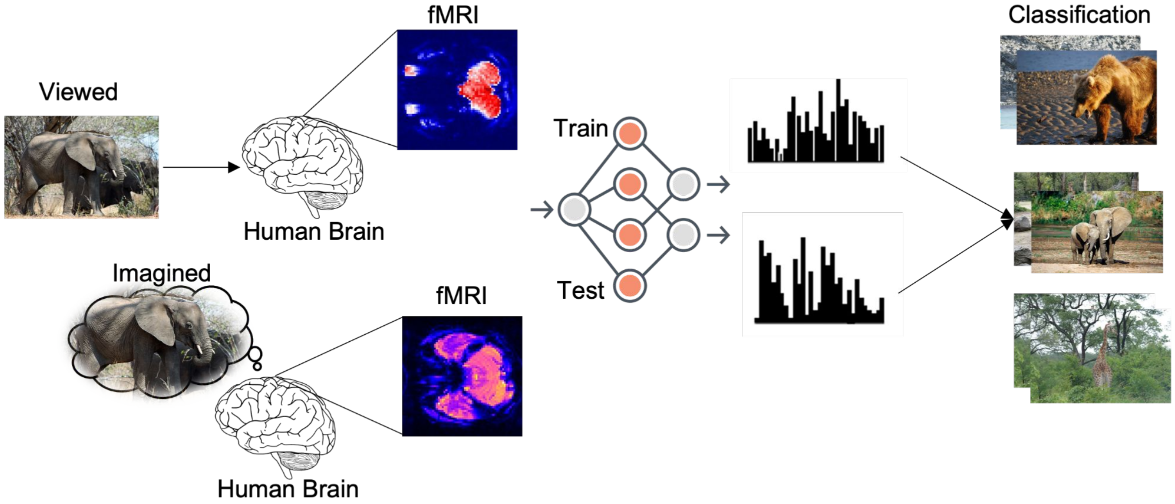
interpret-fMRI

Decoding Imagery and Perception for Object Category Prediction



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Muhammad Kamran Janjua, Abdul Wahab

What do you think a Blue Angel looks like?

Context

- It is called Glaucus Atlanticus
- It is an aquatic
- It looks like a slug
- It is blue in color

Given this context, now what do you think about it?

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Blue Angel

Picture Credits: Google Images

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Introduction

- Mental imagery is a form of a perceptual experience that a subject undergoes in the absence of any visual stimulus
- This is called ‘quasi-perceptual experience’ - some sort of mental representations
- Perception is an experience given some stimulus - also mental representations
- Imagery phenomenon exists and draws on the same neural machinery as perception in the brain [1,2,3]

[1] Giorgio Ganis, William L Thompson, and Stephen M Kosslyn. Brain areas underlying visual mental imagery and visual perception: an fmri study. Cognitive Brain Research, 20(2):226–241, 2004.
[2] Nigel J.T. Thomas. Mental Imagery. In Edward N. Zalta, editor, The Stanford Encyclopedia of Philosophy. Metaphysics Research Lab, Stanford University, Fall 2021 edition, 2021.
[3] Radoslaw M Cichy, Jakob Heinzle, and John-Dylan Haynes. Imagery and perception share cortical representations of content and location. Cerebral cortex, 22(2):372–380, 2012.

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Perky's Banana Experiment (1)

- Explores the link between perception and imagery
- Subjects were asked to fixate at a point on the screen upfront and imagine objects
- Experimenters projected a faint blob (matching color/shape of the object) from behind the screen with increasing intensity - subjects did not know
- Subjects mistook this projection as a product of their imagination
- They described details related to the stimulus such as veins in a leaf, title of a book - modified as the projection intensified
- Participants reported vivid imagination pertaining to the projections

