Week 2 Lecture 1

Overview: Medical Signal Processing

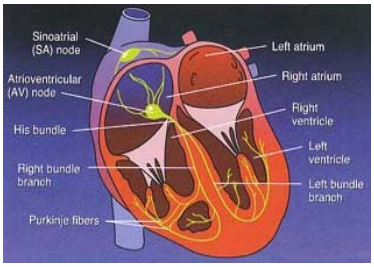
Why Medical Signal Processing?

Purposes:

- - Raw medical signals: Difficult to diagnosis
- - After transform, easier to find features
- - In many times, we need to use Machine Learning to further find "patient symptoms" from those features. This is called "Signal Learning".
- - Sometimes we compress signals to save storage overhead.
- - Many times we need to remove noise from signals.
- - Use filters to remove high or low frequency components.
- - Many other signal processing purposes …

Example: ECG signal analysis

- How do we know a patient has heart disease?
- Note: a cardiac doctor is not present – Thus we can only use computer to automatically recognize heart disease
- Today people use ECG sensor to collect heart beat signals
- Given an ECG sensor signal, how do we know if it is normal or not?

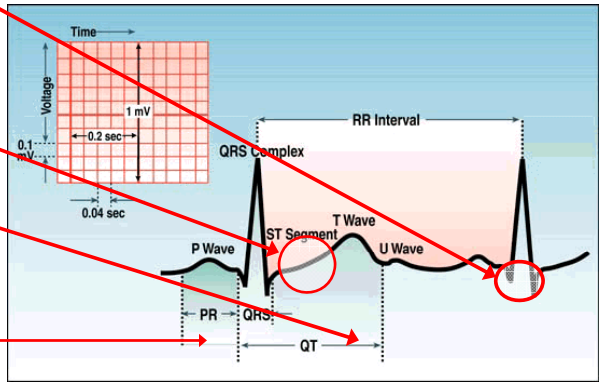


From a textbook on cardiology

Clinically Relevant Parameters

• QRS duration
Bundle brand block
depolarization

- ST segment
  ischemia
- QT interval
  ventricular fibrillation
- PR interval SA → ventricles



Rhythm example

- Rate? 70 bpm
- Regularity? occasionally irreg.
- P waves? 2/7 different contour
- PR interval? 0.14 s (except 2/7)
- QRS duration? 0.08 s

Interpretation? *NSR with Premature Atrial Contractions*

Classification of ECG signals

E. Classification

① Linear discriminant analysis (LDA)

$$y = \alpha S + \varepsilon = \alpha_0 + \sum_{i=1}^{n} \alpha_i S_i + \varepsilon$$

② Quadratic discriminant analysis (QDA)

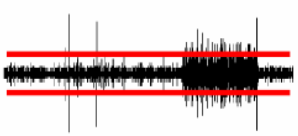
$$y = \alpha S + S^T \beta S + \varepsilon = \alpha_0 + \sum_{i=1}^{n} \alpha_i S_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} S_i S_j + \varepsilon$$

③ K nearest neighbor (KNN) rule

The present paper uses the Euclidean metric to measure "closeness" in the KNN classification model

Denoising

Threshold:



Stein's Unbiased Risk Estimate (SURE).

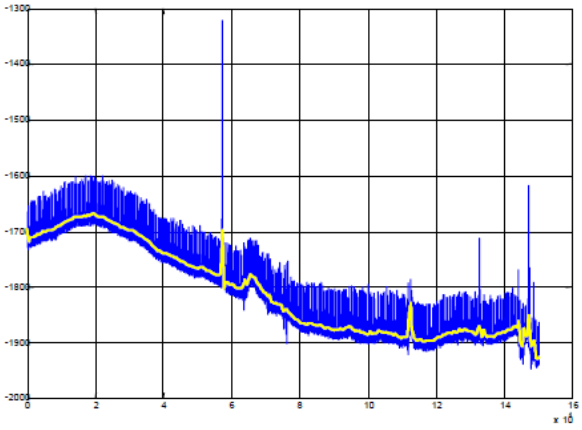
Donoho: $\lambda = \sigma\sqrt{2\log(n)}$ n:Sample size
σ:noise scale

