NEURAL COMPUTATION

OR

NEUROSCIENCE FOR COMPUTER SCIENTISTS

Prof. Alexander Huth

8/31/2017

TODAY

* Overview of class

* What I do

* Syllabus

BIG QUESTION

* Given a system that computes something,

  * what does it compute?

  * how does it work?

  * what are the ***internal representations*** that support that computation?

WHAT DOES IT MEAN TO UNDERSTAND?

* David Marr (1945 - 1980), *Vision* (1982)

*** Levels of analysis:**

* Computational

* Algorithmic/Representational

* Implementation

COMPUTING SYSTEMS

* Biological: brains

* Artificial: neural networks

* Artificial: microcircuits

TOPICS

* Brains

  * Strategies for neuroscience / philosophies of experimental design

* Dealing with real, noisy data & uncertainty

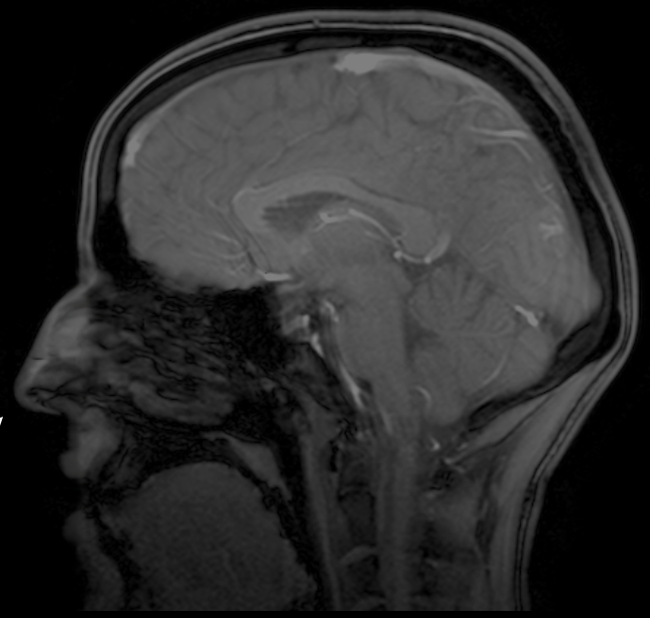
* Fitting predictive encoding & decoding models (& examining philosophies thereof)

TOPICS

* Artificial neural networks
  * Strategies for gaining understanding
* Microcircuits (ever so briefly)

MY WORK

VOXELWISE MODELING



NATURAL STIMULI

fMRI DATA

ESTIMATION

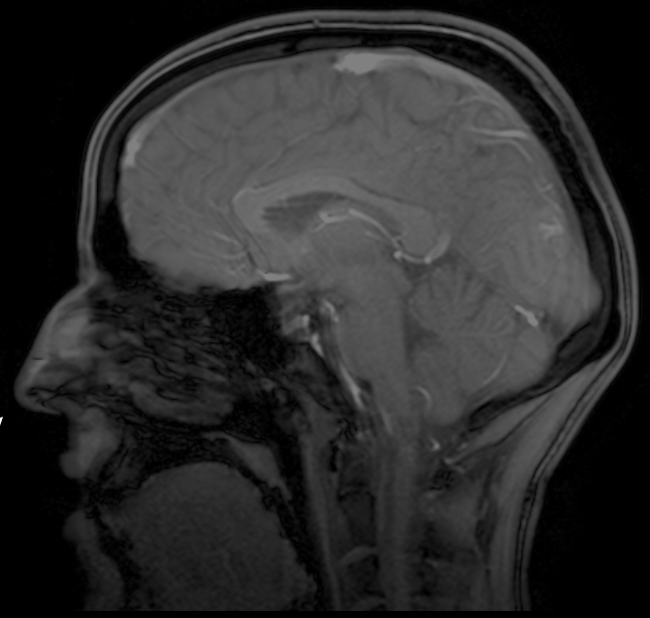
HYPOTHESIZED FEATURE SPACE

VOXELWISE REGRESSION MODELS

Kay et al. *Nature* (2008), Naselaris et al. *Neuron* (2009),
Nishimoto et al. *Current Biology* (2011), Huth et al. *Neuron* (2012), etc.

