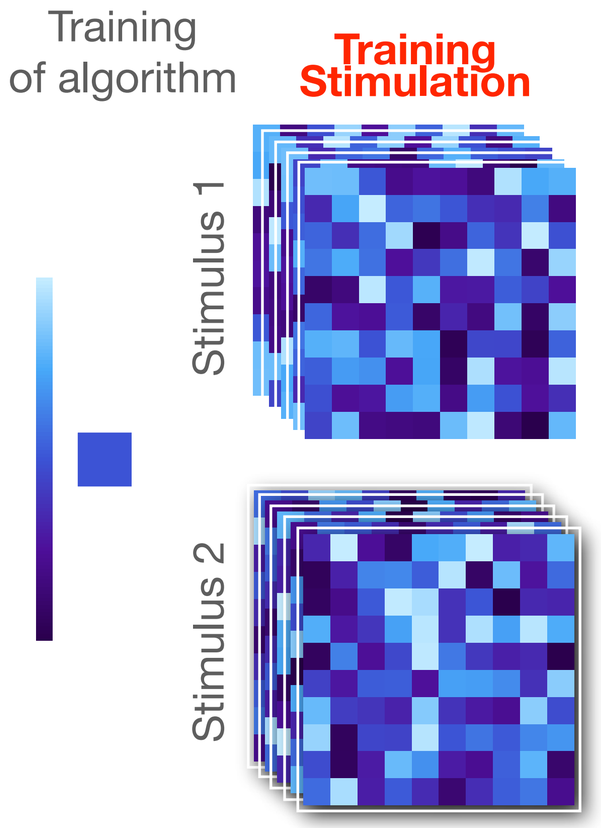
Encoding Models (Receptive Fields in fMRI)

Brain Imaging 2022

Decoding

Decoding

Not mean signal intensity, but the **pattern** of activity in a certain region of interest is used to classify what the brain state is.



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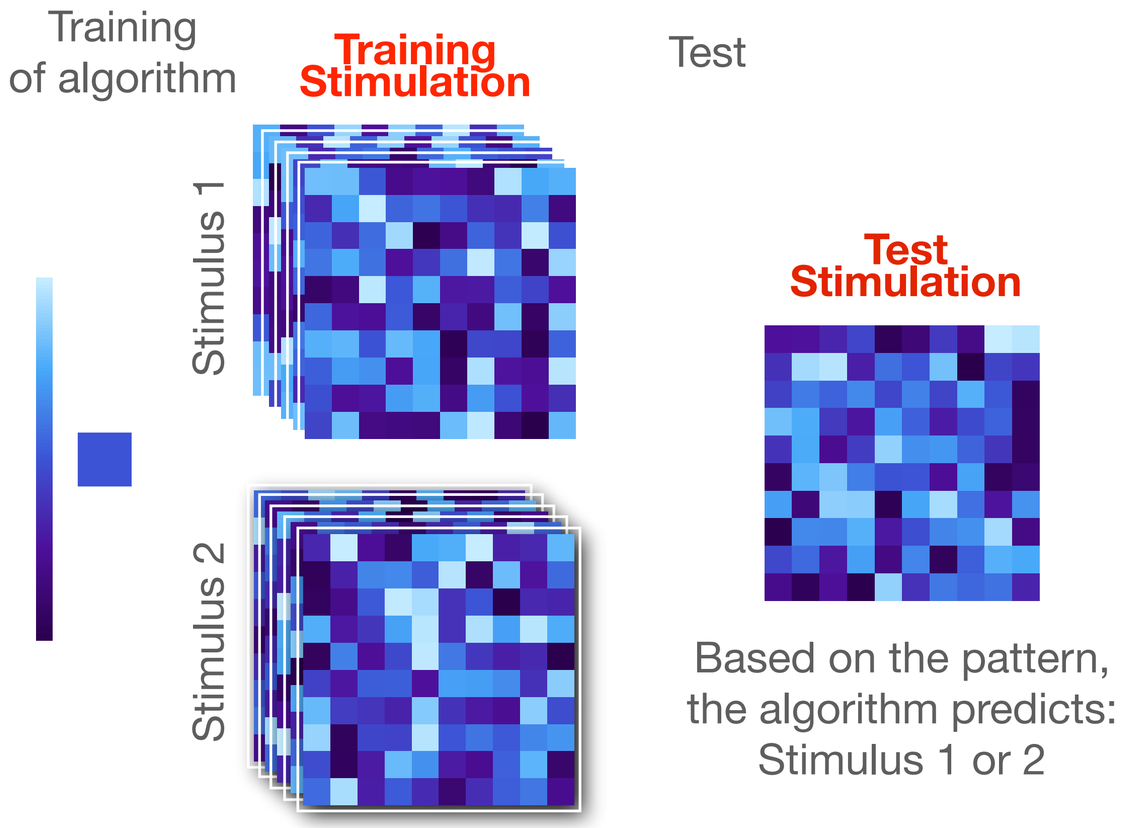

