

MATLAB EXPO

深度学习在雷达/无线通信领域应用
单博, MathWorks 中国应用工程师



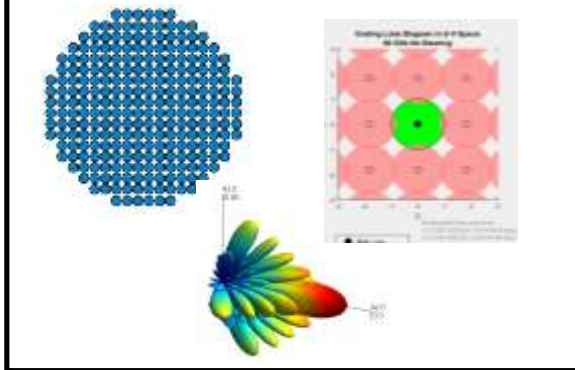
提纲



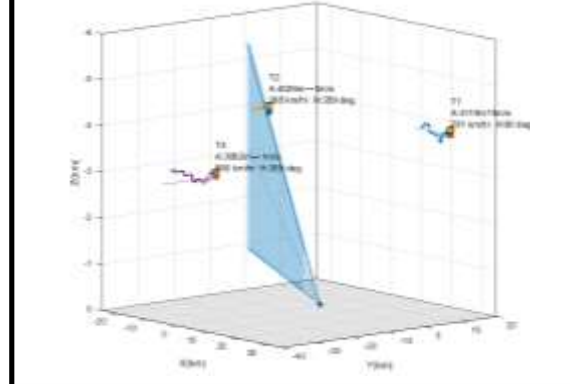
- 简介
- 深度学习流程
- 连接软件无线电（SDR）与雷达硬件
- 预处理、特征提取及标注
- 实例演示- 采用合成数据训练模型，实采数据进行模型测试

采用MATLAB和Simulink进行雷达系统设计

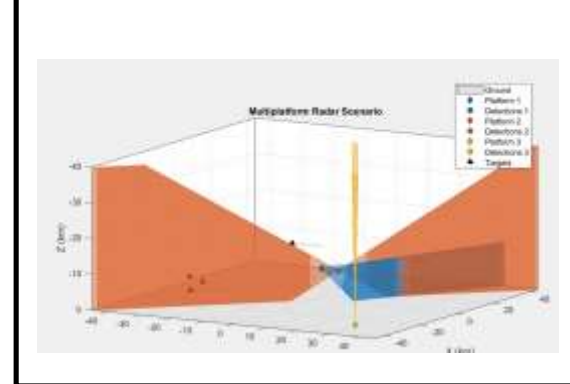
Antenna Arrays/RF



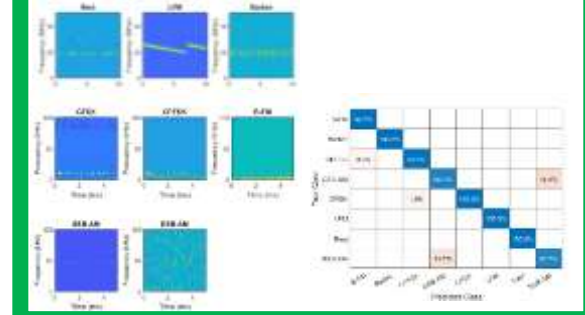
Sensor Fusion/Tracking



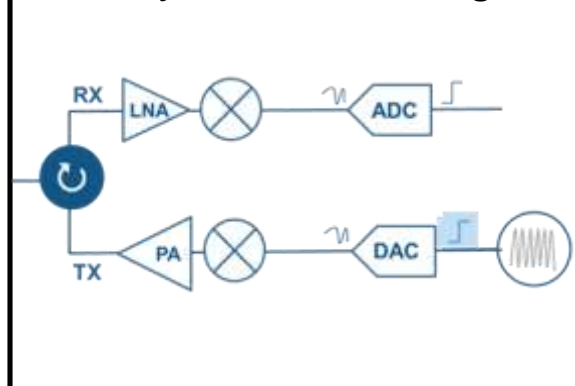
Scenario Generation



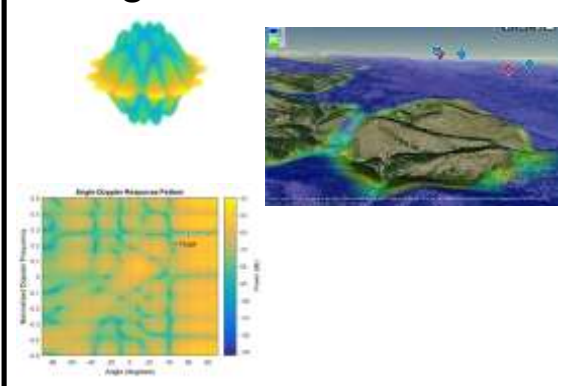
Data Synthesis for Deep Learning



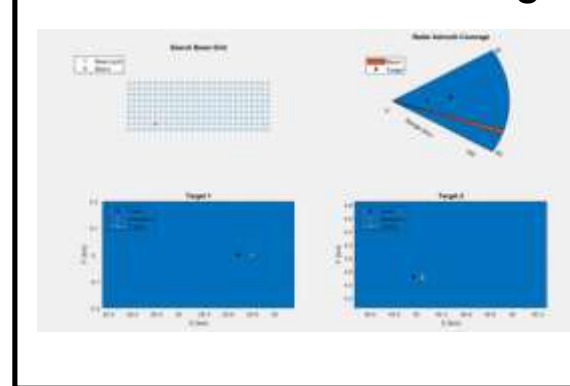
System Modeling



Targets & Environment



Resource Scheduling

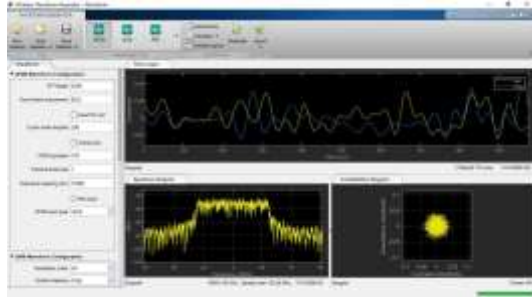


Deployment



采用MATLAB和Simulink进行无线通信系统设计

Waveform Generation



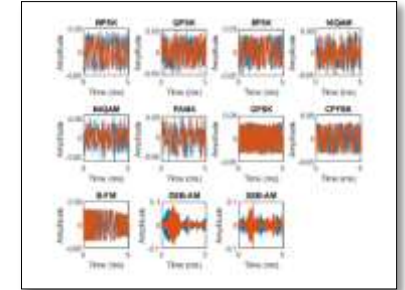
Measurements



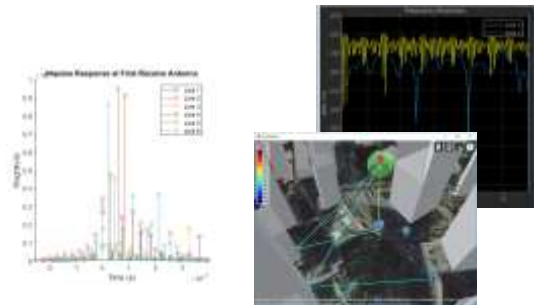
Standards



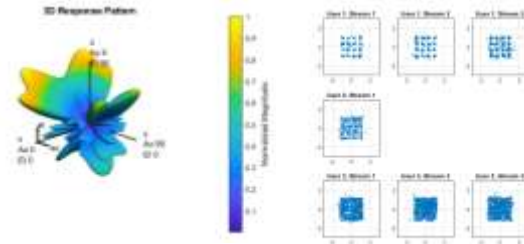
Data Synthesis for Deep Learning



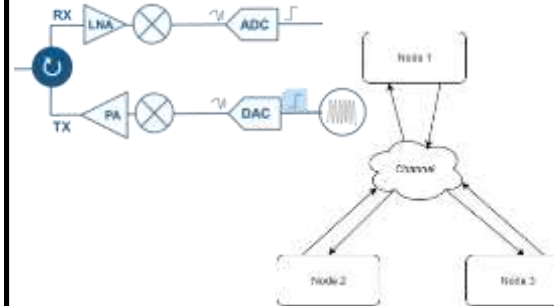
Channels, Impairments & RF Propagation



MIMO Processing



PHY/MAC Simulation



Deployment



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深度学习开发流程

CREATE AND ACCESS
DATASETS

PREPROCESS AND
TRANSFORM DATA

DEVELOP PREDICTIVE
MODELS

ACCELERATE AND
DEPLOY

Data sources



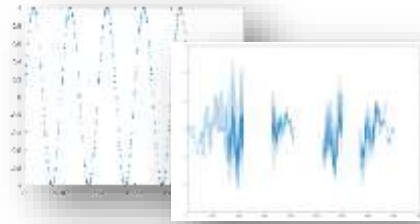
Simulation and
augmentation



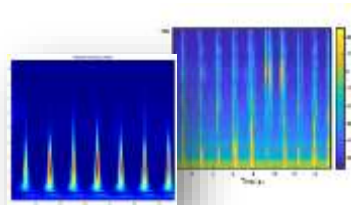
Data Labeling



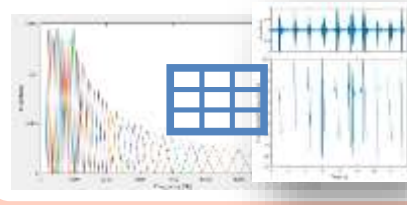
Pre-Processing



Transformation



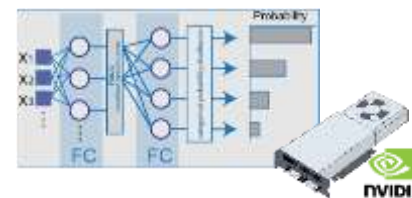
Feature extraction



Import Reference Models/
Design from scratch



Hardware-Accelerated
Training



Analyze and tune
hyperparameters



Desktop Apps



Enterprise Scale Systems

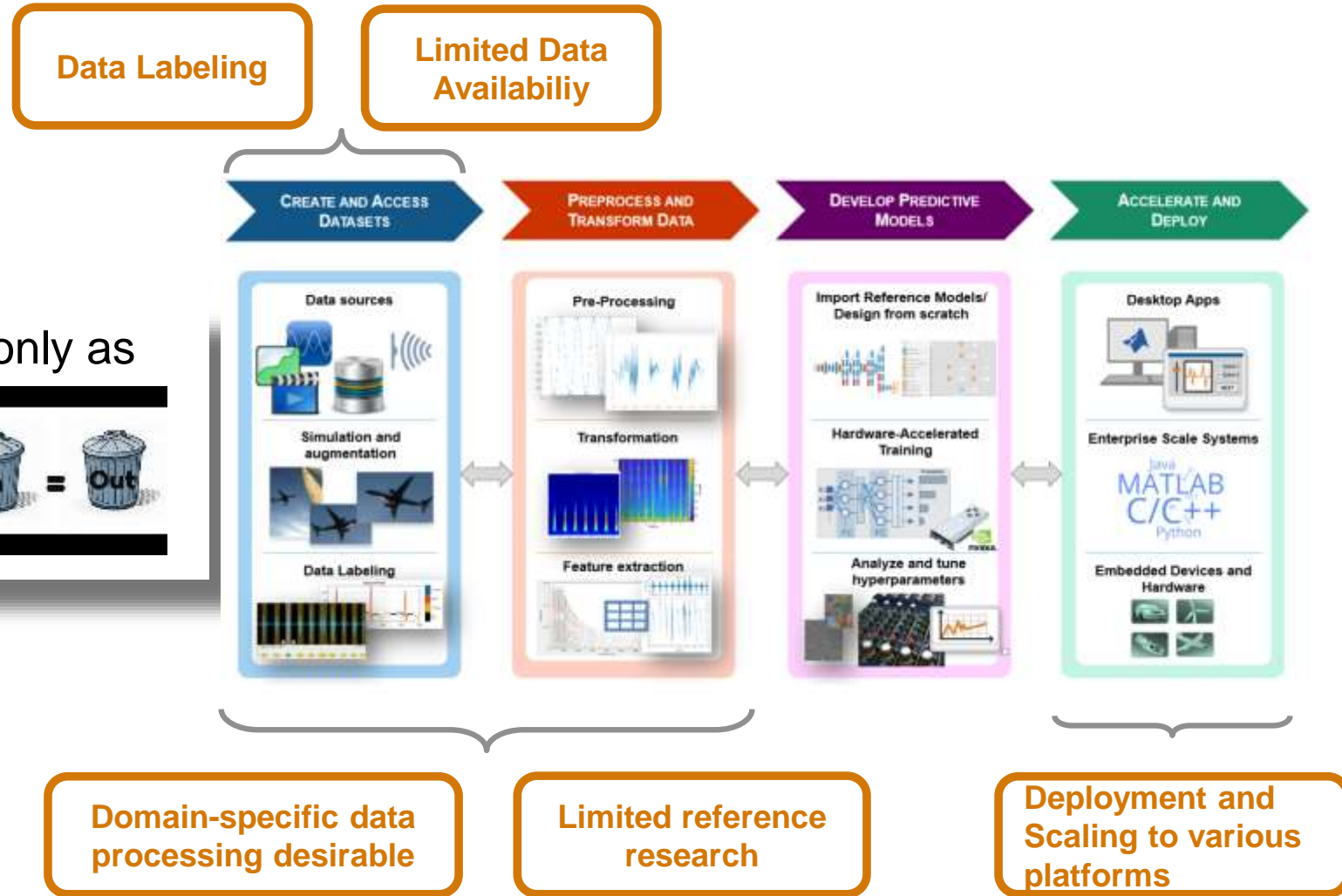
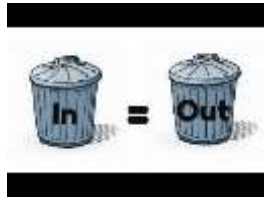
Java
MATLAB
C/C++
Python

