A common high-dimensional linear model of representational spaces in human cortex

Jim Haxby
Center for Cognitive Neuroscience, Dartmouth College
Center for Mind/Brain Sciences (CIMeC), University of Trento

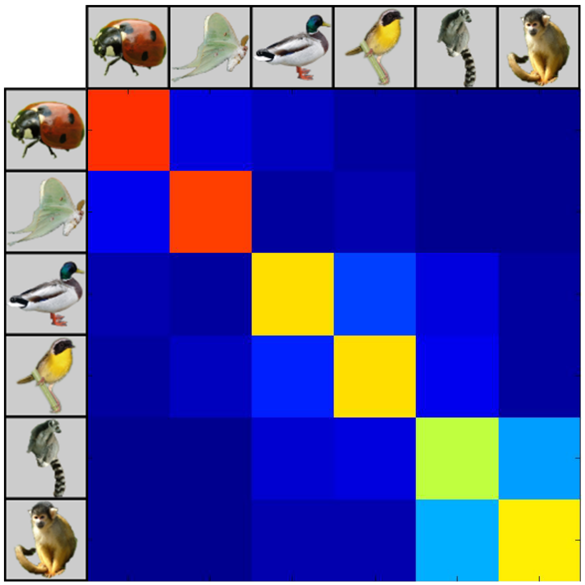
Supported by NSF CRCNS German-US Collaboration

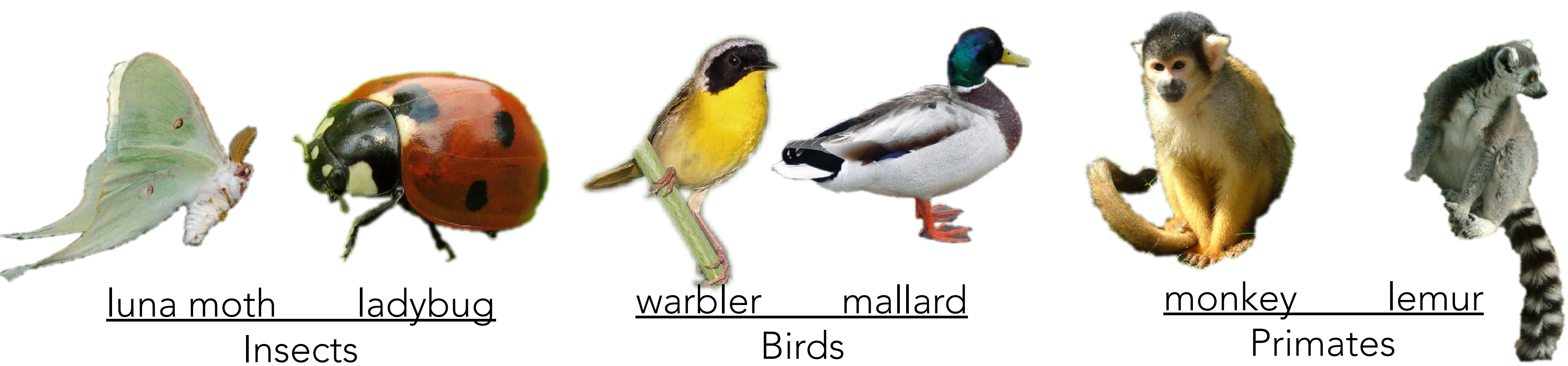
Modeling representational spaces in human cortex

- MVPA – decoding population responses from fMRI
- Hyperalignment – building a model bases on tuning functions that are shared across brains
- HyperCortex – proposal for a functional atlas based on a common, high-dimensional model of representational spaces in human cortex

MVPA:
Decoding fine-grained distinctions distinctions from fine-scale patterns

Within-subject classification
(new model for each subject)

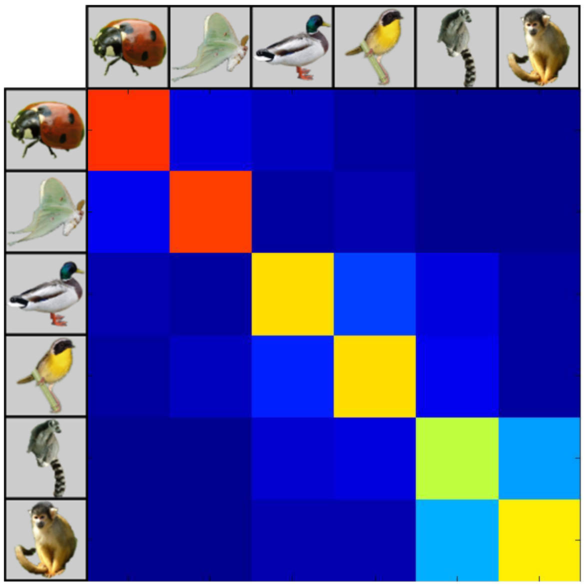




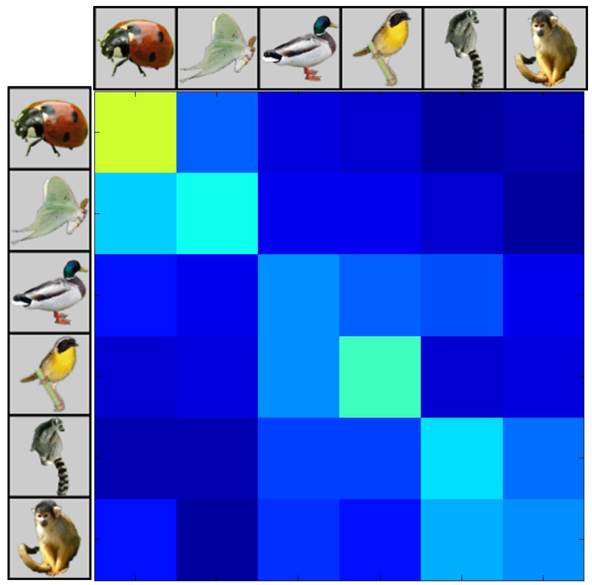
(Haxby et al. 2011; Connolly et al. 2012)

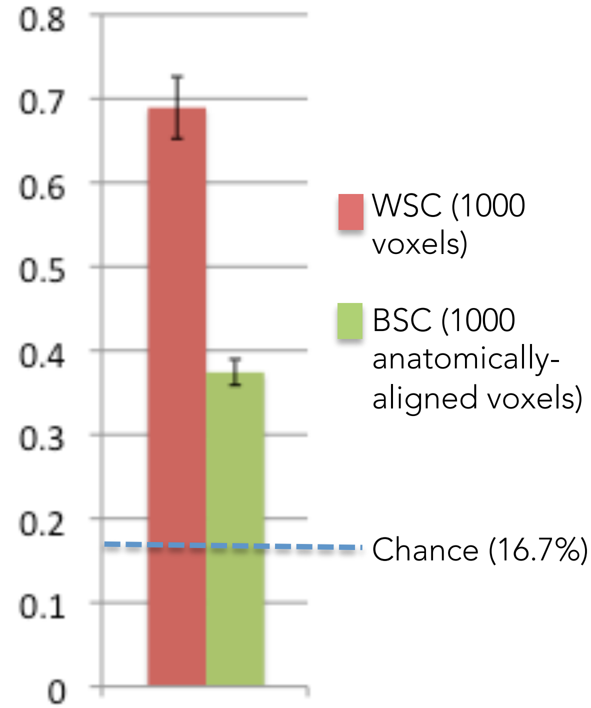
MVPA – The problem:
Fine-scale patterns are individual-specific

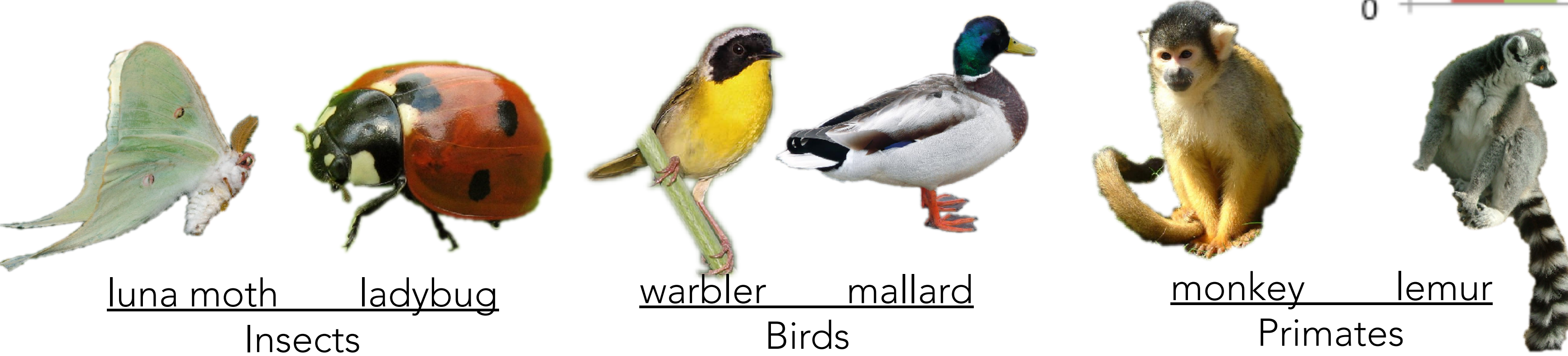
Within-subject classification
(new model for each subject)



