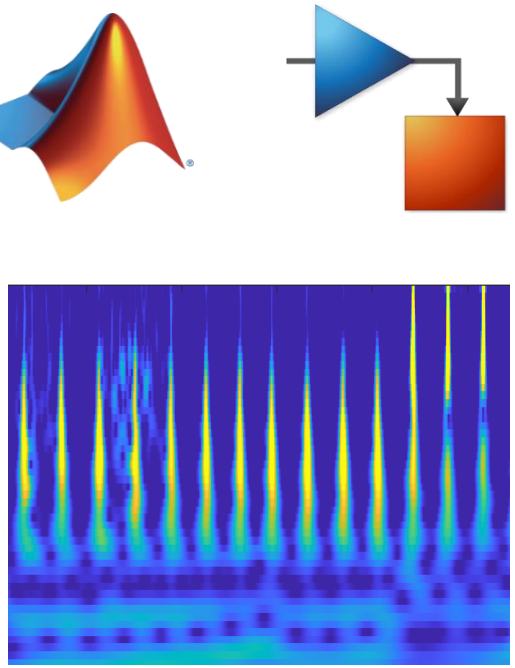
Electroencephalogram (EEG) Classification using a Convolutional Neural Network (CNN)

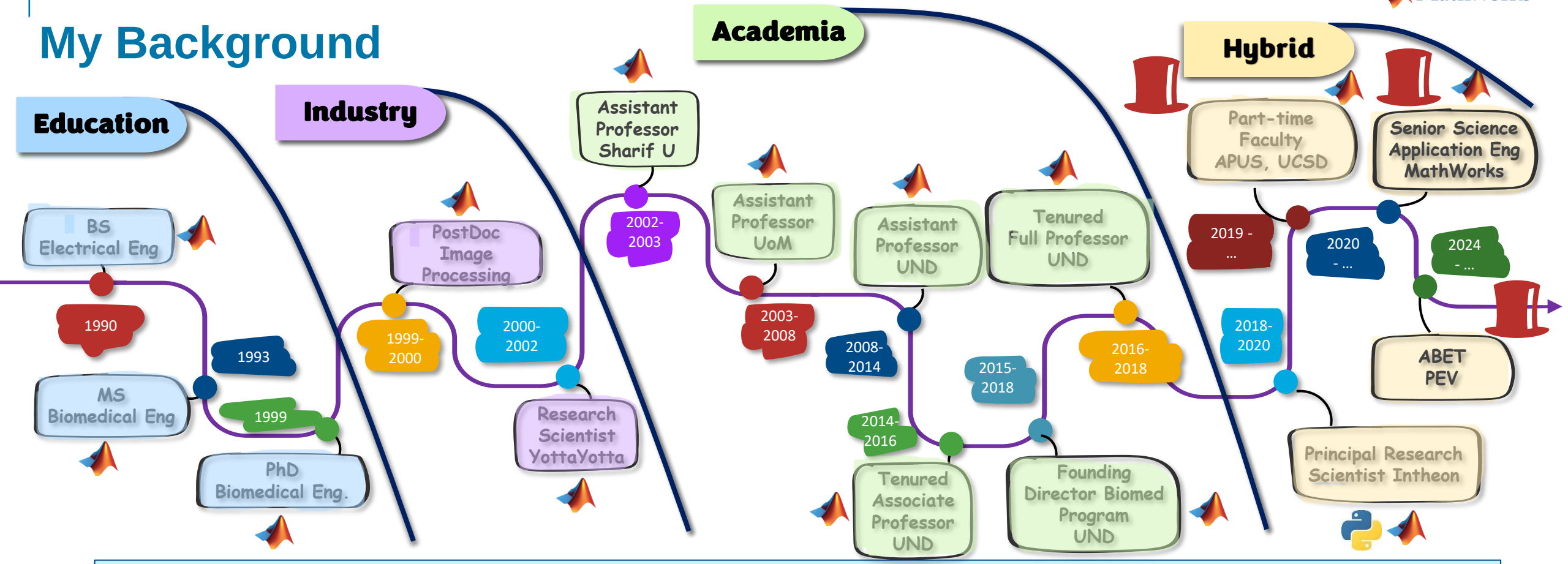


Reza Fazel-Rezai, Ph.D., P.Eng.
Senior Science and Education Application Engineer
rfazelre@mathworks.com

