MATLAB EXPO

UNITED KINGDOM

Master Class: How to Develop Next Generation AI-Based Wireless Communications Systems

Daniel Aronsson, MathWorks

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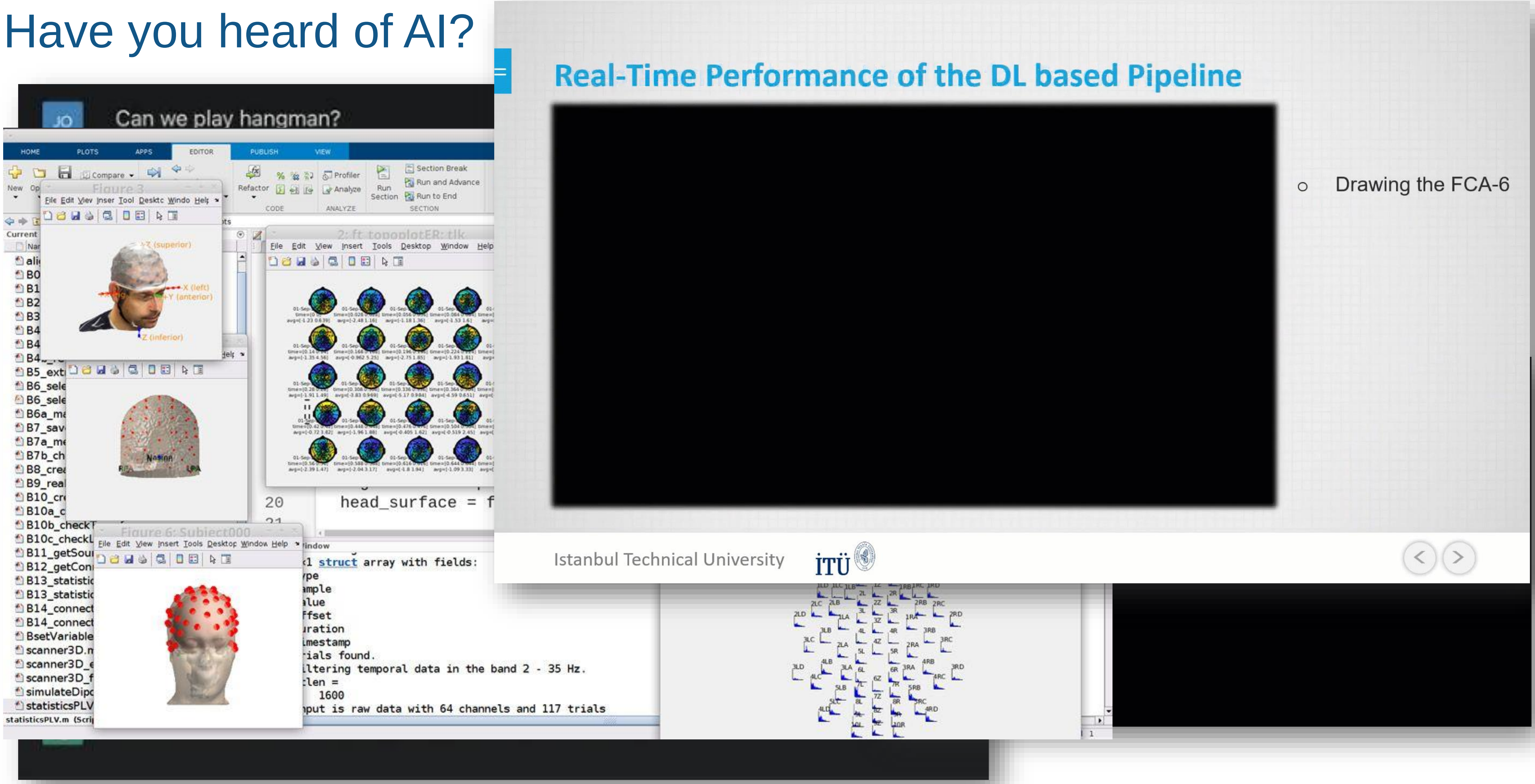
Have you heard of AI?



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AI in Wireless Today

NOKIA

Nokia to drive AI-powered technology innovation at new Open Innovation Lab in MEA

Press Release

How is Vodafone working with AI?

AI supports our network maintenance and performance

We are using AI to power applications that help us operate our networks smartly, or optimise them across markets. For example:

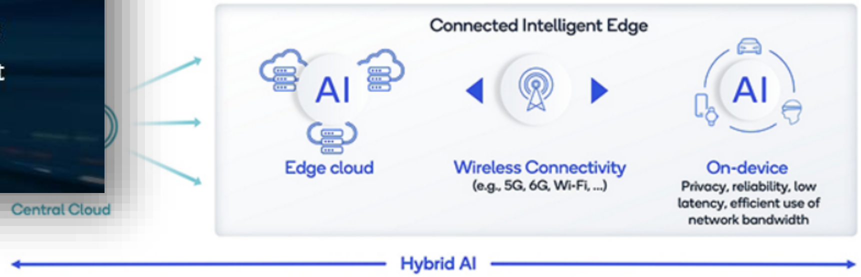
- AI can help us spot anomalies in our radio networks, or detect radio interference and determine where it is coming from
- AI can help us predict future problems with equipment, enabling us to act faster and carry out preventative maintenance
- AI can help predict changes in network traffic, allowing us to ensure we can meet demand and continue providing a great user experience for our customers

Qualcomm

From revolutionizing industries to reshaping our daily routines, there is no denying the profound impact of Artificial Intelligence (AI), making it one of the most disruptive technologies on the horizon. Thanks to the recent surge in media attention surrounding ChatGPT, the momentum for cutting-edge AI research is reaching unprecedented heights, propelling us towards innovations that can open new possibilities. Our mission with AI is to responsibly bring its benefits to more people around the world, elevate everyday mobile experiences, and enable new efficiencies for a wide range of consumer, enterprise and industrial applications.

> **However, scaling AI to reach its full potential is no trivial undertaking. To do so efficiently, it's imperative for AI ...essing to be intelligently distributed between the ...d and edge devices.**

...we believe the future of AI is hybrid. AI computation is split where ...appropriate, to provide enhanced experiences and ensure efficient ...urces.



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https://www.qualcomm.com/news/onq/2023/07/wireless-ai-igniting-the-5g-advanced-technology-revolution
https://www.vodafone.com/about-vodafone/what-we-do/innovation/artificial-intelligence

3GPP 5G NR Evolution: Release 18 5G ADVANCED towards 6G

Work in progress

Flexible spectrum use

NR for <5 MHz, enhancements to DSS, multicarrier & duplex operation

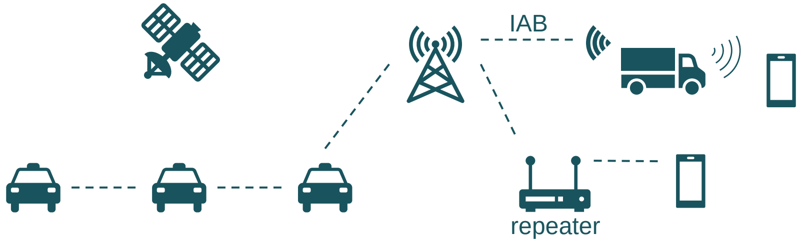
Diverse 5G devices

Smartphones, XR, RedCap, UAVs, V2X

Enhanced 5G performance

Energy saving, coverage, MIMO, positioning, mobility & MBS

Evolved network topologies



NTN, mobile IAB, sidelink relays, network-controlled repeaters

AI/ML for 5G

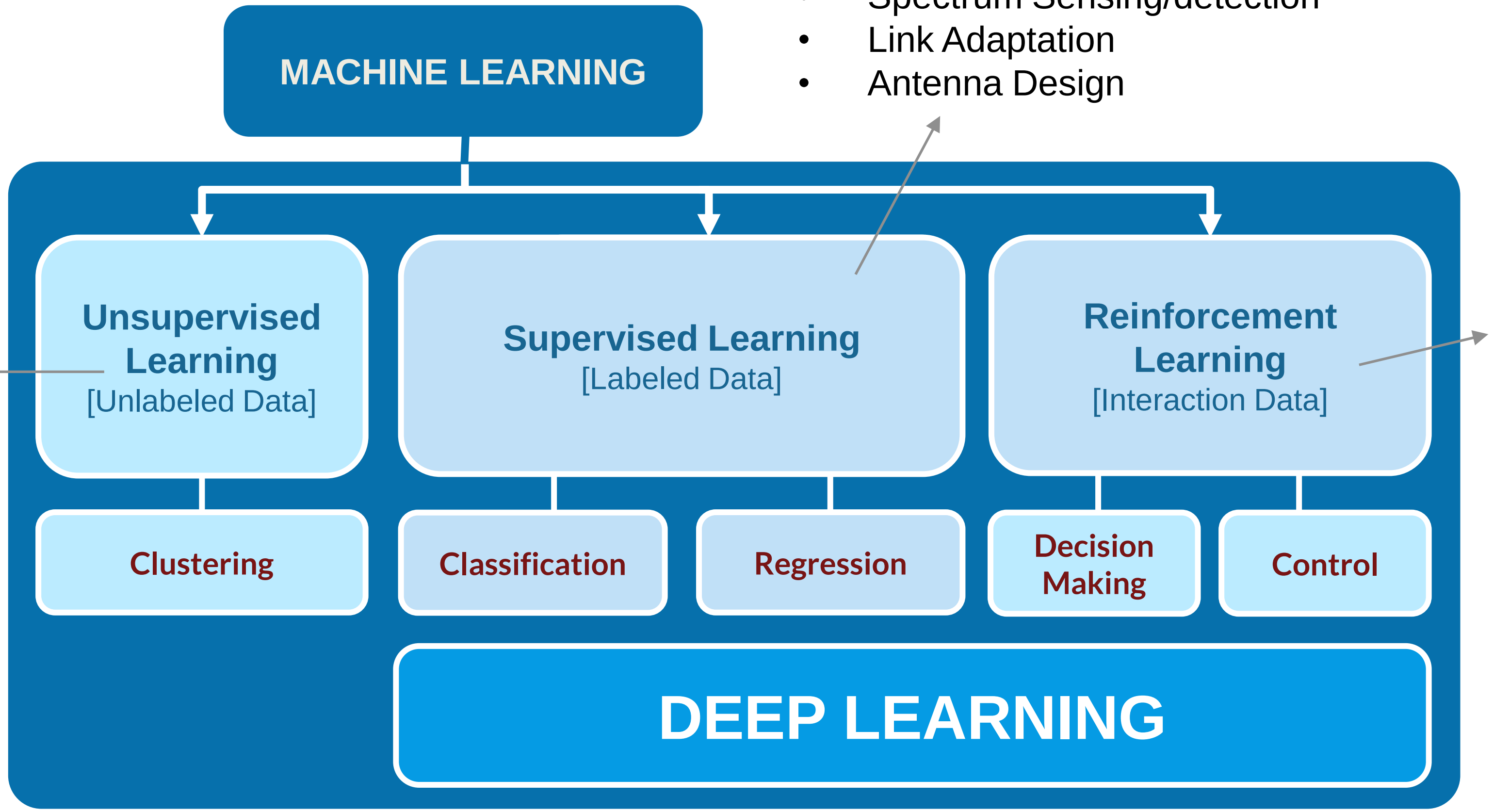
AI/ML for air interface, data collection enhancements

