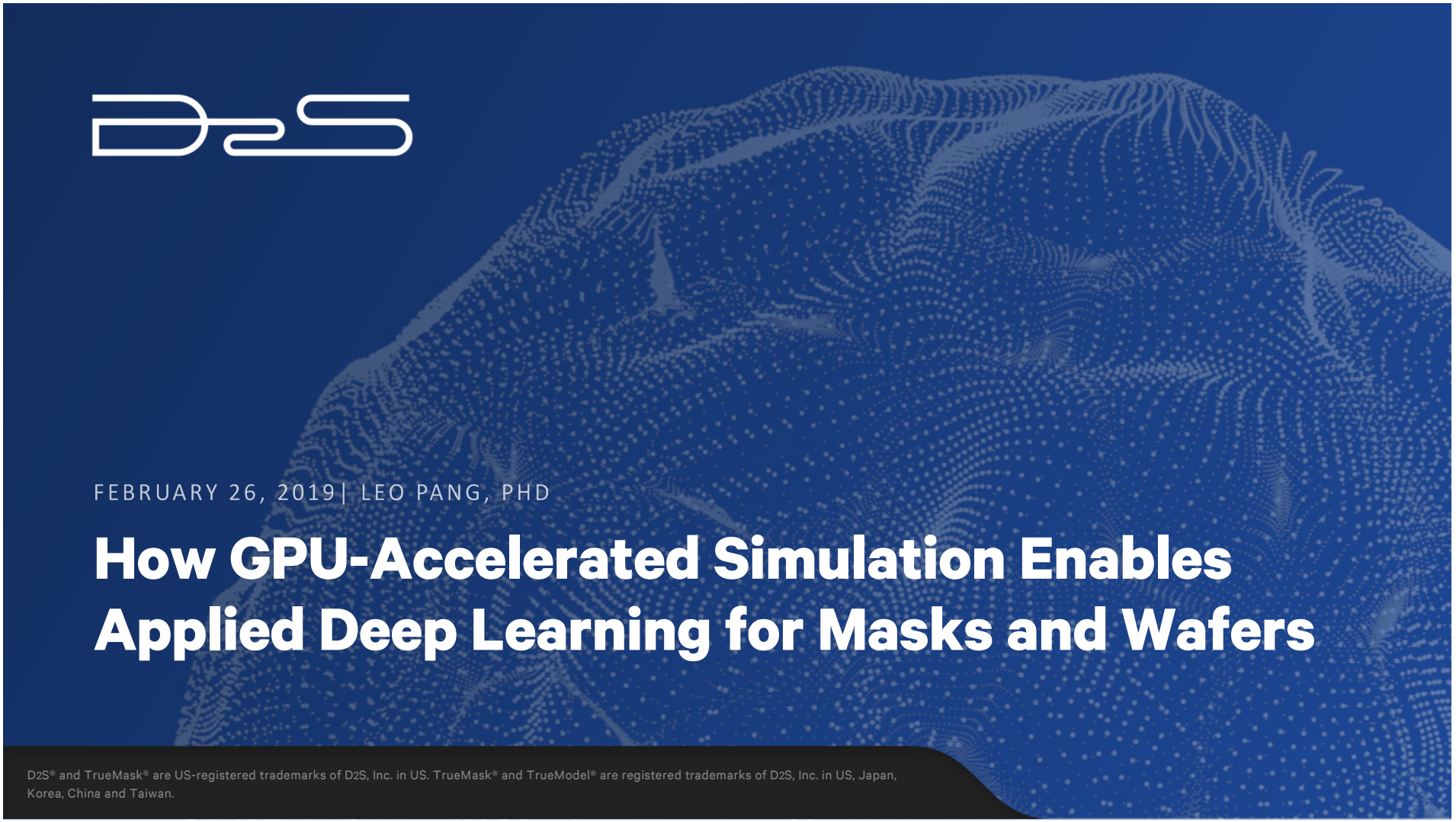


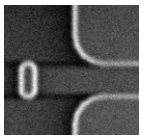
FEBRUARY 26, 2019| LEO PANG, PHD

How GPU-Accelerated Simulation Enables Applied Deep Learning for Masks and Wafers

D2S® and TrueMask® are US-registered trademarks of D2S, Inc. in US. TrueMask® and TrueModel® are registered trademarks of D2S, Inc. in US, Japan, Korea, China and Taiwan.

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Rigorous eBeam and SEM Simulation



Rigorous Mask 3D Simulation (EUV and ArF)

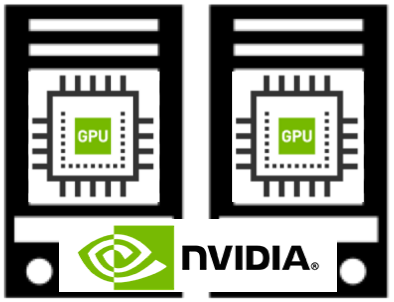
Wafer Simulation

Deep Learning Engine(s)

Mask Simulation

Verification

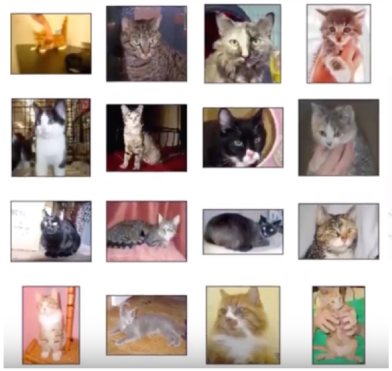
Geometry Libraries



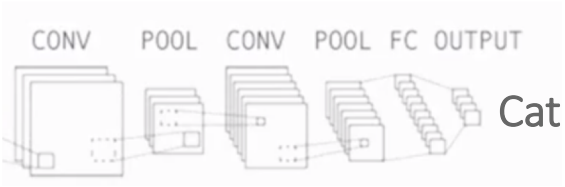
Computation Platform

Pre-trained Deep Learning Neural Networks

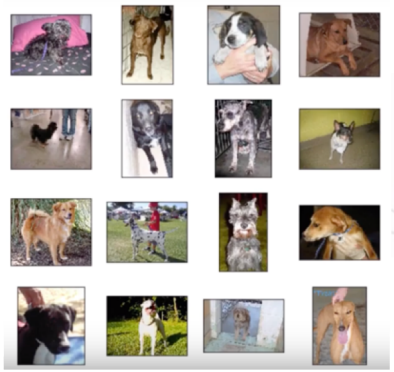
Deep Learning (DL) Doesn't "Reason" – It Pattern Matches