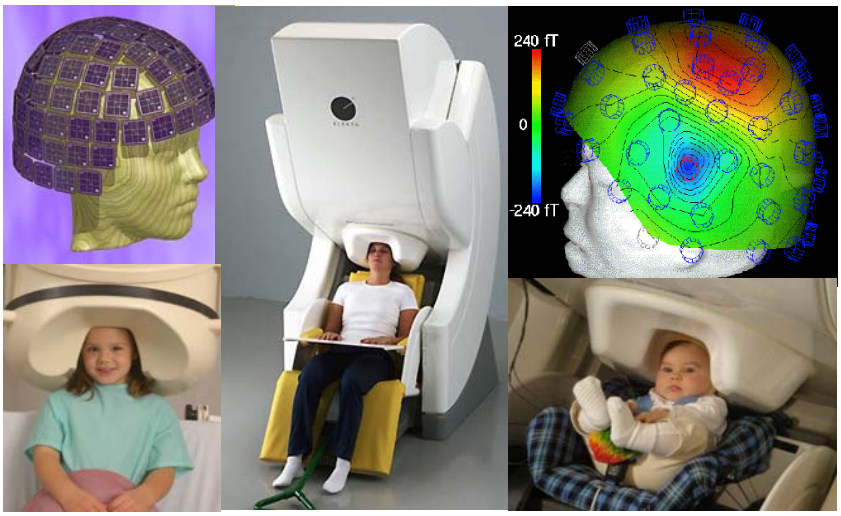
Minimax

Adaptive: based on singular or smooth regions
(in practice, heuristic indep. of sample size)

Long-Term ECG Evolution

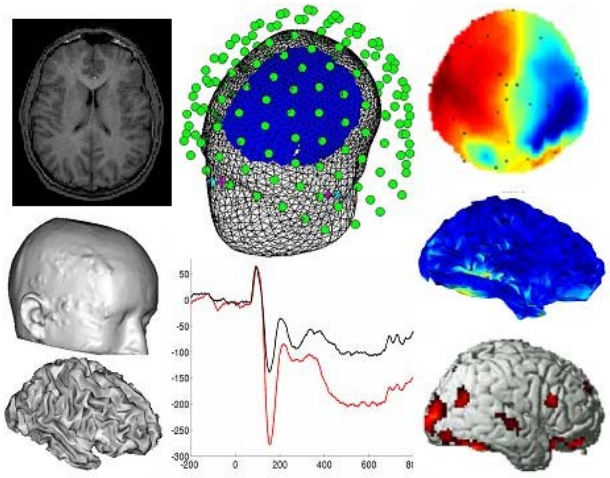
- Application: Electrocardiogram baseline wandering reduction





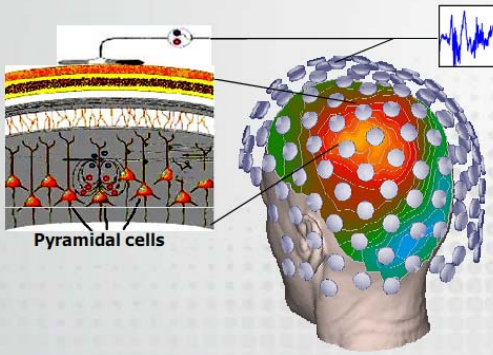
Magnetoencephalography (googled images)

Multimodal Imaging



- Combining MEG data with FMRI results in a hybrid image which has both good temporal and spatial resolution.

EEG



- Tool for evaluating the physiological state of the brain
- Offers excellent spatial and temporal resolution to characterize rapidly changing electrical activity of brain activation

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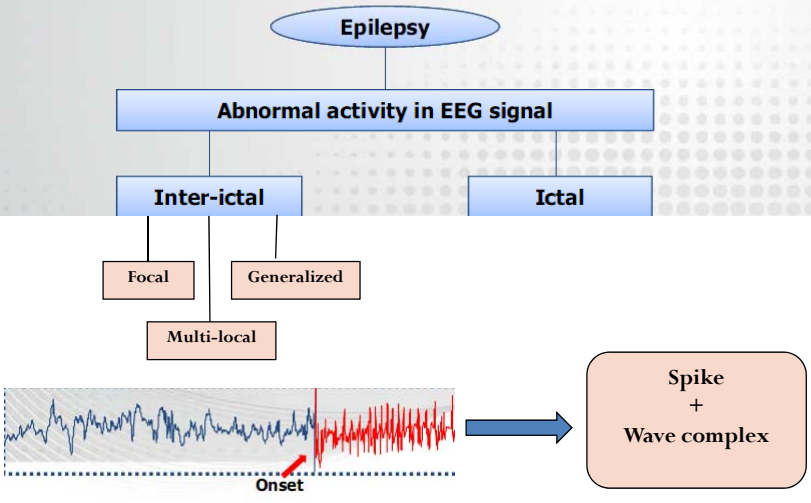
Epilepsy & EEG



