Introduction to Radars and Its Use for Machine Perception

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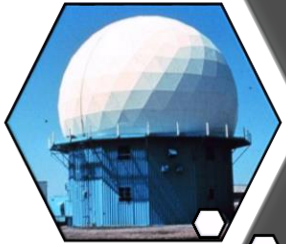
Overview

- Radar Uses
- Radar Basics
- Radar Signal Processing
- Recent Advancements with Radar-AI Networks

Radar Uses, Sensors in Various Systems, and Radar (In Focus)

Uses of Radars: Traditional vs Current and New Avenues



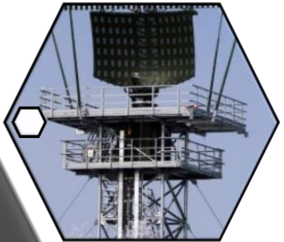
Military:

Surveillance (target tracking),

Anti-collision System (aircrafts)

Weather Monitoring:

Short time weather forecasting



Commercial:

Air traffic control,

Aircrafts to assist landing in bad weather,

Speed Gun

Gesture Recognition:

Wearables, IoT,

Gaming

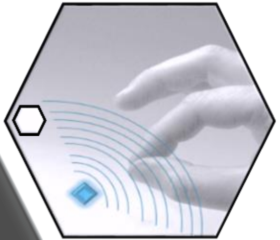
Sensing:

Automobile (ADAS),

Industrial robots,

Commercial,

Medical



Surveillance (SAR):

Drones (air borne),

Through wall

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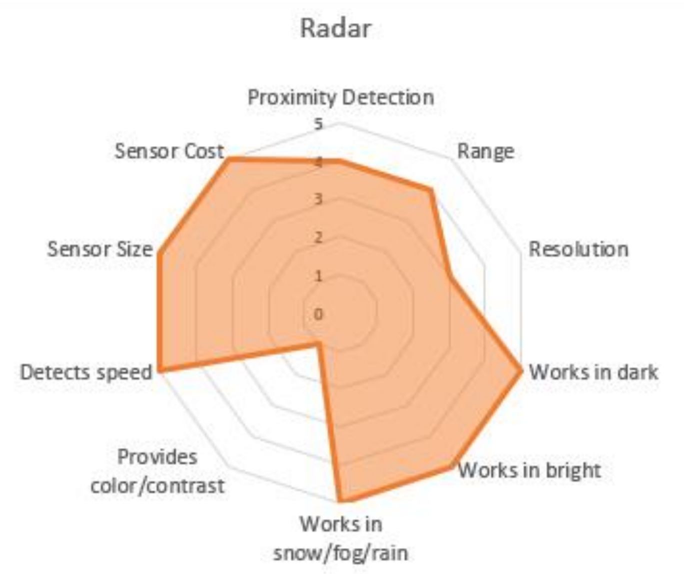
Comparative View of Sensors

	Camera	Radar	LiDAR	Ultrasonic	LiDAR+Radar+ Camera
Object detection	Yellow	Green	Green	Green	Green
Object classification	Green	Red	Yellow	Red	Green
Distance estimation	Yellow	Green	Green	Green	Green
Object edge precision	Green	Red	Green	Green	Green
Lane tracking	Green	Red	Red	Red	Green
Range of visibility	Yellow	Green	Yellow	Red	Green
Functionality in bad weather	Red	Green	Yellow	Green	Green
Functionality in poor lighting	Yellow	Green	Green	Green	Green



Credits

Radar Basics

Basic Principle of a Radar

Image Credits

Functions of a Radar and Classification

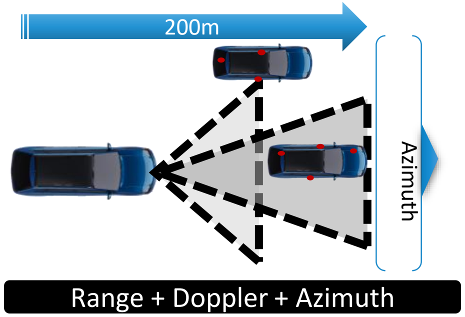
- Range determination:
  - How far is the target?
- Velocity determination:
  - How fast is the target moving w.r.t. to the radar?
- Angle of arrival determination:
  - The direction of the target and its movement