VOXELWISE MODELING

NEW NATURAL STIMULI



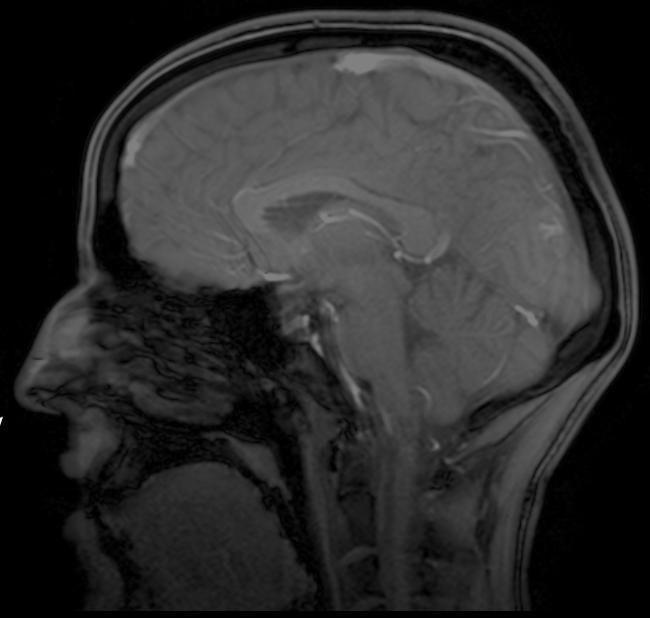
NEW fMRI DATA

PREDICTION

HYPOTHESIZED FEATURE SPACE

VOXELWISE REGRESSION MODELS

VOXELWISE MODELING



NEW NATURAL STIMULI

HYPOTHESIZED FEATURE SPACE

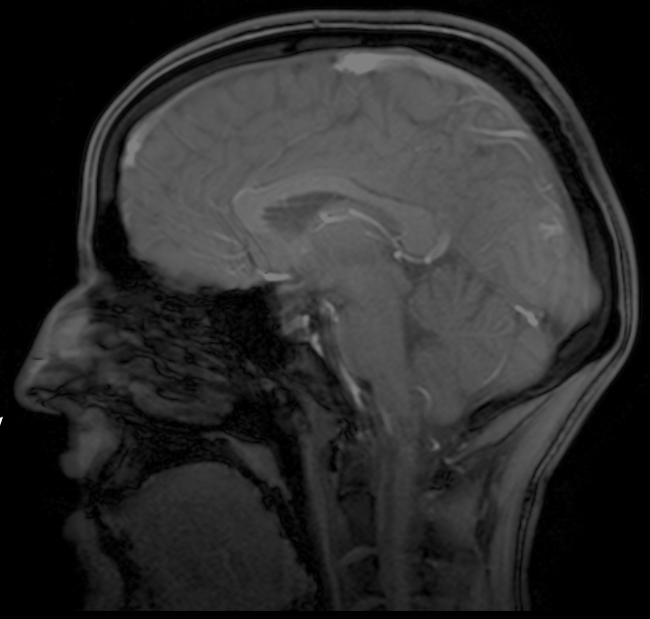
VOXELWISE REGRESSION MODELS

fMRI DATA

PREDICTION

INTERPRETATION

VOXELWISE MODELING



fMRI DATA

NEW NATURAL STIMULI

ESTIMATION

PREDICTION

FEAT. SPACE A

FEAT. SPACE B

FEAT. SPACE C

VOXELWISE REGRESSION MODELS

NATURAL LANGUAGE EXPERIMENT

- Subjects listen to over 2 hours of naturally spoken, narrative stories
- BOLD responses recorded from whole brain using GE-EPI fMRI
  - Voxel size: 2.24 x 2.24 x 4.1mm
  - Repetition time (TR): 2.0045 s
  - Custom water-excitation RF pulse

Huth, de Heer, Griffiths, Theunissen, & Gallant. *Nature* (2016)

fMRI DATA VISUALIZATION

VOXELWISE MODELING

SIMPLEST MODEL:

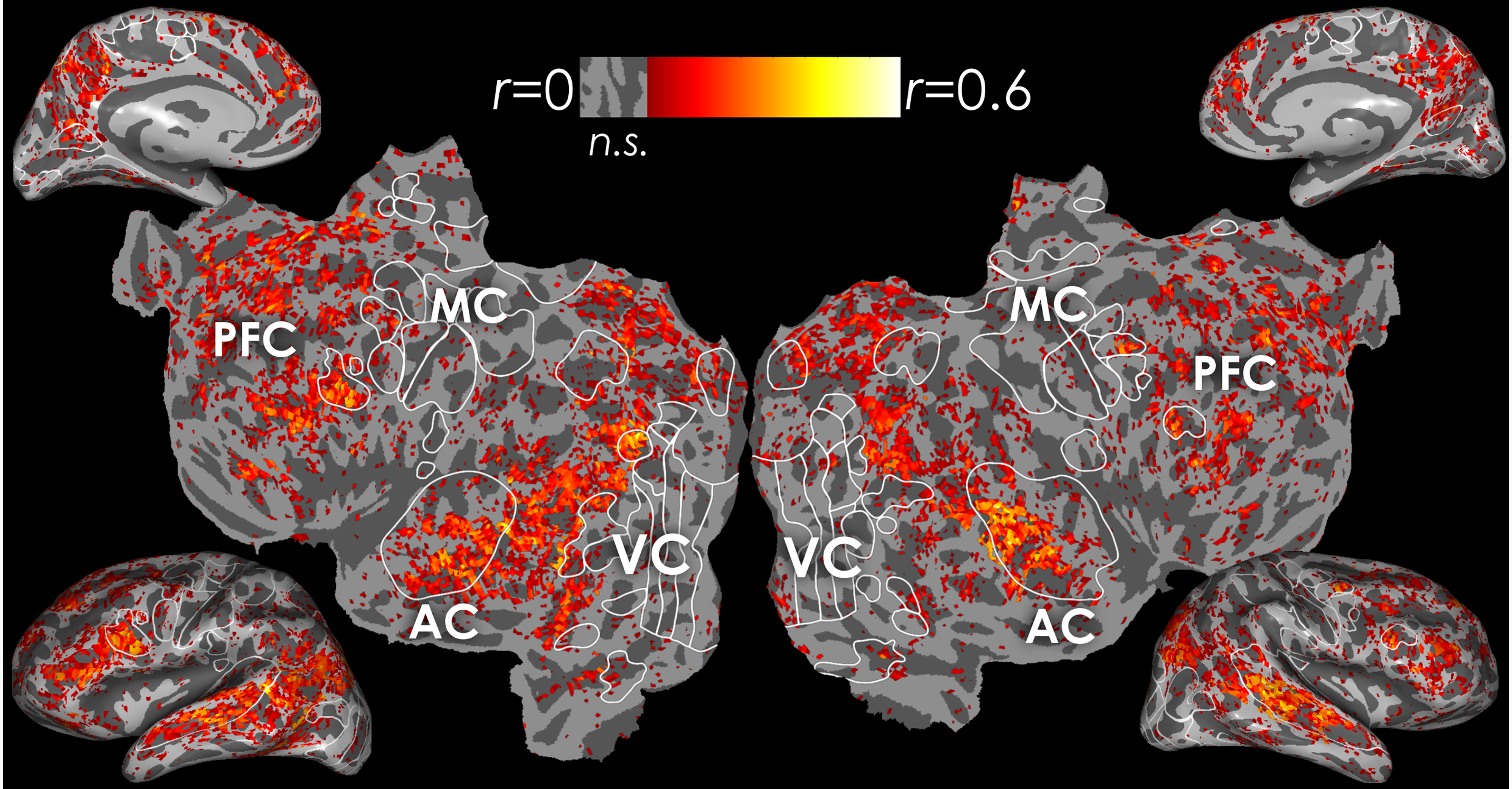
each voxel responds (some amount) to each word