AI/ML Applied to Wireless

Application Examples

- Channel Estimation/detection
- Beam Selection
- Modulation recognition/classification
- User location/behaviour
- Spectrum Sensing/detection
- Link Adaptation
- Antenna Design

- Small cell clustering
- Device-to-device user clustering
- Anomaly/intrusion detection

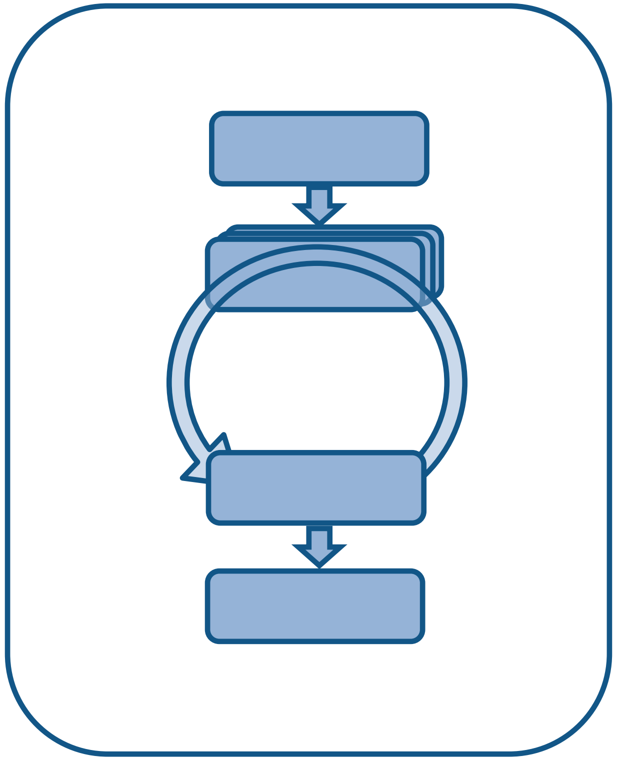


- Resource Allocation
- Transmission Power Control (cognitive radio)

Complex systems pose complex challenges

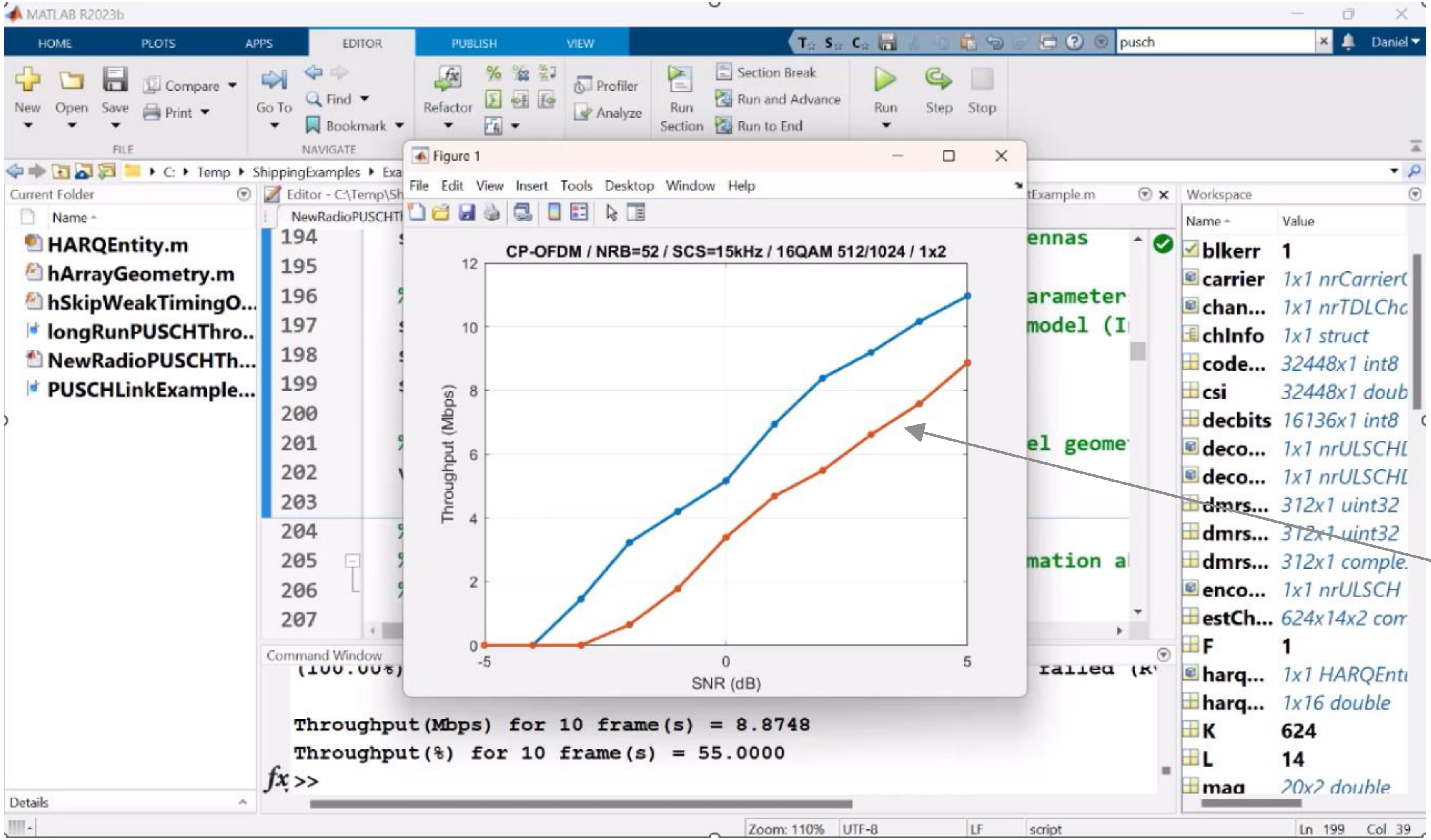
- What tools do I use to develop our algorithm?
- What should the workflow/methodology be?
- How do I obtain good training data?
- How do I validate the performance of the network?
- Do I have enough compute power or memory?
- How do I augment my data if performance is poor?
- How long does this take?
- How do I deploy my network?

Let’s go through a real-life case study!