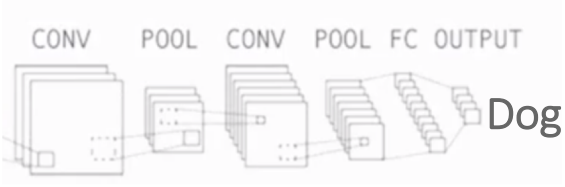


Training



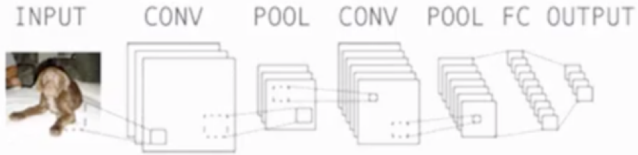
Cat

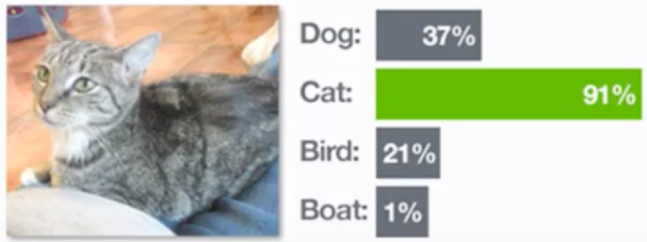




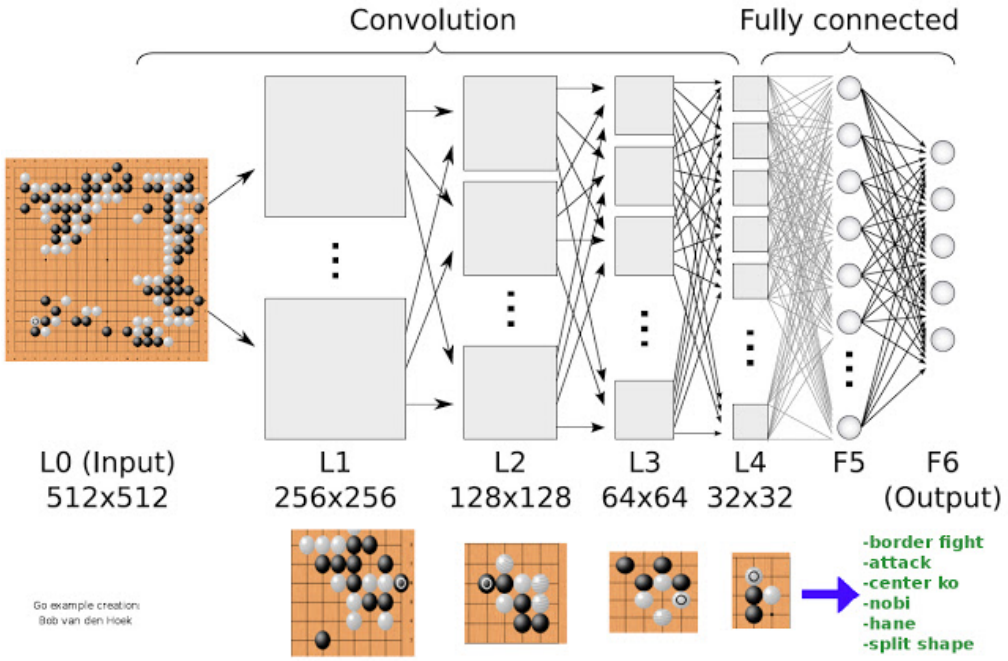
Dog

Inference

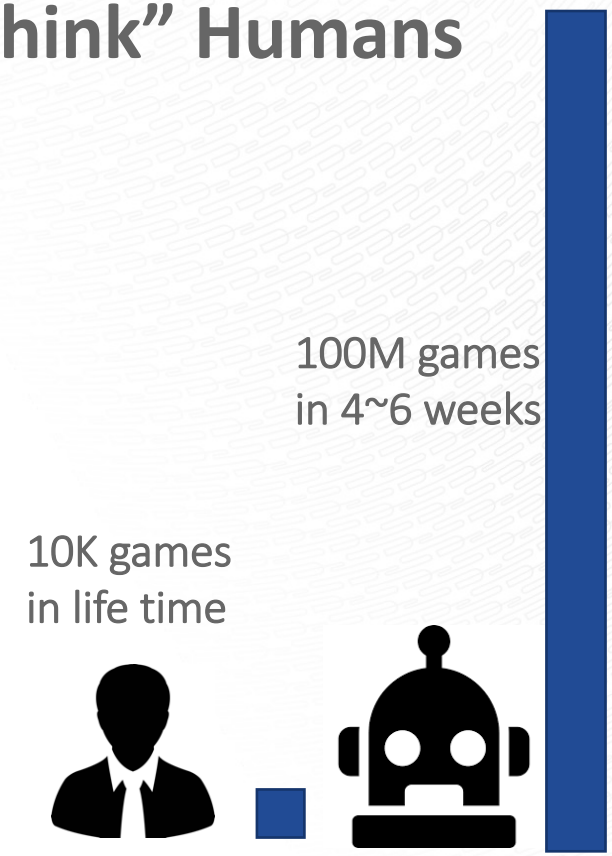




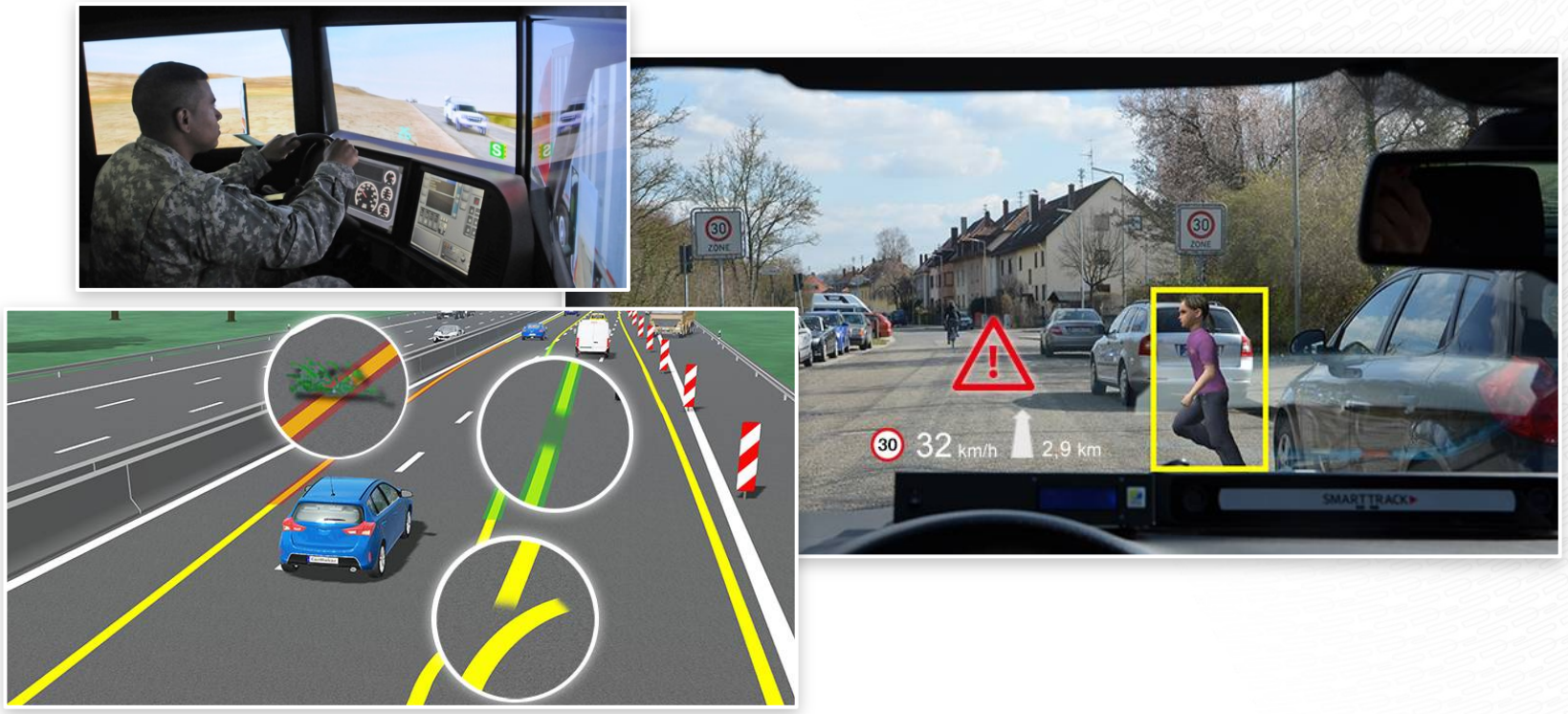
But With Tireless Learning From Pattern-Matching, Deep Learning (DL) Can "Out-think" Humans



Source: Bob van den Hoek's blog, "Deep Learning: Sky's the Limit?"



“Enough Data” Needed to Learn Similar Situations



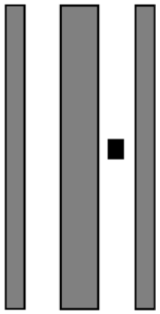
