Inria

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Vendredi 12 avril 2019

13h à 14h

Salle Ada Lovelace

Algorithmes évolutionnaires

Par Pierrick Legrand (CQFD)

DÉVELOPPEMENTS ET APPLICATIONS INSPIRÉS DU DARWINISME ARTIFICIEL

Evolutionary Algorithms. Developments and applications inspired by Darwinism

Pierrick Legrand

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Université de Bordeaux

April 2019, 12

PART 1: Artificial Evolution

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

April 2019, 12

Images courtesy of E. Lutton.

Darwinism

Artificial Darwinism

Evolutionary engine

Genetic Algorithms

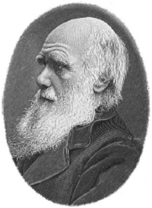
Evolution strategies

Genetic Programming

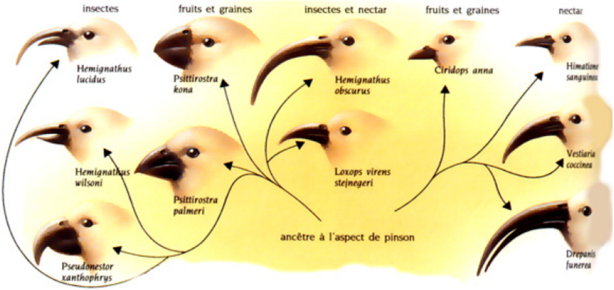
Black Box problem solving

Darwinism, evolutionism

Charles Robert Darwin (1809-1882).
1831 - 5 years on the HMS Beagle to Galapagos Islands.
November 1859, book "On the origin of species".



The Darwin Finch



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.

Artificial Darwinism

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

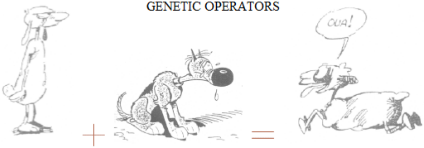
Evolutionary Algorithms	Genetic Algorithms (GA)
	Evolution Strategies (ES)
	Genetic Programming (GP)
	...

Ingredients

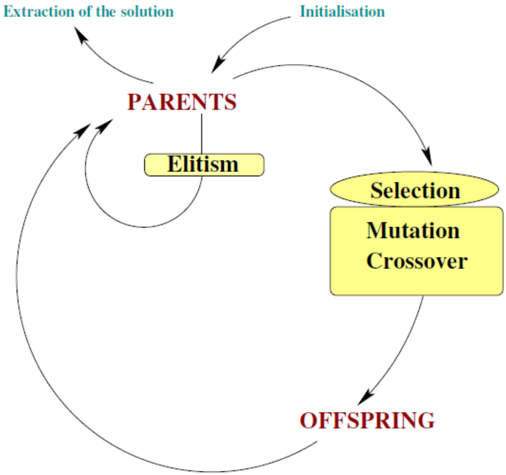
POPULATION

SELECTION

GENETIC OPERATORS

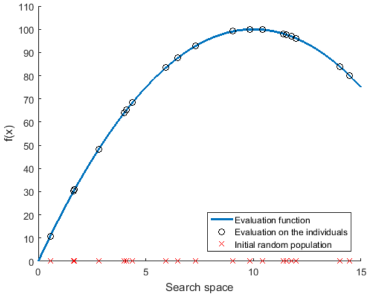


Evolutionary loop

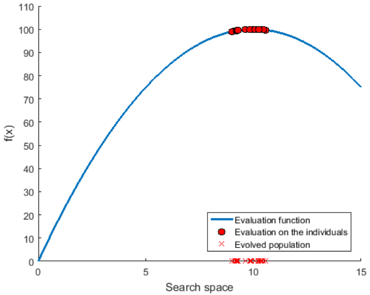


Optimize an "adaptation to the environment"

Potential Solutions = Individuals in a population



Initial random population



Evolved population

Vocabulary

Evolutionary algorithms	Optimization methods
individual	solution
population	set of solutions
chromosome	coding of the solution
crossing or recombination	operation on two codes
mutation	operation on a code
environment	search space
degree of adaptation to the "Fitness" environment	value of the evaluation function
evolution	maximizing the evaluation function

The evolutionary engine

1. **Evaluation**: estimate the quality of an individual.
   $\rightarrowtail$ "Fitness", "performance", "evaluation function", "adaptation to the environment".
2. **Selection**: select the best individuals.
   $\rightarrowtail$ roulette wheel, selection on the rank, by tournament.
3. **Reproduction**: apply genetic operators, crossover and mutations, with probabilities P_c and P_m.
4. **Replacement**: to make the next generation.
   $\rightarrowtail$ elitism, percentage of population renewal, strategies $(\mu + \lambda)$ or (μ, λ).

Initialisation / End of the process

Initialisation

- Sampling of the search space (random, regular)
- introduction of initial solutions
- restrictions on the search space

Stop

After N generations or after convergence...

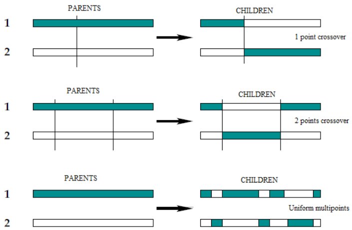
Extraction of the solutions

The best individual of the last generation !