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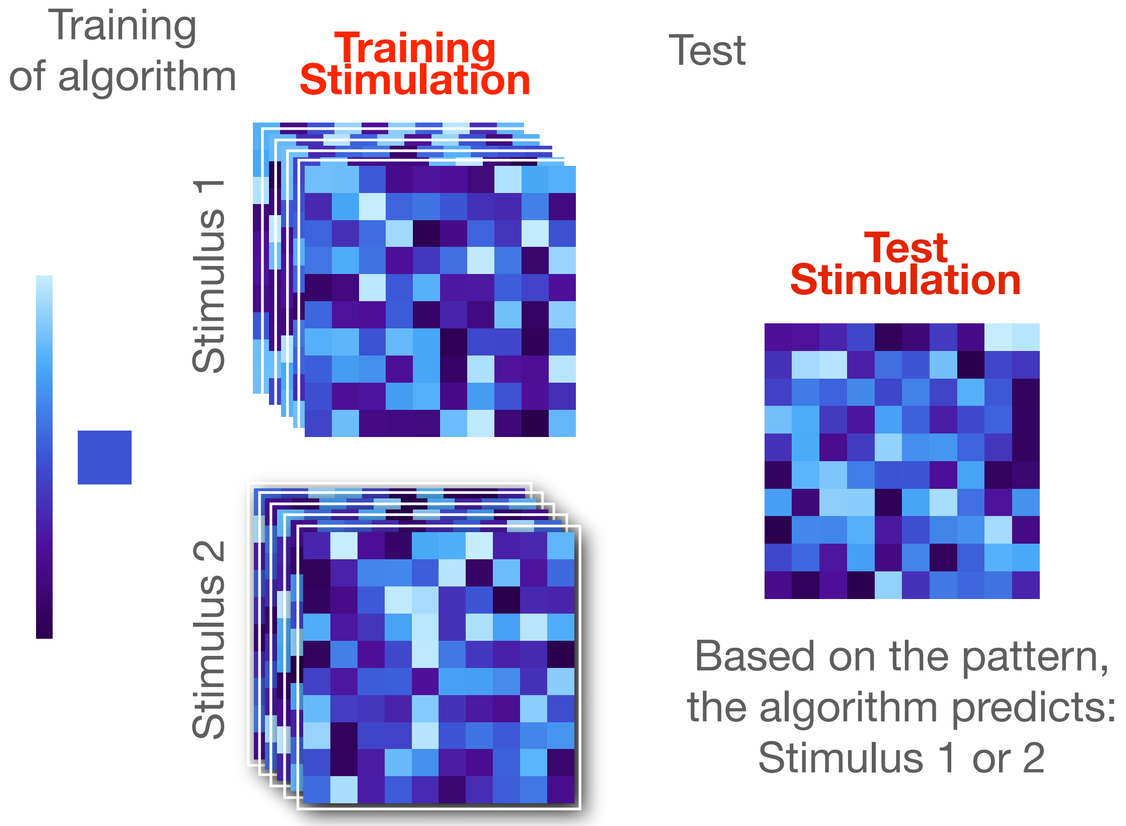

Performance of algorithm expressed as accuracy

gauge on information content in a specific region of interest

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The classifier draws a relation between the input space (conditions, images, sounds, etc) and the patterns of brain activation found in a given region

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If the pattern of activations contains information regarding the input space, the classifier can successfully decode.

Decoding

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Strong debates:
How do these patterns relate to neural mechanisms?

Is fMRI sampling sub-voxel information, or merely basing itself on the global structure within a region?