But some situations are too dangerous or rare for “real life” training

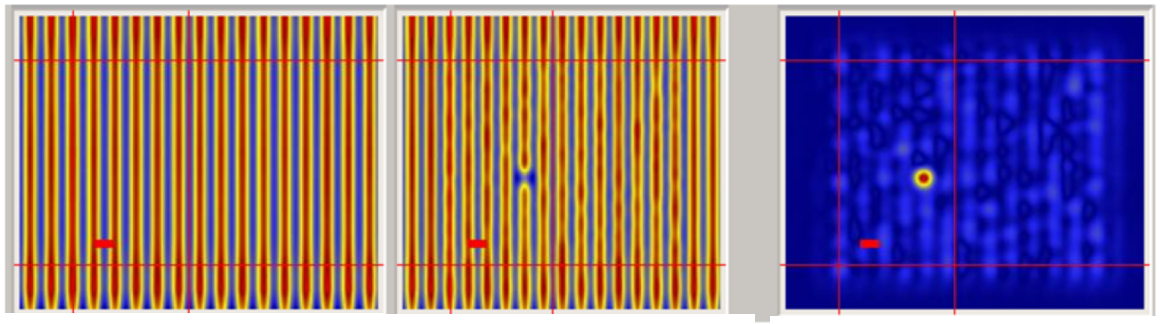
Simulation: Test, Validate Billions of Miles Safely

- Deep Learning (DL) training focuses on corner cases
  - Millions of similar “normal” driving miles don’t add to the learning
- Simulation allows combinations of effects to be automatically generated
  - Traffic, weather, accidents…
- Indispensable for debugging
  - Controlled environment
  - Easy fault insertion
  - Learning without machine time

