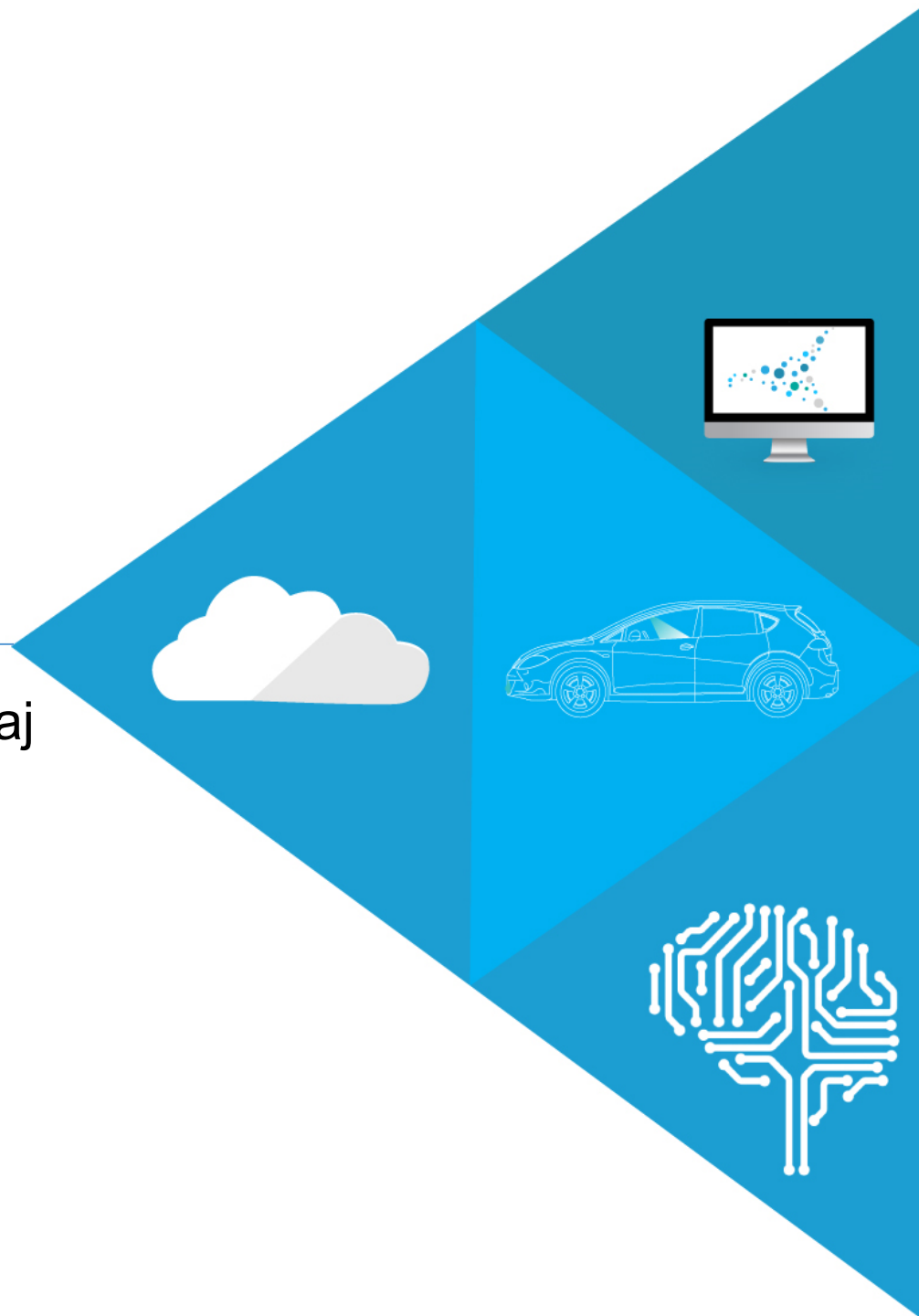
PATHPARTNER

Development of Machine learning algorithms for Radar based Automotive applications



-by Santhana Raj
-Mar 2020

Synopsis

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- PathPartner – Company Introduction
- Automotive Radar capabilities of PathPartner
- Requirement and Use case
- Problems with radar based classification
- Project approach
- Machine Learning Toolbox
- Training & Testing
- New challenges & Re-Design
- Final Development

Executive Overview

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CORPORATE OVERVIEW

- Incorporated in 2006 as embedded multimedia systems organization later on changed the vision to Intelligent system
- HQ in Bangalore, India. R&D centre in Bangalore, India and Bay Area, USA. Sales presence in India, USA, Japan, Europe & China
- Focus verticals : Automotive, Internet of Things & Digital Media Products
- Key offerings : Embedded systems, Multimedia, Imaging, Connectivity, Machine intelligence
- Credentials : 13+ years, 100+ customers, 300+ projects
- Processes : ISO 9001:2015, ISO 27001:2013

ATHPARTNER IN AUTOMOTIVE

- Leveraging competencies in embedded systems, multimedia, imaging, & embedded vision, Automotive vertical established in the year 2011
- Started with multimedia adjacencies such as infotainment and gradually grew as an expert in automotive offerings across infotainment, ADAS, digital cockpit and connected services
- Strategic growth through partnerships with key automotive IC majors – TI, NVIDIA, Qualcomm, NXP, STM, Renesas, Cadence, Synopsys
- Delivered accelerated solutions to automotive tier-1s across the globe – US, Germany, Japan
- Follow ISO 26262 compliant processes

Automotive Radar Offerings

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Complete firmware and software development for radar systems

Radar algorithm pipeline
Algorithm design | Algorithm consulting| Porting & Optimization | Tuning | Testing

Sensor fusion
Radar | Camera | Lidar

BSP & System software
Board bring-up | Sensor integration | Comm Stacks (LVDS, CSI2, CAN, Ethernet)

System Integration & Applications
Integration with other systems | Use-case specific app development

Functional safety
ISO 26262 Part 6 (MISRA-C, Static Analysis, Code Coverage)

Automotive Use-cases

Object detection & tracking | Blind Spot Monitoring | Surround view | Park Assist
Occupancy detection | Gesture recognition | Vibration Monitoring

PathPartner Radar SDK

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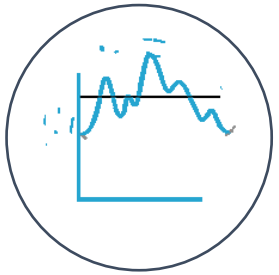
PathPartner offers end to end algorithm package for radar application across various domain. We expertise in all formats (LRR, MRR and SRR) of radar application. PathPartner possesses expertise to deliver the algorithm pipeline to any different board for custom integration.

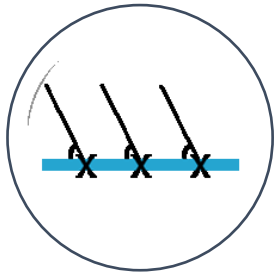
Range & Doppler Estimation

- Considering the complexities and performance, FFTs are the best for range and doppler estimation



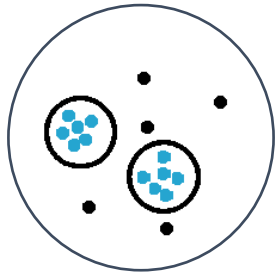
Threshold

- Adaptive threshold algorithms are required especially in radar use case for effective noise removal



Direction of Arrival

- Considering the limited number of antennas in automotive use cases, Super resolution algorithms with increased accuracy is mandatory



Clustering

- A proper algorithm is high required for grouping of detection points to objects in the noisy radar environment

Tracking

- Non linear tracking algorithm is necessitated by
  - To avoid mis detection due to occlusion
  - To track any object continuously across the RoI
  - Remove random radar clutter

Classification

- Depending of use cases, classification can very from simple decision tree to classify static clutter objects to complex Random Forest classifier for pedestrian classification

PC Tool UI

- Special features of display UI to ease the developers and testing
- Detection area selection, ADC data capture and analysis, point cloud data capture and replay etc.,

Please contact PathPartner for full details of the algorithms supported in Radar SDK

Our custom algorithms give better results in extreme conditions compared to any off the shelf algorithms. Our algorithm pipeline are sensor fusion ready, where in they can be used with imaging sensor too.