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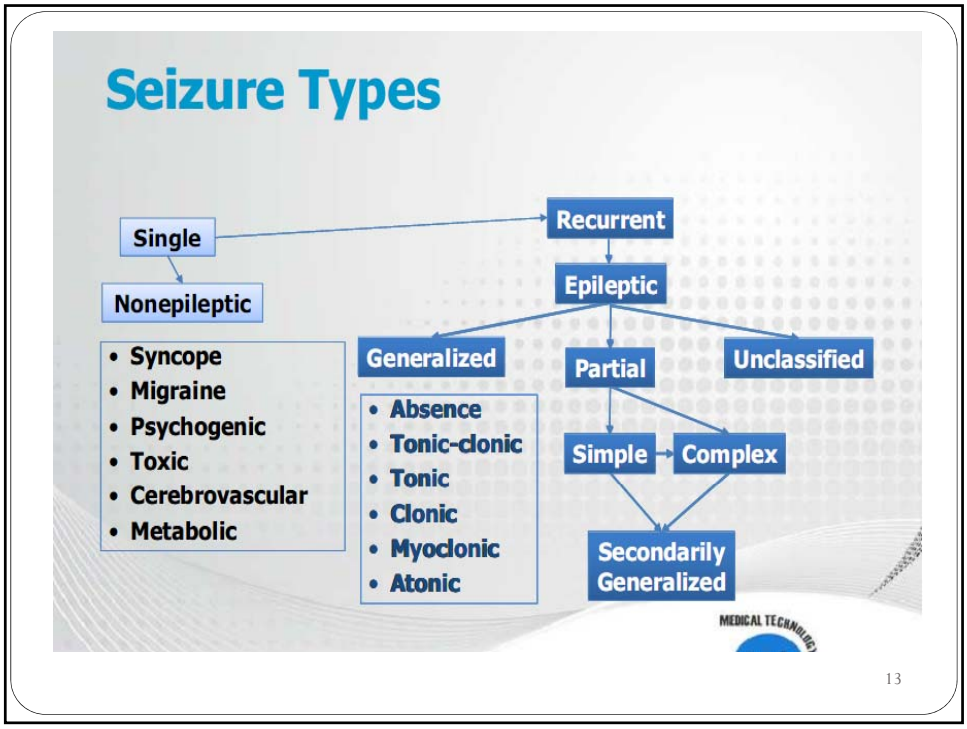
Seizure Types
Single
Recurrent
Nonepileptic
Epileptic
• Syncope
• Migraine
• Psychogenic
• Toxic
• Cerebrovascular
• Metabolic
Generalized
Partial
Unclassified
• Absence
• Tonic-clonic
• Tonic
• Clonic
• Myoclonic
• Atonic
Simple
Complex
Secondarily Generalized
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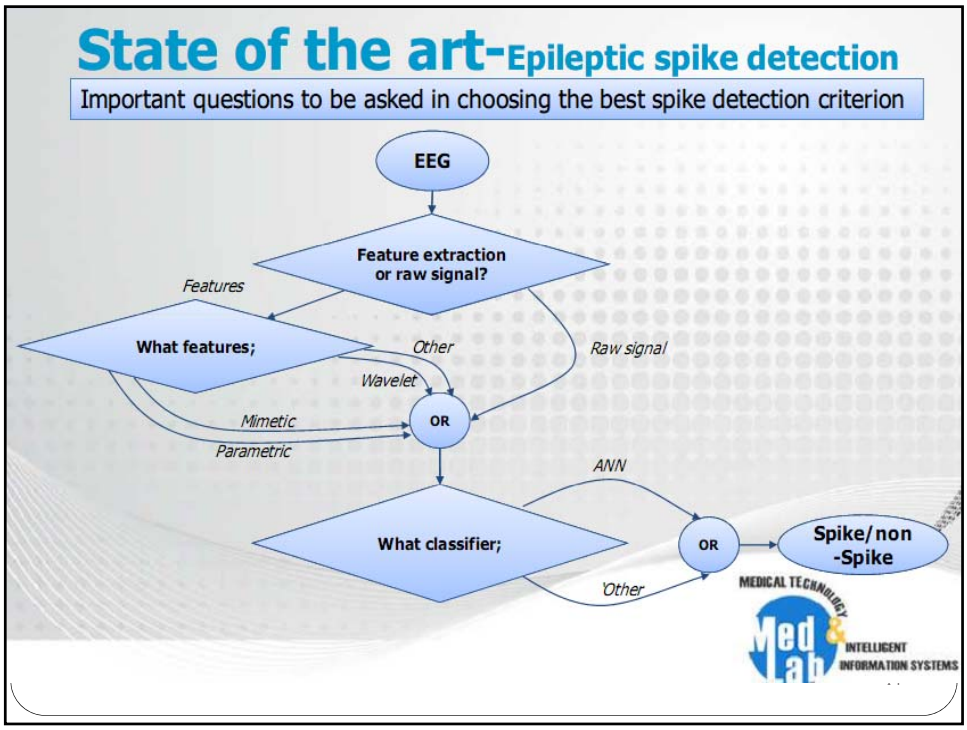
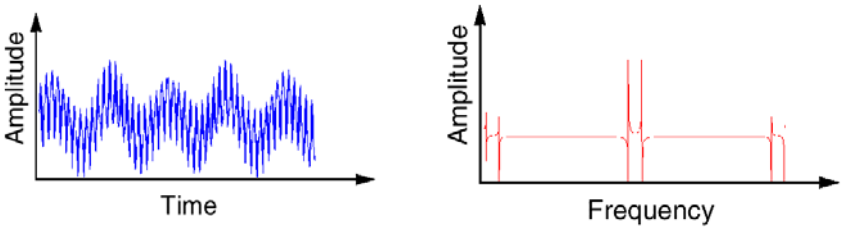