Simulation Offers the Same Advantages for Deep Learning (DL) in Semiconductor Manufacturing

Simulated mask inspection images





Simulated reference aerial image

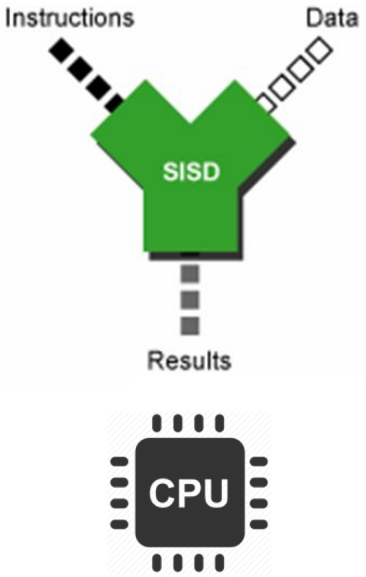
Simulated defect aerial image

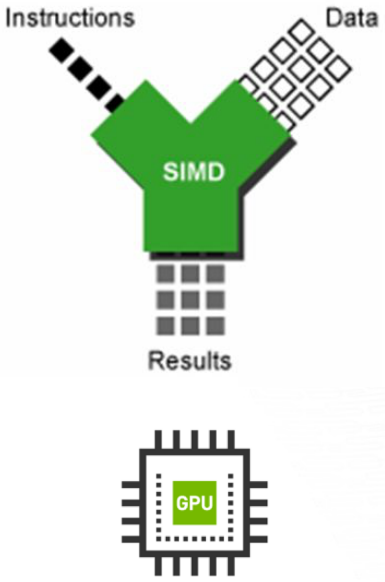
Differential aerial image

Defects Are a Very Small Percentage of all masks and wafers, But for Deep Learning Training, We Need A LOT of Them

Source: L. Pang, et. al, "Computational inspection applied to a mask inspection system with advanced aerial imaging capability", SPIE Advanced Lithography, 2010

GPU Excels at Simulation and Training for Deep Learning





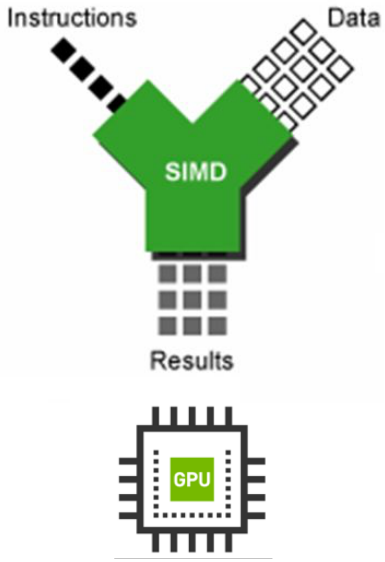
Caffe2

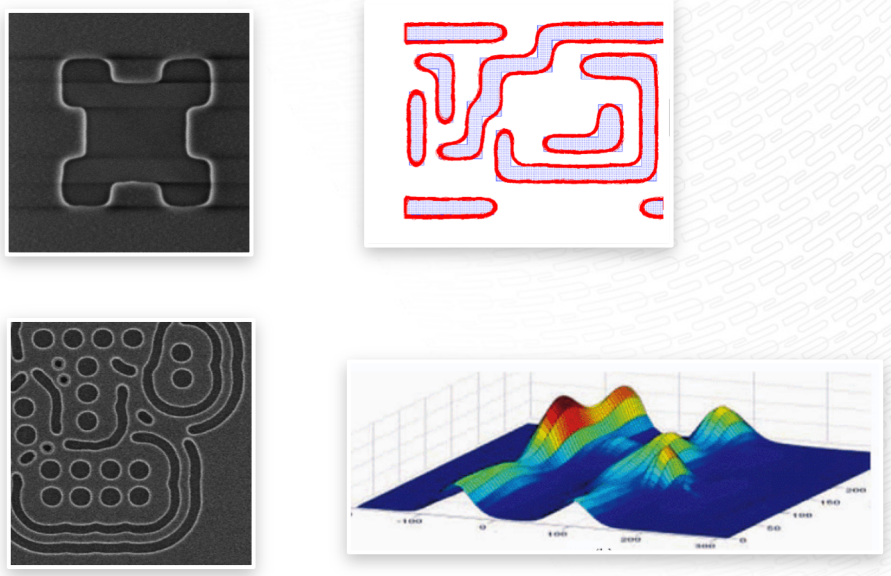
PyTorch

TensorFlow™

YOLO

GPU Also Excels at Mask and Wafer Simulation

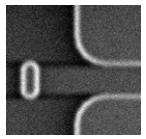




GPU (SIMD) is perfect for pixel data, which is shape-independent

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Rigorous eBeam and SEM Simulation



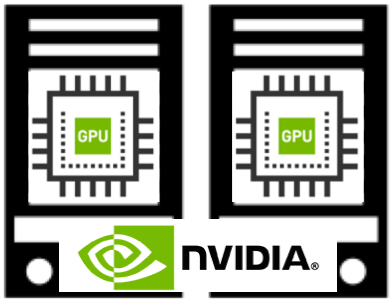
Rigorous Mask 3D Simulation (EUV and ArF)