Decoding

Decoding

Perhaps, ***the single voxel is important.***

Perhaps, if we value the single voxel, we may
learn more about the brain's underlying mechanisms that lead to patterns...

Decoding

We don’t care about what each voxel is doing, but only about the distribution of values (‘pattern’) across a certain region.

Perhaps, ***the single voxel is important.***

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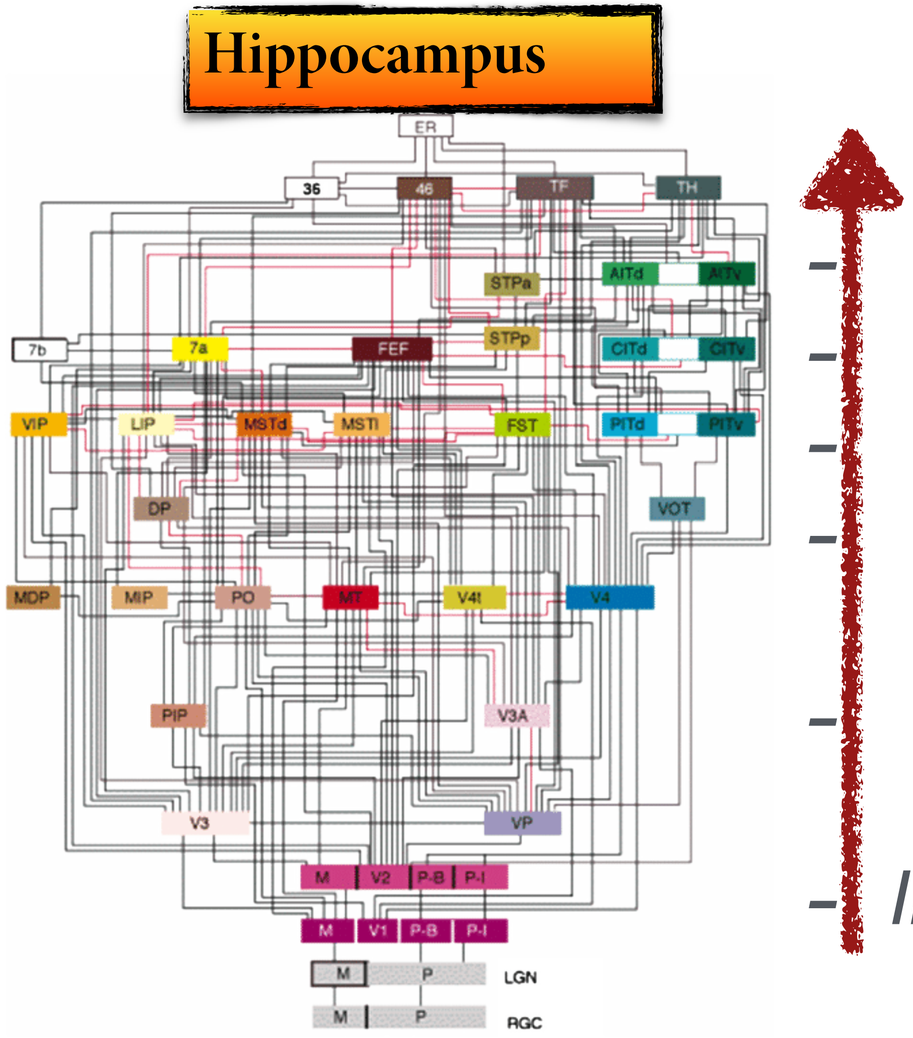
Once we know this, we can reverse this process, and see for a whole group of neurons/sensors/voxels, what their pattern of activations tells us about conditions, stimuli, etc. - ***encoding-model based decoding***



Arrow of:

Increased Abstraction

Increased Invariance

Increased Specialization

Increased Multi-Sensory Integration

Increased Temporal Integration

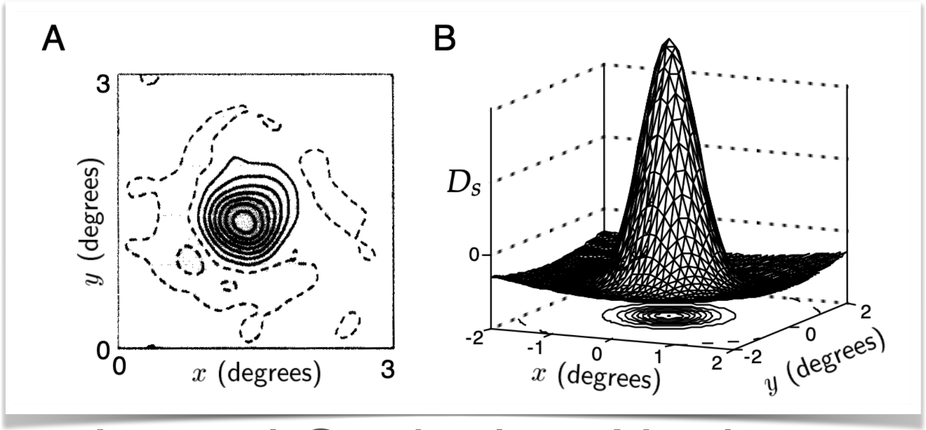
Increased Action-Perception Integration

Hubel & Wiesel

Hubel & Wiesel

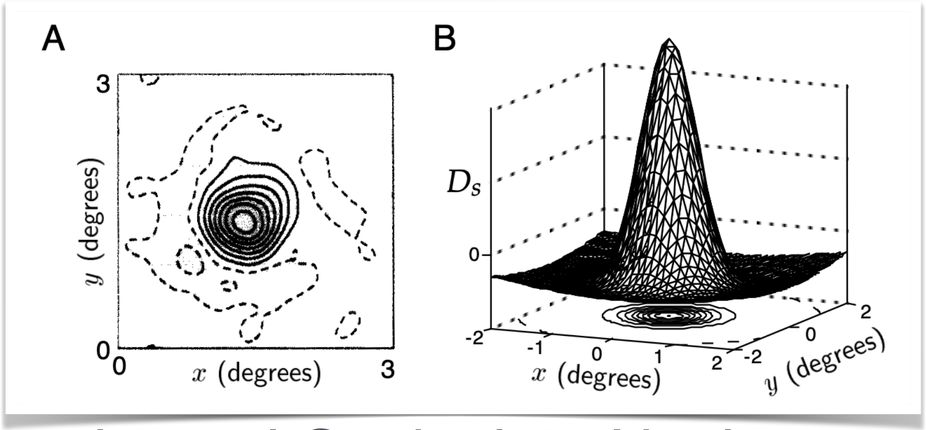
Visual Receptive Fields

Visual Receptive Fields



Lateral Geniculate Nucleus
LGN

Visual Receptive Fields



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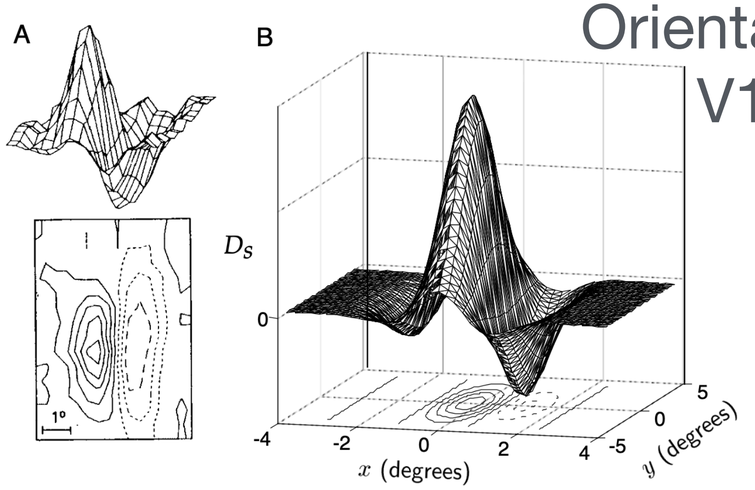
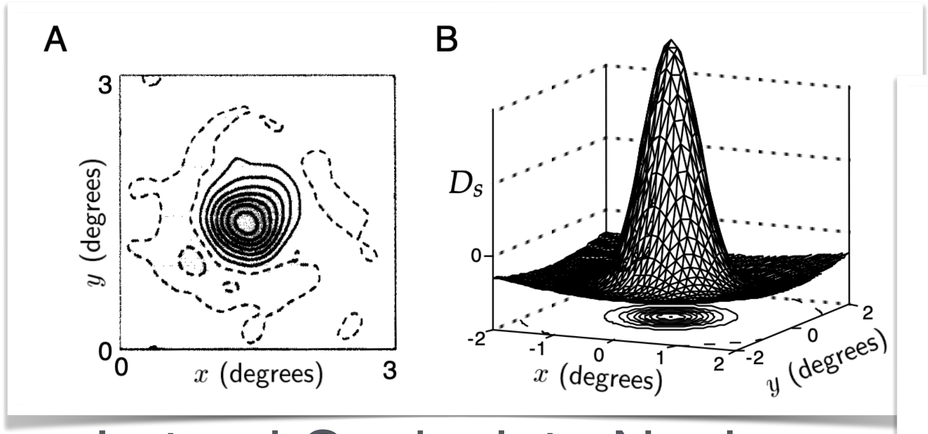


