APEREST

Approximately Periodic Representation of Stimuli

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People behind the scenes

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Objectives

The IT Problem - Knowledge Representation

- Developing a periodic-based coding scheme of perceptual information
  - *vs.* equilibrium-based
    - Biologically inspired Chaos/synchronization–based signal recognition (+learning) algorithm
- Bio-inspiration of the engineering & Biological verification at microscopic level
  - Neuronal
    - Understand of the role of irregular/periodic oscillations of neurons in coding imprecise information
- Physiological verification at macroscopic level (EEG)
  - cortico-cortical connectivity assessment
    - Nonlinear signal processing/modeling tools for classification/analysis of cortical activity

leitmotiv:

chaos based implicit representation of incertitude/diversity

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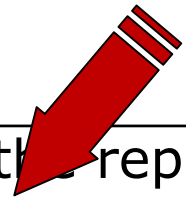
Methods

leitmotiv



- Dynamical complex phenomena for the representation and categorization of stimuli
  - chaos-based representation of uncertainty
  - synchronization-based stimuli categorization
- Cutting edge measuring techniques
  - microscopic: on the somatosensory and hippocampus system of rats (tactile information and visual information) & multi recording (voltage sensitive dice based) under visual stimuli
  - macroscopic: task induced and sleep multi-channel EEG recording
- Cutting edge nonlinear signal processing & modeling
  - nonlinear identification
  - periodic control
  - nonlinear information theory oriented signal processing

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Modeling Diversity by Chaos and Classification by Synchronization

How Chaos-based Modeling of Diversity Works
and Its application on EEG signals

The Classification Problem

Consider classes of approximately periodic signals

(common for physiological signals, suitable for chaotic approach)

- Find an algorithm that, given a signal, and given a class, decides
  - whether the signal belongs to the class
  - whether the signal does not belong to the class
- Difficulty of problem depends on the signal class, and how the class is defined
- Main problem is DIVERSITY
  - from the stereotype to the class
    - how to represent it
    - how to deal with it