Wafer Simulation

Mask Simulation

Verification

Geometry Libraries

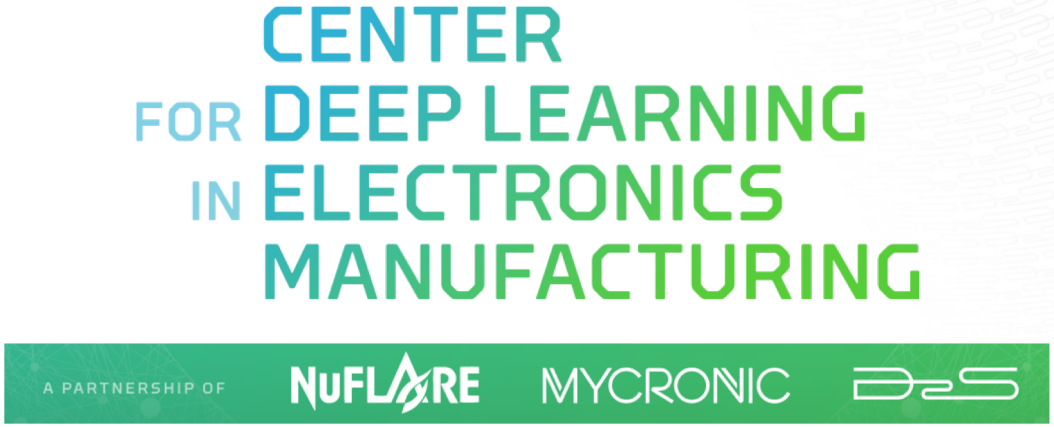


Computation Platform

Deep Learning Engine(s)

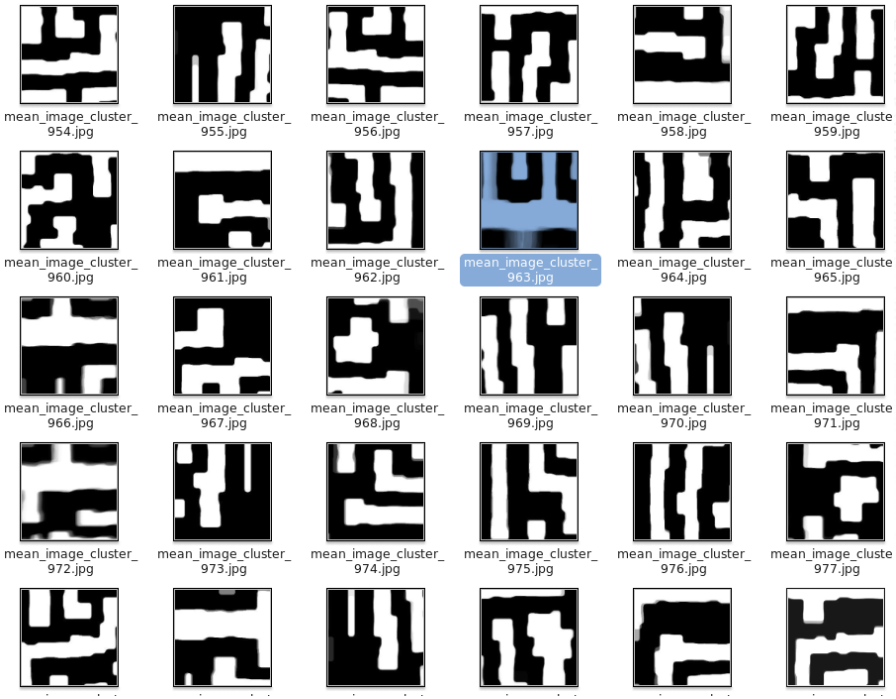
Pre-trained Deep Learning Neural Networks

Platform Application: D2S Project at CDLe



DL Mask Pattern Classifier Trained with Simulated Mask Pattern and Autoencoder

Different Groups Classified by Deep Learning

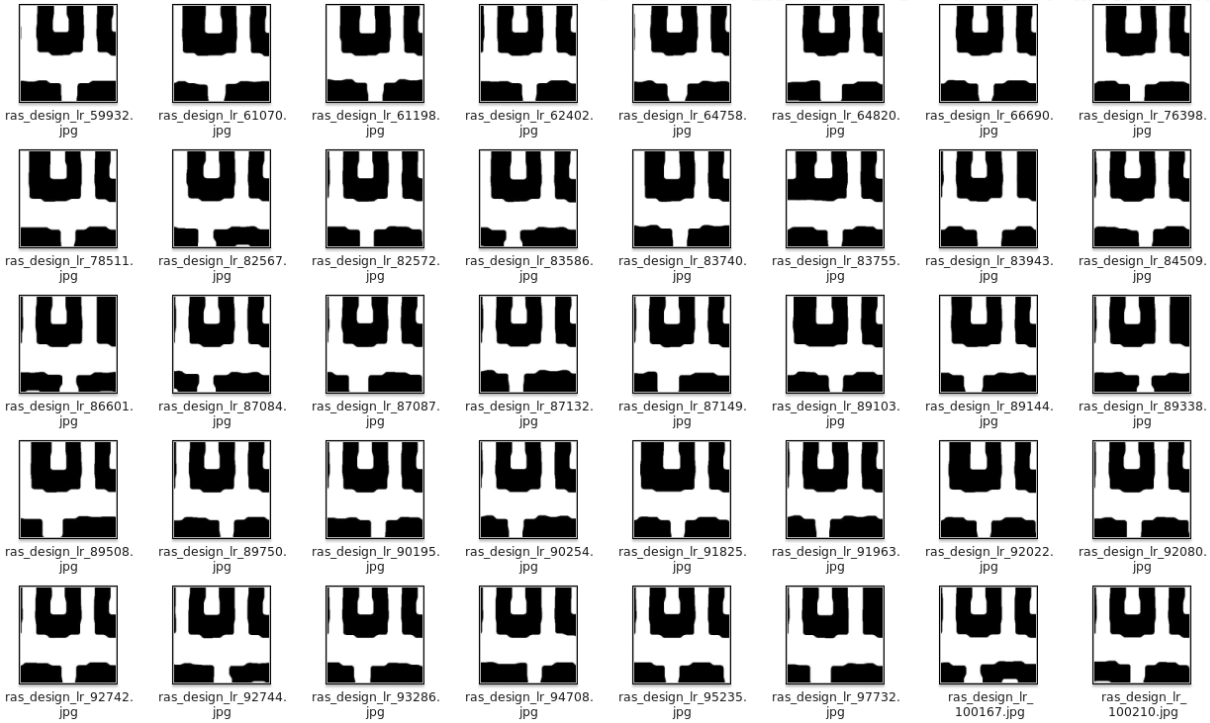


D2S PATENTED TECHNOLOGY
Proprietary to Center for Deep Learning in Electronics Manufacturing and its IP Members.

