Visualizing Representational Dynamics with Multidimensional Scaling Alignment

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Abstract

Representational similarity analysis (RSA) has been shown to be an effective framework to characterize brain-activity profiles and deep neural network activations as representational geometry by computing the pairwise distances of the response patterns as a representational dissimilarity matrix (RDM). However, how to properly analyze and visualize the representational geometry as dynamics over the time course from stimulus onset to offset is not well understood. In this work, we formulated a pipeline to understand representational dynamics with RDM movies and Procrustes-aligned Multidimensional Scaling (pMDS), and applied it to neural recordings of macaque IT cortex. Our results suggest that the the multidimensional scaling alignment can genuinely capture dynamics of the category-specific representation spaces with multiple visualization possibilities, and that object categorization may be hierarchical, multi-staged, and oscillatory (or recurrent).

Method

- Representational Similarity Analysis
- Multidimensional Scaling (MDS)
- Generalized Procrustes Analysis (GPA)
- Procrustes-aligned MDS (pGPA):

We apply GPA to the MDS embeddings computed from RDMs at each time point, such that each frame is optimally aligned to all other time frames (Procrustes with only rotation and reflection, as the scaling contains information about how representations diverge and converge over time.)

Data

Macaque single-electrode recordings from the inferior bank of the ST segment [1], shown 100 grayscale object images from five different categories (faces, fruits, places, body parts and objects). RSA was further applied to select visually-responsive neurons and extract single-trial response patterns from the spike-density function. The recordings were truncated into sections of 821 ms (starting from 100ms before stimulus onset). RDM movies were generated using a sliding window of 21 ms with cross-validated spike rate distance (SRD) as the reponse-pattern dissimilarity measure.

