Developing Real-Time Cognitive EW Systems

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Agile Electromagnetics

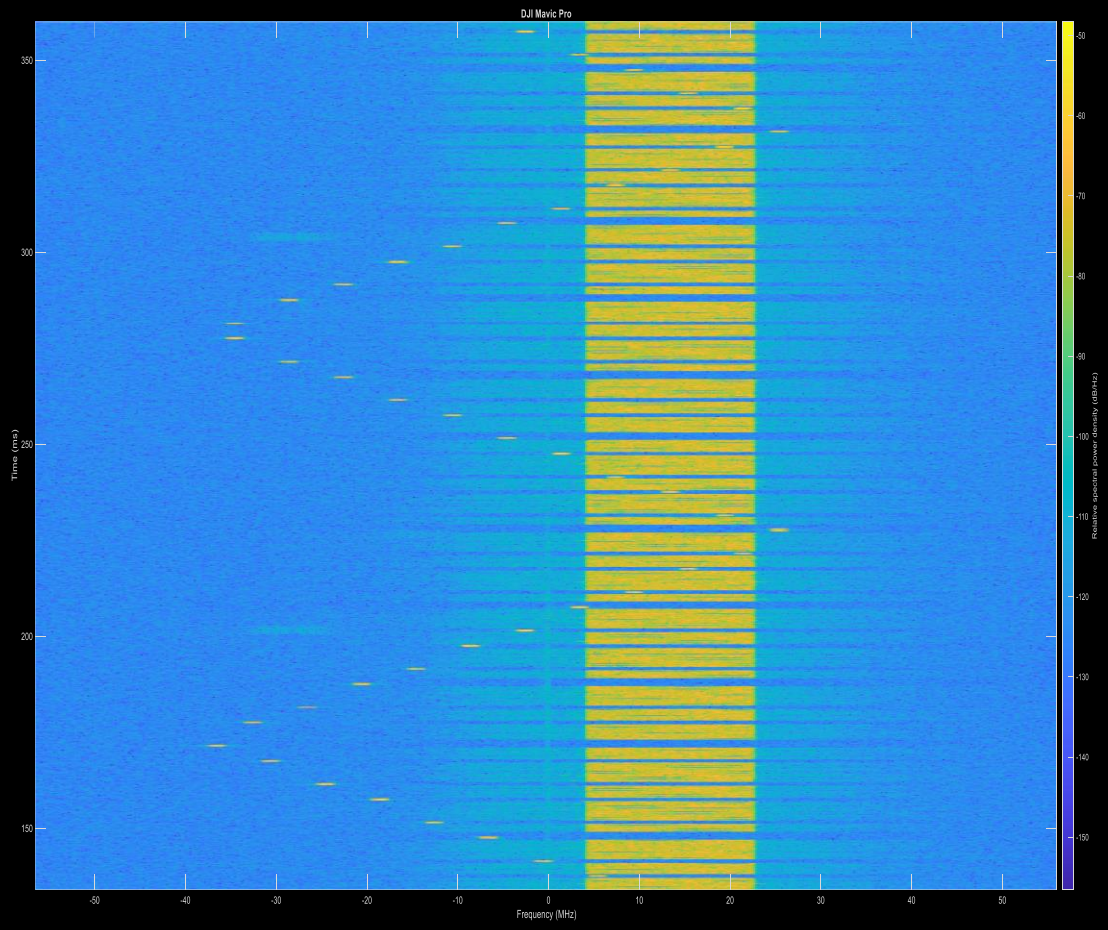
Introduction

Objective:

- Explain how modern machine learning can be applied to the challenges we face in the contested spectrum
- Discuss how Agile EM has taken those concepts to realized systems and the complexity we have encountered in doing so

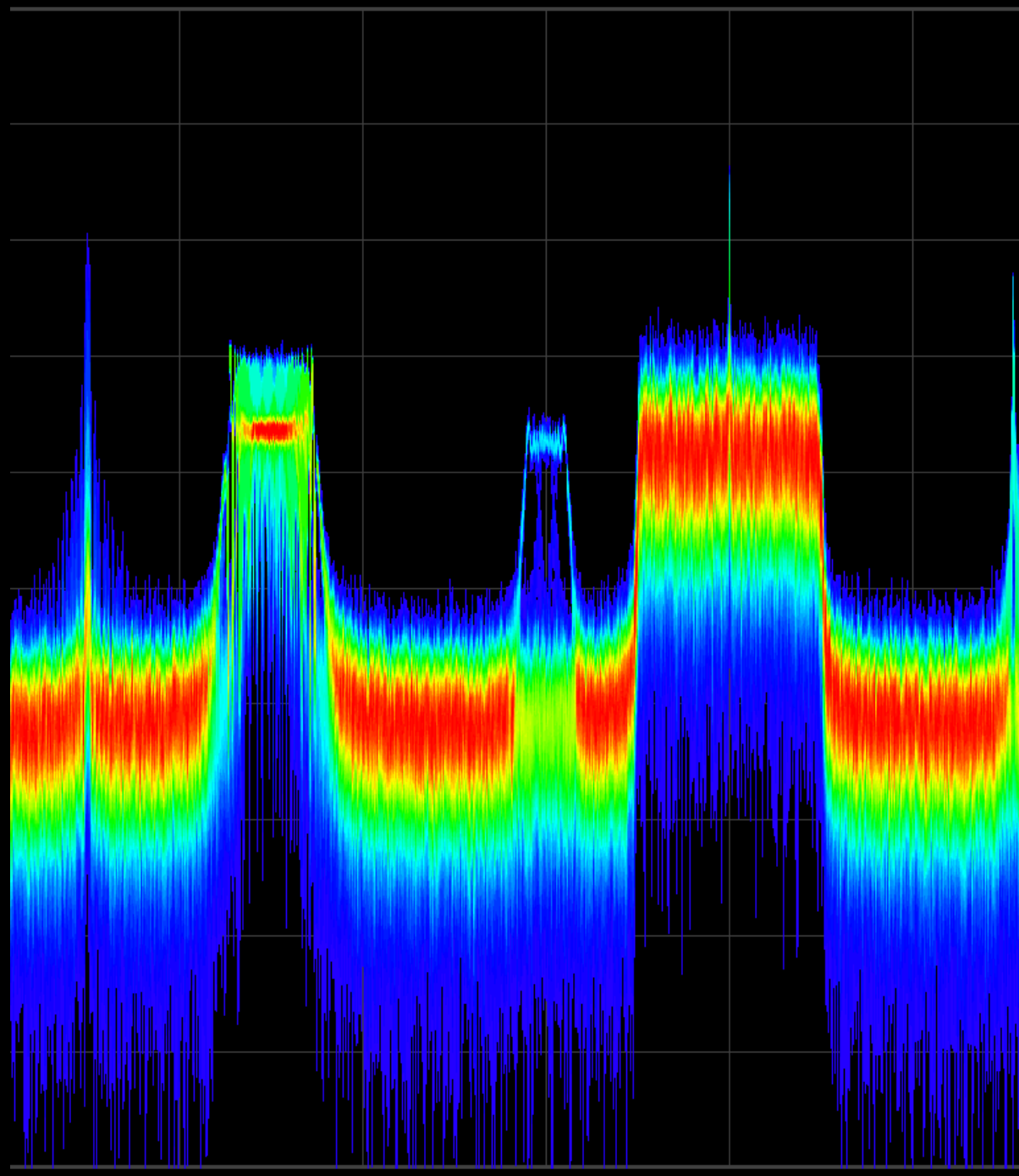
Agile Electromagnetics

- Cognitive EW systems / networks
- Multi-function apertures
- C-UAS



Introduction to Cognitive EW

Real-Time Cognitive EW Systems



Problem = Data

Sensors are becoming lower cost, networked, and need to produce understanding, not just information

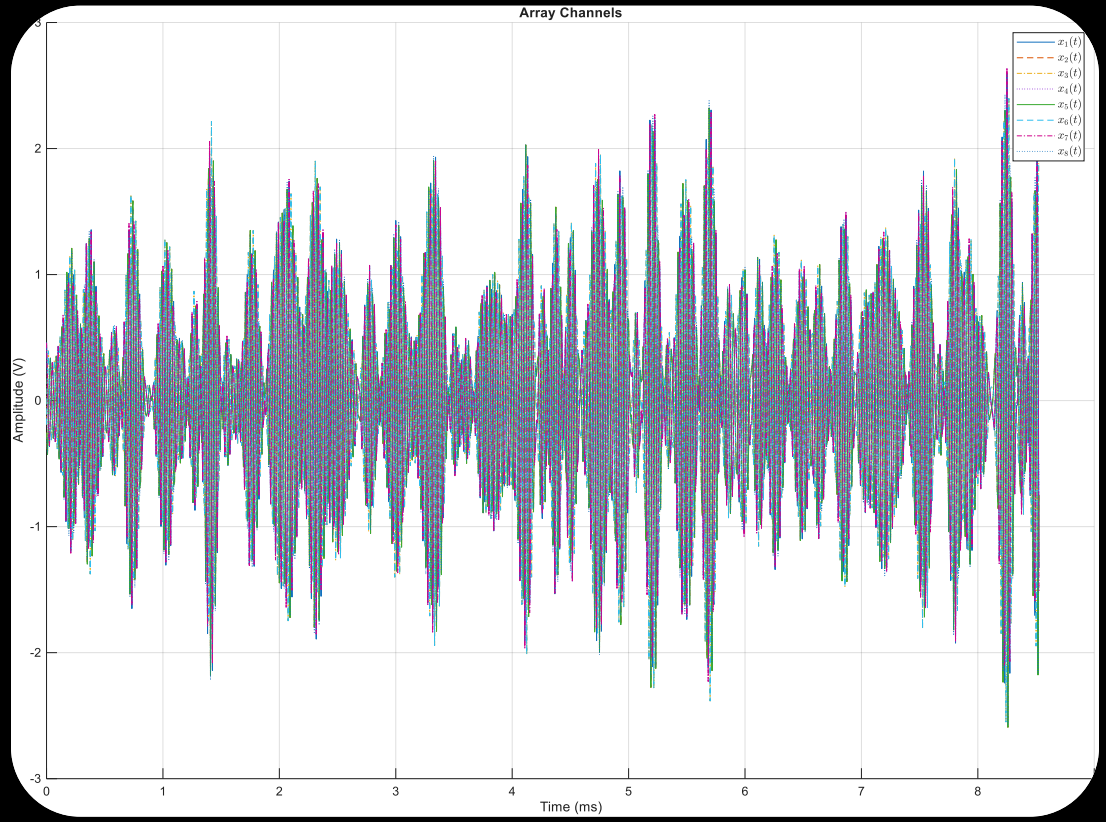
- Our digital array produces > 4 Tbps
- Networked 4 sensors = 16 Tbps
- Congested spectrum
- Mean-time to Intercept (MTI) / Probability of Intercept (POI)