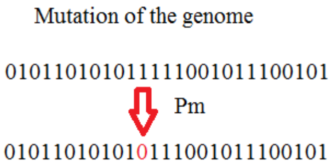
Discrete representation: Genetic Algorithms

Each individual is represented by a binary string.

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



Crossover



Mutation

Continuous representation: Evolution Strategies

Each individual is a vector in R^n. **Hans-Paul Schwefel (1970)**

Barycentric crossover

$\forall i \in \{1, .., n\}, x_i^{children} = \alpha x_i^{father} + (1-\alpha) x_i^{mother}$

α random value in $[-\epsilon, 1+\epsilon]$.

Gaussian mutation

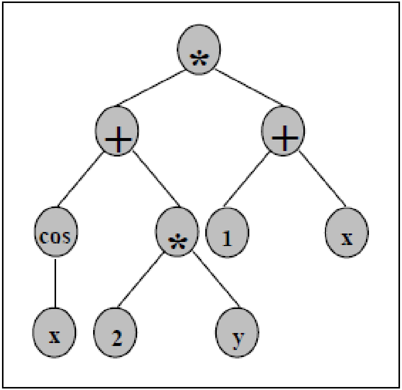
$\forall i \in \{1, .., n\}, x_i^{children} = x_i^{children} + N(0, \sigma)$

Two parameters P_m and σ.

Functional representation: Genetic programming

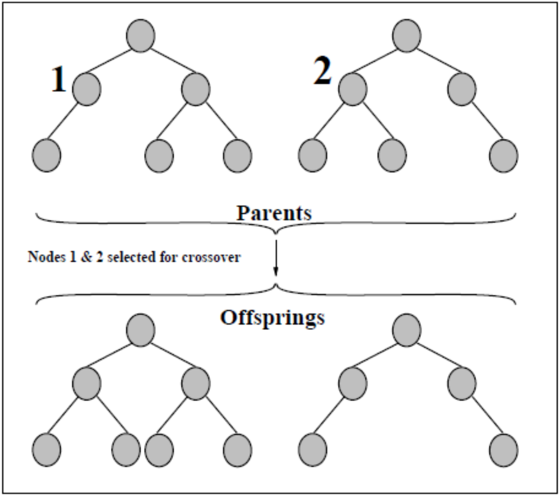
Create programs without programming !
Tree representation

John Koza (1990)

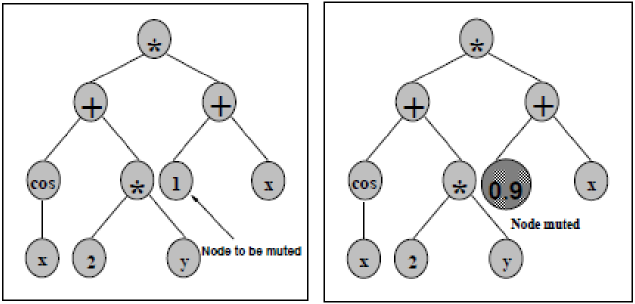


Function $(cos(x) + 2y)(1 + x)$

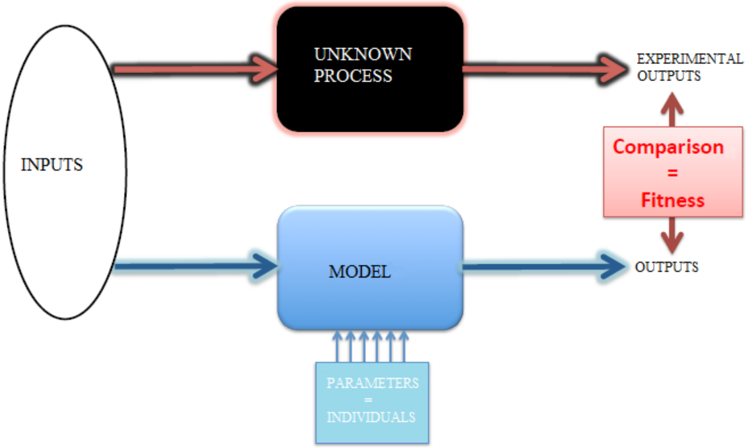
GP Crossover



GP Mutation



Black box inverse problems solving



PART 2: Cochlear implant fitting with evolutionary algorithm

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Université de Bordeaux

April 2019, 12

Joint work with Vincent Pean, Evelyne Lutton, Claire Bourgeois-Republique, Bruno Frachet, Jacques Levy-Vehel, and Pierre Collet. **RNTS PROJECT 04T550 HEVEA**.