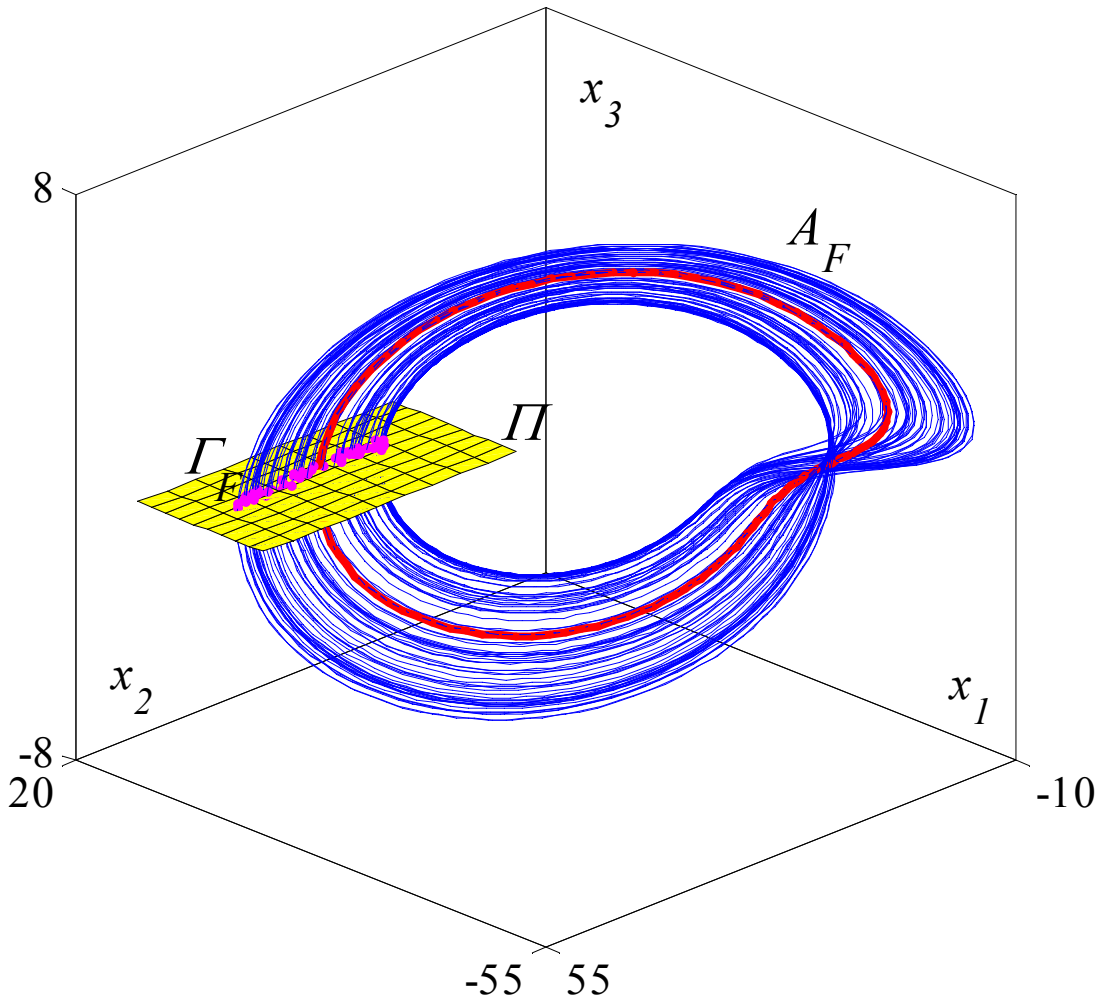
Modeling Classes of Signals

- Classical technique: stochastic process
  - Identify periodic stereotype and model variations about it
    - by probability distributions of parameters
    - Hidden Markov Models
    - Support Vector Machines
    - etc…
- Our approach: a dynamical system
  - model variability within a class by a chaotic system
    more precisely, by a chaotic attractor
- Implicit representation

