Neurotopics: Unsupervised learning for discovering functional regions of the brain

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Introduction

- A primary goal of cognitive neuroscience: identifying relationships between the brain and cognitive functions
- Traditional fMRI studies focus on identifying individual functional regions
  - Small sample sizes, low statistical power
- More recently: Big-data approaches based on statistical learning of corpus data

Statistical learning approaches

Two primary approaches:

Statistical learning approaches

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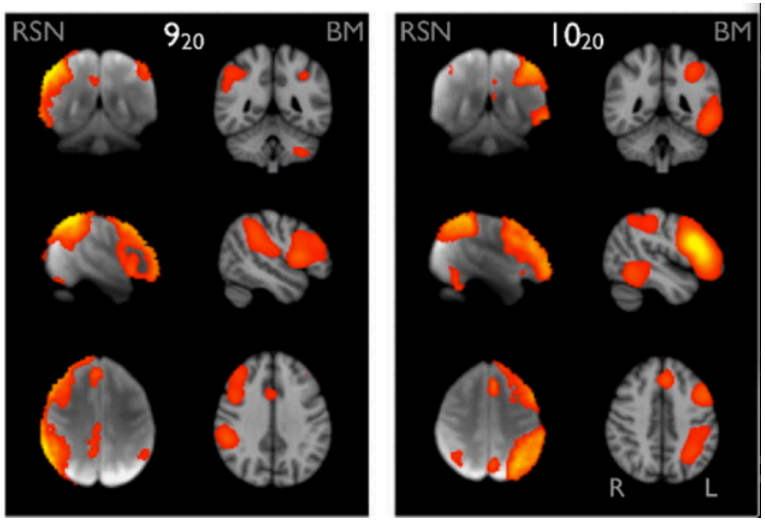
1. Network mappings of functional activation using dimensionality reduction (e.g., ICA or PCA)
   - These networks are spatially diffuse
   - Span multiple regions with distinct functions



Statistical learning approaches

Two primary approaches:

1. Network mappings of functional activation using dimensionality reduction (e.g., ICA or PCA)
   - These networks are spatially diffuse
   - Span multiple regions with distinct functions
2. Clustering/parcellation type approaches (e.g. k-means clustering)
   - Hard-assignments of all voxels to a single region
   - Does not allow for single location to be involved in multiple functions (i.e., no “one-to-many” mapping)

Statistical learning approaches

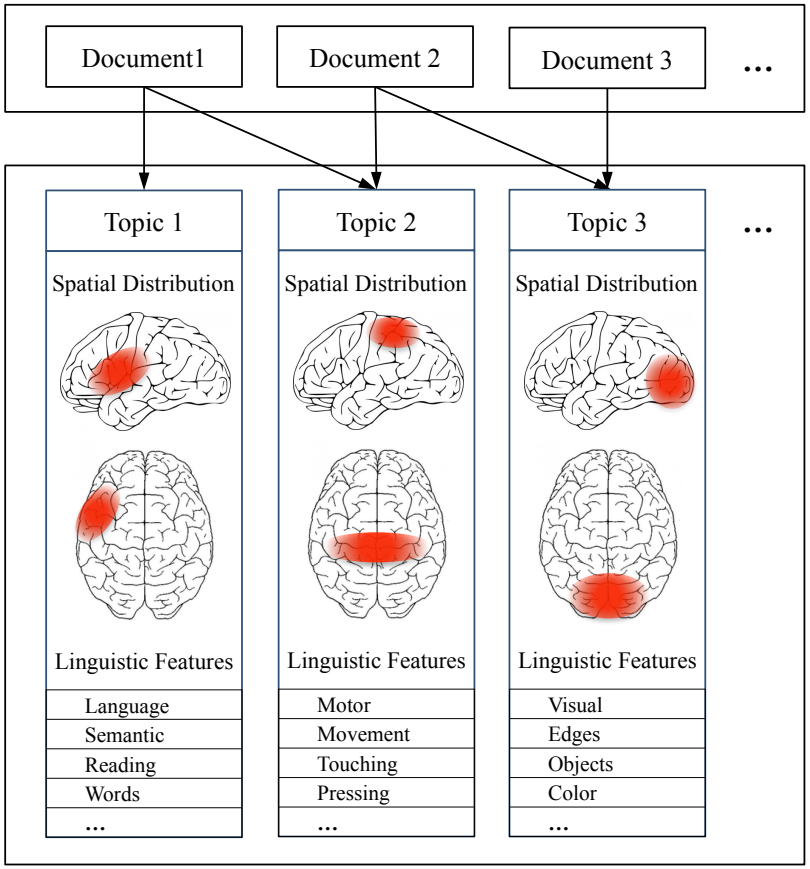
- Additional concern: spatial components are typically extracted *independent of function*:
  - First, spatial components are extracted
  - After, these components are mapped onto cognitive functions
- To optimally produce a mapping: these components should be jointly extracted