High accuracy | Optimized | Ready to integrate

Approaches to High Performance Radar Solutions

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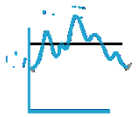
- Zoom FFT can produce high accurate range and doppler detections.
- FFT is performed with highly optimised intrinsic DSP libraries or on Hardware accelerators

FFT



- CFAR is an adaptive thresholding technique which sets the threshold based on nearby data.
- CFAR-OS implementation has both algorithm level optimisation and intrinsic optimisation

Threshold

- Super resolution DoA algorithms has the advantage of accuracy, resolution and noise immunity even with limited antennas
- DoA algorithms require high level of optimisation to compensate for the heavy computation requirement

DoA

- Modified DBSCAN with effective density calculation algorithm can remove clutter points from active objects.
- DBSCAN is implemented with optimisation on both memory and computation

Clustering

- A cluster point is considered valid only if it is present for more than 2 consecutive frames
- Non linear tracking performs well in case of highly noisy inputs

Tracking

- Embedded classifiers like SVM and Random Forest with intrinsic optimisation provide promising results
- Micro Doppler feature based classification of pedestrian

Classification

Use Case & Requirement

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- Main Objective: Development of Radar based object classification
- Scope of project: To design and develop a classifier based on radar point cloud detection. Two sub sections, namely:
  - Detection of objects with considerably small RCS
  - Classification of Human (VRUs) from other objects
- Application: Detection of Vulnerable Road Users in urban environment is necessary for level 3 and above autonomous vehicles. Radar based VRU classification system can perform better than camera in no light/fog/snow conditions. It can at worst assist or provide redundant information to camera based system

Radar In Automotive - Introduction

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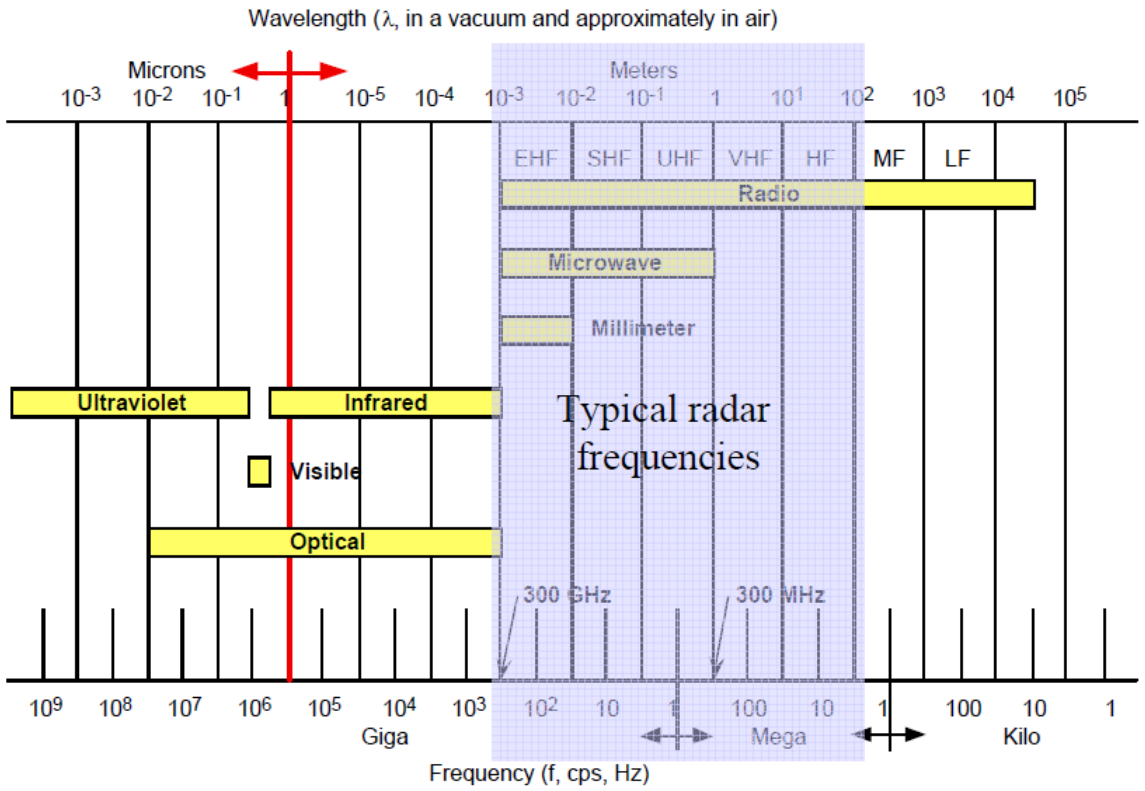
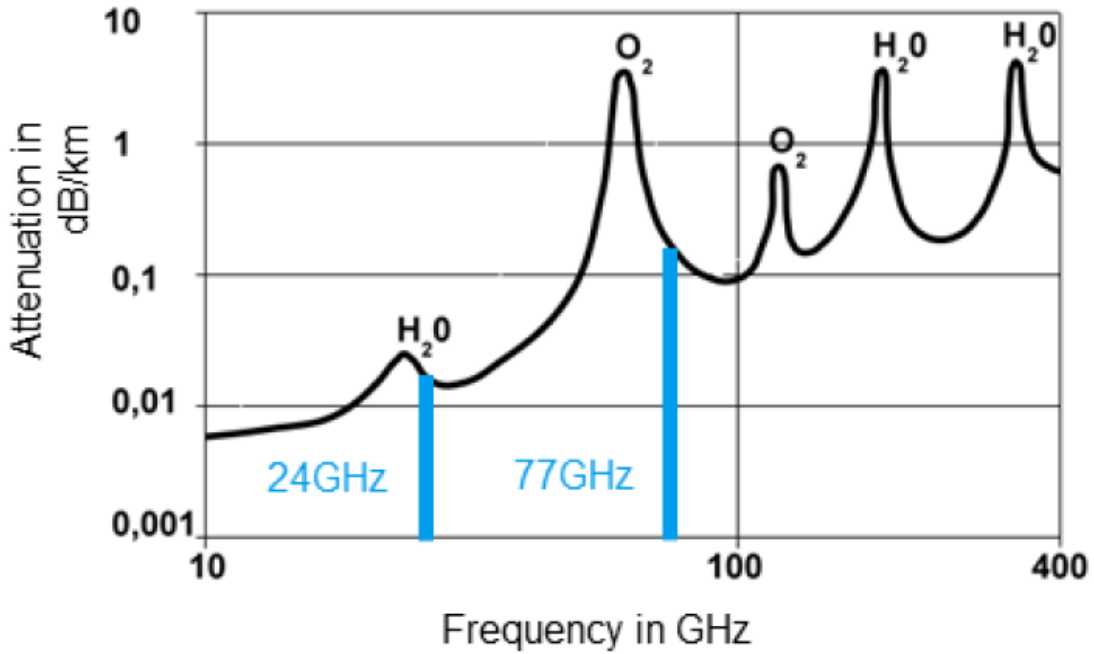
- Automotive Radar is gaining importance nowadays as camera based systems cant meet all the requirements for autonomous driving
- Advantages like visibility at night, very long distance viewing, good performance in bad weather conditions etc are major plus for radar
- Major advancements are already done wrt Military systems to detect aeroplanes and ballistic missiles.
- Applications not restricted to automobile, but from Drones, UAVs, Robotic systems, satellite imagery etc.,
- Classification using Automotive Radar and human detection is a challenging area

Automotive Frequencies





Images from Slonik book

24 GHz

- Smaller Bandwidth (200 MHz)
- Interference with radio astronomy, satellite services etc.,
- Will be phased out in Europe by 2022

77 GHz

- Larger Bandwidth (4GHz)
- higher frequency : Smaller antenna (1/3rd)
- More Attenuation by atmosphere

Project Requirement

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- Current State of the art: Mostly Camera is used for classification applications in automotive. This has issues in unfavorable environment conditions, cost and privacy
- Project Objective: Radar based VRU detection can overcome all these problems and provide efficient solution for this purpose