Between-subject classification
(common model based on anatomy)

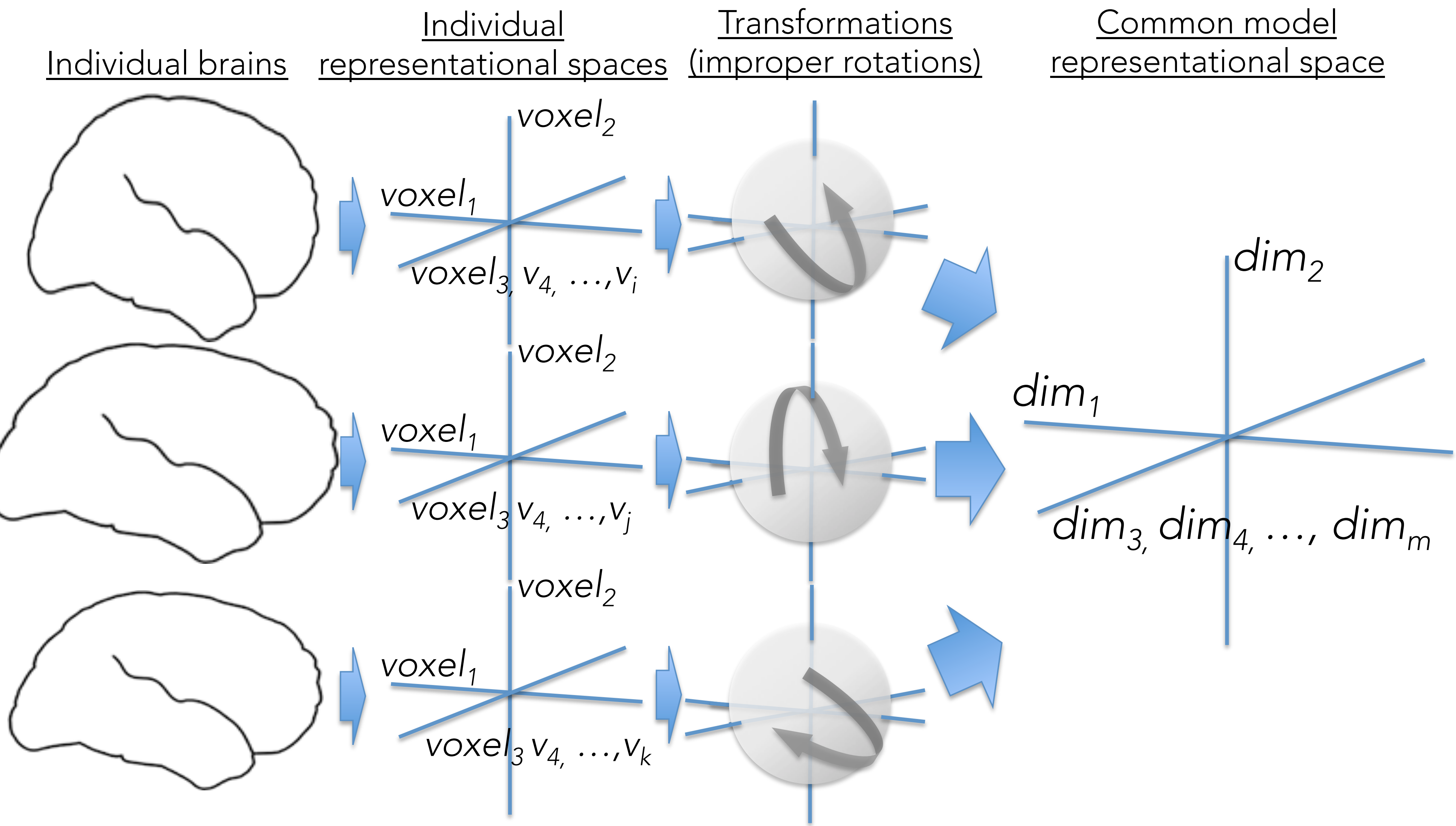




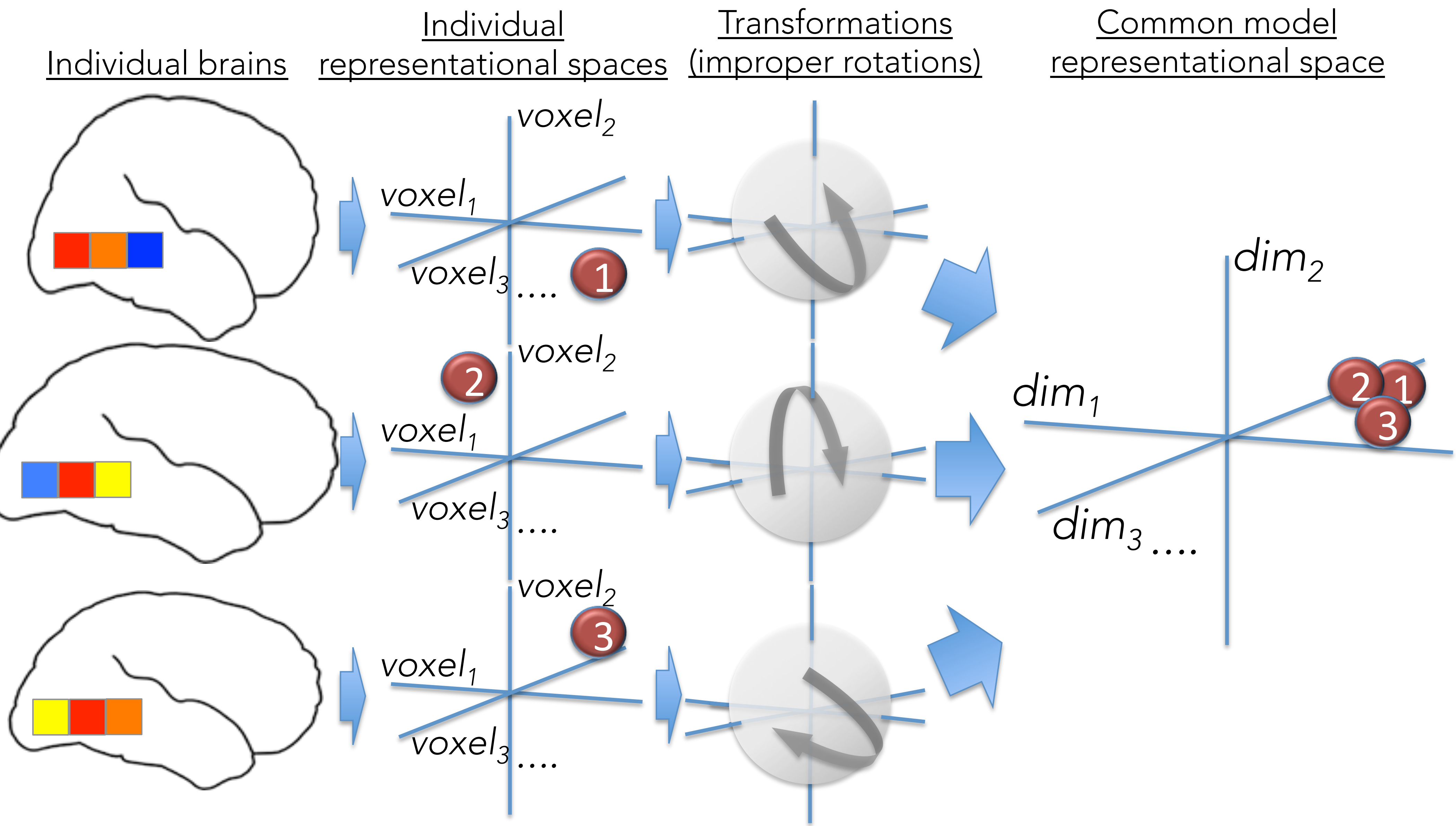


(Haxby et al. 2011; Connolly et al. 2012)

Hyperalignment:
Individual representational spaces <=> common representational space



Hyperalignment:
Individual representational spaces <=> common representational space



Hyperalignment parameters are estimated from responses recorded during movie viewing

