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

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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)

<table>
<thead>
<tr>
<th>luna moth</th>
<th>ladybug</th>
<th>warbler</th>
<th>mallard</th>
<th>monkey</th>
<th>lemur</th>
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<tbody>
<tr>
<td>Insects</td>
<td></td>
<td>Birds</td>
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<td>Primates</td>
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(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)

(luna moth) (ladybug) (warbler) (mallard) (monkey) (lemur)

Insects Birds Primates

(WSC (1000 voxels)) (BSC (1000 anatomically-aligned voxels))

Chance (16.7%)

(Haxby et al. 2011; Connolly et al. 2012)
Hyperalignment:
Individual representational spaces $\iff$ common representational space
Hyperalignment:
Individual representational spaces $\iff$ 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 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

$\times [ ] =$

S2
Individual representational spaces

Procrustes transformations (improper rotations)

Common model representational space

\[ x [ ]_{s_2} = \]

\[ x [ ]_{s_3} = \]
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

luna moth ladybug Insects
warbler mallard Birds
monkey lemur Primates

(Haxby et al. 2011; Connolly et al. 2012)
Modeling representational spaces in all human cortex with searchlight hyperalignment

Voxels in overlapping searchlights are hyperaligned across subjects and aggregated into a whole cortex matrix.

Data in individual brain anatomy are transformed into data in a common model space.
Hyperalignment parameters are estimated from responses recorded during movie viewing.

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

Individual brains

Individual representational spaces

Transformations (transposed rotations)

Common model representational space

Individual brains

Individual representational spaces

Transformations (transposed rotations)

Common model representational space

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

Individual brains

Individual representational spaces

Transformations (transposed rotations)

Common model representational space
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

Correlation between measured and projected

Horizontal meridian

Vertical meridian

LH | V3 | V2v | V1v | RH

LH | V3 | V2v | V1v | RH

Graph showing correlation between anatomical and hyperalignment.
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>
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<tr>
<th>Region</th>
<th>Talairach Coordinates</th>
<th>Mean T</th>
<th>mm³</th>
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<tr>
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<td>44  -69  -7</td>
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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

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An automated meta-analysis of 376 studies

Neurosynth.org
Functional Brain Atlas: Current State of the Art
The function of a locus is described as a “word-cloud”
Functional Brain Atlas: Current State of the Art

The function of a locus is described as a “word-cloud”

Why are anatomical coordinates inadequate for capturing neural representation?

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Neurosynth.org

An automated meta-analysis of 376 studies

- MT
- action observation
- visual motion
- video clips
- hands
- movement
- body
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