Using AI to Improve the Performance in 5G

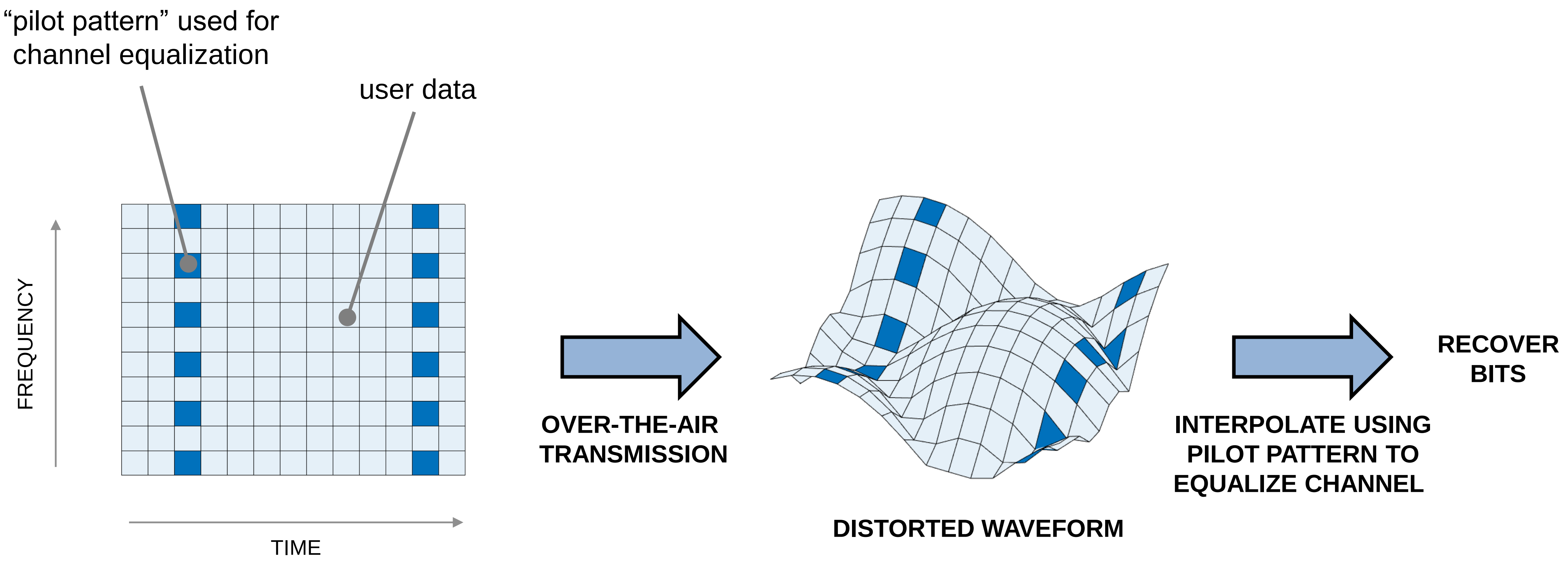
Throughput in 5G



Challenging channel conditions lower the throughput

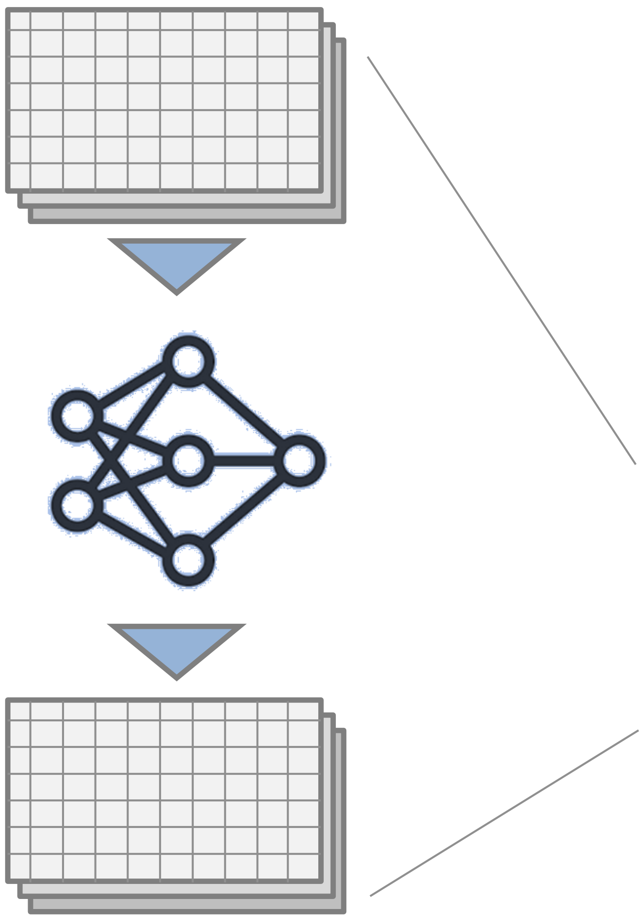
Can AI do a better job?

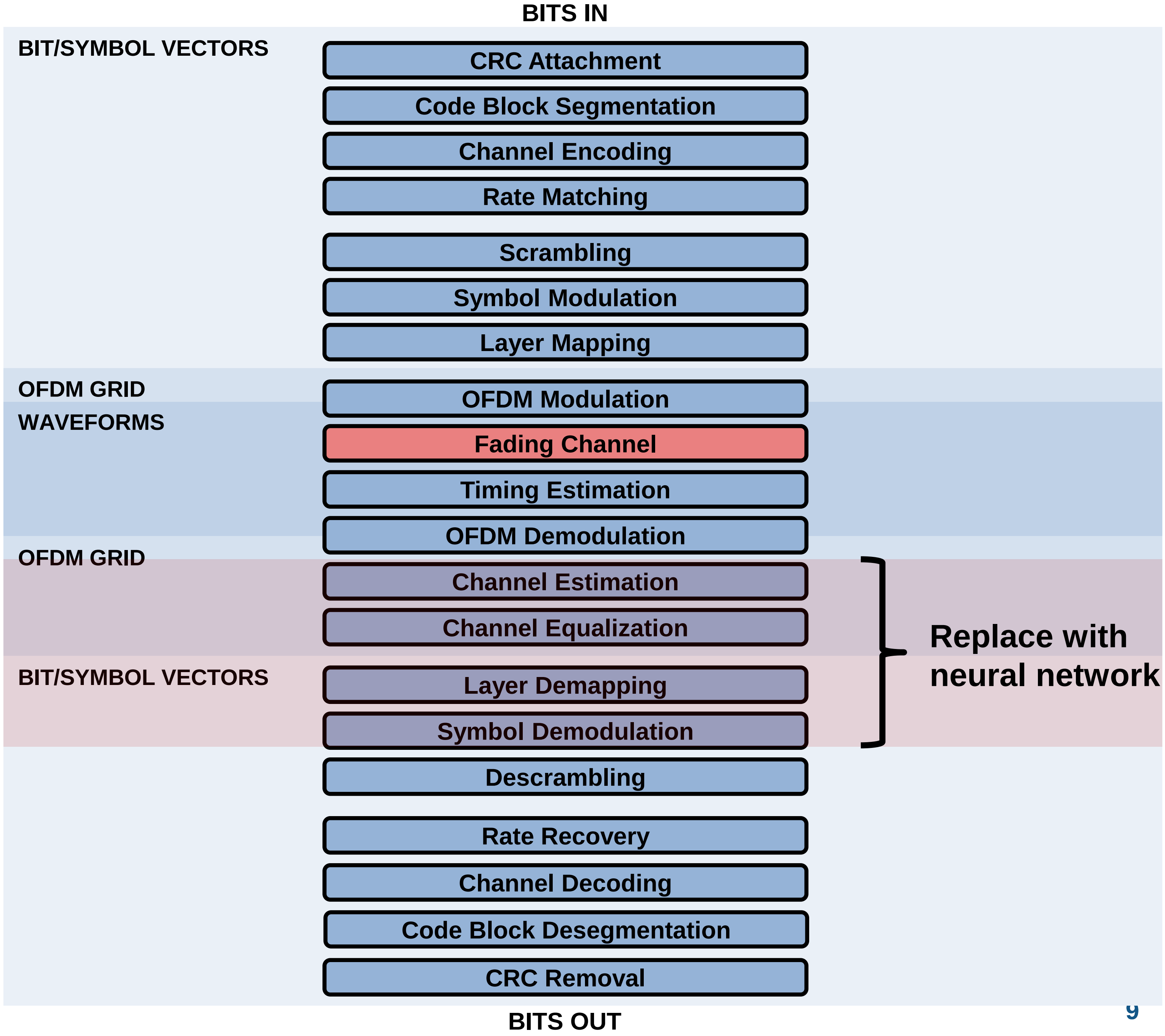
5G Uplink



Can AI do a better job than these conventional methods?