Raiders of the Lost Ark

Life on Earth

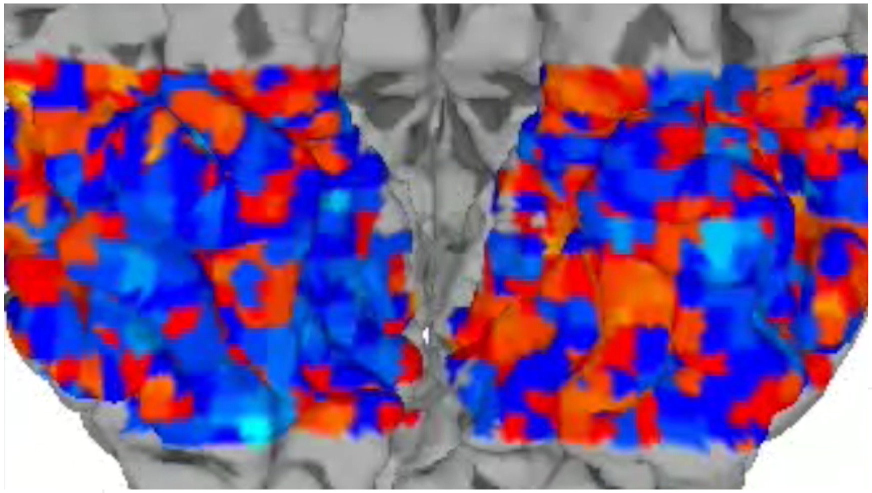
The Wire

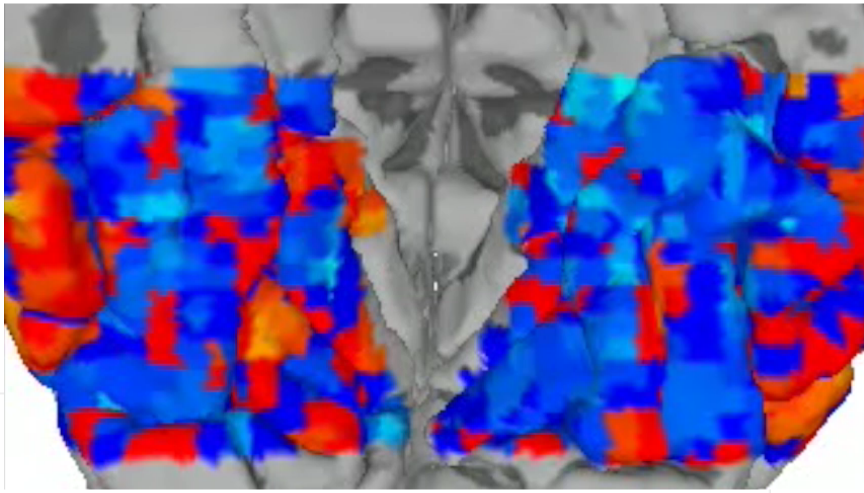
Broad sampling of a neural representational space with a movie

S1

S2

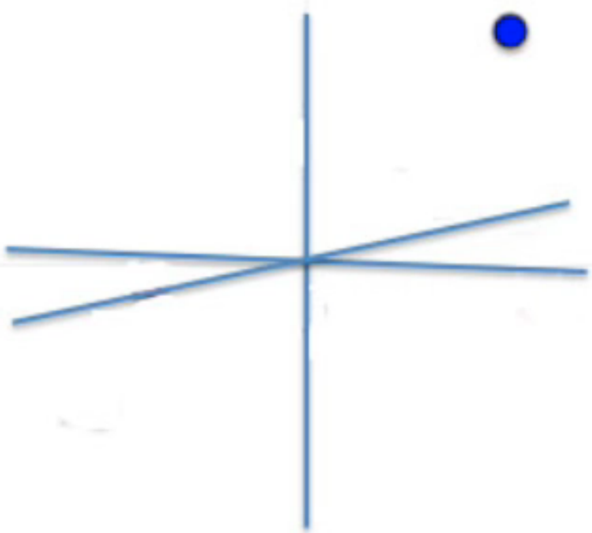
Response patterns in cortex

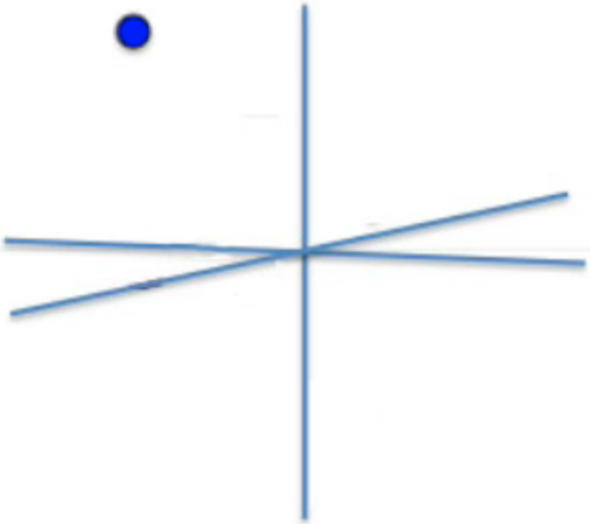


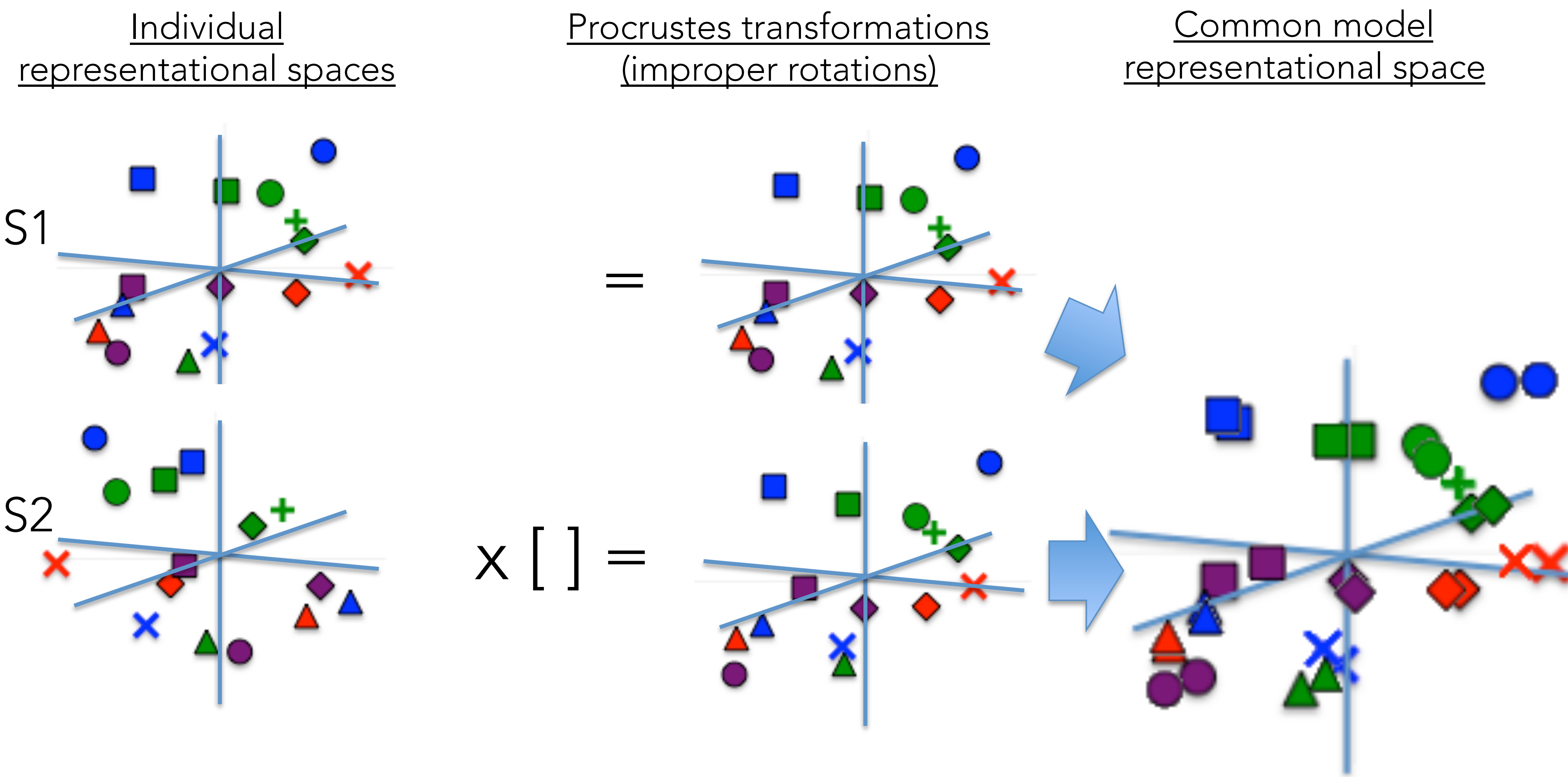


15 response pattern vectors in individual 3D representational spaces

(full exp't has >2600 vectors in >50,000D space)