Agenda

- Introduction
  - Time, Frequency, and Time-Frequency Domain Digital Signal Processing
- Demo: EEG Classification using CNN

My Background



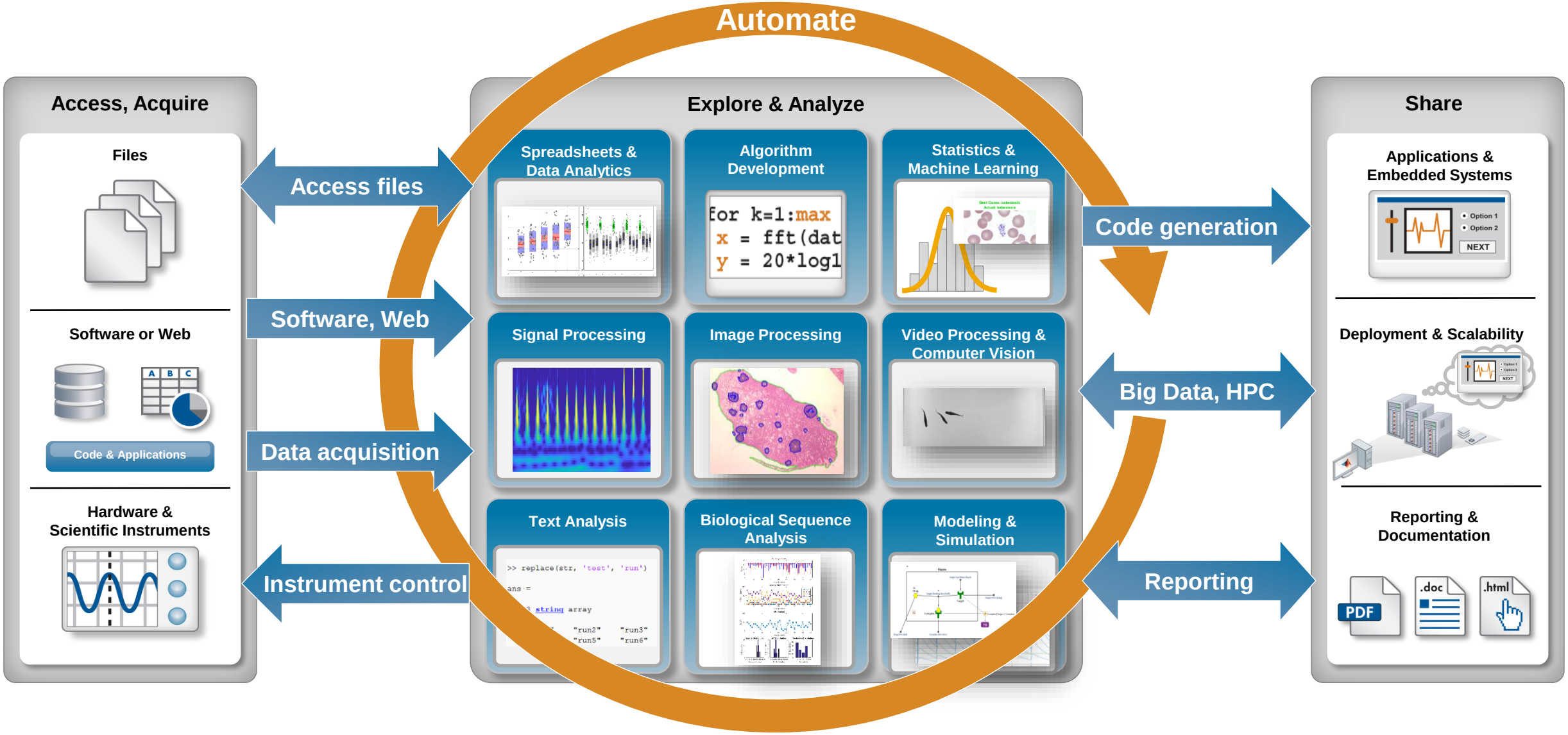
- Biomedical Signal (EEG, EMG, ECG, ….) Processing
- Image (MRI, CT, …) Processing
- Brain Computer Interface (BCI), Seizure, Concussion, …
- Artificial Intelligence, Machine Learning, Deep Learning,…

