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AI Techniques in MATLAB for Signal, Time-Series, and Text Data

Sylvain Lacaze
AI and Deep Learning for Signals in the News

Deep Learning developed and evolved for image processing and computer vision applications.

It is now increasingly and successfully used on signals and time series.
The Use of Deep Learning is Growing Across Industries

Aerospace, Defense and Communications
- Communications devices, security
- Multi-standard communications receivers, drone recognition

Automotive
- Voice control enabled Infotainment
- Sensor processing, automated driving

Consumer Electronics and Digital Health
- Voice assistants
- Digital health

Industrial Automation
- Condition monitoring
- Predictive maintenance

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Application Examples Using MATLAB – Audio and Speech

Speech Command Recognition (a.k.a. "Keyword Spotting")

Music Genre Classification
Application Examples Using MATLAB – Industrial and physiological sensors

Human Activity Recognition


ECG Signal Classification

Application Examples Using MATLAB – Radar and Communications

Modulation Classification

Agenda

▪ Deep Learning – Basic ideas

▪ Deep Learning Model Development for Signals, Time Series, and Text

▪ Conclusions
What is Deep Learning?

Deep learning is a type of machine learning in which a model learns from examples.
Common Network Architectures - Signal Processing

Time-Frequency Transformation

Convolutional Neural Networks (CNN)

Long Short Term Memory (LSTM) Networks
Common Network Architectures – Text Analytics

Feature Engineering

Convolutional Neural Networks (CNN)

Long Short Term Memory (LSTM) Networks

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Deep Learning Workflow

**Create and Access Datasets**
- Data sources
  - Simulation and augmentation
  - Data Labeling

**Preprocess and Transform Data**
- Pre-Processing
  - Transformation
  - Feature extraction

**Develop Predictive Models**
- Import Reference Models/Design from scratch
  - Hardware-Accelerated Training
  - Analyze and tune hyperparameters

**Accelerate and Deploy**
- Desktop Apps
  - Enterprise Scale Systems
  - Embedded Devices and Hardware
Deep Learning Workflow Challenges – Signals and Time Series

Deep learning models only as good as training data

- Data Labeling
- Limited Data Availability

Domain-specific data processing desirable
Limited reference research
Deployment and Scaling to various platforms
Agenda

▪ Deep Learning – Basic ideas

▪ Deep Learning Model Development for Signals, Time Series, and Text
  – Data
  – Processing and transformation
  – Model design and optimization
  – Acceleration, prototyping, and deployment

▪ Conclusions
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Current Investments – Models vs. Data

From "Troubleshooting deep neural networks" (Josh Tobin et al., Jan 2019)
What does a large dataset look like?
How to navigate, index, read (aka “ingest”) a large dataset?

How to...

▪ Build a list of all data and labels?
▪ Review basic statistics about available data?
▪ Select data subsets without nested for loops, dir, ls, what, ... aplenty?
▪ Jointly read data and labels?
▪ Automatically distribute computations?
Label quality impacts model performance as much as the quality and quantity of the actual recordings
Use appropriate tools to help you label signals

- Programmmatically…
- … or via Apps

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What if available data isn't enough?

Data augmentation allows building more complex and more robust models.

Augmented Dataset
N times as much data
Simulation is key if recording and labelling real-world data is impractical or unreasonable – Communications Signals
Simulation is key if recording and labelling real-world data is impractical or unreasonable – Radar Signals

Radar Target Simulation

Micro-Doppler Analysis
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Common types of network architectures used in signal processing and text analytics applications

Feature Engineering

Time-Frequency Transformation

Convolutional Neural Networks (CNN)

Long Short Term Memory (LSTM) Networks
Time-Frequency Transformations

- **Reframe** (e.g. Buffer) → **To frequency** (e.g. FFT)

- **Basic spectrogram**
  - Easiest to understand and implement

- **Perceptually-spaced (e.g. Mel, Bark) Spectrogram**
  - More compact for speech & audio applications

- **Wavelet scalogram**
  - Best resolution, for non-periodic signals

- **Constant Q transform**
  - Better resolution at low frequencies
Extracting Features from Signals: Application-Agnostic Examples

BW measurements

Spectral statistics

Harmonic analysis

Octave spectrum

**Frequency domain**

**Time domain**

Find peaks

Find signal patterns

Detect change points

Find signal envelope
Domain-Specific Features and Transformations – Examples

Speech and Audio
- MFCC
- GTCC
- MDCT
- Pitch, harmonicity
- Spectral shape descriptors
- ...