Diversity of Chaotic Dynamical Systems

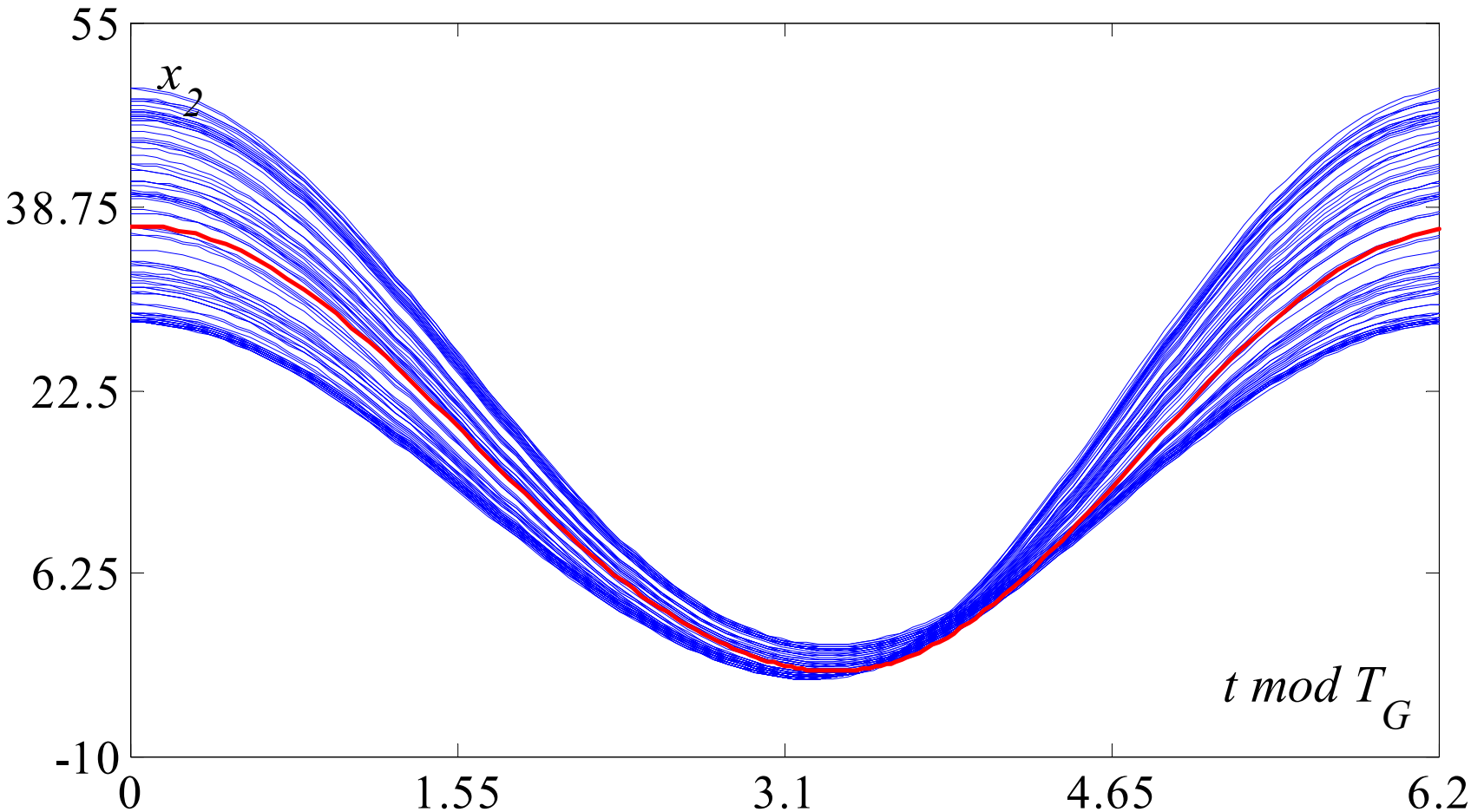
given a deterministic dynamical system

$$\dot{x} = F(x) \quad x \in \Re^n$$

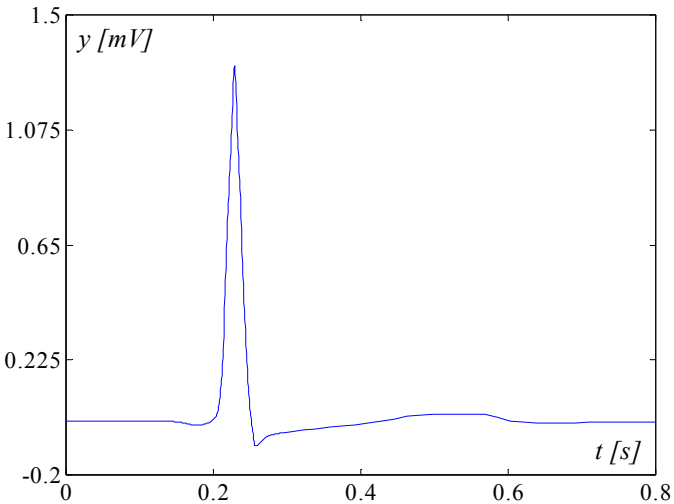


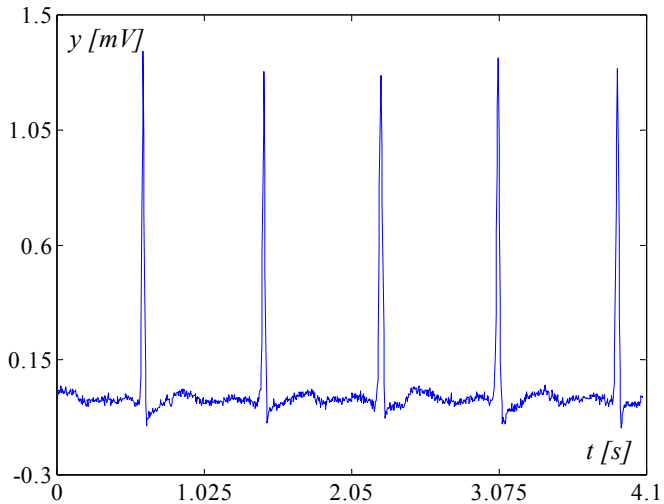
The Class of Signals Defined by a Chaotic System

Diversity of waveforms within one "period":

