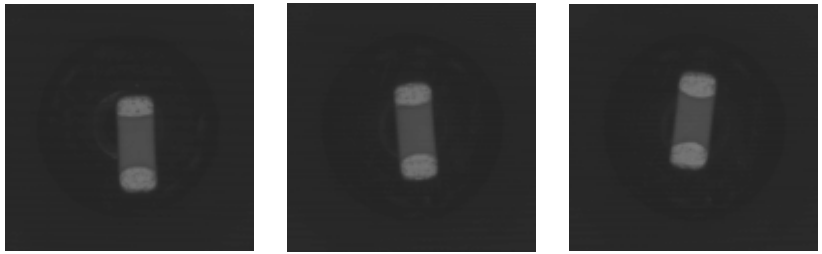
Object classification uses deep CNN



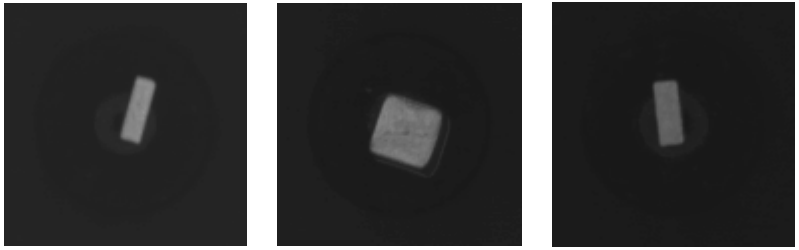
https://neurohive.io/en/popular-networks/vgg16/

CNN based classifier was used to identify “Bad” PnP

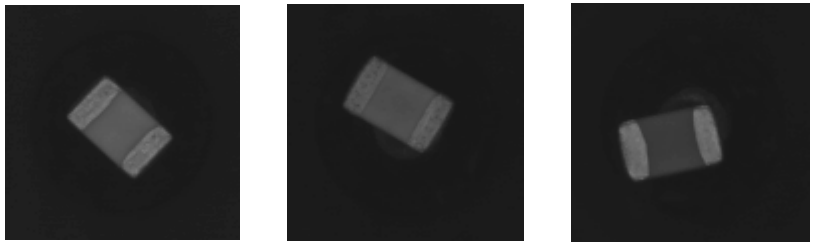
Accuracy 99.76%, even on different machines



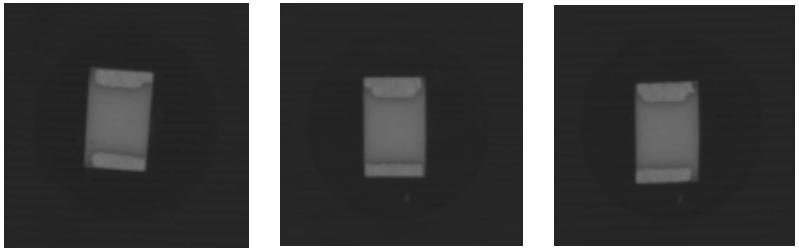
Bad-”Billboarded”



Bad-”Tombstone”



Bad - “Wrong pick angle”



OK

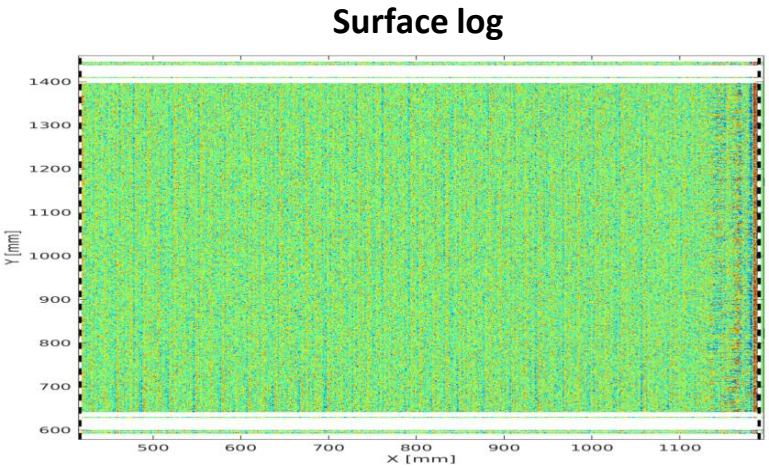
Recipe #4:
Servo log anomaly detection for Flat Panel Displays (FPD)