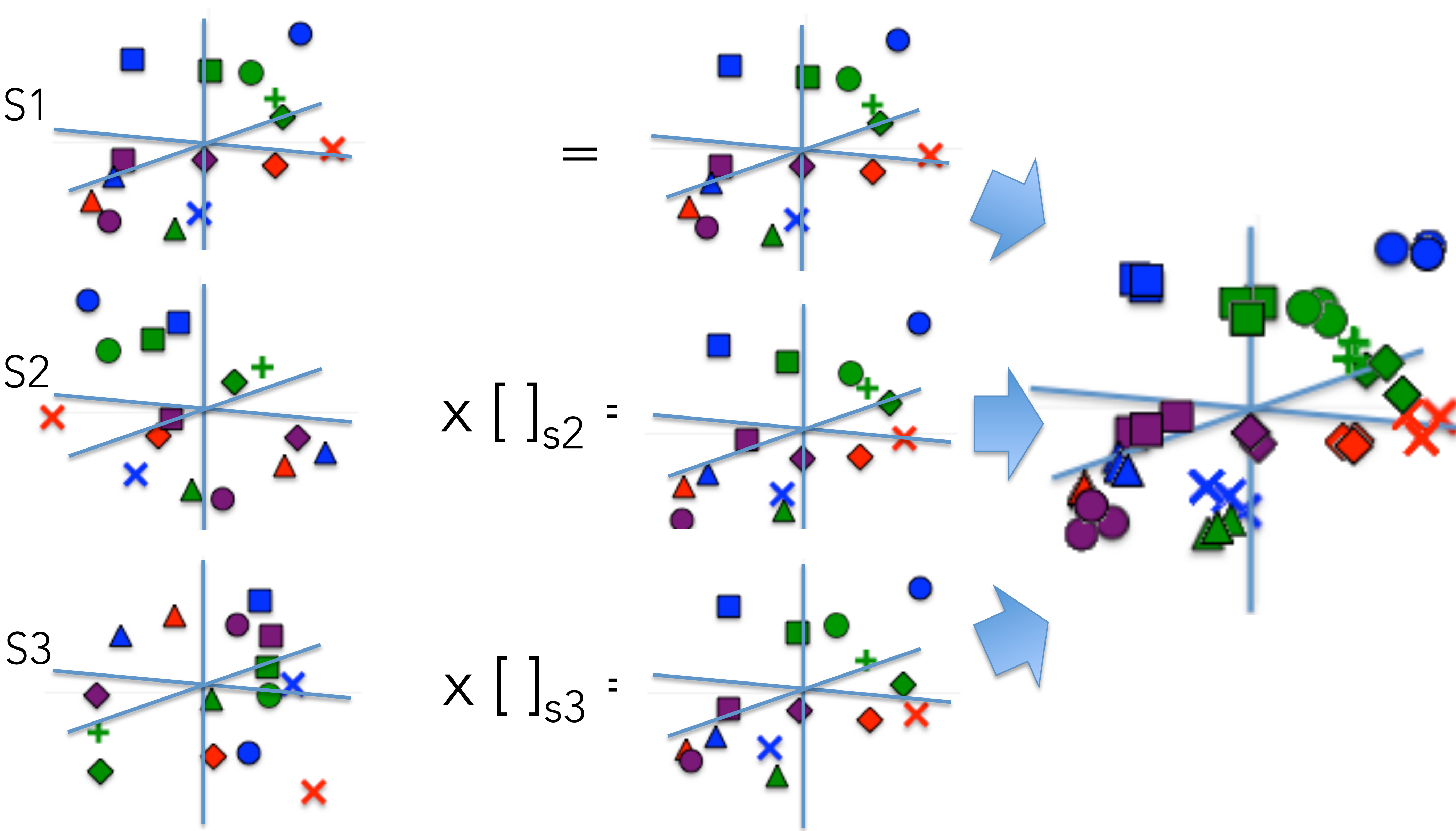



Individual
representational spaces
Procrustes transformations
(improper rotations)
Common model
representational space
S1
S2
=
x [ ] =

Individual representational spaces

Procrustes transformations (improper rotations)

