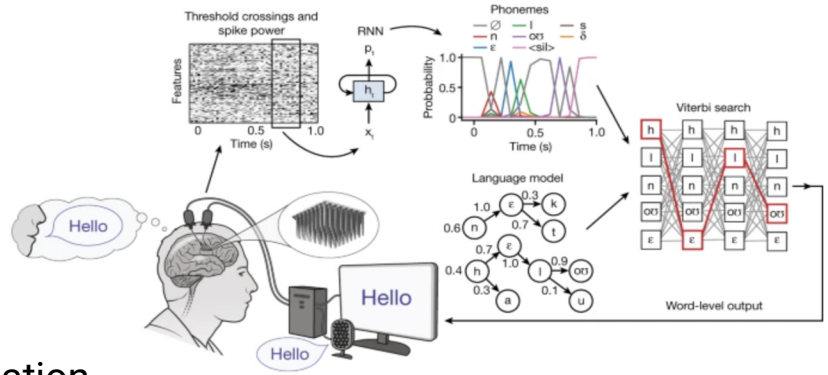
Topology Data Analysis To Phoneme Neural Signals

Team : TOPOGNITION
Alex Mikhael
Joshua Roldan
Xiaoxuan(Andrina) Zhang

MOTIVATION



- Effective communication
- Expressing thoughts, emotions, needs, and ideas
- Constantly chatting, texting, and connecting

- Losing the ability to speak can be devastating

- Speech prosthesis : independence, communication, social interactions → better quality of life

- Willet phoneme dataset

Willett, F.R., Kunz, E.M., Fan, C. *et al.* A high-performance speech neuroprosthesis. *Nature* 620, 1031–1036 (2023).

Key Question

1. How are the neural dynamics encoding the phonemes?

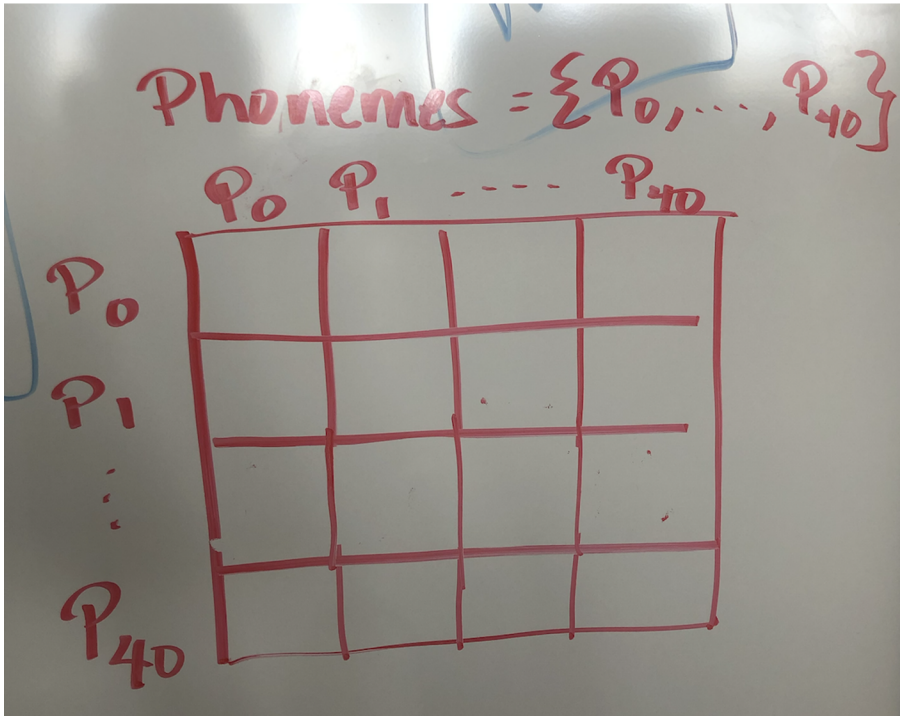
2. How different are the neural dynamics between phonemes?
    a. (Dis)Similar dynamics should correspond to (dis)similar phonemes. (‘Bah’, ‘Fah’ versus ‘Bah’, ‘gOOse’)

Knowing the *distances* between neural dynamics, can help identify different regimes, and allow further probing into the underlying mechanism(s).