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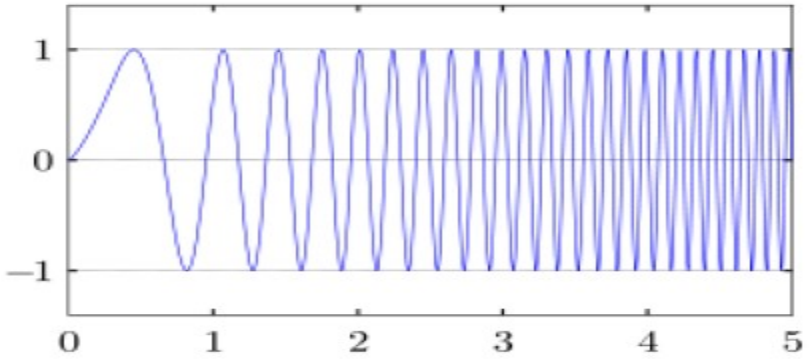
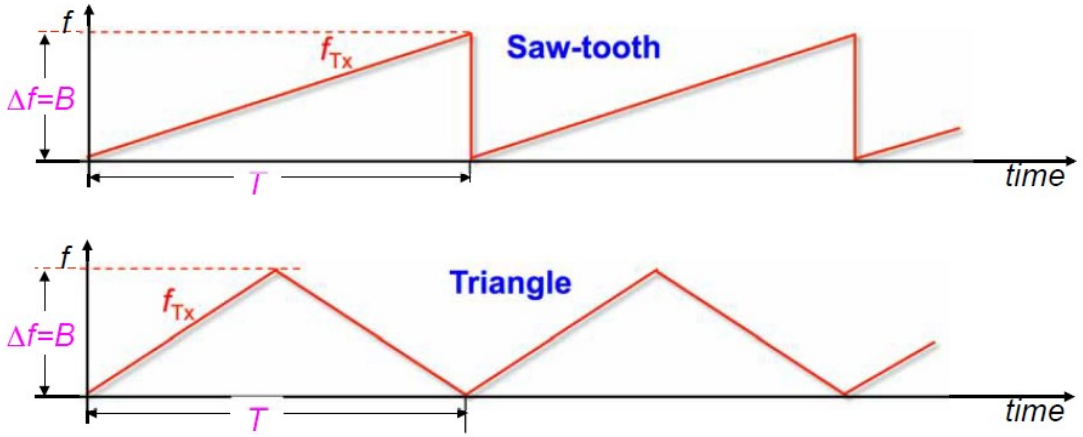
- Frequency Modulated-Continuous Wave Radars
- The waveform is sinusoidal with Linearly increasing frequency in time
- It can be Sawtooth or Triangular
- Triangular waveform has the advantage to distinguish multiple objects with unambiguous velocity.
- Sawtooth is generally used as it is easier to generate with simple hardware.





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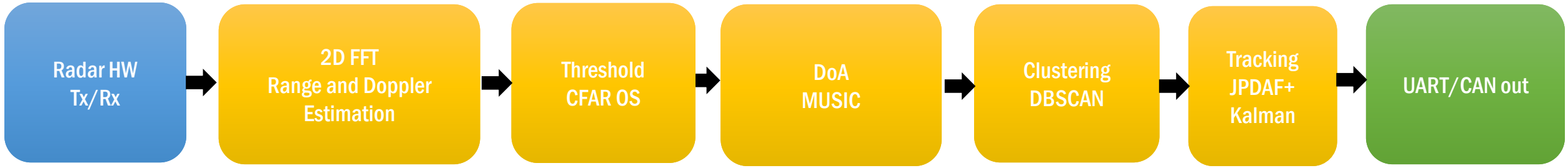
- Radar Hardware supported at PP
  - Texas Instruments' AWR1243, AWR1443, AWR1642, AWR1843, IWR1443, IWR1642, IWR1843, IWR6843
  - NXP's TEF810x
  - Infineon's BGT60TR13C

- PathPartner provides Radar Signal Processing algorithms that are
  - RF frontend agnostic
  - Partner SoC Agnostic
  - OS agnostic
  - Frequency band Agnostic (79GHz or 60GHz)

General Radar algorithm processing pipeline is provided below.



The classification block is introduced right after Clustering or Tracking

Classification

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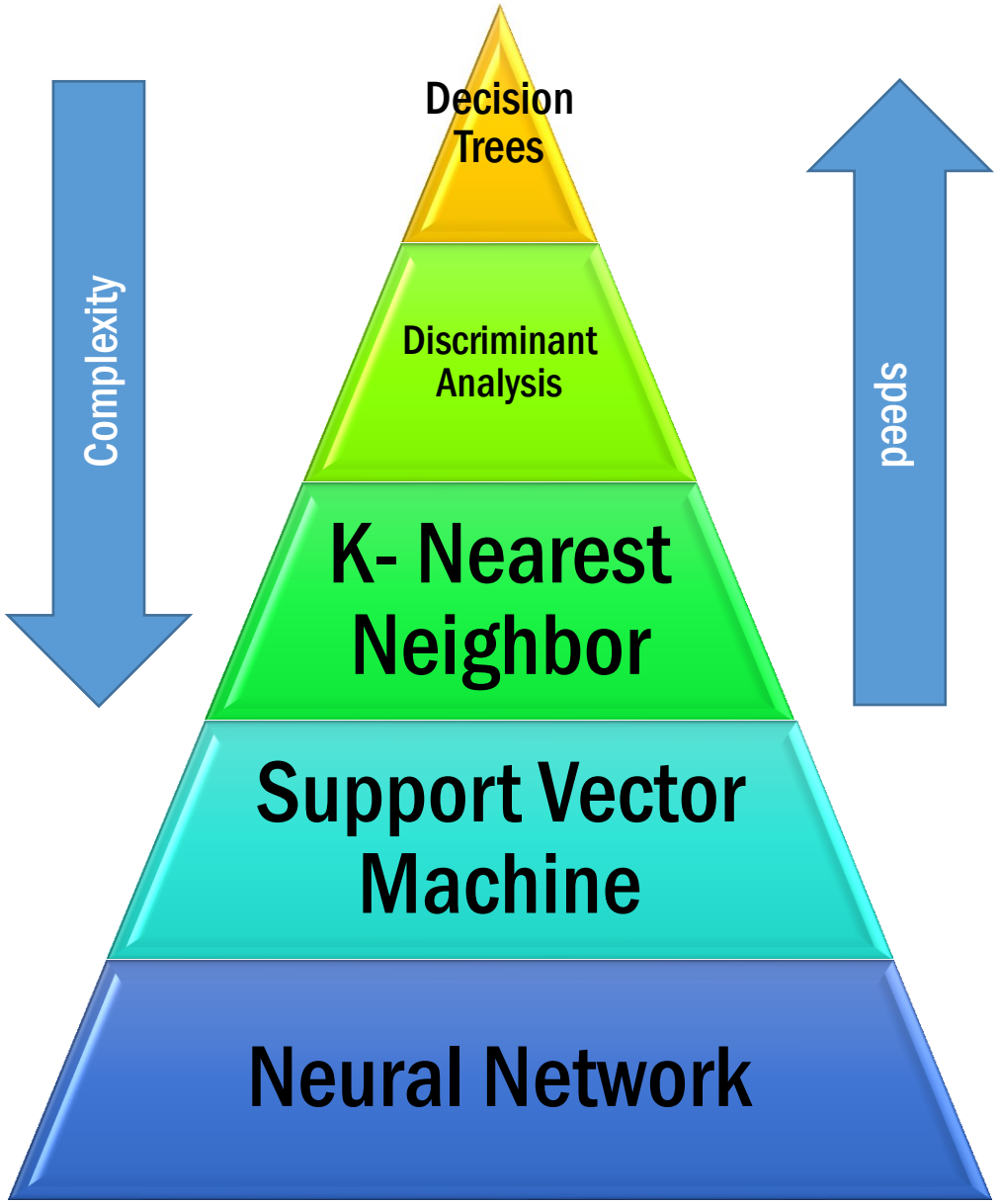
- Various types of Classification methods. No single method is an universal solution.
- Based on the complexity of the application and the required accuracy of classification, the method is chosen.
- No of features determine the dimensionality – Higher the dimension, more difficult to properly classify



Radar Based Classification

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- Automotive solution depends mostly on camera to perform the classification. No commercial only - Radar based classification is available in the market
- Major issues:
  - Detections
    - No of detection is low
    - No direct relevance to shape or size of the object
  - Embedded implementation
  - Moving radar sensor
- Solvable????