- Some radars have only a few of the above functions
- Frequency Modulated Continuous Wave (FMCW) radar can determine range, velocity, and the angle of arrival

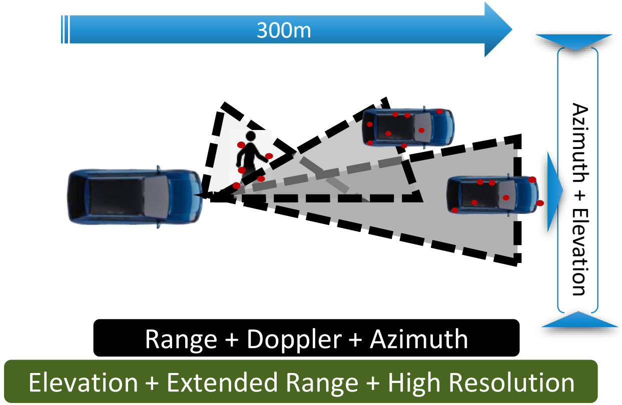
Functions of a Radar and Classification

- Properties of a FMCW Radar system
  - Maximum determinable: range, velocity, FOV
  - Resolution: range, velocity, and angle

- Classification of radar based on system properties as follows:
  - Short, medium, long-range radars
  - 3D (conventional), and 4D (imaging) radars