$$R(t) = \sum_{i=0}^{N} \beta_i W_i(t)$$

$$\hat{\beta} = \underset{\beta}{\operatorname{argmax}} P(R|\beta, W)$$

likelihood

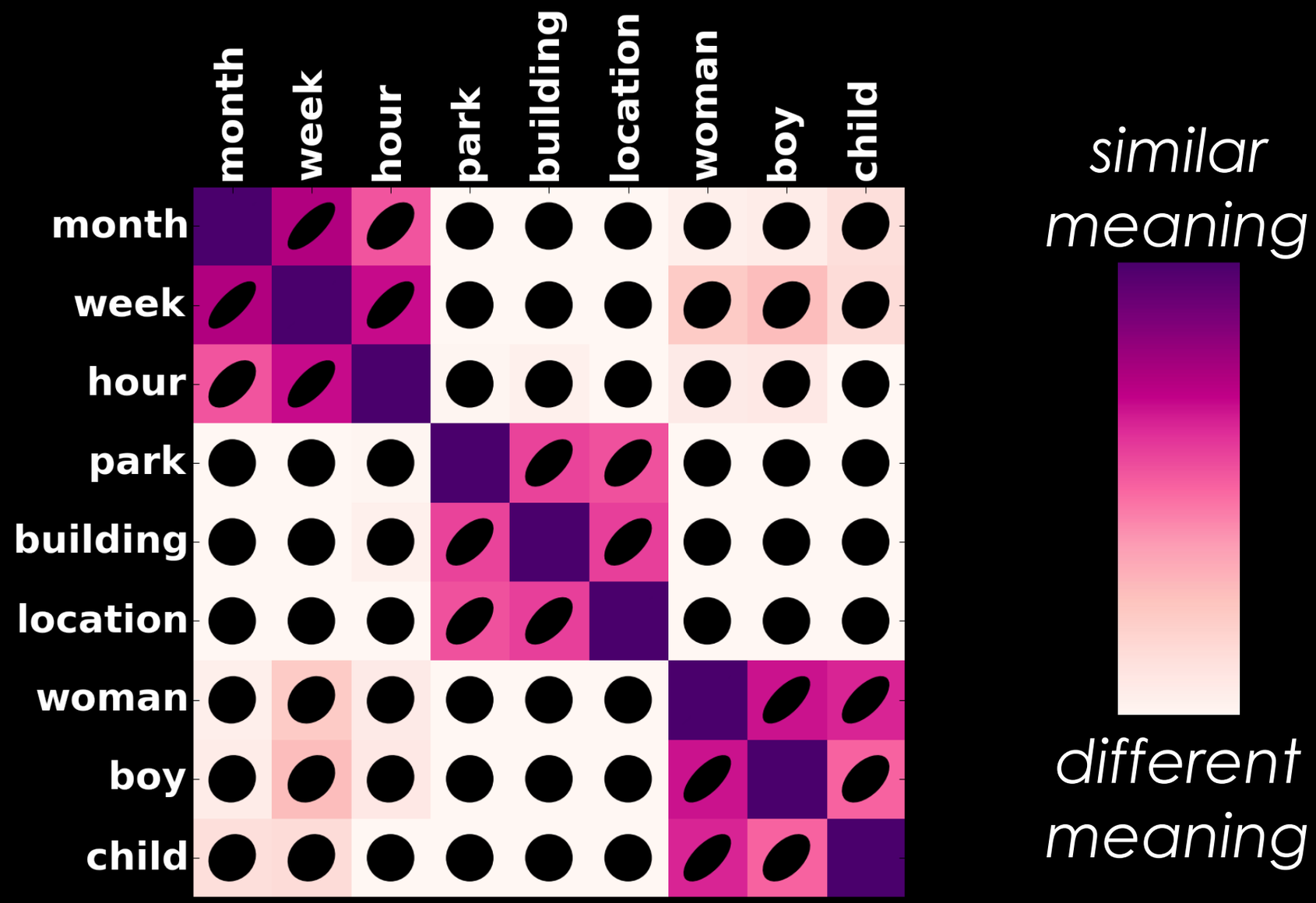
WORD MODEL PERFORMANCE: MEDIOCRE



SEMANTIC PRIOR

IMPROVED MODEL:

similar responses to words with similar meanings



SEMANTIC PRIOR

Distributional hypothesis:

"You shall know a word by the company it keeps"

J. R. Firth (1954)

SEMANTIC PRIOR

…

difficult

…

husband

…

potato

…

remember

…

CO-OCCURRENCE MATRIX

10,470 words

SEMANTIC PRIOR

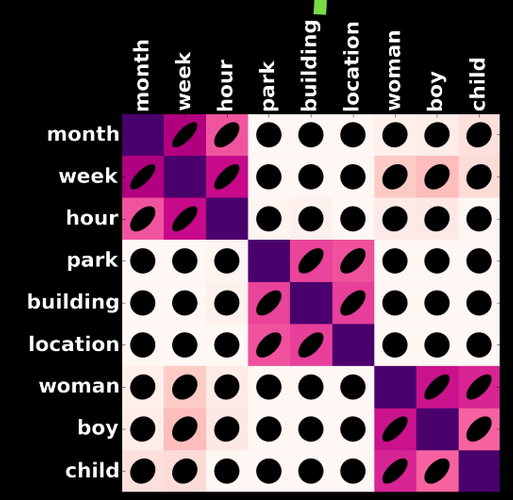
IMPROVED MODEL:

similar responses to words with similar meanings

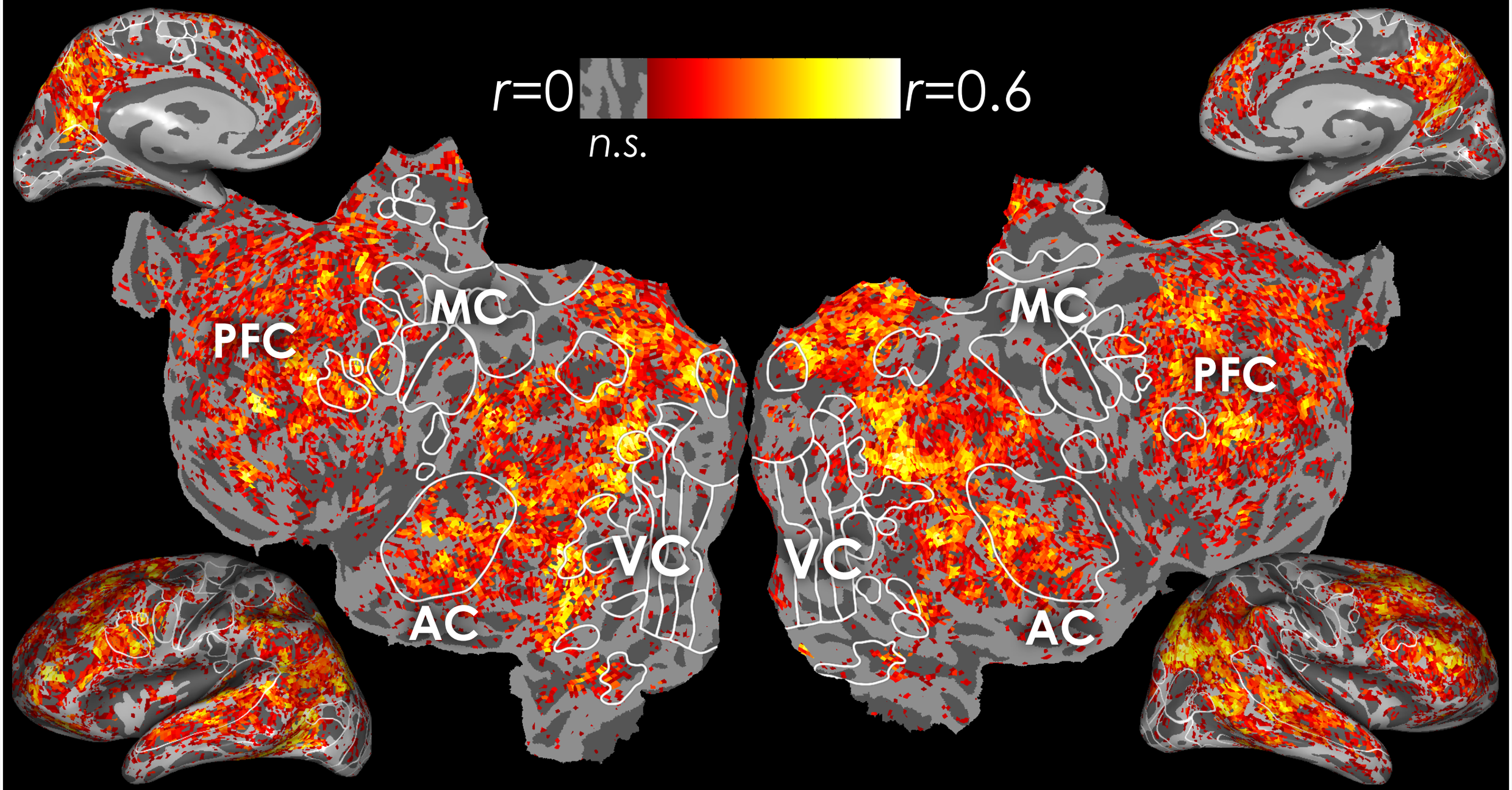
$$\hat{\beta} = \underset{\beta}{\operatorname{argmax}} \; P(R|\beta, W) \; P(\beta)$$