RDM and MDS over time

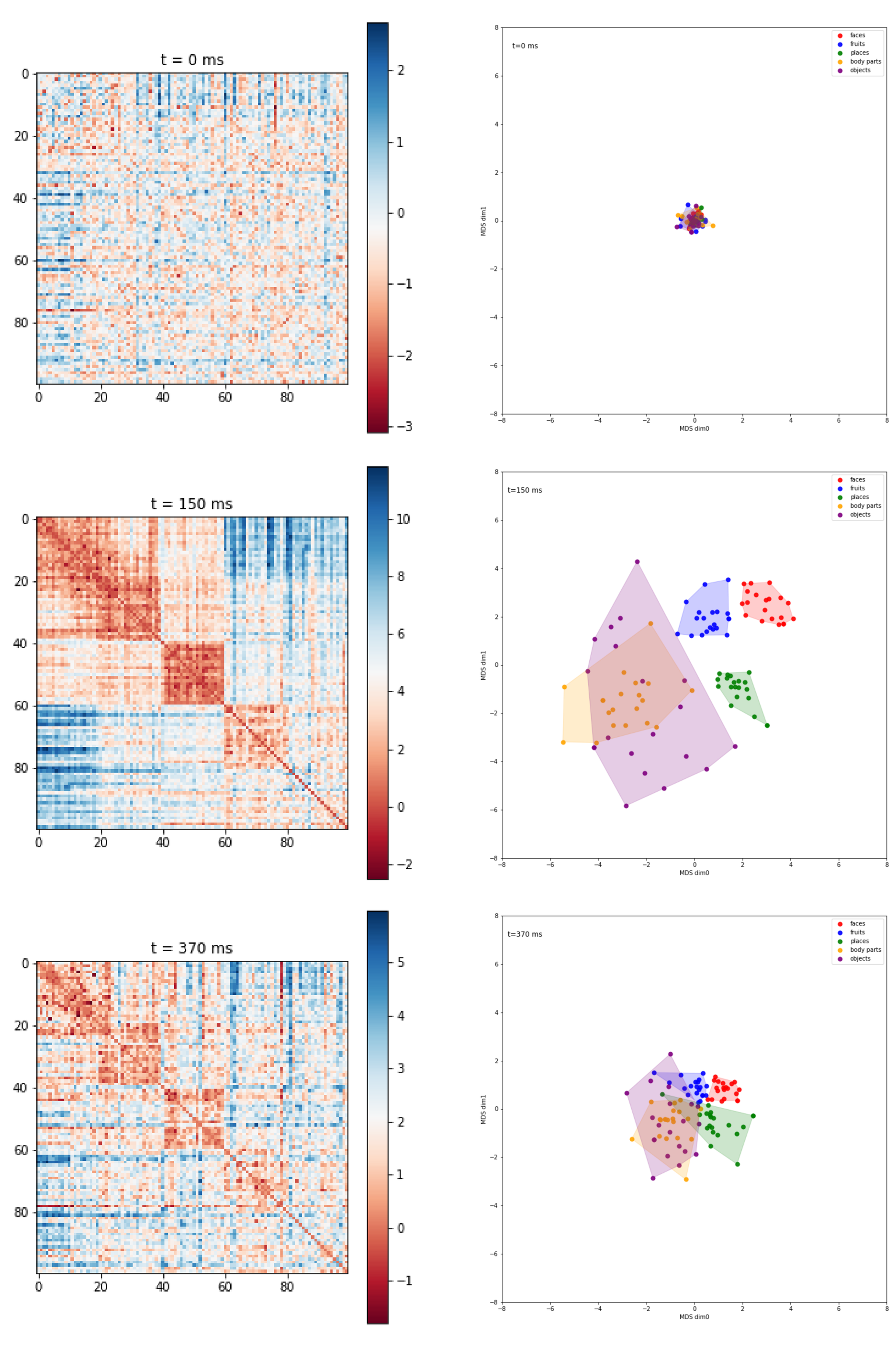

Figure 1: Comparison of RDM and MDS at example time points (0, 150, and 370ms after stimulus onset, stimulus offset at 370ms).