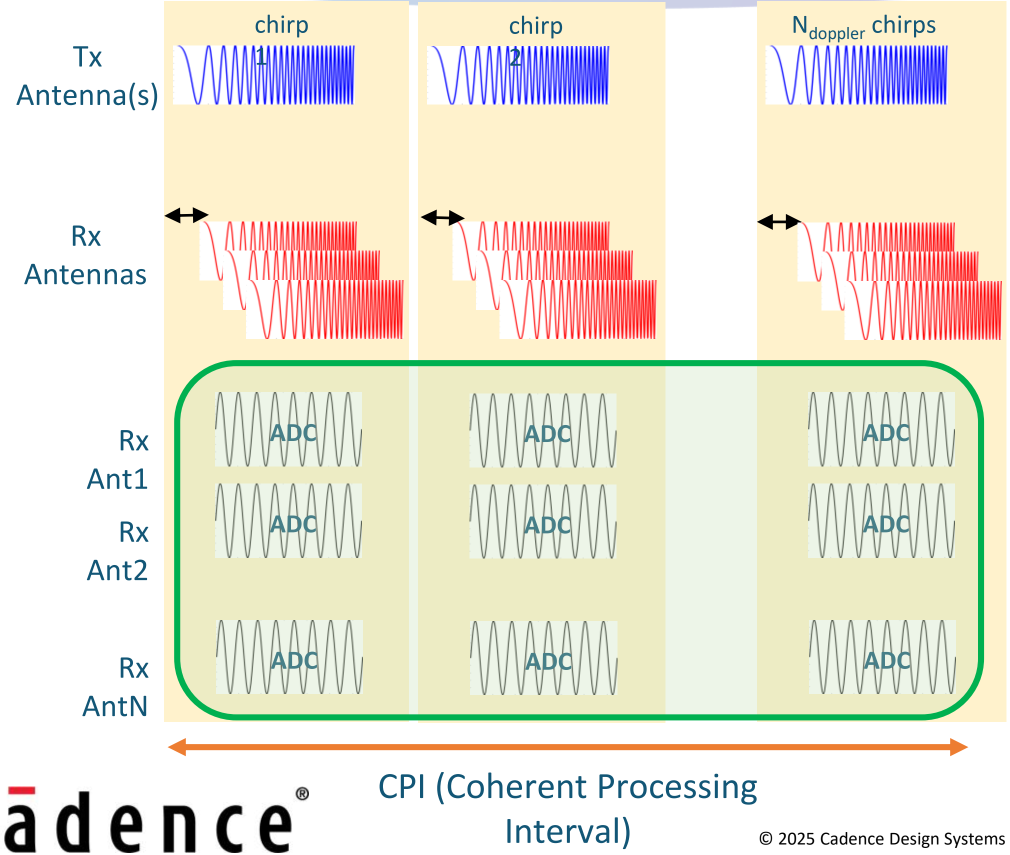


Conventional Non-Imaging Radars



4D- Imaging Radars

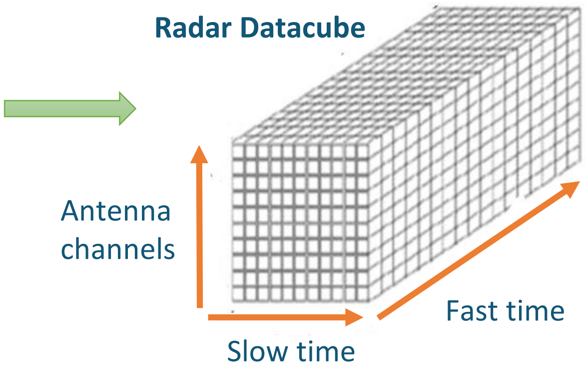
FMCW Radar and Datacube Generation



Example System/ Waveform Parameters

- λ= 3.9 mm (77 GHz)
- BW = 150 MHz
- Chirp duration = 12 µs
- CPI duration = 25 ms
- Number of chirps in CPI = $N_{doppler}$ = speed resolution