Methodology: (Output) Distance Matrix

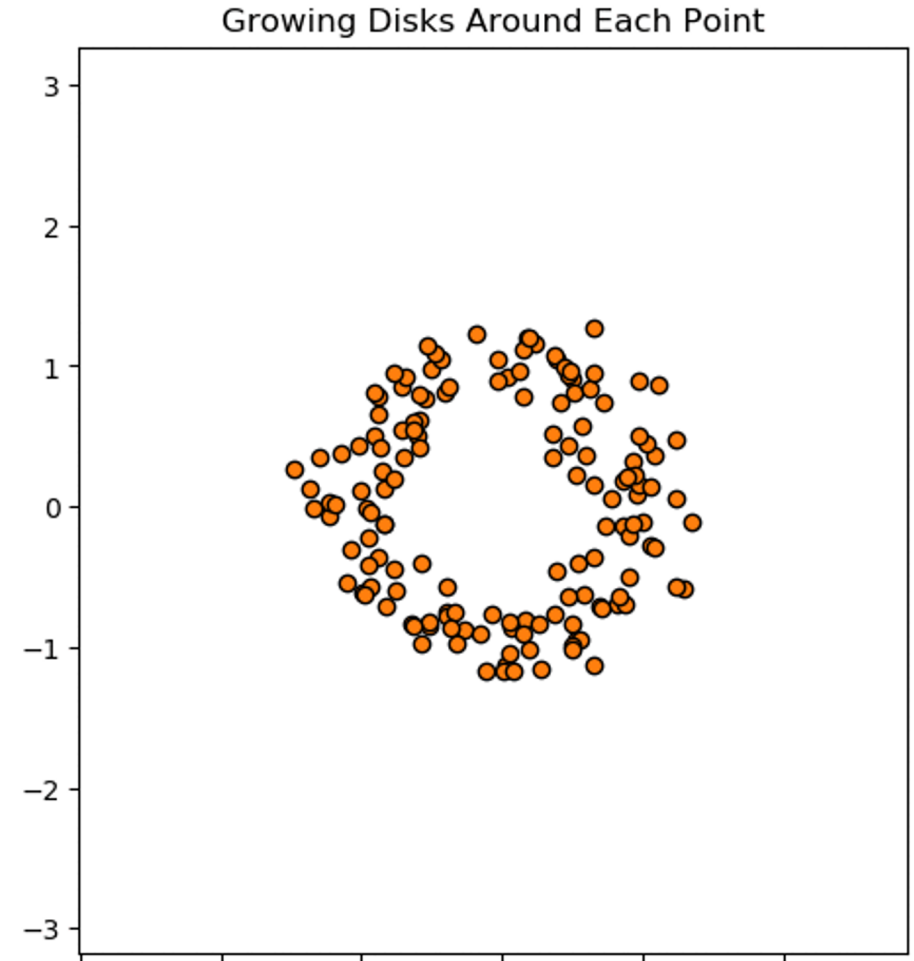
- Output: Distance Matrix
- Entry (i, j) is the distance between phoneme p_i and p_j