Project Approach

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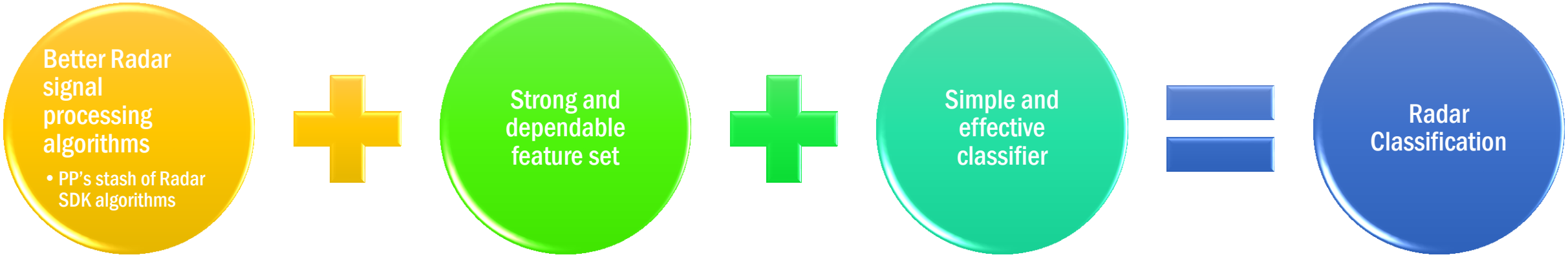
The confidence to solve the current radar problems in classification comes from :

- Better RSP algorithms and PathPartner's accessibility to them. This includes super resolution DOA, hybrid clustering and tracking, noise immune CFAR etc.,
- Embedded implementation requires a simple classifier which mandates a strong feature set
- Classifier with low memory footprint and complexity



Machine Learning toolbox

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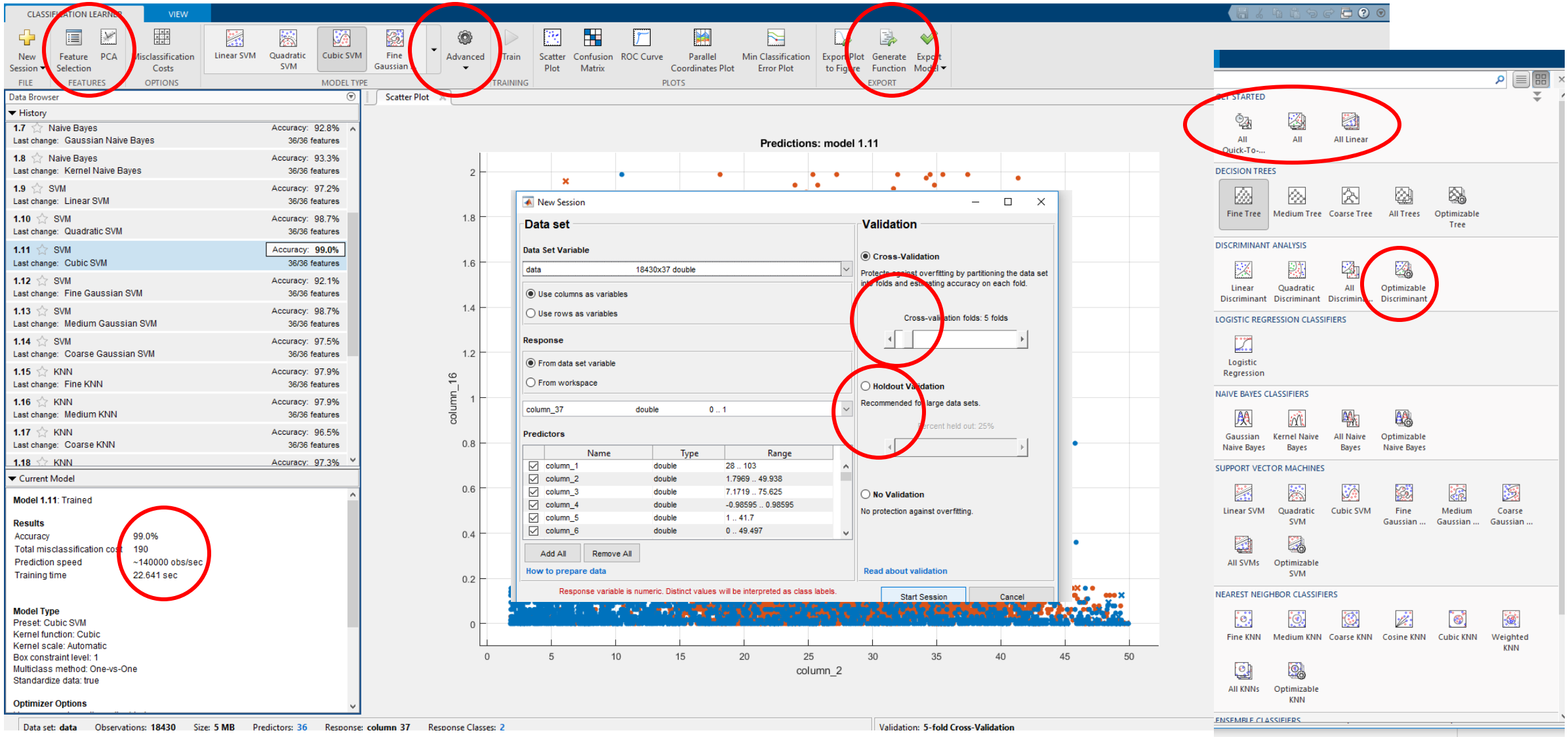

Feature Selection & Extraction

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- From the grouped radar object, various features can be extracted, which are fed to classification module.
- Feature selection helps in identifying the features which better represent the variance in the dataset with respect to classification parameters
- Inbuilt analysis methods can be done to determine how good the feature set is and rank the features based on maximum contribution to classification and lesser repetition of same information
- Feature Extraction is to combine multiple features in a way to reduce the final numbers of features. It helps in overcoming the “Curse of Dimensionality”
- Its requirement depends on the no of features selected after Feature Selection step and the classification method’s accuracy and ability to handle multiple features

Functionality	Matlab in built commands		Toolbox
Feature Selection	fscmrmr fscnca	relieff	Statistics and Machine Learning Toolbox
Feature Extraction	rica	pca	Statistics and Machine Learning Toolbox
Visualization	Tsne		Statistics and Machine Learning Toolbox