Credit fraud detection uses deep learning

DL technique used: Deep anomaly detection (unsupervised learning)

https://contentpond.com/how-ai-can-analyse-the-fraud-detection-in-credit-card/

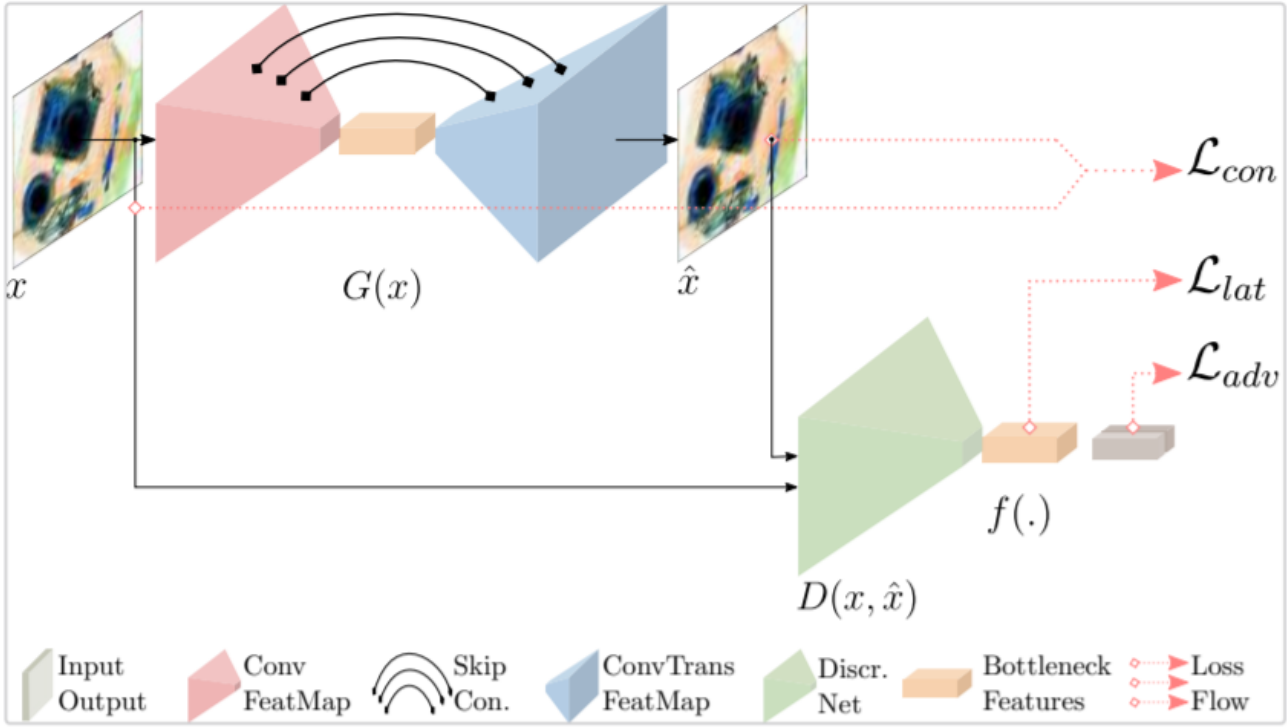
“Muras*” are unwanted defects in FPD mask writing



Servo parameter logs record values for every x,y position of plate
Surface log is used to identify “Muras”

*Mura means irregularity in Japanese

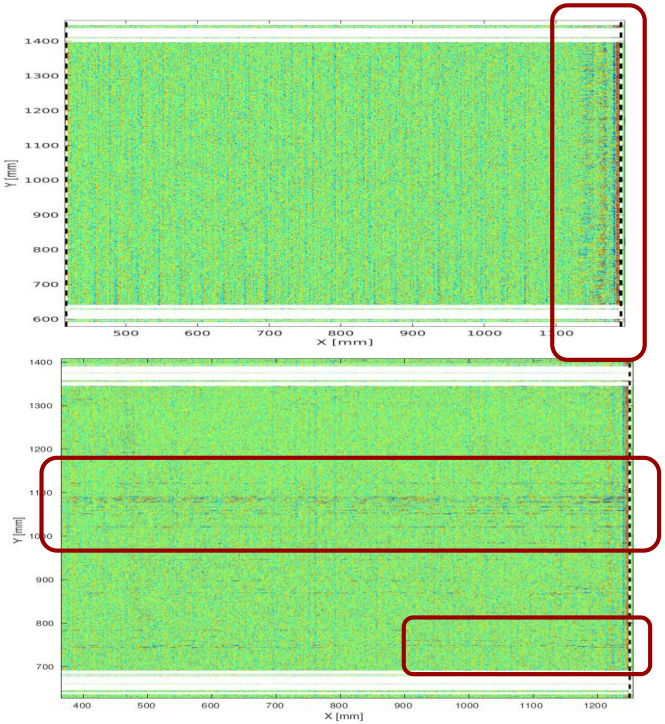
Anomaly detection use Generative Adversarial Networks (GAN)