This project is a collaboration between mathematicians, computer scientists and medical practitioners. The following institutions are involved in this project:

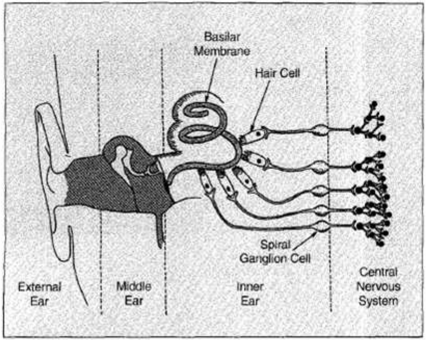
- Hopital Avicenne (B. Frachet)
- Innotech (V. Péan)
- Institut de Mathématiques and University of Bordeaux (P. Legrand)
- INRIA Bordeaux, CQFD TEAM (P. Legrand)
- INRIA Saclay, AVIZ TEAM (E. Lutton)
- INRIA Saclay, REGULARITY TEAM (J. Levy-Vehel)
- MXM-Neurelec
- University of Bourgogne (C. Bourgeois-Republique)
- University of Strasbourg (P. Collet)

The aim is to

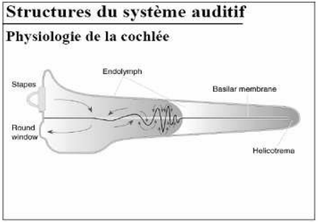
- Simplify the process of cochlear implants fitting (after a deaf patient has been surgically implanted).
- Make the implant more adaptable to the environment.

Transmission of sound to the cochlea

The **external ear** receives the wave of acoustic pressure.

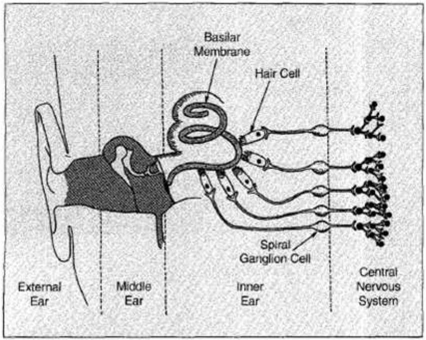


▲ 2. *A diagram (not to scale) of the human ear (reprinted with permission from [85]).*



Transmission of sound to the cochlea

The **external ear** receives the wave of acoustic pressure. The **middle ear** transforms the acoustic wave onto a mechanical vibration.



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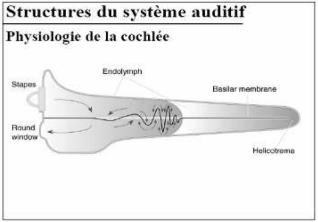
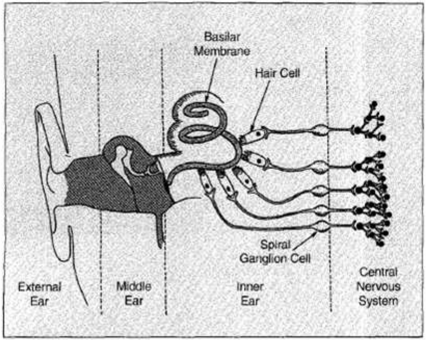


Transmission of sound to the cochlea

The **external ear** receives the wave of acoustic pressure. The **middle ear** transforms the acoustic wave onto a mechanical vibration.This mechanical vibration moves the oval window (which is connected to the middle ear) and the fluid contained in the **cochlea** is set into motion.



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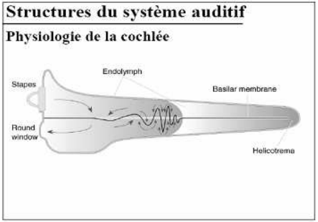

Transmission of sound to the cochlea

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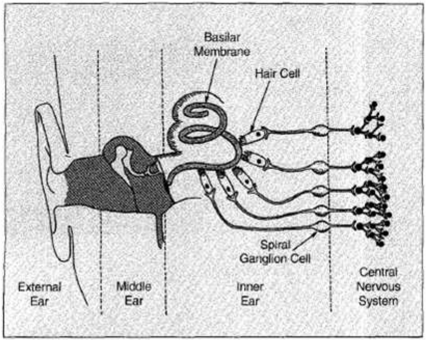

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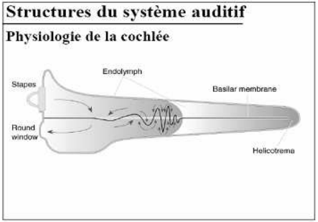
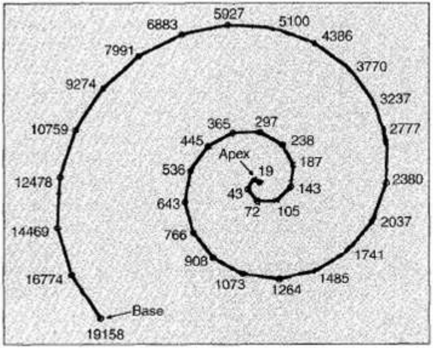


Coding of the cochlea

The basilar membrane is a filter.



▲ *3. Diagram of the basilar membrane showing the base and the apex. The position of maximum displacement in response to sinusoids of different frequency (in Hz) is indicated.*

Coding of the auditive nerve

Frequencies coding

- The movement of the basilar membrane encodes information of the frequency in the acoustic signal.

