신호 및 시계열 데이터를 위한 인공지능
김종남 부장
Machine Learning and Deep learning have grown rapidly over the last decade
Use of AI in signal processing applications is growing rapidly

UT Austin Researchers Convert Brain Signals to Words and Phrases Using Wavelets and Deep Learning

“MATLAB is an industry-standard tool, and one that you can trust. It is easier to learn than other languages, and its toolboxes help you get started in new areas because you don’t have to start from scratch.”
— Dr. Jun Wang, UT Austin

Classifying the brain signals corresponding to the imagined word “goodbye” using feature extraction and deep neural networks.

Shell performs Seismic Event Detection with Deep Learning

Challenges
- Terabytes of passive seismic data from geophones
- Traditional methods time/labor intensive (5 months & ~ $100K)
- Event detection inconsistent/unreliable in 'low' signal to noise records

Solution
- Train LSTM network to detect P-wave and S-wave arrivals via sequence-to-sequence classification

Results
- >98% accuracy for arrival prediction
- Networks generalizes to other data (sites, source mechanisms)

Battelle Neural Bypass Technology Restores Movement to a Paralyzed Man’s Arm and Hand

“The algorithms we developed using MATLAB gave the participant back basic control of his arm and hand. By the end of the study, he could grip a bottle, pour out its contents, and set it down, as well as pick up a stir stick and execute a stirring motion.”
— David Friedlander, Battelle

Patient using the Battelle NeuralLife system.

Voice Interface: The Touchscreen of the Next Century

How AI and Signal Processing Came Together to Track the DNA of Sound
Modulation Classification of RF waveforms

TRANSMITTER
(Software Defined Radio)

RECEIVER
(Software Defined Radio)

Modulation Type

Intelligent Receivers
Spectrum Management
Radar Interference Detection
AI-driven system design

Data Preparation
- Data cleansing and preparation
- Human insight
- Simulation-generated data

AI Modeling
- Model design and tuning
- Hardware accelerated training
- Interoperability

Deployment
- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

Iteration and Refinement
Preparing and labelling data

Q. How to label collected data?

Q. What if it is not possible to collect data?
Labeling Signals with Signal Labeler App
Generate Synthetic Data for various applications in MATLAB

- Simulate data using Simulink models
  - Triplex Pump with Faults
  - Copyright 2017-2018 The MathWorks, Inc.

- Generate wireless waveforms

- Generate Radar Returns

- Generate and Augment Audio Data
  - text2speech
Generation of wireless communication waveforms with impairments

• Modulate digital baseband signals using built-in functions
  • BPSK, QPSK, 8PSK, FM, DSB-AM, SSB-AM, GFSK, PAM4

• Easily account for various impairments
  • RF / Hardware impairments (Frequency/Phase Offsets etc.)
  • Channel Impairments (Multipath Fading Channels)

• Generate Datasets for Deep Learning
  • 5000 frames generated for each modulation type
  • 80% data – Training; 10% data – Validation; 10% data - Test
Q. Can I use raw data?

Q. How do I extract the right features for my data?
Use of raw data for AI models

High Dimensionality

Need for more data

Need for specialized models

IQ waveform

Q waveform

I waveform
Feature extraction with signal processing techniques

**Time-Domain Features**
- Signal Patterns
- Changepoints
- Peaks
- Signal Envelope

... ...

**Frequency-Domain Features**
- BW measurements
- Spectral Statistics
- Octave Spectrum

... ...

**Time-Frequency features**
- STFT
- CWT
- Constant-Q Transform

... ...

**Domain-Specific Features**
- Speech and audio
- Navigation and Sensor Fusion
- Radar
- Communication

... ...
Building the AI models

Q. How do I select the right model for my application:
  • If I do not have enough data?
  • If I do not have domain expertise?
  • If I need an easily interpretable model?
   .....
Start by using published literature and MATLAB examples
Understanding tradeoffs for model selection

- Data Volume
- Signal Processing
- Domain Knowledge

Deep learning with raw data
Transfer learning with TF maps
Manual Feature Extraction + Machine Learning
Deep learning with few features

Ly Generate Data
Machine Learning

with many features
There are three ways to build AI models in MATLAB:

1. **Writing code**
   - `imageInputLayer([2 spf 1], 'Name', 'Input Layer')`
   - `convolution2dLayer(filterSize, 'Name', 'CNN1')`
   - `batchNormalizationLayer('Name', 'BN1')`
   - `reluLayer('Name', 'ReLU1')`
   - `maxPooling2dLayer(poolSize, 'Name', 'MaxPool1')`

2. **Interactively Design Models with Apps**

3. **Use Transfer Learning for Deep Learning**

**fitcauto/fitrauto**
Iterate to find the best model with Experiment Manager App

- Find optimal training options
- Compare the results of using different data sets
- Compare the results of using different models
Generation of wireless communication waveforms with impairments

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Waveform Generation for Training

Generate 10,000 frames for each modulation type, where 80% is used for training, 10% is used for validation and 10% is used for testing. We use training and validation frames during the network training phase. Final classification accuracy is obtained using test frames. Each frame is 1024 samples long and has a sample rate of 200 kHz. For digital modulation types, eight samples represent a symbol. The network makes each decision based on single frames rather than on multiple consecutive frames (as in video). Assume a center frequency of 902 MHz and 100 MHz for the digital and analog modulation types, respectively.

To run this example quickly, use the trained network and generate a small number of training frames. To train the network on your computer, choose the “Train network now” option (i.e., set trainNow to true).

```matlab
trainNow = Train network now ;
if trainNow == true
    numFramesPerModType = 5000;
else
    numFramesPerModType = 500;
end
percentTrainingSamples = 80;
percentValidationSamples = 10;
percentTestSamples = 10;

sps = 8; % Samples per symbol
spf = 1024; % Samples per frame
symbolsPerFrame = spf / sps;
fs = 200e3; % Sample rate
fc = [902e6 100e6]; % Center frequencies
```

Create Channel Impairments

Pass each frame through a channel with

- AWGN
Selecting the Right Model: Understanding Tradeoffs

- Deep learning with raw data
- Deep learning with TF maps
- Transfer learning with TF maps
- Machine learning with many features
- Deep learning with few features

Data Volume vs. Signal Processing / Domain Knowledge
Continuous Wavelet Transform is used to extract the Time-Frequency maps

- One line of code for generating wavelet time-frequency visualization in MATLAB. Works for any signal
  
  ```matlab
  >> cwt(inputSignal)
  ```

- Localizes sharp transients and slowly varying oscillations simultaneously

- Works with complex data
Using time-frequency maps as inputs to a pretrained CNN
Transfer Learning with Deep Network Designer App
Train and Test Deep Network
Train and Test Deep Network
Testing network with connected hardware
AI-assisted system design

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- Interoperability

Deployment
- Embedded devices
- Enterprise systems
- Edge, cloud, desktop
Deep Learning can be used in each step of the AI workflow

Labeling assistance
classifySound (YAMNet), GoogLeNet, fitcecoc (ResNet18)

Synthetic Data Generation
Generative Adversarial Networks (GANs)
Deep Learning can be used in each step of the AI workflow

features = vggFeatures(audioIn,fs);

Differentiable Signal Processing

dlstft (Differentiable STFT)

Feature Extraction

vggFeatures, waveletScattering
AI-driven system design

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Deploy to any processor with best-in-class performance

Preprocessing, Feature Extraction, AI Model
Deploying complete AI algorithms to embedded processors, GPUs and FPGAs

Modulation Classification Using Wavelet Analysis on NVIDIA Jetson

Generate and deploy a CUDA® executable that performs modulation classification using features extracted by the continuous wavelet
Deploying complete AI algorithms to embedded processors, GPUs and FPGAs

Modulation Classification Using Wavelet Analysis on NVIDIA Jetson
Generate and deploy a CUDA® executable that performs modulation classification using features extracted by the continuous wavelet

Deploy Signal Segmentation Deep Network on Raspberry Pi
Generate a MEX function and a standalone executable to perform waveform segmentation on a Raspberry Pi™.

Speech Command Recognition Code Generation with Intel MK...
Deploy feature extraction and a convolutional neural network (CNN) for speech command recognition on Intel® processors. To generate the

Classify ECG Signals Using DAG Network Deployed To FPGA
Classify human electrocardiogram (ECG) signals by deploying a trained directed acyclic graph (DAG) network.
MATLAB supports the entire AI-driven system design

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Signal Processing apps
Generate Data
Quickly build models
Accelerate training
Deploy to targets with code generation

Feature Extraction Techniques
감사합니다