Goals of our approach

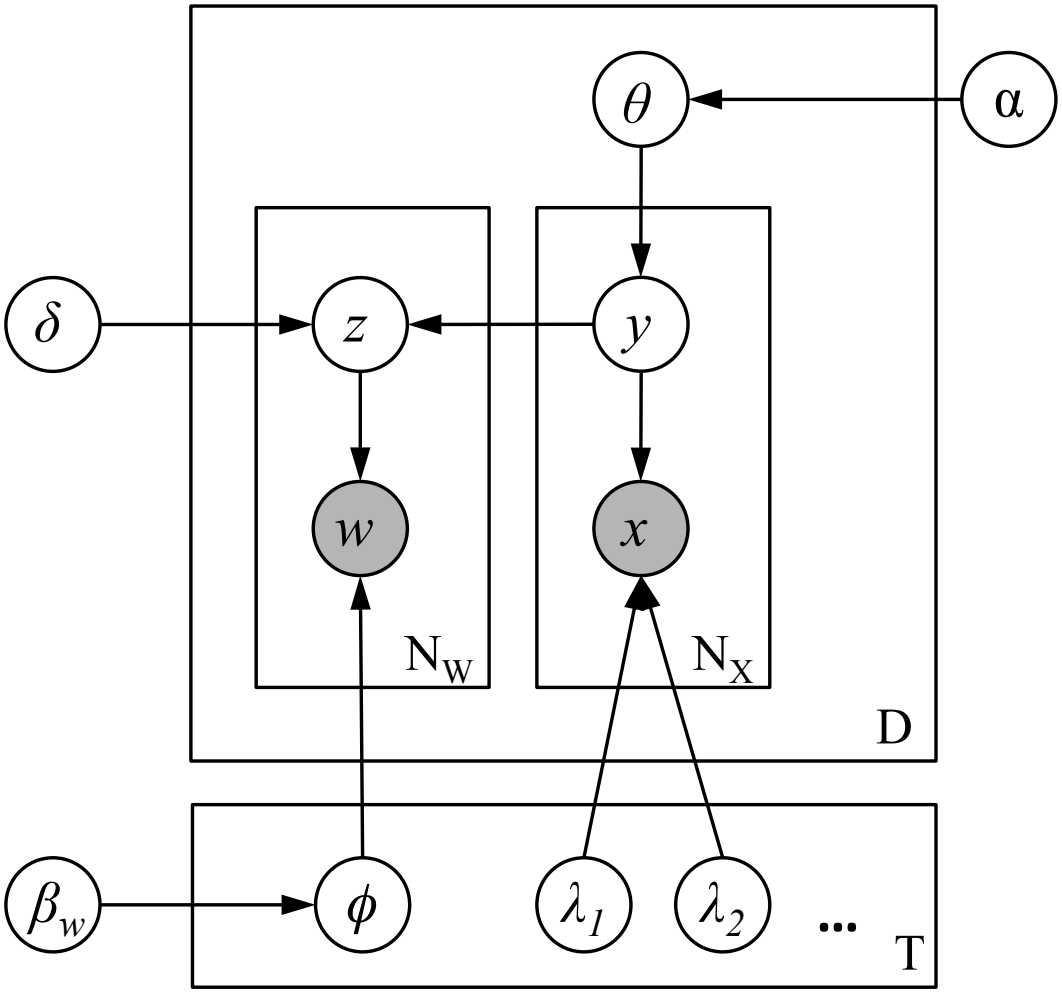
- Identify functional units of brain by *jointly* modeling their spatial and functional components using corpus data
- Allow for “Soft clustering”: a single location can belong to multiple functional regions
- Sensitive to both anatomical and psychological constraints
  - e.g. lateral symmetry, localized function

Generative topic model

- Based on Correspondence LDA model
- Broad idea:
  - Each document is modeled as a mixture of *topics* (i.e., regions)
  - Each region consists of:
    - A spatial probability distribution over neural *activations*
    - A linguistic probability distribution over terms related to the regions function



Graphical model



Training the model

- Trained on the Neurosynth corpus
  - About 11,000 fMRI publications
  - Text from abstracts (~500k tokens)
  - Reported (x,y,z) peak activation coordinates (~400k tokens)
- Extracted 200 Topics
- Model is trained using Bayesian methods

Regarding Spatial distributions:

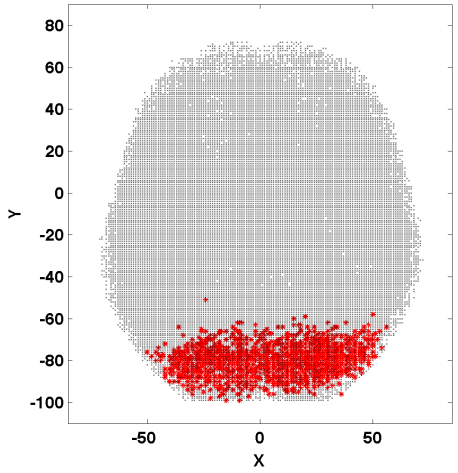
- Our generalized version of correspondence-LDA allows the experimenter to choose an appropriate spatial distribution
- **Simple model:**
  - Regions spatial distribution represented by a single Gaussian distribution