Orientation
V1

Visual Receptive Fields



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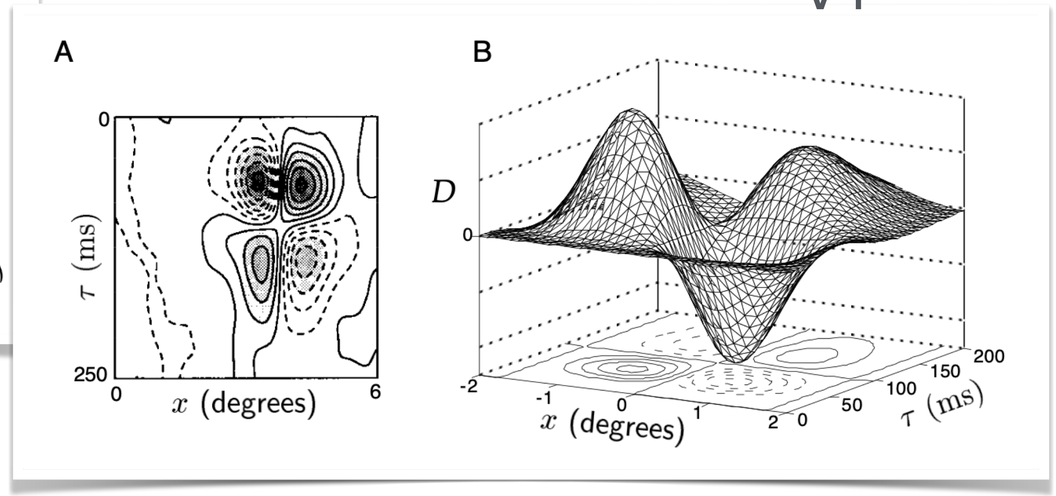
Flicker
V1



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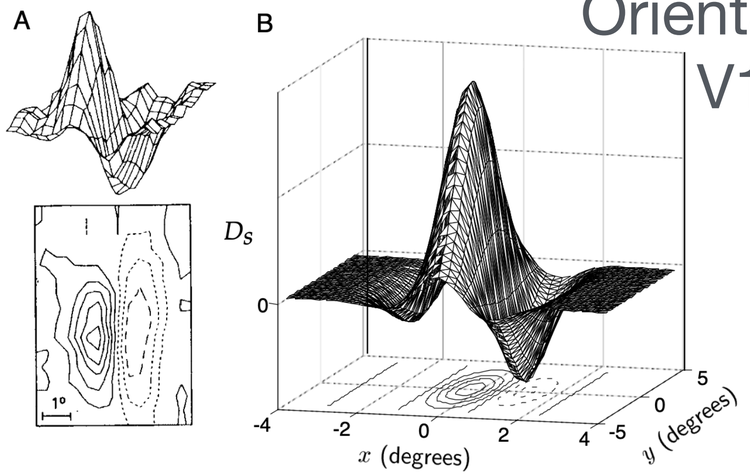