DL Mask Pattern Classifier Trained with Simulated Mask Pattern and Autoencoder

Sum images of Group 963

Each Instance of Group 963



D2S PATENTED TECHNOLOGY
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DL Mask Pattern Classifier Trained with Simulated Mask Pattern and Autoencoder

D2S PATENTED TECHNOLOGY
Proprietary to Center for Deep Learning in Electronics Manufacturing and its IP Members.

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Rigorous eBeam and SEM Simulation

Rigorous Mask 3D Simulation (EUV and ArF)

Wafer Simulation

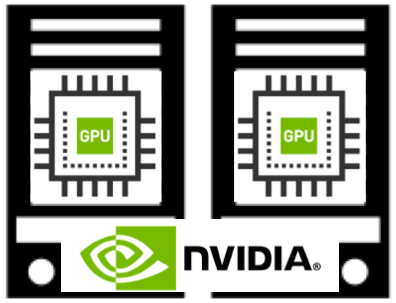
Deep Learning Engine(s)

Mask Simulation

Verification

Geometry Libraries

Pre-trained Deep Learning Neural Networks



Computational Design Platform (CDP)

D2S

GPU-Accelerated Computational Design Platform

- For Deep Learning Acceleration at CDLe
  - 500 TFLOPS SP computing power with NVIDIA V100
  - Reliable, Redundant, Recoverable for 24/7 Clean Room Operations

- Integrated Solution for GPU-Accelerated Deep Learning

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Wafer Simulation

Mask Simulation

Verification

Geometry Libraries

Computational Design Platform (CDP)

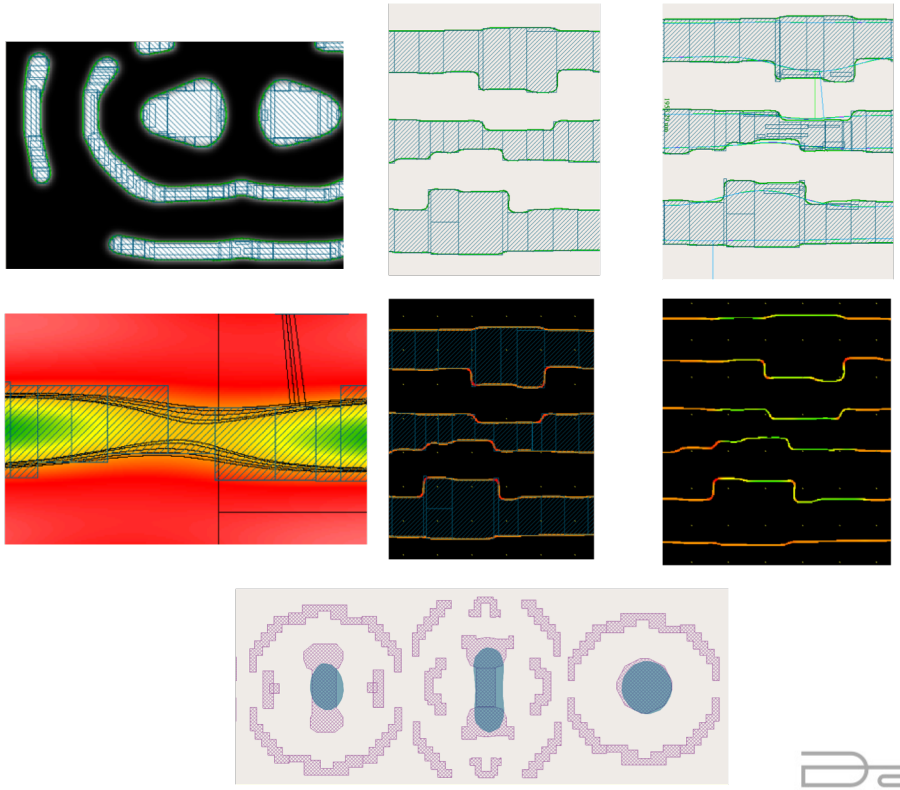
Rigorous eBeam and SEM Simulation

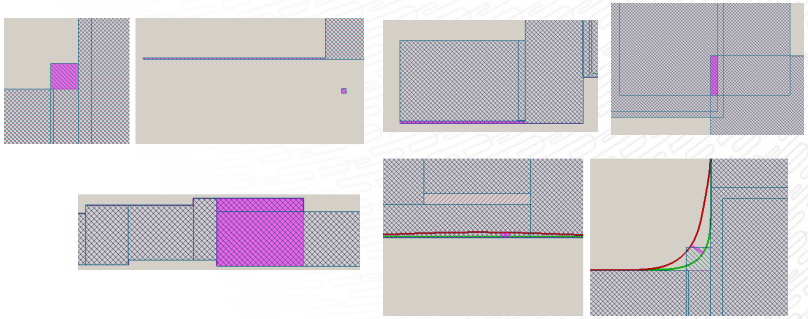
Rigorous Mask 3D Simulation (EUV and ArF)