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- The movement of the basilar membrane encodes information of the frequency in the acoustic signal.
- The sensory cells which are on the basilar membrane oscillate with the membrane.
- The movement of the sensory cells liberates an electro-chimical substance which leads to discharge the neurons. Then these electrical impulses correspond to an excitation at a given position on the basilar membrane.

Coding of the auditive nerve

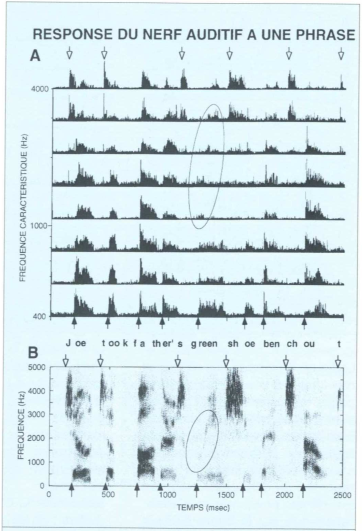

Figure 5. Réponse du nerf auditif à une phrase

Example : Transmission to the brain. The acoustic information is conveyed to the brain by electric impulses.

Audition

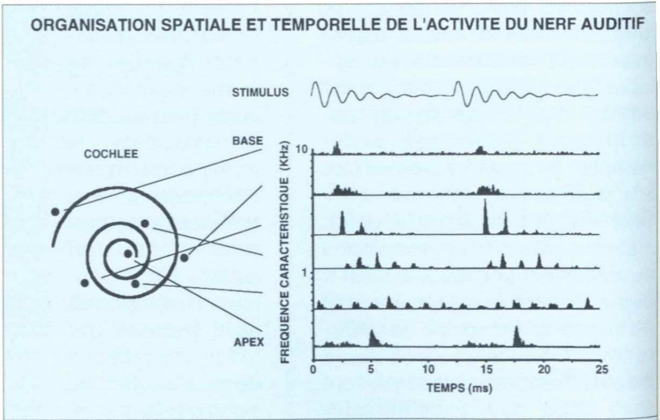

Figure 4. Réponse du nerf auditif à une voyelle simplifiée

Temporal and frequential informations

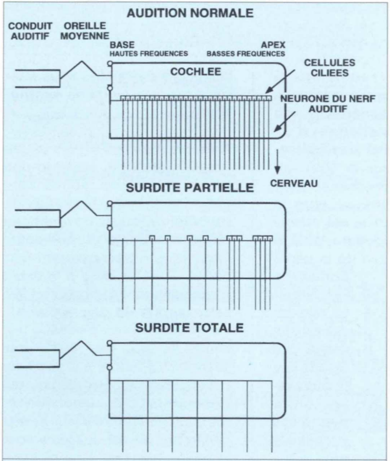

Fig 10. Schéma d'oreille normale et sourde

If the sensory cells are damaged, the auditive system cannot transform the acoustic pressure wave to neuronal impulses.

Cochlear implant

Goal :

To directly stimulate the neurons of the auditive nerve by inserting electrodes in the cochlea.

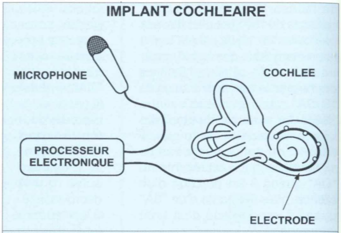

Fig 11. Un implant cochléaire

Necessary conditions

Cochlear implants allow to deaf people to hear again if

- The auditive nerve is not damaged.

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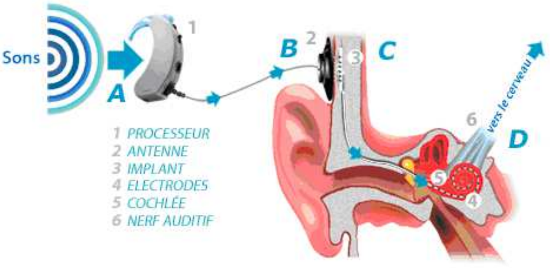
- But some people still encounter difficulties and they prefer to turn off the implant.

This population motivated our work



- A The sound is captured by the microphone, digitalized and processed.
- B The signal is sent to the implant through the skin.
- C The implant gets informations from the outer processor and distributes these informations to the electrodes in the cochlea. Each electrode corresponds to a frequency band of the sound.
- D The nerve endings transmit the electric impulses to the brain and they are interpreted as sounds.

Complexity

Complexity

- Which frequency for each electrode ?

Complexity

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- Which intensity range for each electrode ?

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- ...

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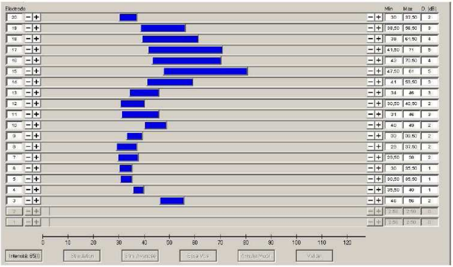
Finding the answer to these questions is a **difficult optimization problem**. This difficulty is not only related to the **dimension of the search space** but also to other causes: **Environment**, **Tiredness**, **brain adaptation**...