Embedded Devices and
Hardware



理解挑战很重要

Deep learning models only as good as training data



需要考虑的折中

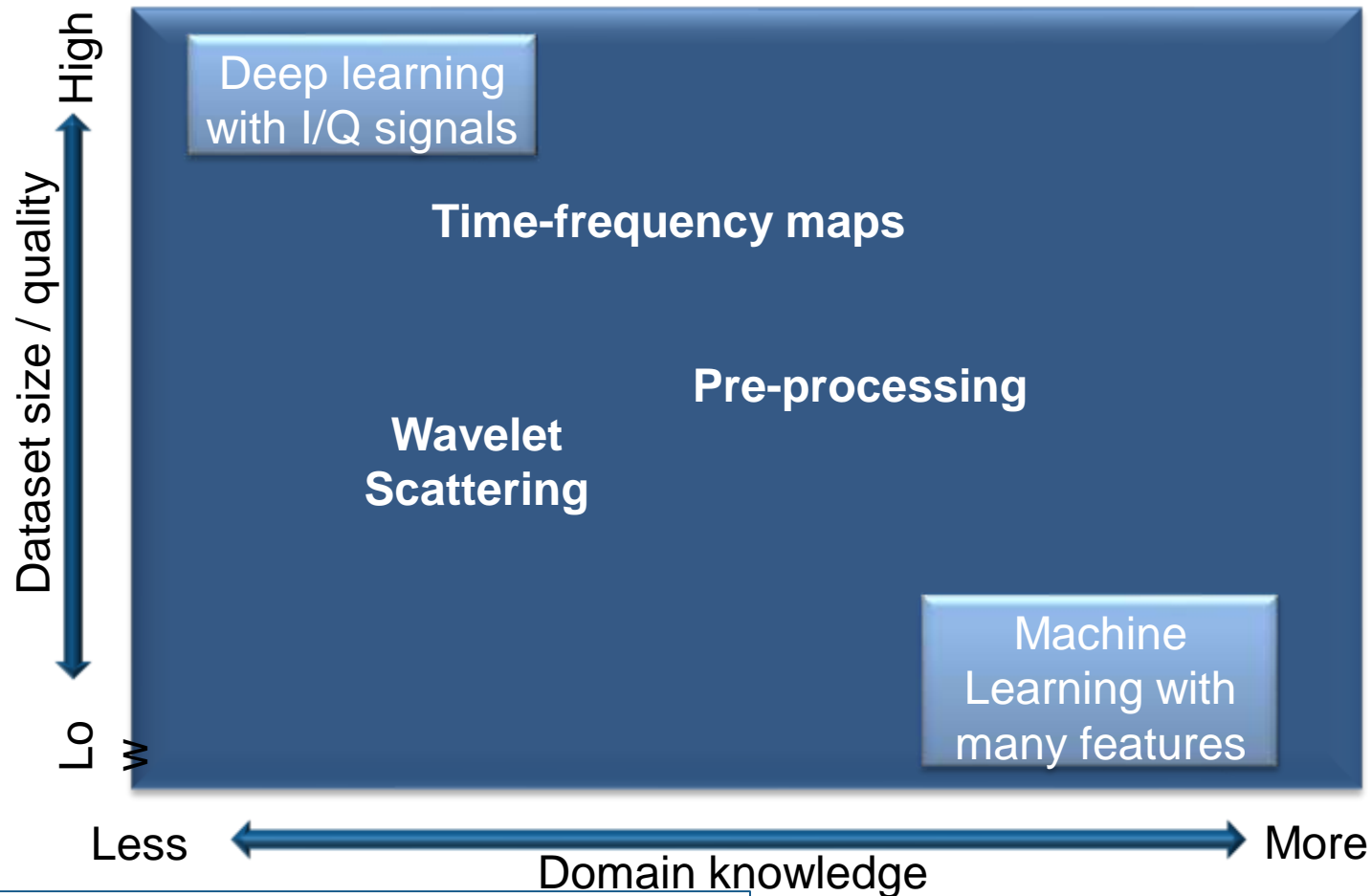
如何获取数据?



Radar

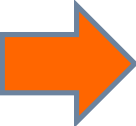
Synthesized data

哪些技术适用于所开发的应用?



数据集大小 vs. 专业知识 vs. 计算资源

提纲

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Hardware connectivity – Software Defined Radios

Add-On Explorer

Contribute | Mar

Clear Filters x Search for add-ons

Filter by Source

- MathWorks 5

Filter by Category

< Clear Categories

Applications

- Signal Processing and Wireless Communications 5
- MATLAB Family 5
- Hardware Interfacing and IoT 1

Using Simulink

- Code Generation 2

Filter by Type


- Hardware Support Packages 5

Filter by Hardware Type

- Hobbyist/Maker 1
- SoC 2
- Software Defined Radio 5

5 RESULTS

Signal Processing and Wireless Communications (5)




Installed

Communications Toolbox Support Package for RTL-SDR Radio

Acquire RF data using RTL-SDR.

399 Downloads ⓘ ★★★★★




Installed

Communications Toolbox Support Package for USRP Radio

Design SDR systems using USRP(R) Radio.

202 Downloads ⓘ ★★★★★




Installed

Communications Toolbox Support Package for Analog Devices...

Prototype and test software-defined radio (SDR) systems using ADALM-PLUTO with MATLAB and Simulink

149 Downloads ⓘ ★★★★★




Not Installed

Communications Toolbox Support Package for Xilinx Zynq-Based Radio

Design and prototype SDR systems using Xilinx Zynq-based radio

94 Downloads ⓘ ★★★★★



Not Installed

Communications Toolbox Support Package for USRP Embedded Series Radio

Prototype and test software-defined radio (SDR) systems using USRP E310 with MATLAB and Simulink

44 Downloads ⓘ ★★★★★

Hardware connectivity – Radar

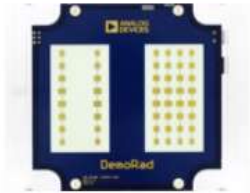


Products Solutions Academia Support **Community** Events

File Exchange

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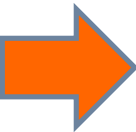
Phased Array System Toolbox Add-On for Demorad

version 1.1 (636 KB) by MathWorks Phased Array System Toolbox Team **STAFF**

Add-On enabling the communication between MATLAB & Simulink and the Analog Devices Demorad Radar Sensor Platform



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ANALYZER

New Open Save Add Waveform Delete Duplicate Real and Imaginary Magnitude and Phase Spectrum Default Layout Generate Simulink Export

FILE LIBRARY MANAGEMENT ANALYSIS LAYOUT EXPORT

Library Real and Imaginary Spectrum Characteristics

Sample Rate (Hz): 1000000

Waveform - [Rectangular]

Parameters

Waveform: Rectangular

PRF (Hz): 10000

Number of Pulses: 1

Pulse Width (s): 5e-05

Propagation Speed (m/s): 300000000

Frequency Offset (Hz): 0

Power Spectral Density of Baseband Signal

Power/Frequency (dB/Hz) $\times 10^{-6}$

Frequency (kHz)

Waveform Name	Range Resolution	Doppler Resolution
Waveform	7.5 km	10 kHz

ANALYZER | **DISPLAY** | **TIME** ?

Display Grid | Clear Display | Legend | Link Time | Data Cursors | Snap to Data | ZOOM & PAN | Time | Spectrum | Time-Frequency | Panner | Extract Signals | Preserve Start Time | TIME LIMITS | SHARE