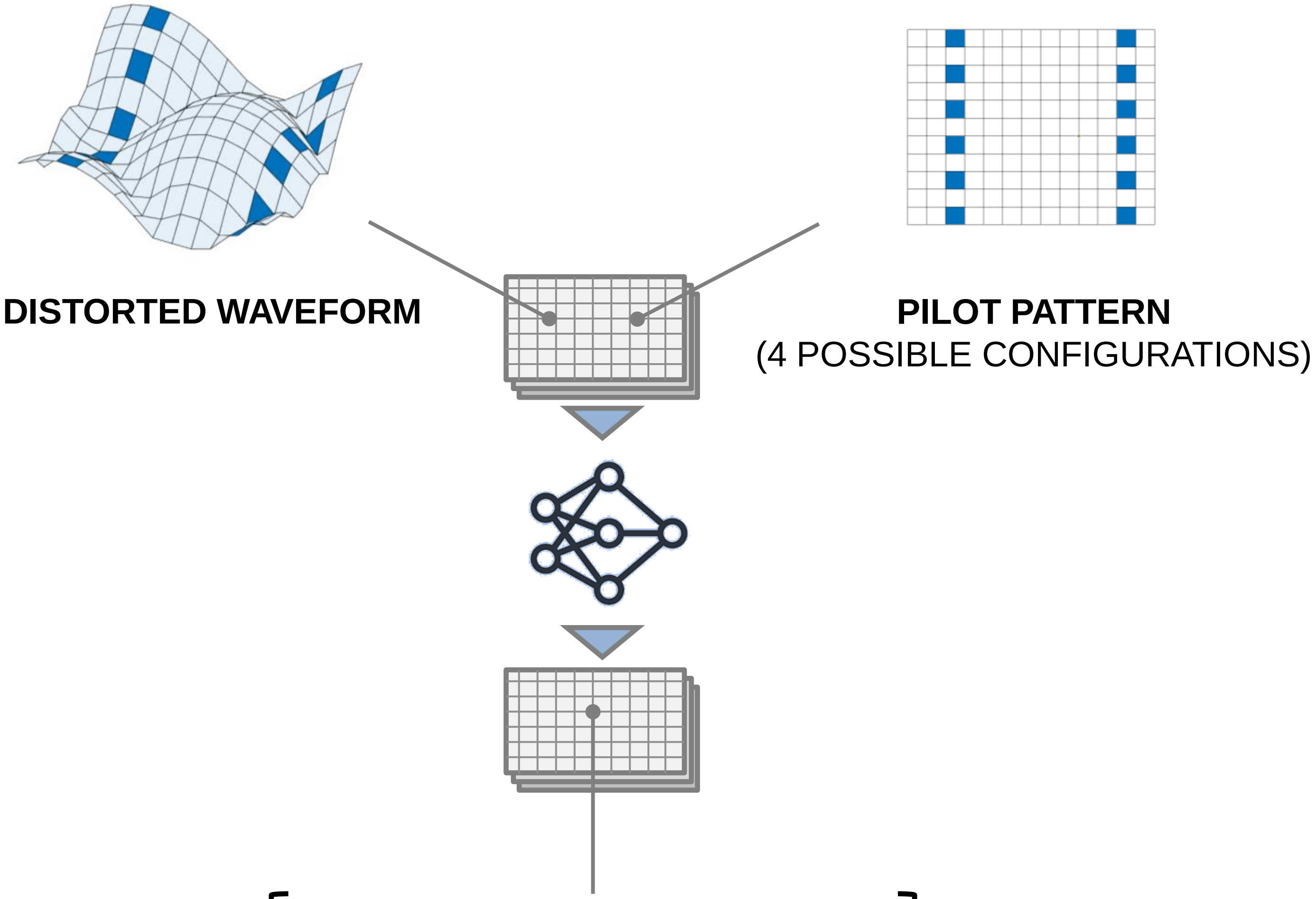
Uplink PHY in 5G





M. Honkala, D. Korpi and J. M. J. Huttunen,
"DeepRx: Fully Convolutional Deep Learning Receiver"

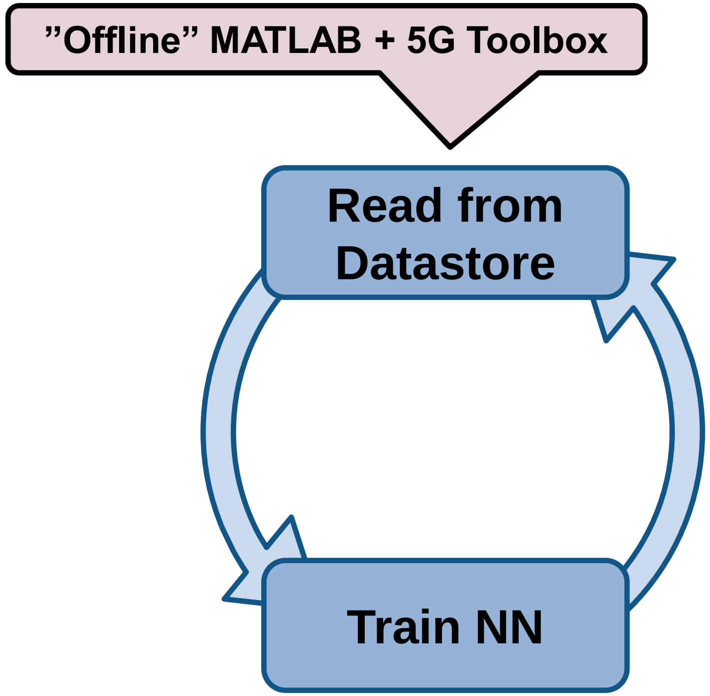
The Neural Network

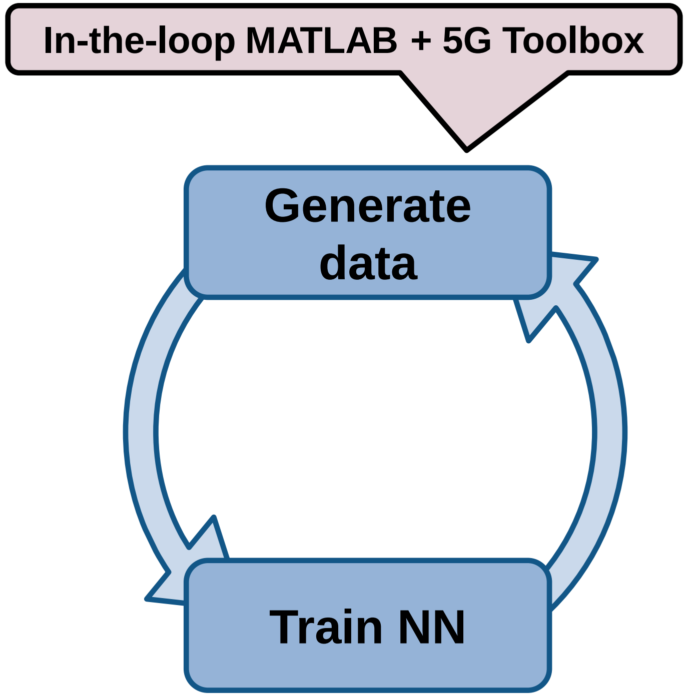


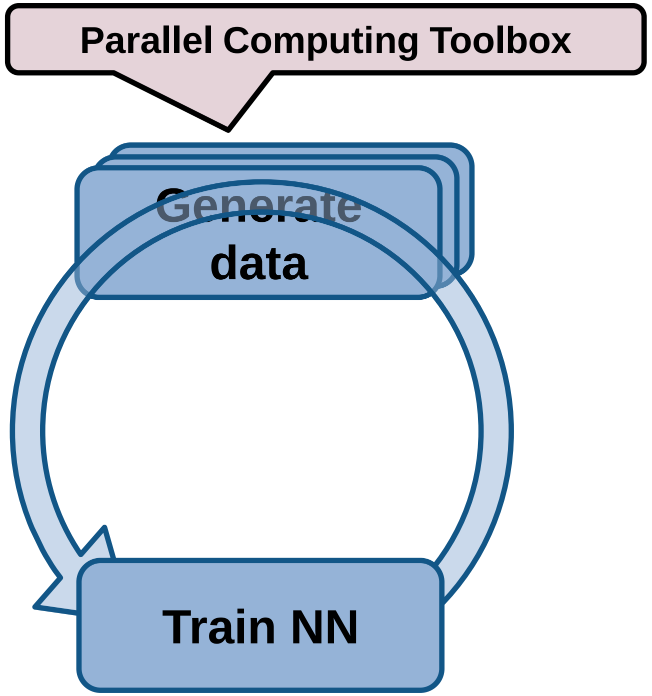
1	1	0	1	0	0	0	0
1	0	0	1	1	1	0	1
0	1	1	0	0	0	0	0
0	0	1	1	1	1	1	0
1	0	1	1	1	1	1	1
1	1	1	0	0	1	1	0

RECOVERED BITS

AI Workflows





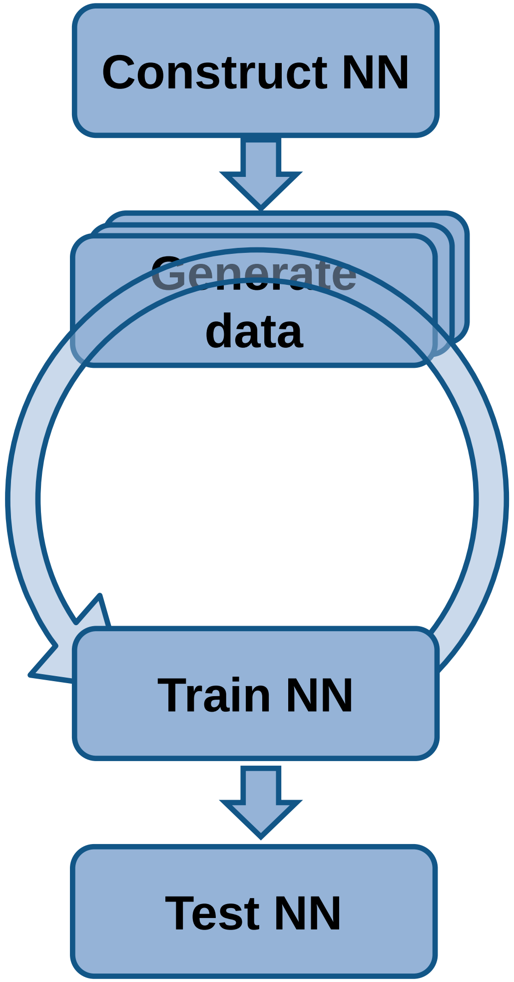


"Classical" workflow
Data regeneration takes a lot of time

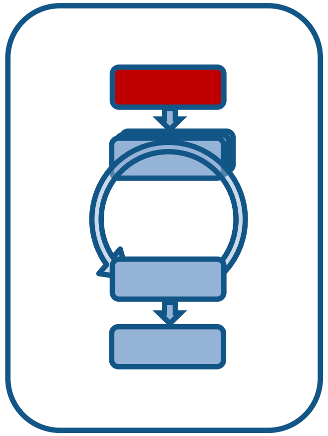
On-the-fly data generation (all in MATLAB)
Single environment, quick to restart