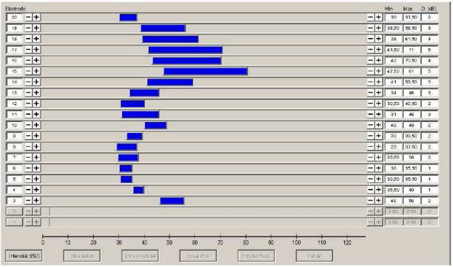
Fitting of the electrodes

- Determinate the functional electrodes.



Fitting of the electrodes

- Determinate the functional electrodes.
- Determinate the intensity thresholds T (threshold) and C (comfort).



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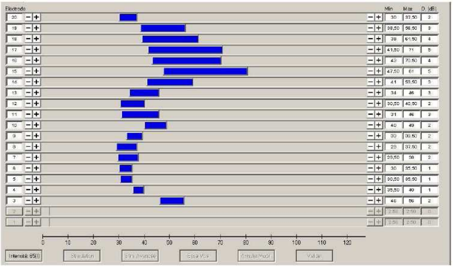
- The practitioner distributes logarithmically the frequency bands on the electrodes (by his background).



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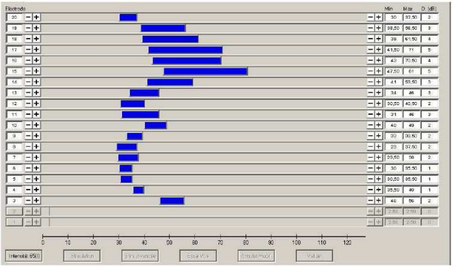

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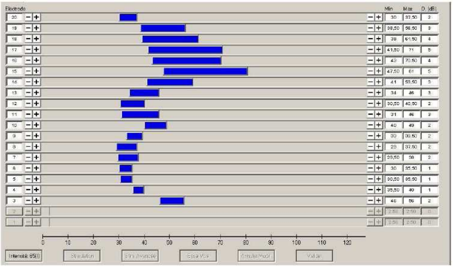
The results are often good but the complete process can take years for some patients.



Contribution: Interactive Evolutionary Algorithm

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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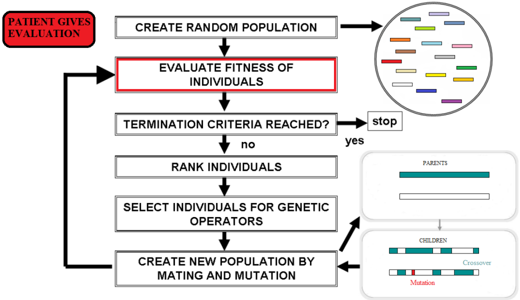

Genotype of an individual

NbOfElectrode	Min Intensity	Max Intensity	Min Frequency	Max Frequency
22	6.45	7.94	506	689
21	9.25	9.43	676	729
...	...	...	...	...
1	7.41	8	6765	7137

Automatic fitting method

Algorithm

- Manual fitting by an expert (for this patient).

Automatic fitting method

Algorithm

- Manual fitting by an expert (for this patient).
- **Initial Population** : 4 parents (=4 fittings $P1$, $P2$, $P3$, $P4$) randomly generated (in the range $[T, C]$ of each electrode).

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- **Evaluation** of the population by the patient during auditive tests (VCV and ASSE). Each individual obtains an evaluation : $N1$, $N2$, $N3$, $N4$.

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- **Generation of children** (3 individuals, $E1$, $E2$, $E3$). Two individuals are randomly selected, the best is selected with a high probability. The previous selection is repeated. In this way, two individuals are selected and then crossed in order to obtain a child. This child undergo mutation with a probability pm.

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- **Evaluation** of the 3 children by the patient: $NE1$, $NE2$, $NE3$.
- **Generation** of the new population among $P1$, $P2$, $P3$, $P4$, $E1$, $E2$, $E3$. Random selection of 2 individuals, selection of the best evaluation. A new population is obtained: $F1$, $F2$, $F3$ and $F4$.

Audio test

VCV test

The Vowel-Consonant-Vowel (VCV) test is used in clinics to evaluate how well a listener can recognize consonants under different conditions. The stimuli consist of audio recordings of an adult speaking VCV nonsense words. The vowel context is /a/-/a/.

1	2	3	4

ASSE test

- Fifteen speech sounds that can be selected
- Selected speech sound presented 3 times
- Scoring is binary
  - Correct: sound heard
  - False: sound not heard

Results

Patient	ASSE manual	ASSE auto	VCV manual	VCV auto
S1	4/7	7/7	20%	27%
S2	5/7	6/7	35%	37%
S3	5/7	6/7	45%	52%
S4	4/7	7/7	20%	27%

- **This method allows to explore a large number of various possible fitting.**
- **First evolutionary algorithm on mobile device.**
- **Fast and easy to use.**

PART 3: Evolutionary computation for EEG classification

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

April 2019, 12

Joint work with Marie Chavent, Frédérique Faïta and Laurent Vezard

EEG data Acquisition

Acquisition Protocole

Feature Extraction

Slope Criterion

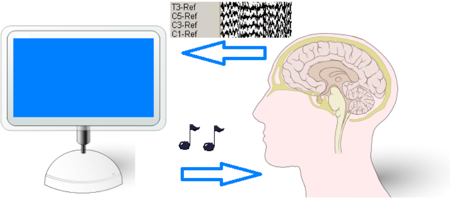
Evolutionary Algorithm

Design

Results

Goals

- **Characterize the state of alertness of a person from his electroencephalogram (EEG).**
- Create a brain-computer interface.
- Influence a person's state of alertness with synthesized music.