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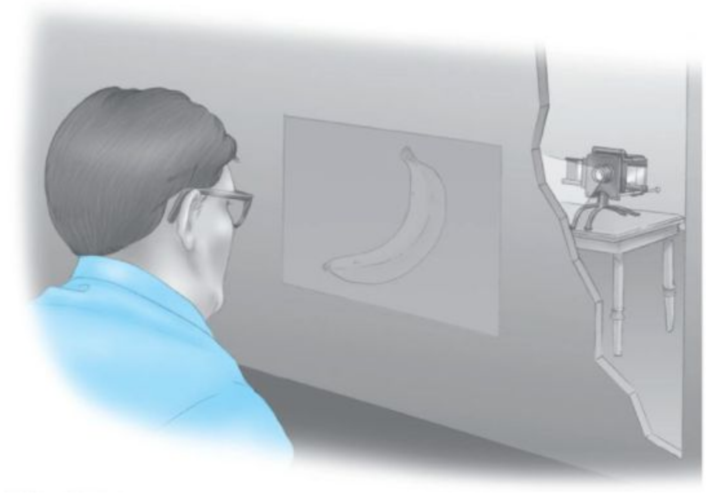
[1] Cheves West Perky. An experimental study of imagination. The American Journal of Psychology, 21(3):422–452, 1910.

Perky’s Banana Experiment (2)

- The projected stimulus modified the subjects’ experience
- They reported that banana is vertical and not horizontal as they had previously imagined as the projection intensified
- The descriptions matched with the actual projections during the course of the experiment



Picture Credits: Google Images

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The Perky Effect

With the Banana experiment, Perky introduced ‘The Perky Effect’

“The tendency of an imagined stimulus to interfere with seeing an actual target stimulus when the imagined form is close to that of the target” [1]

- Visual mental imagery is thought to interfere with visual perception

[1] Cheves West Perky. An experimental study of imagination. The American Journal of Psychology, 21(3):422–452, 1910.

Problem Statement

- Perception and Imagery representations are correlated and shared in the human brain and help provide a crisp understanding of the environment

- In this work, we study if a similar correlation exists in artificial neural networks and if the correlation is strong enough to use the corresponding fMRI data of both perceptual and quasi-perceptual experiences interchangeably for downstream tasks (object category prediction)

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Why is studying this important?

- How is phenomenon like imagery processed by an ANN?
- Is it similar to what a human brain does?
- Are those representations that are shared in the human brain, also shared in the ANN?
- Are these both representations correlated in ANNs? How strong is this correlation?
- Can we combine perception and imagery to get vivid/crisp representations when optimizing to downstream tasks?

- Answers to these questions help in understanding the human brain holistically

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Methodology

Methodology

- Correlation between perception and imagery
- Same neuro machinery evoked inside the brain
- How strong is this correlation?
- How similar imagery and perception are?
- Can we use perception and imagery interchangeably?
- Downstream task: Object category prediction

Methodology: Previous work

- Similar approach to this work [1]
- Category prediction using Nearest Class Mean (NCM)
- Predictions based on averaged features
- Replace NCM classifier with ANN classifier
- Predictions based on individual data points
- More suited for interpretability task

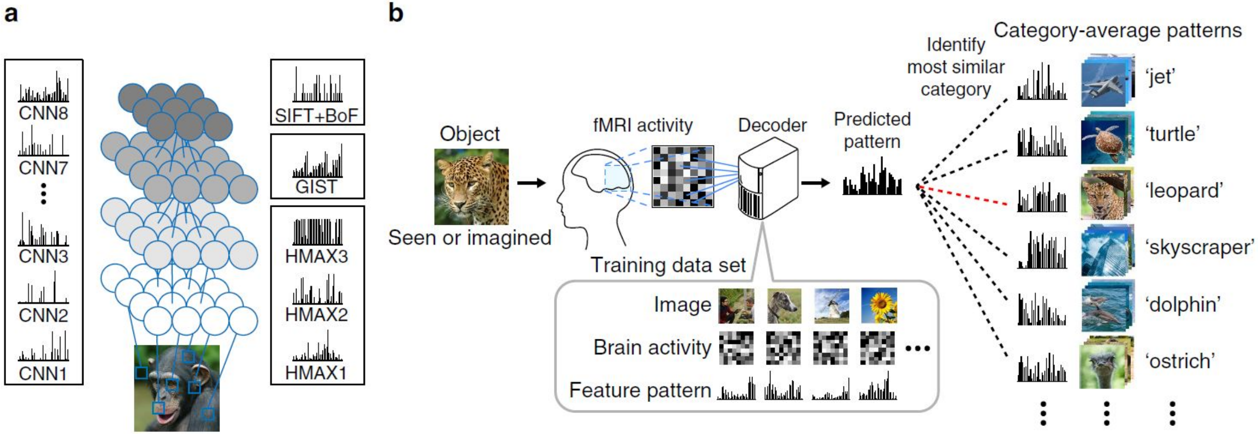

Figure from paper [1]