- Published Papers, Books, Book chapters (+190)
- Supervised Students (+30 graduate & +100 BS)
- Received Research Grant (~$8M as PI/Co-PI)
- Taught 27 Different Courses (Biomed, EE)

MATLAB and Simulink

Python

MATLAB: A Single Integrated Platform for Entire Workflow

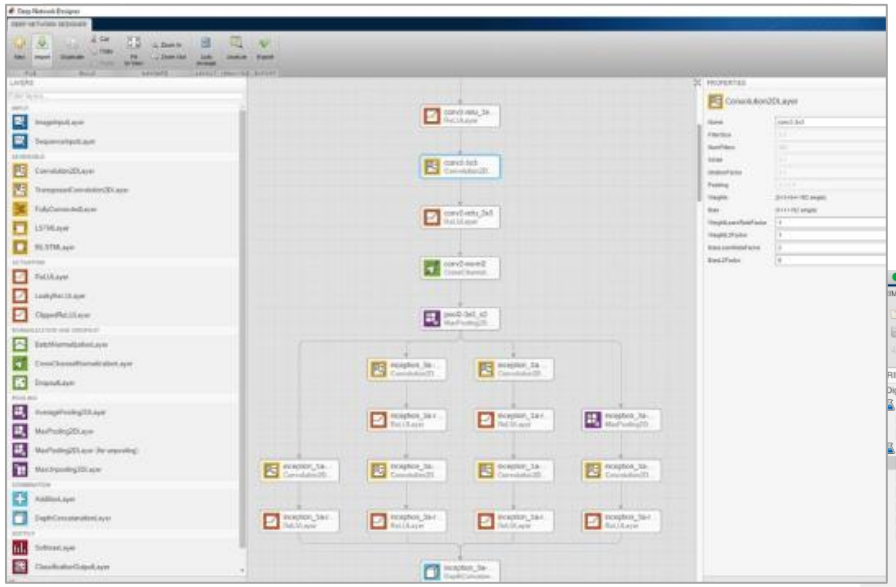


Deep Network Designer and Experiment Manager Apps

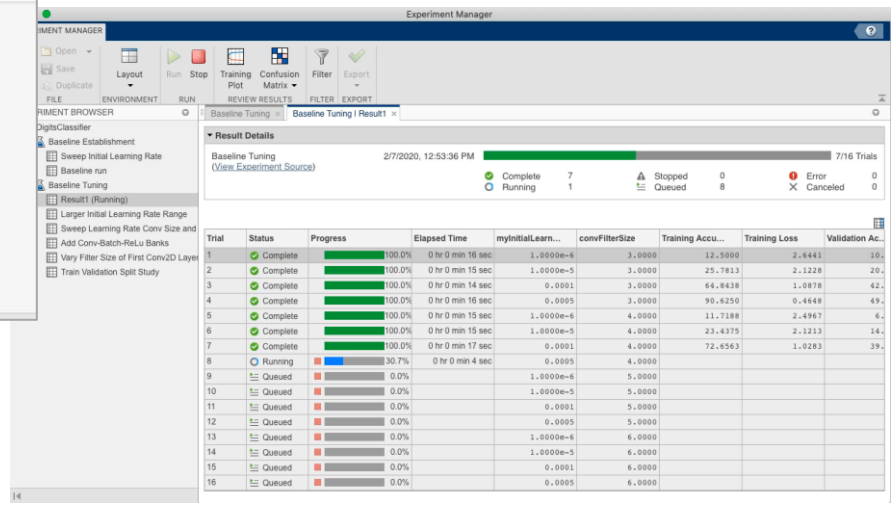
Use MATLAB Apps to design deep learning networks, explore a wide range of classifiers, detectors, regression models, and more.

AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability



Deep Network Designer app to build, visualize, and edit deep learning networks



Experiment Manager app to manage multiple deep learning experiments, analyze and compare results and code