EEG data Acquisition

Acquisition Protocole

Feature Extraction

Slope Criterion

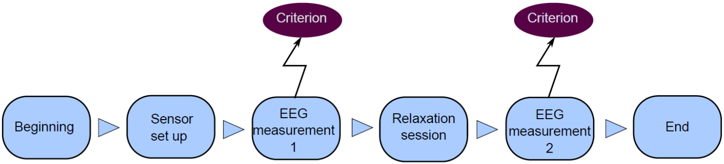
Evolutionary Algorithm

Design

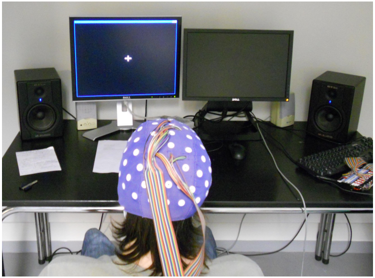
Results

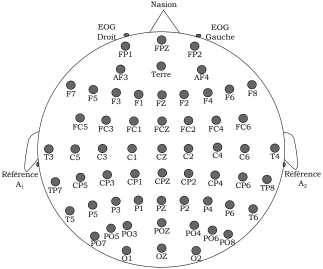
Acquisition Protocole

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



Acquisition Protocole





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

Campaigns:

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

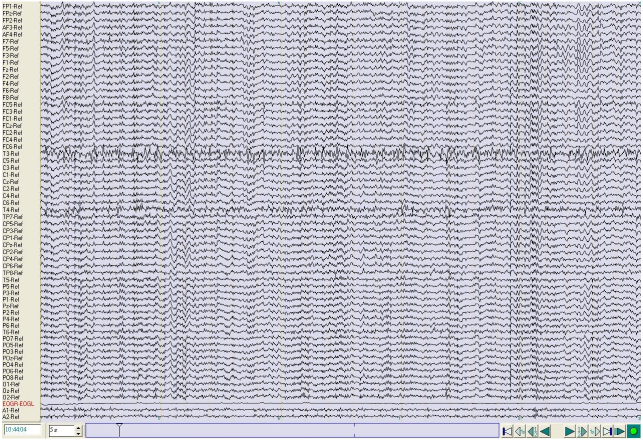
Relaxation session

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).

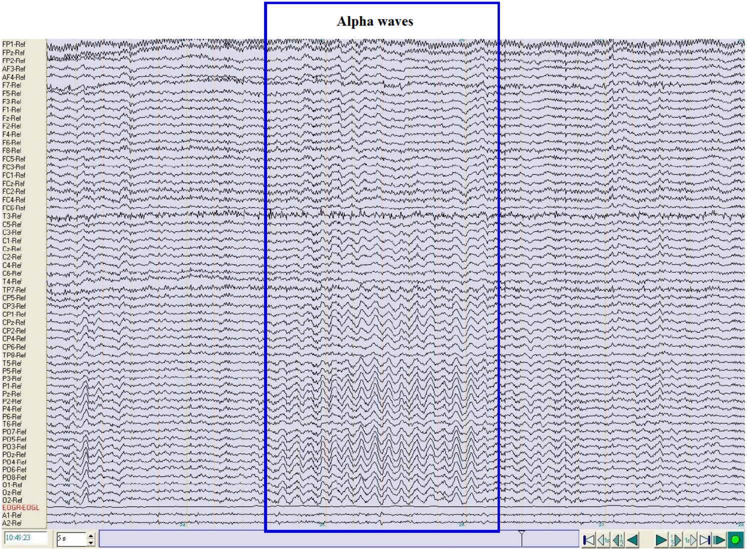
Acquisition Protocole

3 minutes of EEG recording before relaxation.



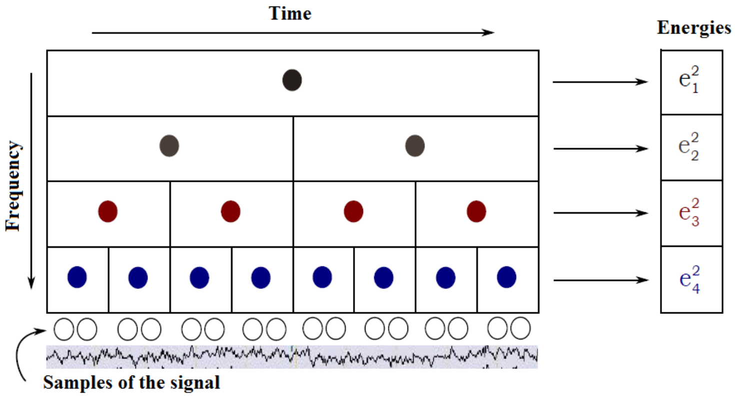
Acquisition Protocole

3 minutes of EEG recording after relaxation.