Machine learning tools are mature solutions to EW signal processing problems

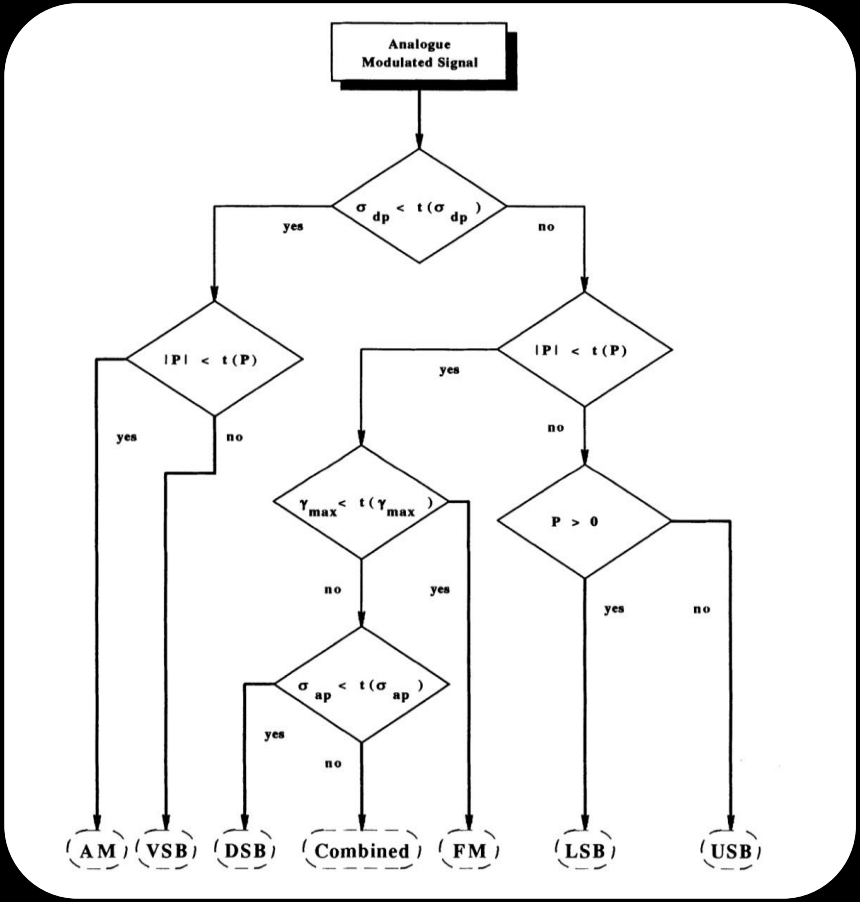
- Classification
- Clustering
- Deinterleaving

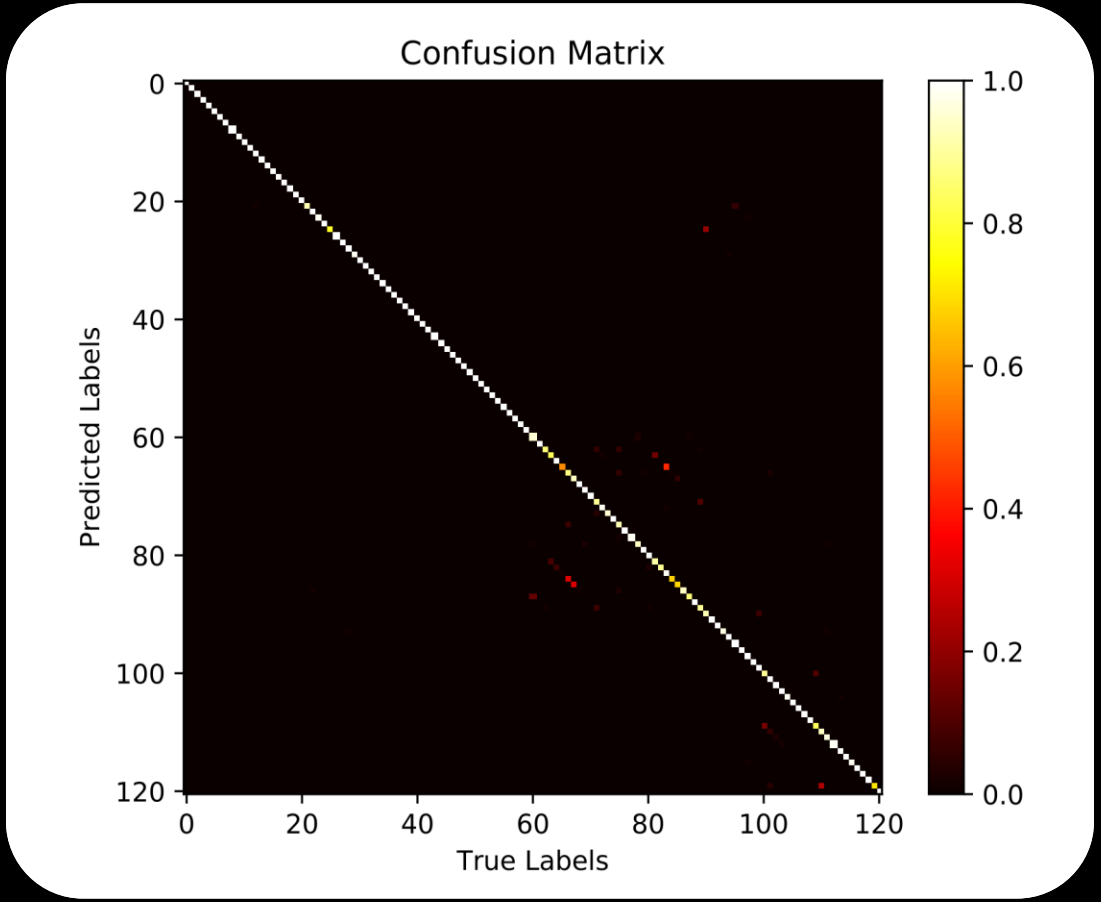
How do exploit these tools to move from

N soldiers : 1 sensor to **1 soldier : N sensors**?

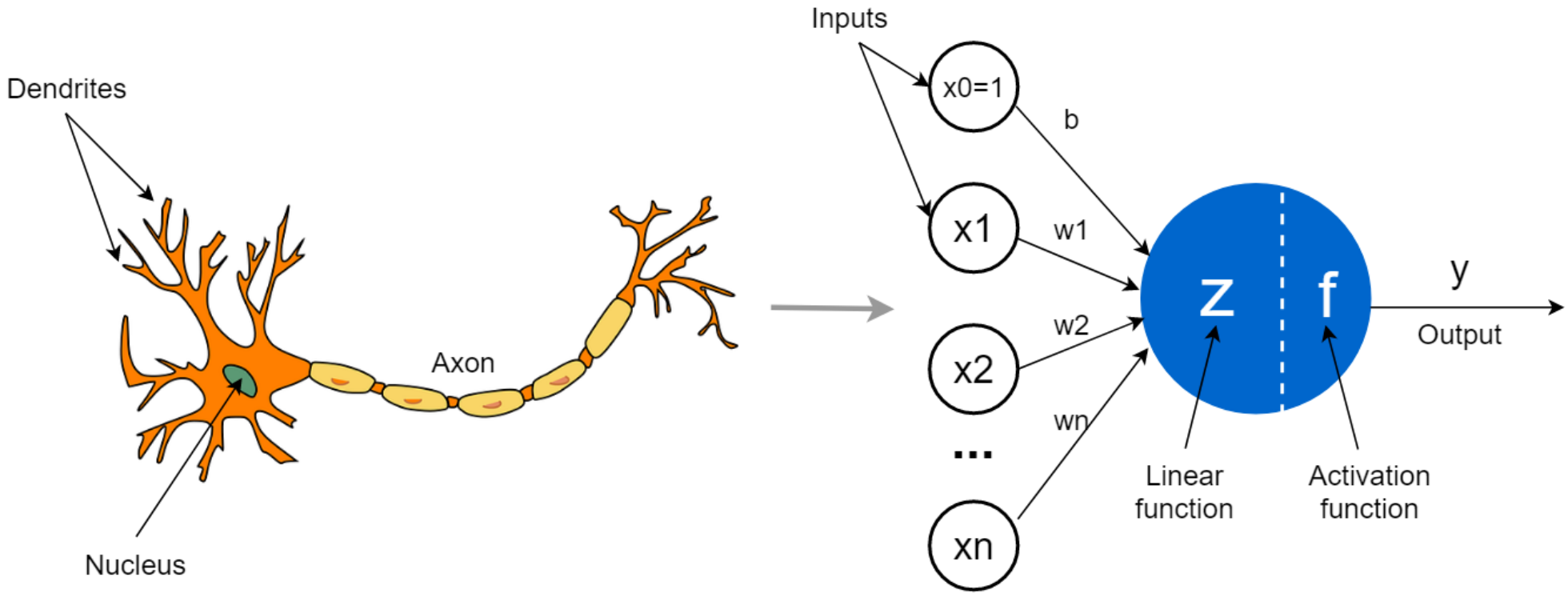


Classification in EW





Neural Networks



Clustering

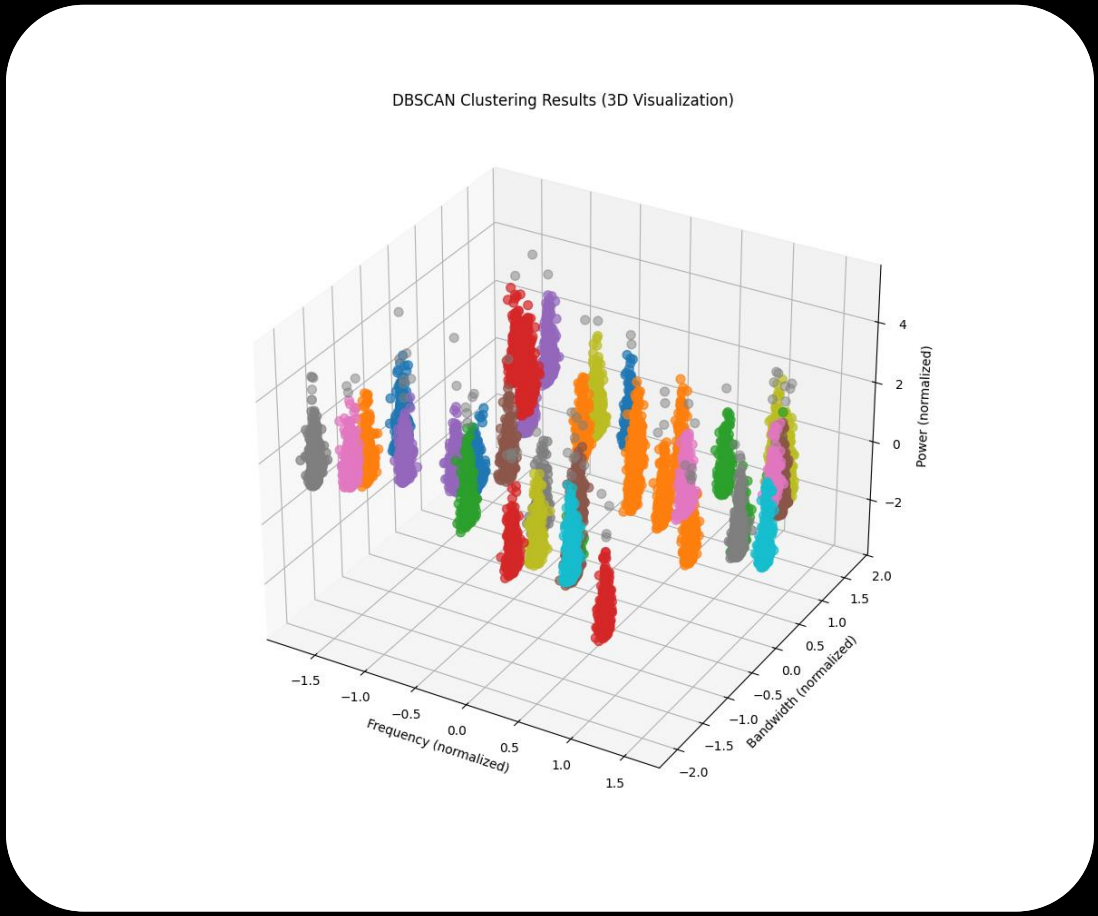
No labeled data

Common problem in EW

- Associating PDWs
- Deinterleaving pulse trains
- Geolocation in a sensor network

How do we cluster the data?

