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# Artificial evolution on EEG signals for the classification of psychophysiological states

# **Pierrick Legrand**

Inria, ASTRAL Team IMB, Institut de Mathématiques de Bordeaux, UMR CNRS 5251 Université de Bordeaux

March 2023, 28



Innín -



Pierrick Legrand - ASTRAL IMB/INRIA/UBX

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ASTRAL TEAM, Inria and Naval Group joint team Advanced StatisTical infeRence And controL

### Scientific objectives:

Development of advanced statistical and probabilistic models for the analysis and control of complex systems.

## **Research activities**

Our project is focused on the classical triptych:

- Statistical/stochastic modeling
- Estimation/calibration
- Control/decision



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Preliminary comment: Artificial Intelligence (AI): ML, NN, AE...

There is a frequent confusion in the public debate between "artificial intelligence" (AI), machine learning (ML), neural network (NN) and deep learning (DL). **However, these notions are not equivalent, but are intertwined**. And among the techniques contained in the broad spectrum of AI, we also find **artificial evolution**.

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  model: dozens or even hundreds of layers of neurons are stacked to bring more
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  Warning: very efficient but requires a large amount of data

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   Warning: very efficient but requires a large amount of data.
- Artificial Evolution : Stochastic optimization which uses mechanisms inspired by the biological evolution, such as reproduction, mutation, selection and survival of the strongest individuals.

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Darwinism						

# Darwinism

"We can say, by metaphor, that natural selection seeks, at every moment and worldwide, the slightest variations; it repels those that are harmful, it preserves and accumulates those that are useful; she works in silence, imperceptibly, everywhere and always, as soon as the opportunity arises, to improve all organized beings relative to their organic and inorganic living conditions", Darwin, 1859.

# Simple mecanisms

- 1 Variations, macroscopic and microscopic, within species.
- 2 Fight for survival.
- 3 Natural selection: triumph of the lineage that has a useful variation in its environment.

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A collection of stochastic techniques

Artificial Darwinism / Evolutionary Algorithms / Artificial Evolution

## Artificial Darwinism

Stochastic optimization which uses mechanisms inspired by the biological evolution, such as reproduction, mutation, selection and survival of the strongest individuals

# A set of techniques grouped under a generic term

Evolutionary Algorithms	Genetic Algorithms (GA)
	Evolution Strategies (ES)
	Genetic Programming (GP)

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Common element	s					

## Ingredients

POPULATION



SELECTION





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## Evolutionary loop



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Example						

## Optimize an "adaptation to the environment"

Potential Solutions = Individuals in a population



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Focus 1						

Discrete representation: Genetic Algorithms

Each individual is represented by a binary string.

John H. Holland (1960, 1975), David Goldberg (1989)



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 Focus 2

Continuous representation: Evolution Strategies

Each individual is a vector in  $\mathbb{R}^n$ .

Hans-Paul Schwefel (1970)

## Barycentric crossover

$$\begin{aligned} \forall i \in \{1, .., n\}, x_i^{children} &= \alpha x_i^{father} + (1 - \alpha) x_i^{mother} \\ \alpha \text{ random value in } [-\epsilon, 1 + \epsilon]. \end{aligned}$$

# Gaussian mutation

 $\forall i \in \{1,..,n\}, x_i^{children} = x_i^{children} + N(0,\sigma) \\ \text{Two parameters } P_m \text{ and } \sigma.$ 

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# Application: Evolutionary computation for EEG classification

# Goal

Characterize the state of alertness of a person from his electroencephalogram (EEG).

# Constraints

- Space-saving and easy to install system.
- Obtaining the results in real time.

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Acquisition Proto	cole					





- EEG headset installation time: 45 minuts.
- Subject with open eyes.
- Sampling frequency: 256Hz.
- Recording time: 3 minuts (46000 sample points).

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Acquisition Proto	cole					

- First EEG recording: subject in a normal state of alertness: "normal"
- Second EEG recording: subject in a state of low vigilance: "relax"



## $\Rightarrow$ Is the relaxation session effective?

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## Verification of data quality



Two steps added to perform a test VCN (Variation Contingence Negative)

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## Verification of data quality - CNV measurement

## 50 occurrences



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## Verification of data quality - CNV graphical interface



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# Campaigns:

- 58 electrodes renumbered from 1 to 58
- Subjects under 35, right-handed and non-smoker
- 58 subjects  $\Rightarrow$  16 preserved

# **Relaxation session**

20 minutes with a recorded voice offering 3 exercises:

- Autogenic training [Schultz1958]: repetition of sentences, self-hypnosis.
- Progressive muscle relaxation [Jacobson1974].
- Mental visualization (familiar places, smells, noises).

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## 3 minutes of EEG recording before relaxation.

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## 3 minutes of EEG recording after relaxation.