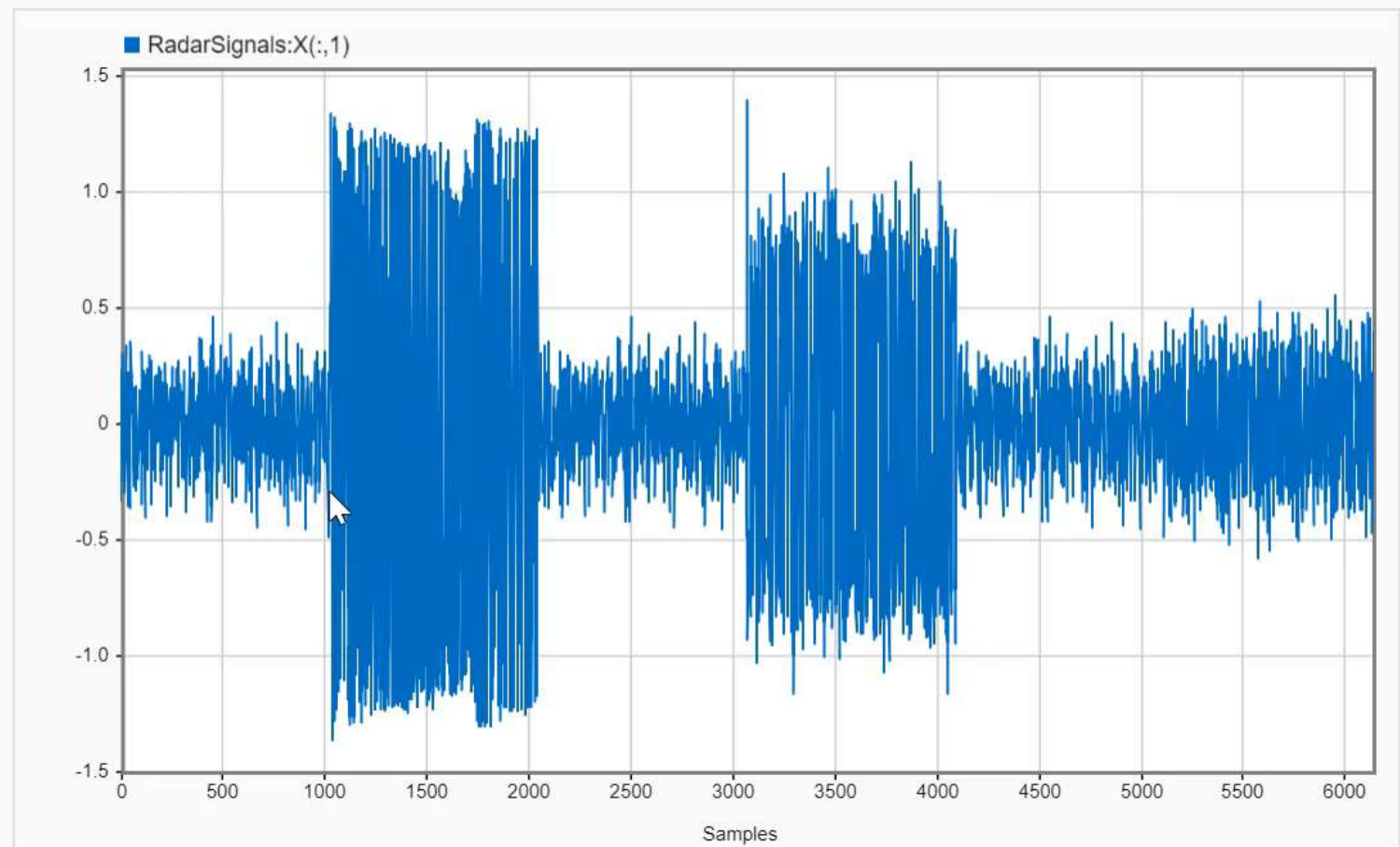
DISPLAY OPTIONS | MEASURE | ZOOM & PAN | VIEWS | REGION OF INTEREST

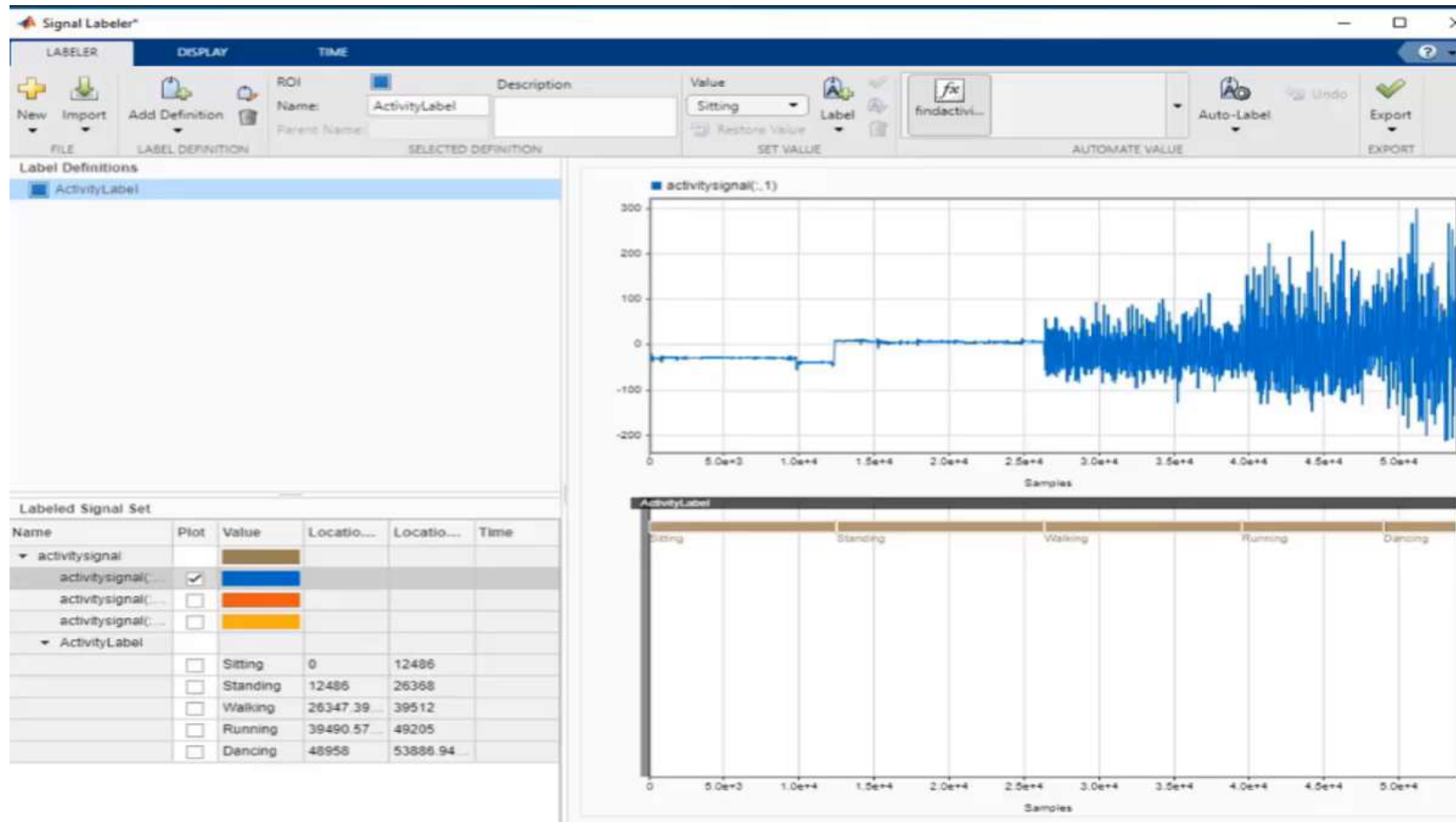
Filter Signals

NAME	LINE	INFO	TIME	START
Radarsignals				
Radarsignals:X				
<input checked="" type="checkbox"/> Radarsignals:				
<input type="checkbox"/> Radarsignals:				

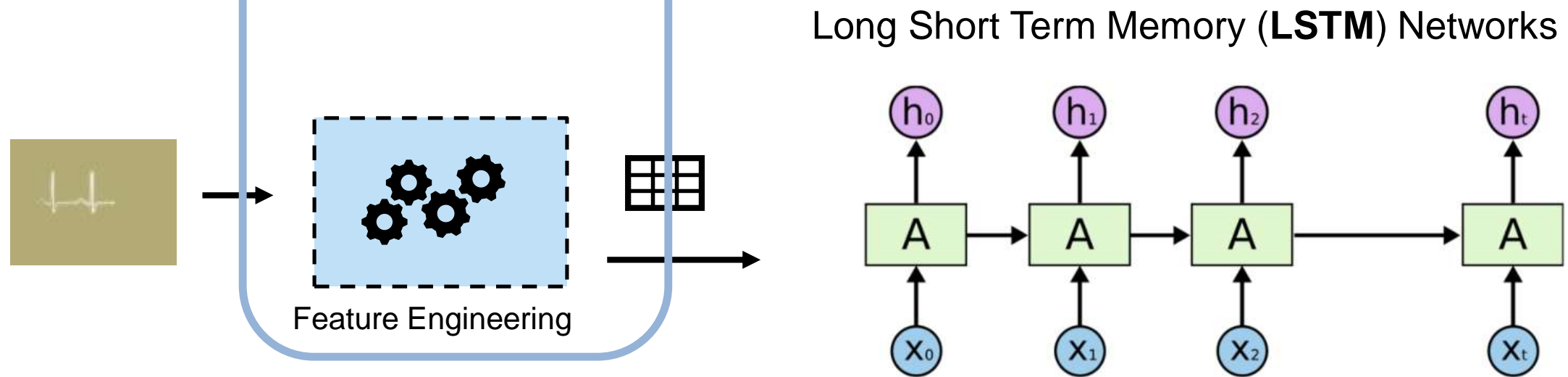
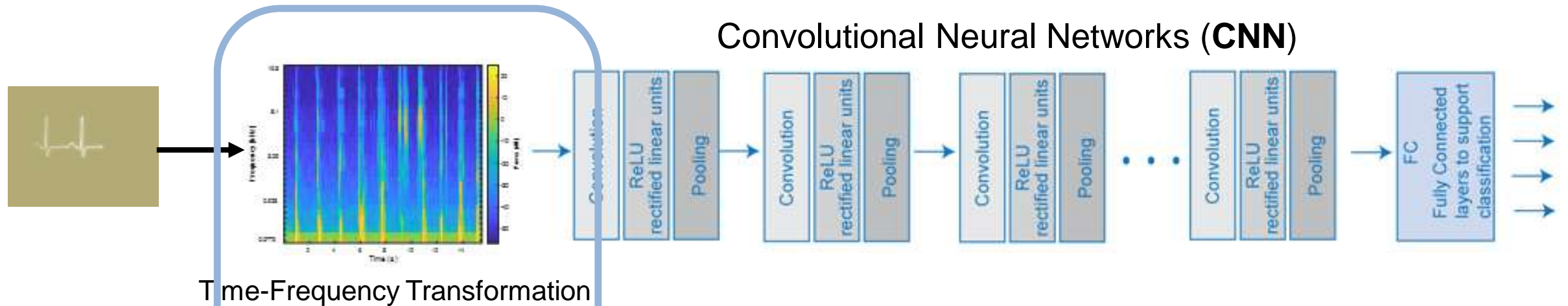
Workspace Browser

NAME	SIZE	CLASS
noise	1024×1	double
Radarsignals	1×1	labeledSign.
sig	6144×1	double (co...
sigReal	3072×1	double
t	3072×1	double
X	6144×2	double

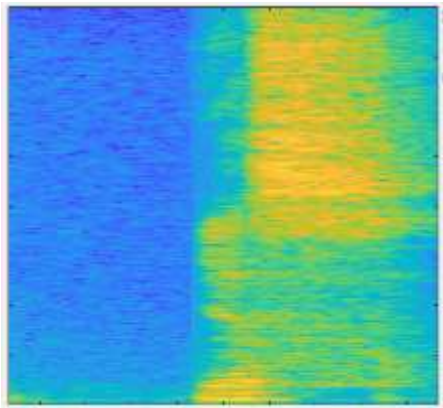
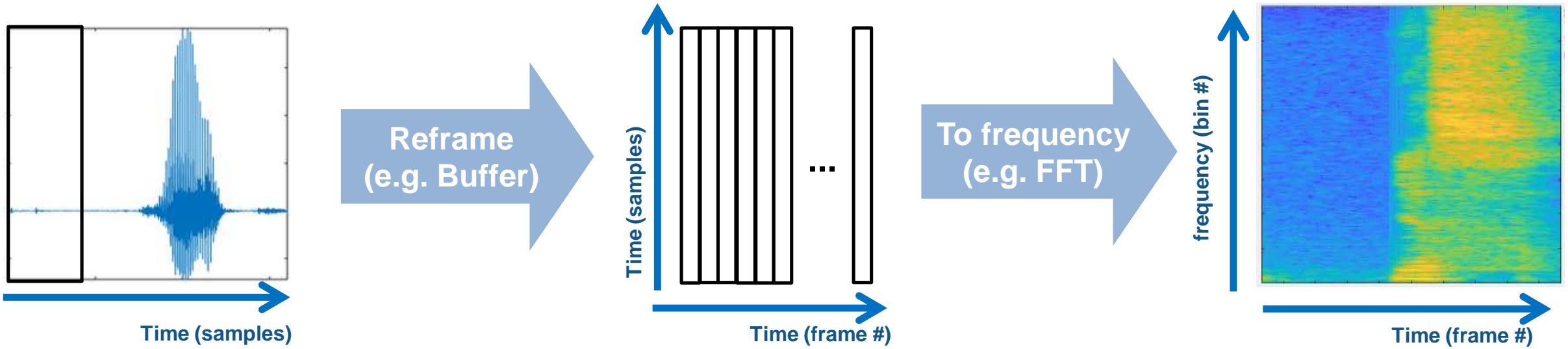