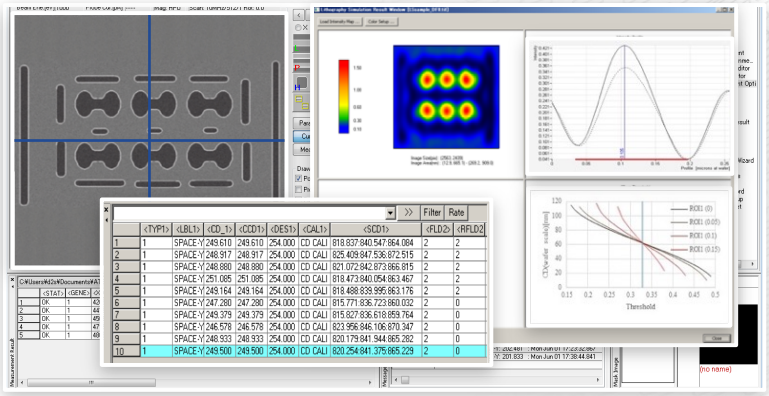
Deep Learning Engine(s)

Pre-trained Deep Learning Neural Networks

D2S TrueMask®: GPU-Accelerated Curvilinear Mask/Litho Simulators, Geometry Engine, Verification for DL Training

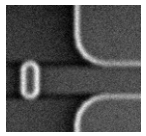






GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Rigorous eBeam and SEM Simulation



aBeam technologies

Rigorous Mask 3D Simulation (EUV and ArF)

Fastlitho

Wafer Simulation

Mask Simulation

Verification

Geometry Libraries

Deep Learning Engine(s)

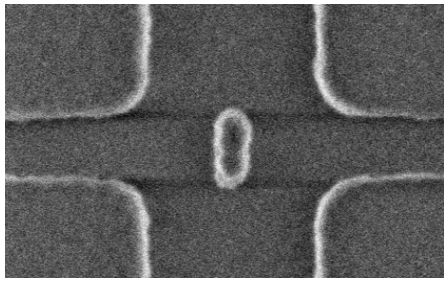
Pre-trained Deep Learning Neural Networks

GPU GPU NVIDIA

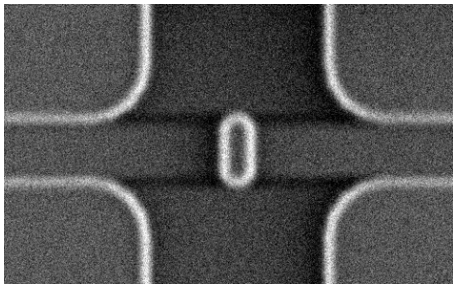
Computational Design Platform (CDP)

GPU-Accelerated Rigorous eBeam/SEM Simulators and EUV Mask 3D Simulators from Partners for DL Training