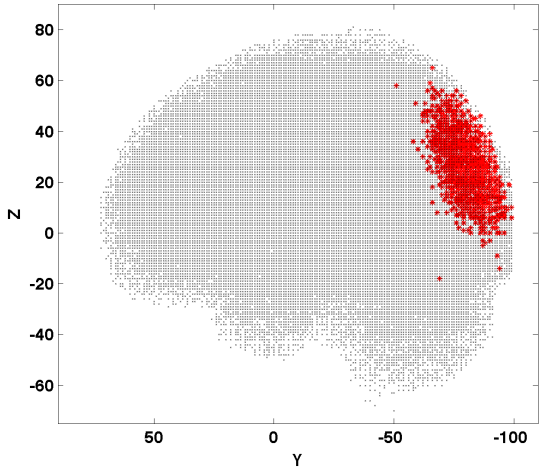
Results: Single-region model

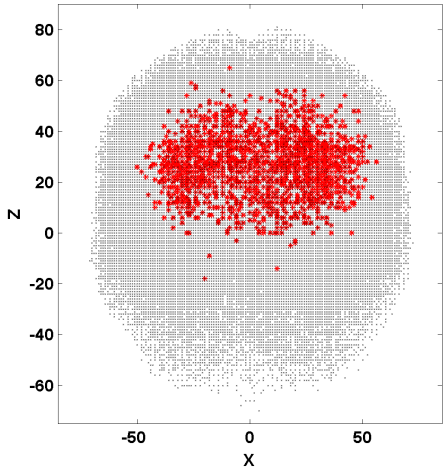
Axial | Medial | Coronal

Topic 62

visual
spatial
visuospatial
locations
space
stream
visuo
location
coding
target

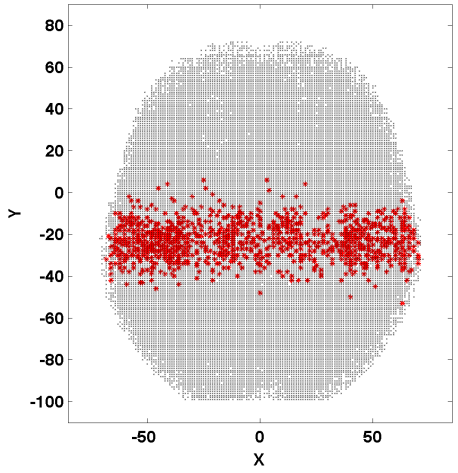


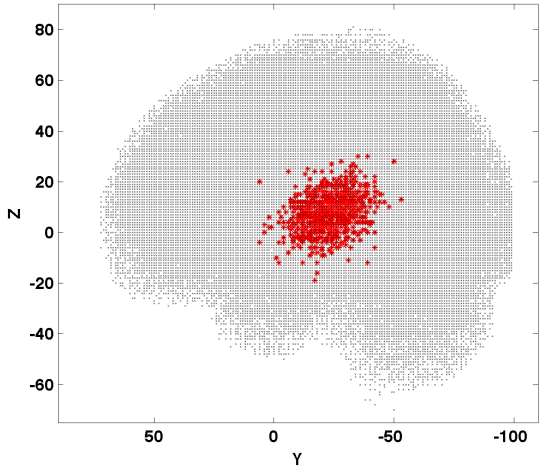


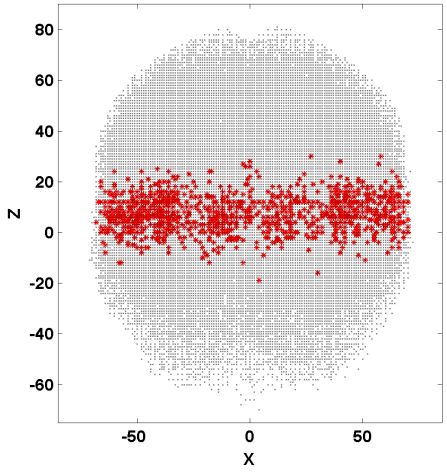


Topic 150

auditory
pitch
sound
tone
sounds
tones
laughter
prosody
prosodic
ear





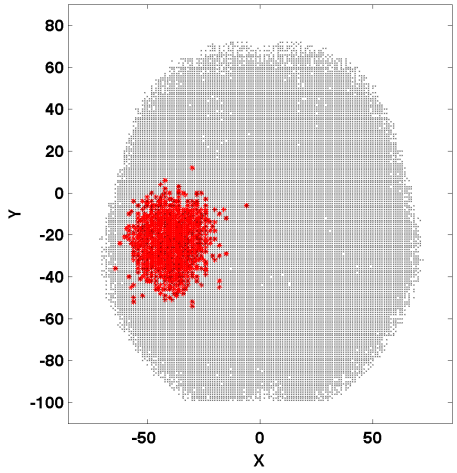


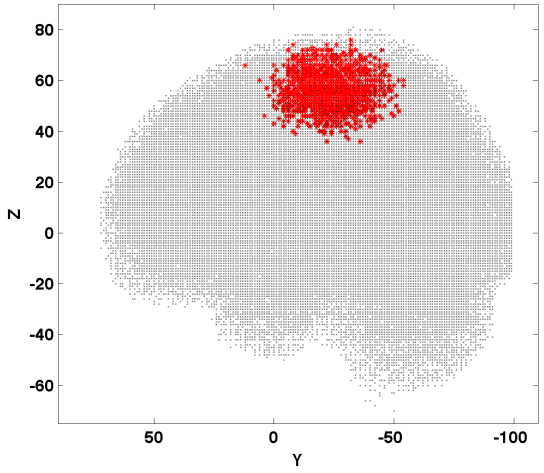
Results: Single-region model

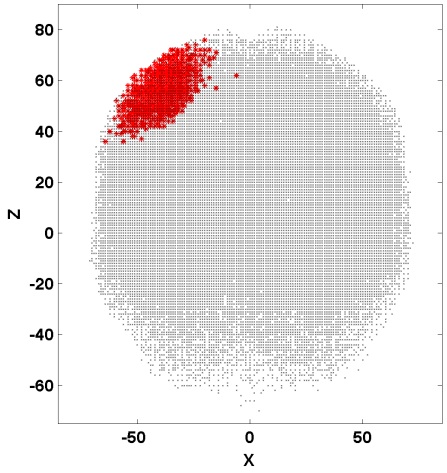
Axial | Medial | Coronal

Topic 117

motor
finger
changes
bimanual
somatosensory
sensorimotor
movements
movement
coordination
unimanual

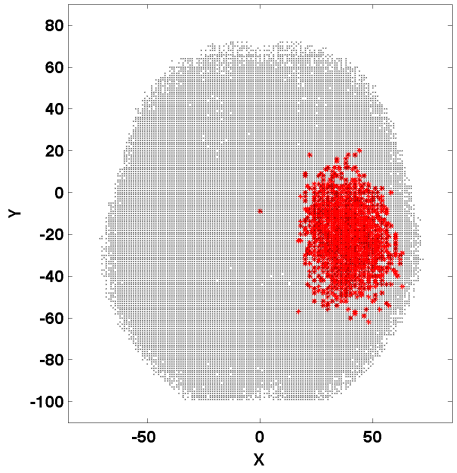


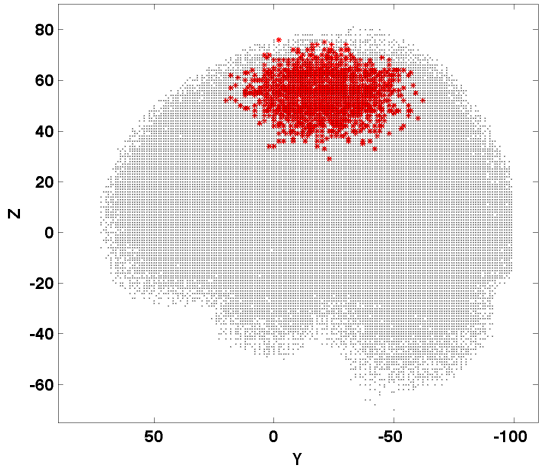


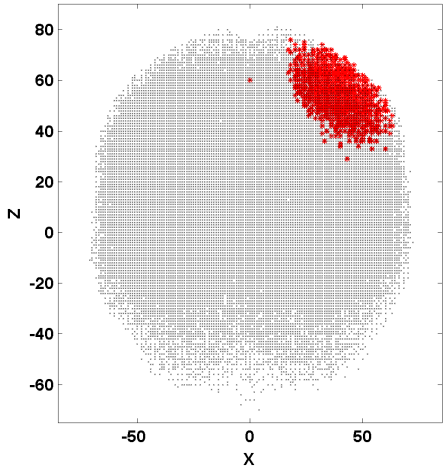


Topic 152

motor
movement
movements
finger
changes
execution
sensorimotor
paced
handed
spatial







Spatial distributions:

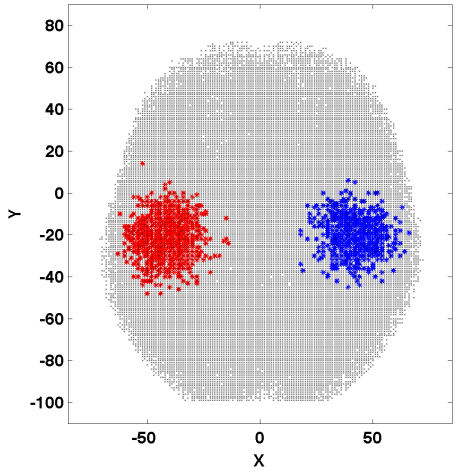
- **Anatomically constrained model:**
  - Regions represented by a weighted mixture of two Gaussian distributions
  - Laterally symmetric (with respect to the brain hemispheres)

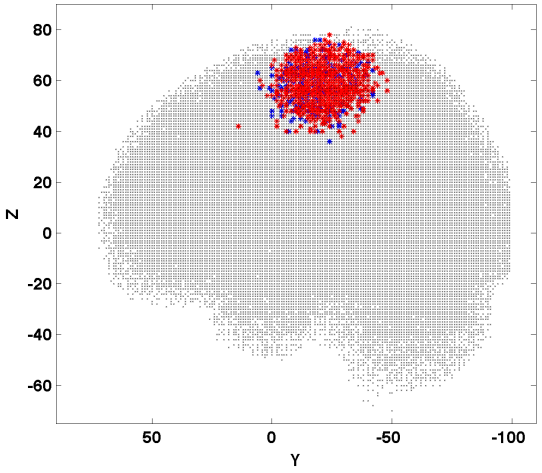
Results: Symmetric Subregions

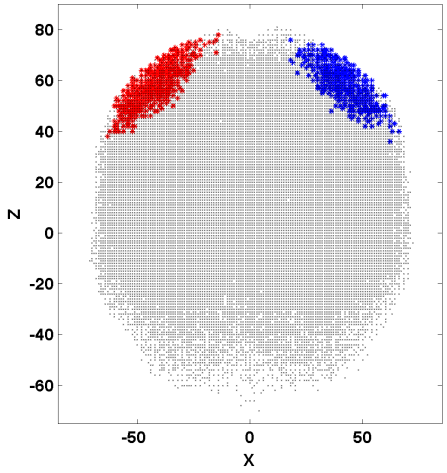
Axial | Medial | Coronal

Topic 79

motor
stimulation
finger
somatosensory
transcranial
sensorimotor
repetitive
mep
plasticity
handed

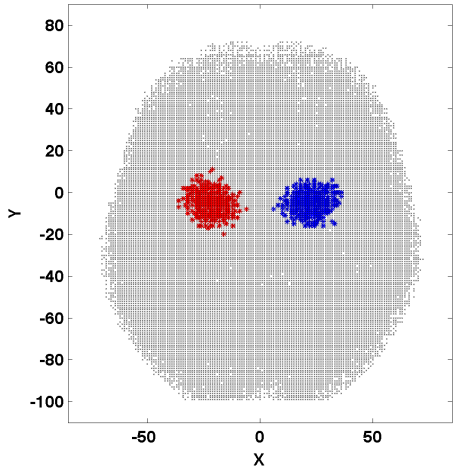


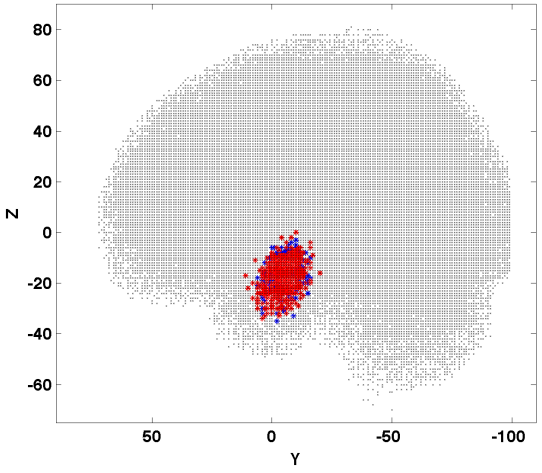


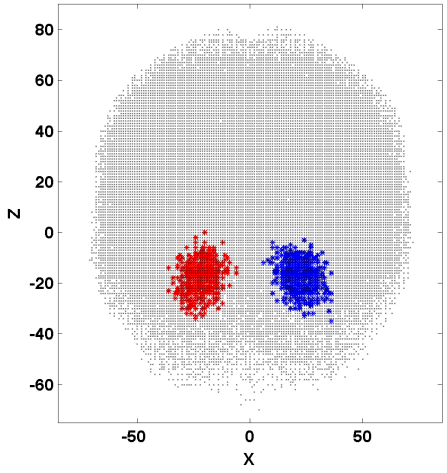


Topic 29

emotional
emotion
pictures
affective
faces
ratings
affect
fearful
perception
distraction





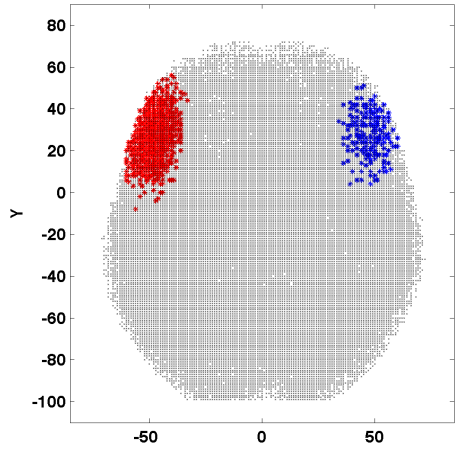


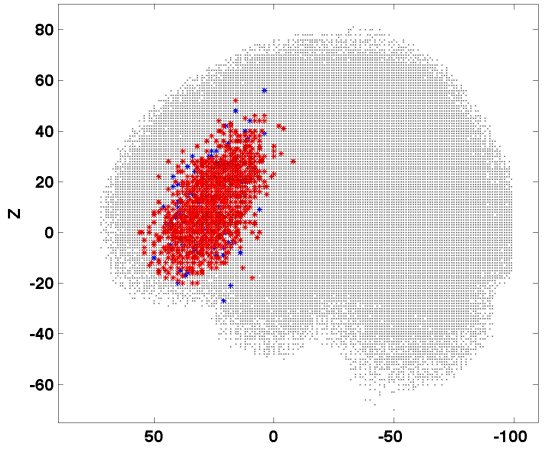
Functional Lateralization

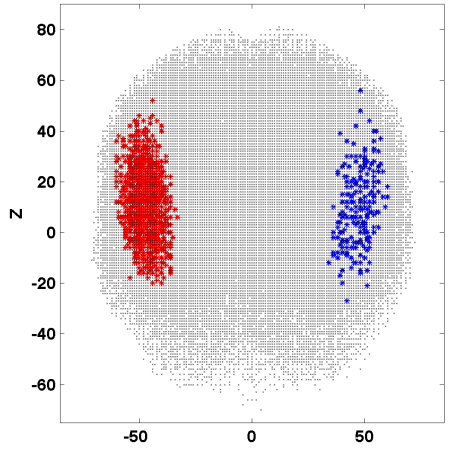
Axial | Medial | Coronal

Topic 200

semantic
fluency
semantic_processing
selection
retrieval
verbal
demands
judgment
meaning
verbal_fluency