10

Signal Processing: Classical Time and Frequency Approaches

Time-Domain Analysis

This is the most common approach

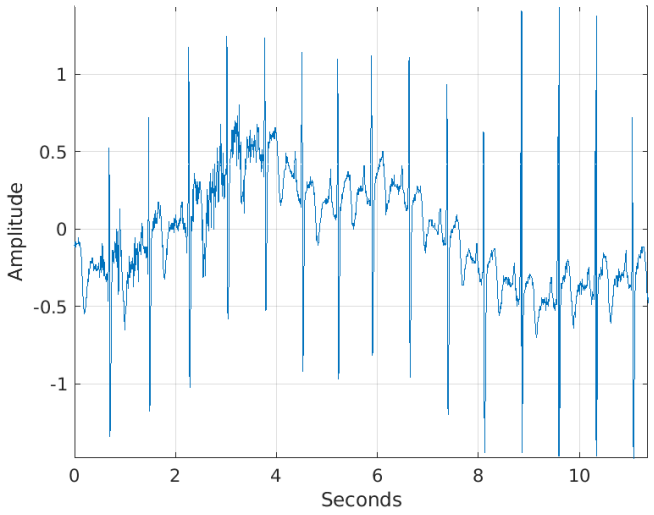
- Amplification
- Correlation
- Statistical Feature Extraction
- Chaotic Parameters
- …

Frequency-Domain Analysis

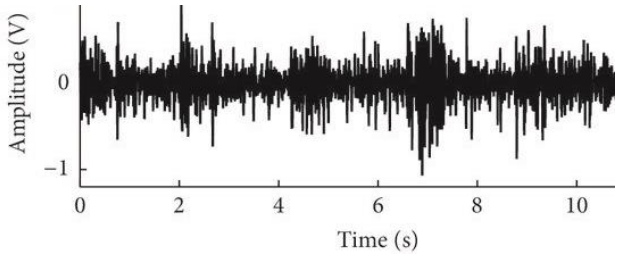
Determining the frequency contents of a signal

- Fourier Transform
- DFT
- FFT
- Spectrum
- …

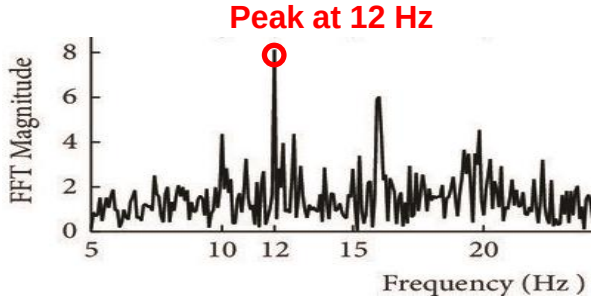
ECG Signal

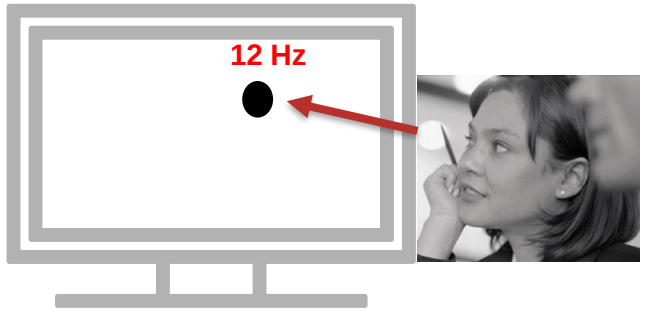


EEG in a SSVEP BCI Experiment



Peak at 12 Hz





Frequency-Domain Analysis

Topics	MATLAB Functions
❑ Magnitude and Phase Information of the FFT	➢ fft
❑ Finding Signal Periodicities	➢ ifft
❑ Measuring Power	➢ periodogram
❑ Finding Spectral Components	➢ findpeaks
❑ Frequency Resolution	➢ pwelch
	➢ bandpower

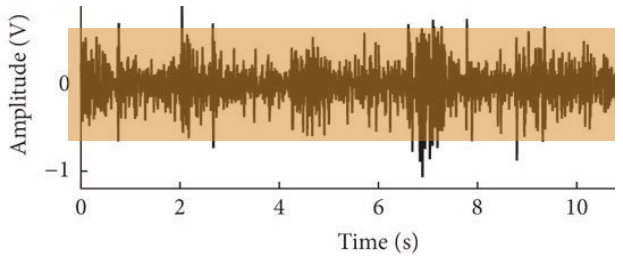
Time-Frequency Analysis

- There are cases when the frequency changes over time and it is nonstationary, in most biomedical signals.
- We analyze a signal by breaking it down into small, overlapping, and equally spaced time segments, each containing a finite number of samples.
- Using these segments, we can examine how the frequency content of the signal changes over time, providing us with a time-varying spectrum of the signal.