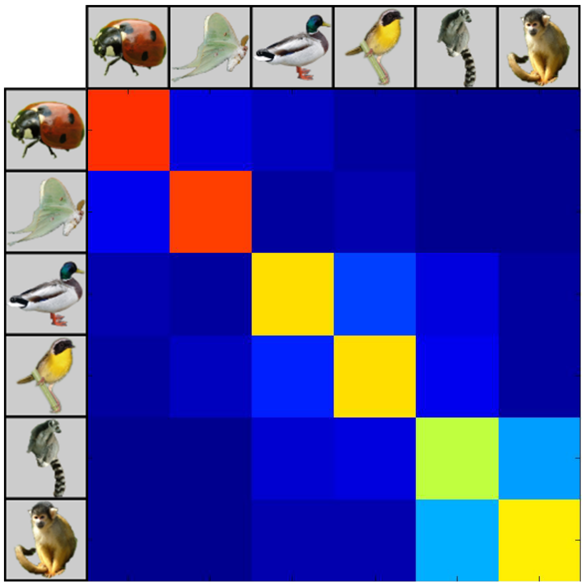
Common model representational space



MVPA – The problem:
Fine-scale patterns are individual-specific

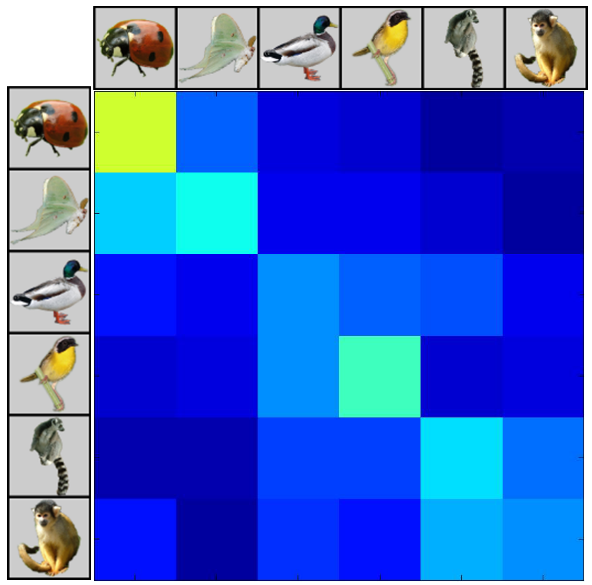
Within-subject classification

new model for each subject

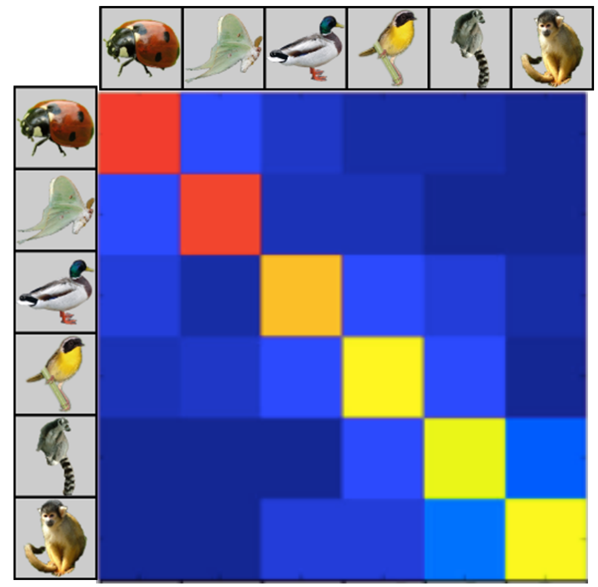


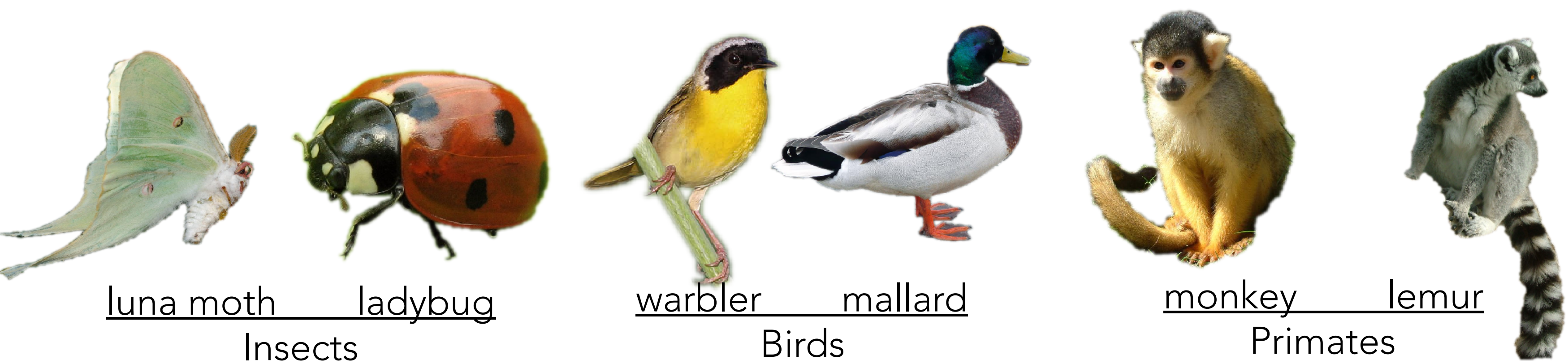
Between-subject classification

common model based on anatomy



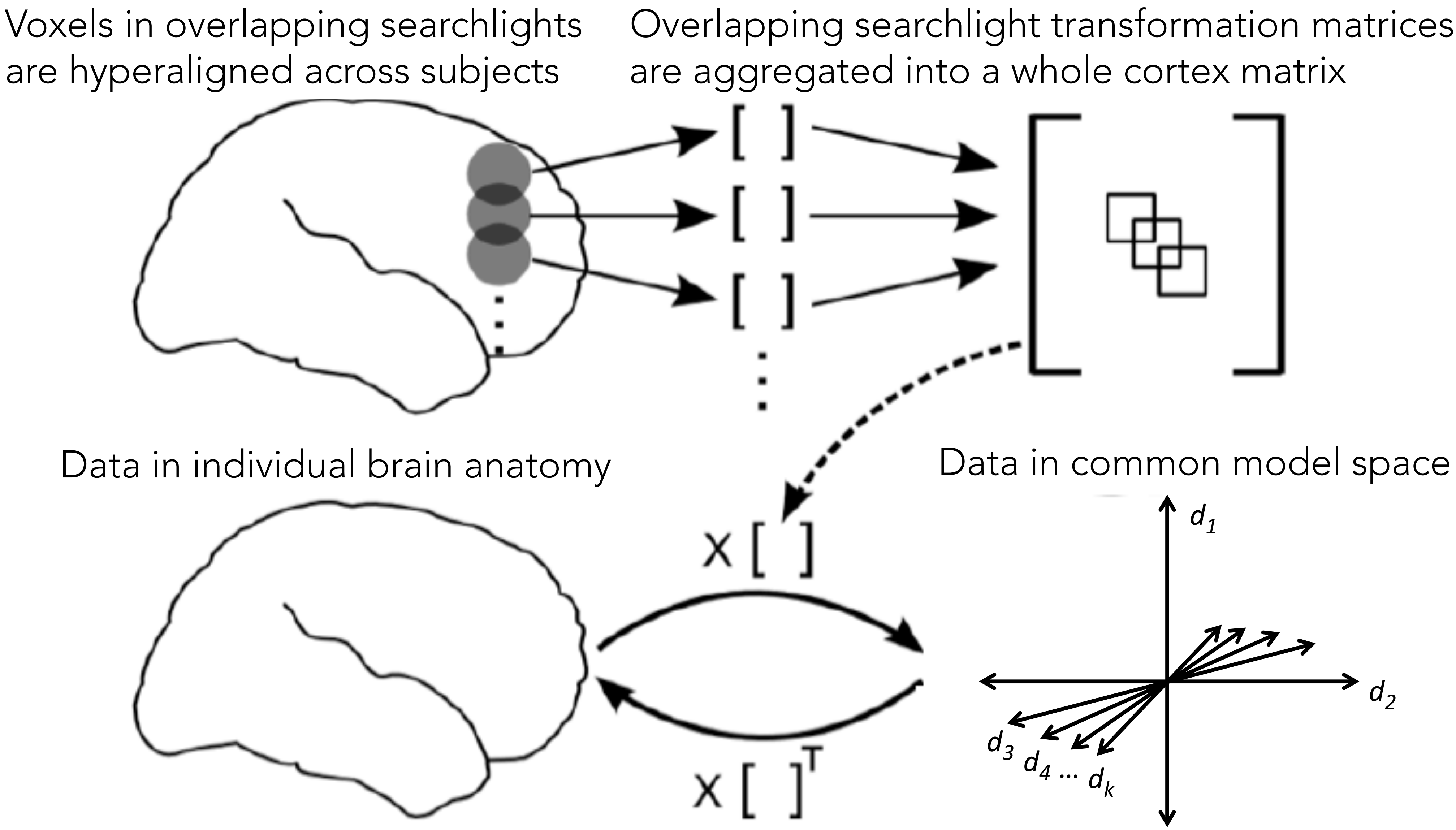
common model using movie-based hyperalignment parameters





(Haxby et al. 2011; Connolly et al. 2012)

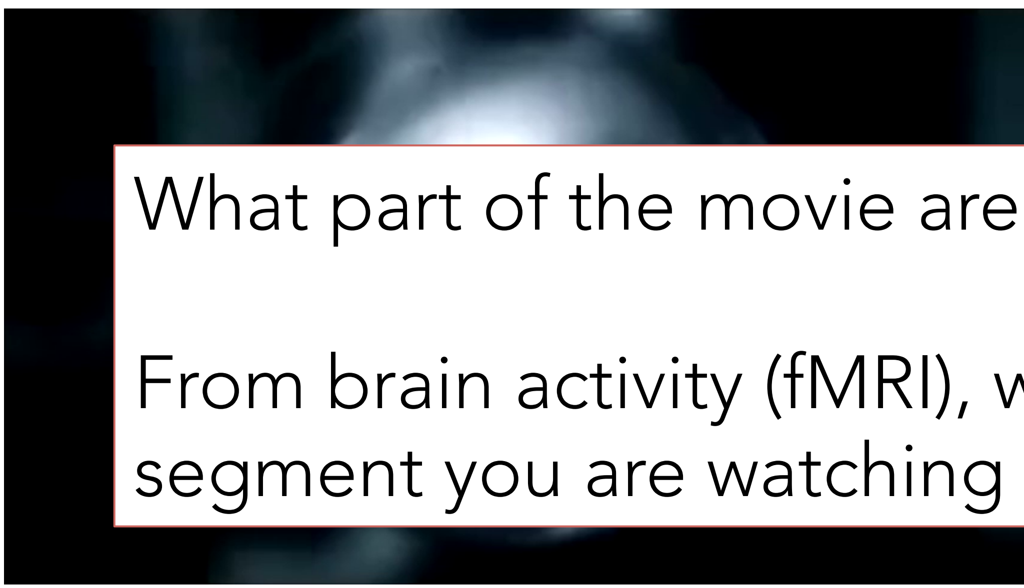
Modeling representational spaces in all human cortex with searchlight hyperalignment

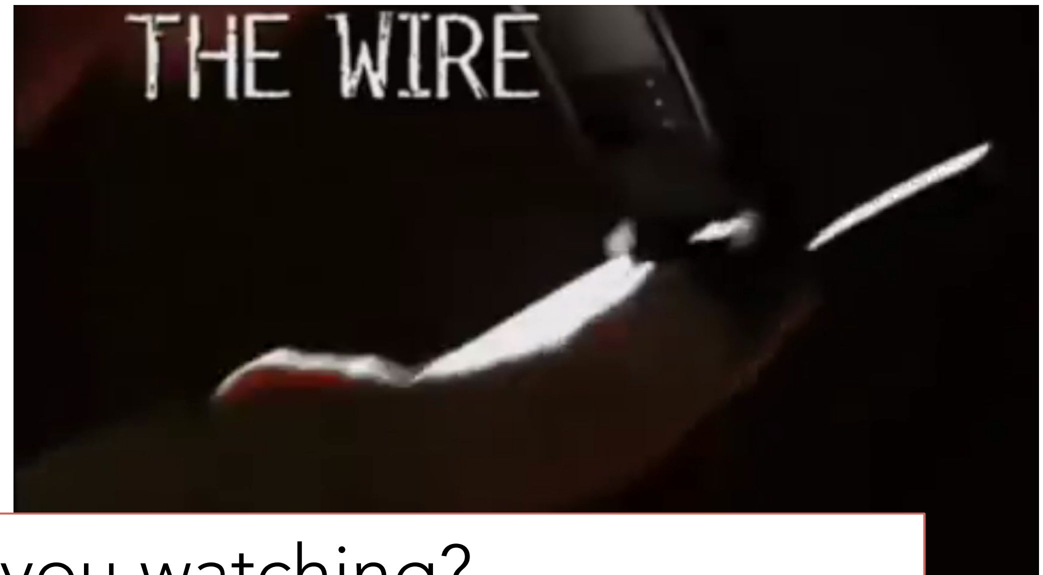


Hyperalignment parameters are estimated from responses recorded during movie viewing