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

Methodology: Dataset

- fMRI data collected and presented in paper [1]
- Two types of data:
  - Perception fMRI (acquisition: 9 seconds TR: 3 seconds)
  - Imagery fMRI (acquisition: 15 seconds TR: 3 seconds)
- Preprocessing:
  - Motion Correction SPM5
  - Coregistration
  - Re-Interpolation
  - Normalization

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

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Methodology: Dataset

- Data averaged across 3 volumes for perception
- Data averaged across 5 volumes for imagery
- Multiple data collection sessions
- Final data distribution:
    - **Training fMRI Data:** A total of 1200 images from 150 ImageNet categories were shown to the 5 subjects. Total of 6000 fMRI training data samples for all of the subjects.

    - **Perception fMRI Testing Data:** A total of 50 images, 1 for each of the 50 selected object categories were shown to the 5 subjects 35 times. Total 8750 perception fMRI data samples for testing.

    - **Imagery fMRI Testing Data:** The 5 subjects were told to imagine the object category for the same 50 selected categories used during testing for 10 times. Making it a total of 2500 imagery fMRI data samples.

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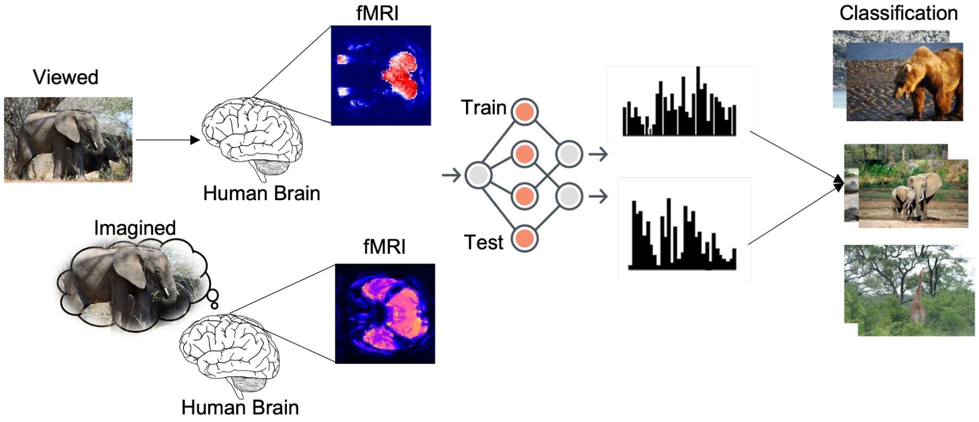
Methodology: Components

- The three main components of our project are:
- Input:
  - Preprocessed fMRI data used by authors in paper [1]
  - fMRI decoded to visual features used by the authors in [1]
  - Raw fMRI data without any preprocessing
- Prediction Model:
  - Logistic Regression
  - 8 layer ANN model
  - 2 layer ANN model
- Output: Object category



Methodology: Experiments

- For each architecture and data-type, performed series of experiments
  - Train a model on Perception data, and test it on Perception data
  - Train a model on Imagery data, and test it on Imagery data
  - Train a model on Perception data, and test it on Imagery data
  - Combined training on Perception and Imagery data and test on Perception data
  - Combined training on Perception and Imagery data and test on Imagery data
- Are perception and imagery representations interchangeable?

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Results

Types of Datasets for Experiments

- Preprocessed imagery and perception data [1]
- Raw imagery and perception fMRI data
- Decoded imagery to visual features [1]

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

Types of Architectures for Experiments

- Logistic Regression
- 8-layer FC Net
- 2-layer MLP Net (vanilla ANNs)

