Sample entropy and regularity dimension in complexity analysis of gray matter

Presented by: Guilherme Gâmbaro and Julia Oliveira

OVERVIEW

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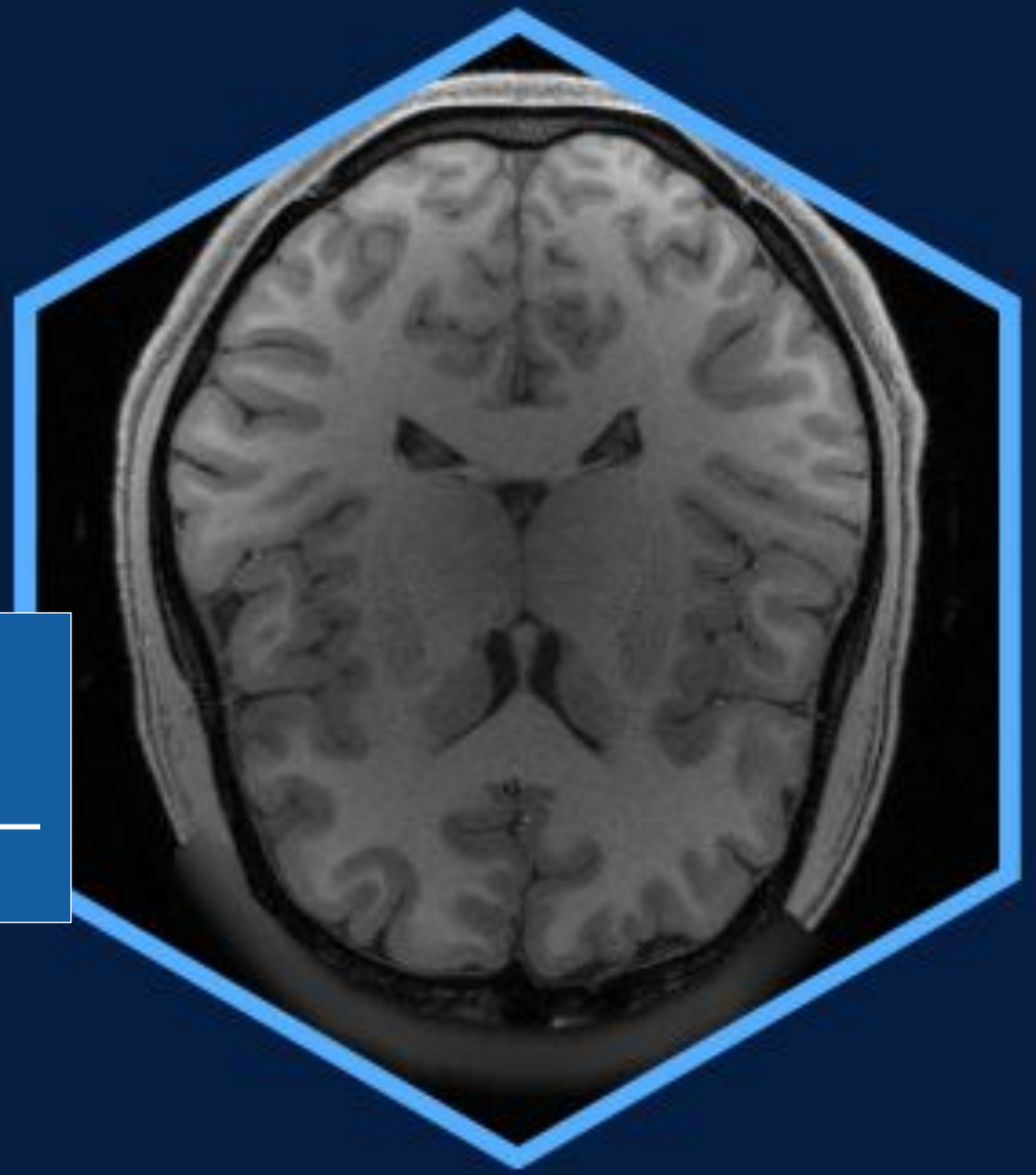

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Computational neuroscience

Sample entropy and regularity dimension in complexity analysis of cortical surface structure in early Alzheimer's disease and aging