- K-means
- HDBSCAN
- GMM



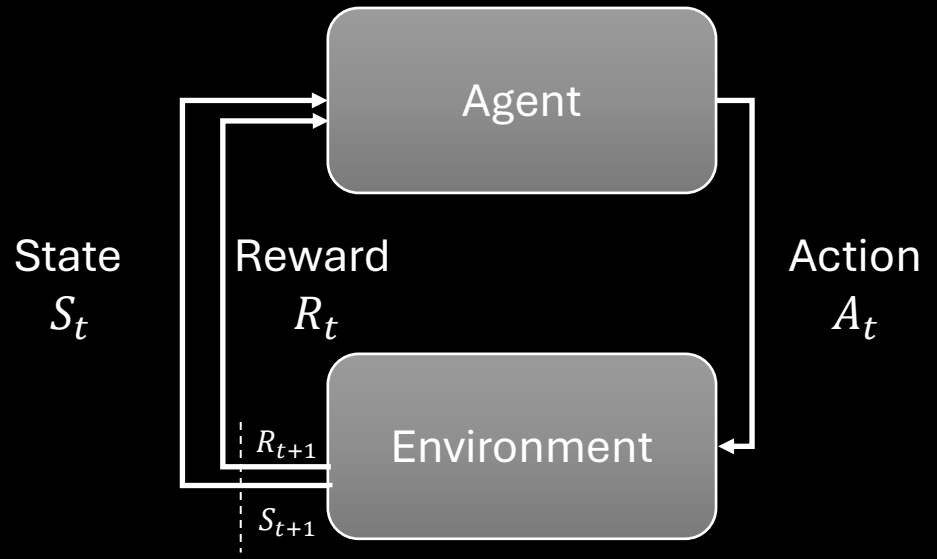
Reinforcement Learning

The algorithm now has:

- State
- Action

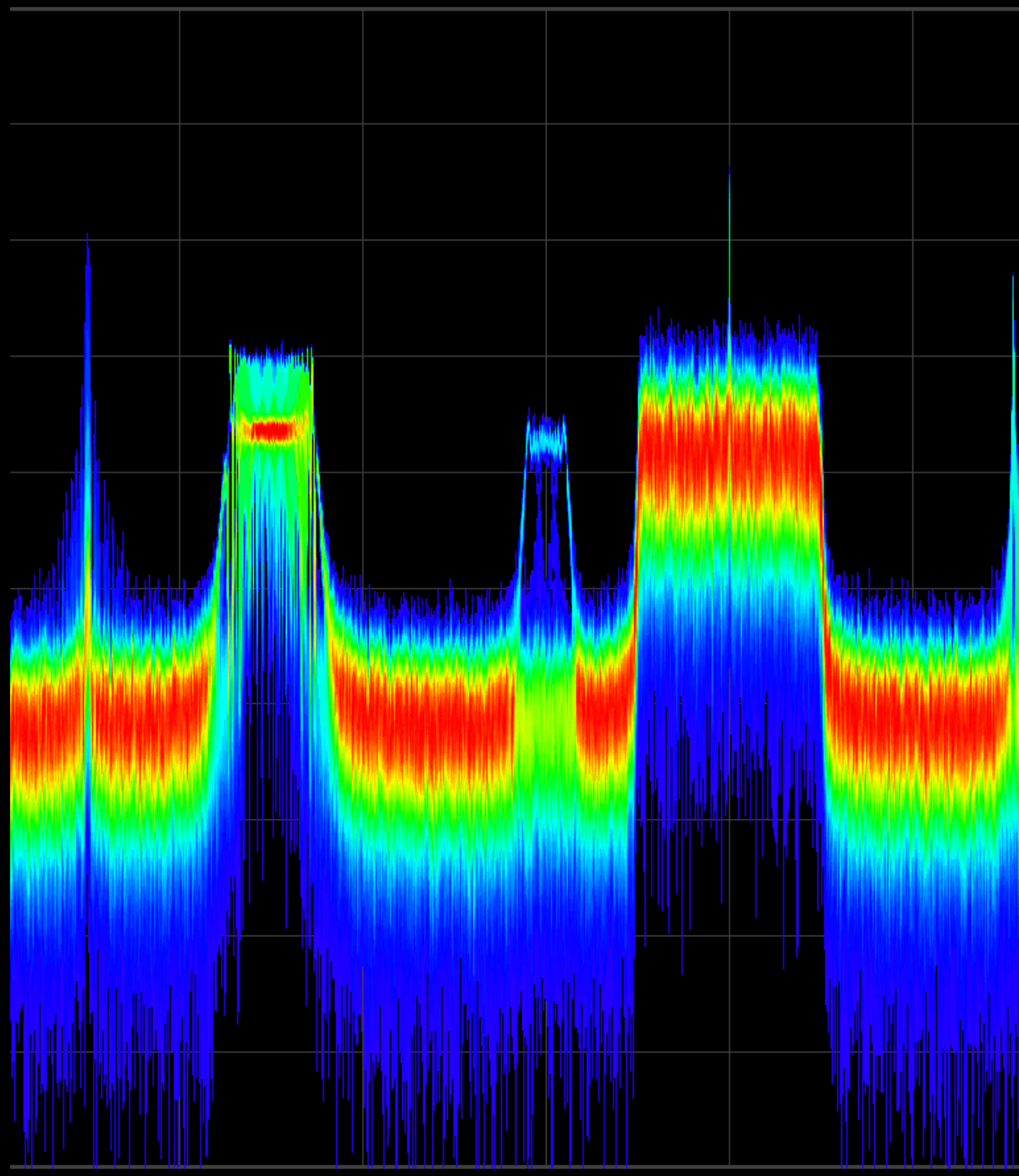
The goal is to learn to optimize:

- Policy
- Reward
- Value



Processing Hierarchy

Real-Time Cognitive EW Systems



Processing Hierarchy

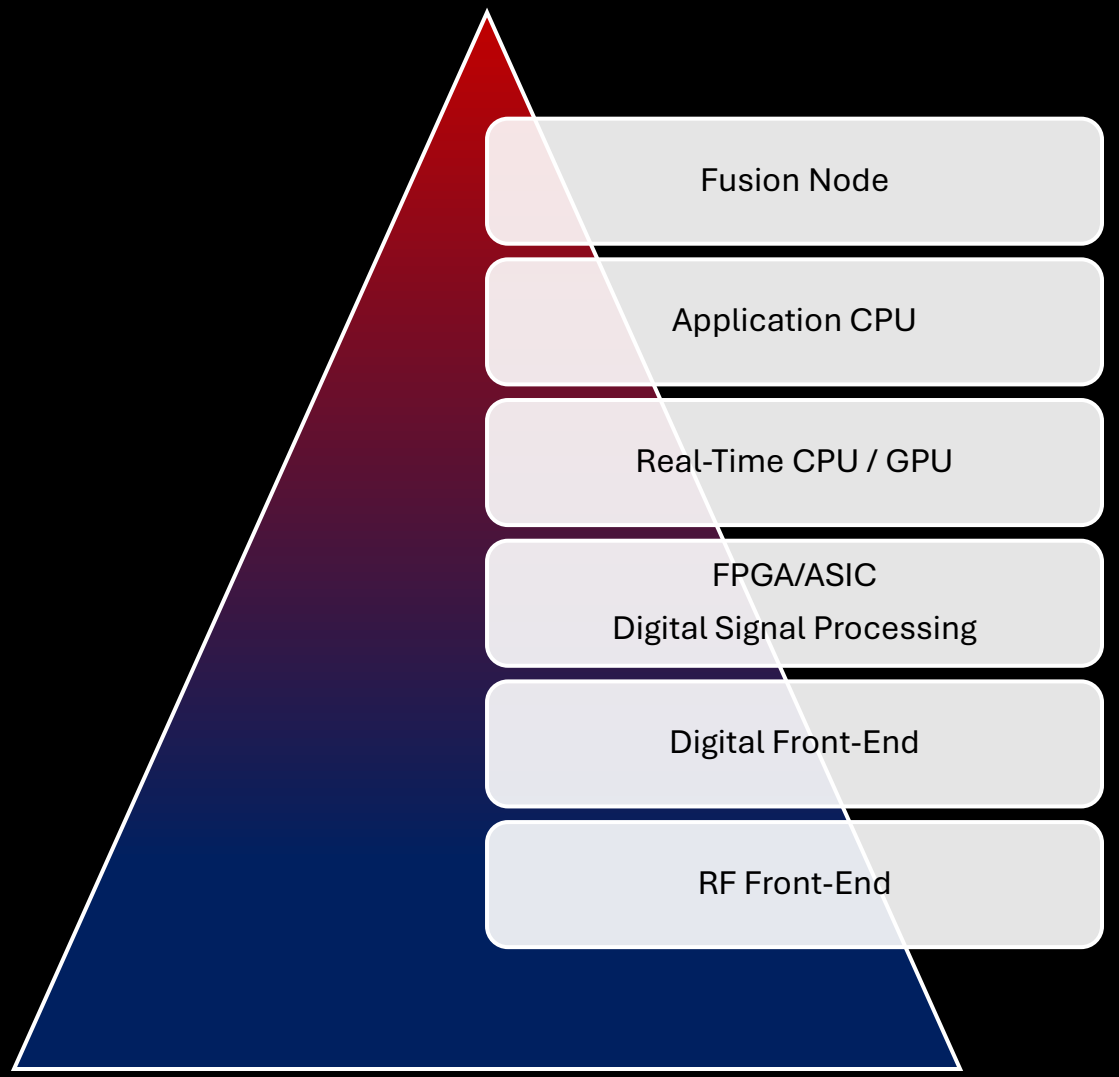
Assume a sensor/effector network:

- Processing capacity is higher at the bottom
- Flexibility is higher at the top

Data moves across layers as needed

FPGA focusses on I/Q data

CPUs control data and perform low throughput processing



Sampled I/Q Data

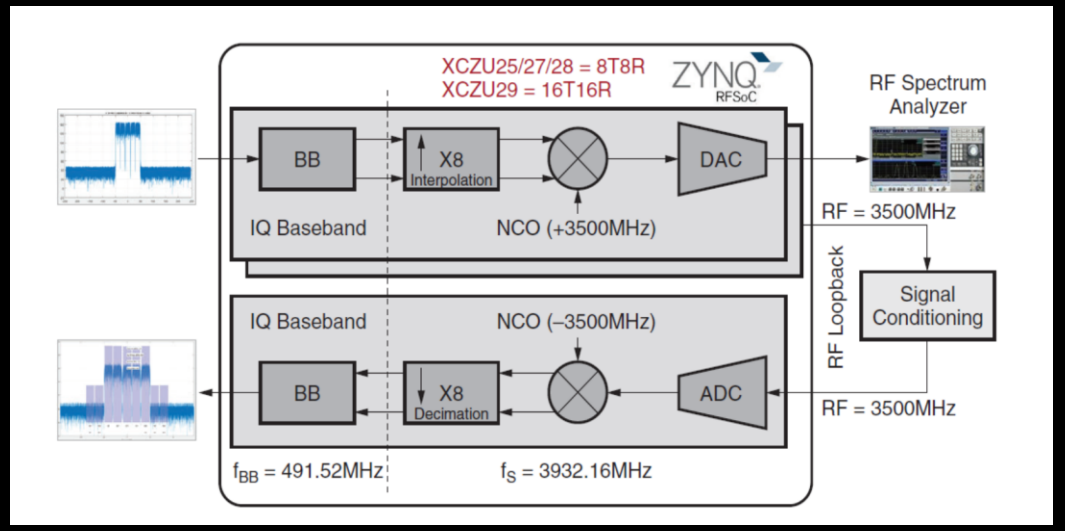
The received signal is represented by a 2D matrix that is $N \times L$ in size.

