Sparse components distinguish visual pathways & their alignment to neural networks

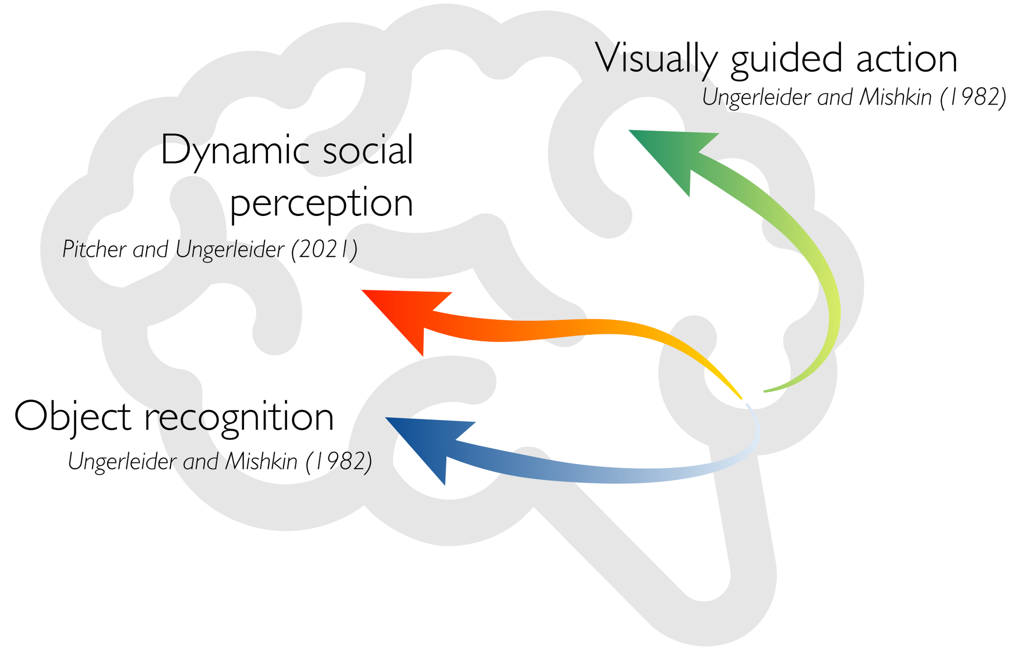
Ammar Marvi[1,2], Nancy Kanwisher[1,2], Meenakshi Khosla[3]

[1]Massachussetts Institute of Technology, Cambridge MA, USA
[2]McGovern Institute for Brain Research, Cambridge MA, USA
[3]University of California, San Diago, La Jolla CA, USA
Contact: amarvi@mit.edu

Original design by Vivian C. Paulun

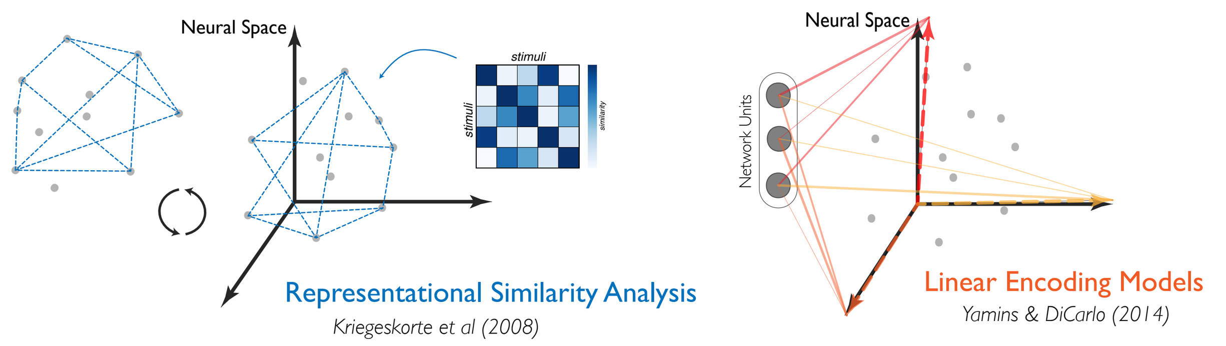
BACKGROUND

Extensive evidence suggests three functionally distinct pathways in the human visual cortex



yet

Using standard metrics of alignment, DNNs trained for object recognition capture responses in the three proposed pathways similarly well, suggesting that they share a similar representational geometry



Measures of representational alignment fall into two categories: stimulus-by-stimulus comparisons of population-level similarity (left) and explicit mappings of neural dimensions (right) *Sucholutsky et al (2023)*

QUESTIONS

What distinguishes the representations and computations of the ventral, dorsal, and lateral pathways of visual cortex?