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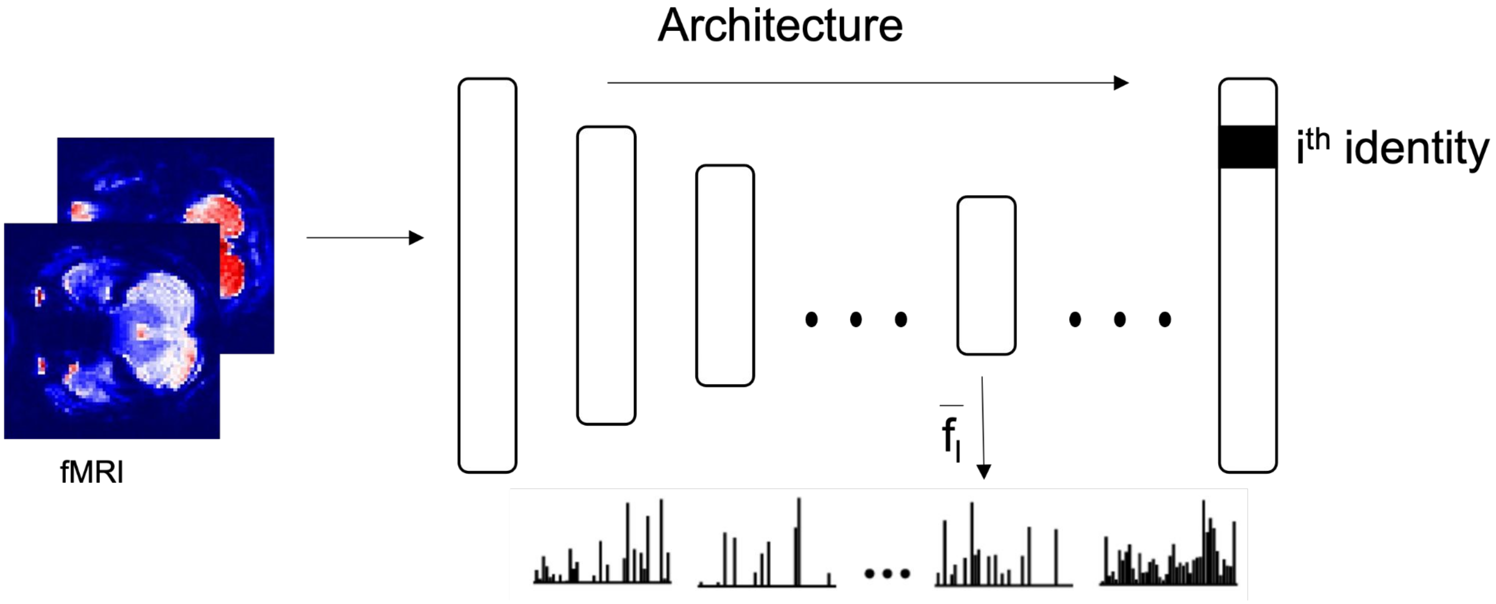
Overview of Experiments

1. Logistic Regression
    a. Train on Perception test on Perception
    b. Train on Imagery test on Imagery
    c. Train on Perception test on Imagery
    d. Combining Perception/Imagery for training and testing
2. 8-layer FC Net
    a. Train on Perception test on Perception
    b. Train on Imagery test on Imagery
    c. Train on Perception test on Imagery
    d. Combining Perception/Imagery for training and testing
3. 2-Layer MLP
    a. Train on Perception test on Perception
    b. Train on Imagery test on Imagery
    c. Train on Perception test on Imagery
    d. Combining Perception/Imagery for training and testing

Generic Architecture Diagram



Experiment # 01: Preprocessed fMRI

Input: Preprocessed fMRI (perception and imagery)

Output: 50-way Category Classification

Trainset - Testset	Logistic Regression	8-Layer FC Net	2-layer MLP
	Test Accuracy (%)	Test Accuracy (%)	Test Accuracy (%)
Perception-Perception	**96**	54.6	**71.7**
Imagery-Imagery	0.0	0.0	1.2
Perception-Imagery	2.4	1.2	1.8
Combined - Perception Combined - Imagery	91.0 0.0	**55.1** 2.4	63.8 1.2

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Best results bold and colored blue

Experiment # 02: Raw fMRI

Input: Raw fMRI (perception and imagery)

Output: 50-way Category Classification

Trainset - Testset	Logistic Regression	8-Layer FC Net	2-layer MLP
	Test Accuracy (%)	Test Accuracy (%)	Test Accuracy (%)
Perception-Perception	14.7	4.4	10.8
Imagery-Imagery	**51.6**	**11.5**	**34.9**
Perception-Imagery	2.1	1.8	2.9
Combined - Perception Combined - Imagery	**14.4** **32.9**	**4.5** **11.27**	**8.3** **26.6**

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Best results bold and colored blue
reliable results on both perception and imagery bold and colored green