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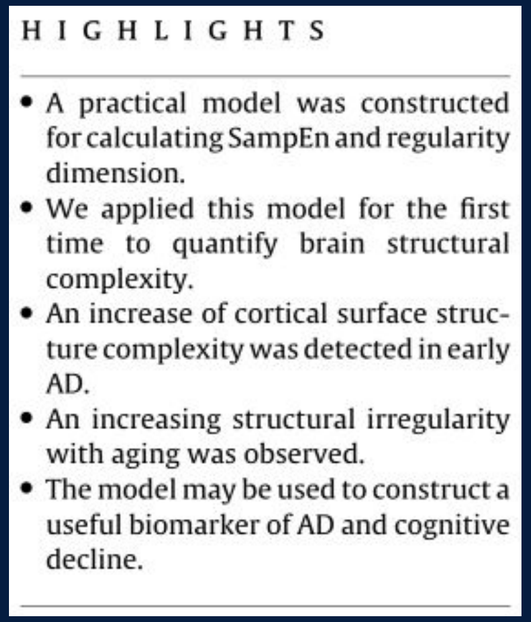
Introduction

In this article, they used sample entropy (SampEn) and a regularity dimension model to measure the structural complexity of the brain using magnetic resonance imaging (MRI) for Alzheimer's disease and aging. For this, they used structural MRI images provided by a database, segmented the outer edges of the gray matter, and calculated the distance from these edges to the center, creating a series. Finally, they calculated the regularity dimensions, Dm. They have demonstrated the increase of global cortical surface structure complexity in early AD. The increase of SampEn and the regularity dimension are also found to be accompanied with aging which might indicate an age-related exacerbation of cortical structural irregularity. The provided model can be potentially used as an imaging bio-marker for early prediction of AD and age-related cognitive decline.



HIGHLIGHTS

- A practical model was constructed for calculating SampEn and regularity dimension.
- We applied this model for the first time to quantify brain structural complexity.
- An increase of cortical surface structure complexity was detected in early AD.
- An increasing structural irregularity with aging was observed.
- The model may be used to construct a useful biomarker of AD and cognitive decline.

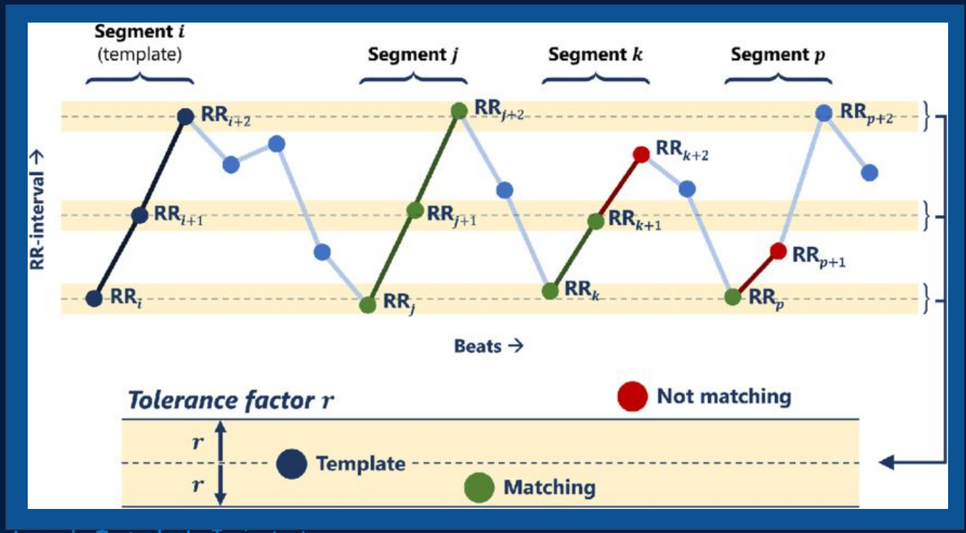
In this project: we will reproduce the methodology, obtaining the regularity dimension of structural images.

Sample entropy

Sample entropy (SampEn) is a measure of complexity and regularity, where it measures the negative natural logarithm of the conditional probability that two sequences, which are similar for m points, will continue to be similar for the next point, m+1.

$$SampEn(m, r, N) = -ln\left(\frac{C^{m+1}(r)}{C^{m}(r)}\right)$$

The calculation involves taking a series of N points and dividing it into vectors of size m, where *C^{m}* represents the number of vectors of size *m* whose distance to other vectors is less than a tolerance factor *r*. Similarly, *C^{m+1}* corresponds to the same calculation but for vectors of size *m+1*.