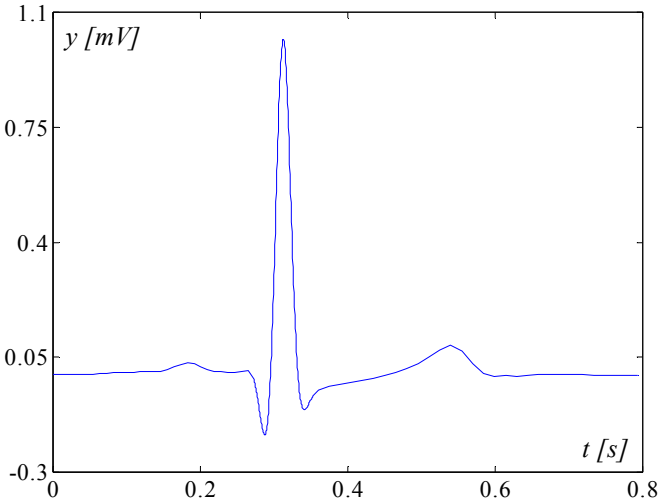


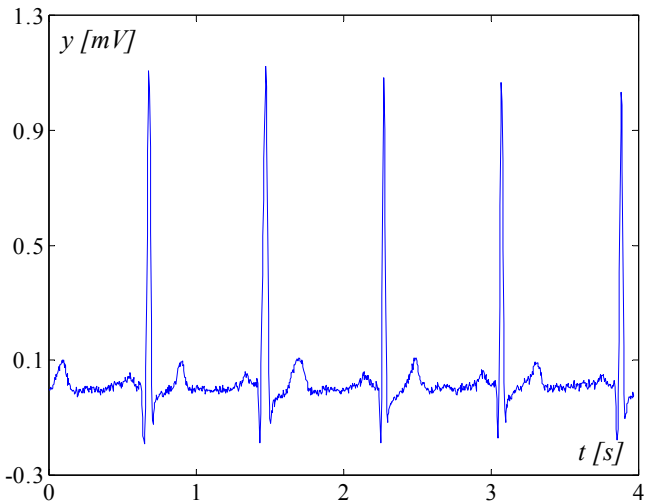
Examples of Signals





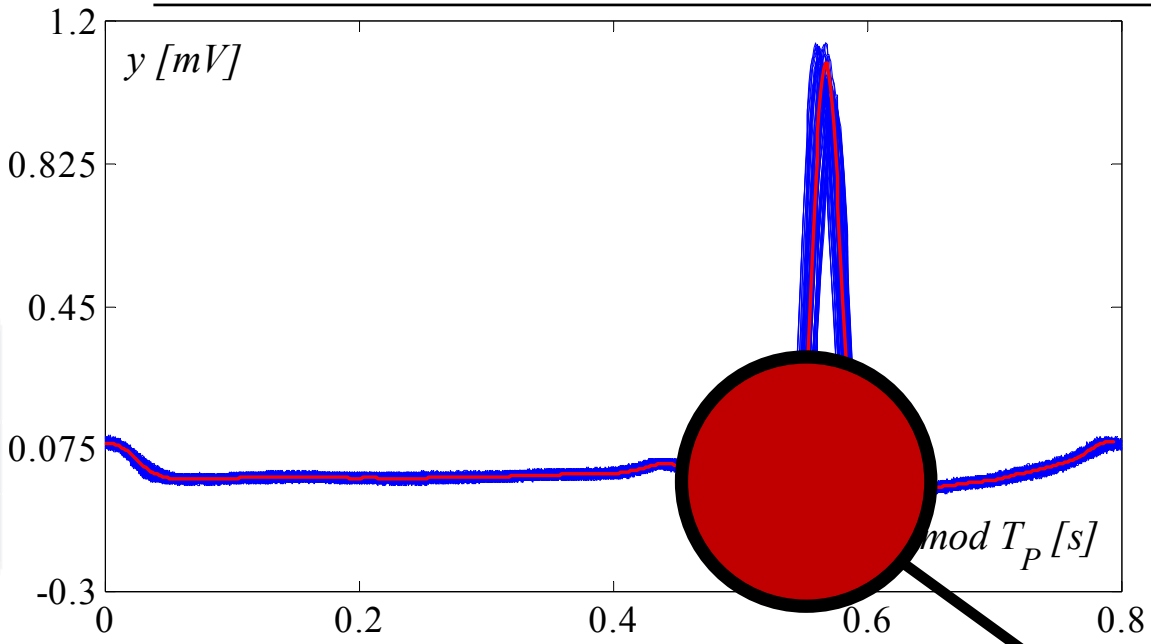
pathological electrocardiogram



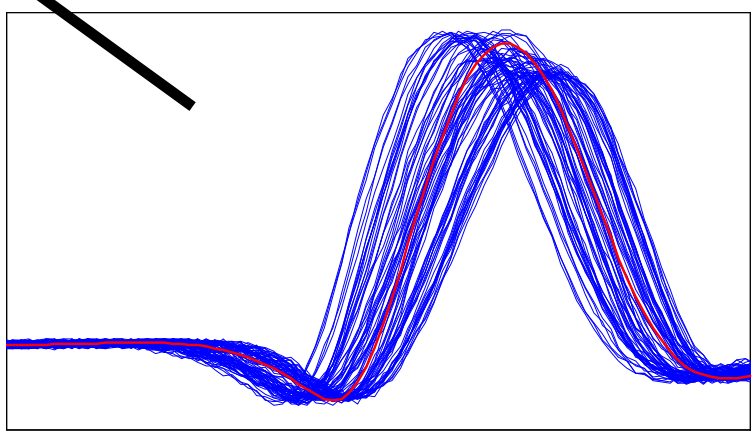


healthy electrocardiogram

Example of Signal Diversity



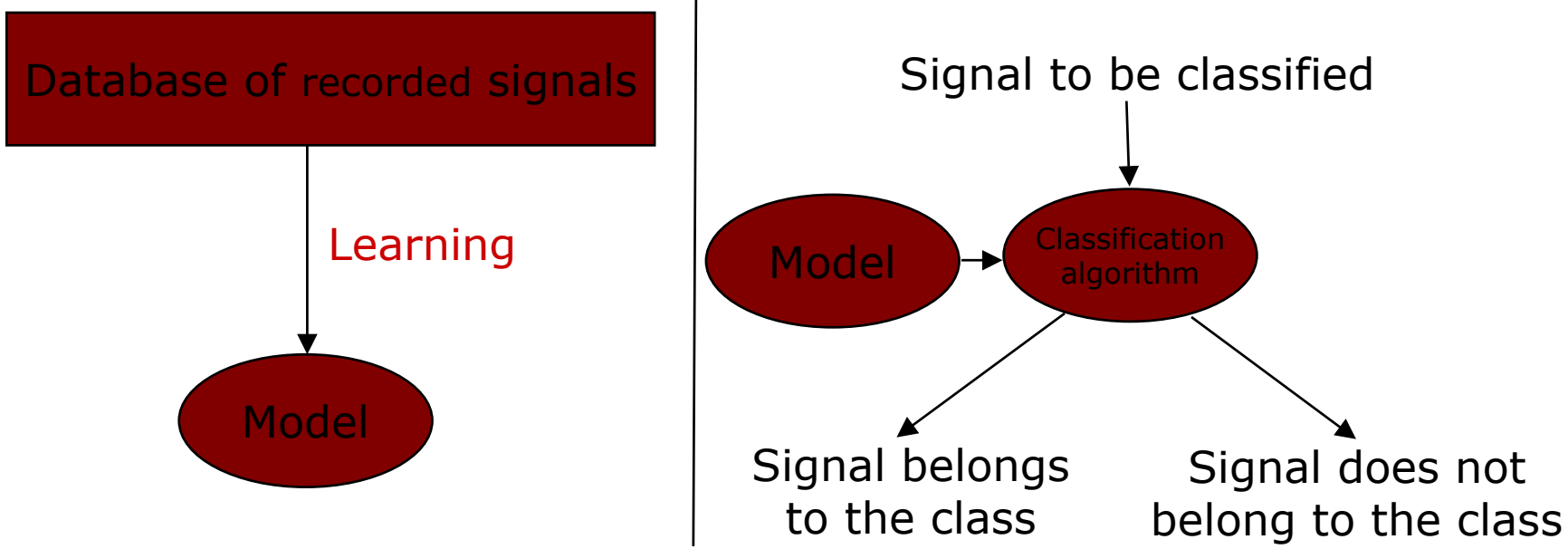
Diversity of waveforms of ECG within one "period"



Building Classes Models from Examples and Classification

Two steps

- Build a model of the signal class from data
  - learning
- Use the model to classify
  - classification



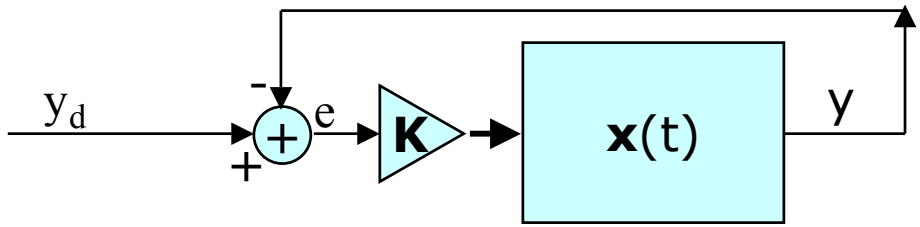
The Two Steps in Our Approach

- Learning: nonlinear dynamical system identification
  - building a chaotic model implicitly representing the entire class of example signals
- Classification: chaos-synchronization
  - drive the above model with a test signal and see if the system synchronize with it

What does synchronization mean?

Classification by Synchronization

drive the system by an input signal:



$$\frac{d\mathbf{x}}{dt} = \mathbf{F}(\mathbf{x}) + \mathbf{K}(y_d - y) \qquad \mathbf{x} \in \mathbb{R}^N, y, y_d \in \mathbb{R}$$

$$y = H(\mathbf{x})$$

Idea:
If y_d is close to signals that the attractor of the system would have produced, y will synchronize approximately with y_d