Experiment # 03: Decoded to Visual Features

Input: Decoded preprocessed fMRI (imagery) to visual features

Output: 50-way Category Classification

Trainset - Testset	Logistic Regression	8-Layer FC Net	2-layer MLP
	Test Accuracy (%)	Test Accuracy (%)	Test Accuracy (%)
Perception-Perception	N/A	N/A	N/A
Imagery-Imagery	0.0	1.2	1.2
Perception-Imagery	N/A	N/A	N/A
Combined - Perception Combined - Imagery	N/A	N/A	N/A

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Some Additional Experiments

1. Decoded imagery to perception
   a. Performed the decoding, approach similar to decoding to visual features [1]
   b. Used preprocessed imagery data and decoded to perception
   c. No reliable results were obtained

2. Applied PCA on raw fMRI
   a. Since raw fMRI gave most reliable results on both imagery and perception (when trained on combined raw data)
   b. Performed only for one case to check the effects of dimensionality reduction
   c. No reliable results were obtained

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

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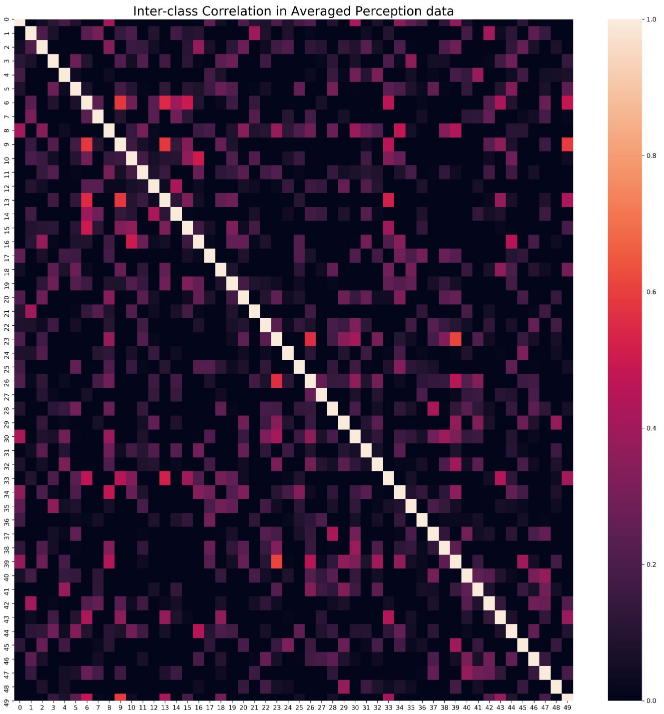
Discussion

Discussion

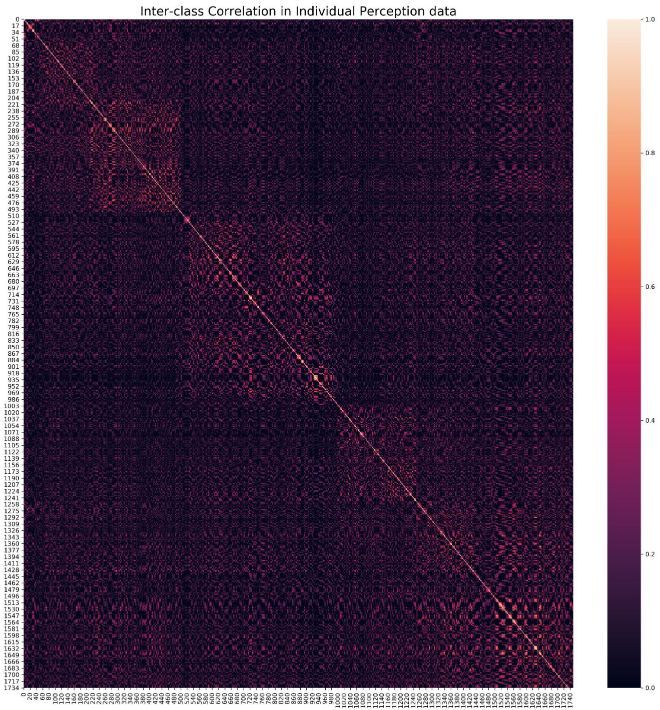
- Why does the model not learn on preprocessed imagery fMRI?
- Why does the model learn on preprocessed perception fMRI?
- Imagery data is not as indicative of category labels
- Inter-class similarity in preprocessed fMRI data
- Correlation matrix!