aBeam technologies

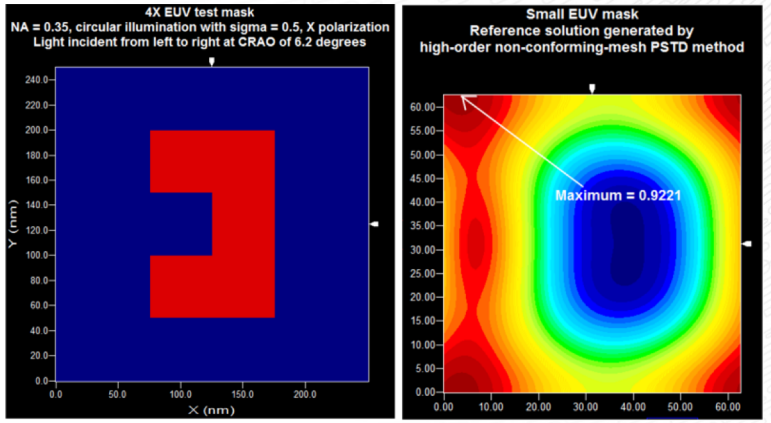


Actual SEM



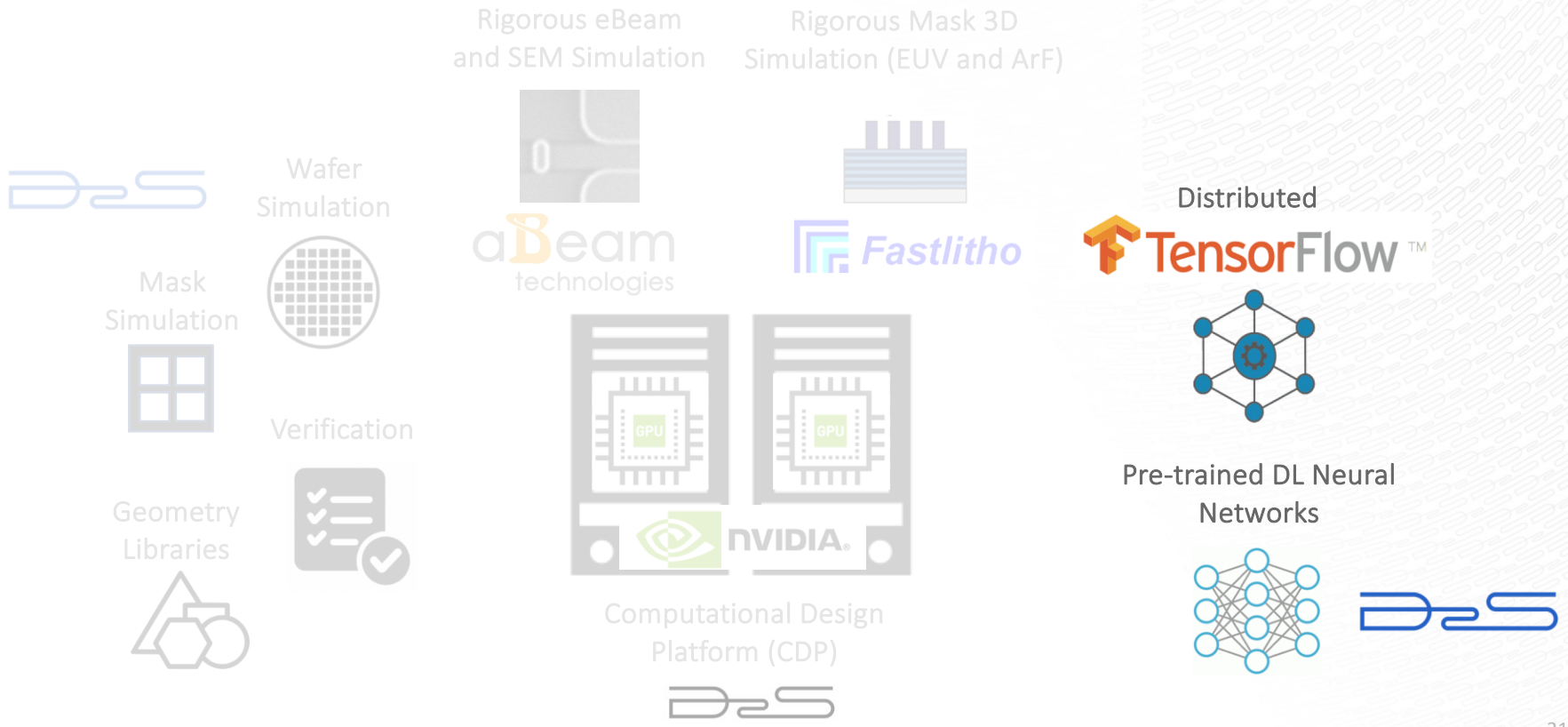
Simulated SEM

Fastlitho

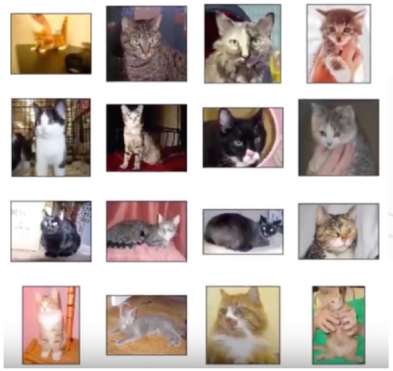


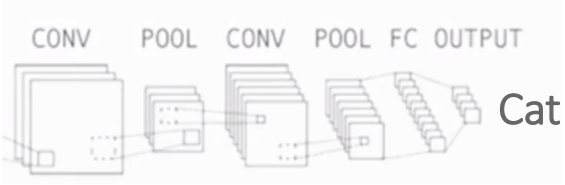
Fast Rigorous EUV Mask 3D Simulation

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

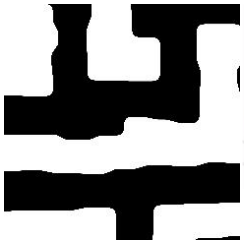


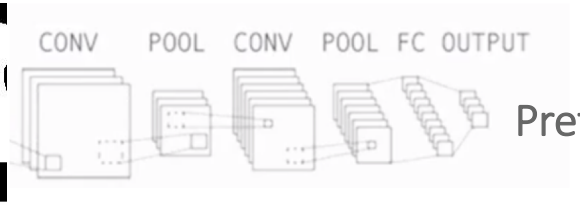
Pre-Trained Deep Learning Neural Network Models for Masks and Wafers





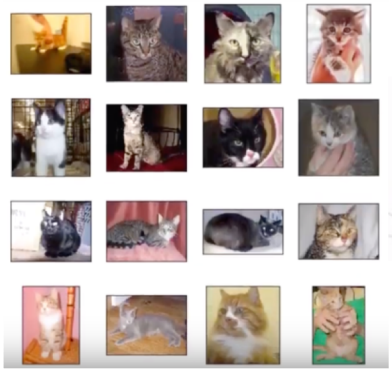
Cat

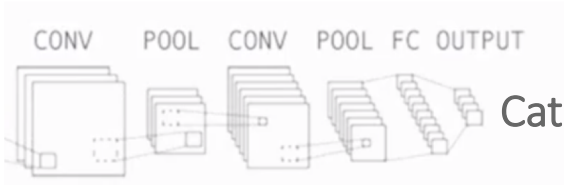


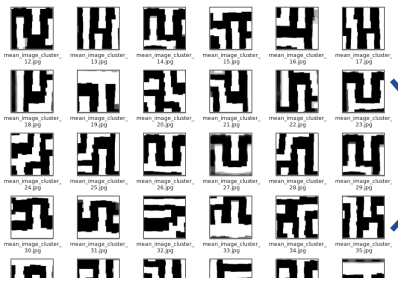


Pretzel

Pre-Trained Deep Learning Neural Network Models for Masks and Wafers





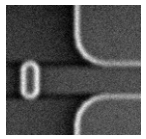


Pre-trained DL Neural Network Model for Mask and Wafer → Hotspot/Defect Classification

The network training required to identify a cat is very different from the network training required to identify a wafer defect

GPU-Accelerated Platform for Deep Learning (DL) to Boost Your Internal R&D

Rigorous eBeam and SEM Simulation



aBeam technologies

Rigorous Mask 3D Simulation (EUV and ArF)

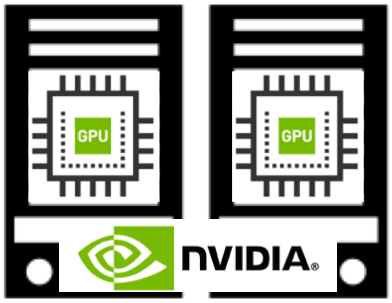
Fastlitho

Wafer Simulation

Mask Simulation

Verification

Geometry Libraries



Computational Design Platform (CDP)

Distributed TensorFlow™

Pre-trained Deep Learning Neural Networks