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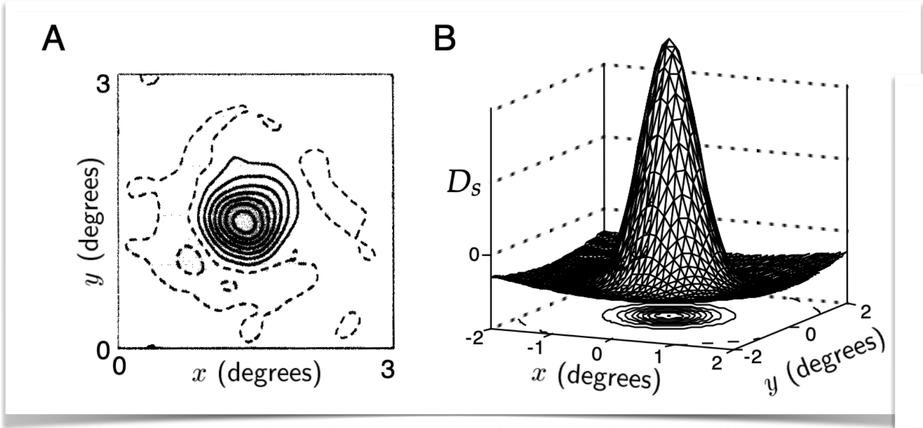

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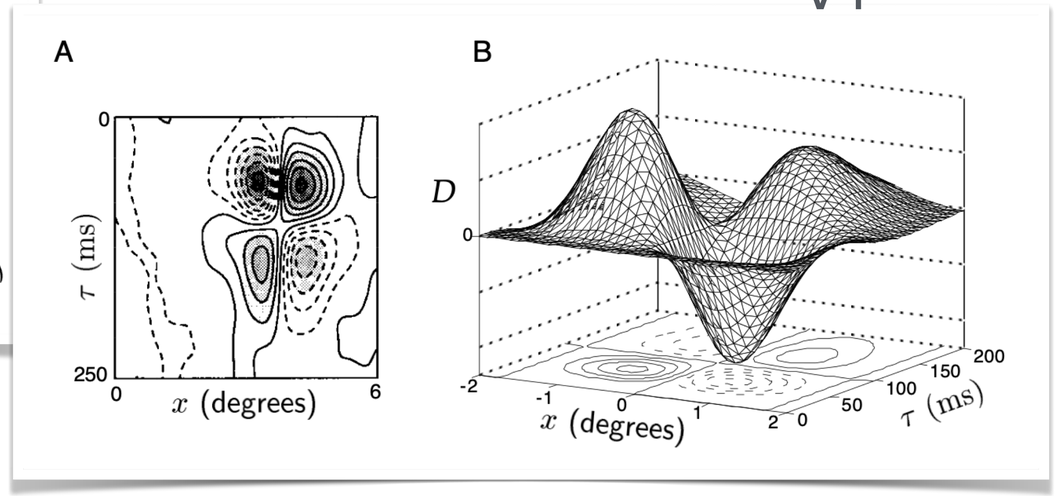