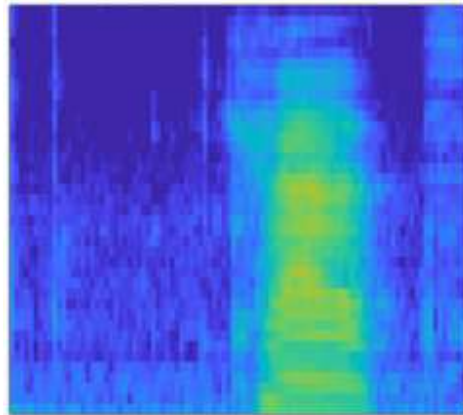
• 常用神经网络结构-信号处理



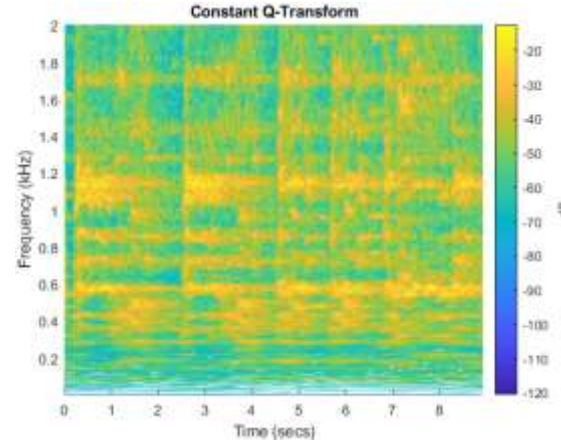
• 时频变换



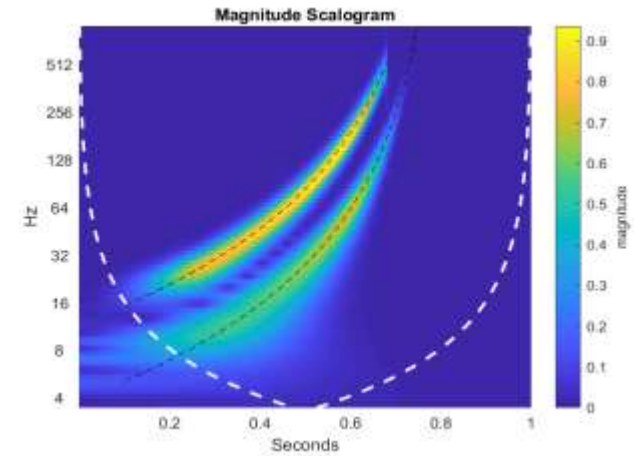
Basic spectrogram



Perceptually-spaced (e.g. Mel, Bark) Spectrogram



Constant Q transform

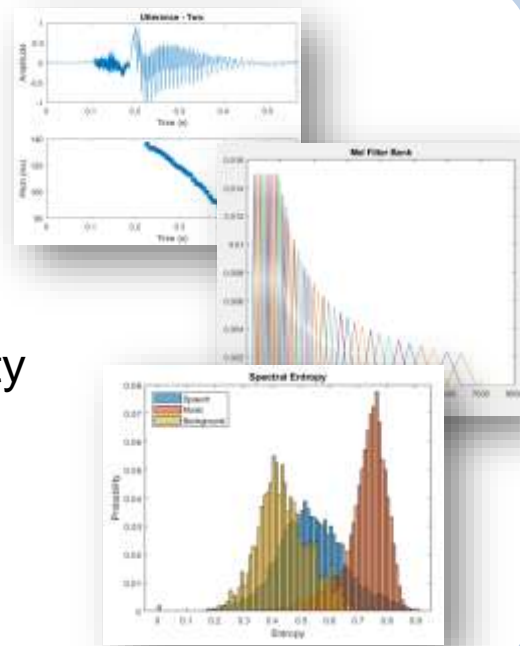


Wavelet scalogram

各专业领域的特征和变换

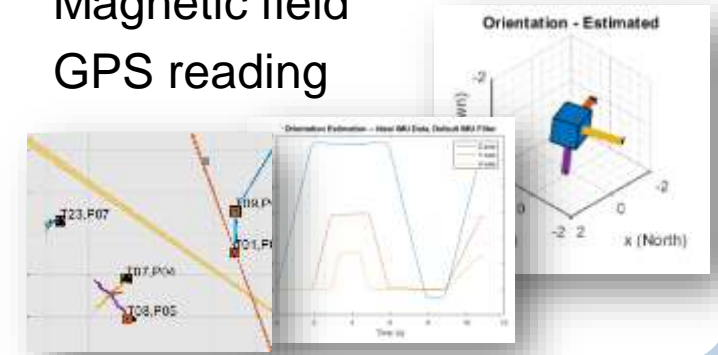
Speech and Audio

- MFCC
- GTCC
- MDCT
- Pitch, harmonicity
- Spectral shape descriptors
- ...



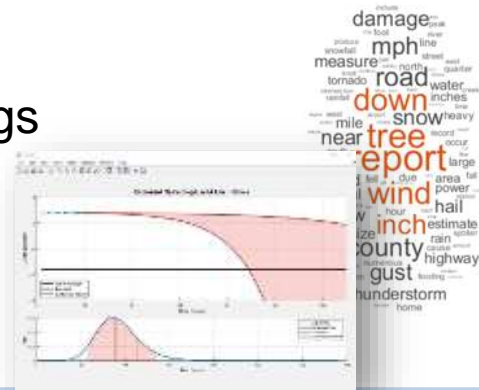
Navigation and Sensor Fusion

- Orientation
 - Height
 - Position
 - Multi-object tracking
 - ...
- from
- Acceleration, angular velocity
 - Magnetic field
 - GPS reading



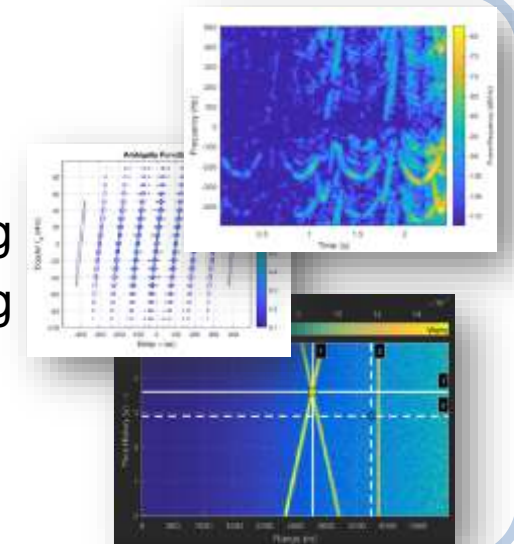
Text Analytics

- Train Word Embeddings
- Word2Vec
- Topic Modeling
- ...

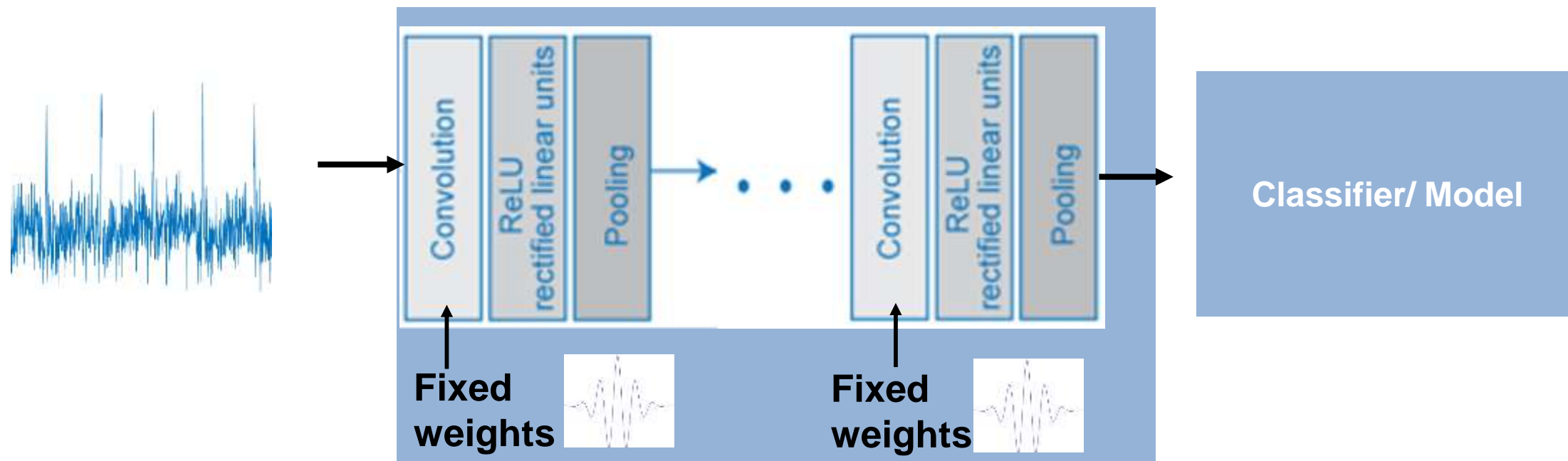


Radar

- Micro-Doppler analysis
- Range-Doppler processing
- Synthetic aperture imaging
- Spectral analysis
- Waveform ambiguity
- ...



分布式小波网络提供自动特征提取

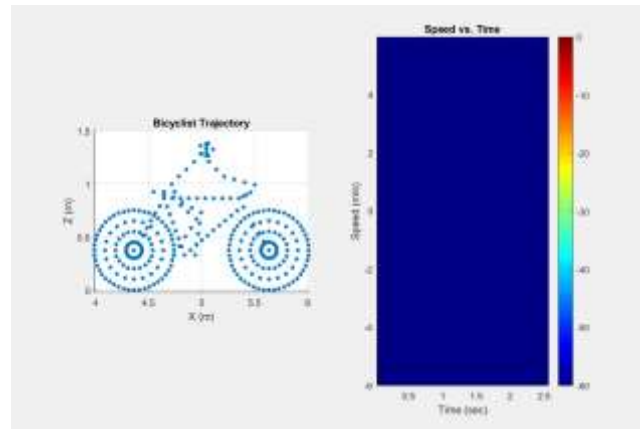
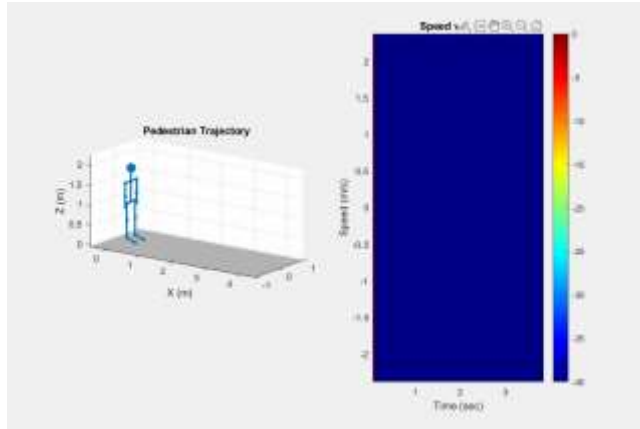


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基于微多普勒特性识别行人和骑车人



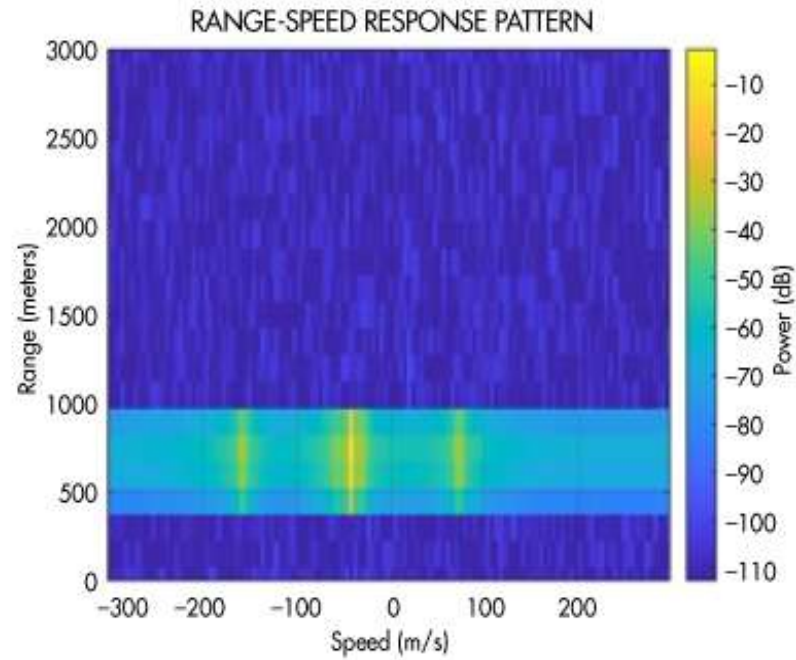
- One pedestrian
- One Bicyclist
- Two pedestrians
- Two Bicyclists
- One pedestrian and one bicyclist