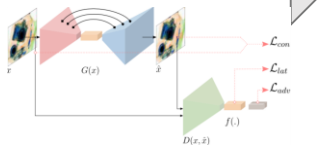
https://arxiv.org/pdf/1901.08954.pdf

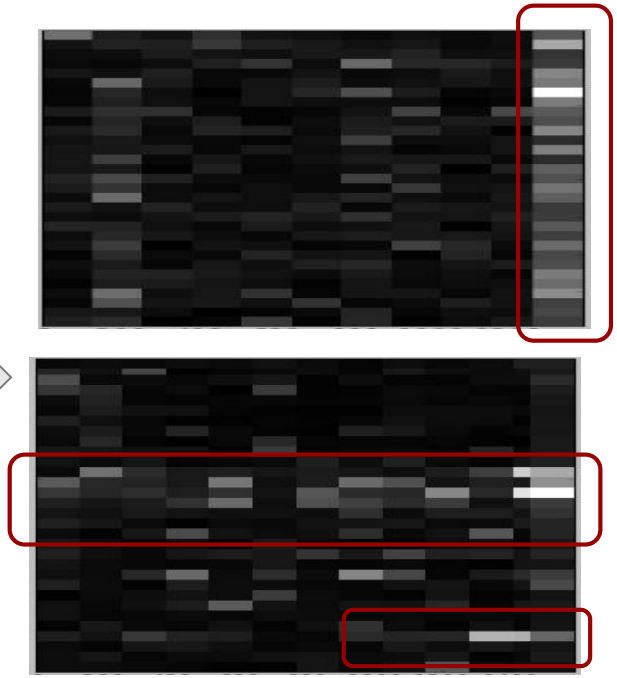
CDLe

“Muras” can be identified by unsupervised DL



Deep Anomaly Detection



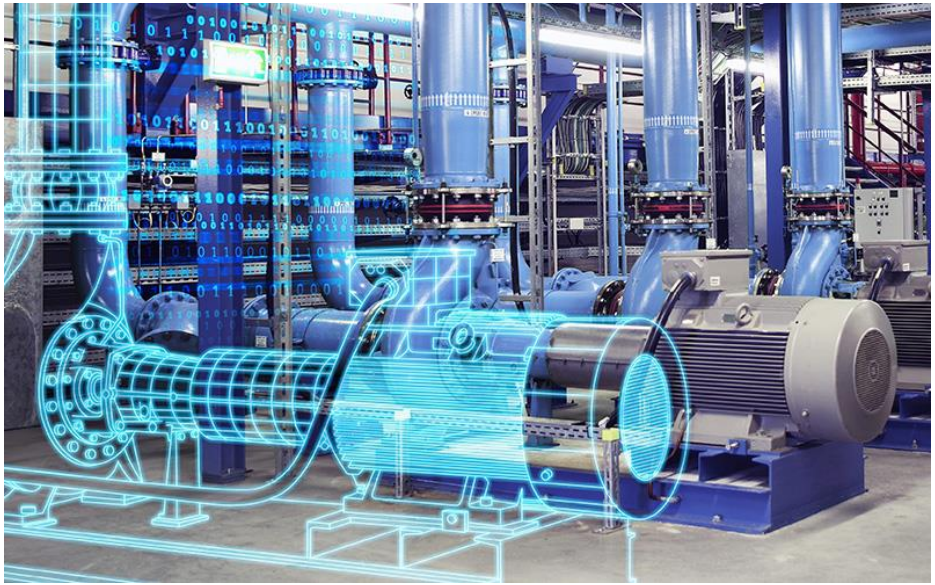


Bright regions are anomalies

Recipe #5:
Digital twins creation

Digital twins can benefit from deep learning

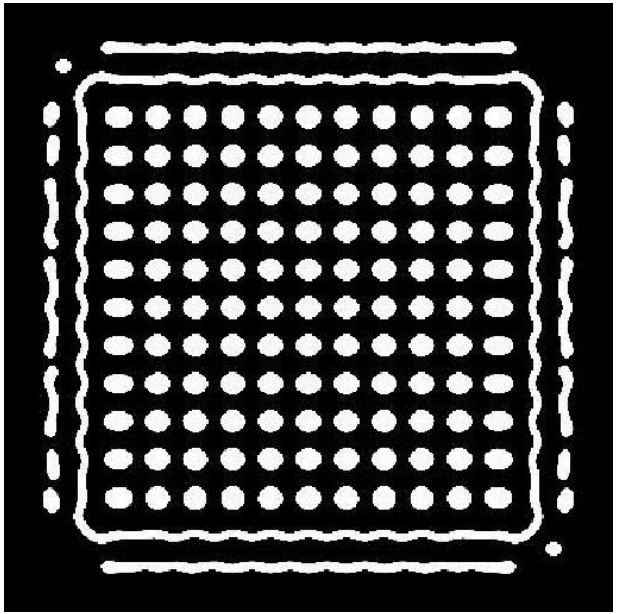
DL technique used: mixture models, GANs (semi-supervised DL)