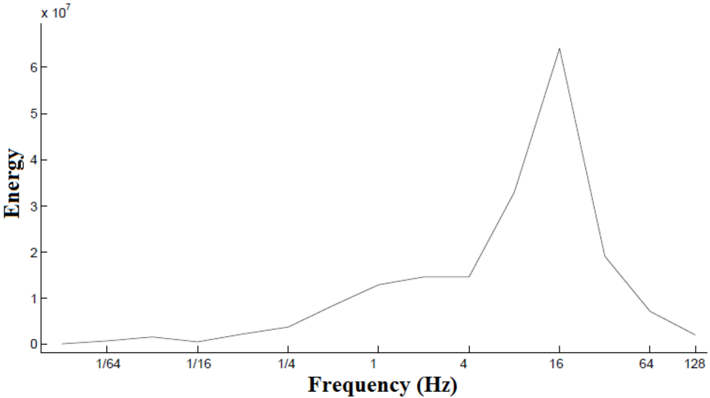
Slope Criterion

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



Slope Criterion

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



Linear regression between 4 and $16Hz$.

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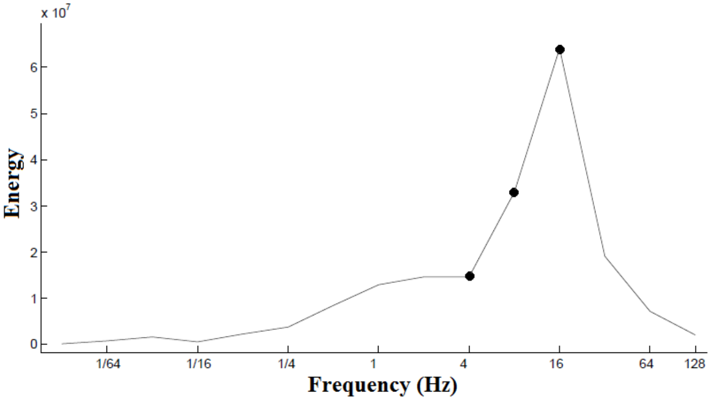

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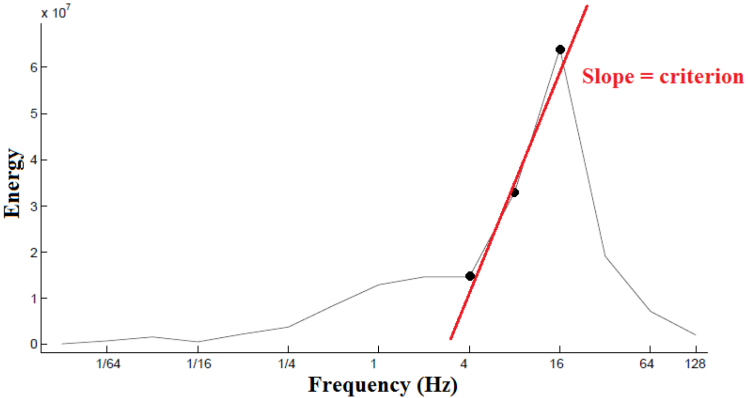

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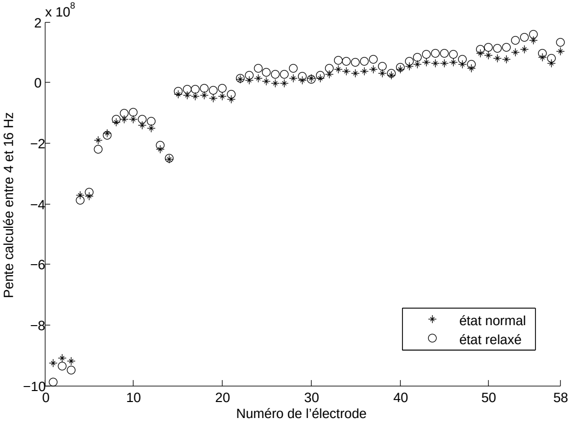
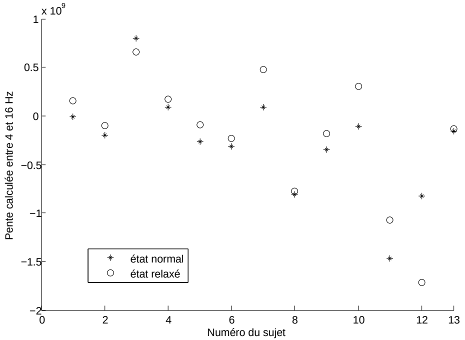


Slope criterion, sum on subjects for each electrode

Slope Criterion



Slope criterion, sum on electrodes for each subjects

⇒ Very strong inter-subject variability

⇒ This criterion that does not allow to build a powerful classifier for different subjects.