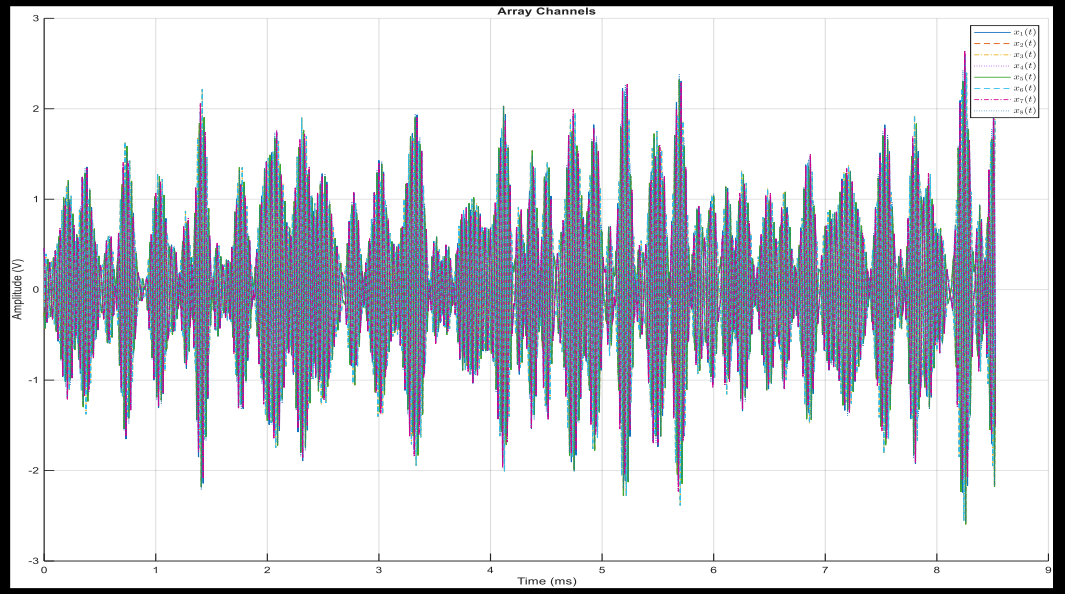
However, the data is now represented as complex numbers that are 32-bits in size (16-bits real / 16-bits complex):

$$\vec{x}[\vec{k}] = \begin{bmatrix} x_1[k_1] & \dots & x_1[k_L] \\ \vdots & \ddots & \vdots \\ x_N[k_1] & \dots & x_N[k_L] \end{bmatrix}$$

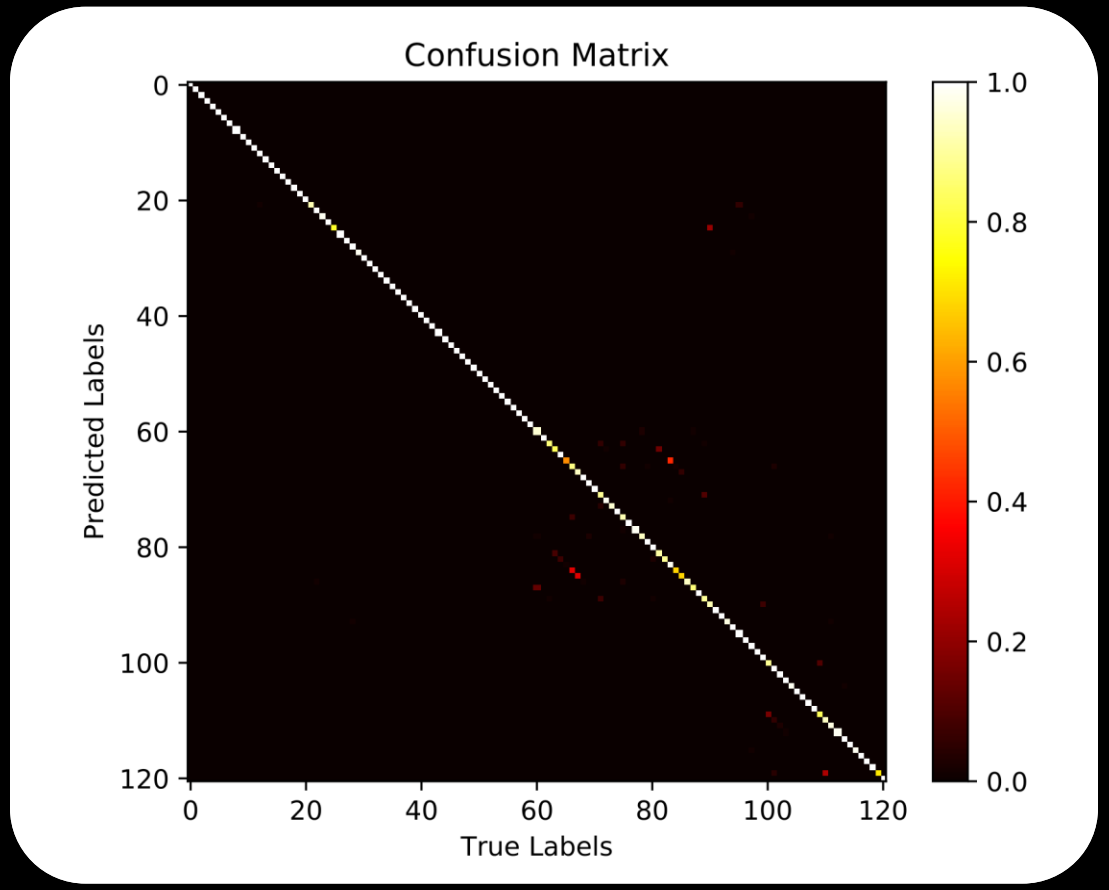
Each row represents a channel (antenna) of the N-channel array.

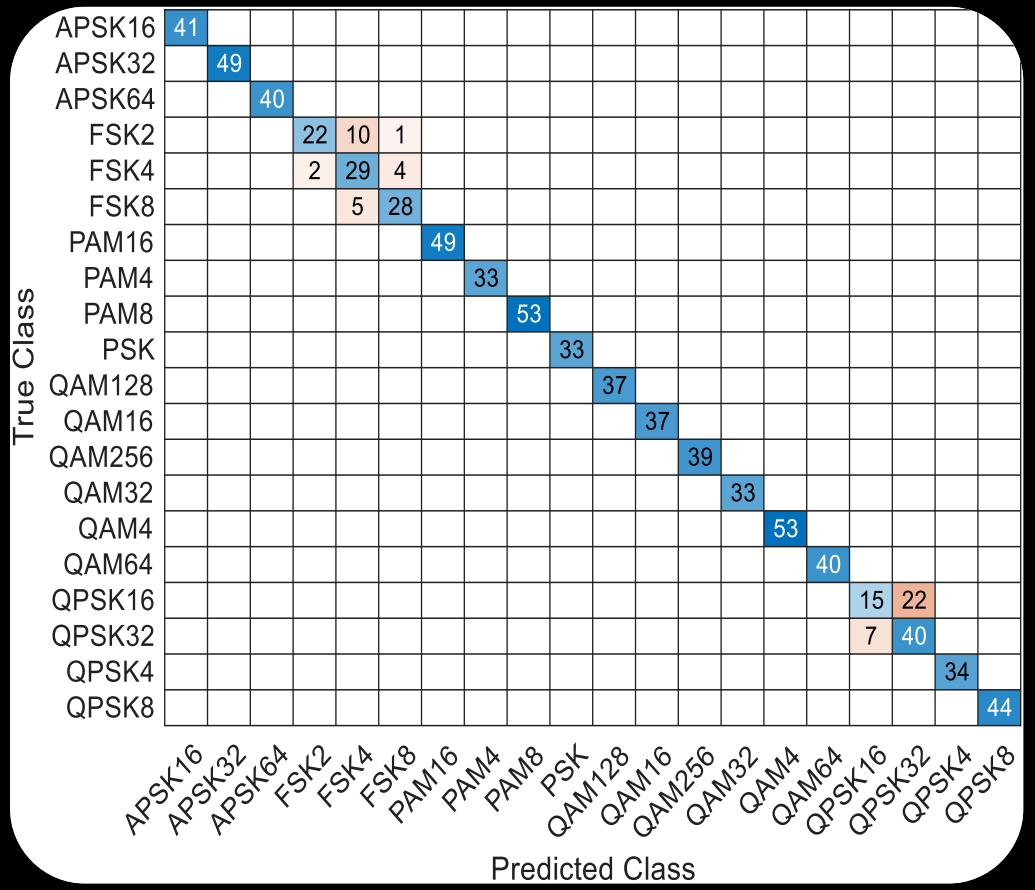
Each column represents a time element, with a total of L samples.





Classifier Example





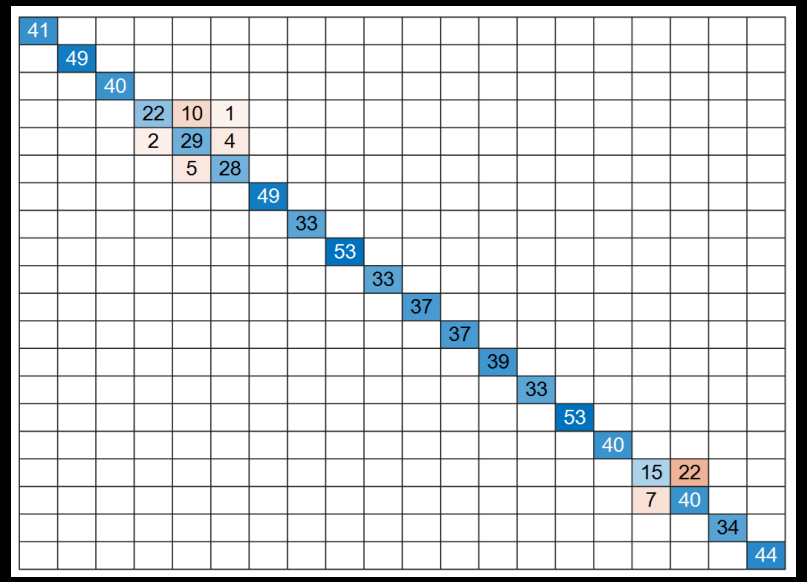
Observations

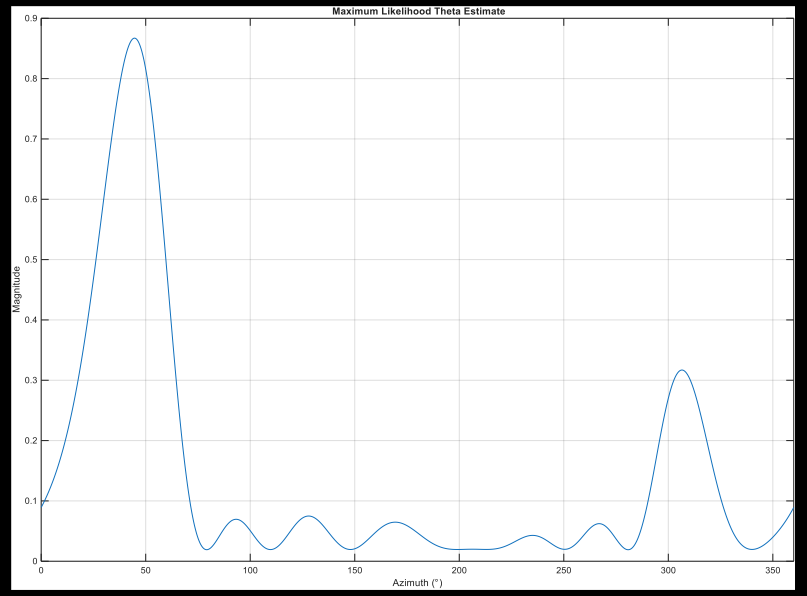
The goal of the observation is to encode low level RF data into a vector representation for use in data fusion and machine learning

$$\vec{\rho} = \begin{bmatrix} s \\ \vec{r}_s \\ t_o \\ \vec{f} \\ \vec{\sigma}_f \end{bmatrix}$$