DATA SYNTHESIS

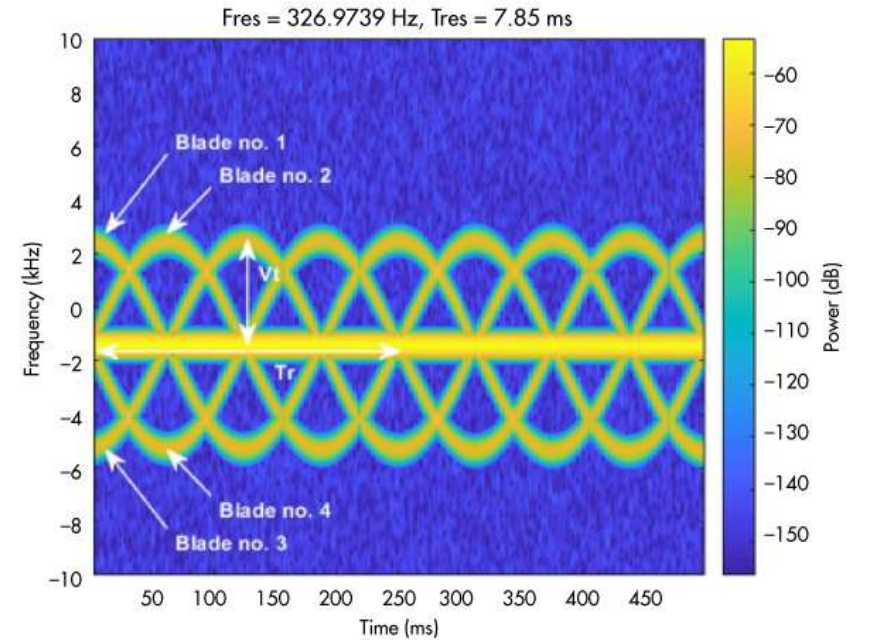
TIME-FREQUENCY TRANSFORMATION

BUILD CNN MODEL

微多普勒特性

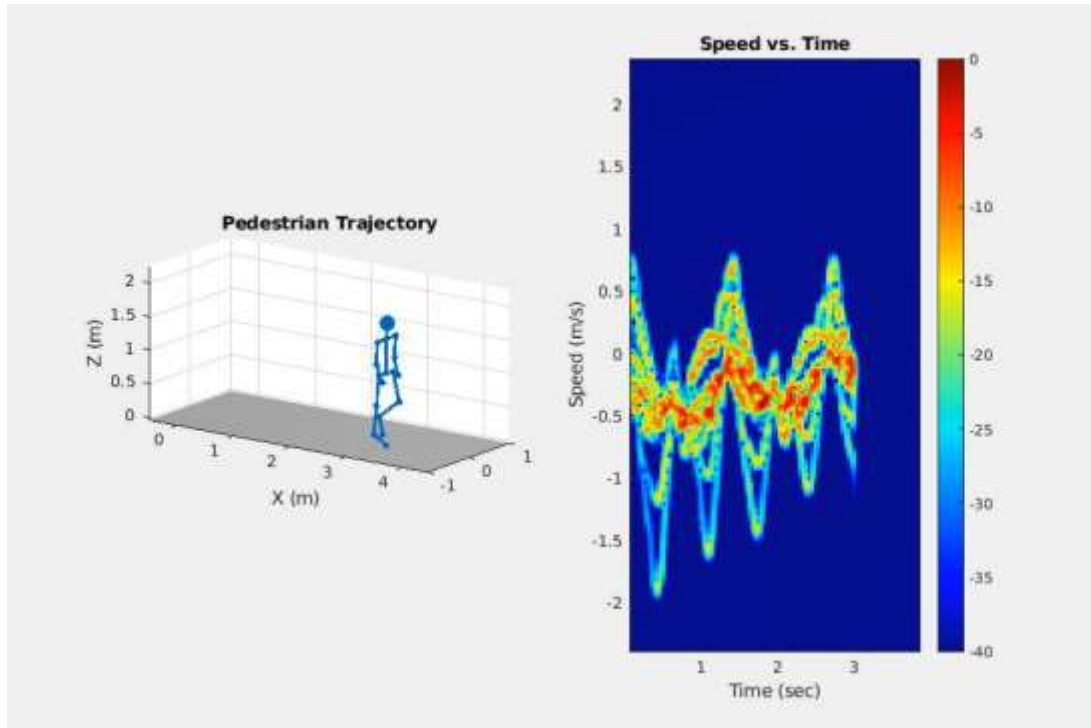


Doppler response for a helicopter in motion



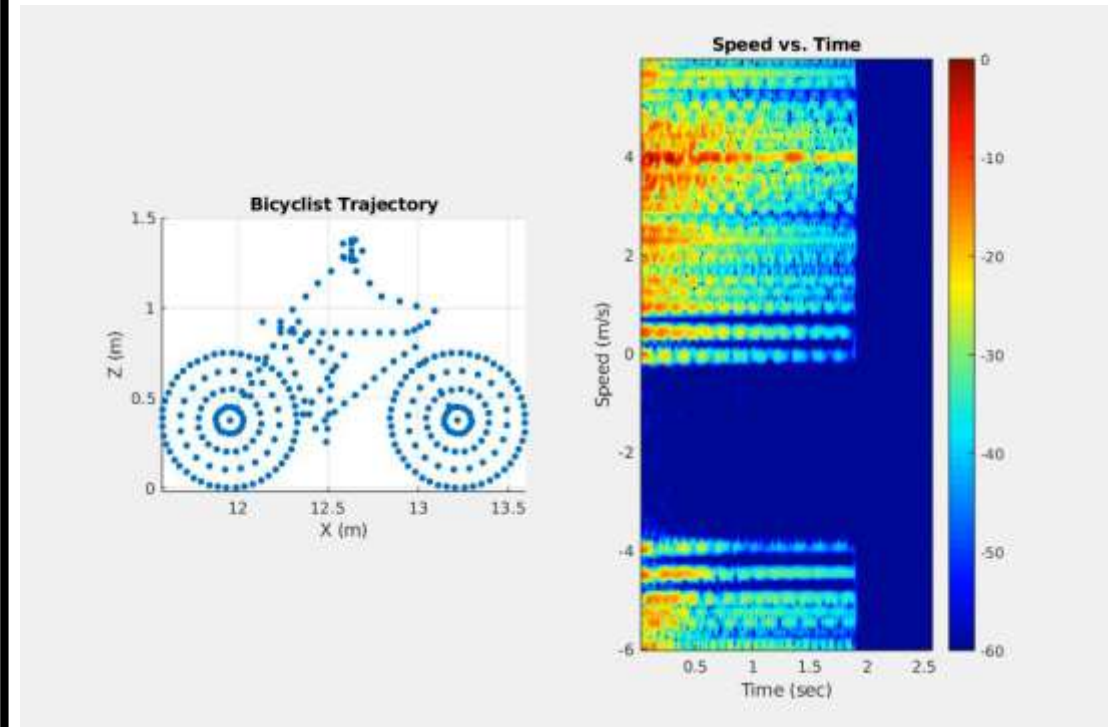
Micro-Doppler response for a helicopter in motion

数据合成: 创建多散射模型



Pedestrian

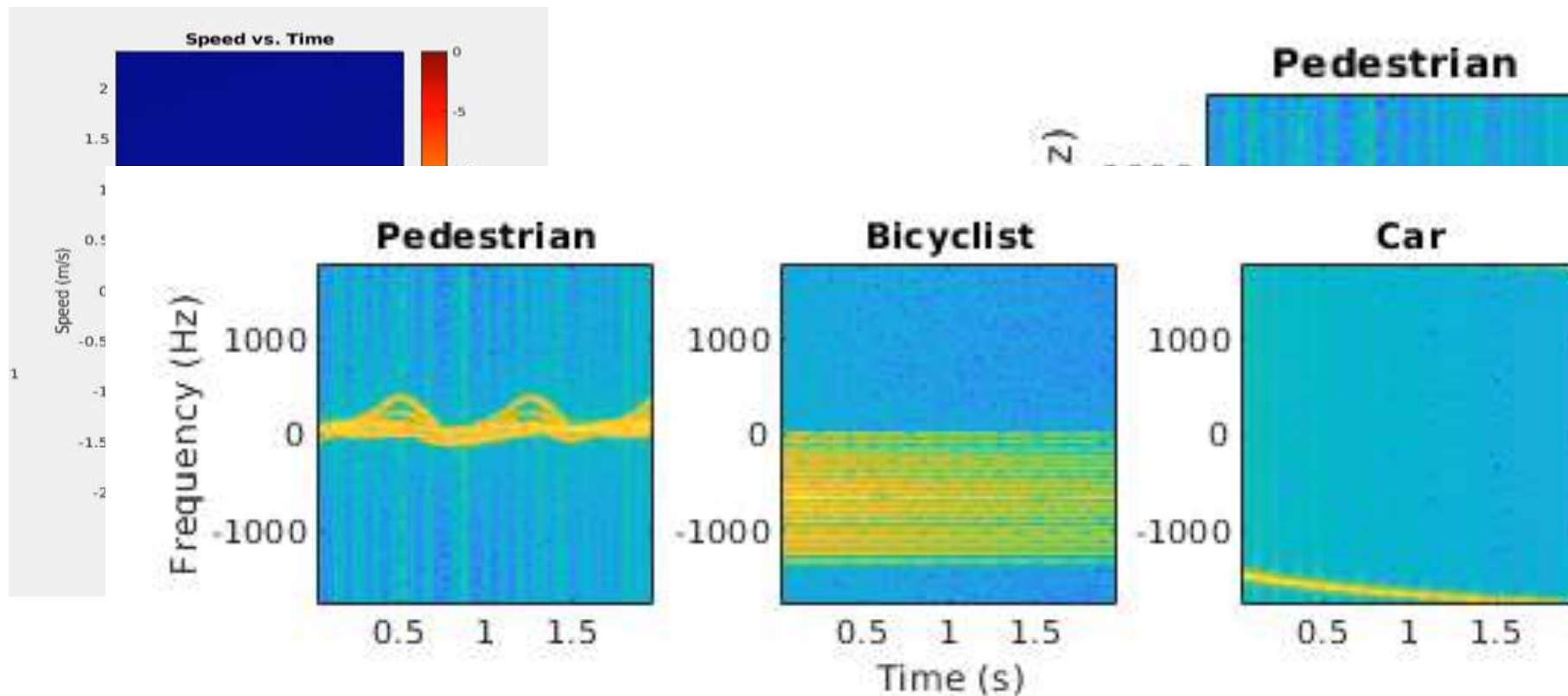
```
pedestrian = backscatterPedestrian( ...  
    'Height',2,'WalkingSpeed',0.5, ...  
    'InitialPosition',[0;0;0],'InitialHeading',90);
```