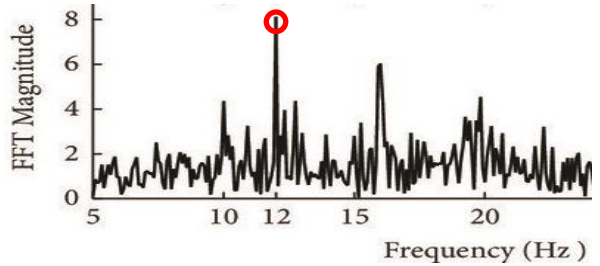
Frequency vs Time-Frequency Analysis

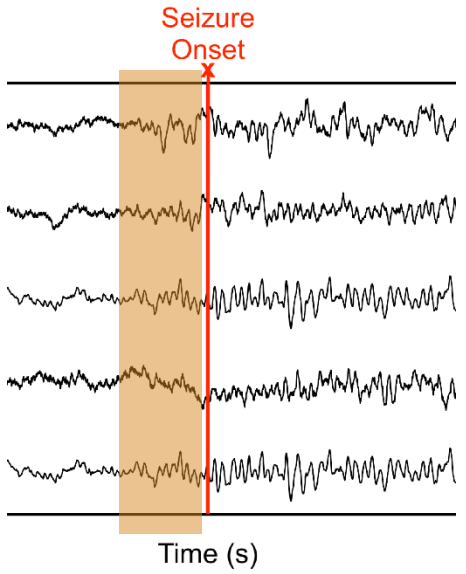
- There is no **"Unique Time-Frequency Method"**, but there are various approaches such as:
  - Short-Time Fourier Transform (STFT)
  - Wavelet Transform
  - Wigner-Ville Distribution
  - Hilbert-Huang Transform

EEG in a SSVEP BCI Experiment

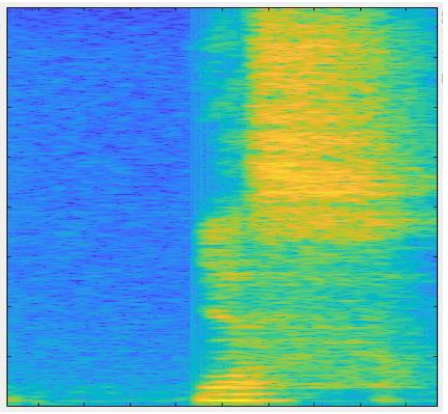


Peak at 12 Hz

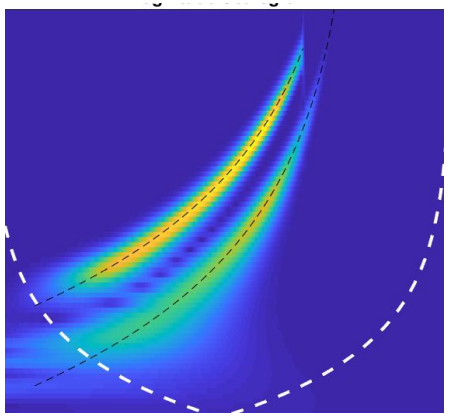




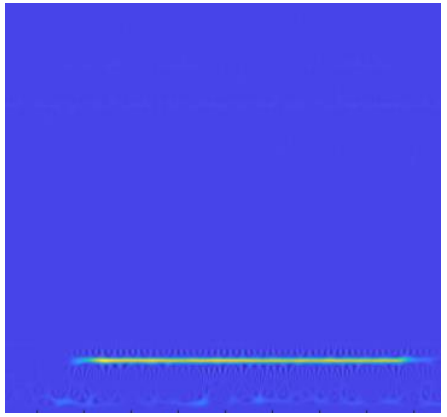
Different Types of Time-Frequency Transforms