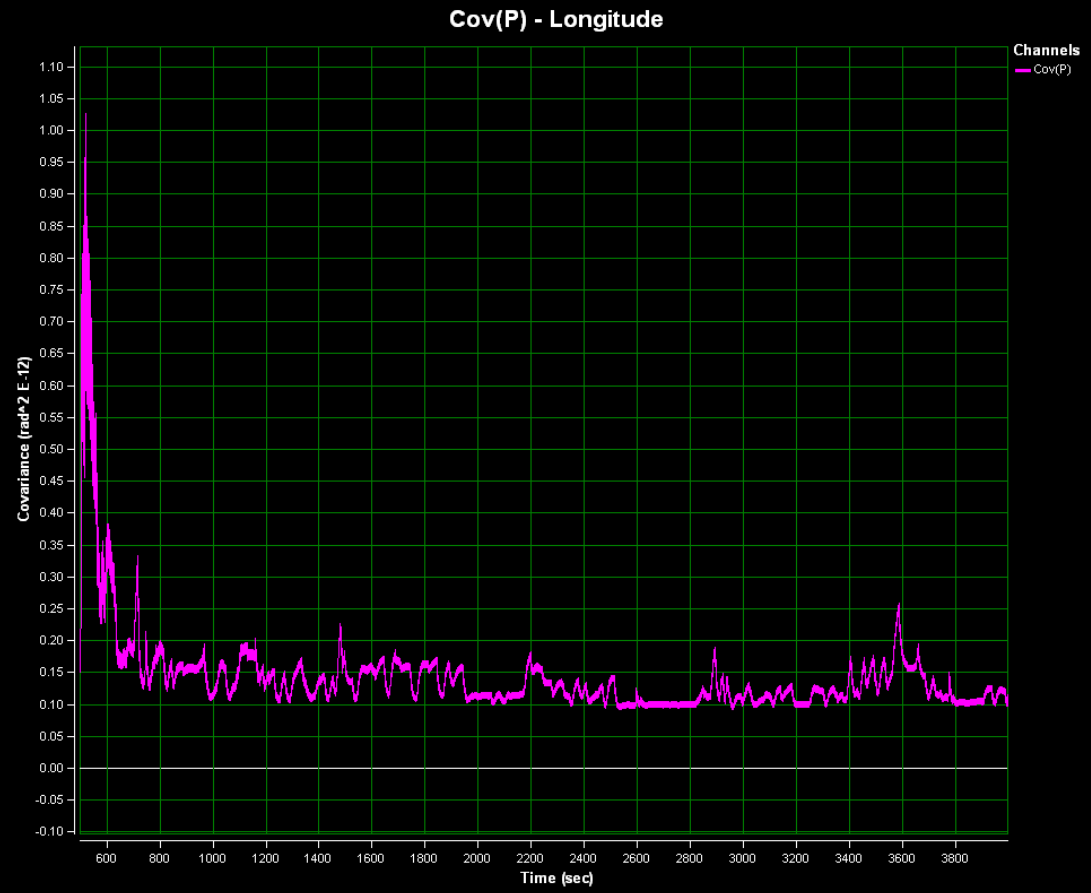
Critical metric is accuracy in encoding features