Radar Datacube



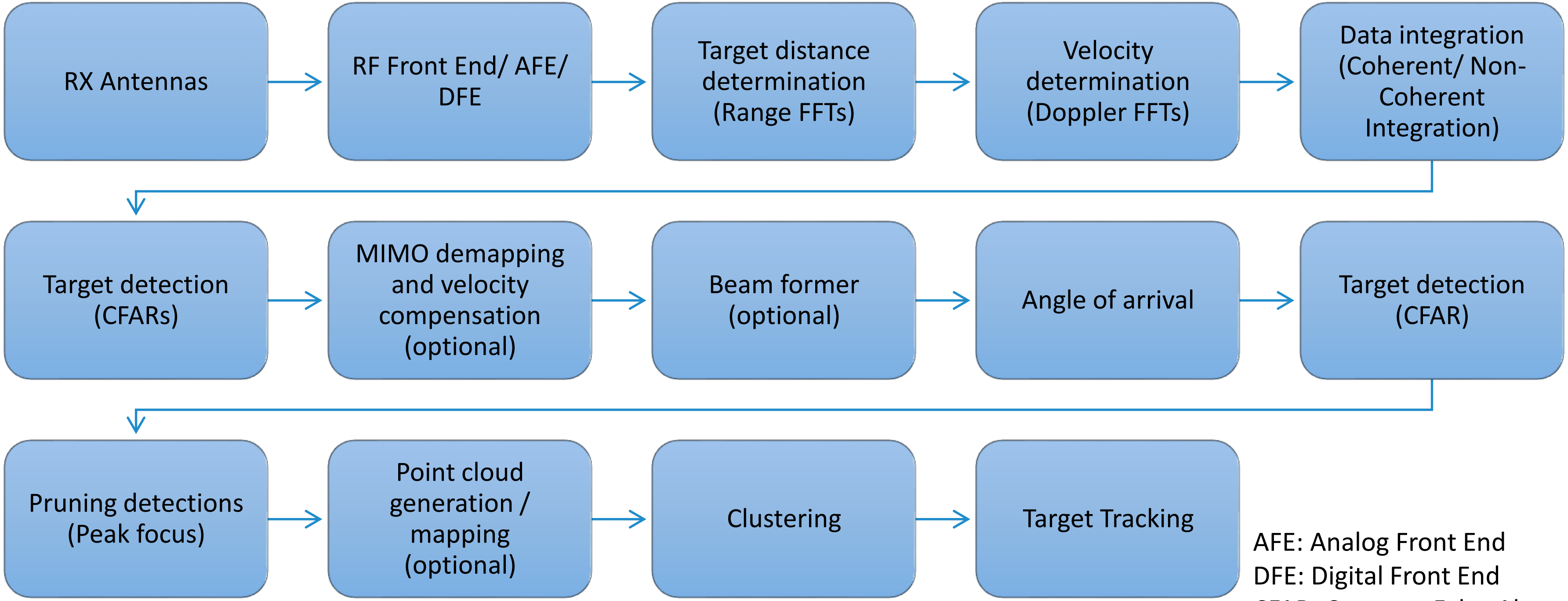
FMCW Radar and Datacube Generation

- Types of FMCW: Based on the number of TX antennas
  - Single input, multiple output (SIMO)
  - Multiple input, multiple output (MIMO)
- Based on the mode of TX multiplexing
  - Time division multiplexing (TDM)
  - Frequency division multiplexing (FDM)
  - Doppler division multiplexing (DDMA)
- Advantage of MIMO
  - Increase angular resolution with an efficient use of antennas
  - Example: Using 8 TX and 8 RX physical antennas enables a 64 (8x8) virtual-antenna array

Radar Signal Processing

Classical 4D Imaging Radar Signal Processing Algorithms

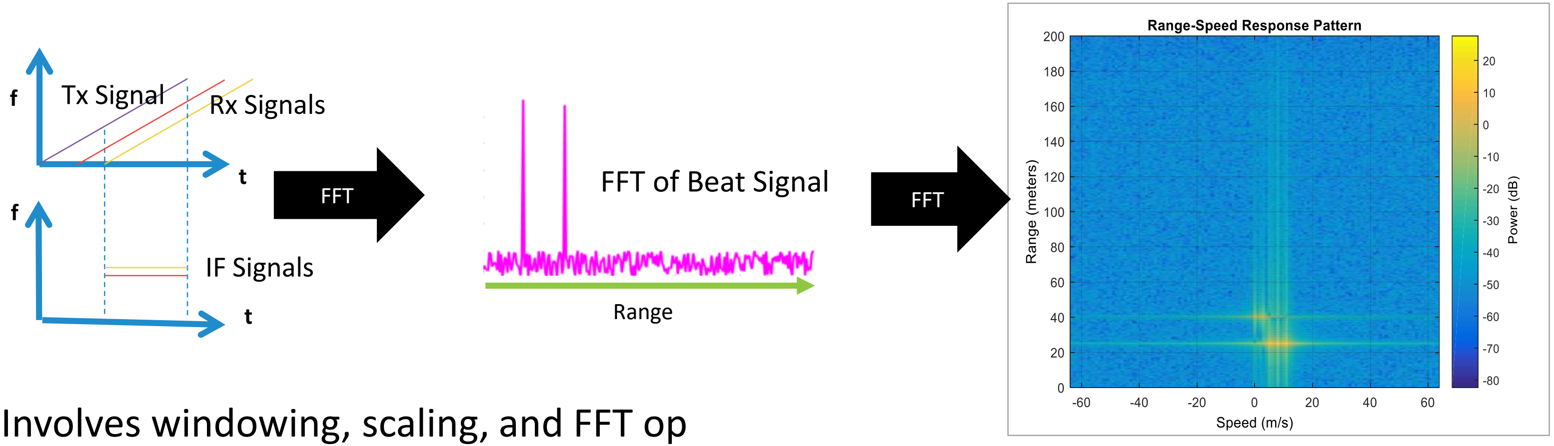
- A typical radar processing chain based on classical signal processing