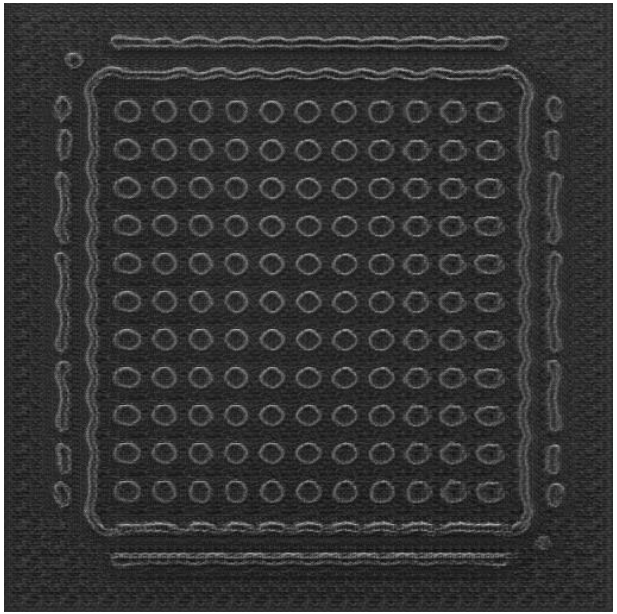
Today's 3 PM talk "Making digital twins using the Deep Learning Kit (DLK)" will cover digital twins in more details

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

SEM digital twin



Mask shape



Constructed SEM using digital twin from CAD data

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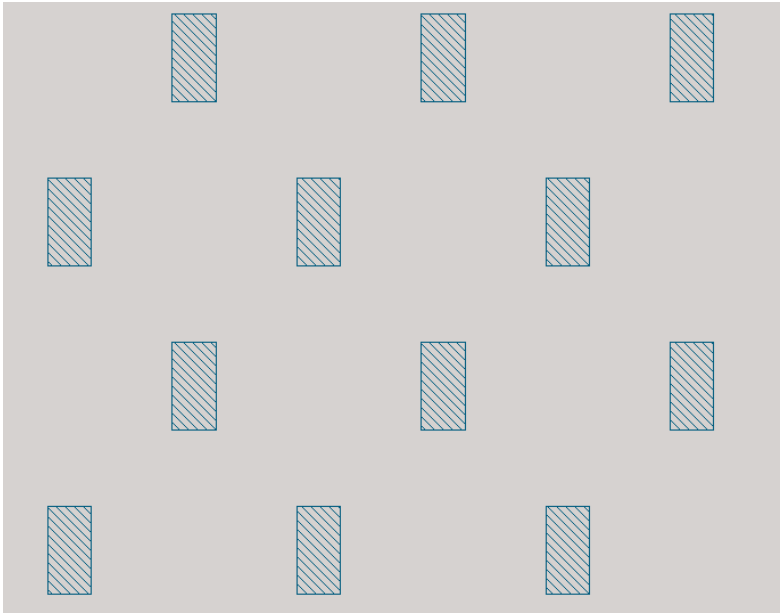
ILT digital twin