State of the art-Epileptic spike detection
Important questions to be asked in choosing the best spike detection criterion
EEG
Feature extraction or raw signal?
Features
What features;
Other
Wavelet
Raw signal
Mimetic
Parametric
OR
ANN
What classifier;
OR
Spike/non -Spike
Other
MEDICAL TECHNOLOGY
Med & Lab
INTELLIGENT INFORMATION SYSTEMS

Tool example: Fourier Analysis

- Breaks down a signal into constituent sinusoids of different frequencies



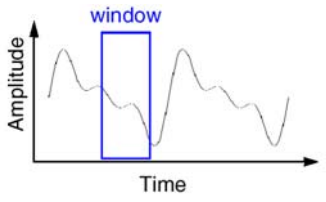
In other words: Transform the view of the signal from time-base to frequency-base.

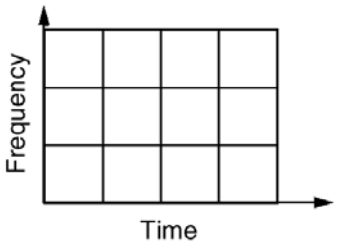
Can we improve Fourier tool?

- By using Fourier Transform , we loose the time information : WHEN did a particular event take place ?
- FT can not locate drift, trends, abrupt changes, beginning and ends of events, etc.
- Calculating use complex numbers.

Short Time Fourier Analysis

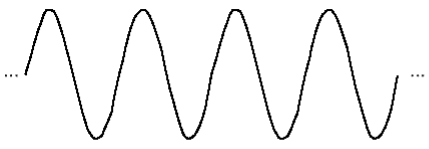
- In order to analyze small section of a signal, Denis Gabor (1946), developed a technique, based on the FT and using *windowing* : STFT





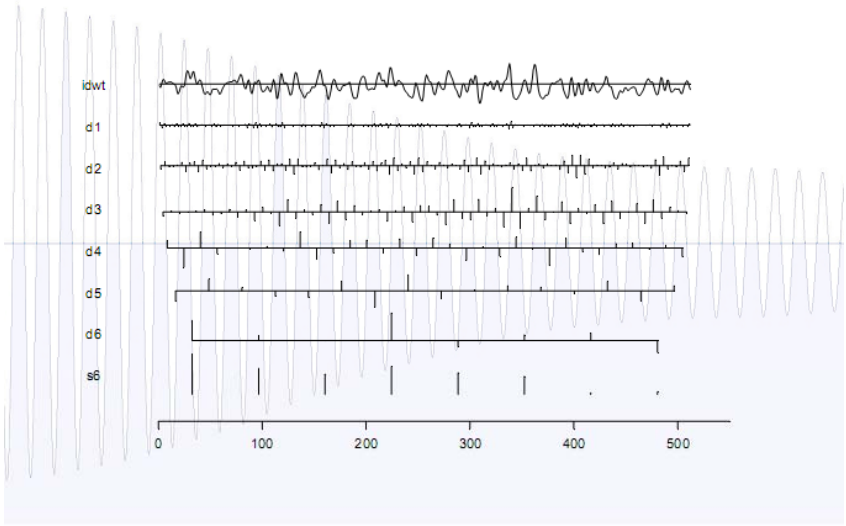
What is Wavelet Analysis ?

- And…what is a wavelet…?



- A wavelet is a waveform of effectively limited duration that has an average value of zero.