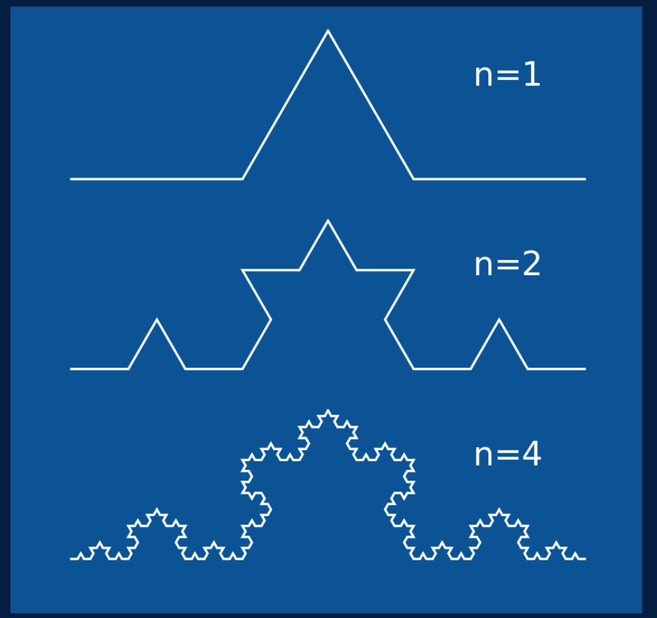
Example, in this figure, the blue vector represents the 'template', while the orange band indicates the tolerance range. When a vector, like the green one, falls within the orange tolerance, we count it as 1. This process is repeated for all combinations of vectors.

Fractal dimension

Fractal dimension is a measure of how "complicated" a self-similar figure is. where N is the number of self-similar pieces, and m is the reduction factor.

$$D = \frac{log(N)}{log(\frac{1}{m})}$$

Example, in this figure, the main structure is repeated four times in each segment, denoted as N, and remove, scaled, 1/3 of the segment, represented by m.



If the image could be transformed into a series, the logarithm of the count of self-similar parts can be approximated by sample entropy. This is the log of the count of similar vectors, with the reduction factor corresponding to the size of the sample entropy vector.