Target wafer

Constructed mask shapes with assist features using digital twin

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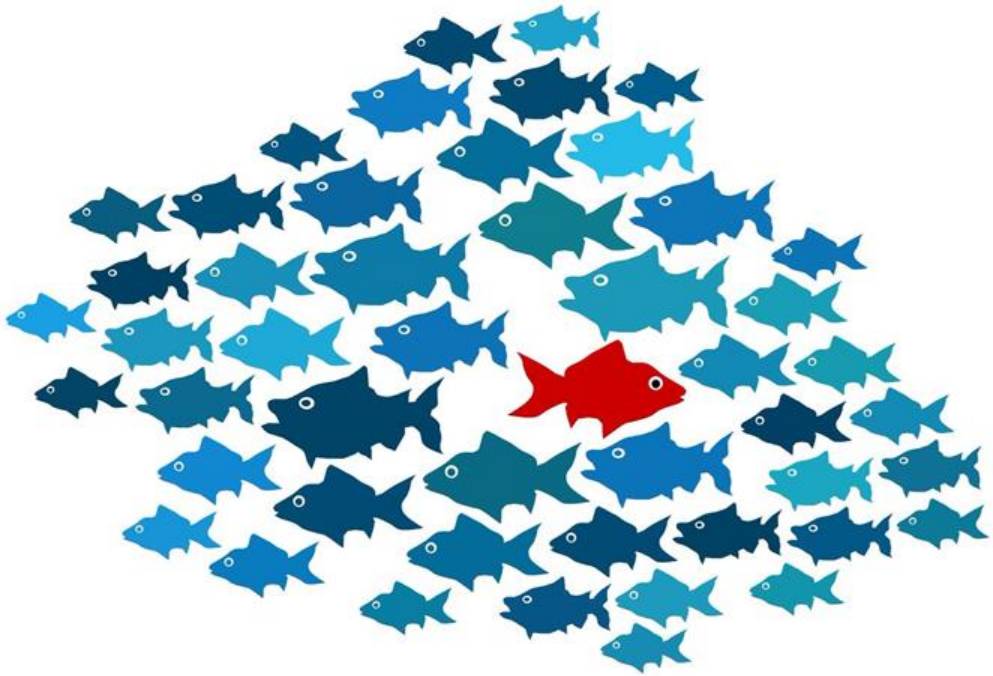
Humans can find an anomaly easily



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

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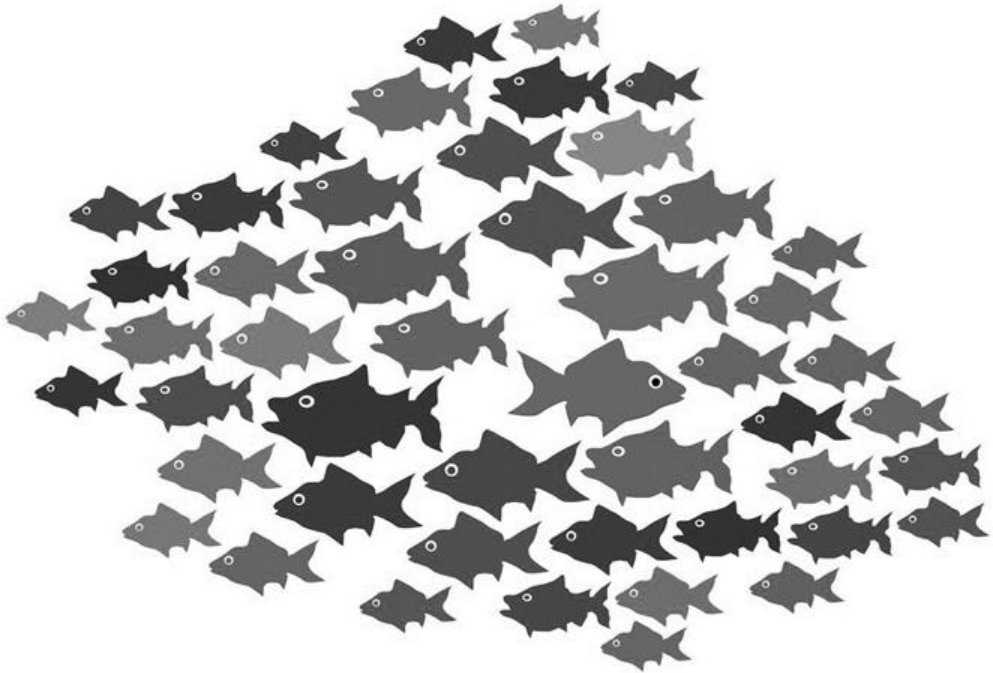
How about now?