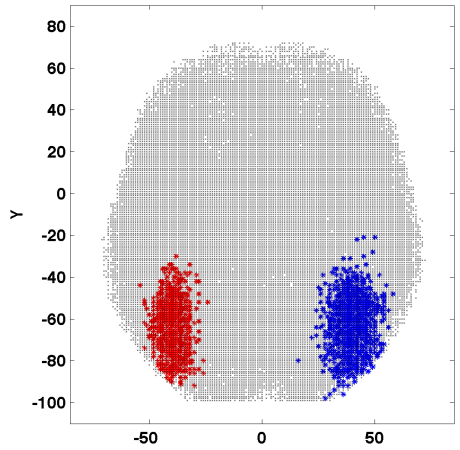


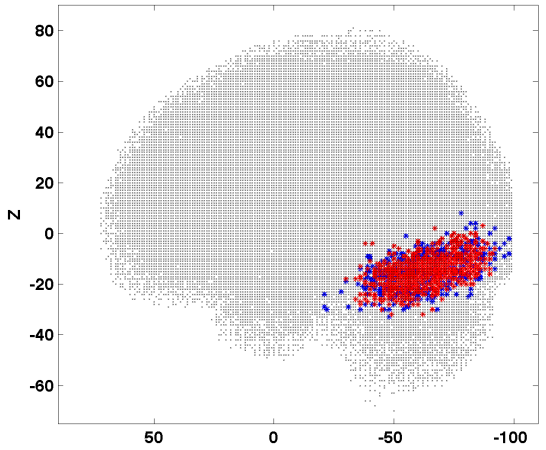


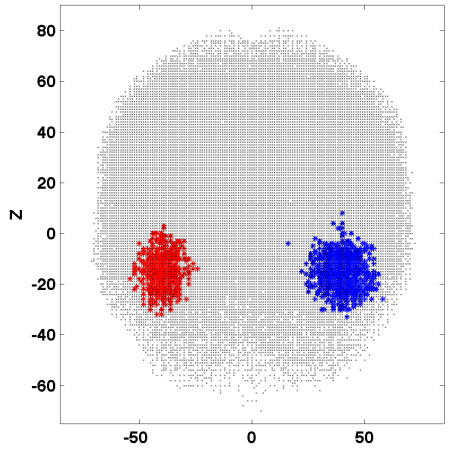
L = .90 R = .10

Topic 09

face
faces
identity
facial
face_recognition
recognition
face_perception
selectivity
upright
inversion





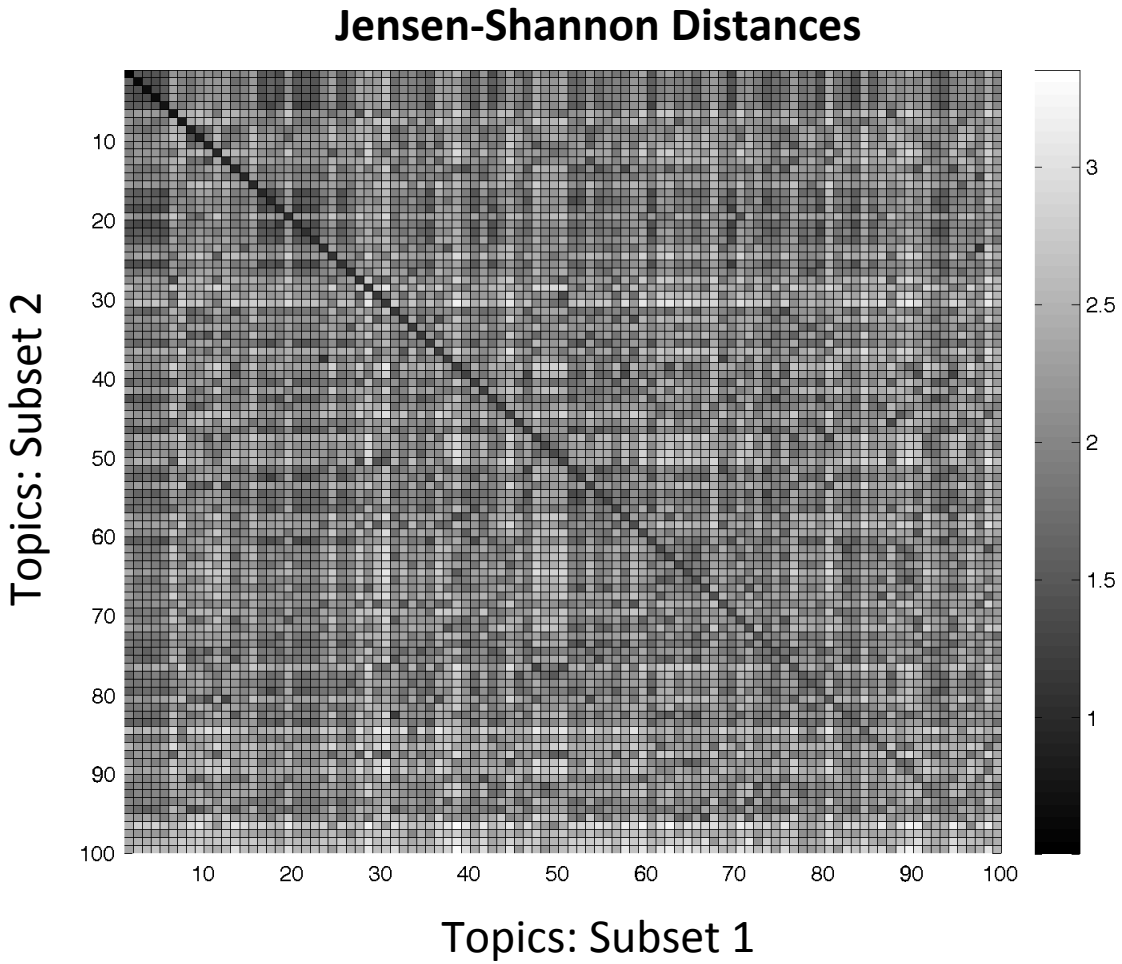


L = .42 R = .58

Topic stability analysis

- Split the dataset in half and trained a symmetric-subregion model separately on each half
- Aligned the topics based on the similarities of the linguistic + spatial distributions
- Evaluate how many topics are consistent independent of the specific training data