AFE: Analog Front End
DFE: Digital Front End
CFAR: Constant False Alarm Rate

Classical Radar Signal Processing Algorithms: Details

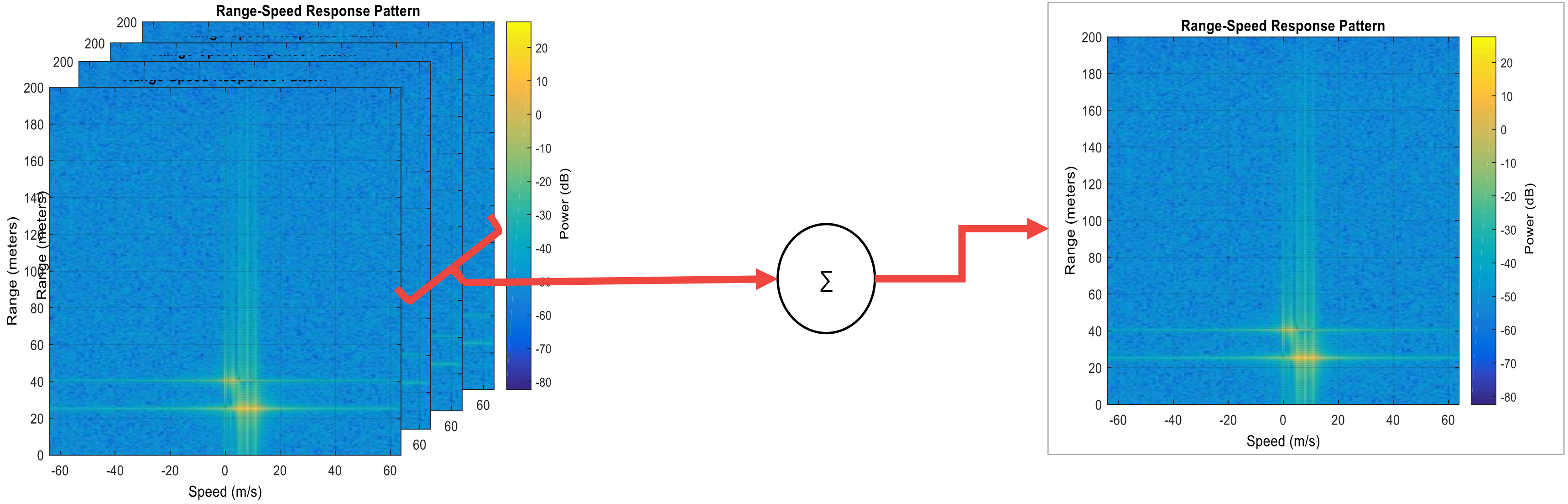
- Range/Doppler FFTs
  - Determines targets distance and velocity using time to frequency domain transforms(FFTs)



  - Involves windowing, scaling, and FFT op
  - 4D Imaging radar FFT workloads → Large → High computation demands

Classical Radar Signal Processing Algorithms: Details

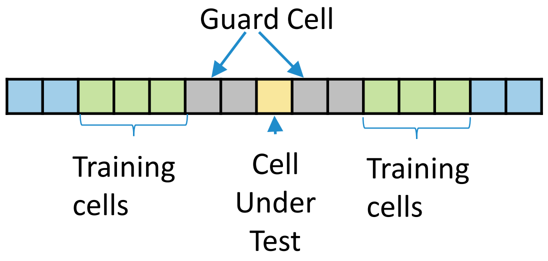
- Data integration
  - Processes FFT'd data for passing to CFARs
  - Integrates signals across antennas with or without phase compensation