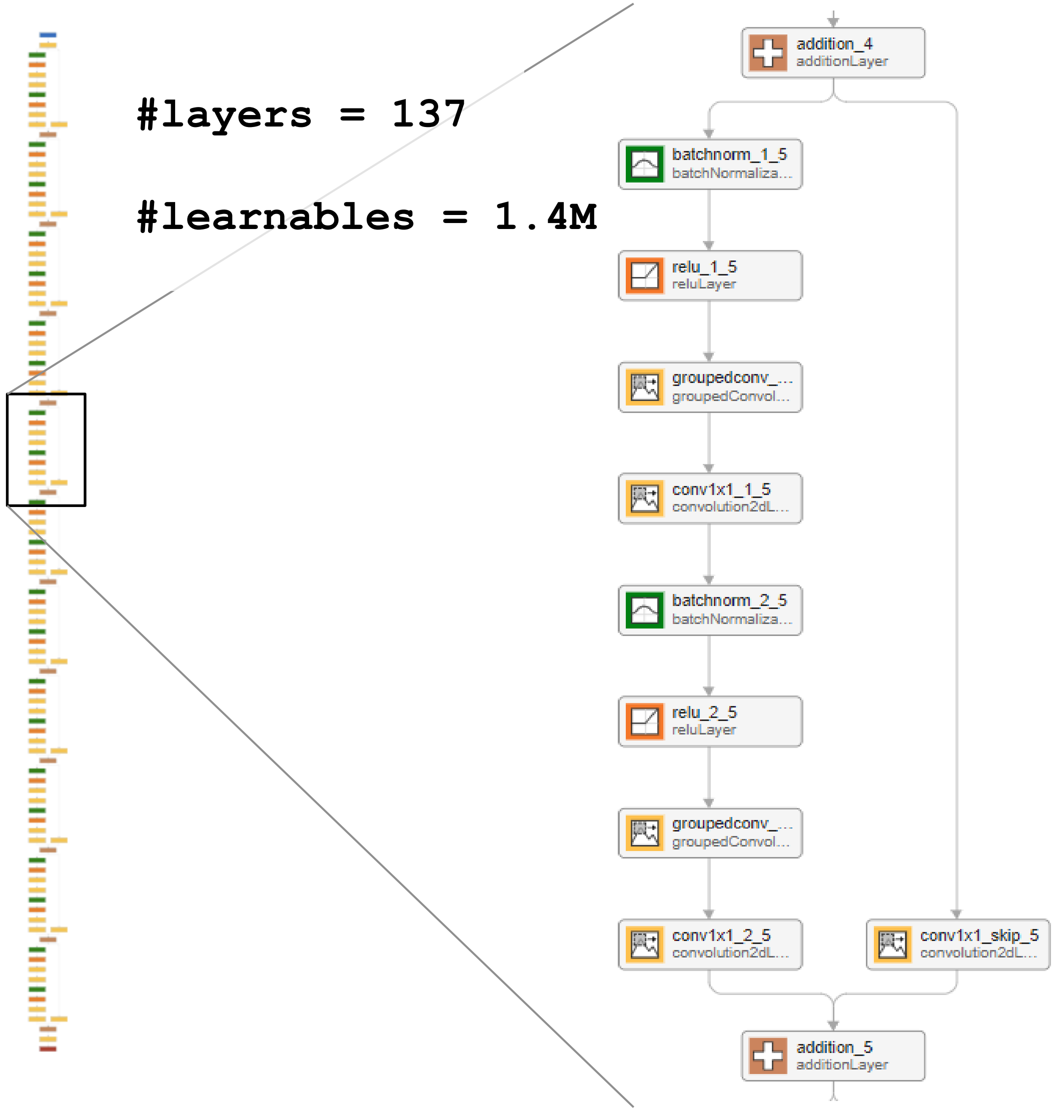
On-the-fly data generation with PCT
All time spent in training – data generation takes no time

A Flexible AI Workflow

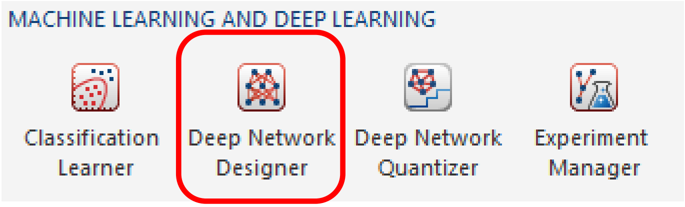


Neural Network Architecture





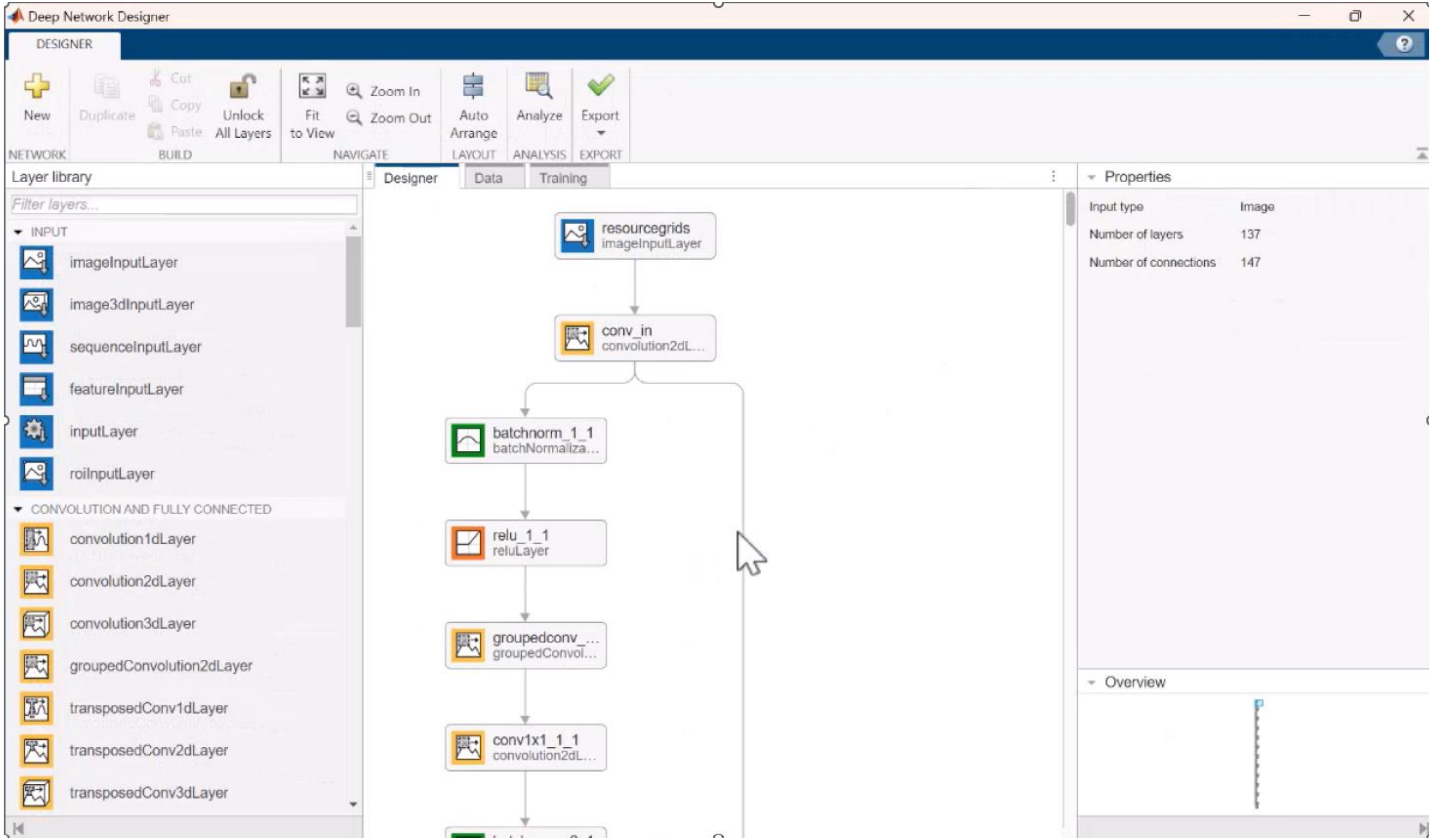
- Use `deepNetworkDesigner` to edit and analyze.

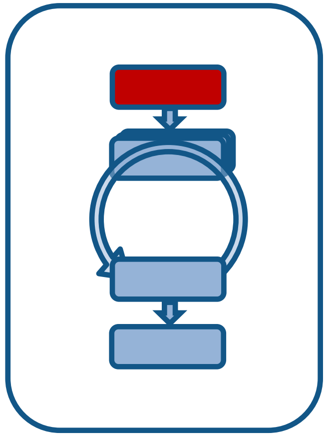


- Use the `layerGraph` datatype and its `addLayers` method to programatically build the network.