Selected Features

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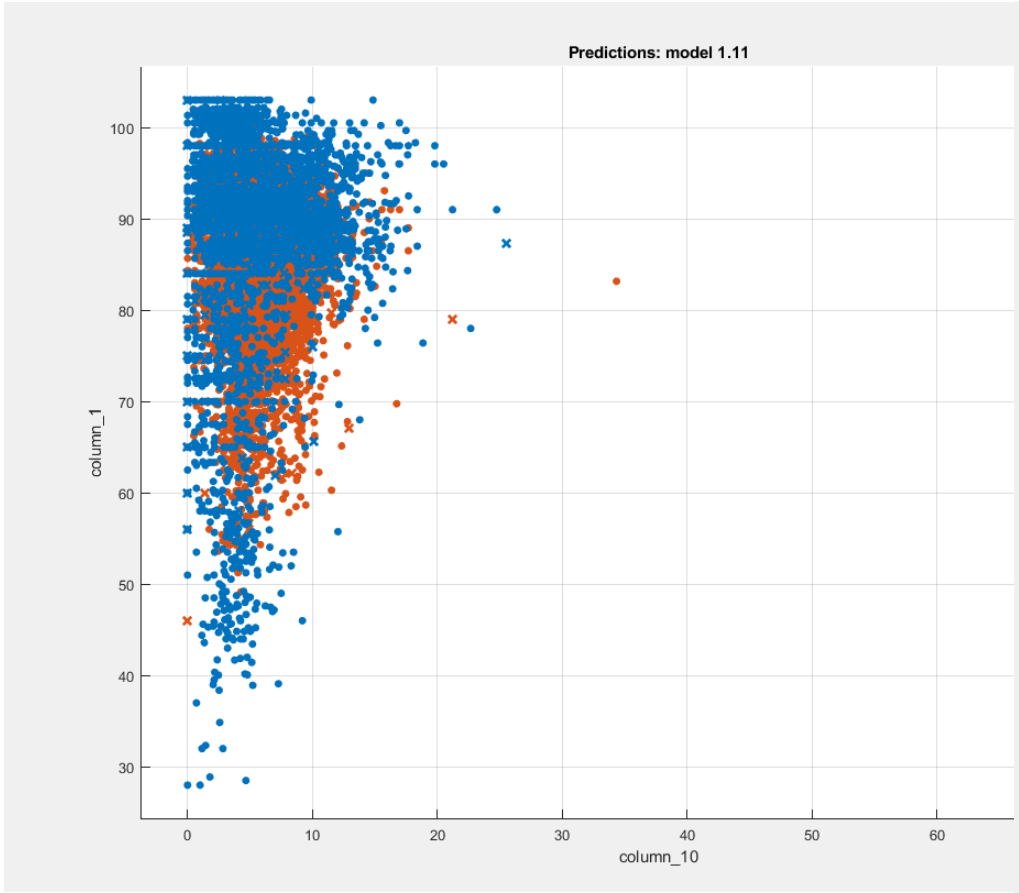
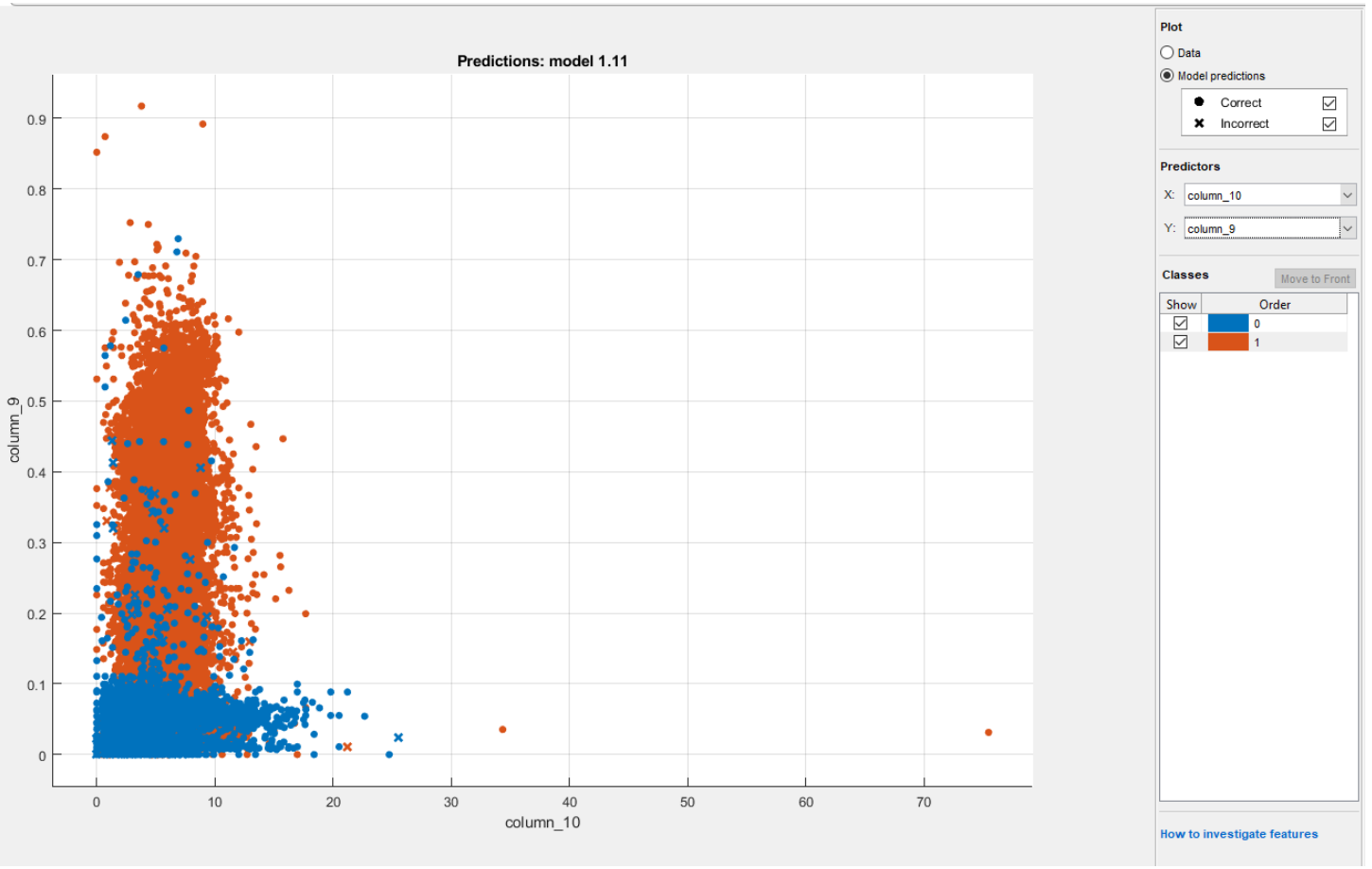
- Exhaustive 21 features were collected from literature and prious experiences
- Feature selection analysis removed many repeating and redundant features.

- Features like Density, number of detections and detection area, provide almost same and redundant info wrt classification.
- Final list of 16 features were decided to be used
- Grouped into three board categories
  - Micro-Doppler based
  - Geometry based
  - RCS based

Sample Feature set
Range
Velocity
Acceleration
Reflectivity
No of scattering centres
Velocity profile centroid
Relative displacement
Velocity profile dispersion
Total instantaneous energy
Total time varying energy
Multi channel integration
Multi channel derivative
Temporal derivative