$$D_m = \frac{SampEn(m)}{log(\frac{1}{m})}$$

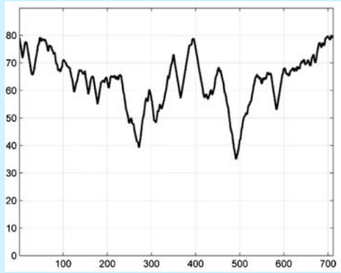
METHODOLOGY

Step 1

- Trace the gray matter boundary
- Find the center of the image

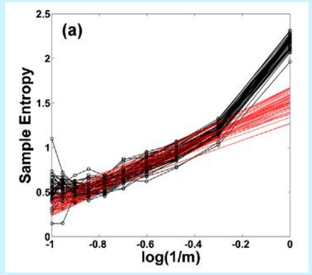
Step 2

- Calculate the distance from the center to boundary



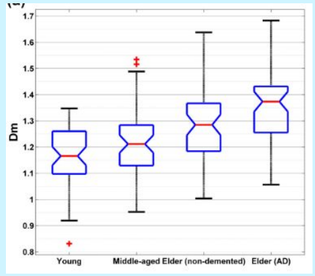
Step 3

- Generate time-series with the distances



Step 4

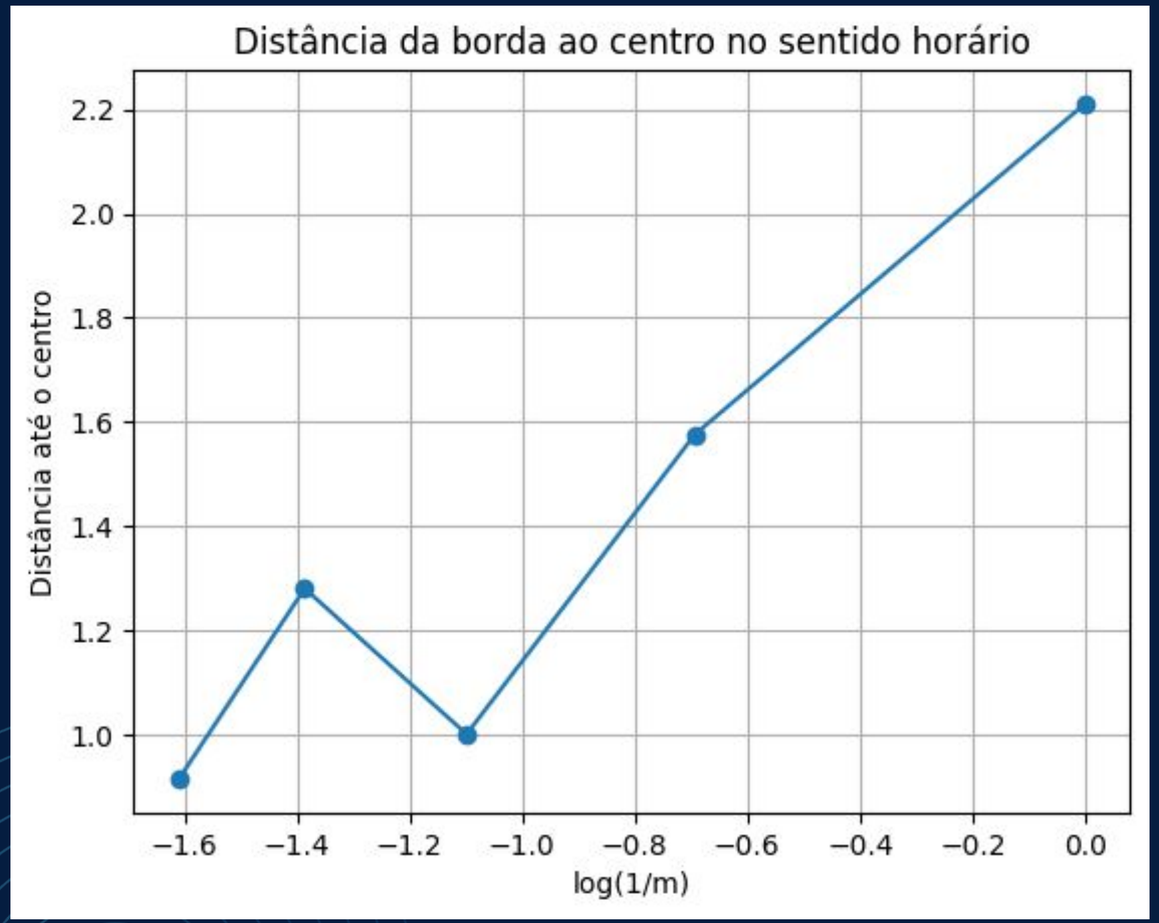
- Calculate the entropy for multiple m values

