Discrimination of resting-state fMRI for Schizophrenia patients with Lattice Computing based features

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Contents

Introduction

- Lattice Computing approach to
  - identify functional networks in resting state fMRI data
  - biomarkers of cognitive or neurodegenerative diseases.
- Use Lattice Auto-Associative Memories to compute a reduced ordering *h*-function
- Thresholded or processed by morphological operators for network detection
- Pearson correlation coefficient between the h-function values and the categorical variable allows to identify the most informative voxel sites
- Classification
- Group analysis is performed on a dataset of healthy controls, schizophrenia patients
- Find functionally connected cluster differences discriminating the subjects suffering auditory hallucination.

Resting state fMRI

- Resting state fMRI data has been used to study brain functional connectivity
  - correlation of low frequency oscillations in diverse areas of the brain reveal their functional relations.
  - connections discovered are a brain fingerprint, the so-called default-mode network.
- do not impose constraints on the cognitive abilities of the subjects.
  - in the study of brain maturation there is no single cognitive task which is appropriate across the aging population.

Schizophrenia

Schizophrenia is a severe psychiatric disease that is characterized by delusions and hallucinations, loss of emotion and disrupted thinking.

Functional disconnection between brain regions is suspected to cause these symptoms, because of known aberrant effects on gray and white matter in brain regions that overlap with the default mode network.

Resting state fMRI studies have indicated aberrant default mode functional connectivity in schizophrenic patients.

Goal of our work is to find differences in connectivity betwee patients with and without auditory hallucinations

Multivariate Mathematical Morphology

Approach to define Multivariate Mathematical Morphology

- **based** on the definition of a supervised ordering
- **built** on the Lattice Auto-associative Memory recall error

Results on the application on resting state fMRI to discover functional connectivity

LAAM definitions

We have introduced several approaches to define reduced supervised orderings based on the recall error of the LAAM.

- input/output pairs of patterns

$$(X, Y) = \left\{ \left(\mathbf{x}^{\xi}, \mathbf{y}^{\xi} \right); \xi = 1, .., k \right\}$$

- a linear heteroassociative neural network

$$W = \sum_{\xi} \mathbf{y}^{\xi} \cdot \left(\mathbf{x}^{\xi} \right)'.$$

- erosive and dilative LAMs, respectively

$$W_{XY} = \bigwedge_{\xi=1}^{k} \left[\mathbf{y}^{\xi} \times \left(-\mathbf{x}^{\xi} \right)' \right] \text{ and } M_{XY} = \bigvee_{\xi=1}^{k} \left[\mathbf{y}^{\xi} \times \left(-\mathbf{x}^{\xi} \right)' \right],$$

where $\times$ is any of the $\boxed{\vee}$ or $\boxed{\wedge}$ operators,

LAAM definitions

- operator $\boxvee$ denotes the max matrix product

$$C = A \boxvee B = [c_{ij}] \Leftrightarrow c_{ij} = \bigvee_{k=1..n} \left\{ a_{ik} + b_{kj} \right\},$$

- operator $\boxwedge$ denotes the min matrix product

$$C = A \boxwedge B = [c_{ij}] \Leftrightarrow c_{ij} = \bigwedge_{k=1..n} \left\{ a_{ik} + b_{kj} \right\}.$$

LAAM definitions and properties

Definition

When $X = Y$ then W_{XX} and M_{XX} are called Lattice Auto-Associative Memories (LAAMs).

- perfect recall for an unlimited number of stored patterns

$$W_{XX} \boxed{\vee} X = X = M_{XX} \boxed{\wedge} X$$

- convergence in one step for any input pattern
  - if $W_{XX} \boxed{\vee} \mathbf{z} = \mathbf{v}$ then $W_{XX} \boxed{\vee} \mathbf{v} = \mathbf{v}$
  - if $M_{XX} \boxed{\vee} \mathbf{z} = \mathbf{u}$ then $M_{XX} \boxed{\wedge} \mathbf{u} = \mathbf{u}$.

Multivariate Mathematical Morphology

The two elementary morphological operators

- erosion: an operation that is distributive with the minimum

$$\varepsilon\left(\bigwedge Y\right) = \bigwedge_{y \in Y} \varepsilon(y)$$

- dilation: distributive with the maximum

$$\delta\left(\bigvee Y\right) = \bigvee_{y \in Y} \delta(y)$$

Image morphological filters:

- morphological gradient

$$g(Y) = \delta(Y) - \varepsilon(Y)$$

- the top-hat

$$t(Y) = Y - \delta(\varepsilon(Y))$$

Multivariate ordering

- The **LAAM** h**-mapping** is defined as the Chebyshev distance between the original pattern vector and the recall obtained from the LAAM.