Correlation matrix perception data

Data averaged across all classes

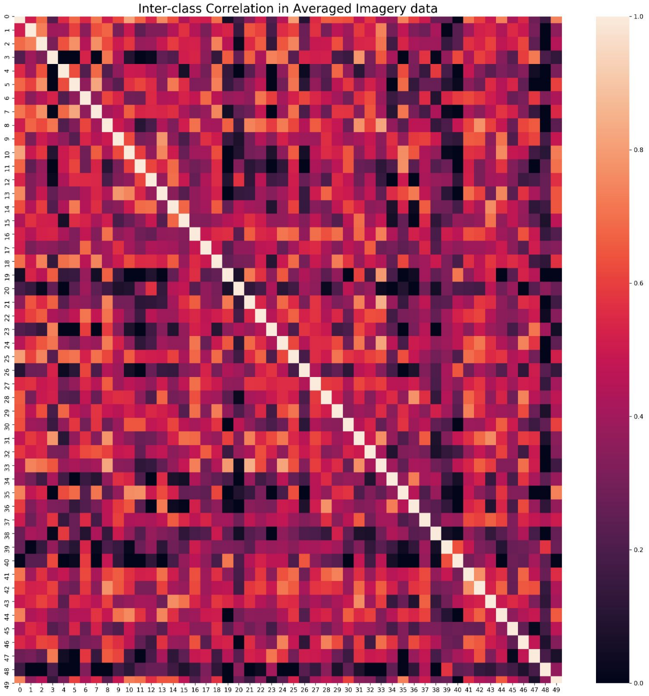


Individual data for all classes

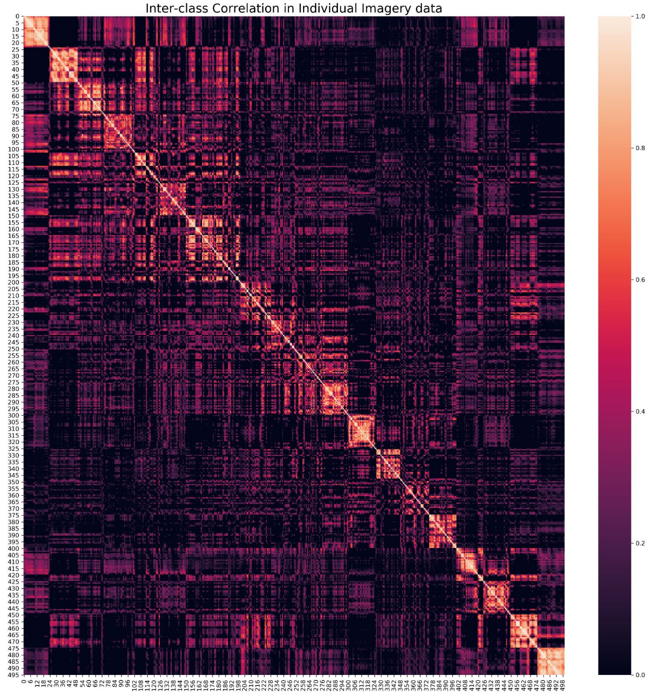


Correlation Matrix Imagery Data

Data averaged across all classes

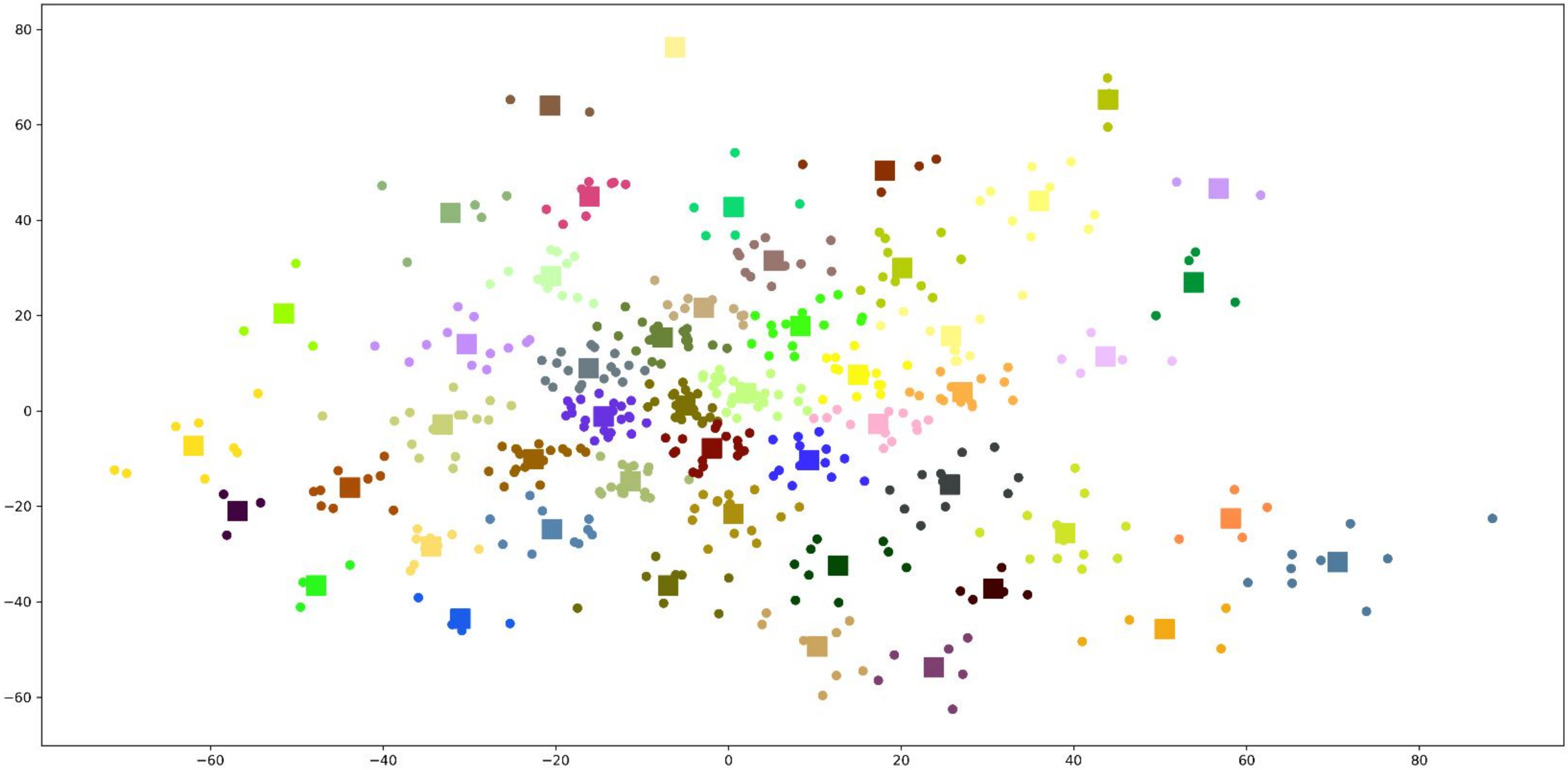


Individual data for all classes



Discussion (1)

- Further investigation on inter-class similarity
- Are training samples enough for learning?
- Applying K-means on preprocessed imagery fMRI data
- Analyzing pseudo and actual labels
- Use pseudo-labels assigned by K-means for training
- Model trained on imagery data using pseudo-labels gives: 53% accuracy



K-means clustering on preprocessed imagery fMRI data

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Discussion (2)

- Potential reason for inter-class similarity: Averaging volumes
- Model learns on raw fMRI without averaging on imagery data
- Most promising results are on raw fMRI data
    - Training on combined data and testing on imagery and perception
- Preserves accuracy
- Use preprocessing and not averaging to get better results

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Discussion (3)

- Prediction based on average features in [1]
- Try prediction using individual data points

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

Challenges and Future Work

Challenges

- Difficulty in training a model on imagery data
- Reproducing the results of the paper [1]
- Compute resources and processing time

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

Future Directions

- Use preprocessing steps on raw fMRI data (without averaging volumes)
- Increase data by combining data from multiple subjects
- Use the approach proposed in [1] for prediction on individual data
- Use fMRI data from different sources

[1] Horikawa, T., & Kamitani, Y. (2017). Generic decoding of seen and imagined objects using hierarchical visual features. Nature communications, 8(1), 1-15.

Thank You

Q&A