Why do standard metrics of alignment to deep neural networks (DNN) often fail to detect these differences?

METHODS

Data-driven Analysis

In the manner of *Khosla et al (2022)* & *Norman-Haignere et. al (2015)*

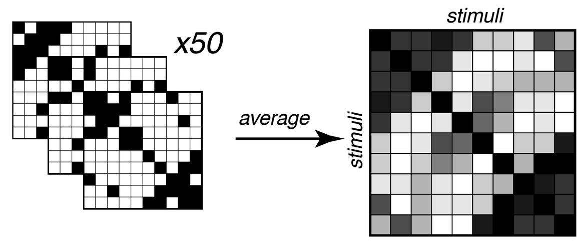
We first applied matrix factorization to identify dominant components of the neural response in the Natural Scenes Dataset*, separately for the dorsal, lateral, and ventral pathways

Next we applied the same method to identify components in DNN activations

*Allen et al (2022)

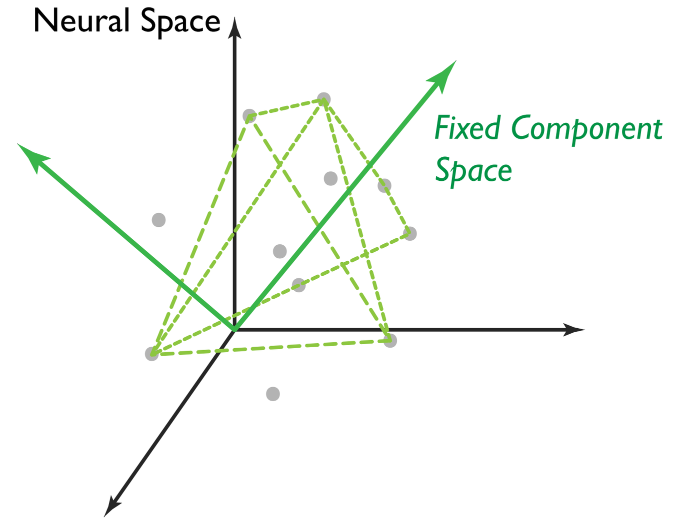
Measuring Alignment

In addition to standard alignment metrics, we introduce and assess ***Sparse Component Alignment***, a population-level measure of similarity that respects the native axes of representation



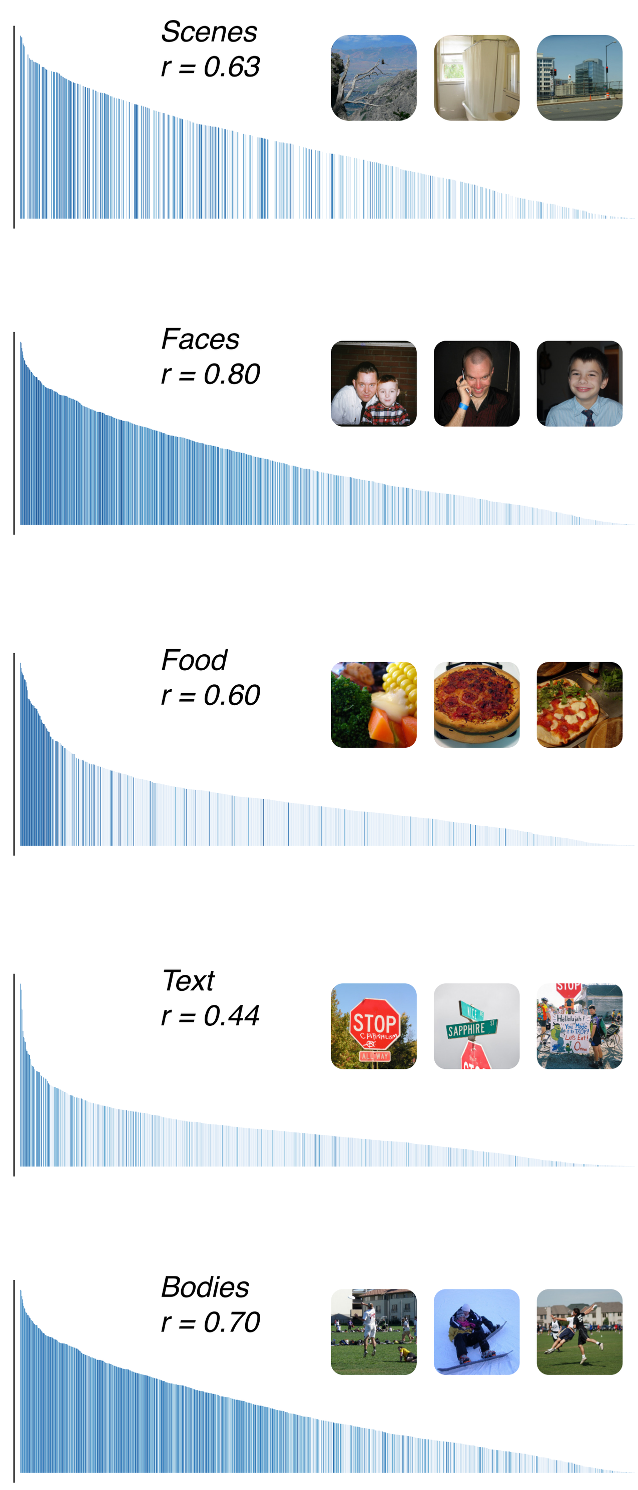
How often do pairs of images share the same dominant component (ie. ***axis of neural tuning****)?*