Navigation and Sensor Fusion
- Orientation
- Height
- Position
- Multi-object tracking
- ...
- 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
- ...

- Acceleration, angular velocity
- Magnetic field
- GPS reading

- Orientation
- Height
- Position
- Multi-object tracking

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

- Train Word Embeddings
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- Radar
- Micro-Doppler analysis
- Range-Doppler processing
- Synthetic aperture imaging
- Spectral analysis
- Waveform ambiguity
Automated Feature Extraction: Wavelet Scattering

- Can relieve requirements on amount of data and model complexity
  - Featured in leader-boards a number of research competitions

- Framework for extracting features [1]

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Developing Deep Learning Models

Design Network

Design

Pre-trained Networks

- AlexNet
- VGG-16
- ResNet-50
- ONNX Converter

Train

Accelerate Training

MATLAB as a container on NGC

Optimize

Bayesian Hyperparameter Optimization

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Exchange Models With Deep Learning Frameworks

ONNX = Open Neural Network Exchange Format

- PyTorch
- TensorFlow
- ONNX
- TensorFlow-Keras
- MXNet
- ONNX
- Core ML
- ONNX
- Chainer
- ONNX
- Caffe
- ONNX
- MATLAB
- ONNX

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Exchange Models With Deep Learning Frameworks

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Deployment and Scaling for A.I.

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Embedded Devices

Enterprise Systems
Deploying Deep Learning Models for Inference

Application logic

Code Generation
Auto-generated Code (C/C++/CUDA)

Intel MKL-DNN Library

NVIDIA TensorRT & cuDNN Libraries

ARM Compute Library

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Enterprise Deployment

Deployment to the cloud with MATLAB Compiler and MATLAB Production Server
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Deep Learning Workflow Challenges – Signals and Time Series

Deep learning models only as good as training data

- Domain-specific processing
- Application-specific algorithms and tools
- Collaboration in the AI ecosystem
- Data-labeling Apps and Examples
- Augmentation and simulation algorithms
- Deployment and Scaling to various platforms

Data sources
- Simulation and augmentation
- Data labelling

Pre-Processing
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Import Reference Models/Design from scratch
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Desktop Apps
- Enterprise Scale Systems
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Domain-Specific Features and Transformations – Examples

Audio
- Speech Command Recognition
- Voice Activity Detection in Noise
- Denoise Speech
- Classify Gender

Signal
- Music Genre Classification
- Human Activity Recognition
- ECG Signal Classification
- Waveform Segmentation

Time-Series and Text
- Classify Time Series Using Wavelet Analysis
- Sequence-to-Sequence Classification
- Classify Text Data Using LSTMs
- Classify Text Data Using CNNs

Comms and Radar
- Radar Waveform Classification
- Modulation Classification
What next?

▪ Deep Learning Onramp

▪ Other talks:
  – Pixels to Features to Models
  – Automated Driving System Design

▪ Demo stands:
  – Deep Learning and Reinforcement Learning
  – Driverless – Science Museum exhibition stand

▪ Application Engineer support
Back up
Summary - Deep learning workflow in MATLAB

Deep Neural Network Design + Training

- Keras
- TensorFlow
- ONNX
- Caffe
- Idea

Deep Learning with MATLAB

Model Exchange

- Trained DNN

Transfer learning

Application design

- Application logic

Standalone Deployment

- Intel MKL-DNN Library
- NVIDIA TensorRT cuDNN Libraries
- ARM Compute Library

Coders

- Inception-v3
- AlexNet
- SqueezeNet
- ResNet-101
- GoogLeNet
- ...

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