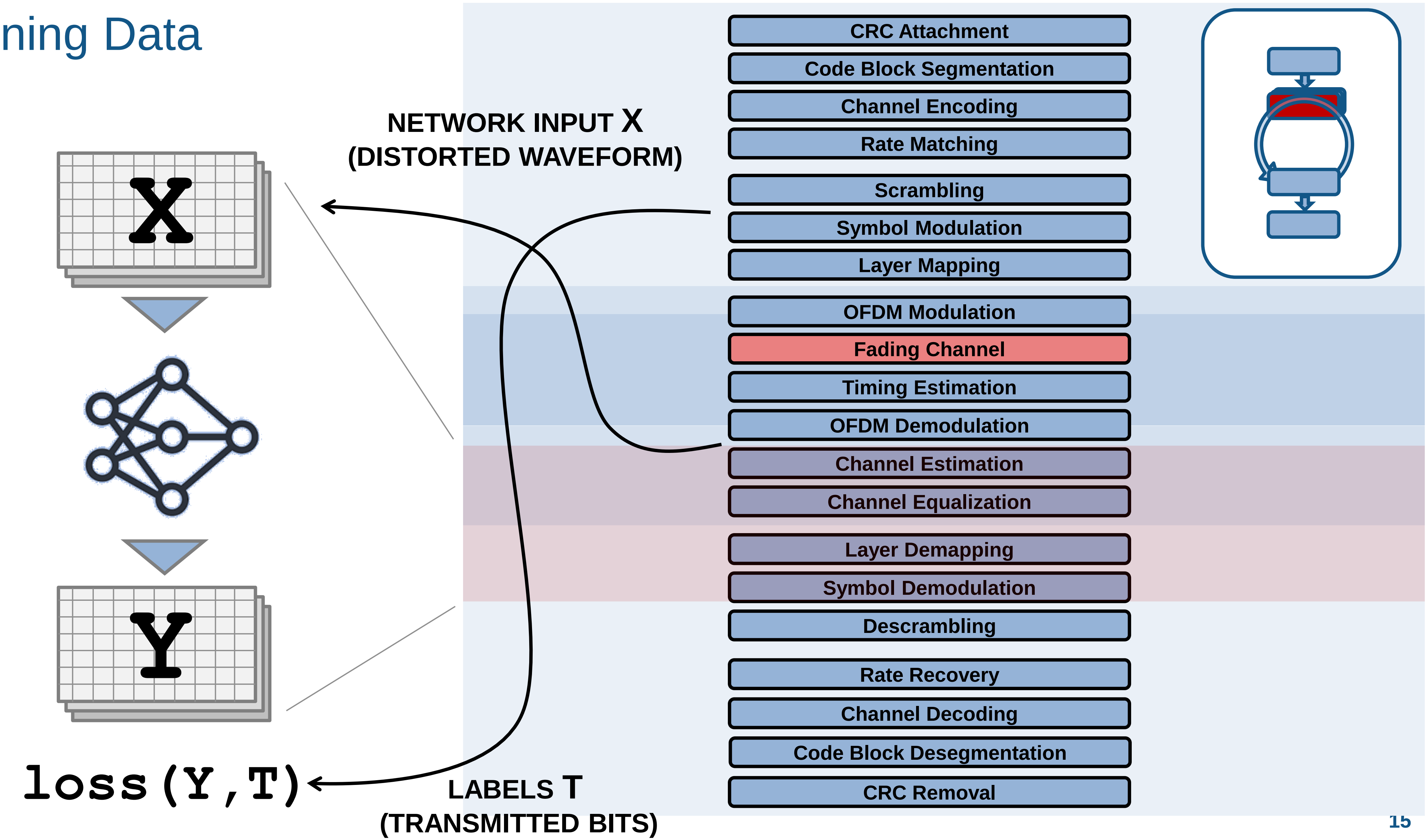
```
lgraph = addLayers(lgraph, xceptionLayers);
lgraph = addLayers(lgraph, convolution2dLayer
lgraph = addLayers(lgraph, additionLayer(2,"N
```

Programmatic Construction of a Neural Network

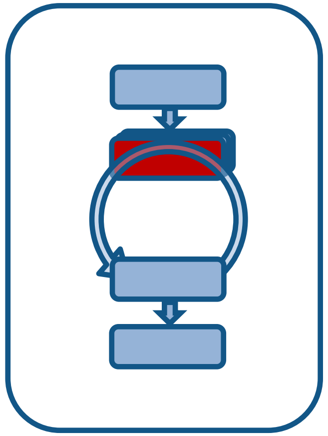




Training Data



Generating Data in the Background



Parallel Computing Use Cases

Parallel for-Loops

- for → parfor

GPU Computing

- gpuArray datatype
- many functions run on GPU
- Deep Learning workflows

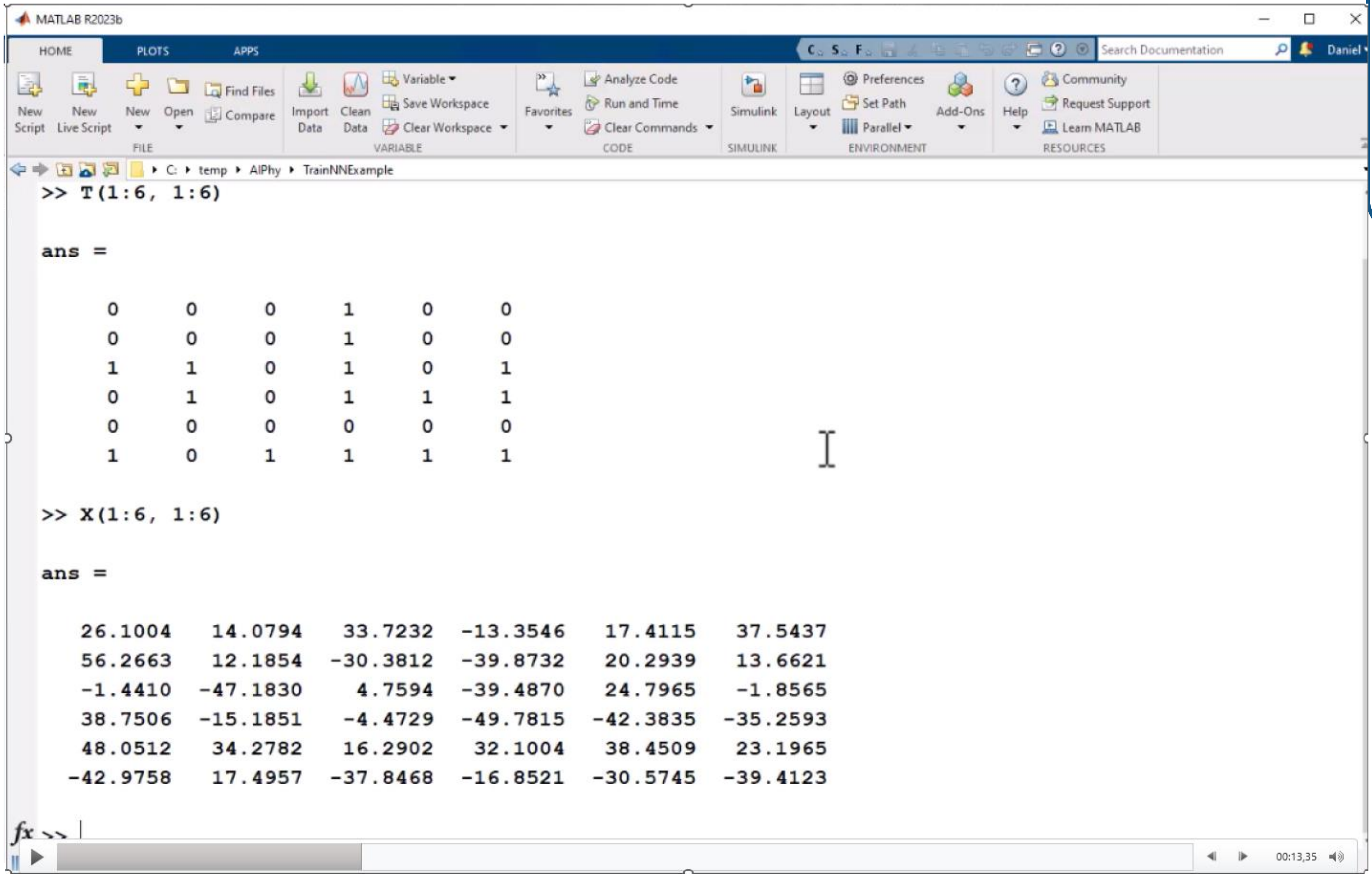
Used automatically for training and inference

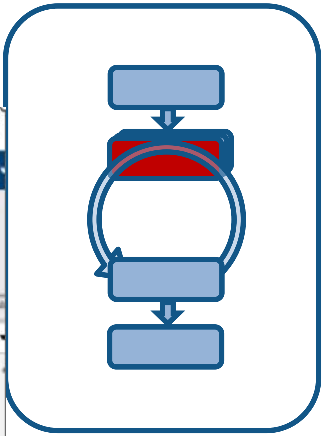
Asynchronous Parallel Programming

- parfeval starts asynchronous work
- Use fetchNext to query work

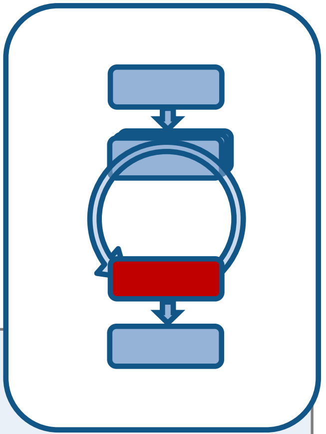
Used for generating data in the background