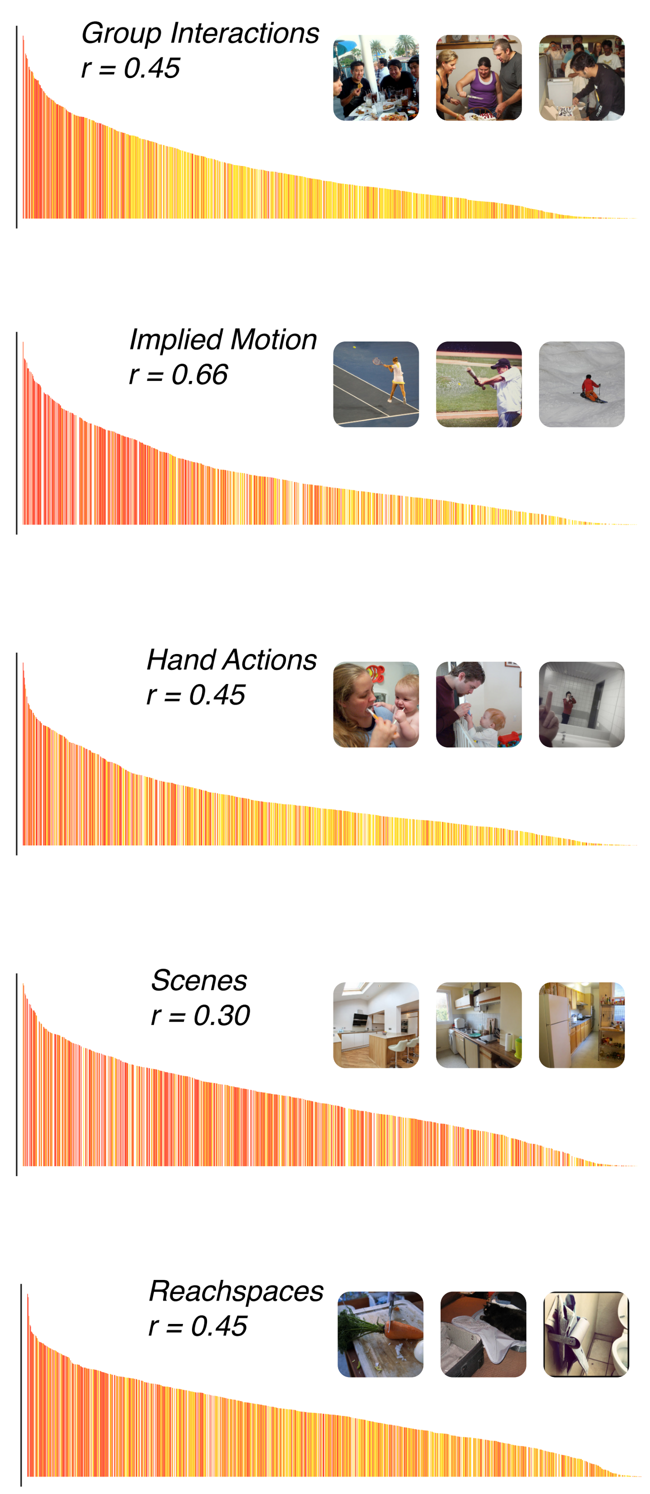
Resulting geometry is axis-sensitive (ie. __not__ rotationally invariant)