Feature Comparison – ML app





Considered ML algorithms

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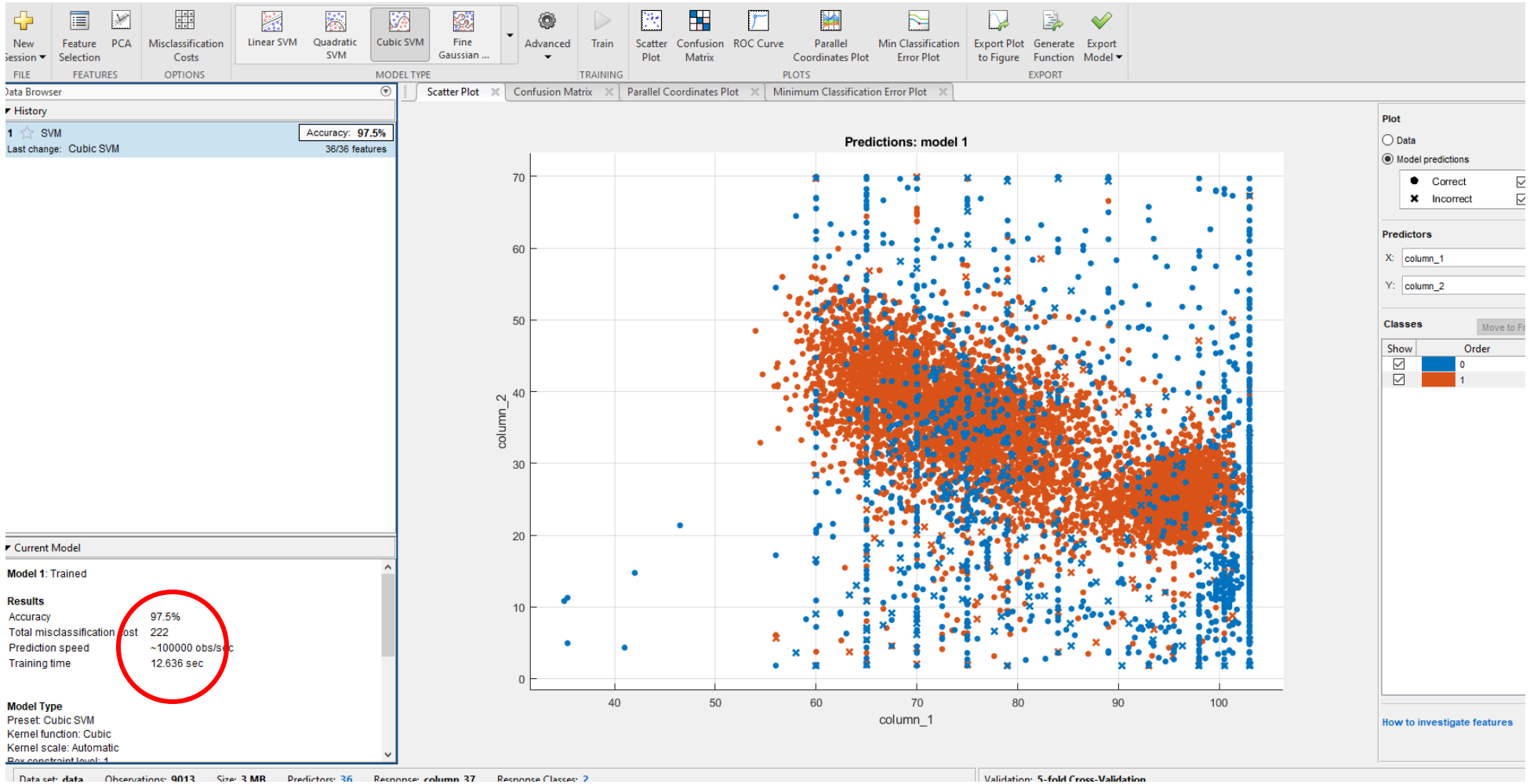
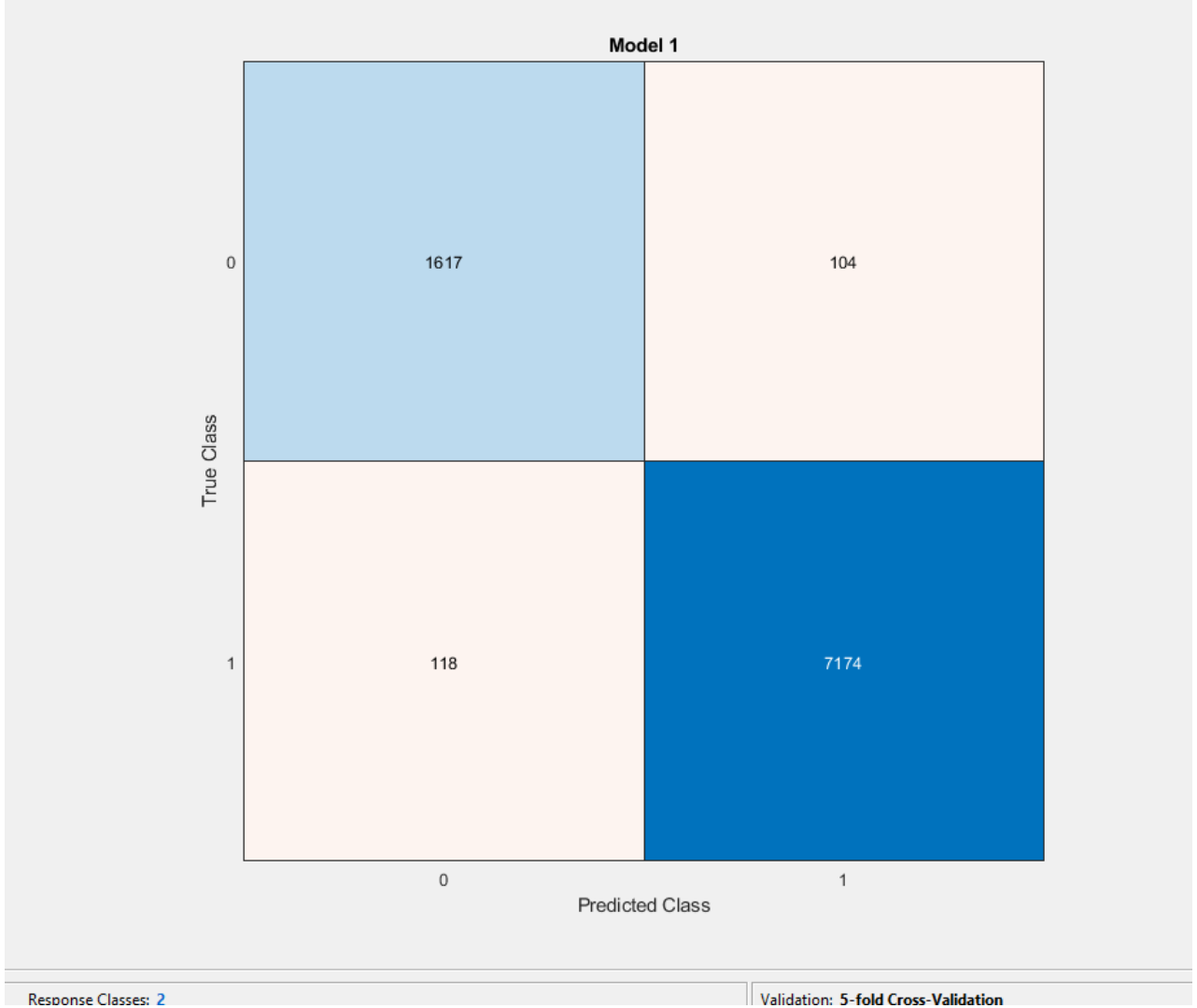
- ML algorithms used in literature for Radar Classification:
  - Neural Network -> People detection in doppler radars
  - Decision tree -> military radar
  - SVM-> VRU detection
  - Random Forest -> Soli for gesture
  - Ensemble bagged trees ->
- Characteristics of dataset:
  - Limited training data
  - Non linear process
- Constraints:
  - Limited memory in embedded hardware : 300kB
  - Less complexity as real time performance is required -> 5 to 10 fps

ML app – Cubic SVM results



Results


Model 1
1617
104
118
7174
0
1
True Class
0
1
Predicted Class
Response Classes: 2
Validation: 5-fold Cross-Validation

New Challenges

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Expected challenges

- Response time
  - The classifier took about 5-8s to classify a human.
  - This is not a acceptable real time implementation.
  - The algorithm was running at 3 fps and the classifier took about 15 frames to classify

Unexpected challenges

- Motorcycle
  - Motorcycle was mostly detected as human. This was because the reflectivity and some characteristics where from the human sitting on the motorcycle.
- Sensor movement
  - When sensor is mounted in a car and the car is moving, the classifier accuracy goes for a toss. This is because the relative velocity is on a different band than stationary sensor

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Response time

- Improved frame time to 5fps
- Created new set of features which are moving averaged values of previous set of feature

Motorcycle

- New data capture and re training

Sensor Movement

- Remove any feature with mean value as a parameter, especially from velocity
- New data capture and re training

Matlab Contribution in Re-design

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- Faster Development time
- Verify and validate increase in accuracy, precision and Recall with:
  - Every new dataset
  - Selection of new features -> moving average values
  - Improvement of old features -> velocity mean removal
  - Inclusion of new features -> ego velocity
  - Retrain and reload data

Activity would usually take 3-5 months for this level of confidence to be developed. Took about 1 month time using Matlab's ML toolbox