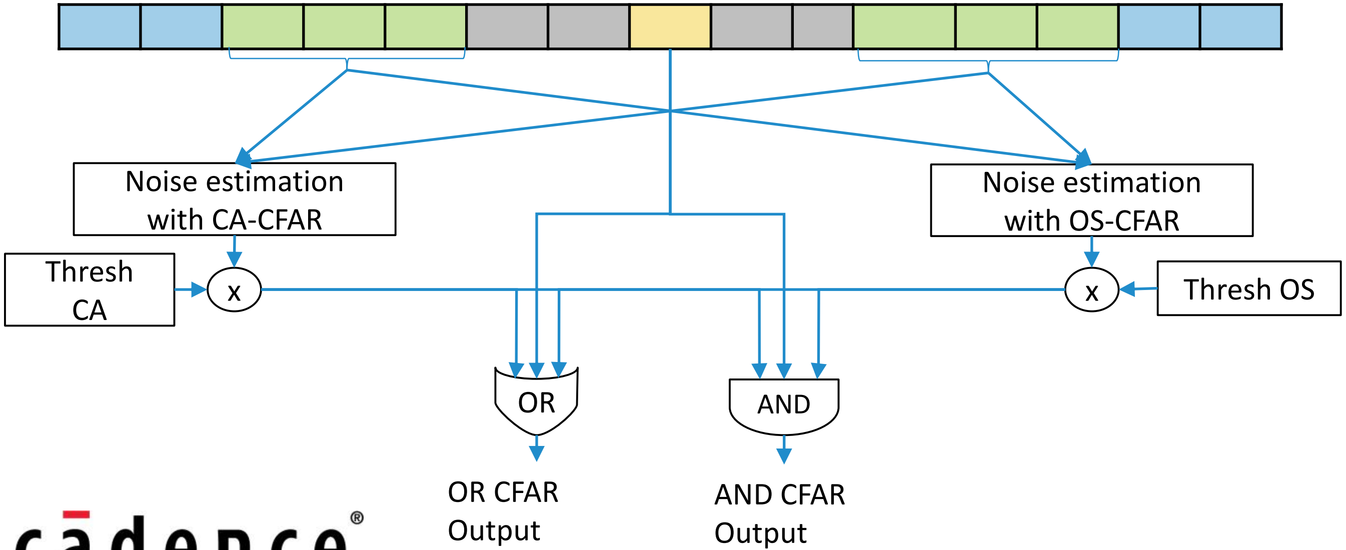
  - Involves magnitude accumulation, phase correction, FFTs, and log compute

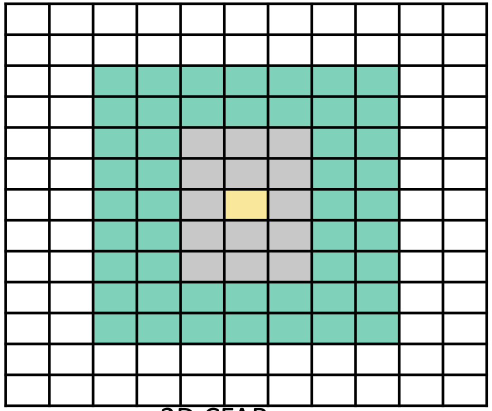
Classical Radar Signal Processing Algorithms: Details

- Constant False Alarm Rate: CFAR
  - Crude target presence detection algorithm
  - 1D, 2D, and 3D in nature. Uses sliding window filter of averaging/ sorting nature to determine threshold to find localized peaks and its associated params