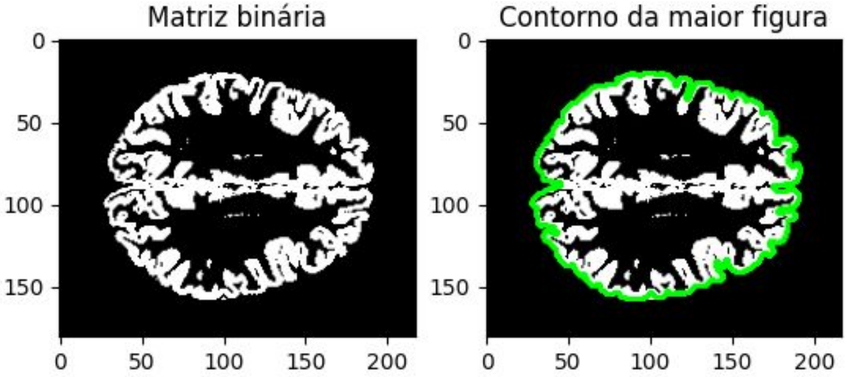


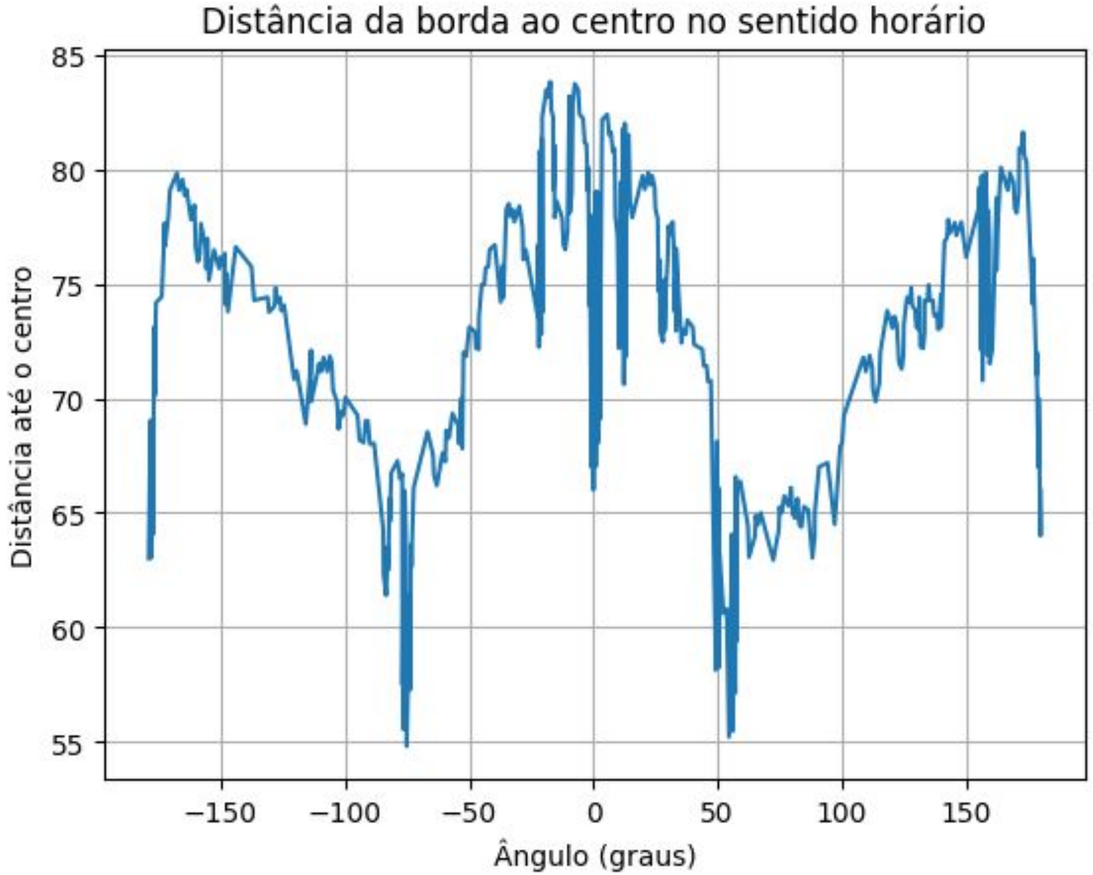
Step 5

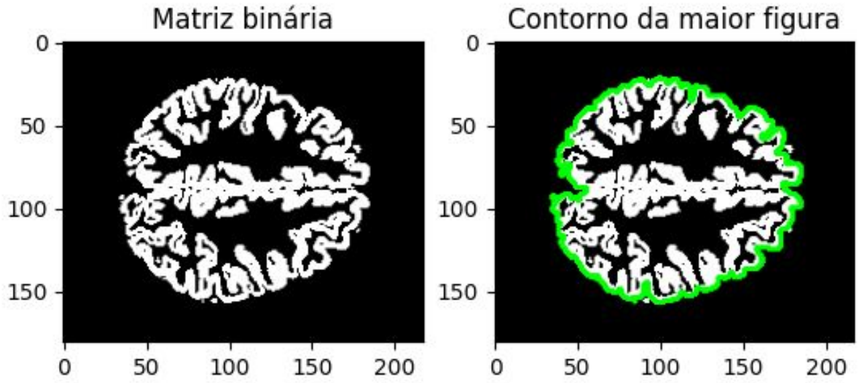
- Calculate the dimension using the angular coefficients