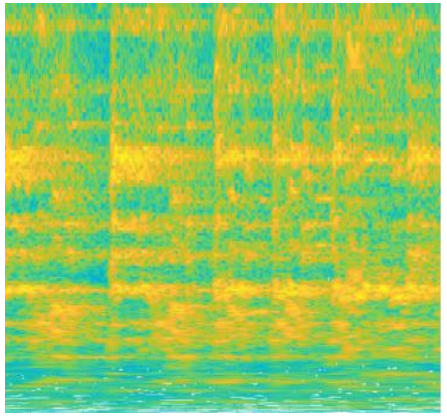
Basic spectrogram



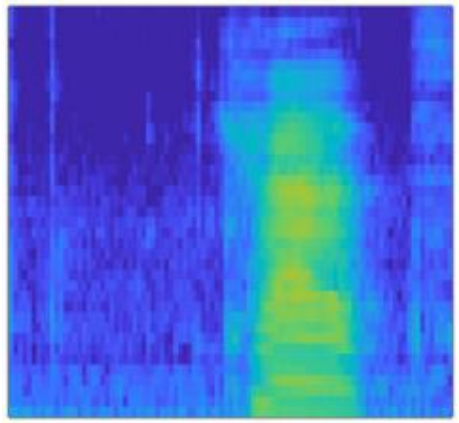
Wavelet scalogram



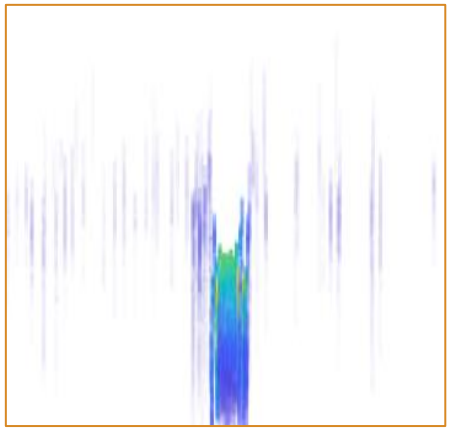
Wigner-Ville Transform



Hilbert-Huang Transform



Constant Q transform



Perceptually-spaced Spectrogram

[MATLAB Time –Frequency Gallery]

Time-Frequency Analysis

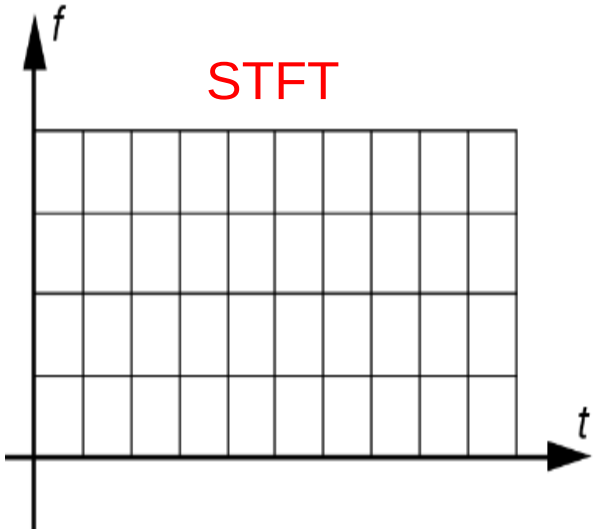
Topics	MATLAB Functions
❑ Time-Frequency Analysis to Identify Numbers Dial Numbers ❑ Trade off Between Time and Frequency Resolution ❑ Time-Frequency Reassignment ❑ Reconstructing a Time-Frequency Ridge ❑ Three-Dimensional Waterfall Visualization ❑ Finding Interferences Using Persistence Spectrum	➢ pspectrum ➢ meanfreq ➢ fsst ➢ ifsst ➢ tfridge

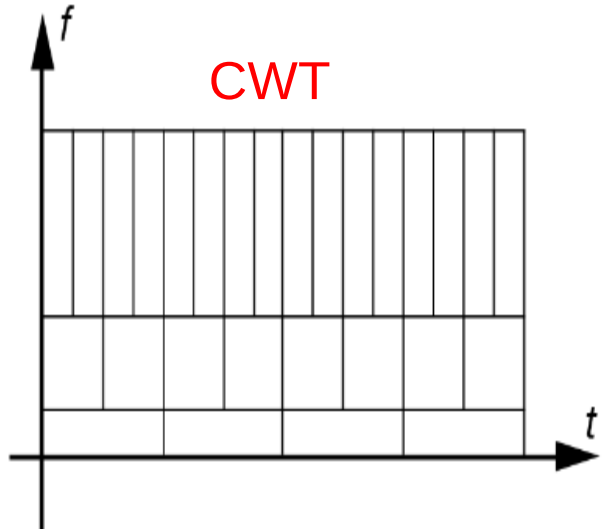
Wavelet Analysis

- Wavelet transforms are mathematical tools for analyzing data where features vary over different scales.
- For signals, features can be frequencies varying over time, transients, or slowly varying trends.
- Wavelet transforms were primarily created to address the limitations of the Fourier transform.