1D Row CFAR





2D CFAR

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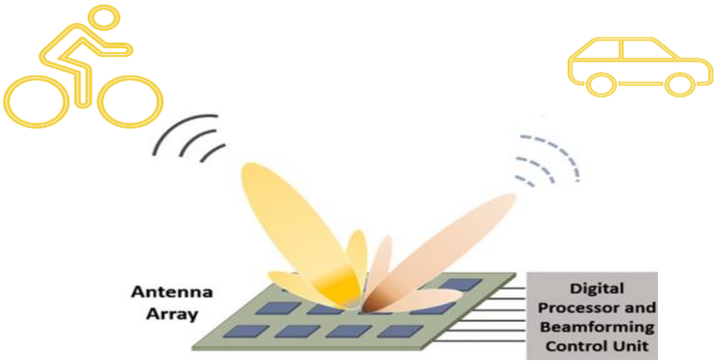
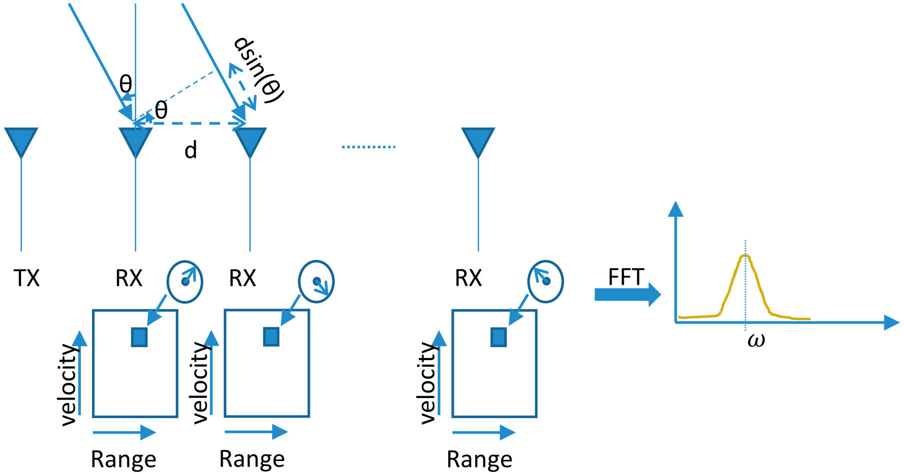
Classical Radar Signal Processing Algorithms: Details

- Angle of Arrival
  - Algorithm to determine the spatial position of the target, in azimuthal, and elevation direction
  - Algorithms used: FFT-based, MUSIC/RMUSIC, beam scan, etc.

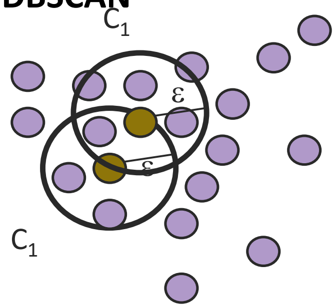




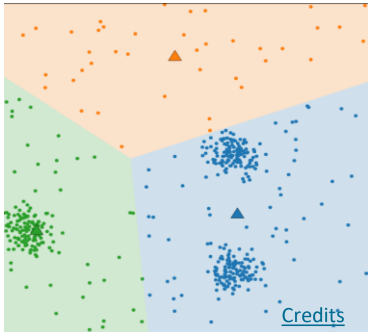
Classical Radar Signal Processing Algorithms: Details

- Clustering
  - Group detections arising from a single target
  - Algorithms used