Data Generation





Training Loops



Simple Training Loop

- Minimal implementation
- Series/DAG/RNN networks
- MSE and crossentropy loss

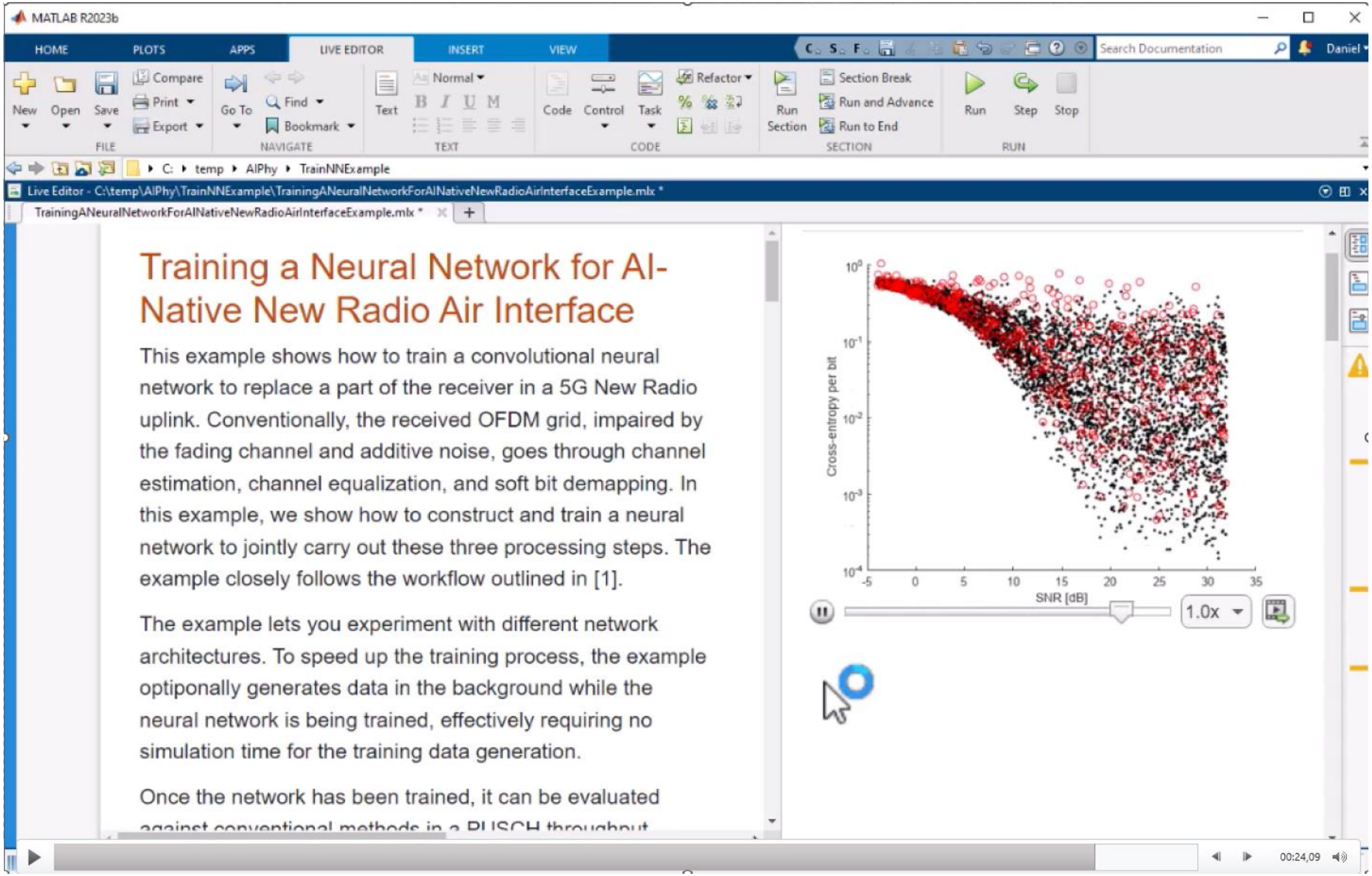
```
net = trainNetwork(datastore, layers,
  options)
```

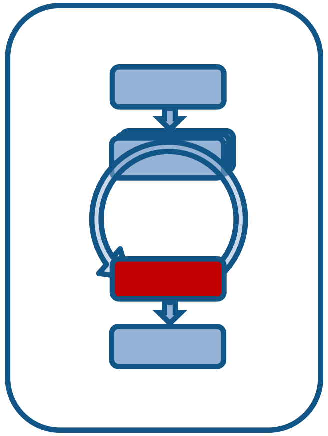
Custom Training Loop

- Full flexibility for training data, architecture, optimizer, loss function

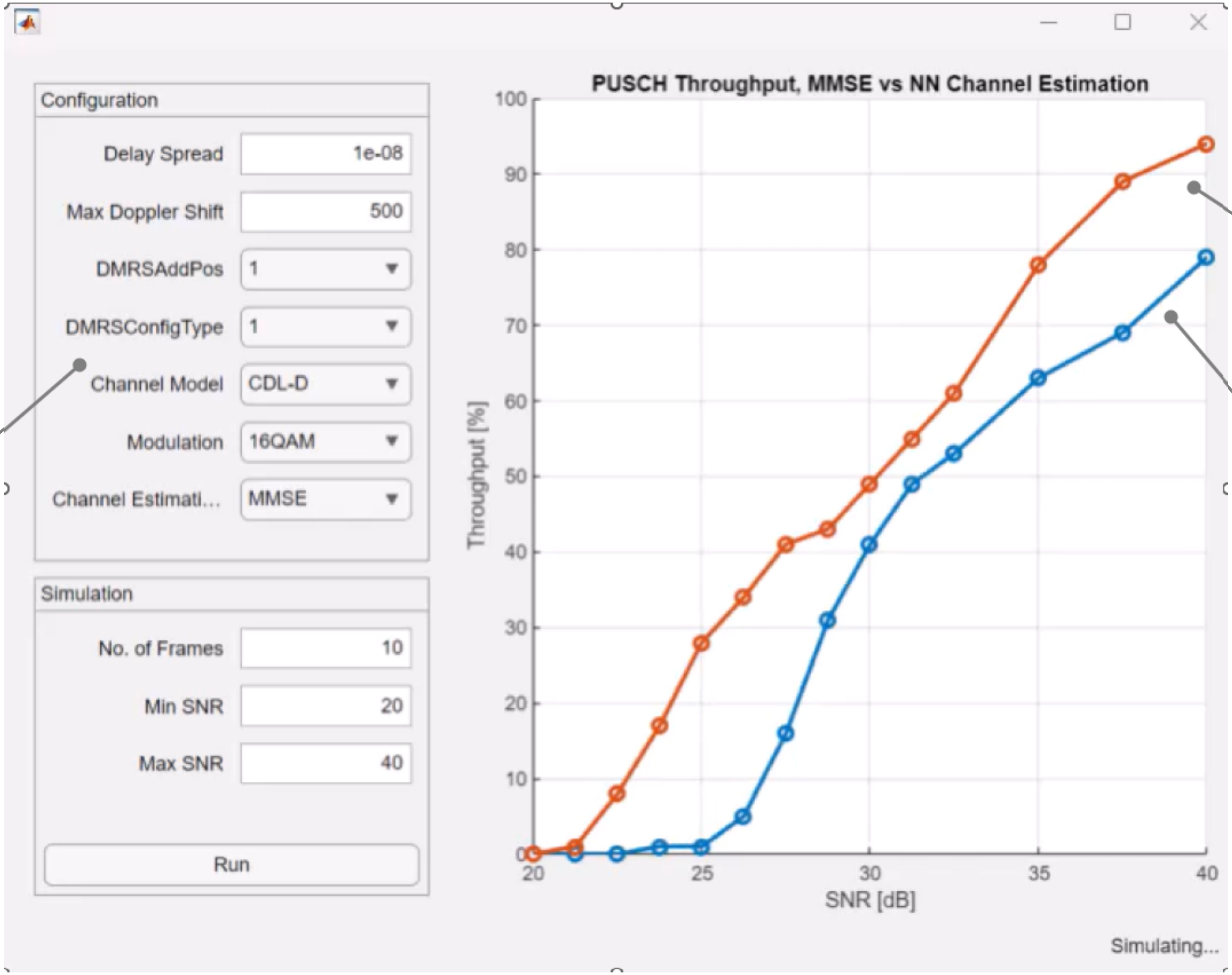
```
[loss, grad, state] = dlfeval(
  @modelLoss, net, X, T)
[net,vel] = dlupdate(fun, net)
```