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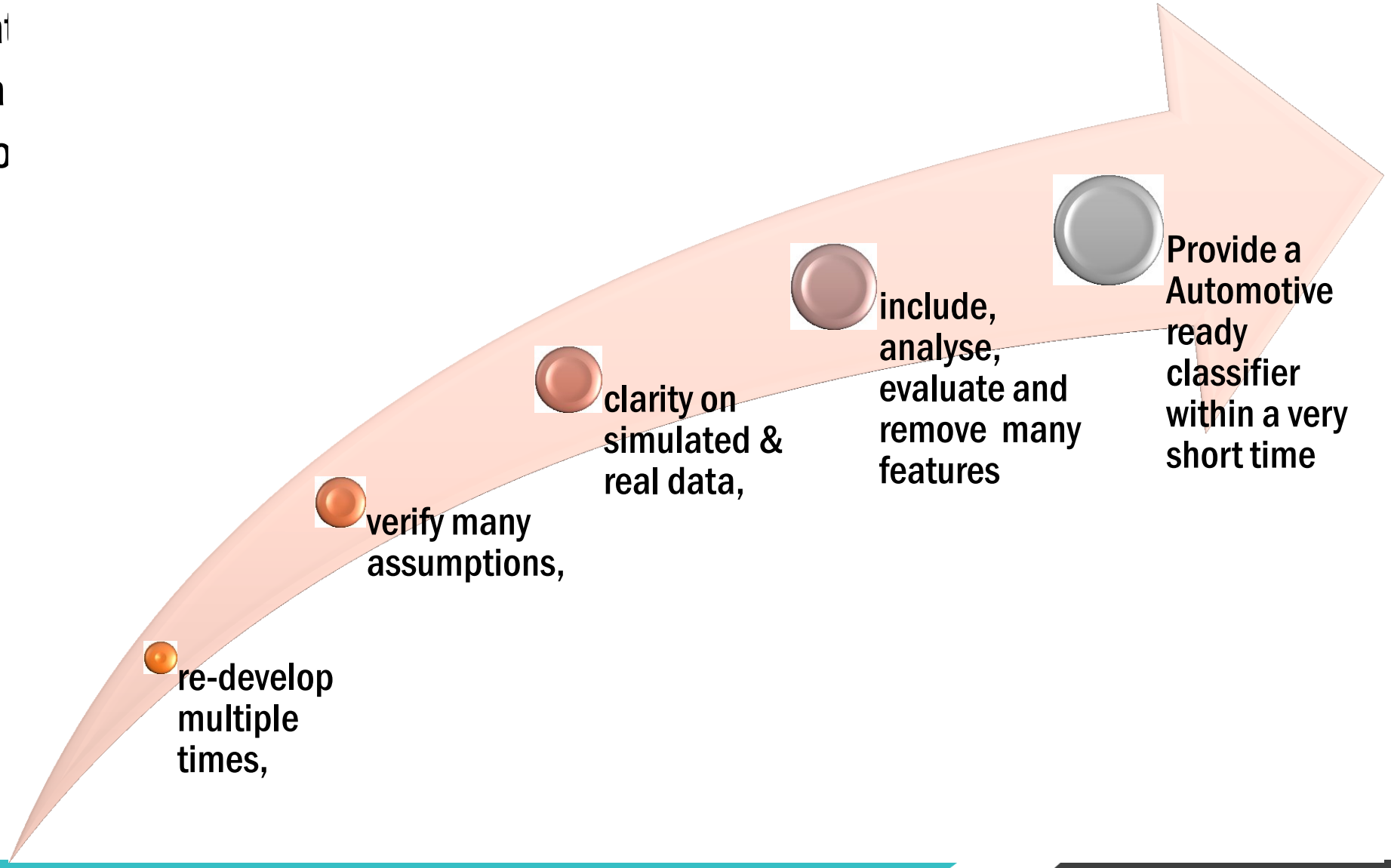
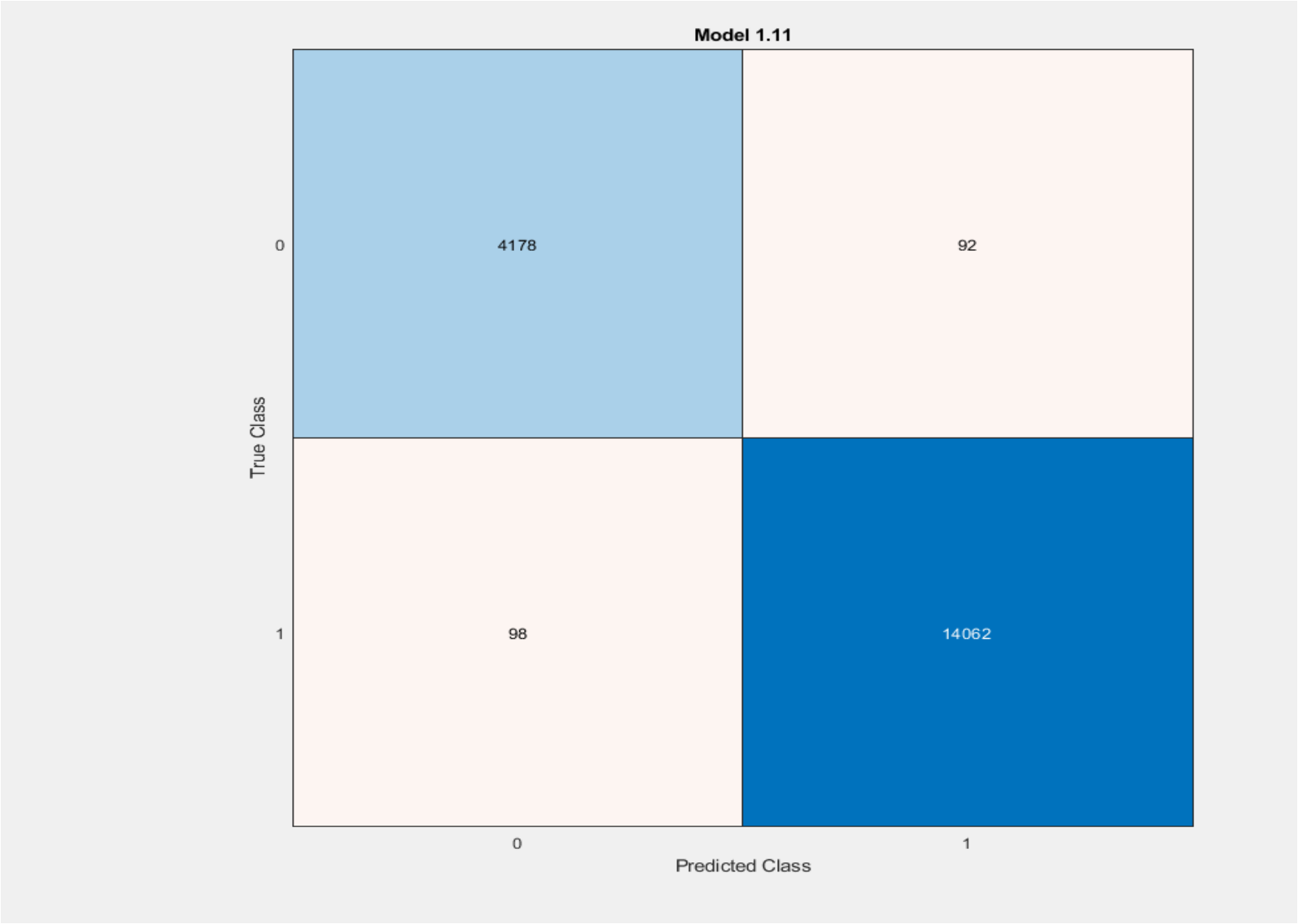
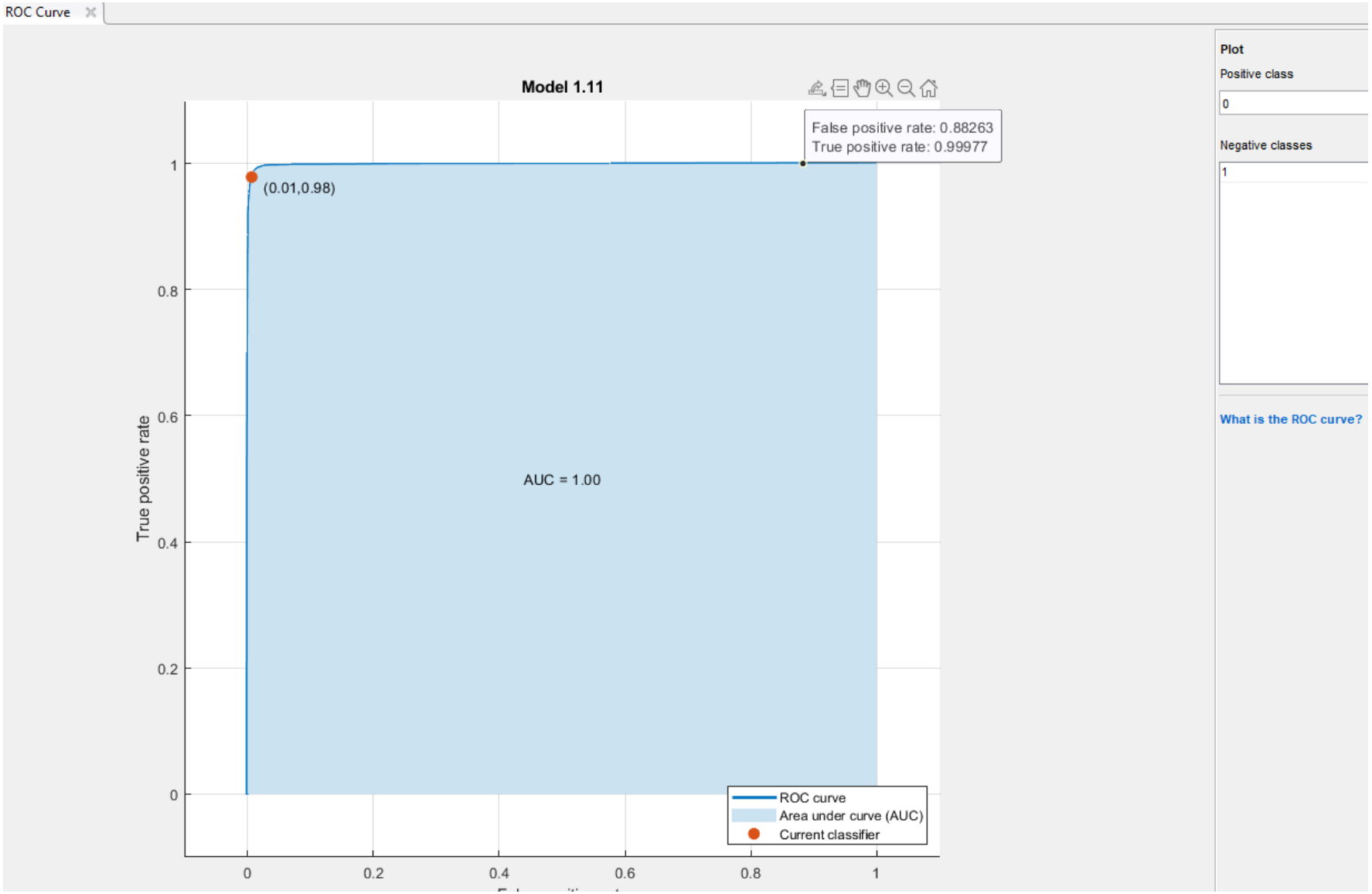
- Any change in Classifier takes about only1 hour of effort which includes:
  - 40 minutes for dat
  - 5 minutes to retra
  - 10 minutes to relo