Raiders of the Lost Ark

Life on Earth



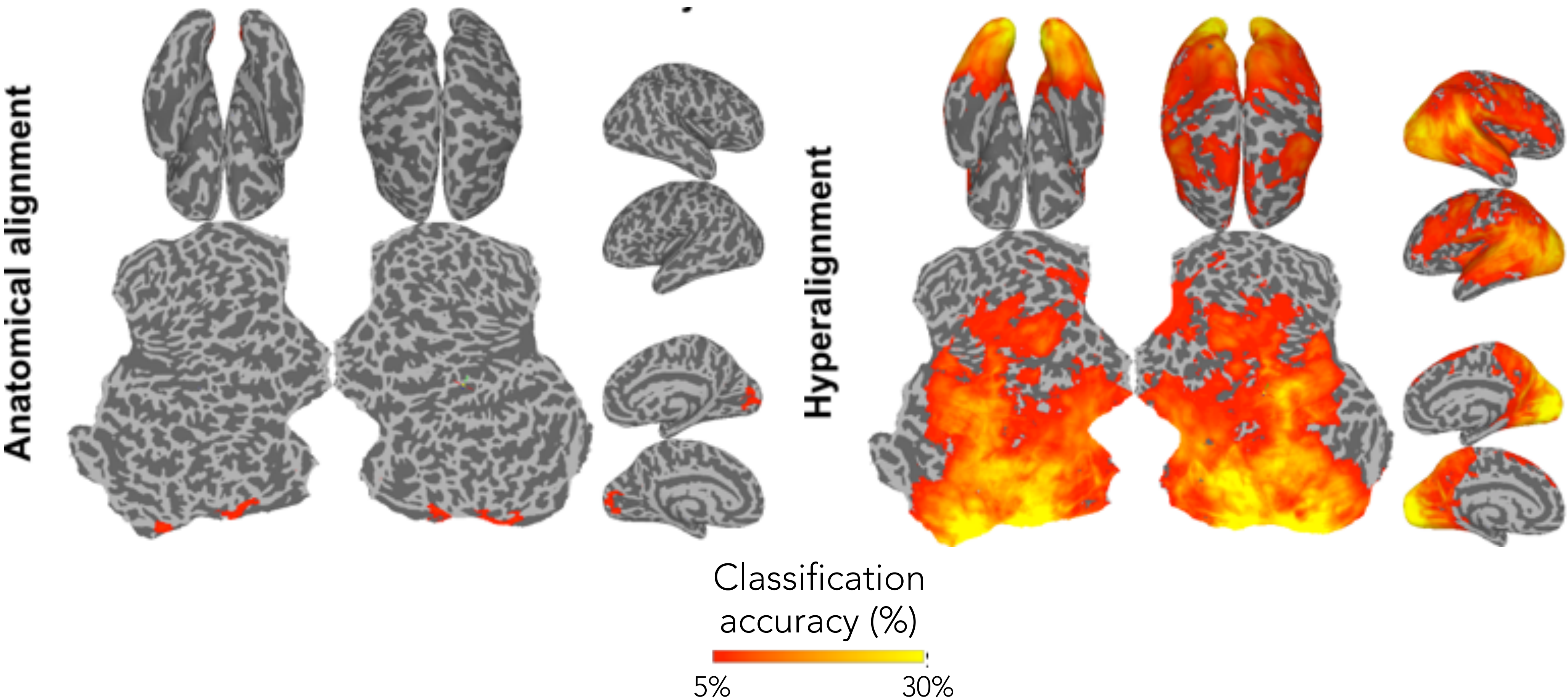


/ire

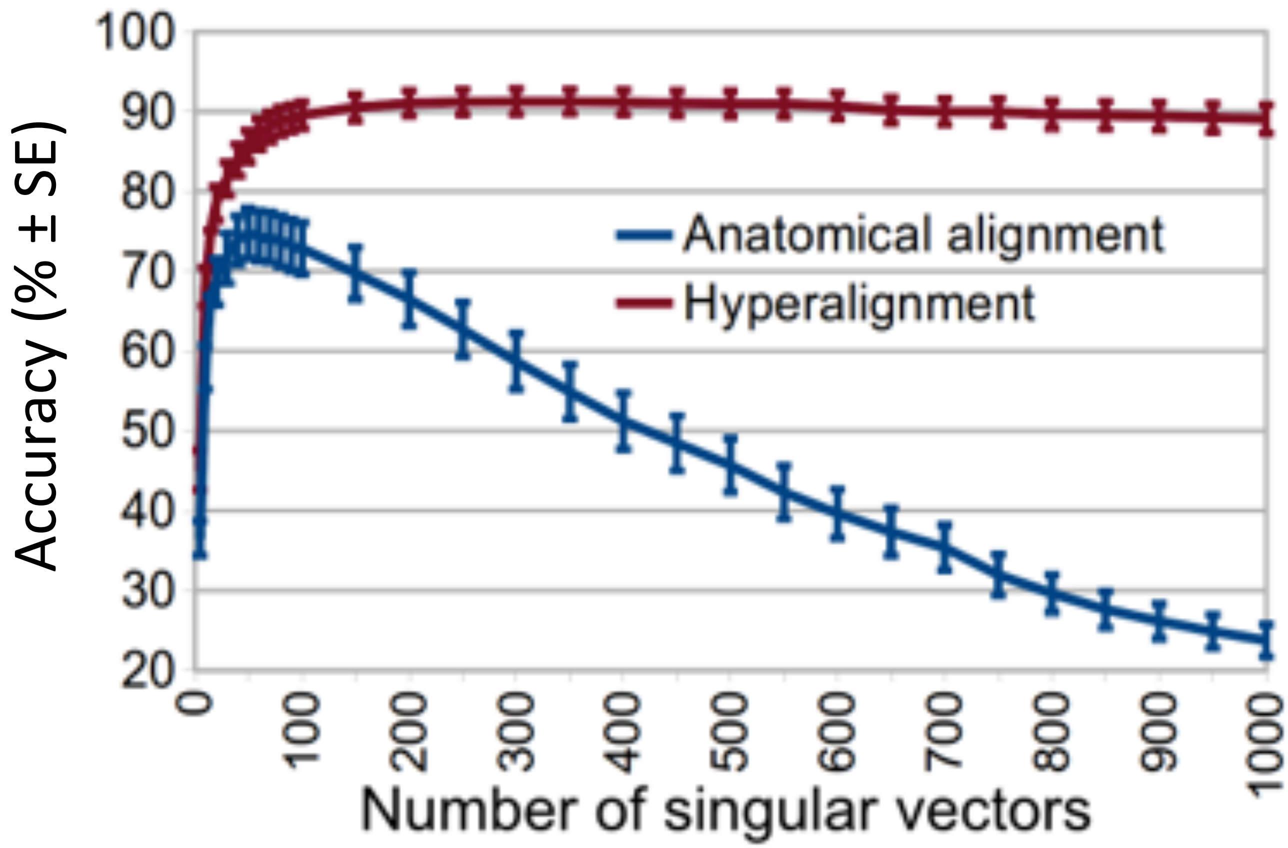
What part of the movie are you watching?

From brain activity (fMRI), we can decode which 15 sec segment you are watching with >90% accuracy

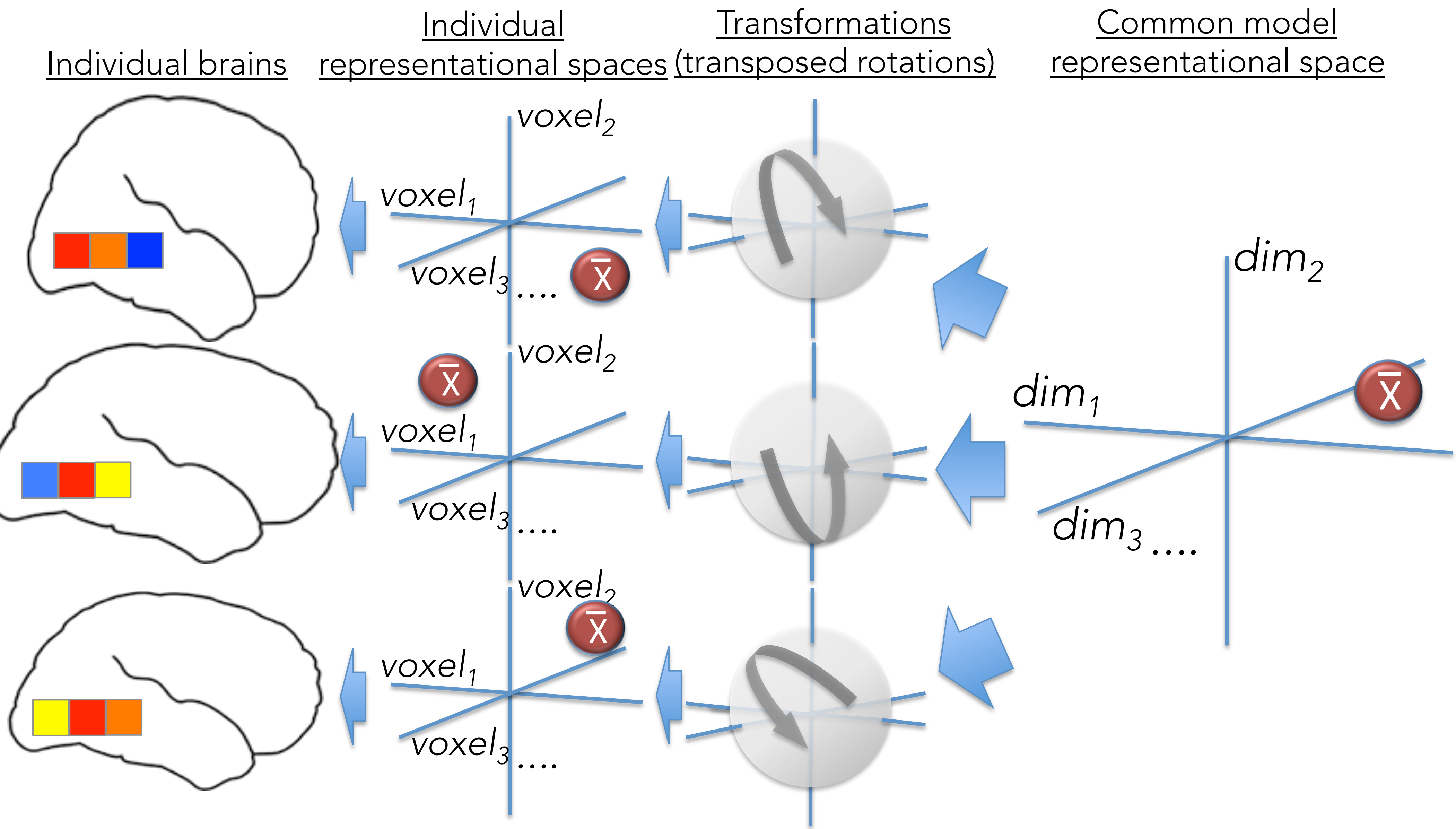
Whole-brain hyperalignment affords between-subject classification of 15 s movie time segments in occipital, temporal, parietal, and frontal cortices



Whole-brain hyperalignment increases between-subject classification of 15 s movie time segments for the whole brain (after SVD dimensionality reduction)