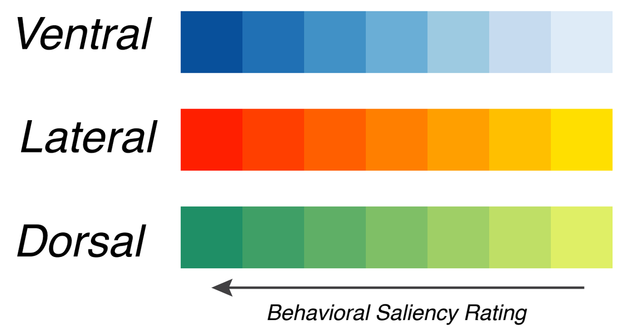
Khosla et al (2024)

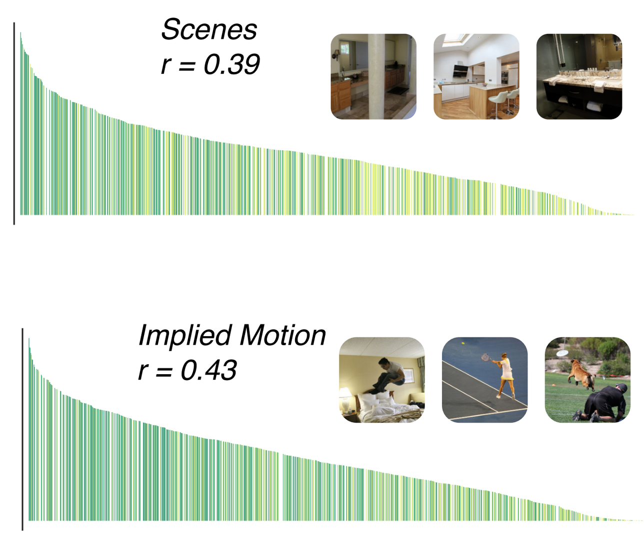
COMPONENT PROFILES



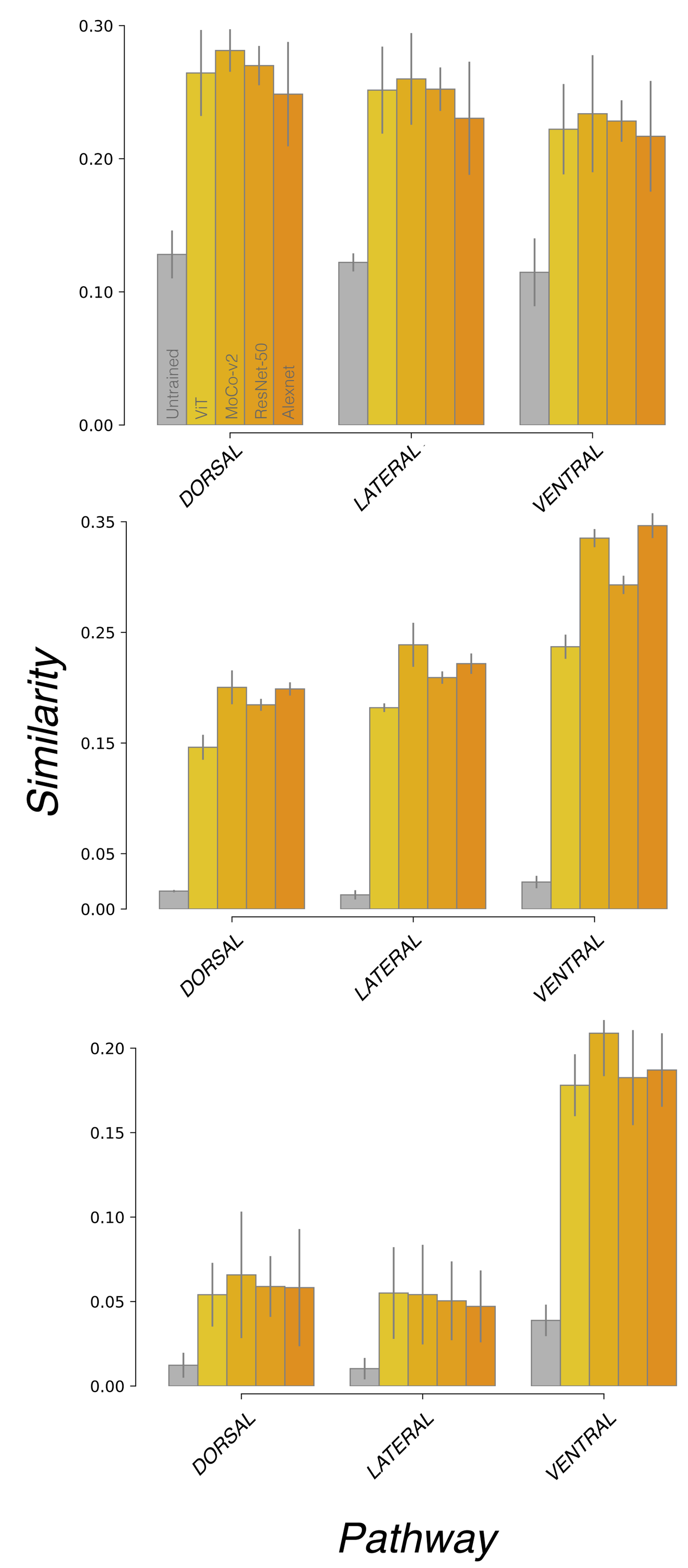


Qualitative examination of ventral, lateral, and dorsal components reveals a handful of differential selectivities with varying levels of interpretability





NETWORK ALIGNMENT



Linear Encoding Models

A linear readout suggests similar predictivity of visual representattions across all three pathways

Representational Similarity Analysis

Intermediate discriminability, with slightly higher alignment to ventral than either dorsal or lateral pathways

Sparse Component Alignment

Markedly higher alignment between representations of DNNs and the ventral pathway

DISCUSSION

Dominant components distinguish representations in the ventral, dorsal, and lateral pathways of visual cortex

We introduce SCA, an axis-dependent measure of representational alignment

Along a native axis of tuning, networks may be more aligned to the ventral than either dorsal or lateral pathways

Allen, E. J., St-Yves, G., Wu, Y., Breedlove, J. L., Prince, J. S., Dowdle, L. T., Nau, M., Caron, B., Pestilli, F., Charest, I., Hutchinson, J. B., Naselaris, T., & Kay, K. (2022). A massive 7T fMRI dataset to bridge cognitive neuroscience and artificial intelligence. Nature neuroscience
Finzi, D., Margalit, E., Kay, K., Yamins, D. L. K., Grill-Spector, K. (2023). A single computational objective drives specialization of streams in visual cortex. bioRxiv preprint