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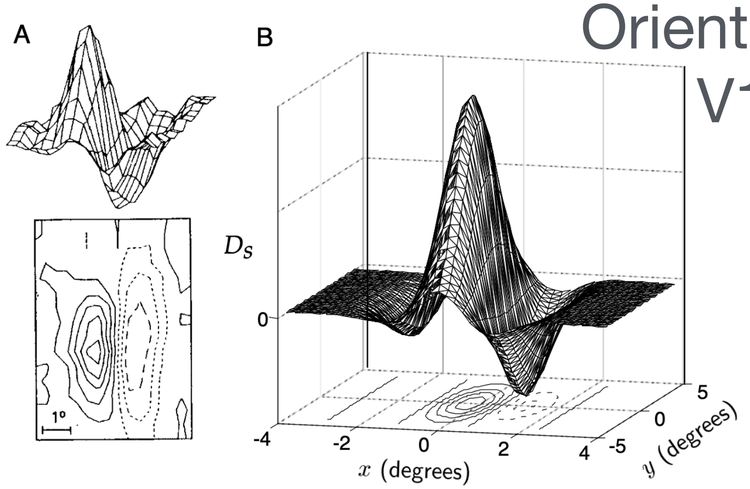
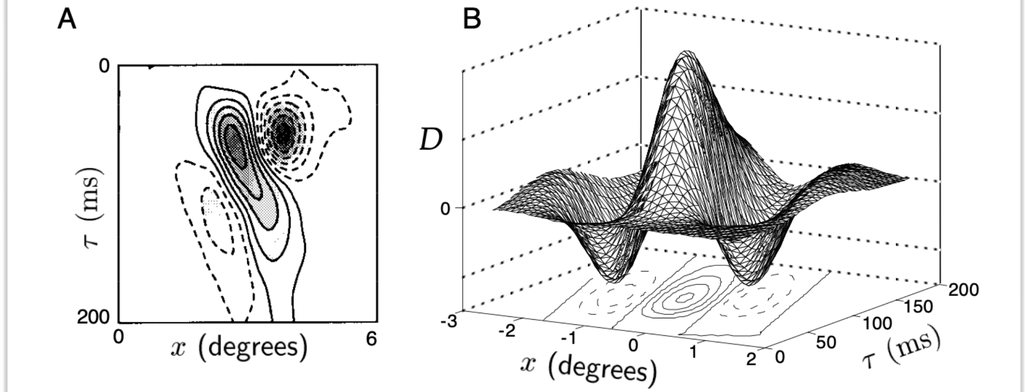