Results

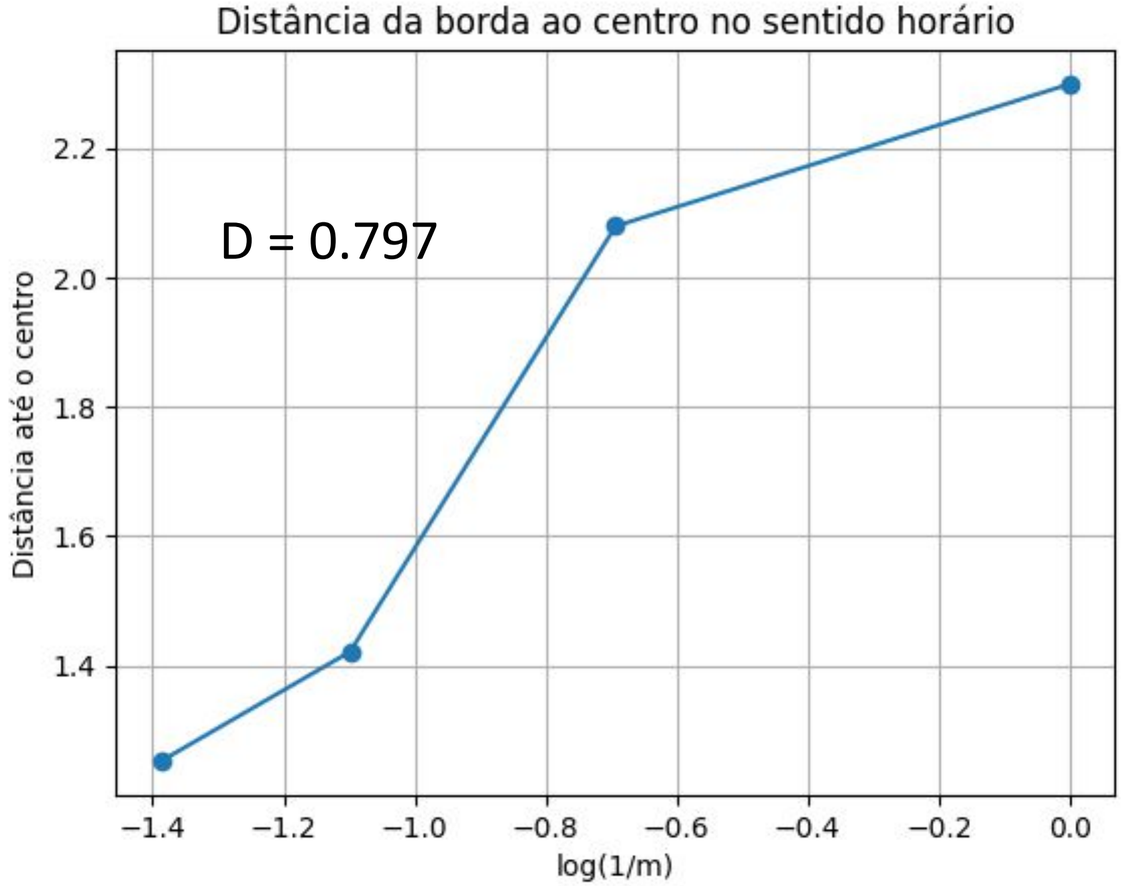

Distância da borda ao centro no sentido horário
Distância até o centro
log(1/m)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0

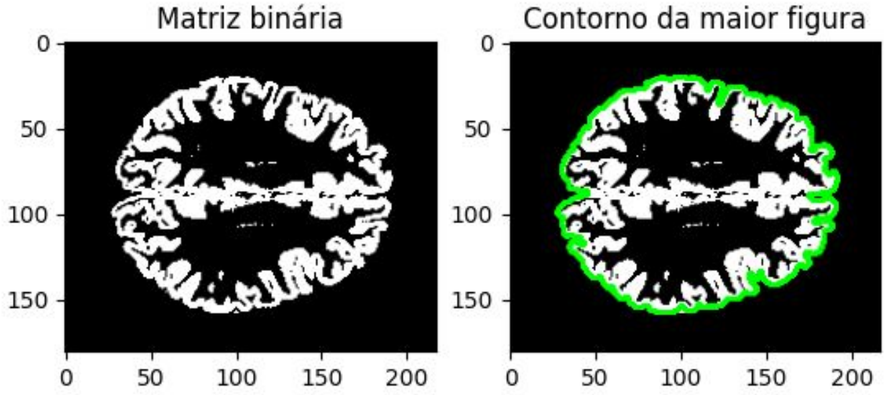

Matriz binária
Contorno da maior figura
0
50
100
150
200


Distância da borda ao centro no sentido horário
Distância até o centro
Ângulo (graus)
85
80
75
70
65
60
55
−150
−100
−50
0
50
100
150