Khosla, M., Williams, A., McDermott, J., Kanwisher, N. (2024). Privileged representational axes in biological and artificial neural networks. In prep
Khosla, M., Murty, N. A. R., & Kanwisher, N. (2022). A highly selective response to food in human visual cortex revealed by hypothesis-free voxel decomposition. Current Biology(2015)
Khosla, M., & Williams, A. H. (2023). Soft Matching Distance: A metric on neural representations that captures single-neuron tuning. arXiv preprint
Kriegeskorte, N., Mur, M., & Bandettini, P. (2008). Representational similarity analysis - connecting the branches of systems neuroscience. Frontiers in systems neuroscience
Norman-Haignere, S., Kanwisher, N.G., McDermott, J.H.: Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition. Neuron (2015)
Pitcher, D., & Ungerleider, L. G. (2021). Evidence for a Third Visual Pathway Specialized for Social Perception. Trends in cognitive sciences
Sucholutsky, I., Muttenthaler, L., Weller, A., Peng, A., Bobu, A., Kim, B., ... & Griffiths, T. L. (2023). Getting aligned on representational alignment. arXiv preprint
Ungerleider LG & Mishkin M 1982. Two cortical visual systems In Ingle DJ, Goodale MA & Mansfield RJW (Eds.) Analysis of Visual Behavior
Yamins, D. L., Hong, H., Cadieu, C. F., Solomon, E. A., Seibert, D., & DiCarlo, J. J. (2014). Performance-optimized hierarchical models predict neural responses in higher visual cortex. Proceedings of the National Academy of Sciences of the United States of America