Confusion Matrix

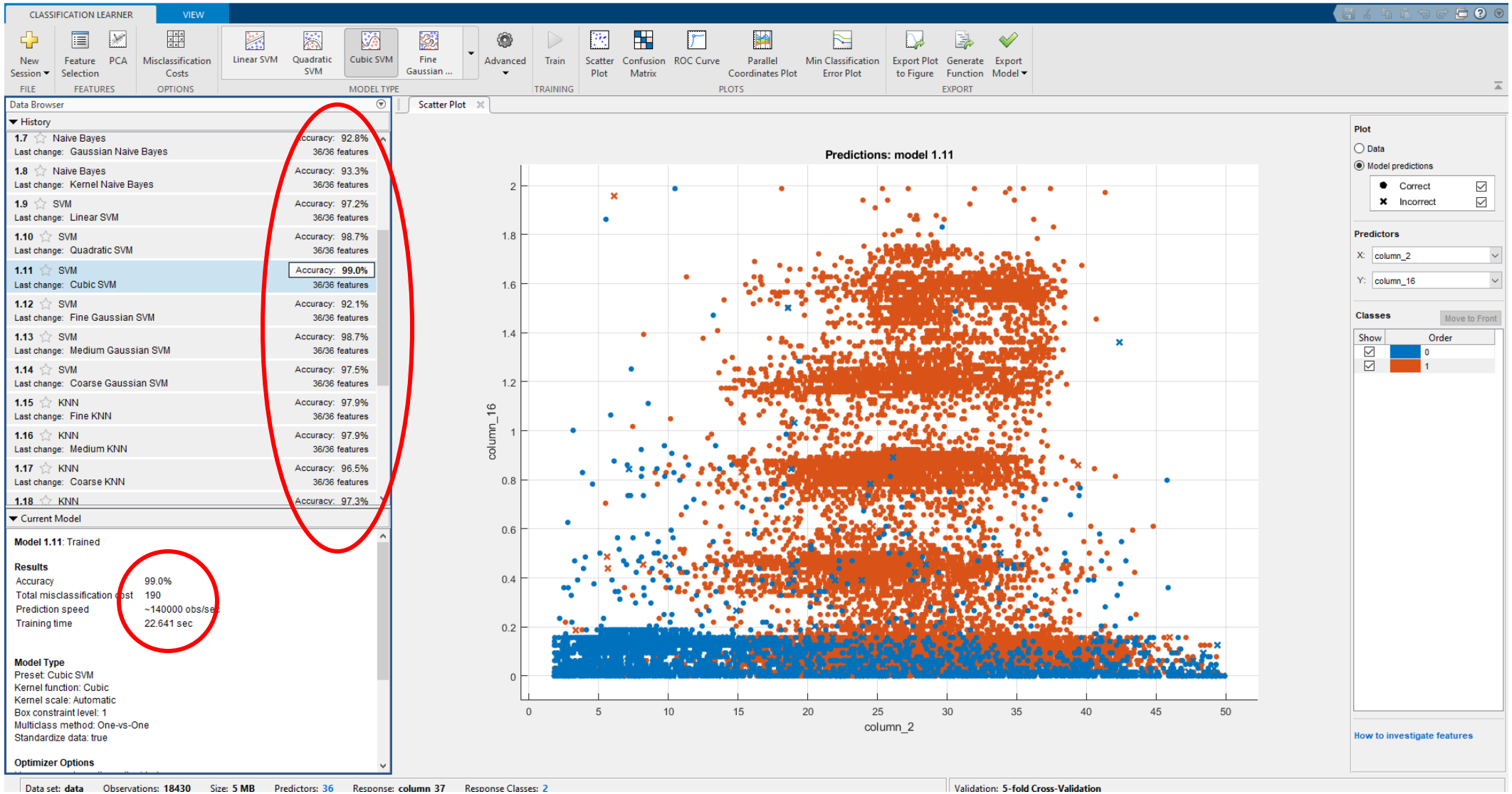


ROC curve


ROC Curve
Model 1.11
False positive rate: 0.88263
True positive rate: 0.99977
(0.01,0.98)
AUC = 1.00
True positive rate
0
0.2
0.4
0.6
0.8
1
ROC curve
Area under curve (AUC)
Current classifier
Plot
Positive class
0
Negative classes
1
What is the ROC curve?

- Changes made in Feature set:
  - Velocity Segmented energy: energy in certain velocity bands
  - Removed mean velocity and mean angle as features
  - Moving average features: Included 18 current frame features and moving average of those 18 features
  - Normalized all features before Classification
- Changes made in Classifier:
  - RBF based SVM classifier : to improve non linear response
  - Implementation of only predict feature to reduce computation
- Results:
  - Accuracy: 99%
  - True positive Rate : 99.97

ML app results



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- Vulnerable Road Users detection
- Future Work:
  - Classify objects into multiple sections like human, bicycle, car and trucks
  - Determine intention of human on pathway : Stationary or walking

- Application use cases:
  - Blind Spot detection in trucks
  - Classification in multi radar Surround View
  - Park Assist use cases
  - Interior Sensing
  - People detection & Tracking in Security scenarios
  - People counting and Fall detection in medical scenarios

PathPartner in other verticals

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Automotive	Intelligent Devices	Digital Media Products
ADAS	Connected cameras	Next gen audio system
Infotainment	IOT & medical devices	Broadcast & video centric solution

Engagement models

- Turnkey
- Resource augmentation

- Fixed price – milestone based
- Time and material

- Onsite
- Offshore

- Hybrid
- ODCs

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THANK YOU

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