likelihood

prior



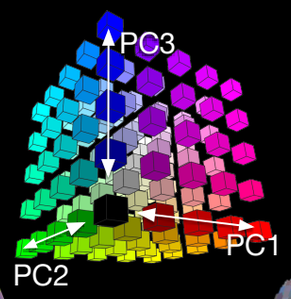
SEMANTIC MODEL PERFORMANCE: EXCELLENT

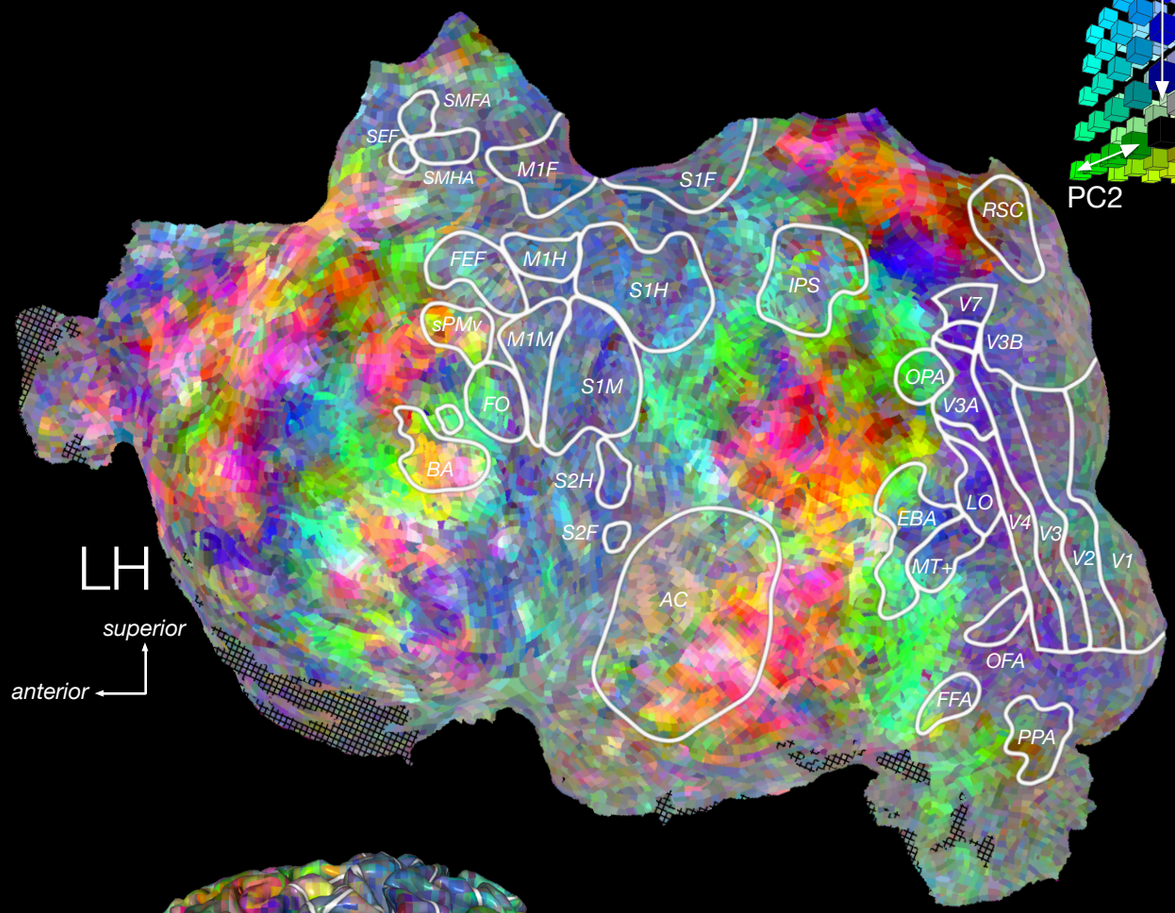


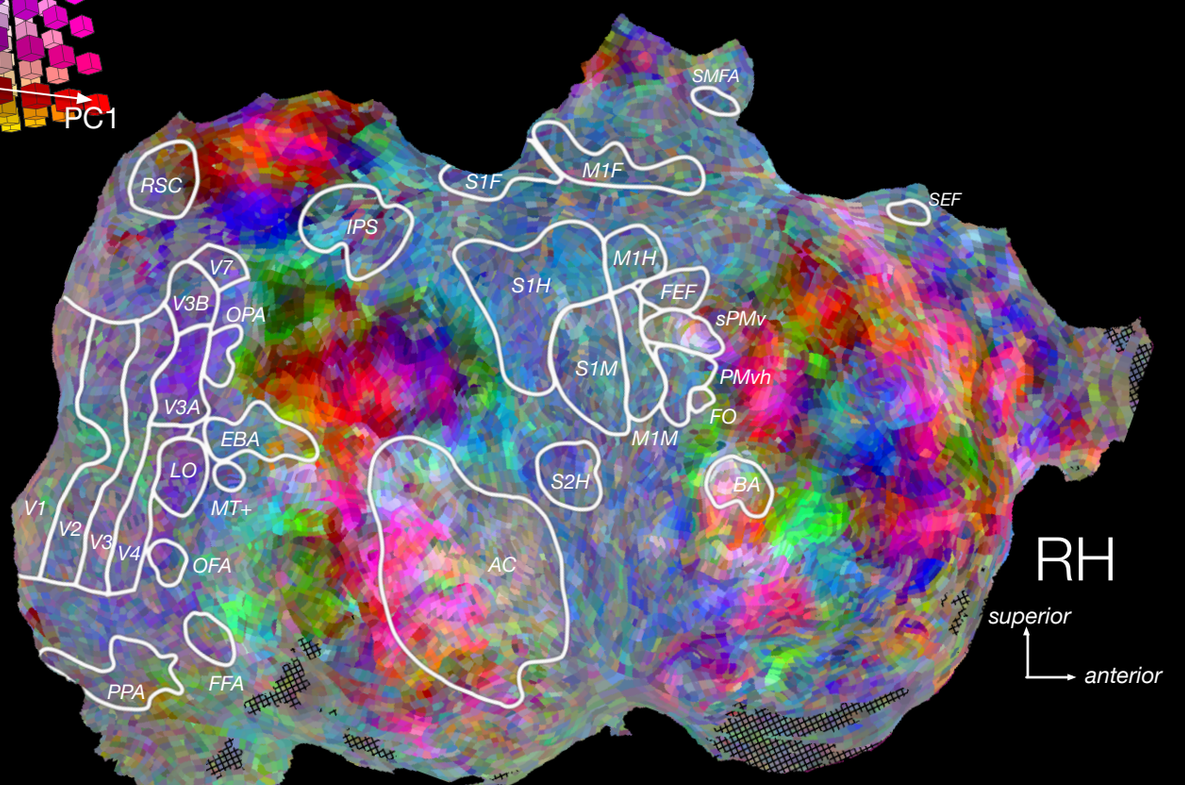
MODEL INTERPRETATION

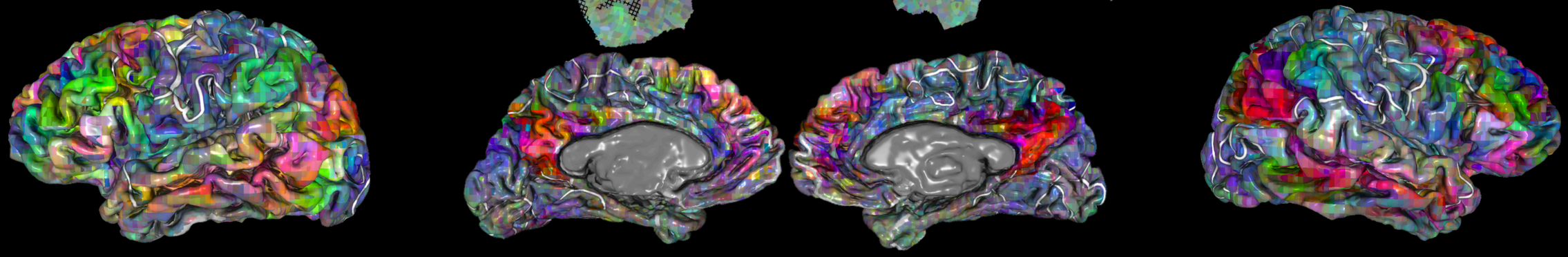
visual
tactile
numeric
abstract
violent
locational
communal
emotional
social
temporal
professional
mental