$$h_X(\mathbf{c}) = d_C\left(\mathbf{x}^{\#}, \mathbf{x}\right),$$

  - where $\mathbf{x}_M^{\#} = M_{XX} \boxtimes \mathbf{x}$,
  - function $d_C(\mathbf{a}, \mathbf{b})$ denotes the Chebyshev distance:

$$d_C(\mathbf{a}, \mathbf{b}) = \bigvee_{i=1}^{n} |a_i - b_i| .$$

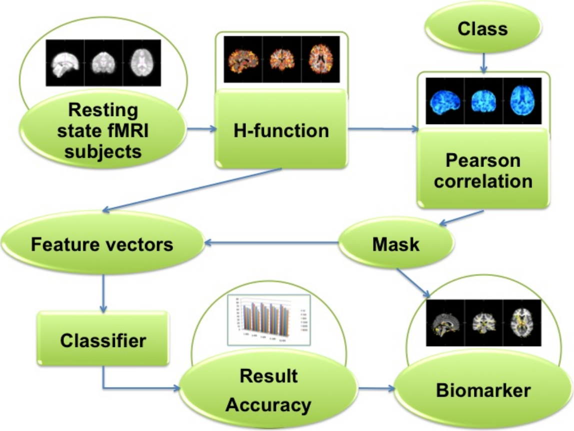
- **Foreground LAAM** h**-supervised ordering**, denoted by $\leq_X$, is defined on the LAAM h-mapping as follows:

$$\forall \mathbf{x}, \mathbf{y} \in \mathbb{R}^n,\ \mathbf{x} \leq_X \mathbf{y} \Longleftrightarrow h_X(\mathbf{x}) \leq h_X(\mathbf{y}) .$$

- **Background/Foreground (B/F) LAAM** h**-mapping** $h_r(\mathbf{x})$ as follows:

$$h_r(\mathbf{x}) = h_F(\mathbf{x}) - h_B(\mathbf{x}),$$

Pipeline



The graphical description of our experimental process aim of the experiments is a proof of concept of the approach

- discrimination of **healthy** control subjects, **schizophrenia** patients **with** and **without** auditory hallucinations.

results find different brain networks depending on the subject using the **same** *h*-function built from selected voxel seeds.

Our experiments aim to obtain network localizations correlated with an **specific voxel** from the **auditory cortex** in order to ascertain some effect related to the **auditory hallucinations**

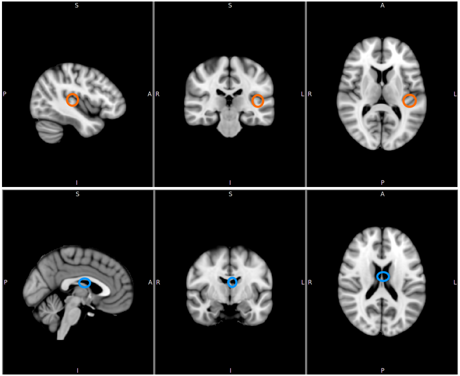
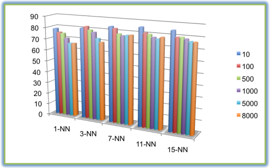
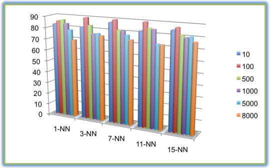


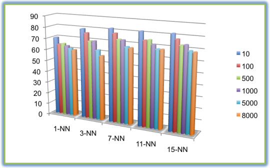
Figure: Foreground voxel seed site from the left Heschl's gyrus (LHG; -42,-26,10). Background voxel seed site from CSF of the ventricle



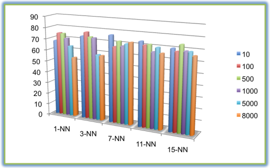
HC vs. Schiz



HC vs. nAH

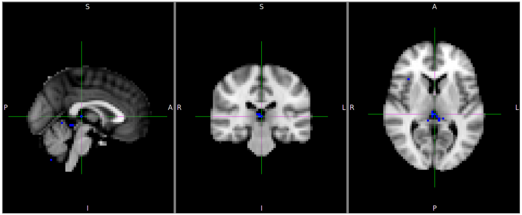


HC vs. AH

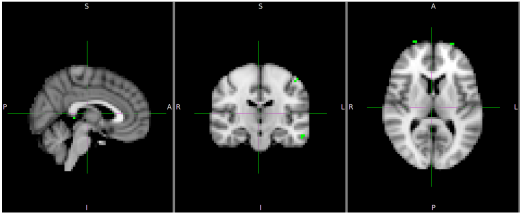


nAH vs. AH

Results of the classification experiments on the discrimination the possible pairs of classes



HC vs. Schiz



nAH vs. nAH

Voxel sites of the feature extraction in the above enumerated cases. These localizations can be taken as biomarkers for additional research.

Conclusions

Using the LAAM reconstruction error measured by the Chebyshev distance as a reduced ordering h-map, we define a Foreground/Background/ LAAMsupervised h-map.

Resting state fMRI data is used for the identication of potential biomarkers for schizophrenia and variants with and without auditory hallucinations by Pearson's correlation.

Biomarkers are evaluated in the terms of the corresponding classication accuracy achieved on the feature vectors extracted from the selected voxel sites.

Best results obtained in the discrimination between healthy controls and patients without auditory hallucinations.

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