Topic-alignment across datasets

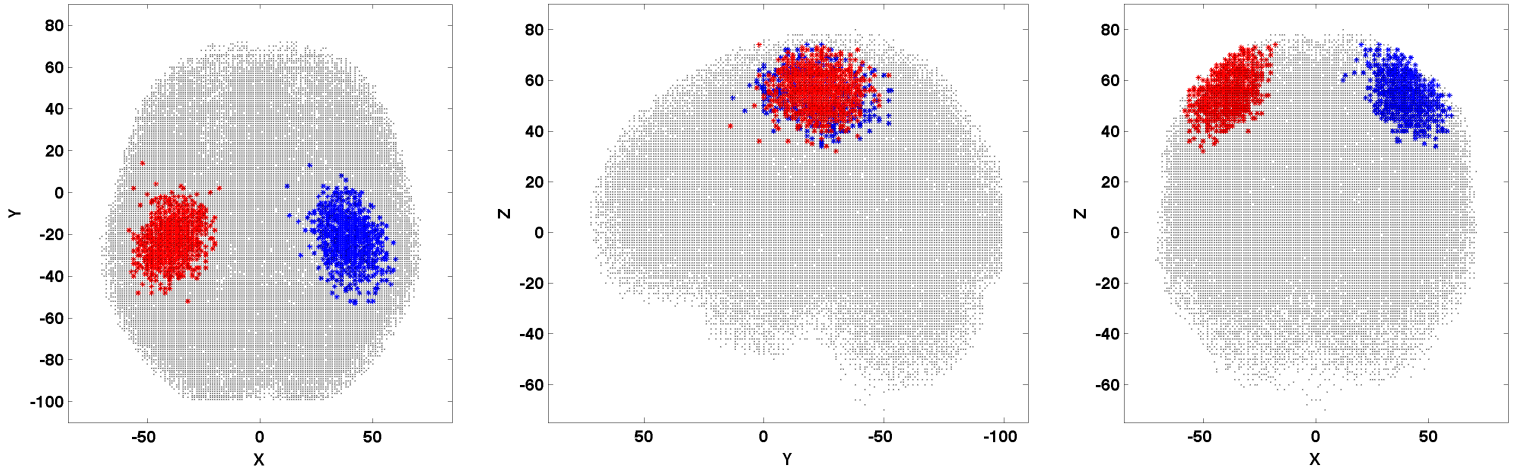


Rank 10

Training Set 1

Topic 55

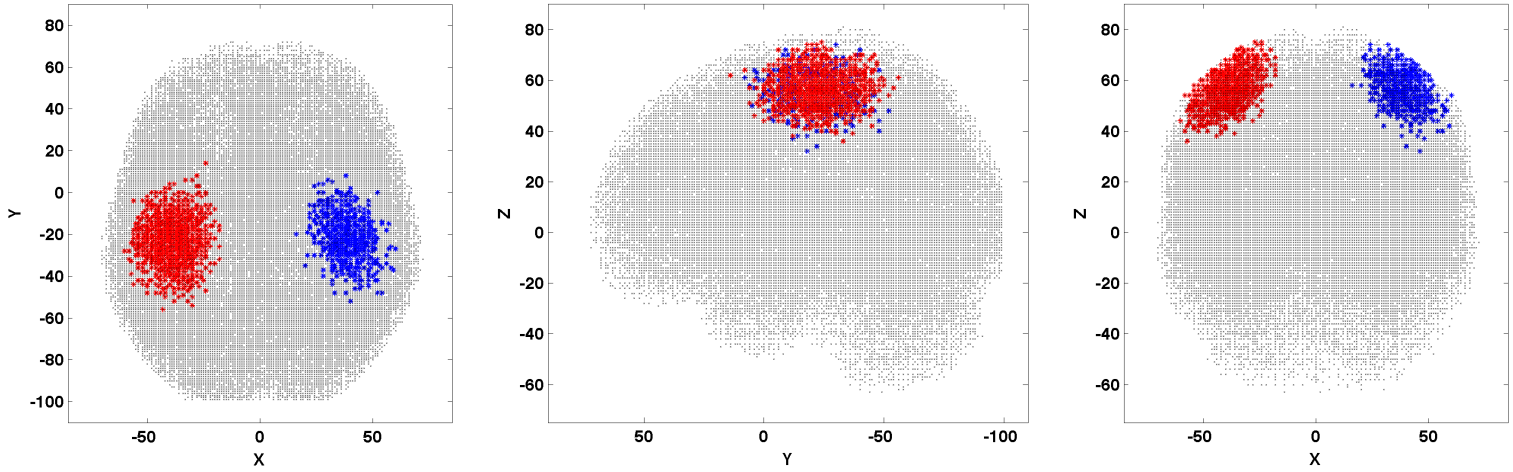
motor
movement
finger
somatosensory
force
movements
sensorimotor
stimulation
grip
fingers



Training Set 2

Topic 51

motor
finger
movements
stimulation
bimanual
sensorimotor
movement
alpha
handed
dominant