Wavelet analysis: coefficient extractions



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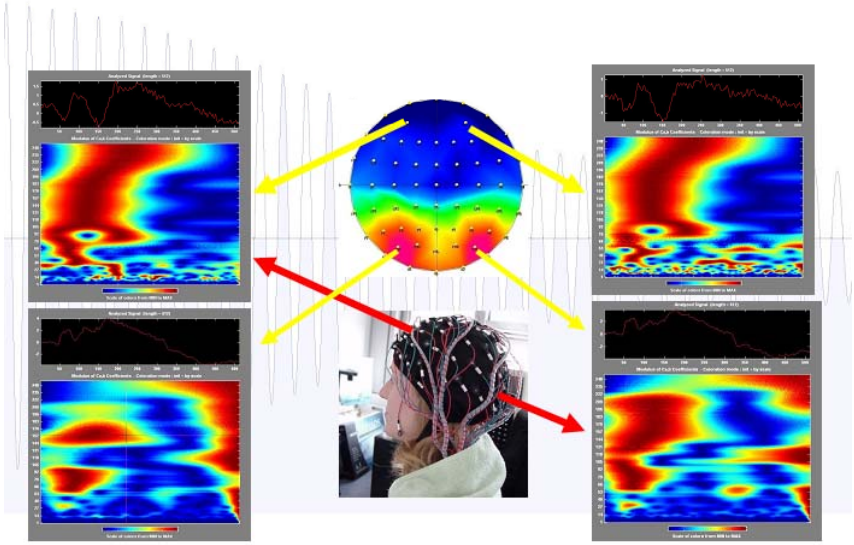
Use Wavelet to analyze brain images

CWT on several electodes



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Machine Learning – A promising signal analysis tool

- Types of Problems Solved using ML

1. Classification (class labels)

– OCR, Handwritten digit recognition

2. Regression (continuous values)

– Ranking web pages using human or click data

3. Clustering

- No-label data classification

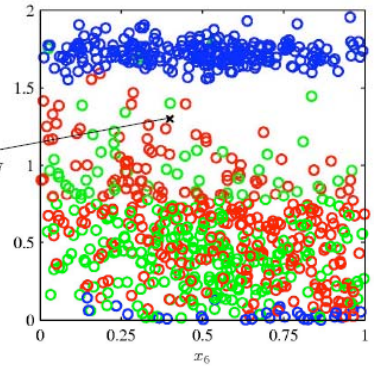
4. Modeling - Inferring a Probability

– seek probabaility distribution parameters

Classification example

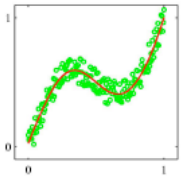
- Three classes (Stratified,Annular,Homogeneos)
- Two variables shown
- 100 points

Which class should x belong to?



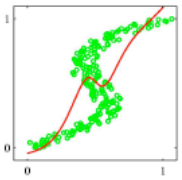
Regression problem

Forward problem data set



Red curve is result of fitting a two-layer neural network by minimizing sum-of-squared error

Corresponding inverse problem by reversing x and t



Very poor fit to data: GMMs used here

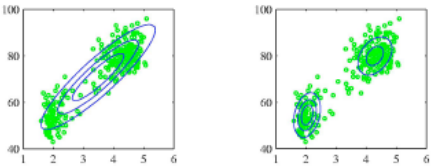
Clustering problem

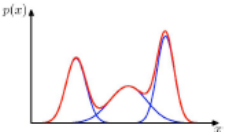
- Old Faithful (Hydrothermal Geyser in Yellowstone)
  - 272 observations
  - Duration (mins, horiz axis) *vs* Time to next eruption (vertical axis)
  - Simple Gaussian unable to capture structure
  - Linear superposition of two Gaussians is better
- Gaussian has limitations in modeling real data sets
- Gaussian Mixture Models give very complex densities

$$p(\mathbf{x}) = \sum_{k=1}^{K} \pi_k N(x \mid \mu_k, \Sigma_k)$$

$\mathbf{p_k}$ are mixing coefficients that sum to one

- One –dimension
  - Three Gaussians in blue
  - Sum in red

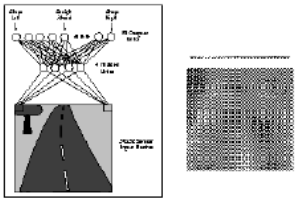




Example Successful Application of Machine Learning

- Learning to drive an autonomous vehicle
  - Train computer-controlled vehicles to steer correctly
  - Drive at 70 mph for 90 miles on public highways
  - Associate steering commands with image sequences

ALVINN [Pomerleau] drives 70 mph on highways



The ML Approach