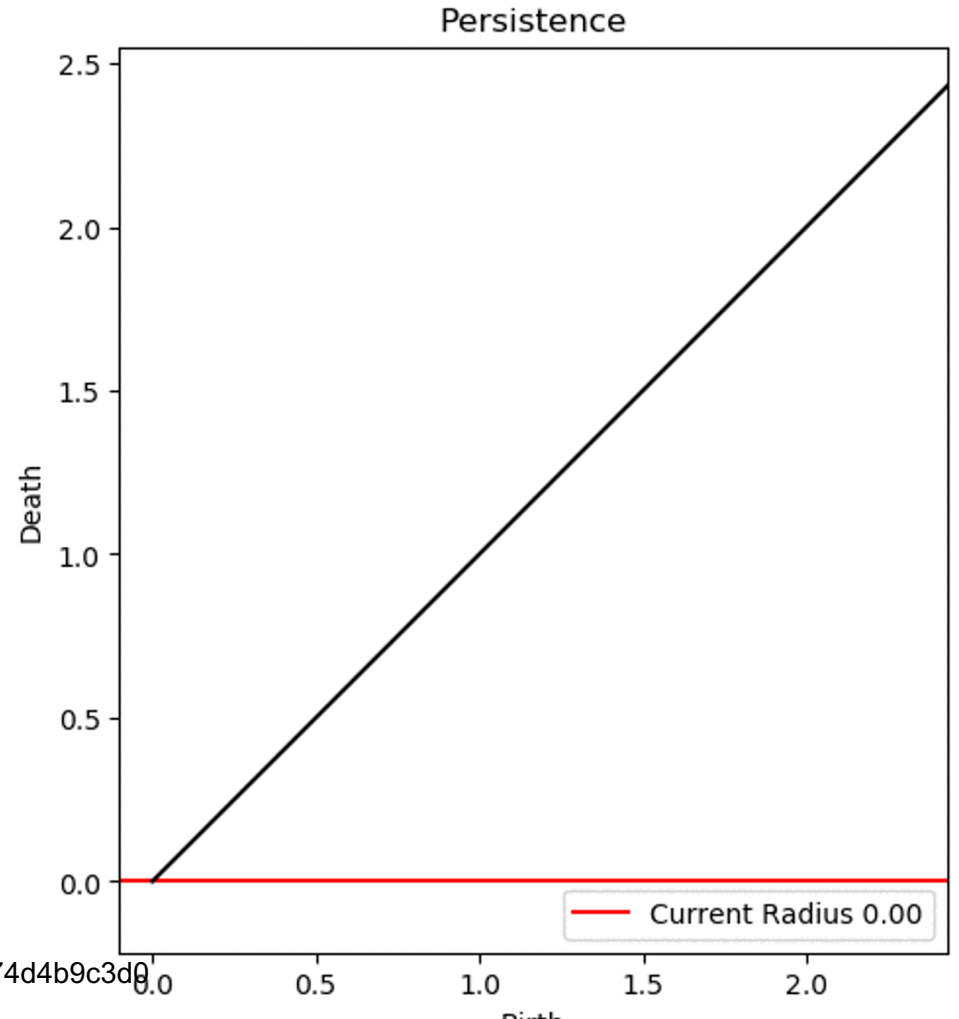
- Alternates to Correlation
- Distance is based on topology!
  - Not necessarily euclidean



Topology - study of most fundamental property of shapes

- # number of holes

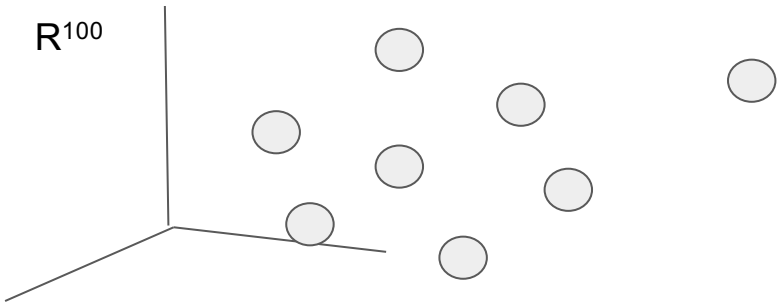




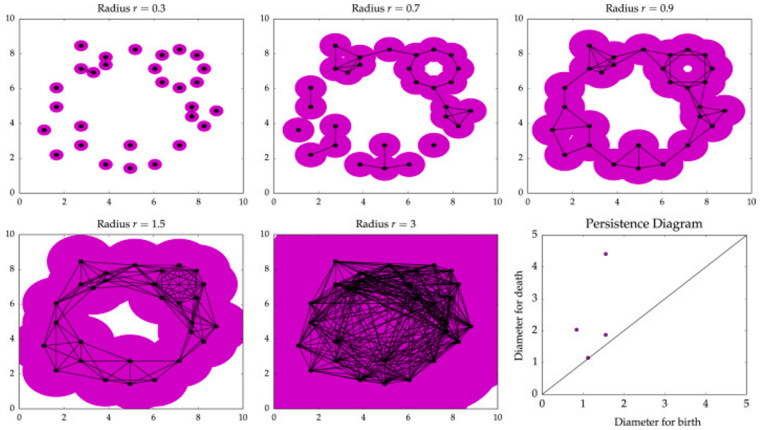
https://towardsdatascience.com/persistent-homology-with-examples-1974d4b9c3d0