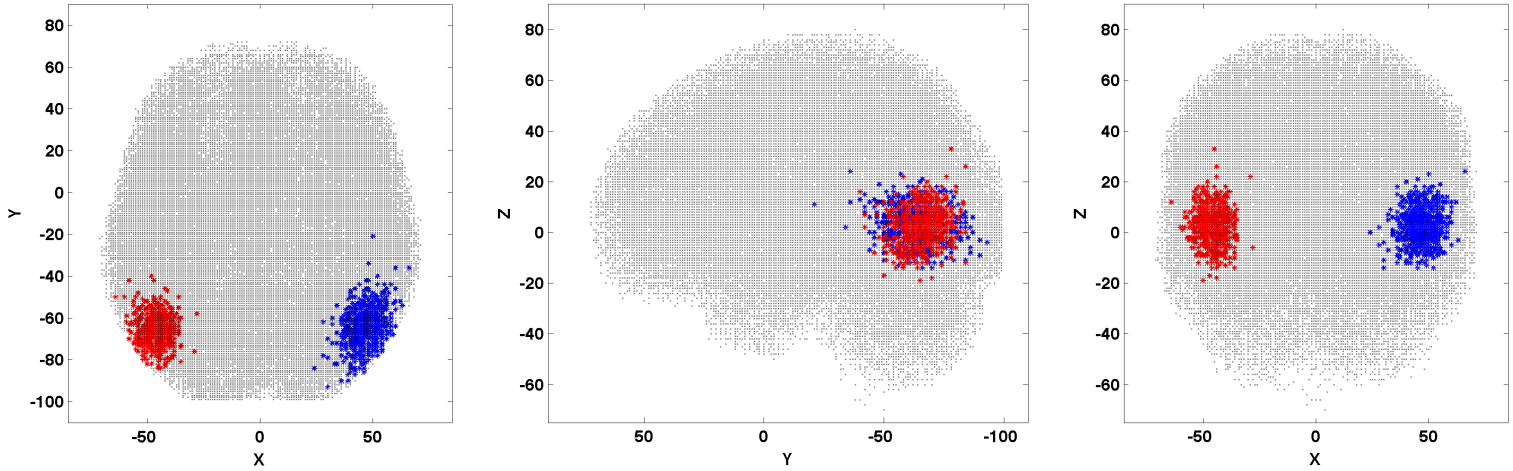


Rank 30

Training Set 1

Topic 50

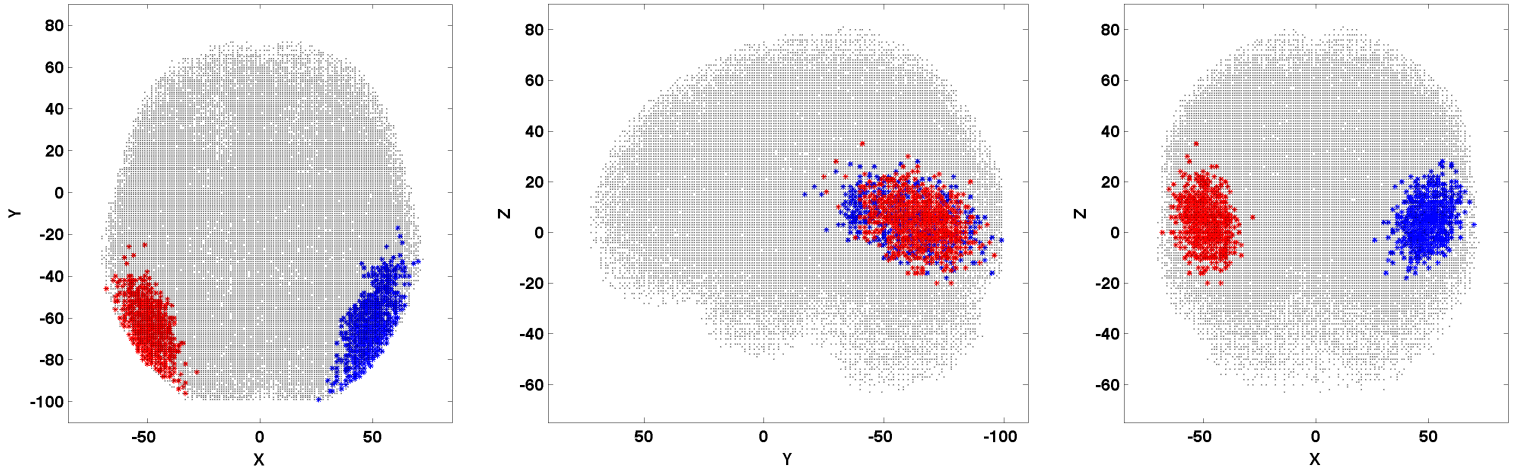
motion
visual
moving
static
direction
body
biological_motion
perception
motion_perception
flow



Training Set 2

Topic 88

body
motion
perception
viewing
actions
biological_motion
videos
gestures
viewed
visual