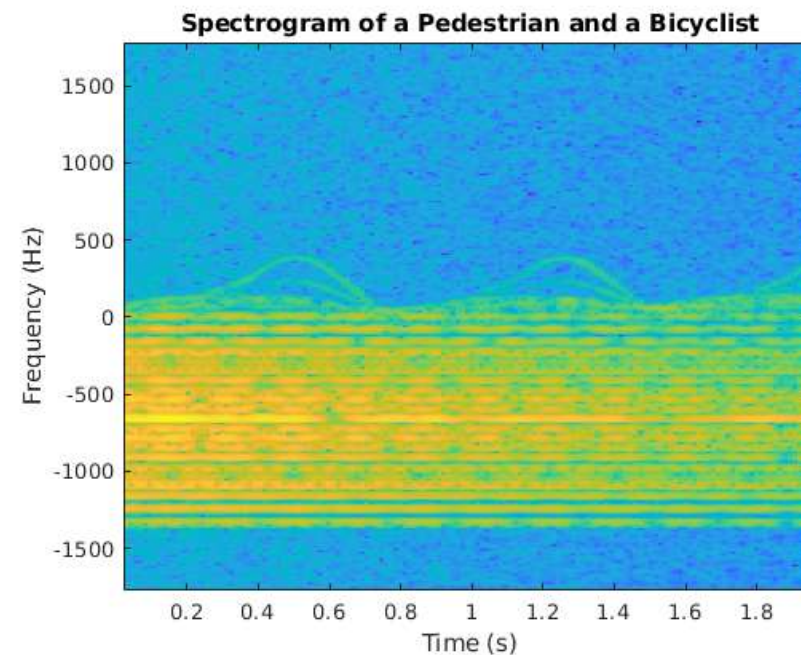
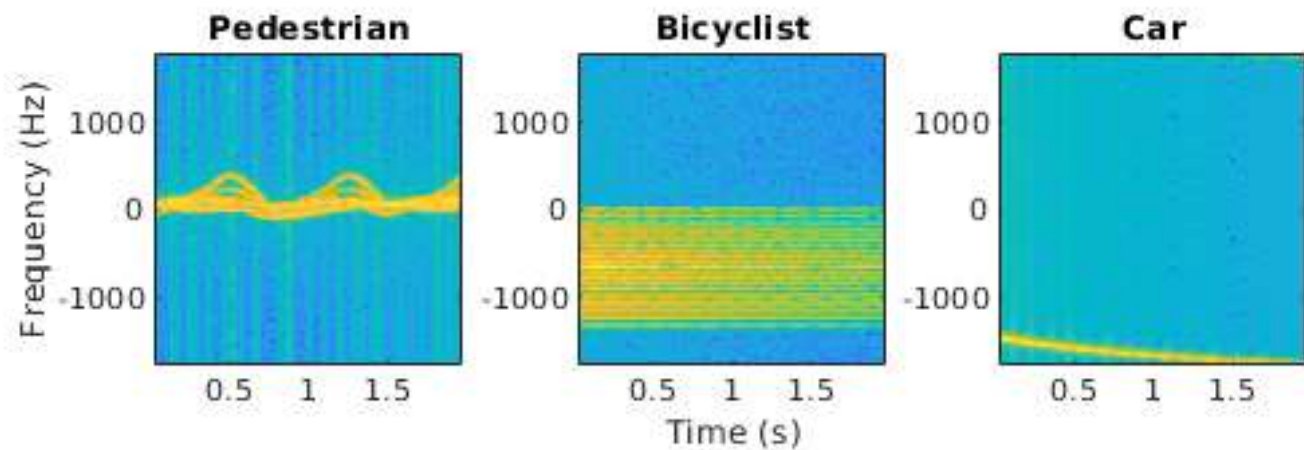
Bicycle

```
bicyclist = backscatterBicyclist( ...  
    'NumWheelSpokes',18,'Speed',10.0, ...  
    'InitialPosition',[0;0;0],'InitialHeading',90, ...  
    'GearTransmissionRatio',5.5);
```

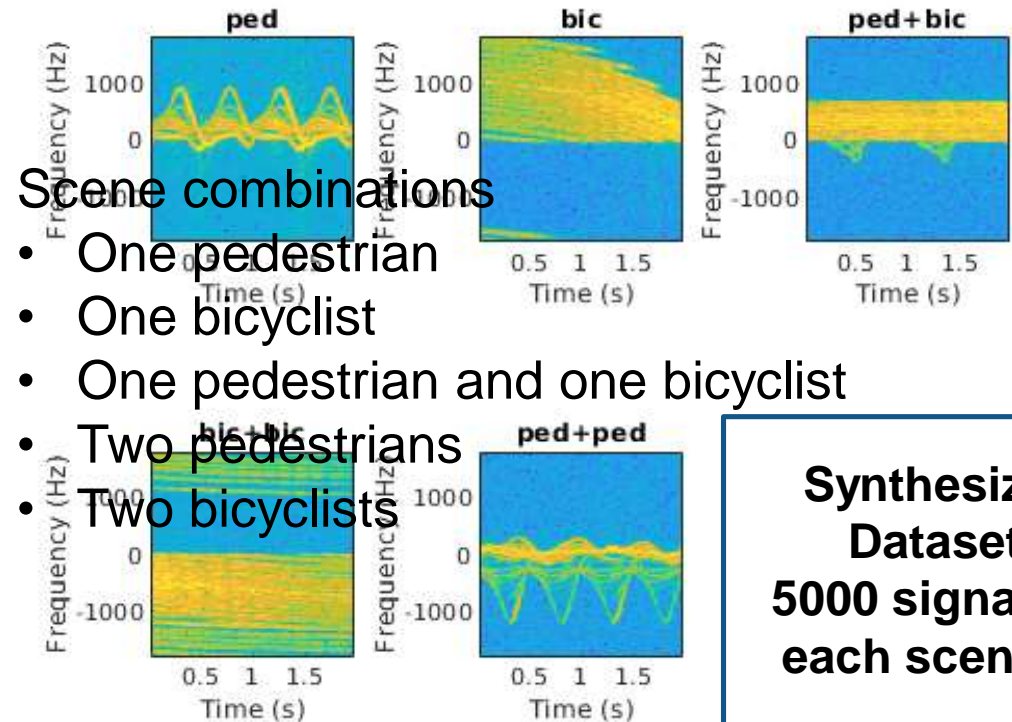
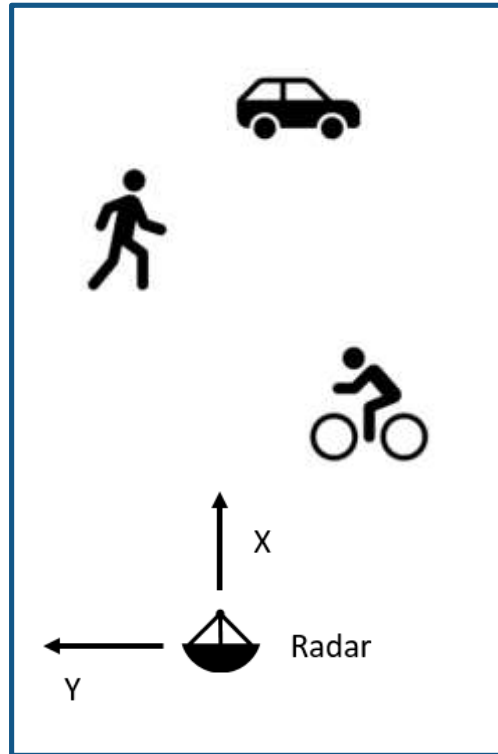
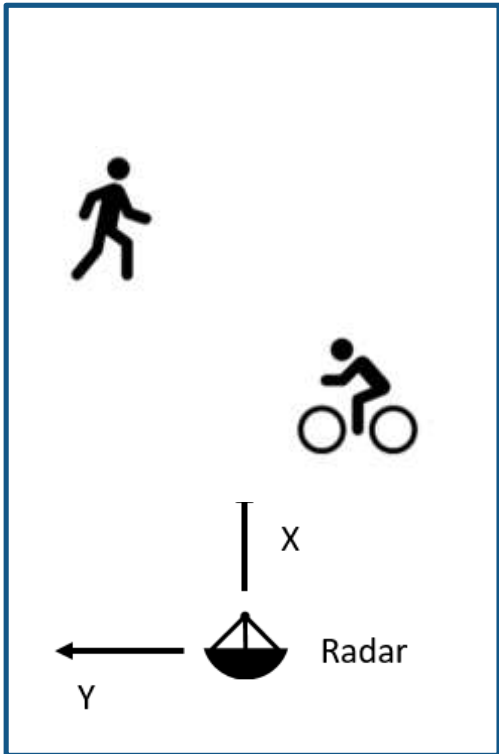
数据合成：合成微多普勒特性数据



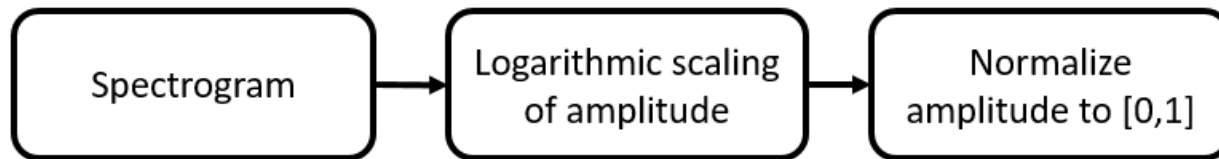
数据合成：合成目标微多普勒数据



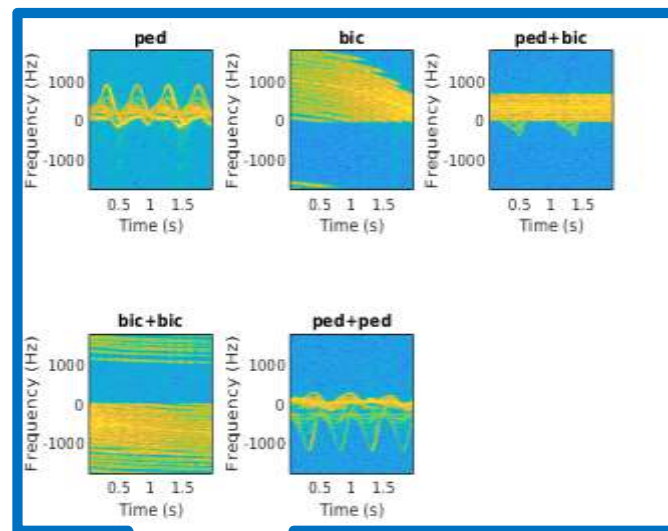
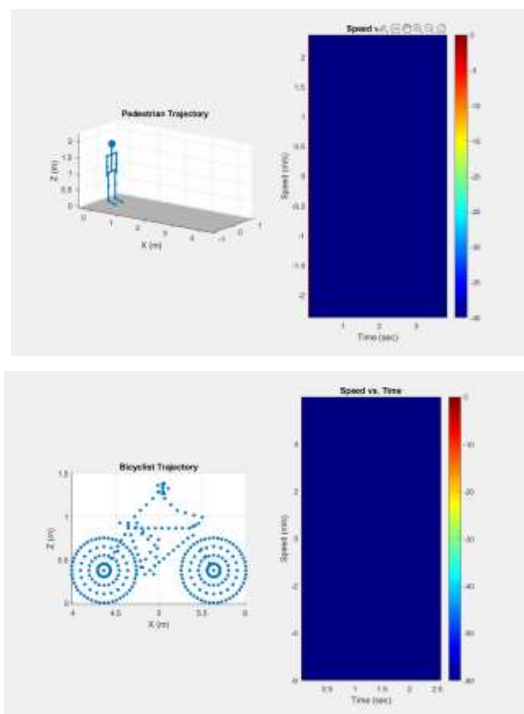
数据合成：场景创建