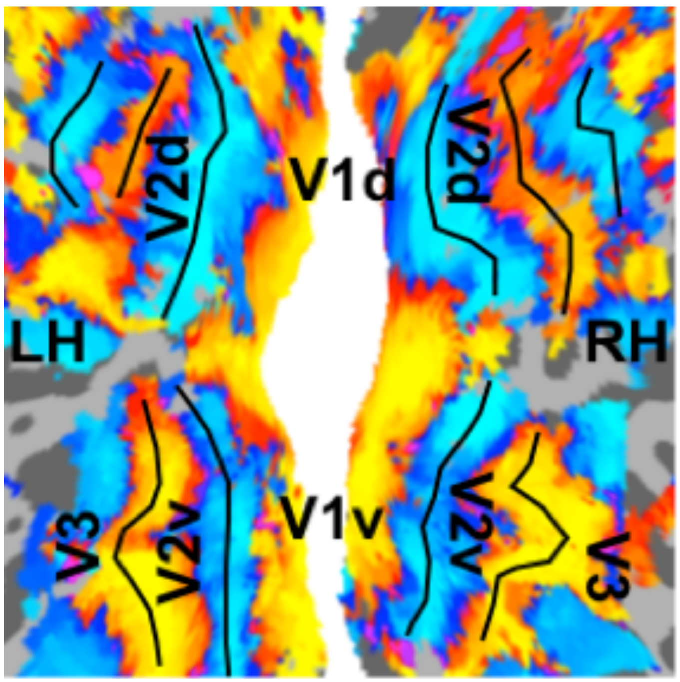


Projecting group data from common model space into individual subject's anatomy

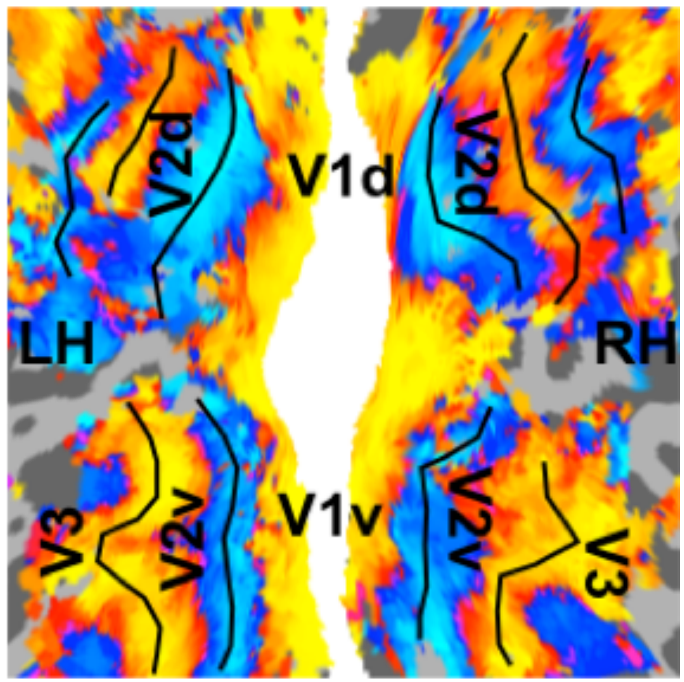


Mapping retinotopy by projecting other subjects' polar angle maps into a different subject's occipital topography

Polar angle from subject's own retinotopy data



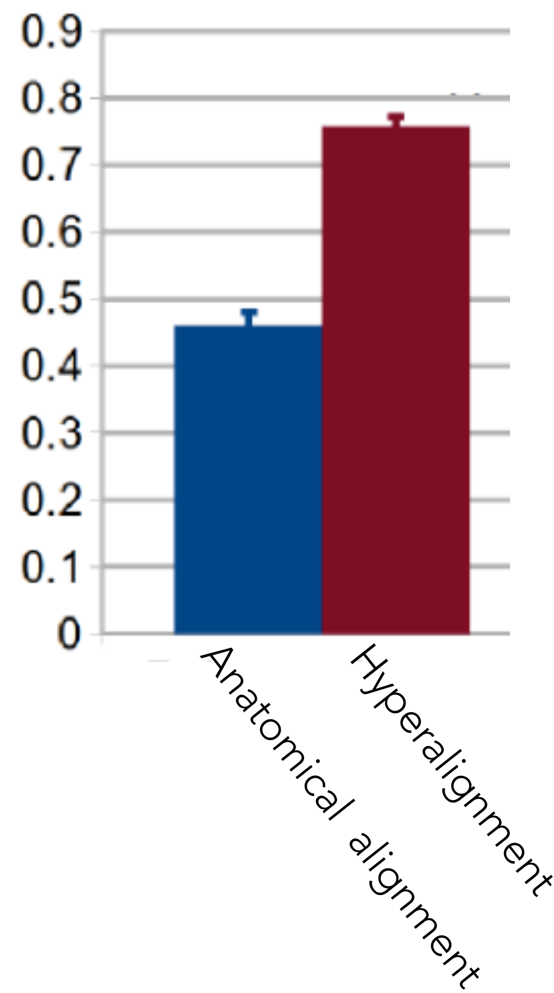
Polar angle from other subjects' retinotopy data



Horizontal meridian

Vertical meridian

Correlation between measured and projected



Can a high-dimensional common model of human cortex be leveraged to build a new type of functional brain atlas?

Brain atlases are an essential tool for functional neuroimaging research

- Provide a common basis for reporting results
- Allow comparisons across studies affording
  - Replication testing
  - Interpretation
  - Meta-analysis
- More generally, afford accrual of knowledge about the functional organization of the human brain

Functional Brain Atlas: Current State of the Art
Results are reported in tables with anatomical x,y,z coordinates

Table 1. Group-Average Activation for the Biological Motion Display

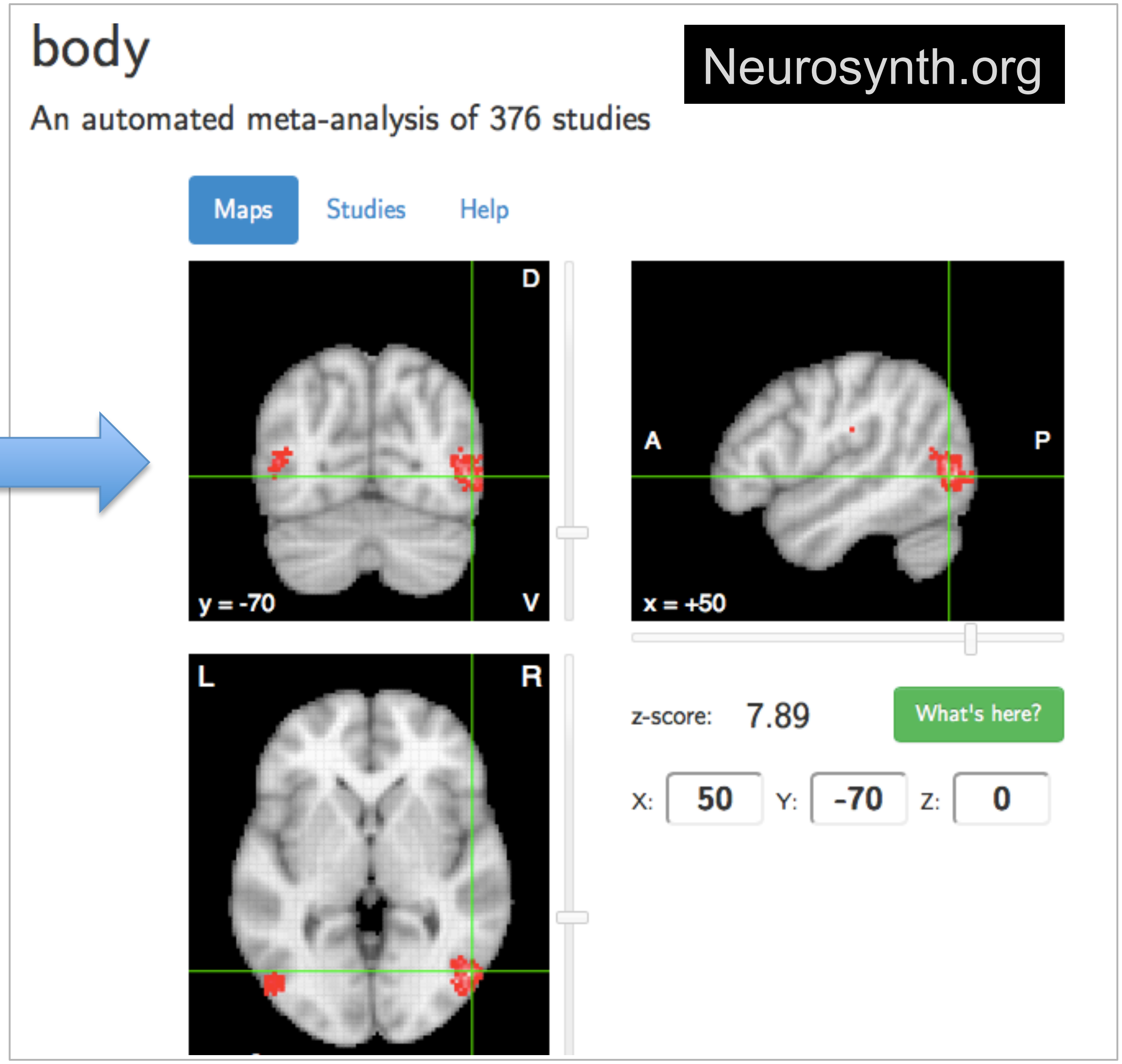
	Talairach Coordinates				
Region	X	Y	Z	Mean T	mm^3
R. ITS	44	−69	−7	4.63	2101
R. ITS	52	−51	3	4.49	920
R. STS	57	−41	21	4.17	112
R. Fusiform	36	−39	−19	4.72	748
R. Fusiform	34	−68	−18	4.32	174
R. Post. Occipital	14	−96	−4	4.43	151
L. ITS	−42	−70	−4	4.59	2544
L. Supramarginal	−56	−39	25	4.37	388

from Peelen & Downing, Neuron, 2006

Functional Brain Atlas: Current State of the Art
Results are aggregated across studies based on x,y,z coordinates