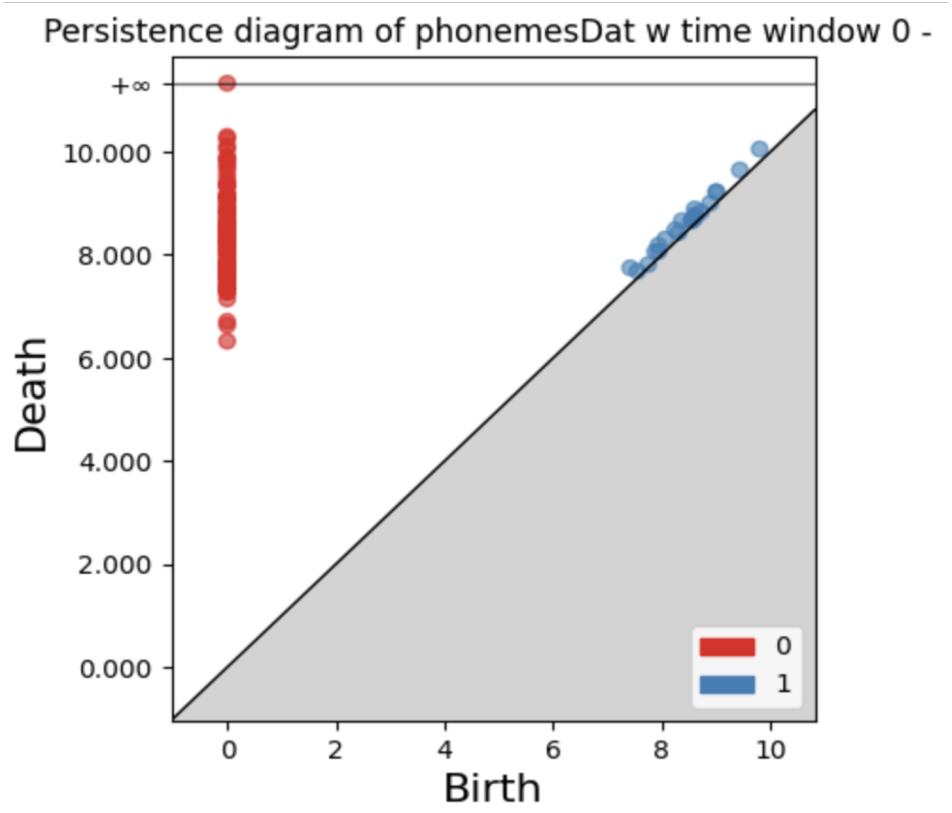
Methodology: Pairwise Distance

- Distance is called **Bottleneck Distance** d_B
- Compute d_B between *persistence diagrams*
- Hence, computes the differences between shapes based on their “holes”
- Point cloud M(p) (phoneme)
  consists of 16 sets (n_trials) ,
  of 256 points (channels),
  living in 100 dim (time)