MDS alignment reveals smooth transition over time

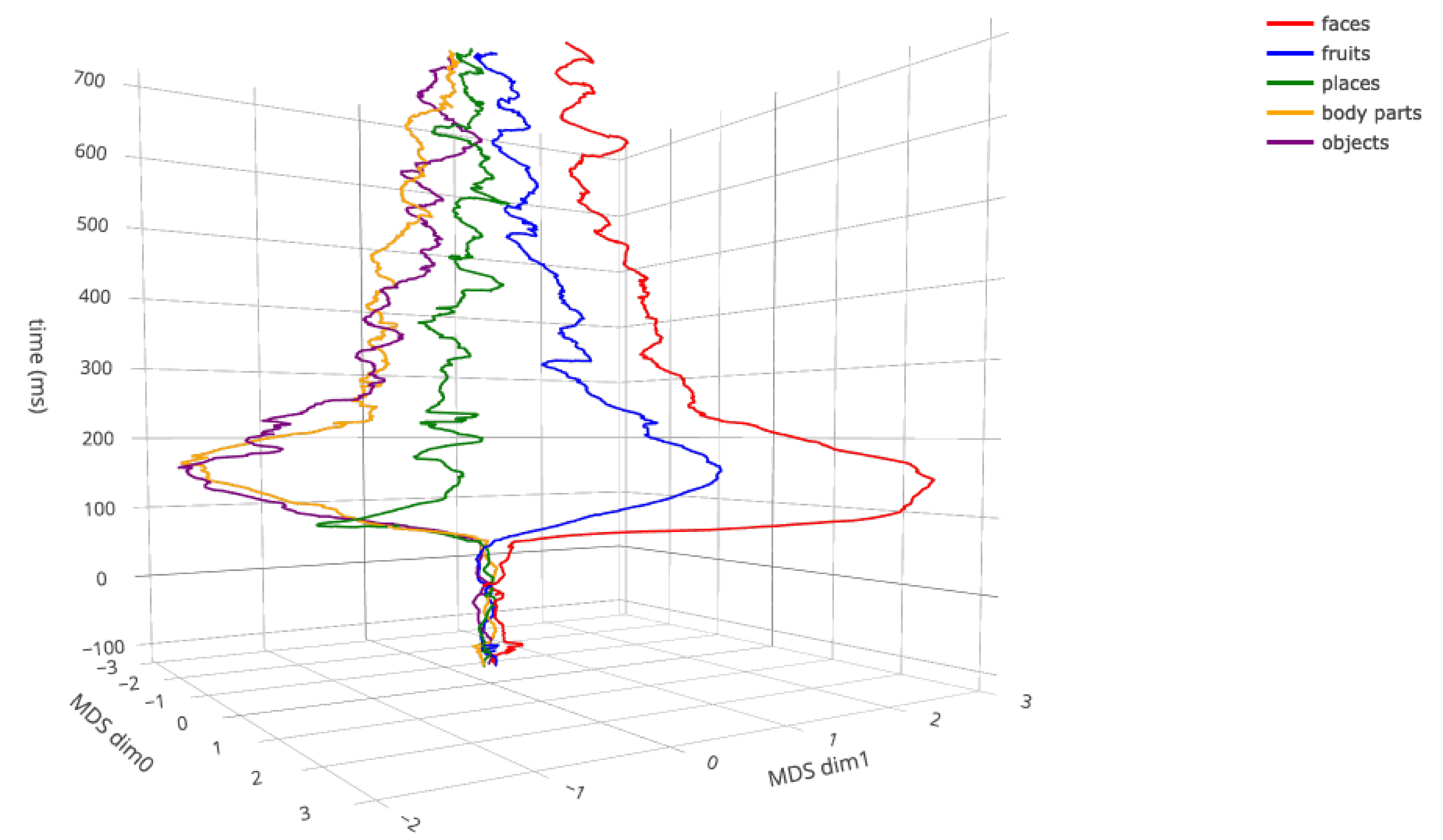

Figure 2: 3D plot of Procrustes-aligned MDS over time.

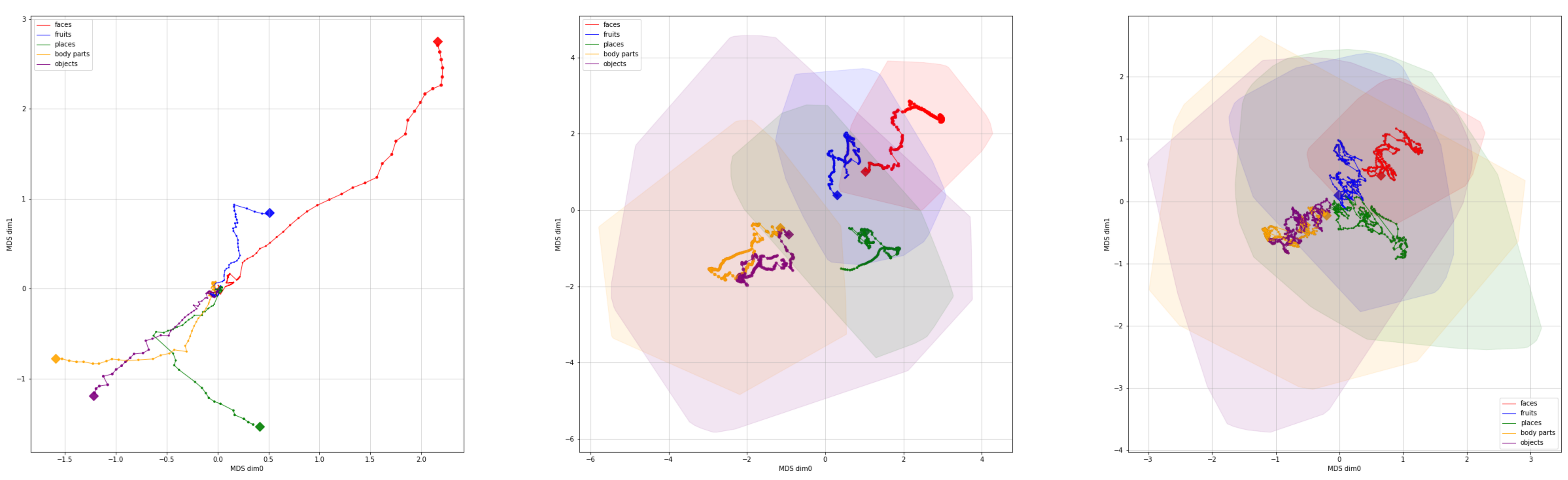

Figure 3: The trajectories of the category representations:(A) 0-100ms, (B) 100-300ms, (C) 300-800ms.