**Synthesized Dataset:
5000 signals in each scenario**



创建卷积神经网络模型

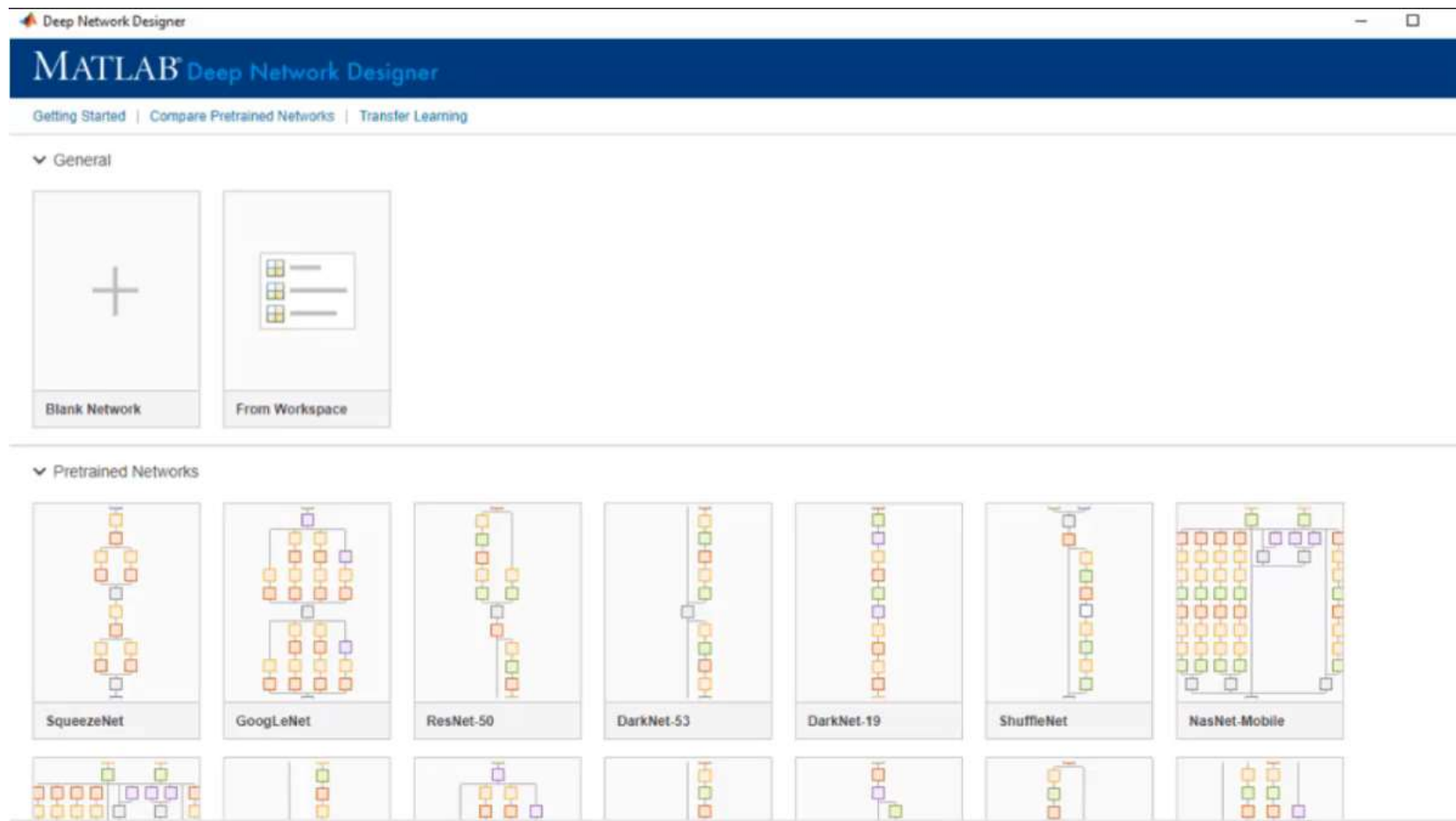


雷达信号合成

时频变换, 尺度变换, 归一化

深度学习
(CNN) 分类器

创建卷积神经网络模型



创建卷积神经网络模型

```
trainedNetNoCar = trainNetwork(trainDataNoCar,trainLabelNoCar,layers,options);
```

```
options = trainingOptions('adam', ...  
    'MaxEpochs',10, ...  
    'Plots','training-progress');
```



Accuracy

73 %

DESIGNER



FILE BUILD NAVIGATE LAYOUT ANALYSIS EXPORT

New Duplicate Cut Copy Paste Fit to View Zoom In Zoom Out Auto Arrange Analyze Export

LAYER LIBRARY

Filter layers...

INPUT

- imageInputLayer
- image3dInputLayer
- sequenceInputLayer
- rollInputLayer

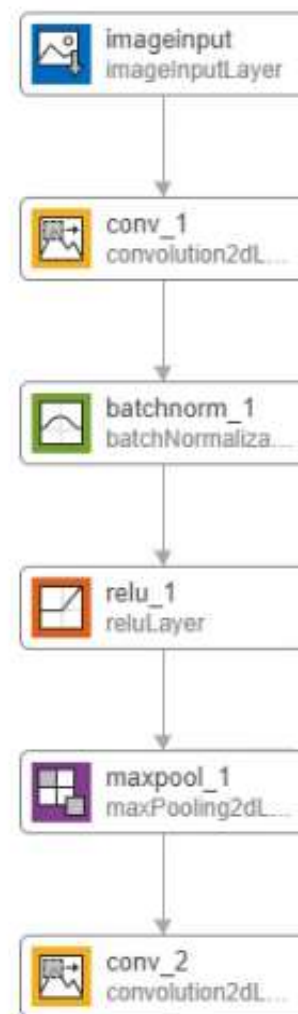
CONVOLUTION AND FULLY CONNECTED

- convolution2dLayer
- convolution3dLayer
- groupedConvolution2dLayer
- transposedConv2dLayer
- transposedConv3dLayer
- fullyConnectedLayer

SEQUENCE

- lstmLayer
- hilstmLayer

Designer Data Training



PROPERTIES

Number of layers	24
Number of connections	23
Input type	Image
Output type	Classification

OVERVIEW



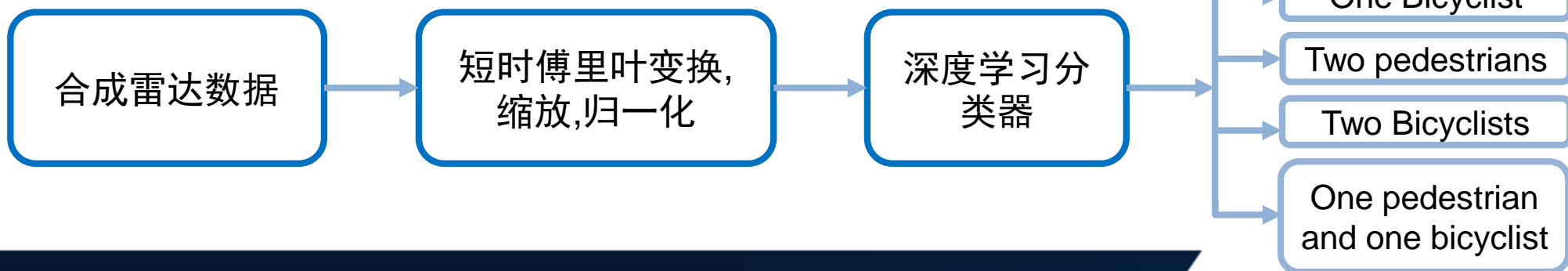
Improving your model performance : Selecting better training options

```
trainedNetNoCar = trainNetwork(trainDataNoCar,trainLabelNoCar,layers,options);
```

```
options = trainingOptions('adam', ...  
    'ExecutionEnvironment','gpu',...  
    'MiniBatchSize',128, ...  
    'MaxEpochs',30, ...  
    'InitialLearnRate',1e-2, ...  
    'LearnRateSchedule','piecewise', ...  
    'LearnRateDropFactor',0.1, ...  
    'LearnRateDropPeriod',10, ...  
    'Shuffle','every-epoch', ...  
    'Verbose',false, ...  
    'Plots','training-progress');
```



模型测试



True Class \ Predicted Class	ped	bic	ped+bic	ped+ped	bic+bic
ped	974			26	
bic	2	979	8		11
ped+bic	3	29	933	16	19
ped+ped	58	1	5	936	
bic+bic		48	9		943

Accuracy **95 %**

Classify Signatures With Car Noise

Classify Signatures with Car Noise

True Class	ped	685	130	81	104	
	bic	43	822	86	8	41
	ped+bic	57	147	743	21	32
	ped+ped	192	83	129	596	
	bic+bic	36	153	68	1	742
		ped	bic	ped+bic	ped+ped	bic+bic
		Predicted Class				

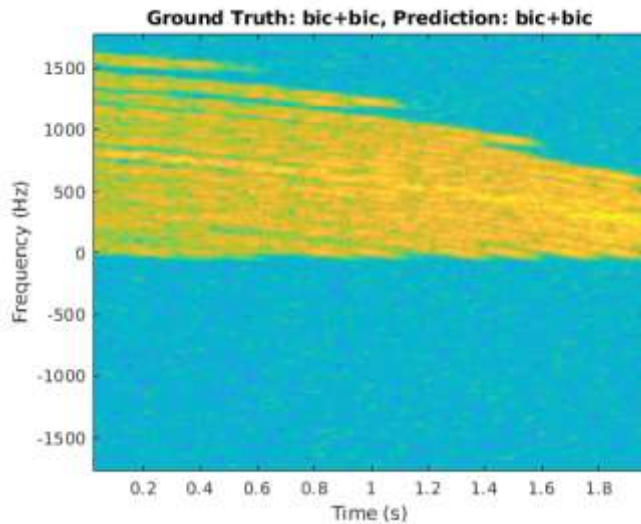
Accuracy = 71%

Retrain CNN by Adding Car Noise to Training Data Set

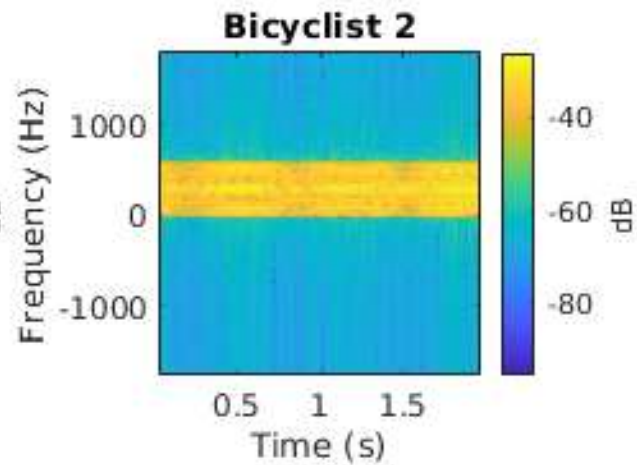
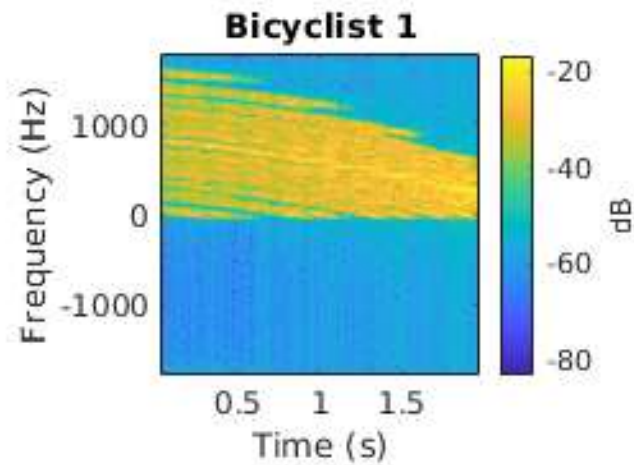
True Class	ped	908	1	1	90	
	bic	15	911	28	3	43
	ped+bic	12	78	835	39	36
	ped+ped	165	1	4	830	
	bic+bic	4	82	33	1	880
		ped	bic	ped+bic	ped+ped	bic+bic
		Predicted Class				

Accuracy = 87.28%

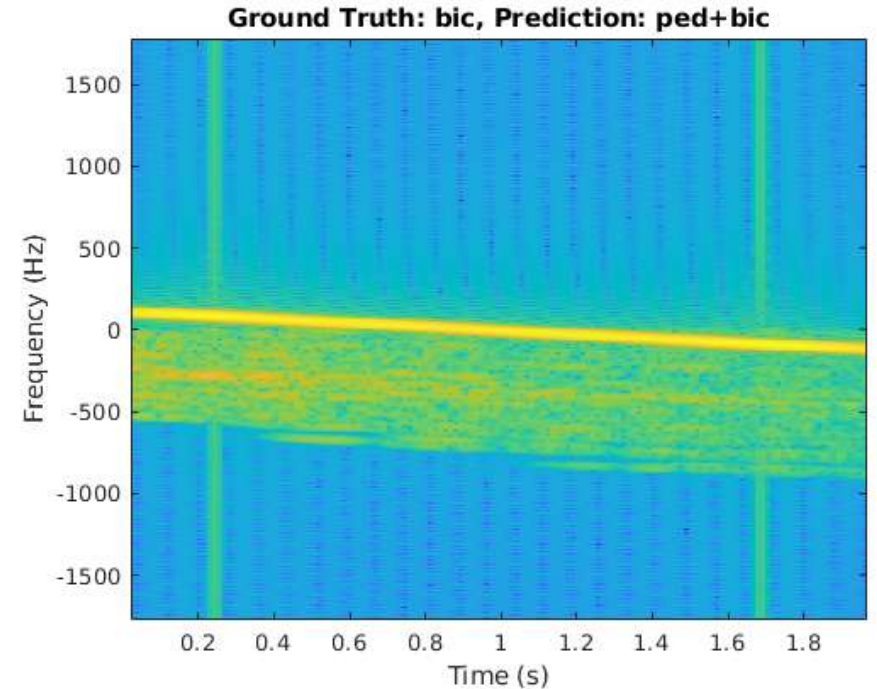
模型正确预测



Ground truth = prediction
Two bicyclists



模型错误预测



Car closely resembles bicyclist pedaling or pedestrian walking slowly

提纲

- 简介
- 深度学习流程
- 连接软件无线电（SDR）与雷达硬件
- 预处理、特征提取及标注
- ➔ ■ 实例演示- 采用合成数据训练模型，实采数据进行模型测试