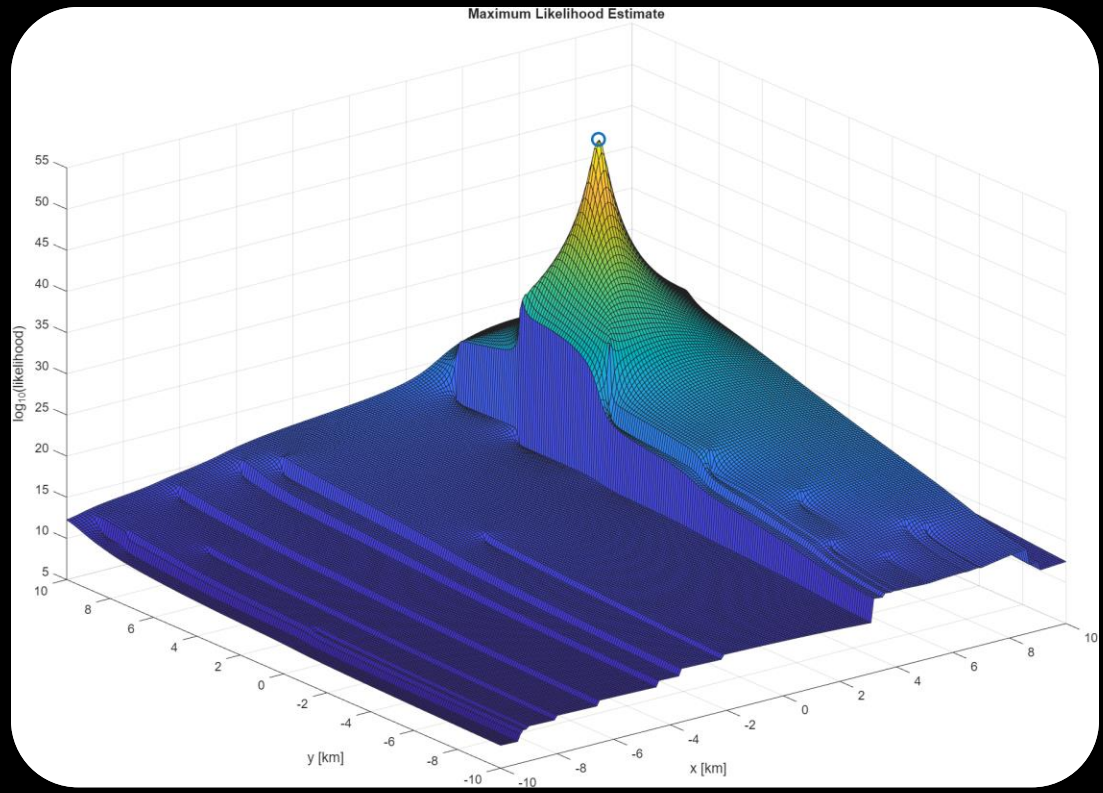
Catastrophic data fusion…





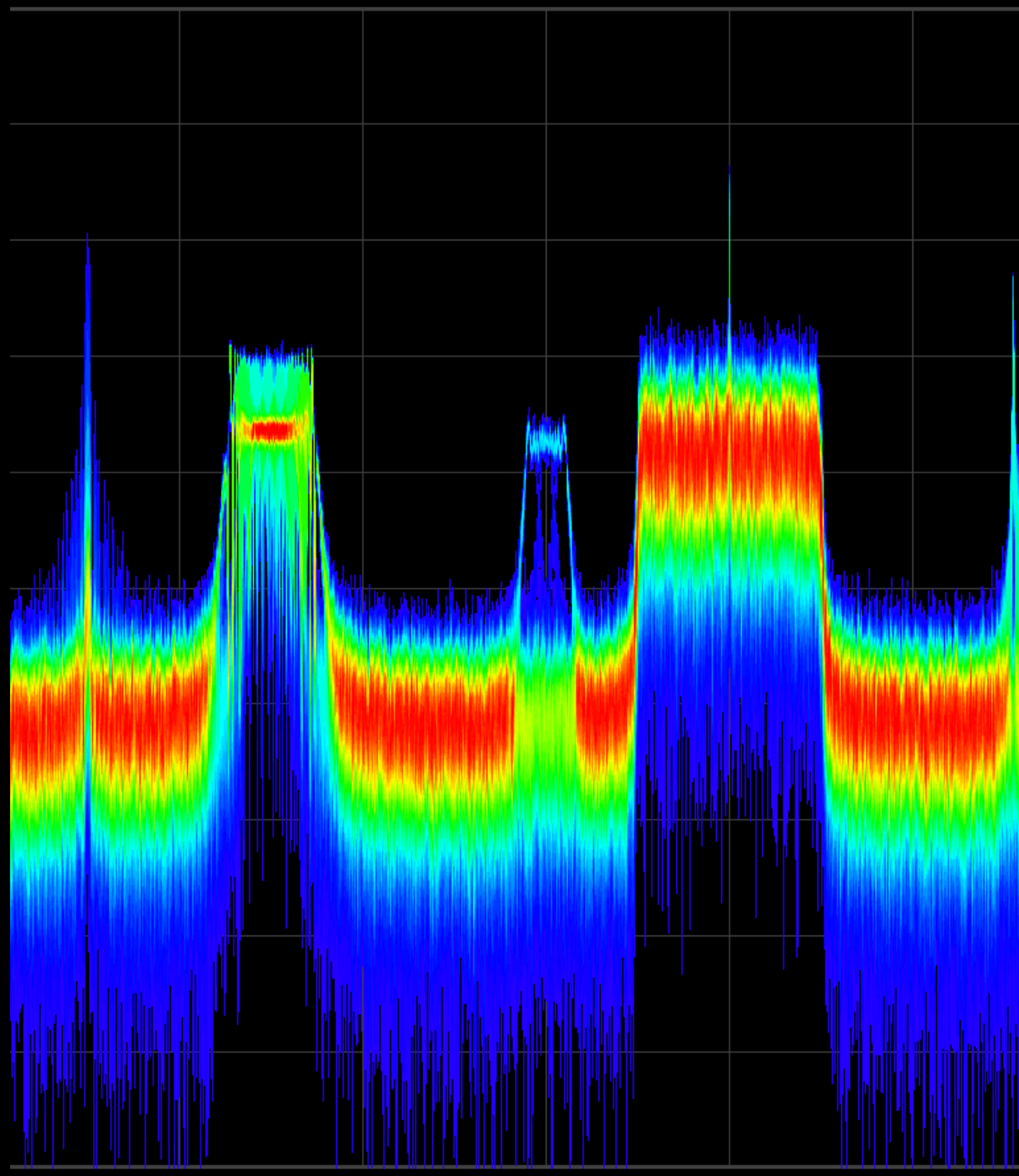
Emitter Tracking





System Implementation

Real-Time Cognitive EW Systems



Open-Source Dataset

DJI Inspire 2

DJI Matrice 100

DJI Matrice 210

DJI Mavic Mini

DJI Mavic Pro

DJI Phantom 4

DJI Phantom 4 Pro Plus

Parrot Disco

Parrot Mambo

Yuneec Typhoon H

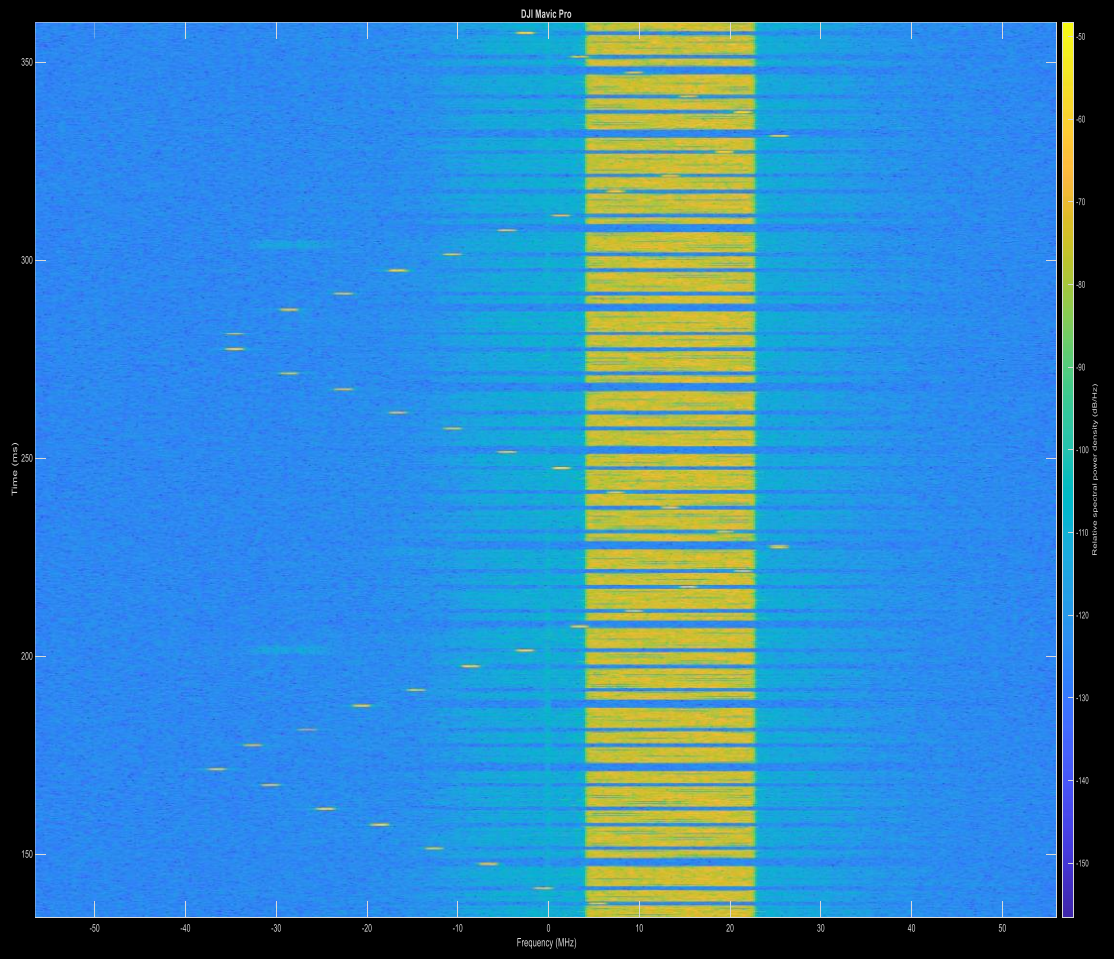
Drone Signals

https://zenodo.org/records/4264467

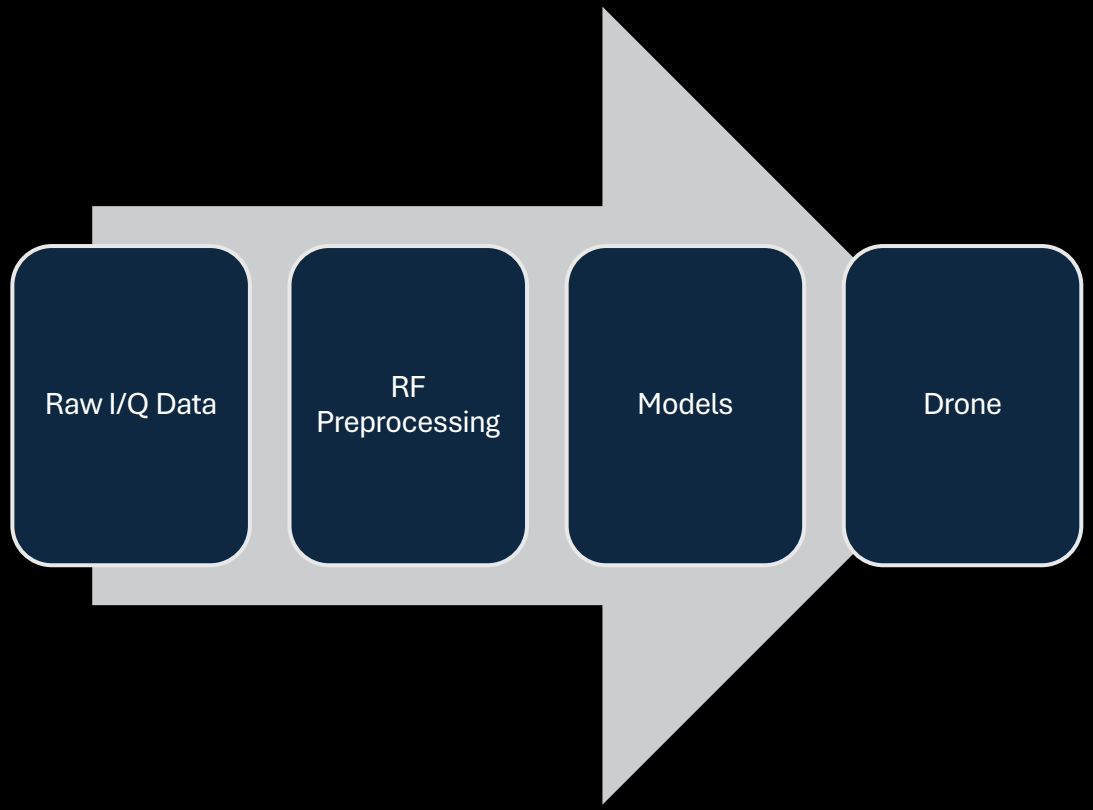
- 16-bit at 120/200 MHz for 2.4/5.8 GHz
- 1 second of signal data
- Anechoic chamber => No interference

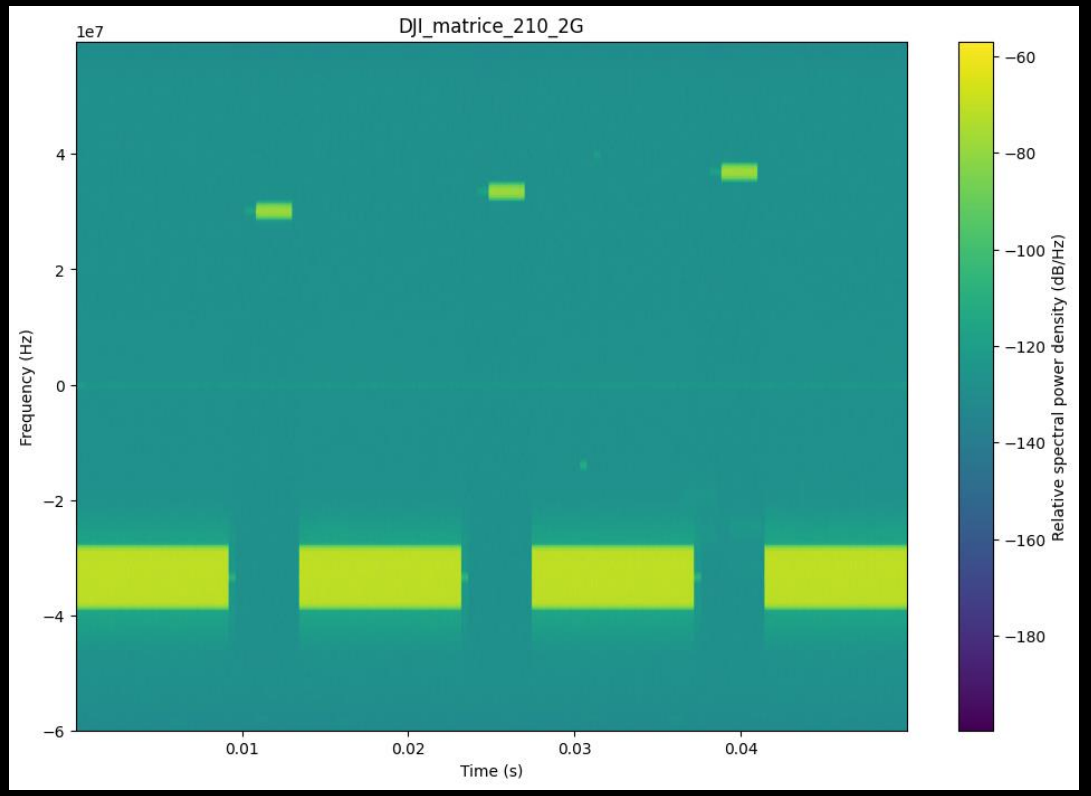
Not a challenging machine learning problem…

If we didn’t need to process in real-time.