Still find anomaly?



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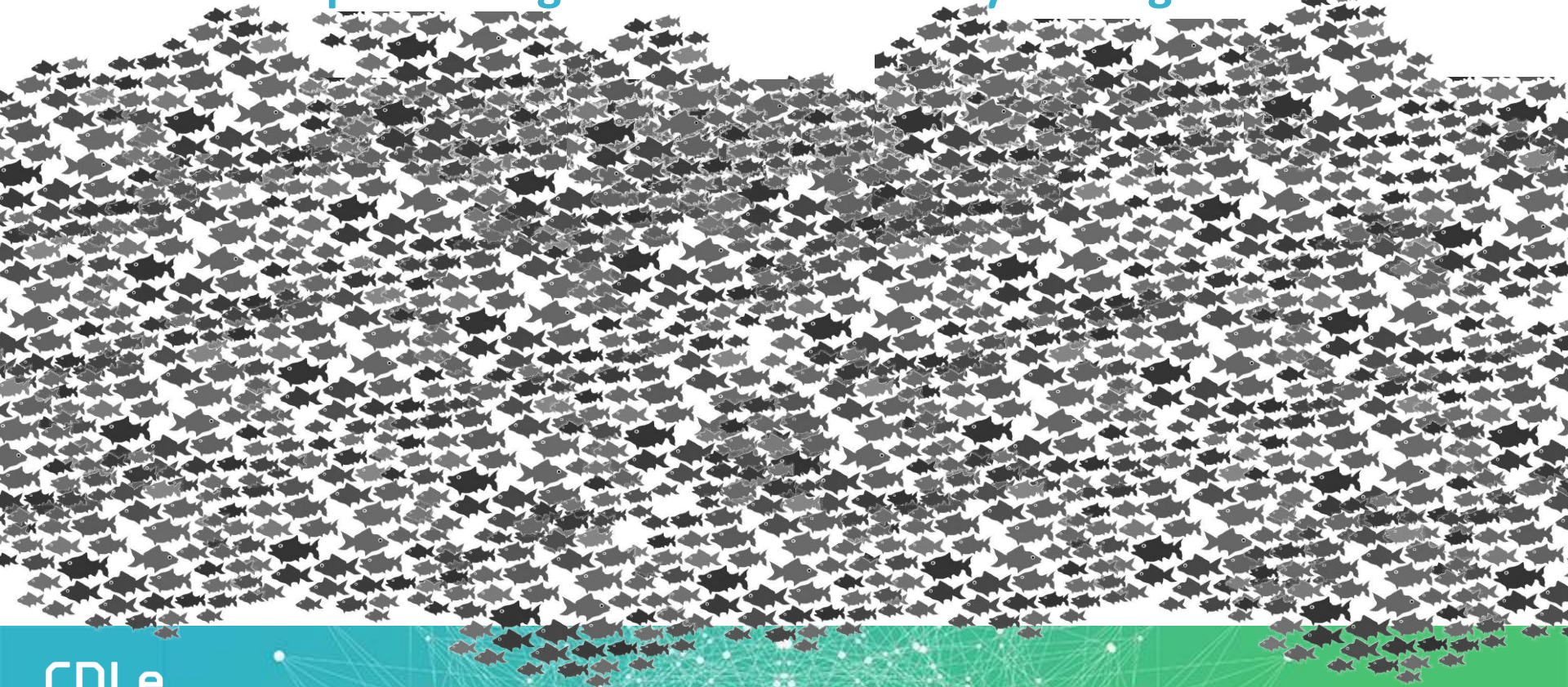
And now?

DL performs great to find anomaly for huge data



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