Use synchronization for temporal signal recognition

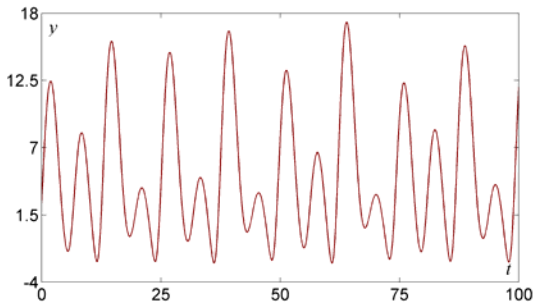
How the Learning Works?
(Identification)

constructing a chaotic model starting from measured signals

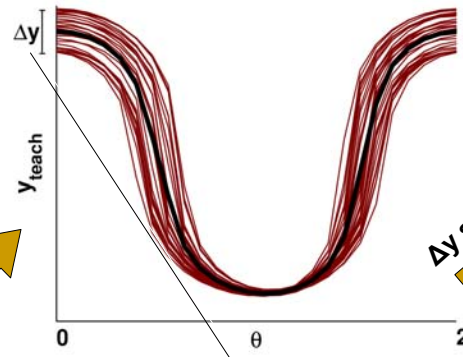
- is the main critical point of the APEREST paradigm
  - the chaos must implicitly represent the diversity of signals
  - must be suitable for the subsequent synchronization
- two distinct methods (research threads)
  - classical: based on the projection over PWL base functions of L2
  - bio-inspired: based on recent ideas on RANN (Jaeger, Maass et al.)

Bio-inspired Identification: RANN

Working principle and analysis

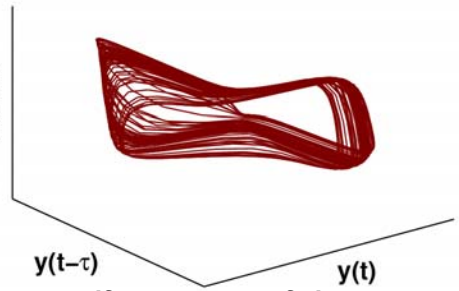


approximately periodic signal



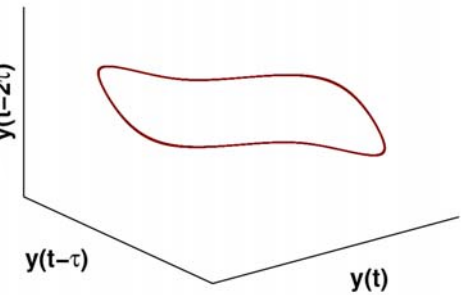
Depending on the nature of Δy chaotic behavior appears to implicitly model the random component of learned signals. Deterministic chaos or strongly colored noise lead to the chaos emergence as opposed to white-like noise which does not.

Δy structured



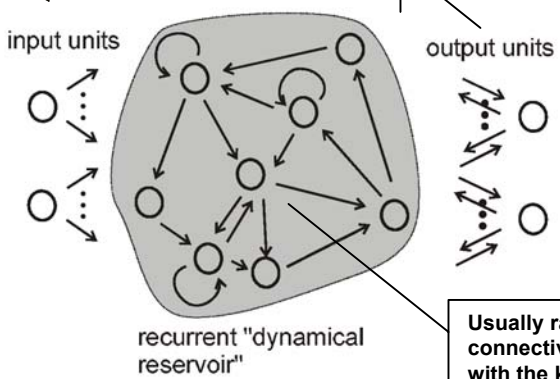
self-emergence of chaos

Δy unstructured



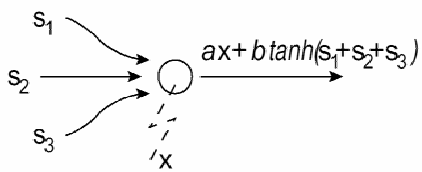
no self-emergence of chaos

connectivity adapted in the learning



teaching sequence in the RANN

Usually random drawn sparse connectivity. Future idea: bias with the knowledge acquired in WP1.
IT COMPOSES THE DYNAMICAL RESERVOIR



node dynamics

APEREST paradigm on ECG

Easy to Interpret Chaos-based modeling and classification

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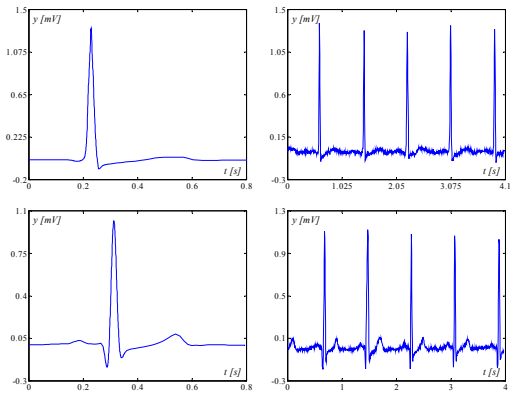
database of ECGs