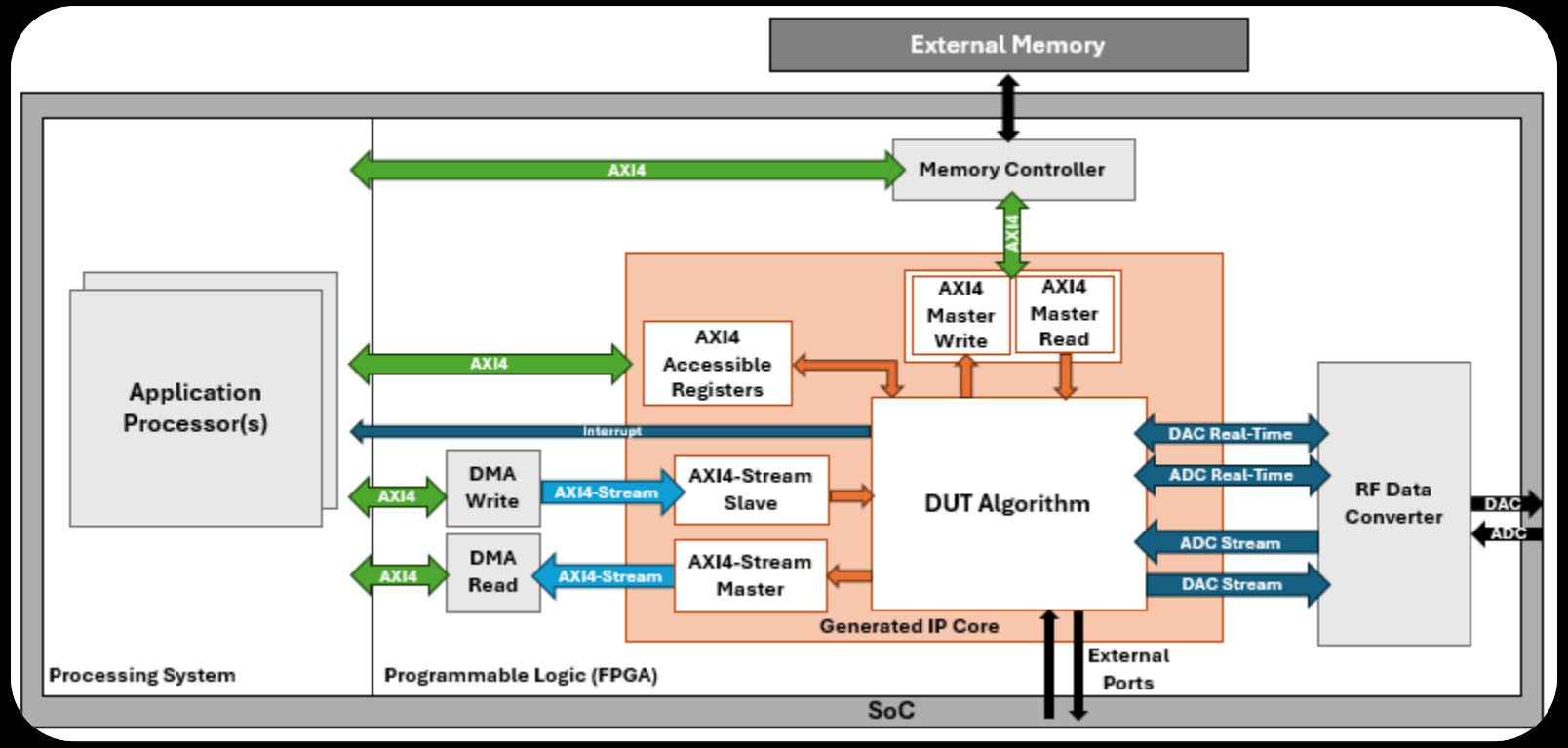


Data Processing





Implementing the System



Model Implementation

Example is implemented on a Pynq Z2 board

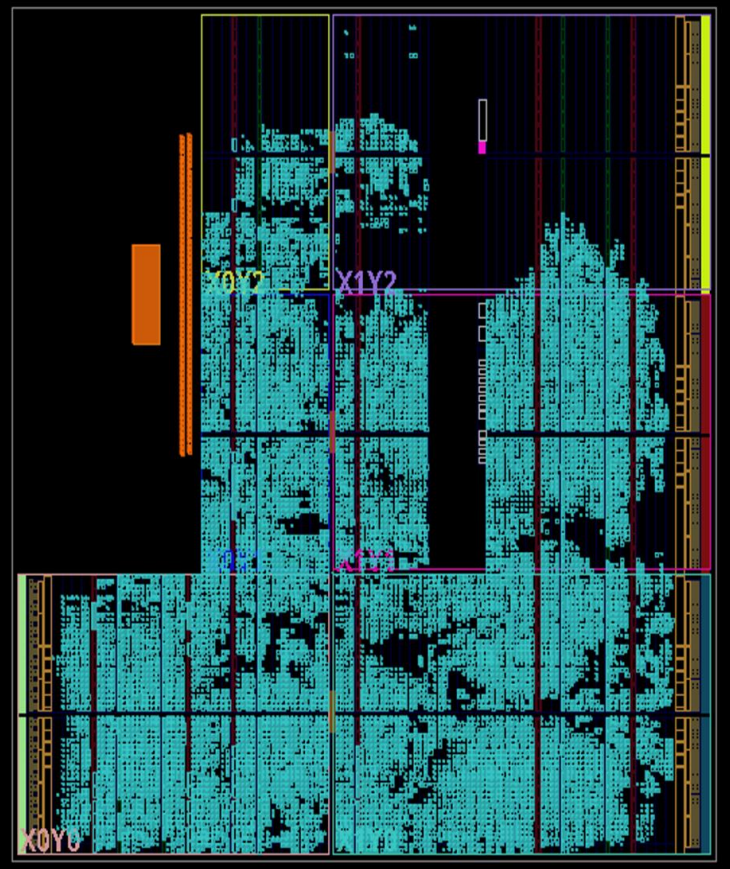
- Artix-7 FPGA fabric
- 53 200 LUTs
- 220 DSP slices

Model occupies most of the FPGA

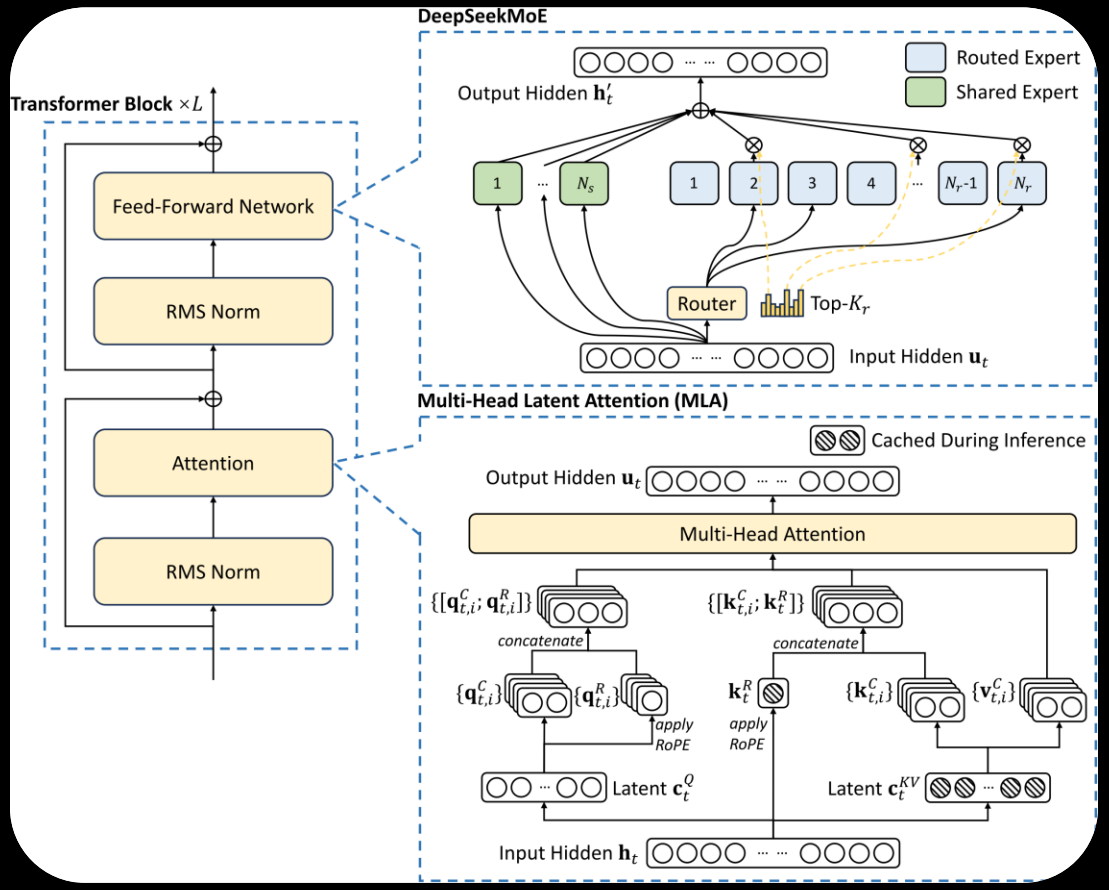
- Small FPGA
- No associated pre-processing
- Fixed-point model