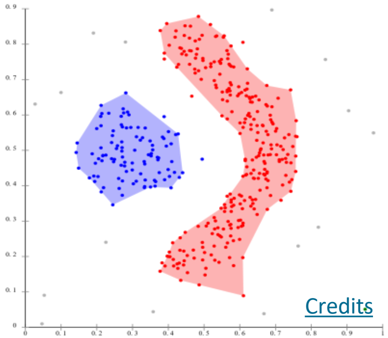
DBSCAN



K-Means



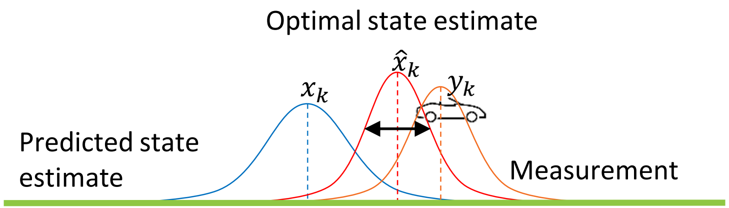
Others

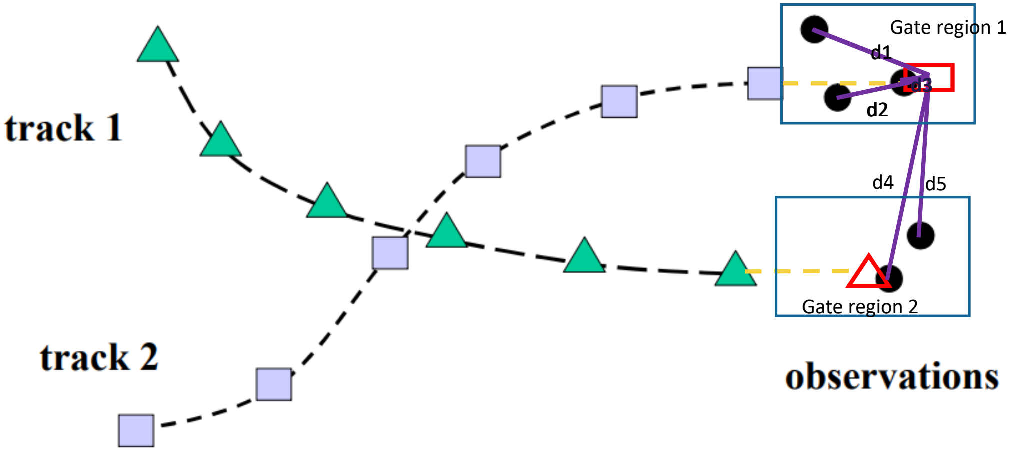


- Involves: Data sorting, data gathering, comparison, data tagging, data reordering, etc.

Classical Radar Signal Processing Algorithms: Details

- Tracking
  - Predicting target position in future frames, associating across frames, managing history (track management, etc.)
  - Uses multiple algorithms like:
    - Prediction/correction: Kalman filters, EKF, UKF, particle filtering, etc.





    - Data gating: Mahalobonis distance-based, etc.
    - Data association: GNN, PDAF, JPDAF, MHT, etc.

Recent Advancements With Radar-AI Networks

Advancements in Radar Signal Processing Using AI

- Applying AI started first with vision sensors followed by the audio domain.
- Since 2019-2020, academia and industry have started applying AI to radar data
- Labeled radar datasets have started appearing in the public domain, with more releases as we speak
- With more datasets being made available, researchers have begun taking a greater interest in this area
- Radar AI engineers have been trying to solve both
  - Classical problems in radar signal processing with greater accuracy
  - Vision like problems(classification/ segmentation/ detection, etc.) using radar data with AI
- Radar datasets are available in various representations
  - Point Cloud (PC), ADC data, RAD cube (Range Angle Doppler), RA (Range Angle), RD(Range Doppler), and spectrogram

Advancements in Radar Signal Processing Using AI

- Radar problems being solved using AI
  - Classical
    - Tracking
    - Detection
    - AOA
    - Clustering
    - Velocity estimation
    - Depth estimation
  - Newer areas
    - Classification
    - Micro-Doppler recognition
    - Multi-class segmentation
    - 2D/3D bounding boxes
    - Ghost detections
    - Interference suppression

Summary

Recap

- We started with various radar use cases and compared sensor capabilities
- We then introduced some basics of the FMCW radar and discussed imaging and non-imaging radars
- We also introduced a typical radar signal processing chain and understood its processing steps in detail
- We then discussed the rise of newer application areas of AI on radar data

Resource Slide

- Cadence Tensilica DSP IP's: https://www.cadence.com/en_US/home/tools/silicon-solutions/compute-ip.html
- Cadence Tools for AI: https://www.cadence.com/en_US/home/tools/silicon-solutions/ai-ip-platform.html#neuroweave-sdk
- Radar SW example apps:
  - 4D High Resolution Radar: https://support.cadence.com/apex/ArticleAttachmentPortal?id=a1OPP0000018ghR2AQ
  - FMCW SIMO 3D Radar: https://support.cadence.com/apex/ArticleAttachmentPortal?id=a1O3w000009fpu9EAA
  - Incabin Radar: https://support.cadence.com/apex/ArticleAttachmentPortal?id=a1OPP000001AZQX2A4