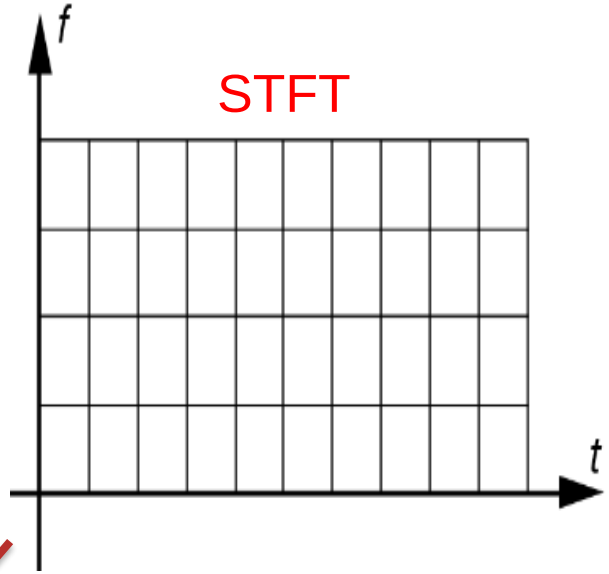
Tiling the time-frequency plane

- Many time-frequency techniques derive their strengths and limitations by the way they tile the (t,f) plane
- The structure of the transform imposes constraints on what can be resolved jointly in time and frequency.
- Each representation has strengths and weakness.



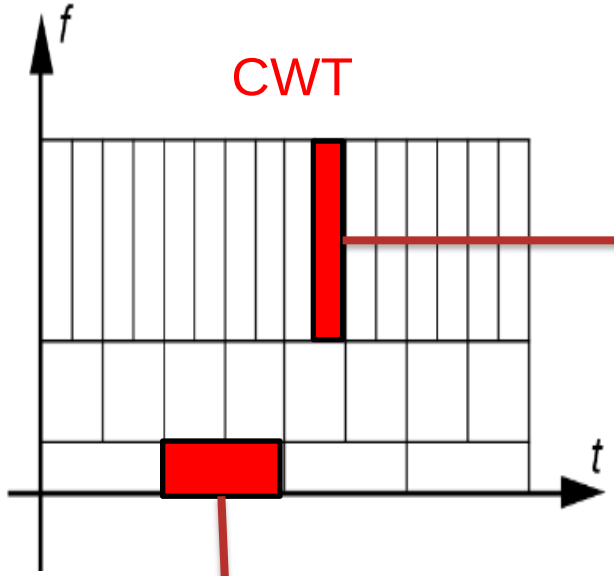


STFT and CWT: How do they tile the (t,f) plane?



STFT

Same time-frequency resolution everywhere



CWT

Time Resolution ↑

Frequency Resolution ↓

Time Resolution ↓

Frequency Resolution ↑

Wavelet Analysis

Topics	MATLAB Functions
❑ Continuous versus Discrete Wavelet Analysis	➢ cwtfilterbank
❑ Filters or Voices Per Octave	➢ wavelets
❑ Logarithmically Spaced Center Frequencies	➢ cwt
❑ Time-Frequency Analysis	➢ pspectrum
❑ Localize Transients	➢ wsst
❑ Sharpen Time-Frequency Analysis	➢ iwsst
❑ Compare Time-Varying Frequency Content in Two Signals	➢ wcoherence

Artificial Intelligence

ARTIFICIAL INTELLIGENCE

MACHINE LEARNING

DEEP LEARNING

A technique that mimics or simulates "**human intelligence**".

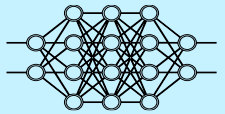
A method that "**learns**" tasks by fitting models to data.

Supervise Learning

Unsupervised Learning

Reinforcement Learning

A "deep neural network" that learns patterns from data.



Today's Demo

ChatGPT

Self-Driving

3 Components to Train any Network

"How much data do I need?"