Table 1. Group-Average Activation for the Biological Motion Display

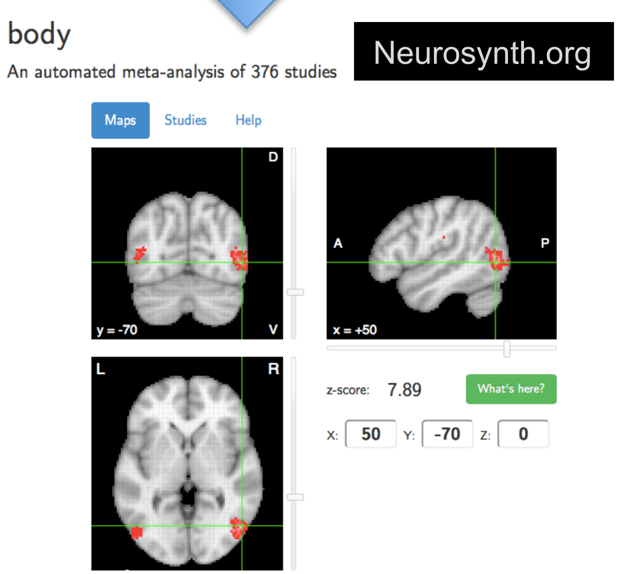
Region	Talairach Coordinates X	Y	Z	Mean T	mm^3
R. ITS	44	−69	−7	4.63	2101
R. ITS	52	−51	3	4.49	920
R. STS	57	−41	21	4.17	112
R. Fusiform	36	−39	−19	4.72	748
R. Fusiform	34	−68	−18	4.32	174
R. Post. Occipital	14	−96	−4	4.43	151
L. ITS	−42	−70	−4	4.59	2544
L. Supramarginal	−56	−39	25	4.37	388

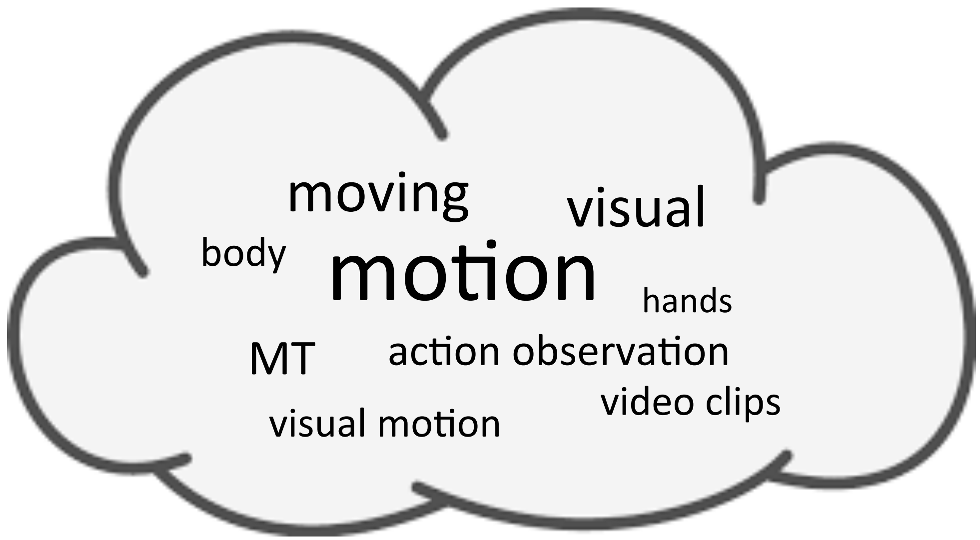


Functional Brain Atlas: Current State of the Art
The function of a locus is described as a "word-cloud"

Table 1. Group-Average Activation for the Biological Motion Display

Region	Talairach Coordinates X	Y	Z	Mean T	mm^3
R. ITS	44	−69	−7	4.63	2101
R. ITS	52	−51	3	4.49	920
R. STS	57	−41	21	4.17	112
R. Fusiform	36	−39	−19	4.72	748
R. Fusiform	34	−68	−18	4.32	174
R. Post. Occipital	14	−96	−4	4.43	151
L. ITS	−42	−70	−4	4.59	2544
L. Supramarginal	−56	−39	25	4.37	388





Functional Brain Atlas: Current State of the Art
The function of a locus is described as a "word-cloud"

Table 1. Group-Average Activation for the Biological Motion Display

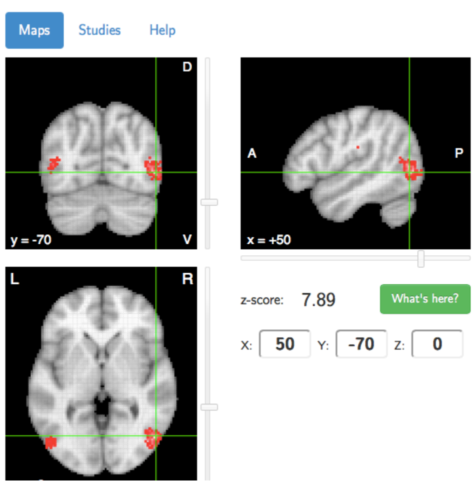
Region	Talairach Coordinates X	Y	Z	Mean T	mm^3
R. ITS	44	−69	−7	4.63	2101
R. ITS	52	−51	3	4.49	920
R. STS	57	−41	21	4.17	112
R. Fusiform	36	−39	−19	4.72	748
R. Fusiform	34	−68	−18	4.32	174
R. Post. Occipital	44	−96	−4	4.43	151
L. ITS	−42	−70	−4	4.59	2544
L. Supramarginal	−56	−39	25	4.37	388

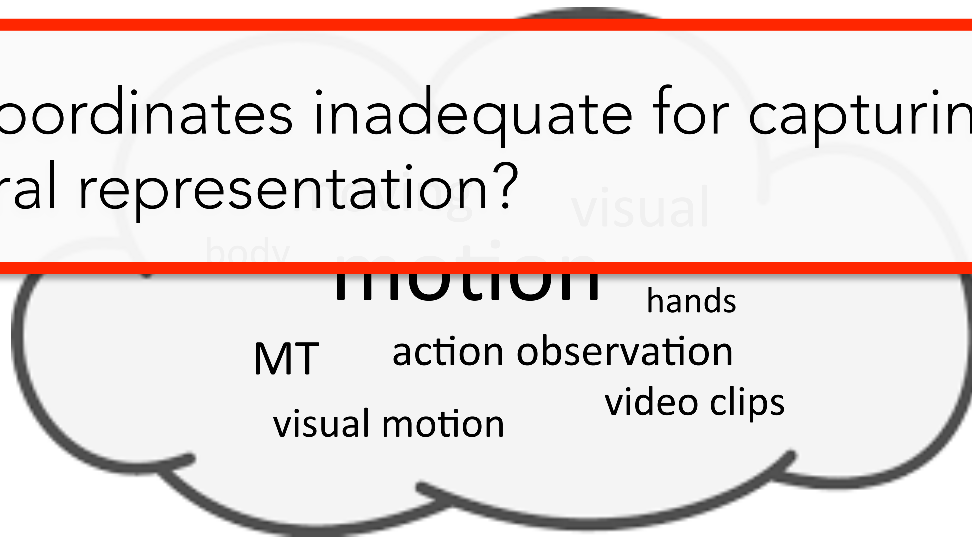
Why are anatomical coordinates inadequate for capturing neural representation?

body

An automated meta-analysis of 376 studies

Neurosynth.org





Why are anatomical coordinates inadequate for capturing neural representation?

- *Response tuning functions* for voxels with the same anatomical coordinates *are highly variable across brains.*

- The *basic unit for neural representation is the population response*, not the responses of single voxels (or single neurons).

HyperCortex
Proposal for a new functional brain atlas
based on a high-dimensional common representational space

- Model dimensions have *response tuning functions* that are *highly similar across brains.*

- *Brain responses are captured as pattern vectors*, reflecting population codes with response basis functions that are shared across brains.

- *Fine-scale topographies are preserved* and can be recreated in each individual brain.

- Data can be shared, interpreted, and subjected to meta-analysis in *a computational structure that captures fine-scale patterns of activity that encode fine distinctions.*

Some acknowledgements

Swaroop Guntupalli
now at Caltech
Hyperalignment development

Peter Ramadge
Electrical Engineering
Princeton University

Yaroslav Helchenko and Michael Hanke
CCN at Dartmouth and the University of Magdeburg, Germany
Software engineering

PyMVPA

http://neuro.debian.net
neurodebian