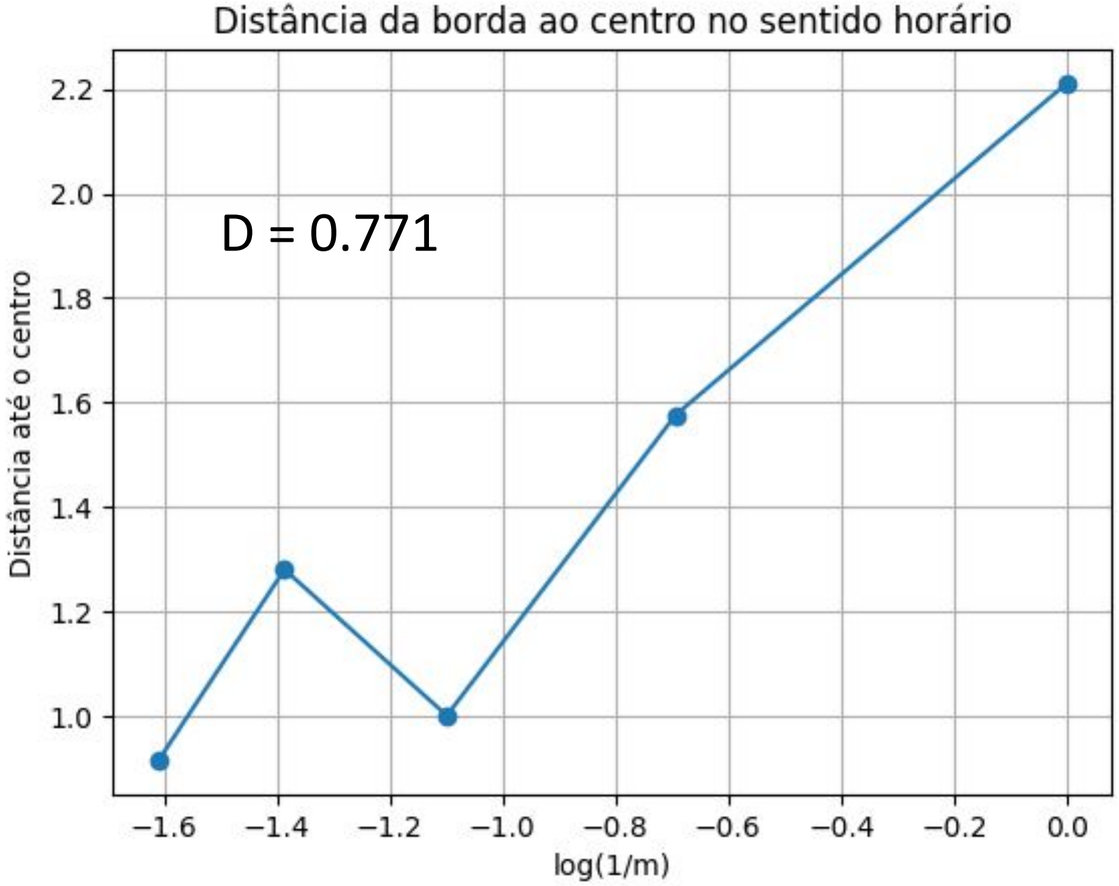

Matriz binária
0
50
100
150
0
50
100
150
200

Contorno da maior figura
0
50
100
150
0
50
100
150
200

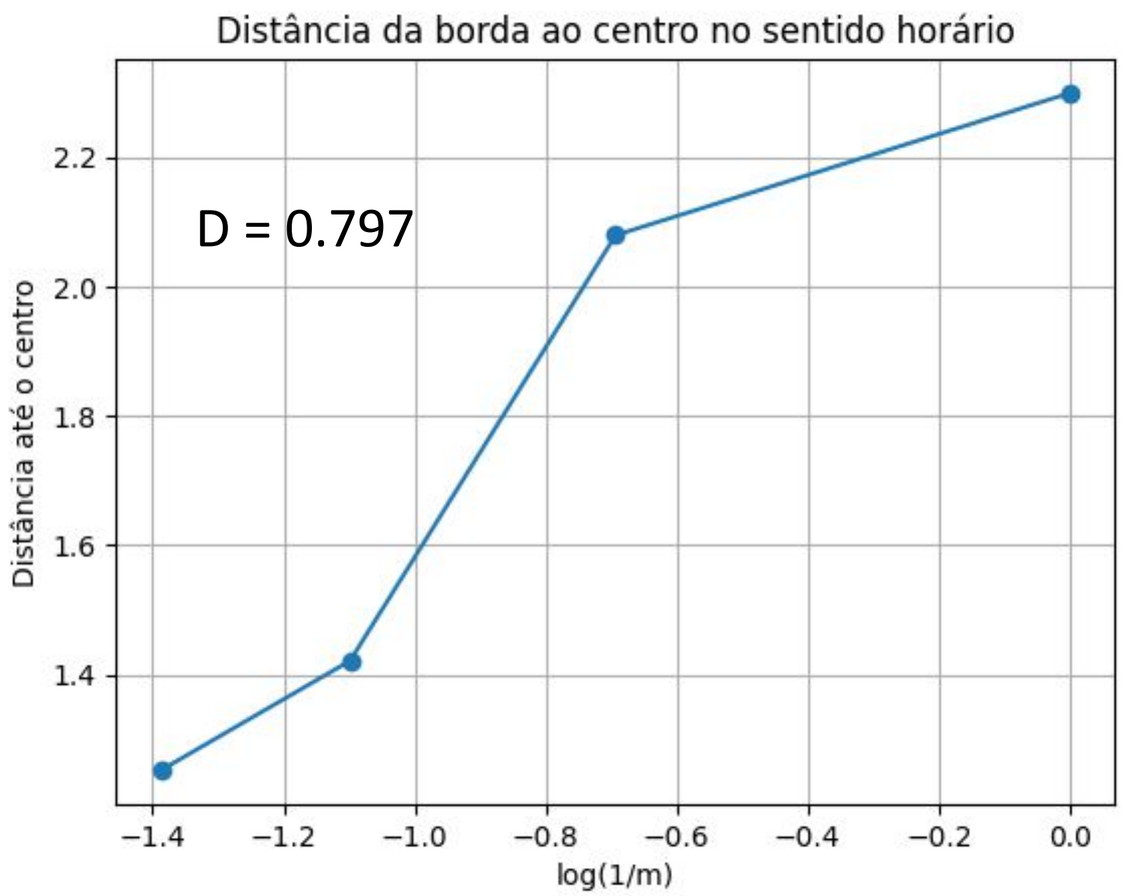

Distância da borda ao centro no sentido horário
D = 0.797
Distância até o centro
2.2
2.0
1.8
1.6
1.4
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
log(1/m)