Hierarchical visual categorization with major stages

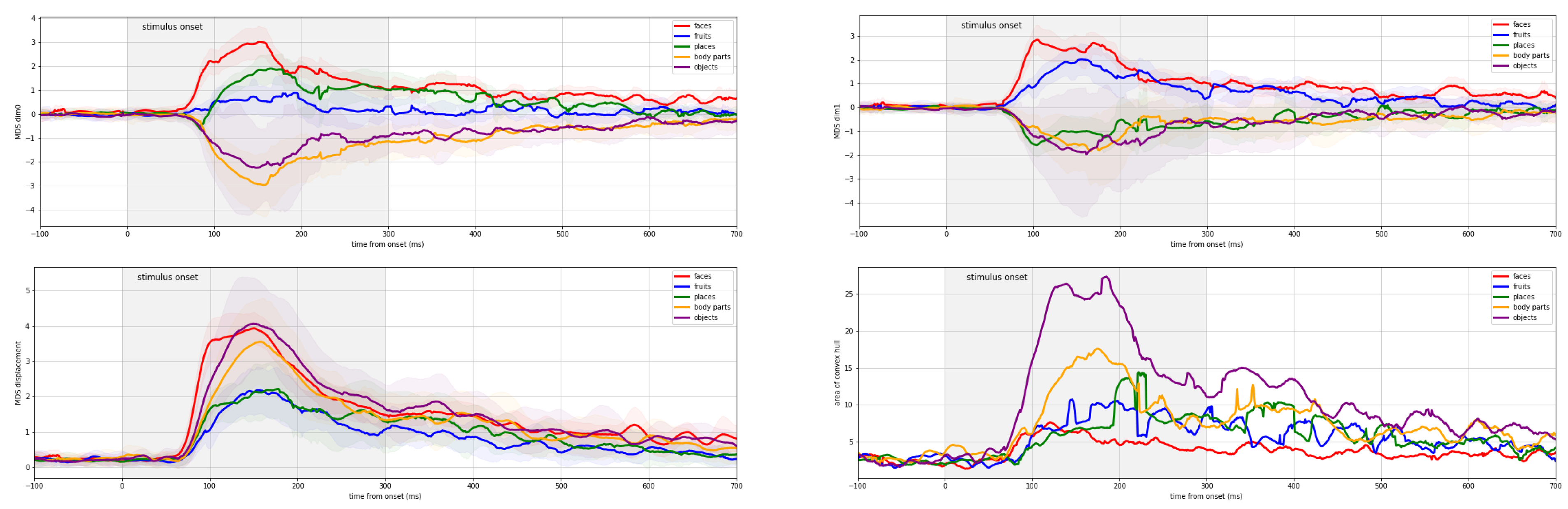

Figure 4: MDS over time: (A) dim0, (B) dim1, (C) the displacement from origin, (D) convex hull area.

Ongoing directions

- Compare to PCA-based methods and MDS with full temporal information.
- Investigate the oscillatory behaviors in the representational space.
- Explore recurrence in neuroimaging data of different brain regions and time scales.
- Visualize the representational dynamics of deep networks in computer vision tasks.

References

[1] Andrew H Bell, Nicholas J Malecek, Elyse L Morin, Fadila Hadj-Bouziane, Roger BH Tootell, and Leslie G Ungerleider. Relationship between functional magnetic resonance imaging-identified regions and neuronal category selectivity. *Journal of Neuroscience*, 31(34):12229–12240, 2011.