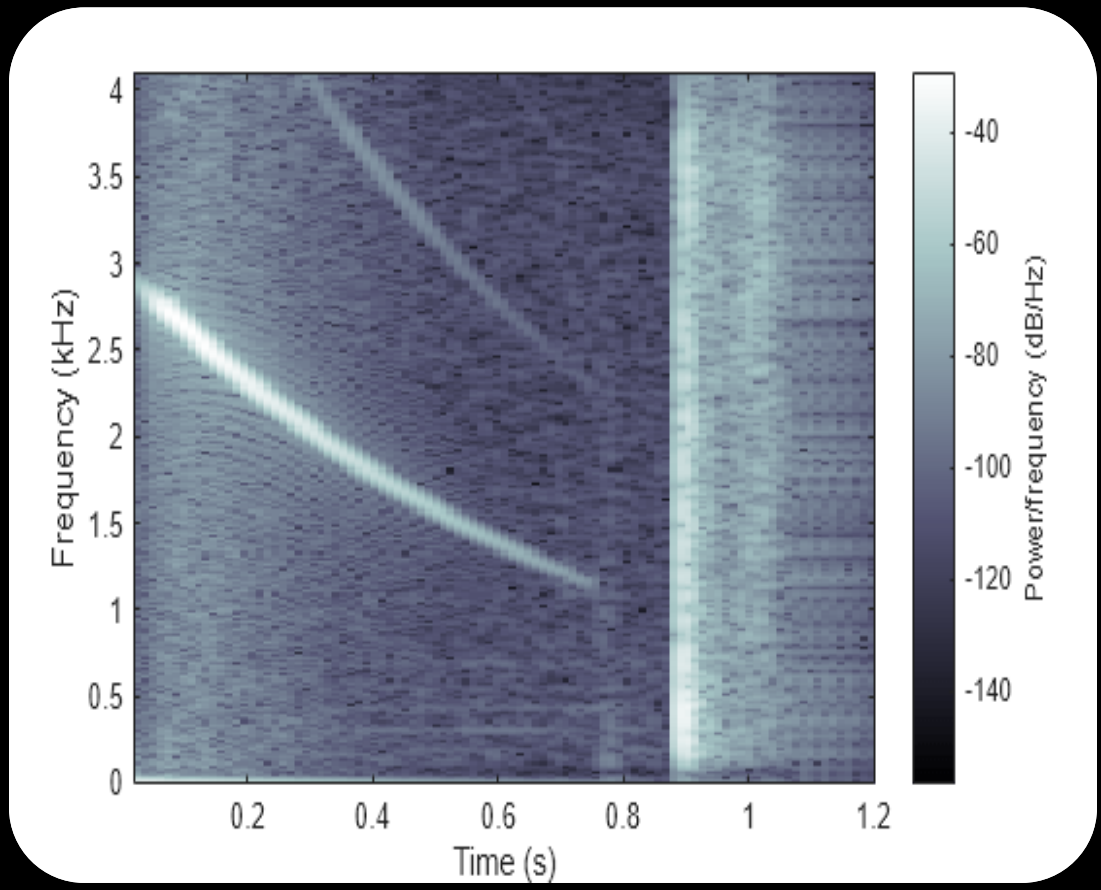
Accuracy ≈ 96 % with RF signals

400 000 classifications per second



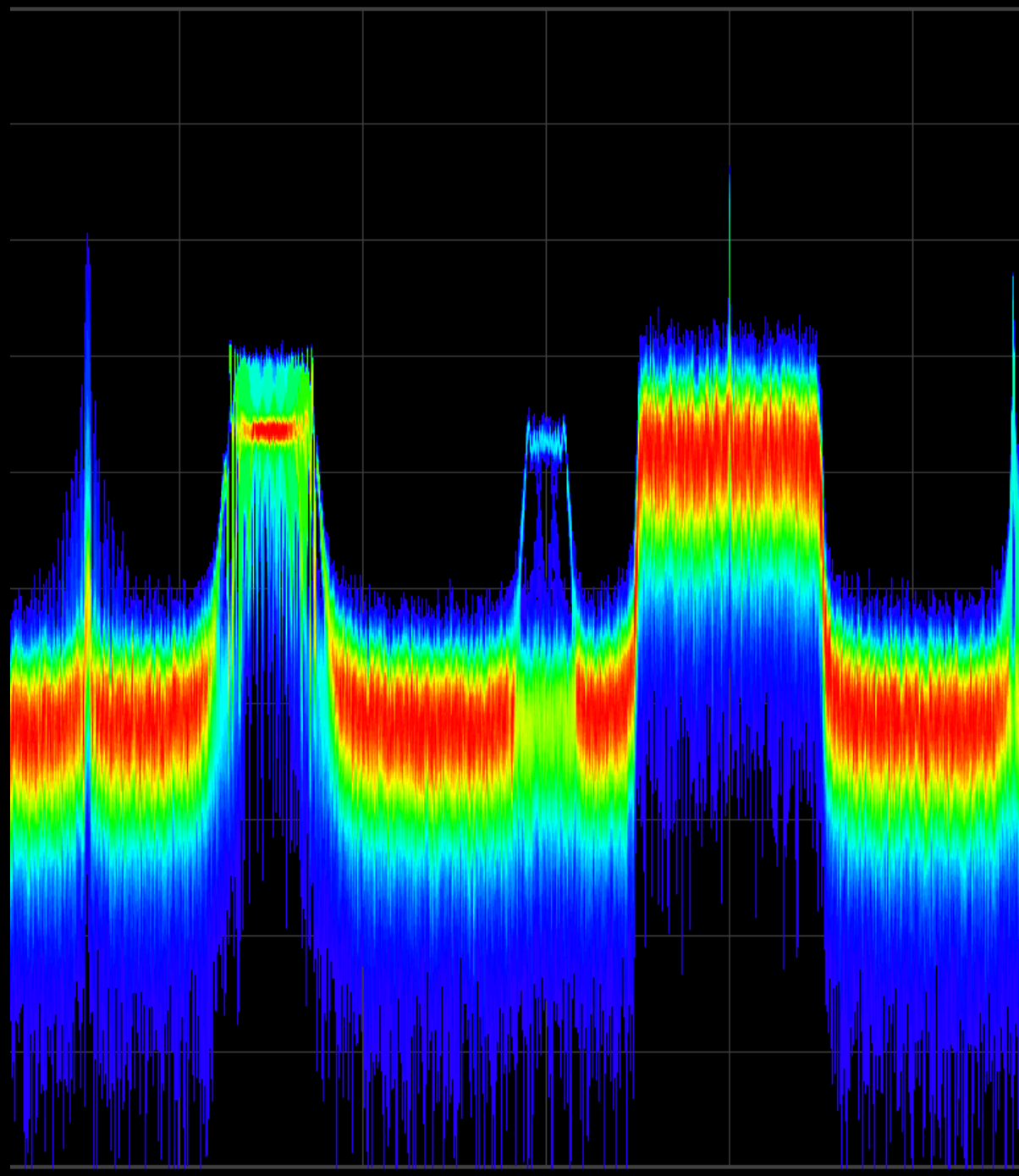
COMINT and LLMs





Conclusion

Real-Time Cognitive EW Systems



Conclusion

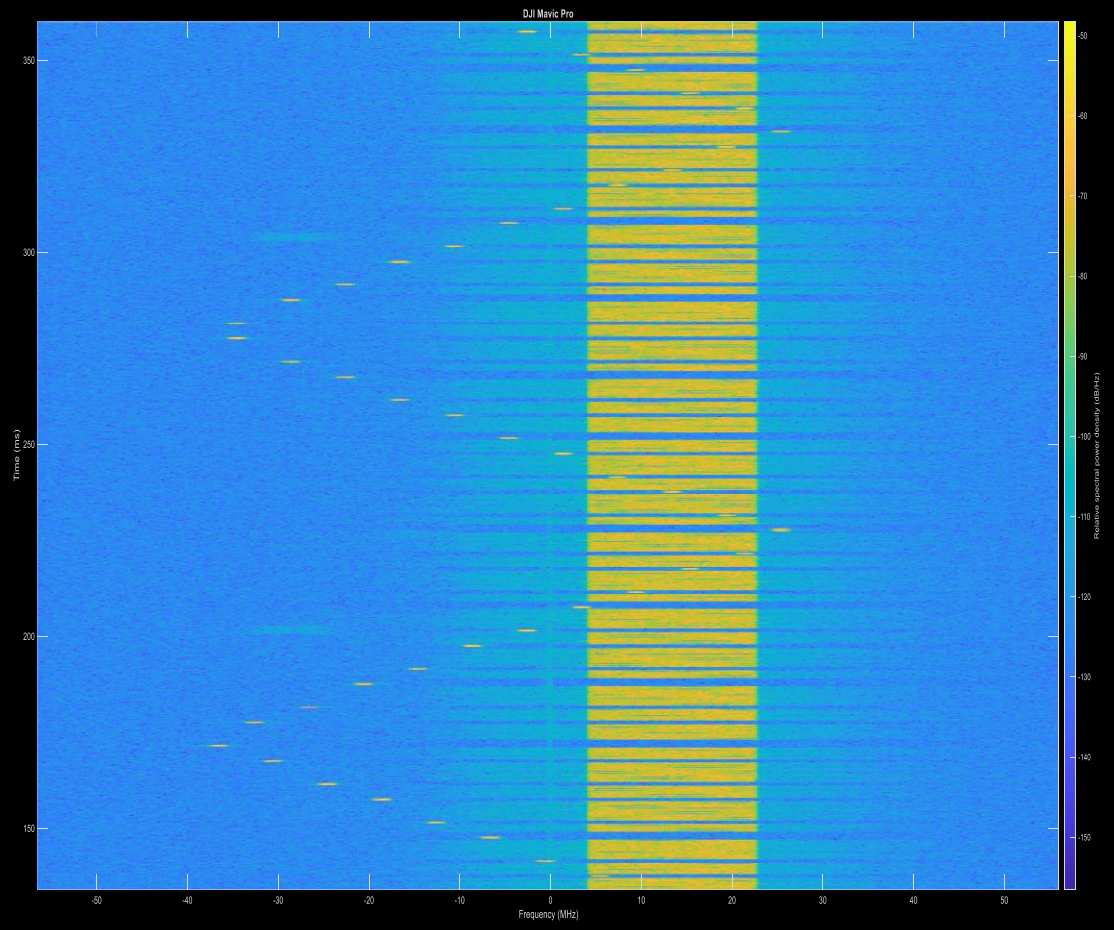
Machine learning and statistical signal processing can solve lots hard conventional EW tasks

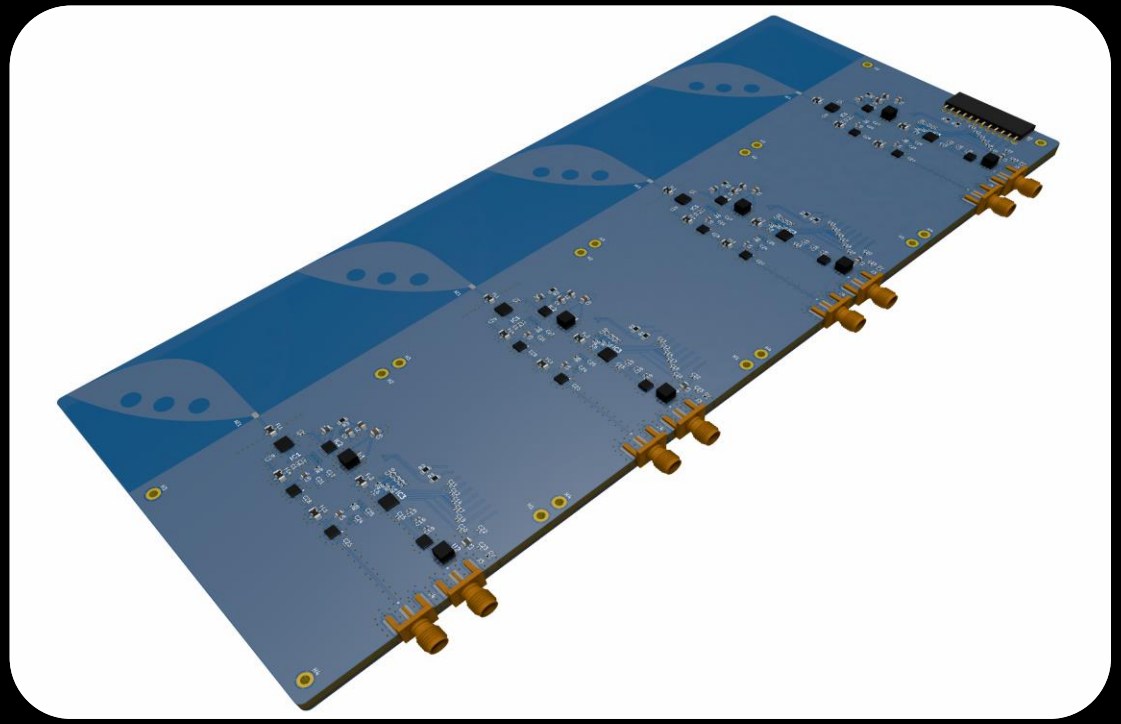
New approach to EW Operational Support

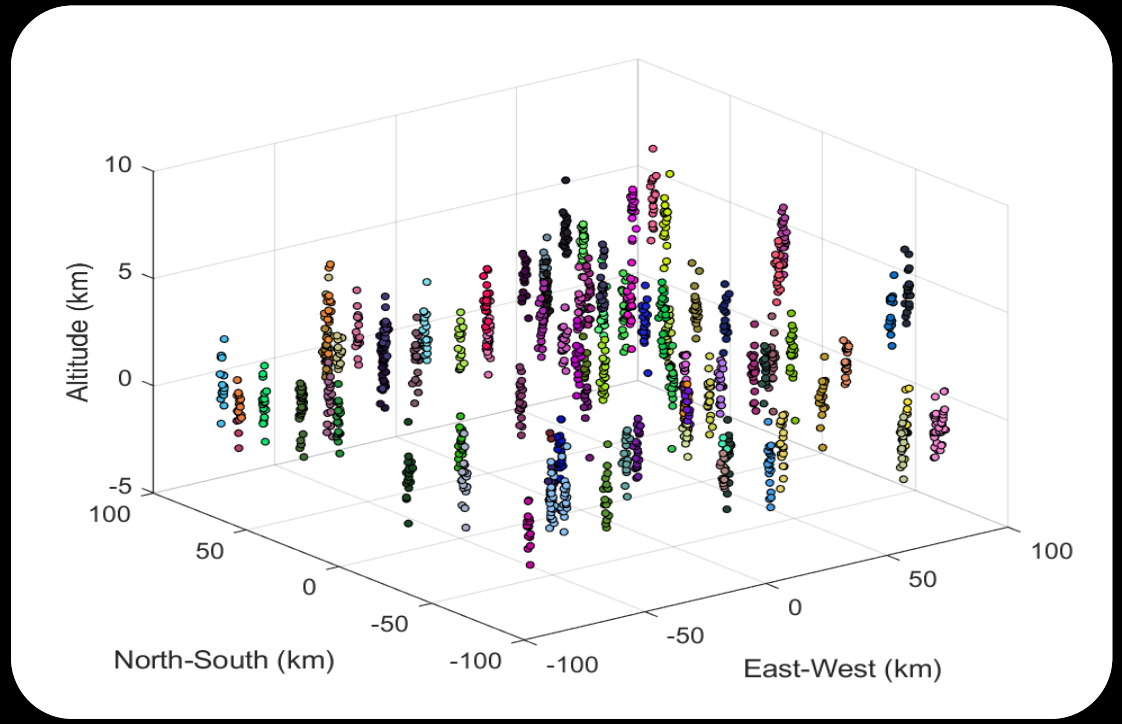
- Training models
- Generative AI

Disciplined approach to:

- Processing resource allocation
- When to stop training







Real-Time Cognitive EW Systems

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