Classification: Usual methods

	K nearest neighbors	Binary decision trees	Random forests	Discriminant PLS	Sparse Discriminant 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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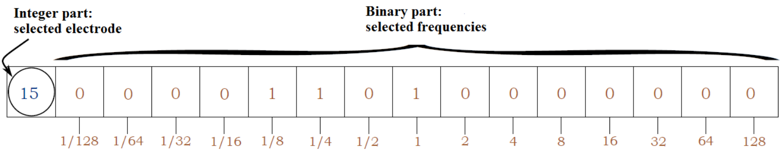
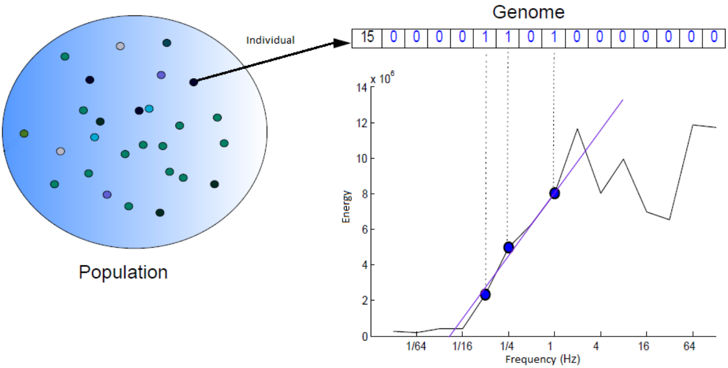
Example of a genome in the evolutionary algorithm



Relationship between the genome and the calculation of the slope criterion



Average correct classification rate

Evaluation Method	CCR	
	Mean	Standard deviation
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.

Best genome

Evaluation method	BEST genome		
	Selected electrode	Selected frequency (Hz)	Correct classification rates
CART	F4	$1/8$, $1/4$, 2, 4 et 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.

PART 4: Regularity estimation with Genetic Programming

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

April 2019, 12

Joint work with Leonardo Trujillo, Gustavo Olague and Jacques Levy-Vehel

Introduction

Hölderian Regularity

Contribution

Introduction

Hölderian Regularity

Contribution

Signal Regularity

- In science and engineering there is one fundamental task: Analyzing and processing signals (natural or artificial) to extract useful information.
- Signals can be too big; where is the information located?
- Usually its smart to focus where signal variation is high (for visual data, you can think of borders, corners and textured areas)

O. Le Meur, P. Le Callet, D. Barba, and D. Thoreau.
A Coherent Computational Approach to Model Bottom-Up Visual Attention.
IEEE Trans. Pattern Anal. Mach. Intell. 28, 5 (May 2006), 802-817.

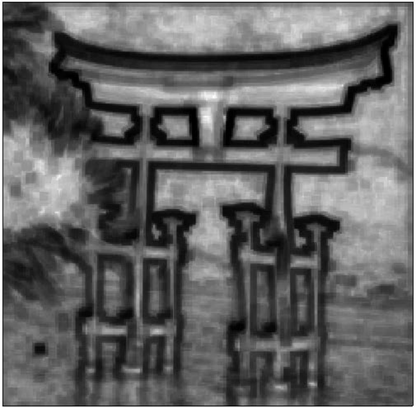
Introduction

Hölderian Regularity

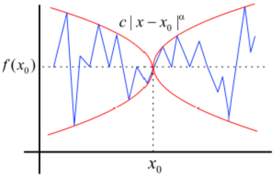
Contribution

Hölder exponent

Mathematical tool that measures the regularity of a signal around each point.



General motivation



$$\alpha_p(x_0) = \liminf_{h \to 0} \frac{\log|f(x_0+h) - f(x_0)|}{\log|h|}$$

Hölderian envelope of signal f at point x_0

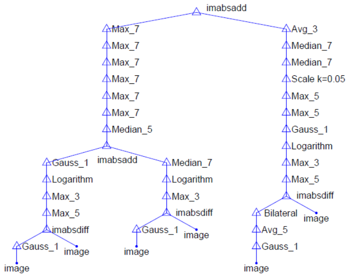
- For real-world signals the Hölder exponent must be estimated for each point.
- Several estimation methods exist, but most methods are SLOW or highly parameterized;
- Therefore there use is not common (particularly in computer vision applications where speed can be of importance)

Introduction

Hölderian Regularity

Contribution

- Evolve estimators of the pointwise Hölder exponent for 2D signals with Genetic Programming!
- GP evolves estimators that are ACCURATE and FAST!
- Evolution is a one-shot process, evolved estimators can be used of-the shelf!



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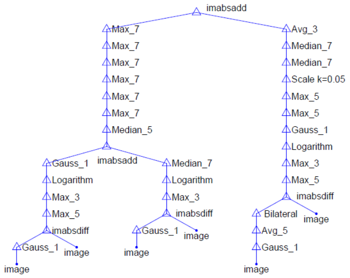

- *Leonardo Trujillo, Pierrick Legrand, Gustavo Olague, and Jacques Levy-Vehel. 2012. Evolving estimators of the pointwise Hölder exponent with Genetic Programming. Information Sciences 209 (Nov. 2012), 61-79.*

- *Humies Award Finalist, GECCO 2013.*

Results: Real Images

Original Image

Traditional Method

GP-Estimator

GP-Estimator

Thank you for your attention