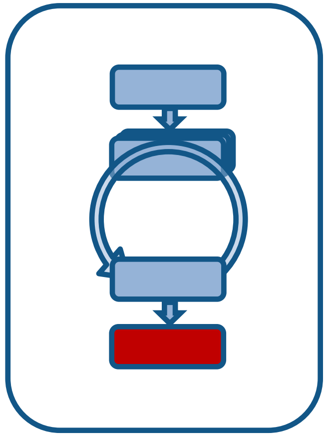
Training the Neural Network





Testing the Neural Network





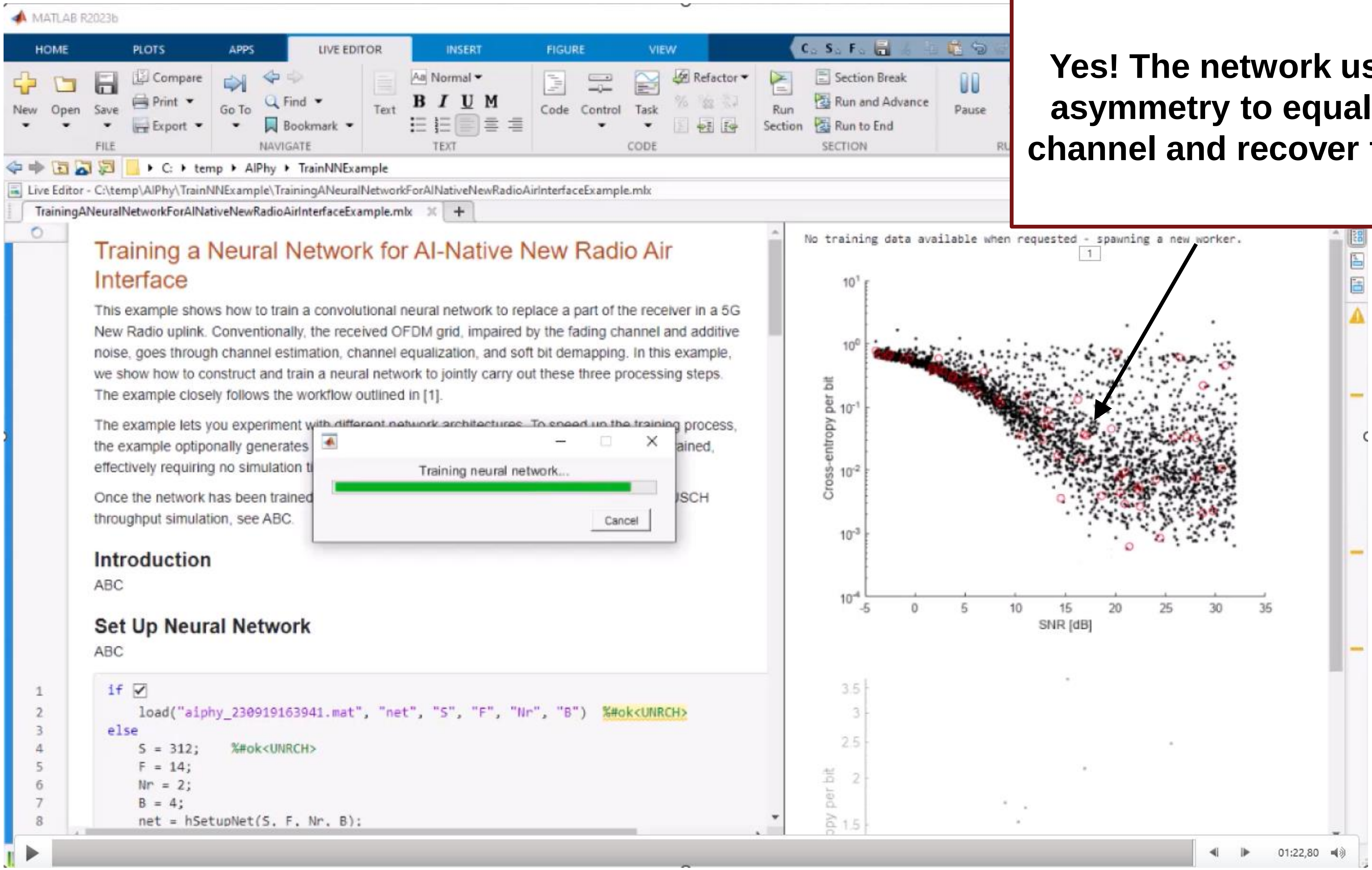
Exploration across a large parameter set

AI

conventional methods

Further exploration: Can the neural net work without a pilot pattern?

Yes! The network uses the asymmetry to equalize the channel and recover the bits.



Conclusion

- Flexible workflow to address the challenges of designing modern AI for wireless systems
  - Synthetic training data
  - Custom training loops
  - Validation
  - Use of GPUs
  - Performance

- Template to apply to any problem!

- Get started by learning the tools

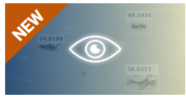
Machine Learning Onramp
6 modules | 2 hours | Languages
Learn the basics of practical machine learning methods for classification problems.

Machine Learning with MATLAB
6 modules | 12 hours | Languages
Explore data and build predictive models.

Deep Learning Onramp
5 modules | 2 hours | Languages
Get started quickly using deep learning methods to perform image recognition.

Deep Learning with MATLAB
11 modules | 7 hours | Languages
Learn the theory and practice of building deep neural networks with real-life image and sequence data.

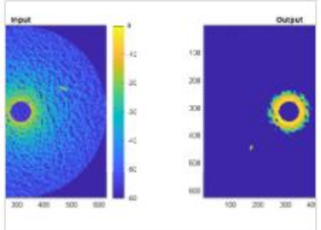
Reinforcement Learning Onramp
5 modules | 2.5 hours | Languages
Master the basics of creating intelligent controllers that learn from experience.



Computer Vision Onramp
6 modules | 2 hours | Languages
Learn the basics of computer vision to design an object detector and tracker.

Wireless Communications Onramp
6 modules | 1 hour | Languages
Learn the basics of simulating a wireless communications link in MATLAB.

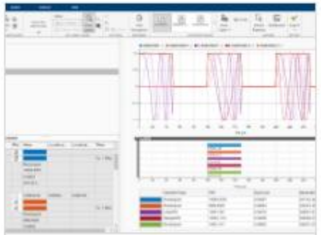
Additional Examples to Get Started



Maritime Clutter Removal with Neural Networks

Train and evaluate a convolutional neural network to remove clutter returns from maritime radar PPI images using the Deep Learning

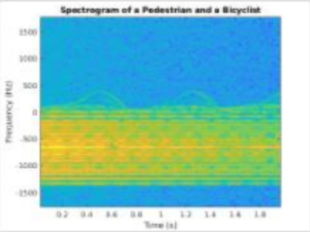
Open Live Script



Label Radar Signals with Signal Labeler

Label the time and frequency features of pulse radar signals with added noise.

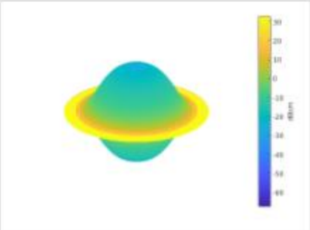
Open Live Script



Pedestrian and Bicyclist Classification Using Deep Learning

Classify pedestrians and bicyclists based on their micro-Doppler characteristics using deep learning and time-frequency analysis.

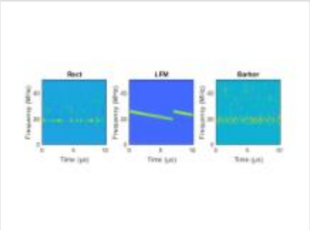
Open Live Script



Radar Target Classification Using Machine Learning and Deep Learning

Classify radar returns using machine and deep learning approaches.

Open Live Script



Radar and Communications Waveform Classification Using Deep Learning

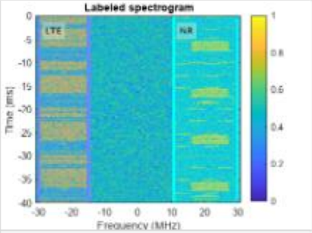
Classify radar and communications waveforms using the Wigner-Ville distribution (WVD) and a deep convolutional neural network (CNN).

Open Live Script

SAR Target Classification using Deep Learning

Create and train a simple convolution neural network to classify SAR targets using deep learning.

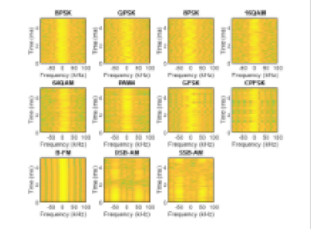
Open Live Script



Spectrum Sensing with Deep Learning to Identify 5G and LTE Signals

Train a semantic segmentation network using deep learning for spectrum monitoring.

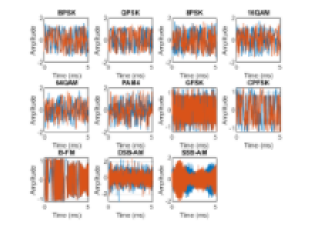
Open Live Script



Modulation Classification with Deep Learning

Use a convolutional neural network (CNN) for modulation classification. You generate synthetic, channel-impaired waveforms. Using the

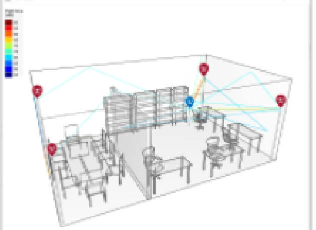
Open Live Script



Modulation Classification by Using FPGA

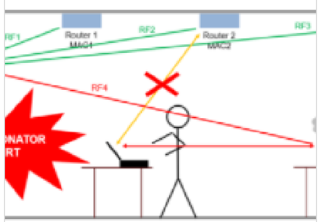
Deploy a pretrained convolutional neural network (CNN) for modulation classification to the Xilinx® Zynq® UltraScale+™ MPSoC

Open Live Script



Three-Dimensional Indoor Positioning with 802.11az Fingerprinting and Deep...

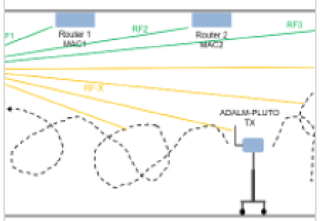
Train a convolutional neural network for IEEE® 802.11az™ localization and positioning.



Design a Deep Neural Network with Simulated Data to Detect WLAN Router...

Design a radio frequency (RF) fingerprinting convolutional neural network (CNN) with simulated data. You train the CNN with simulated

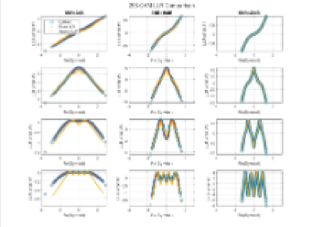
Open Live Script



Test a Deep Neural Network with Captured Data to Detect WLAN Router Impersonation

Train a radio frequency (RF) fingerprinting convolutional neural network (CNN) with captured data. You capture wireless local area

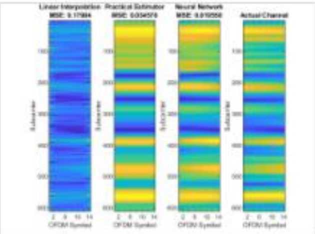
Open Live Script



Training and Testing a Neural Network for LLR Estimation

Generate signals and channel impairments to train a neural network, called LLRNet, to estimate exact log likelihood ratios (LLR).

Open Live Script



Deep Learning Data Synthesis for 5G Channel Estimation

Generate deep learning training data for channel estimation using 5G Toolbox™.

Demo Stations

- Intelligent Radio Capture and RF Modelling for Satellite Systems
- Making Sense of Artificial Intelligence: Techniques for Interpreting Model Decisions
- Generative AI and Large Language Models

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Thank you

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