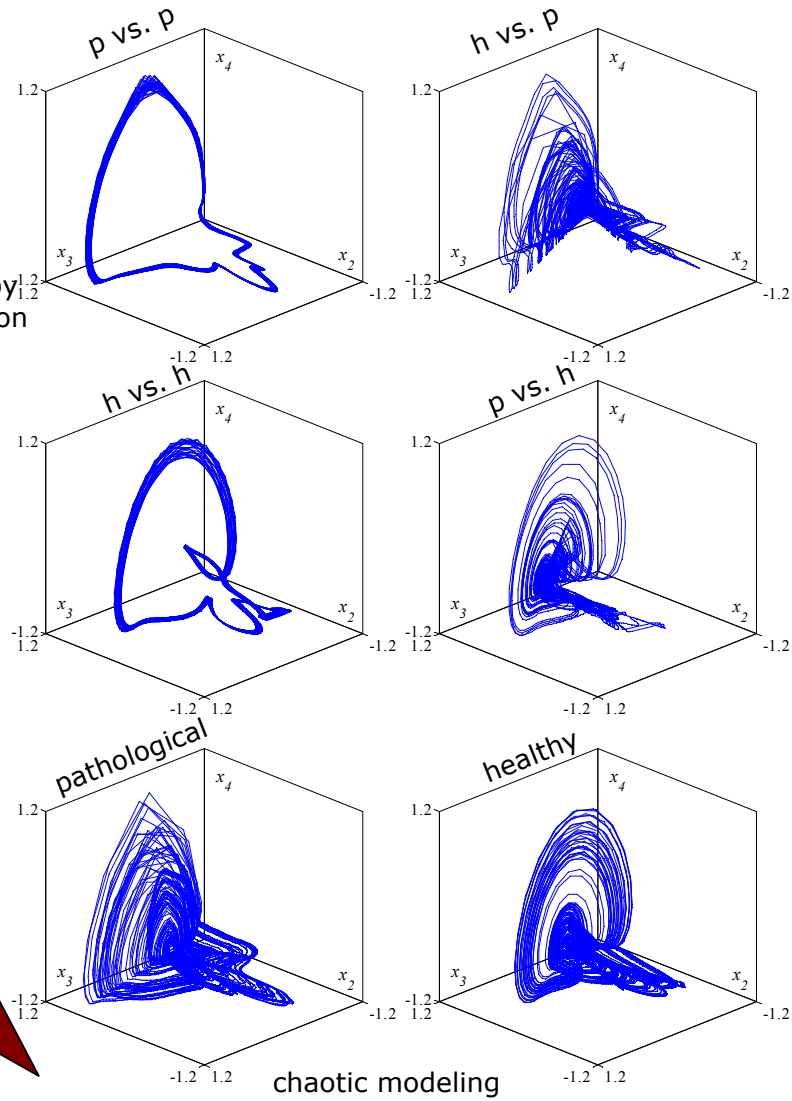


healthy electrocardiogram

pathological electrocardiogram

identification

recognition by synchronization

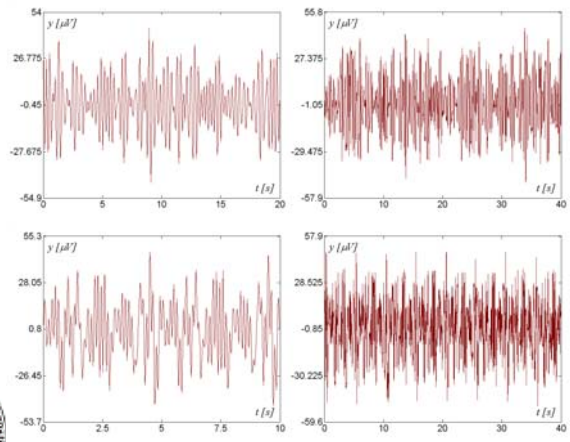


chaotic modeling

APEREST paradigm on EEG signals

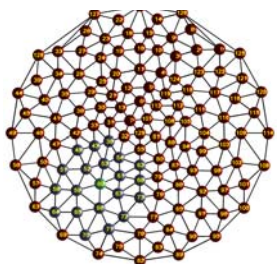
Chaos-based modeling and classification of sleeping EEG signals