It depends…but **A LOT**

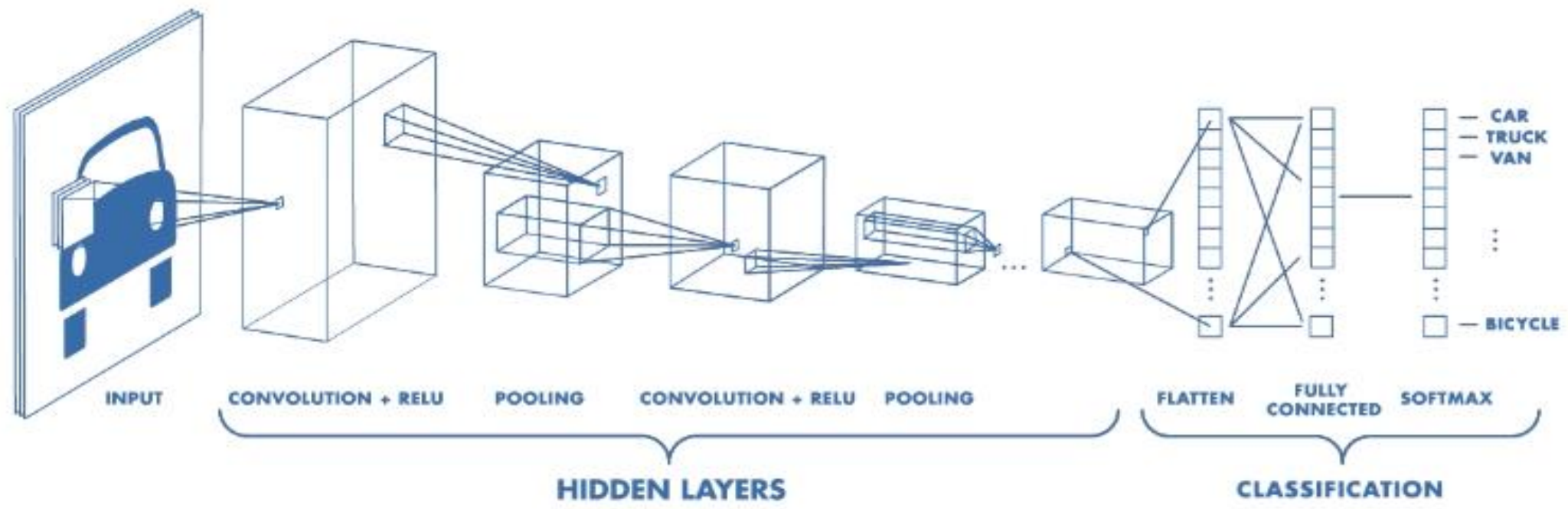
Define inputs and layers for deep learning model

Influence training time and accuracy

- Solver Type
- Initial Learn Rate
- Minibatch Size
- Max Epochs
- …

Convolutional Neural Network (CNN)

- CNNs are typically used to classify images
- Time-Frequency representations of signals can be used as images
- This approach can serve as a good starting point for signal classifications



MATLAB Apps for Signal Processing

Apps	Description
Signal Analyzer:	❑ Visualize and compare multiple signals and spectra
Signal Labeler:	❑ Label signal attributes, regions, & points of interest, extract features
Wavelet Time-Frequency Analyzer:	❑ Visualize scalogram of signals
Signal Multiresolution Analyzer:	❑ Decompose signals into time-aligned components
Filter Designer:	❑ Design, quantize, analyze filters, and modify filters
Deep Network Designer:	❑ Build, visualize, edit, and train deep learning networks
Experiment Manager:	❑ Design & run experiments to train & compare deep learning networks

EEG Classification using a CNN

- **Problem Statement**
  - To classify EEG time series from persons with and without epilepsy recorded from different brain regions
- **Method**
  - 1-D CNN
  - 2-D CNN (based on the CWT).
- **Data**
  - Bonn EEG Data Set
  - Five sets of 100 single-channel EEG recordings selected from128-channel EEG
  - Conditions:
    - A — Normal subjects with eyes open
    - B — Normal subjects with eyes closed
    - C — Seizure-free recordings from patients with epilepsy (opposite to epileptogenic zone)
    - D — Seizure-free recordings from patients with epilepsy (epileptogenic zone)
    - E — Recordings from patients with epilepsy showing seizure activity.

Demo

Thank you! Q & A

Reza Fazel-Rezai, Ph.D., P.Eng.
Senior Science and Education Application Engineer
rfazelre@mathworks.com