PC2
PC1

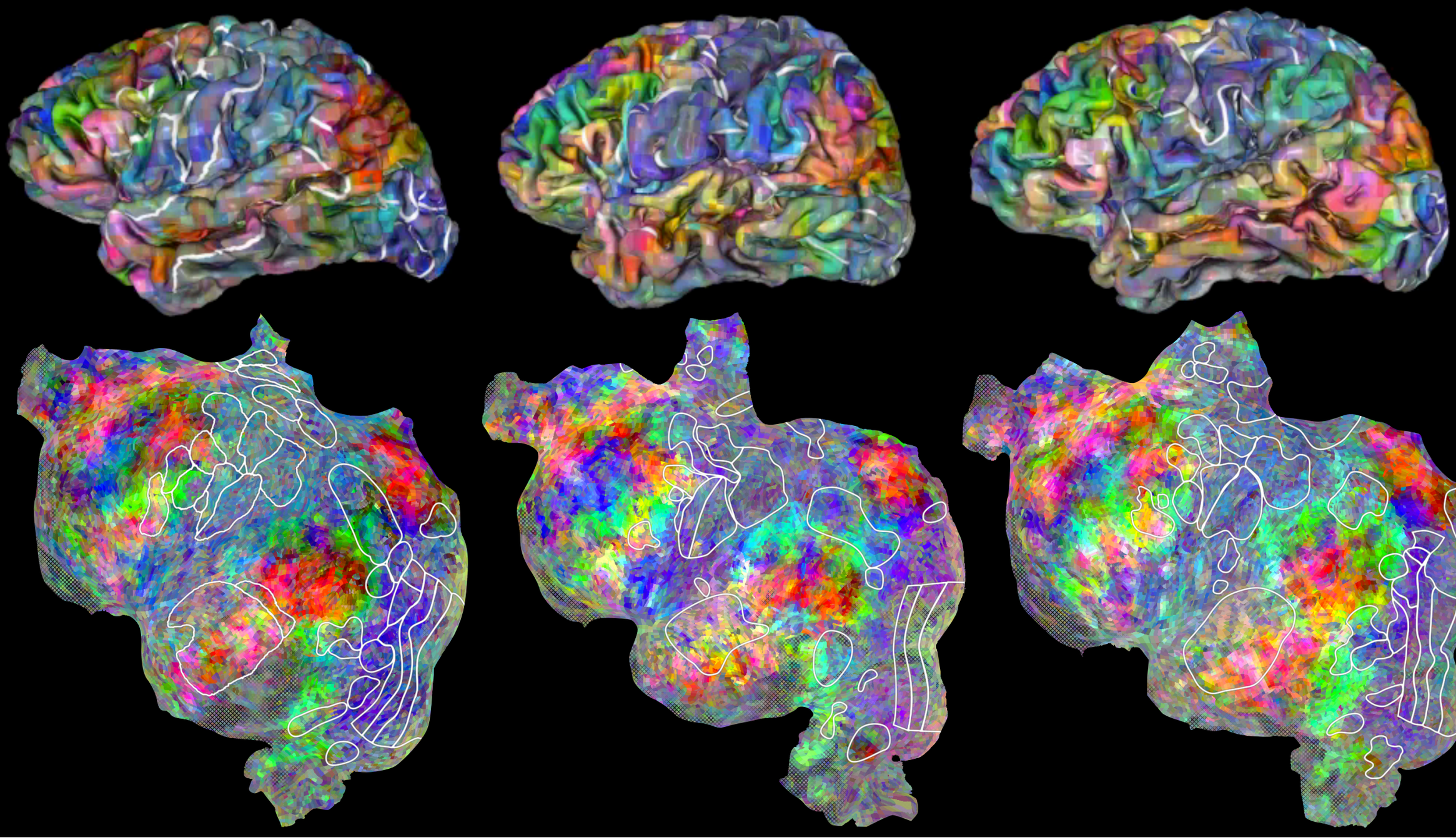






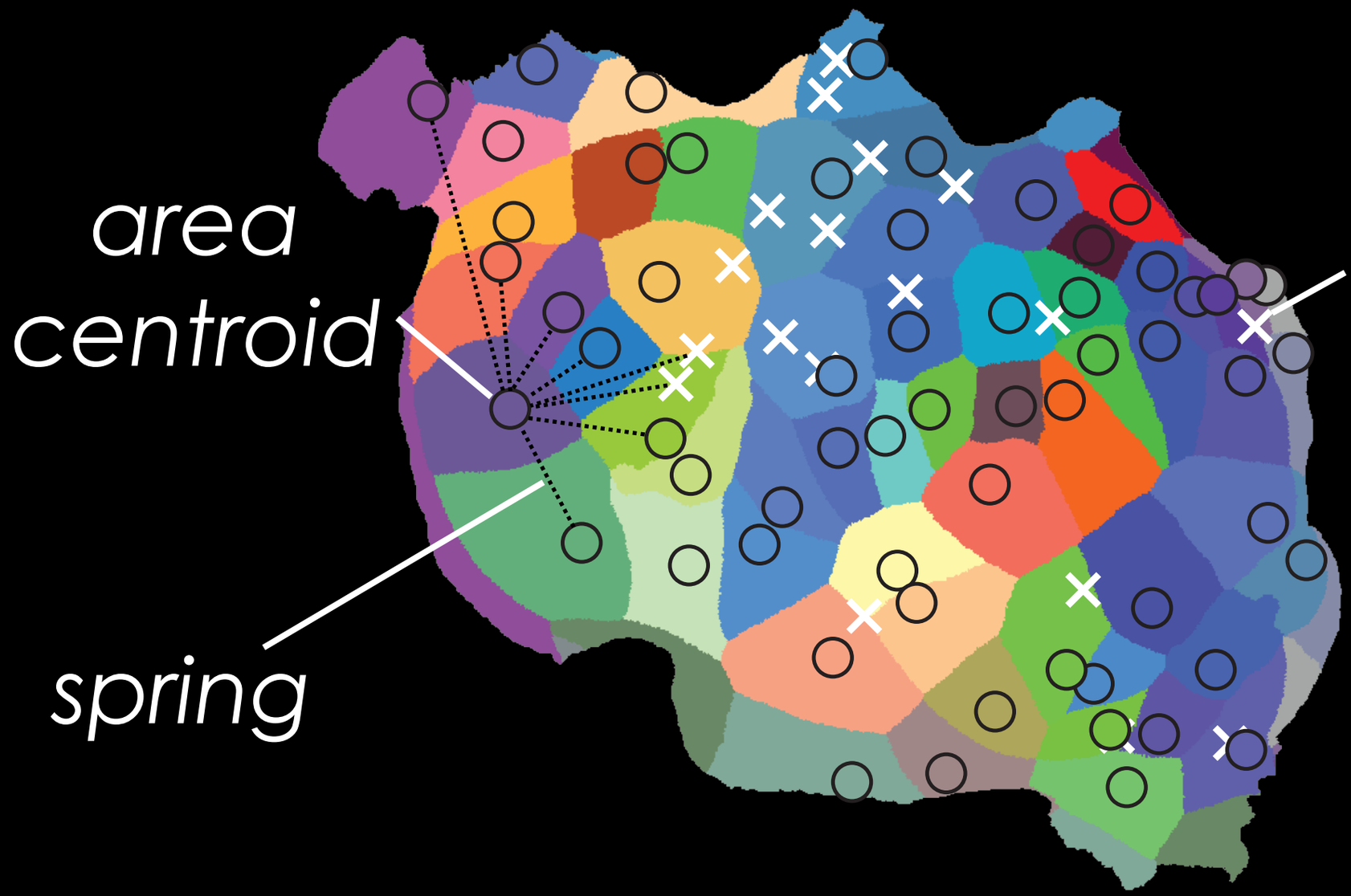


MAPS ARE CONSISTENT ACROSS SUBJECTS



PrAGMATiC

Probabilistic and Generative Model of Areas Tiling the Cortex



PrAGMATiC

SHARED ACROSS SUBJECTS

Ideal Spring Lengths

Spring Constants

Area Semantic Properties

UNIQUE TO EACH SUBJECT

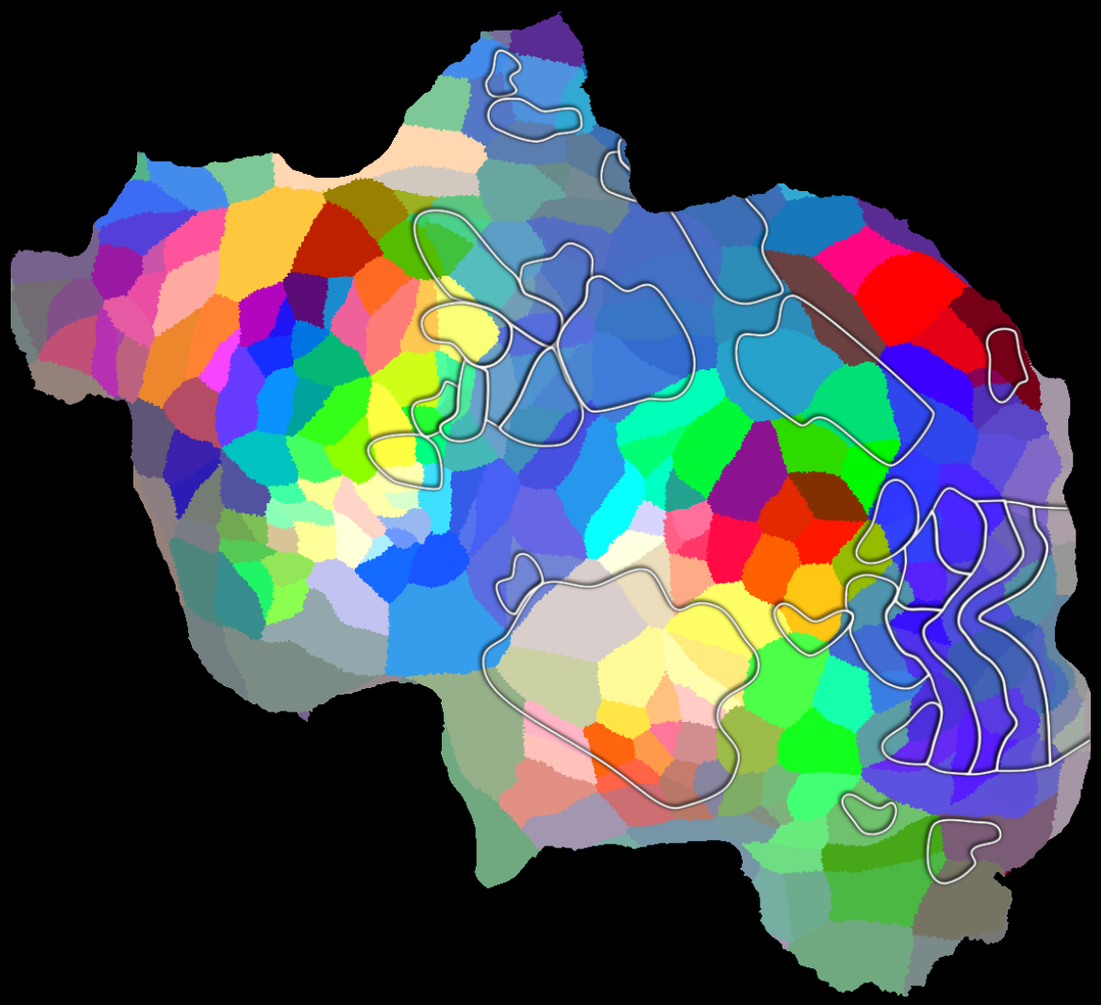
Exact Area Locations

Observed Functional Data

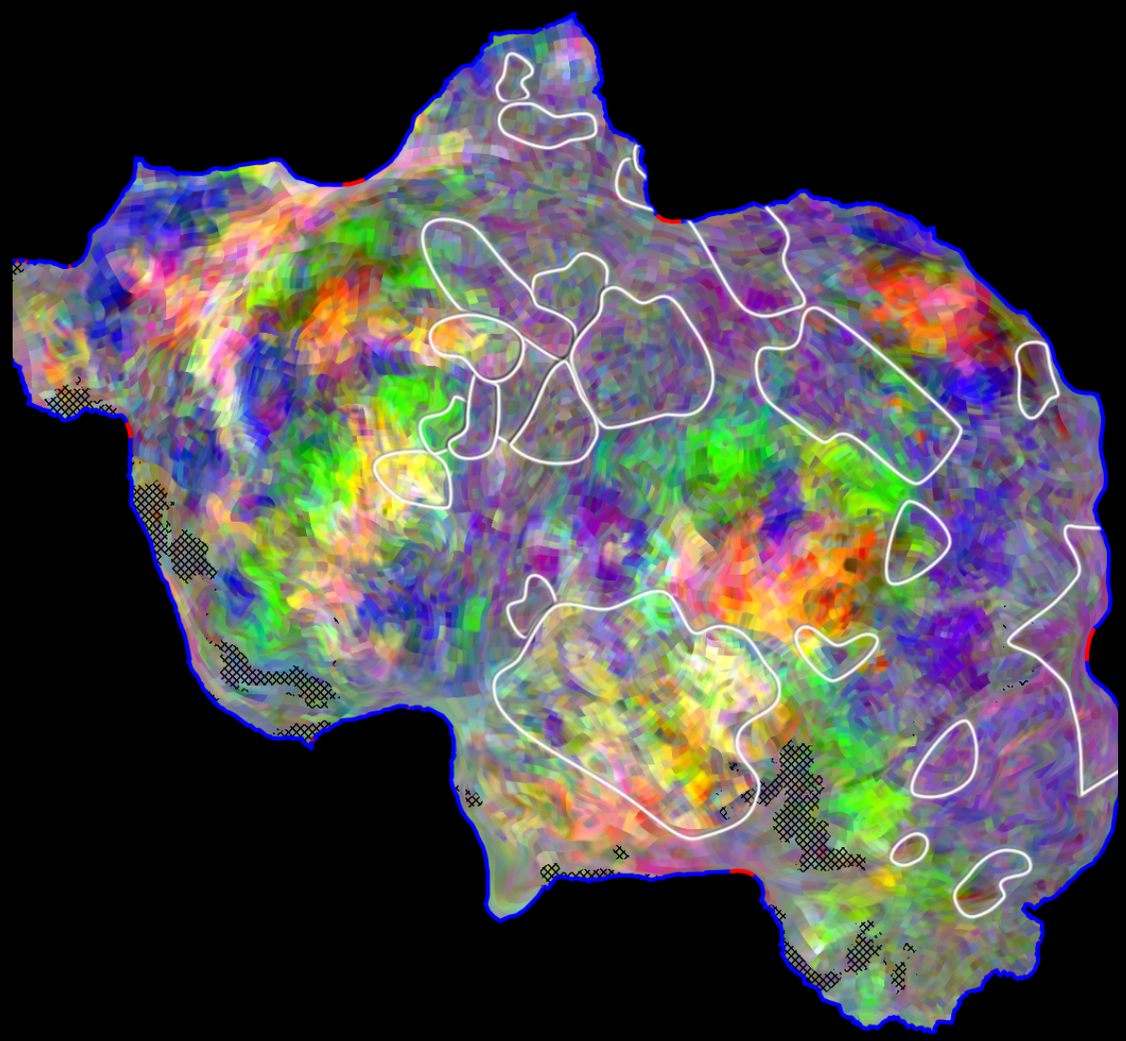
PrAGMATiC

model tested on held-out subjects

Predicted map



Actual map



PrAGMATiC Parameters

Shared across subjects

L - ideal spring lengths

K - spring constants

M - area functional means

Unique to each subject

H - exact centroid locations

V - functional values on cortex

$$P(V, H; M, L, K) = P(H; L, K)\, P(V|H; M)$$

total probability = *arrangement probability* * *map probability*

$$P(H; L, K) \propto e^{-E(H;L,K)}$$

$$E(H; L, K) = \sum_{i,j,s} K_{ij}(d_{ijs} - L_{ij})^2$$

distance between centroids i and j in subject s

$$P(V|H; M) \propto e^{-E(V|H;M)}$$

$$E(V|H; M) \propto \sum_{l,s} (M_{H(s,l)} - V_{ls})^2$$

nearest centroid in subject s

SYLLABUS

* Online: github.com/alexhuth/n4cs-fa2017/wiki

* 2 problem sets (due Oct. 12 & Oct. 26)

* Final project (alone or in pairs)

  * Proposal due Oct. 31

  * In-class presentations Dec. 5 & 7

  * Write-up due Dec. 5

THAT'S IT