#### Alpha waves

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C4-Rei	much man and a second and a second	and the second water and the second s	and the superstant when the superstant and
C6-Rel	When the stand of	and a second and a second and a second and a second a se	al a ser have been a series of the series of
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CP2-Ref	man home mound and and and and and and and and and a		and a show the second and the
CP4-Ref	man por an and a second and a second		a more and a second
CP6-Ref	And the second s		de mar a construction and the second se
TEDU	have a fair the second of the		
P5Rel	a man and a summer and a summer a	and an and a share a share a share	and the second and the second second and the second s
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T6-Rel	a man man man man	and the second of the second o	and a marine marine marine and
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## Wavelets and energy

A discrete wavelet transform is used in order to calculate the energy of the signal.

# Wavelet coefficient

 $C_{j,k}$  denotes the wavelet coefficient at scale j and time k.

$$C_{j,k} = 2^{-\frac{j}{2}} \int_{-\infty}^{\infty} f(t)\psi(2^{-j}t - k)dt$$

# Energy at scale j

$$E_j^2 = \sum_{k=1}^{2^{j-1}} [C_{j,k}]^2$$





## Wavelets and energy

The dyadic grid gives a spatio-frequential representation of the discrete dyadic wavelet decomposition





- Alpha: 8 12Hz.
- Waves characteristics of a relaxed state.



Linear regression between 4 and 16Hz.



- Alpha: 8 12Hz.
- Waves characteristics of a relaxed state.



Linear regression between 4 and 16Hz.



- Alpha: 8 12Hz.
- Waves characteristics of a relaxed state.



Linear regression between 4 and 16Hz.

Artif. Darwinism	Genetic Alg. and Evol. Strat.	Application	EEG data Acqu.	Feature Extract.	Evol. Algo.	Conclusions
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#### Feature Extraction: Slope Criterion



Slope criterion, sum on subjects for each electrode

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#### Feature Extraction: Slope Criterion



Slope criterion, sum on electrodes for each subjects

- ⇒ Very strong inter-subject variability
- $\Rightarrow$  This criterion does not allow to build a powerful classifier for different subjects.

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Feature Extraction: Slope Criterion

## Classification: Usual methods

	K nearest	Binary	Random	Discriminant	Sparse Discriminant
	neighbors	decision trees	forests	PLS	PLS
Mean	37.28	33.98	32.03	40.63	36.25
Standard Deviation	10.47	5.15	6.46	8.55	7.96

Mean and standard deviations of Correct Classification Rates for different classification methods applied on slope criterion.

# This approach is not efficient

**Our contribution**: Design a relevant **evolutionary algorithm** to solve this task of classification.

- $\Rightarrow$  Find the relevant electrodes.
- $\Rightarrow$  Find the relevant frequencies for the calculation of the slope criterion.

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## Example of a genome in the evolutionary algorithm



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Design						

## Relationship between the genome and the calculation of the slope criterion



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## Evaluation of a individual in the evolutionary algorithm



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## Average correct classification rate

Evaluation	CCR		
Method	Mean Standard deviatio		
CART	86.68	1.87	
SVC	83.49	2.37	

Average and standard deviations of the correct classification rates obtained for the 100 runs of the evolutionary algorithm and for two methods of evaluation.

Artif. Darwinism	Genetic Alg. and Evol. Strat.	Application	EEG data Acqu.	Feature Extract.	Evol. Algo.	Conclusions
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## Best genome

Evaluation	BEST genome				
method	Selected	Selected	Correct classification		
	electrode	frequency (Hz)	rates		
CART	F4	1/8, 1/4, 2, 4 <b>et</b> 64	89, 33%		
SVC	F2	1/32, 1/16, 2, 4, 8, 64 et 128	89, 33%		

Table summarizing the two best genomes found during the 100 runs of the genetic algorithm with two methods of evaluation.

One electrode selected => Quick installation of the acquisition system. Results obtained in less than a second => Can be used on real application.

Artif. Darwinism	Genetic Alg. and Evol. Strat.	Application	EEG data Acqu.	Feature Extract.	Evol. Algo.	Conclusions
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# Our contribution

Design of a relevant **evolutionary algorithm** to solve this task of classification.

 $\Rightarrow$  Find the relevant electrodes.

 $\Rightarrow$  Find the relevant frequencies for the calculation of the slope criterion.

# Application on similar real applications

For instance: sleeping non sleeping, alertness tunneling of a pilot, etc. What is needed:

- Data on 2 (or more) conditions
- Use of the same protocol

# Warning:

This method cannot be used when the subject is making pronounced movements. Indeed, the motor activity overwrites the other information contained in the EEG signals.  $\Rightarrow$  One can use other physiological data (eye tracking, EDA, ECG, etc.) and try the same protocol.