sleeping normal surface sampling
EEG analysis



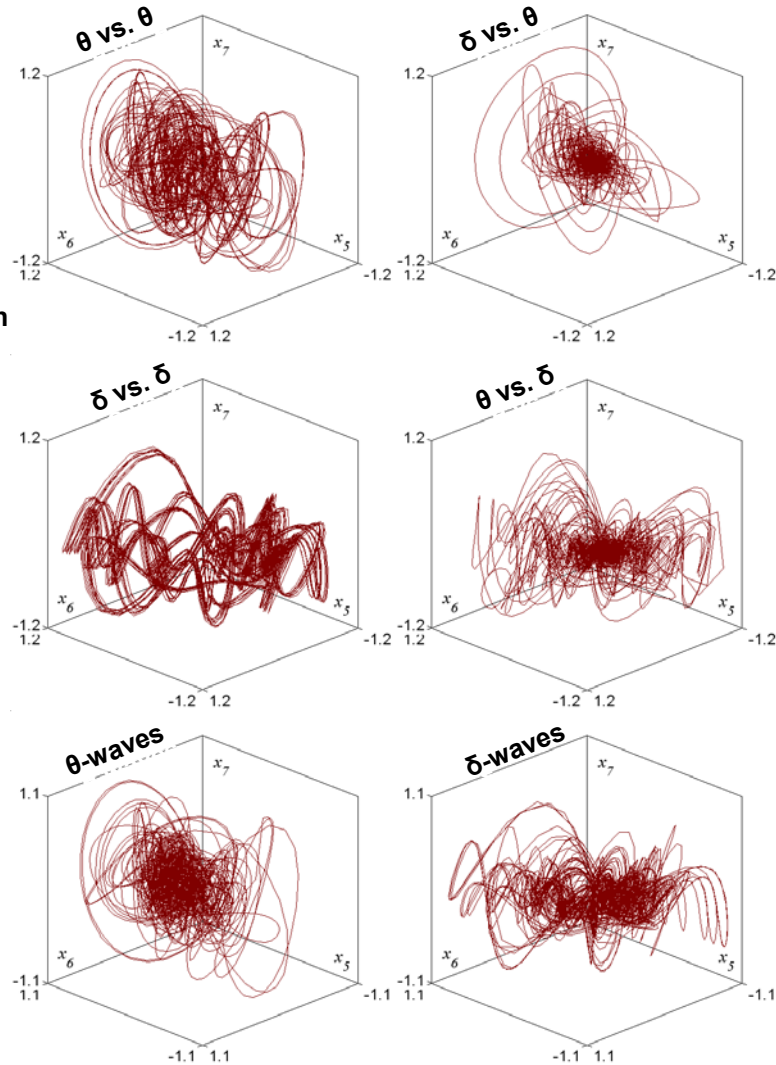
Drowsiness
θ-waves

Sleeping state
δ-waves



spatially localized
PCA state space
reconstruction

recognition by
synchronization



chaotic modeling

Summary & Conclusions

Shown

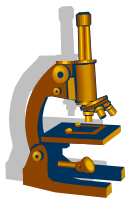
- Working principle of periodic-based coding scheme of perceptual information
  - chaos-based modeling of diversity and
  - synchronization-based categorization of stimuli
- Nonlinear identification of approximately periodic signals
  - from examples of signals to chaotic model of a class
- Application of the APEREST paradigm on macroscopic physiological signals
  - chaos-based modeling and classification successfully applied on sleep EEG signals

Behind the scenes

- Microscopic – Neural level
  - experiments for the collection of data
  - identification of functional neural networks in trigeminal nuclei
    - for the RANN-based identification
  - investigation of periodic beaters in information representation and processing
    - regularly spiking neurons in the trigeminal nuclei
    - theta rhythms in the hippocampus
- Macroscopic – Physiological level (EEG)
  - experiments for the collection of data
  - APEREST paradigm applied on evoked potentials EEG signals
    - assessment of cortico-cortical connectivity

Who does What?

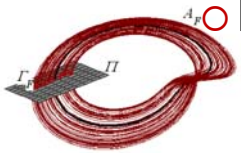
- Experiments design and results interpretation
  - UCM-EPFL for microscopic
  - KI-EPFL for macroscopic



- Microscopic measurements (neural) – UCM
  - Vanessa BONACASA
  - Rocio FERNANDEZ
  - Angel MORENO
  - Fivos PANETSOS
  - Abel SANCHEZ-IMENEZ

- Macroscopic measurements (EEGs) – KI
  - Giorgio INNOCENTI
  - Maria KNYAZEVA

- Engineering – EPFL
  - Oscar DE FEO
  - Norman URS BAIER
  - Marco STORACE (external synergetic collaboration UNIGE)



- Nonlinear data processing – EPFL-UCM
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  - Oscar DE FEO (EPFL)
  - Valeri MAKAROV (UCM)
  - Fivos PANETSOS (UCM)