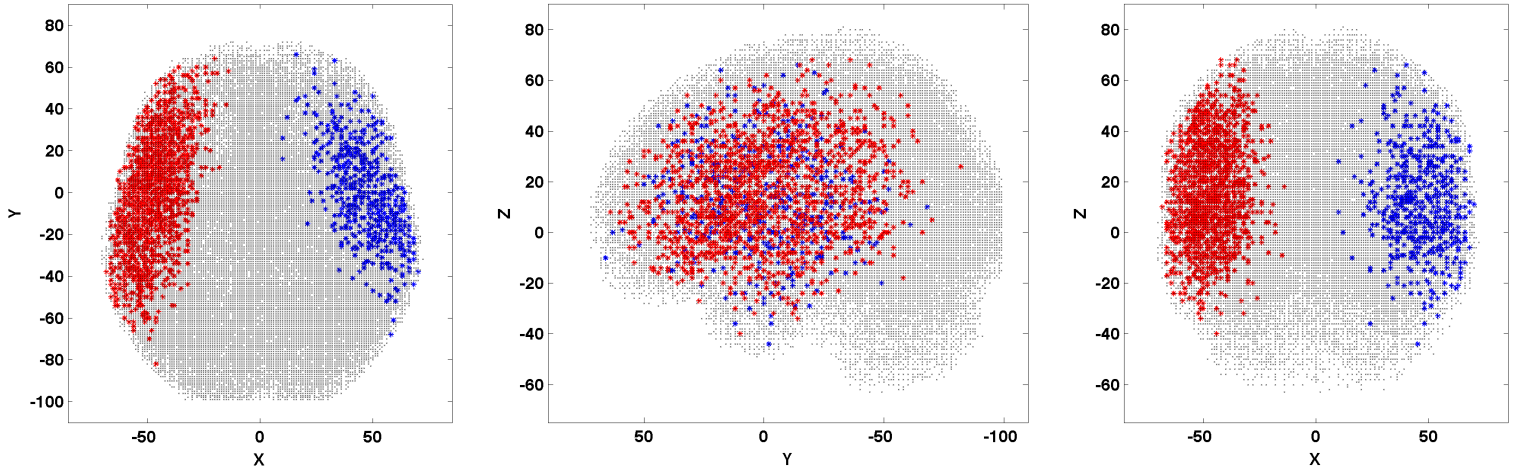


Rank 50

Training Set 1

Topic 65

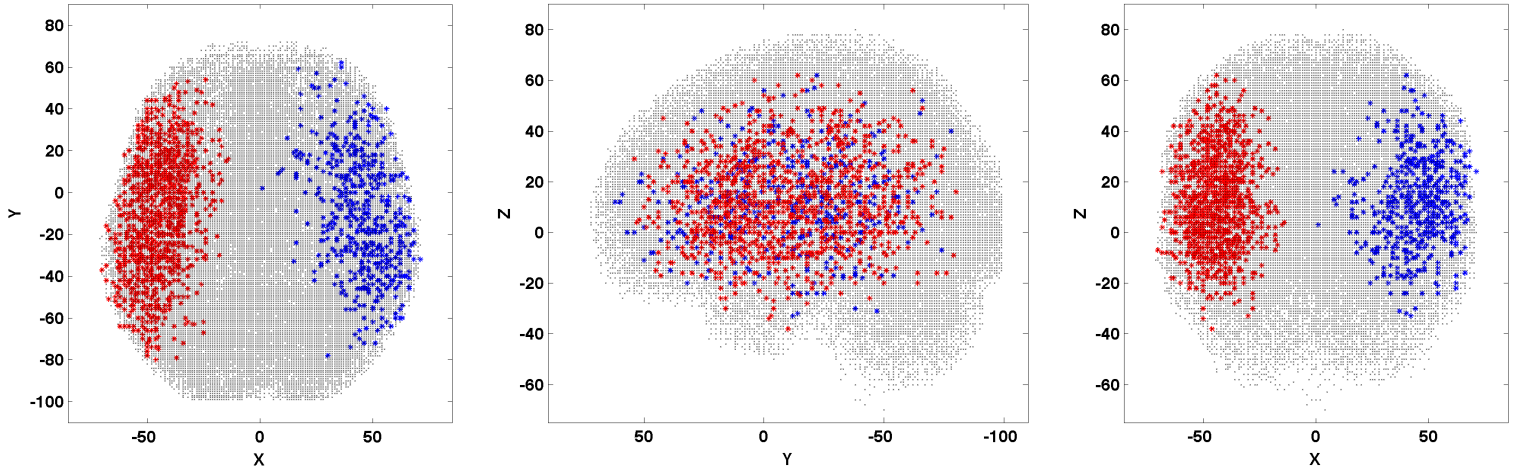
words
semantic
word
lexical
meaning
semantic_processing
picture
competition
language
semantically



Training Set 2

Topic 84

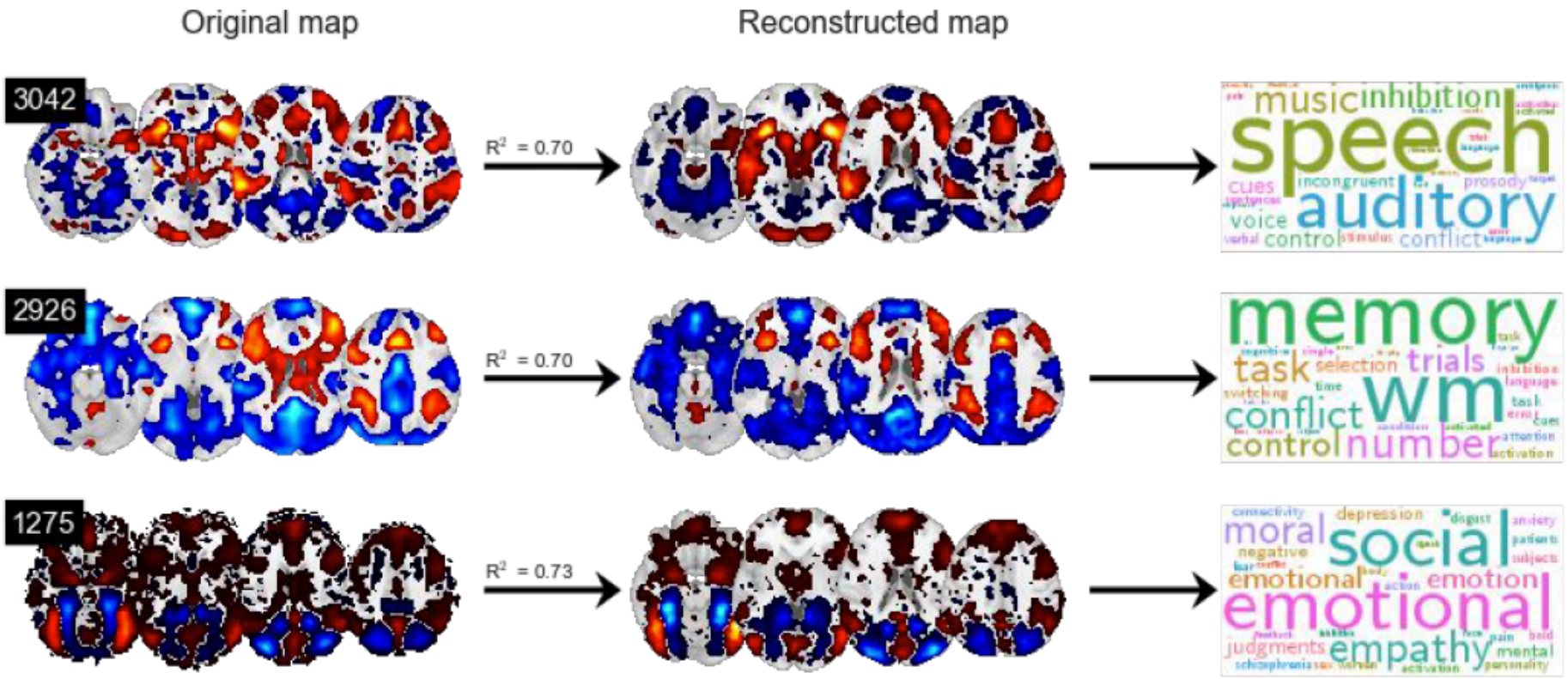
language
native
chinese
languages
hearing
bilinguals
linguistic
japanese
deaf
speakers



Stability analysis

- Approximately 50% of topics are stable, independent of the training data

Image Decoding



Discussion

- Large scale statistical learning approach that learns interpretable functional regions
- Regions are consistent with the literature
- Addresses drawbacks of previous approaches (e.g., “one-to-many” mapping)
- Additionally, provide a measure of the lateralization of cognitive functions

Thanks