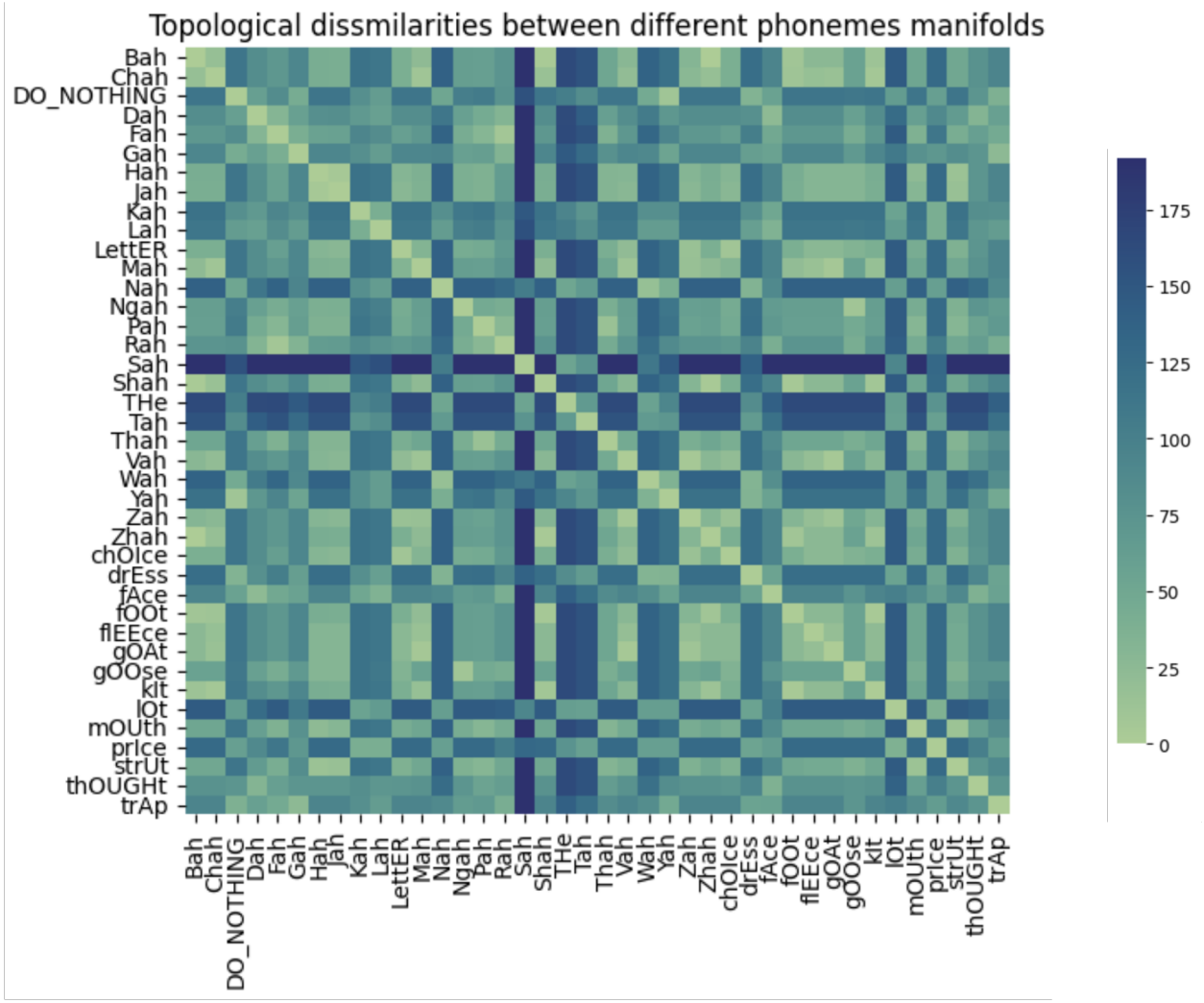


Results


Radius $r = 0.3$
Radius $r = 0.7$
Radius $r = 0.9$
Radius $r = 1.5$
Radius $r = 3$
Persistence Diagram
Diameter for death
Diameter for birth


Persistence diagram of phonemesDat w time window 0 -
+∞
10.000
8.000
6.000
4.000
2.000
0.000
Death
0
2
4
6
8
10
Birth
0
1

Results


Topological dissmilarities between different phonemes manifolds
Bah
Chah
DO_NOTHING
Dah
Fah
Gah
Hah
Jah
Kah
Lah
LettER
Mah
Nah
Ngah
Pah
Rah
Sah
Shah
THe
Tah
Thah
Vah
Wah
Yah
Zah
Zhah
chOIce
drEss
fAce
fOOt
flEEce
gOAt
gOOse
kIt
lOt
mOUth
prIce
strUt
thOUGHt
trAp
175
150
125
100
75
50
25
0

Next Steps

- Use persistent homology on advanced time-series analysis in signals via Takens Embedding
- Compare to other metrics in literature and explore more dimensionality reduction algorithms
- Incorporate unsupervised machine learning models to identify phonemes based on neural data and topology features