Matriz binária
0
50
100
150
0
50
100
150
200

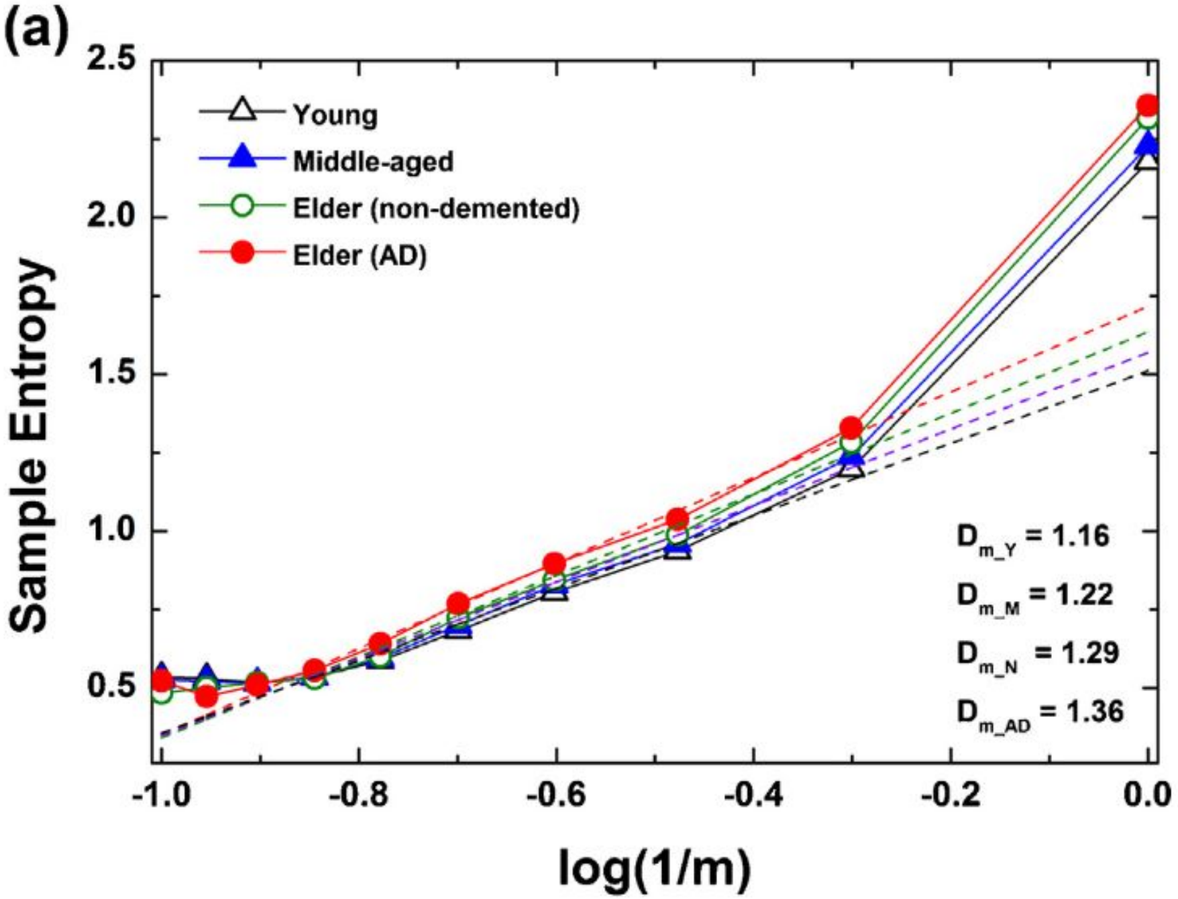
Contorno da maior figura
0
50
100
150
0
50
100
150
200


Distância da borda ao centro no sentido horário
D = 0.771
Distância até o centro
2.2
2.0
1.8
1.6
1.4
1.2
1.0
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
log(1/m)

Our results



Paper results



Conclusion

Reproduction

We successfully reproduced the article methodology!

Limitations

Boundary contorn limitation, slow processing in python, number of studied subjects, parameters choices.

Thank's For Watching