误分类分析

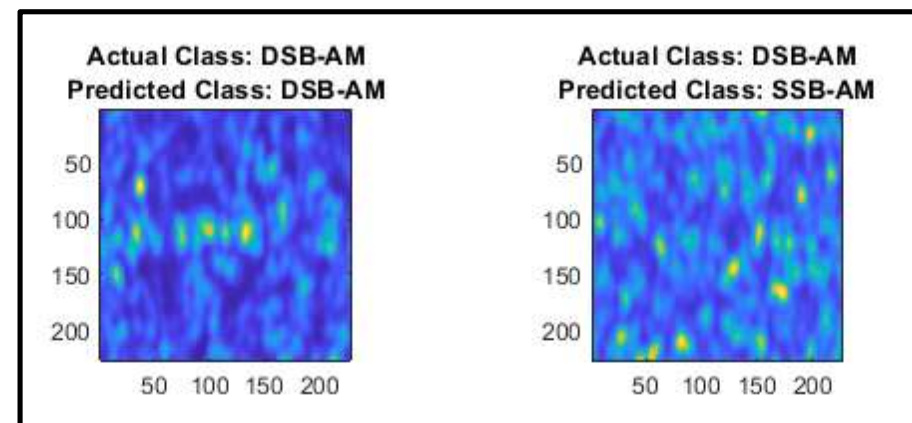
True Class \ Predicted Class	B-FM	Barker	CPFSK	DSB-AM	GFSK	LFM	Rect	SSB-AM
B-FM	99.7%							
Barker		100.0%						
CPFSK	0.3%		99.0%					
DSB-AM				88.3%				14.3%
GFSK			1.0%		100.0%			
LFM						100.0%		
Rect							100.0%	
SSB-AM				11.7%				85.7%

有哪些改善分类精度的方法？

- 更多的训练数据
- 改变网络结构
- 预处理和时频分析

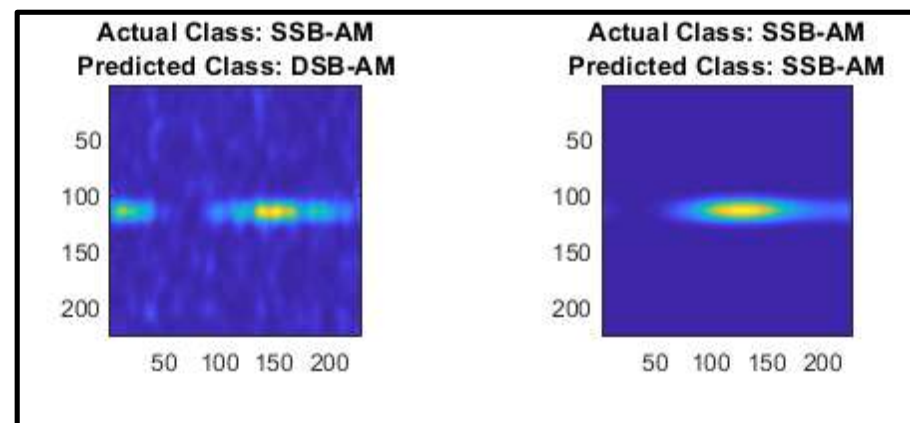
Correct

Incorrect



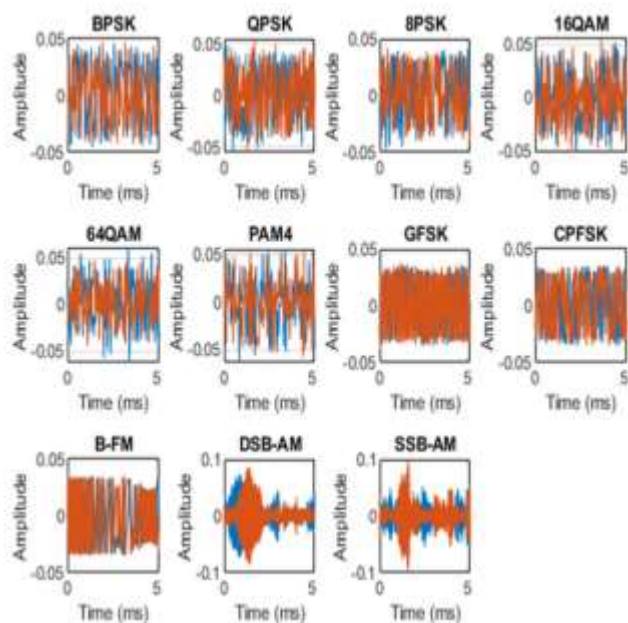
Incorrect

Correct



深度学习的通信调制方式分类

- 生成合成调制信号
- 添加信道损伤
- 训练CNN识别调制模式
- 以实际无线信号验证模型

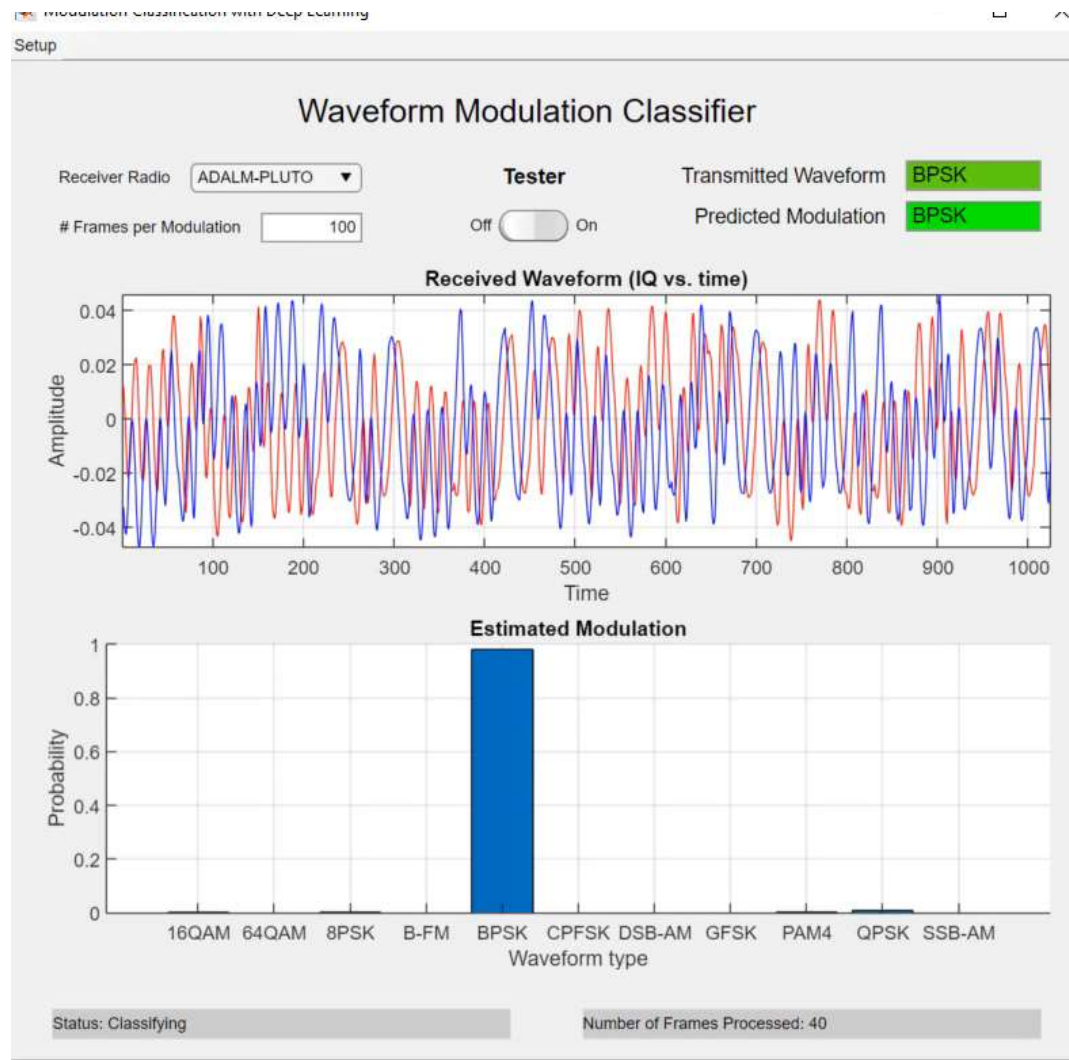


Confusion Matrix for Test Data

16QAM	737	206	26						6	25		73.7%	26.3%	
64QAM	367	611	9						2	11		61.1%	38.9%	
8PSK	5	1	875		1	1			1	116		87.5%	12.5%	
B-FM				999						1		99.9%	0.1%	
BPSK					997	1			1	1		99.7%	0.3%	
CPFSK						1	999					99.9%	0.1%	
DSB-AM								941				59	94.1%	5.9%
GFSK									1000				100.0%	
PAM4	3	3			2					991	1	99.1%	0.9%	
QPSK	8		193			1					798	79.8%	20.2%	
SSB-AM								61				939	93.9%	6.1%

True Class (rows) vs Predicted Class (columns)

波形分类网络连接无线收发器硬件



Confusion Matrix for Test Data

True Class \ Predicted Class	16QAM	64QAM	8PSK	B-FM	BPSK	CPFSK	GFSK	PAM4	QPSK	Accuracy	Miss Rate
16QAM	89	11								89.0%	11.0%
64QAM	1	99								99.0%	1.0%
8PSK			100							100.0%	
B-FM				100						100.0%	
BPSK					100					100.0%	
CPFSK						100				100.0%	
GFSK							100			100.0%	
PAM4								100		100.0%	
QPSK			4						96	96.0%	4.0%



创建和访问数据集

预处理和特征提取

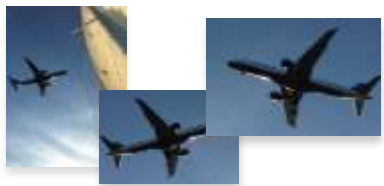
预测模型开发

部署

Data sources



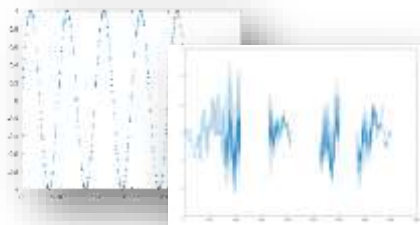
Simulation and augmentation



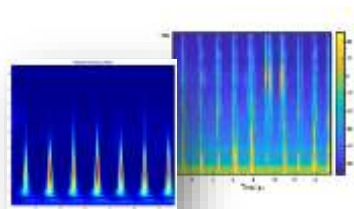
Data Labeling



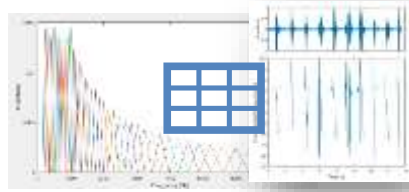
Pre-Processing



Transformation



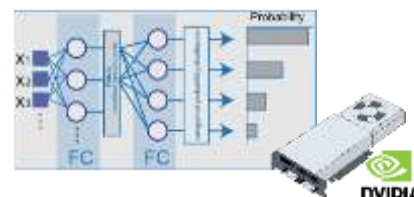
Feature extraction



Import Reference Models/
Design from scratch



Hardware-Accelerated
Training



Analyze and tune
hyperparameters



Desktop Apps



Enterprise Scale Systems

Java
MATLAB
C/C++
Python

Embedded Devices and
Hardware



谢谢!