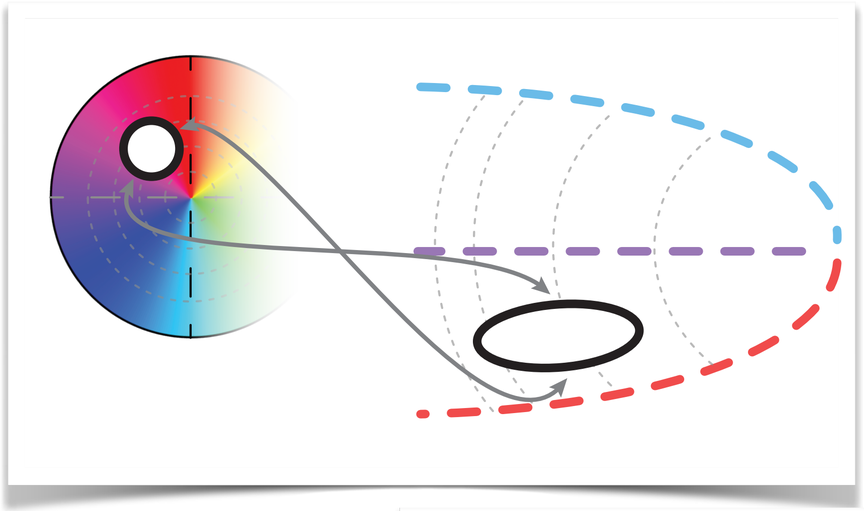
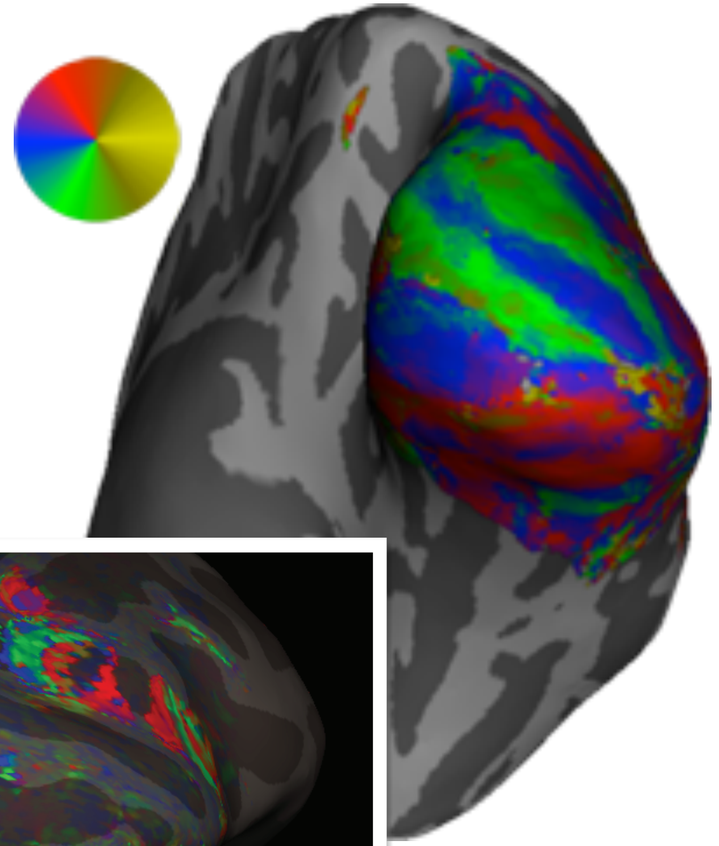
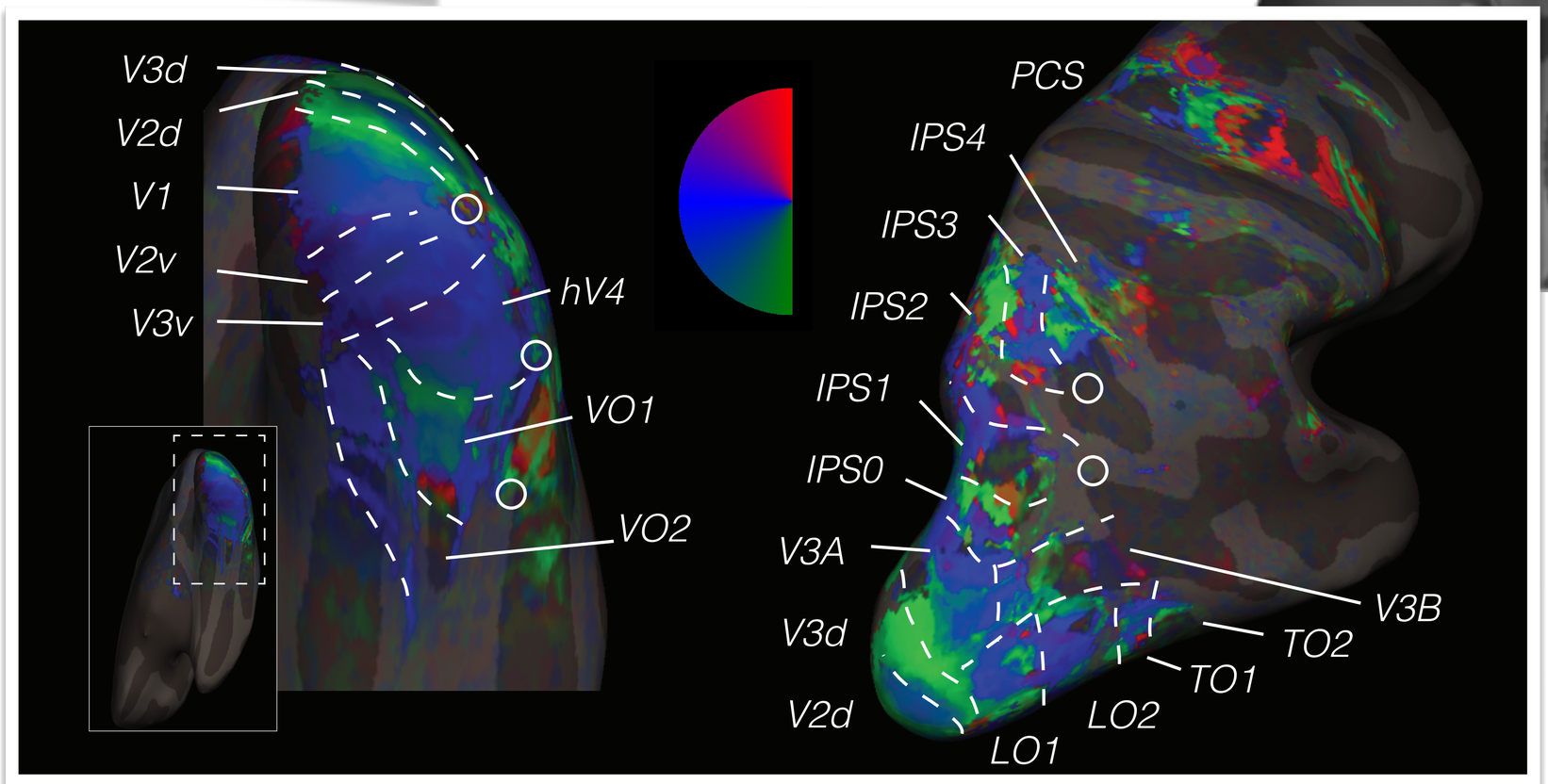


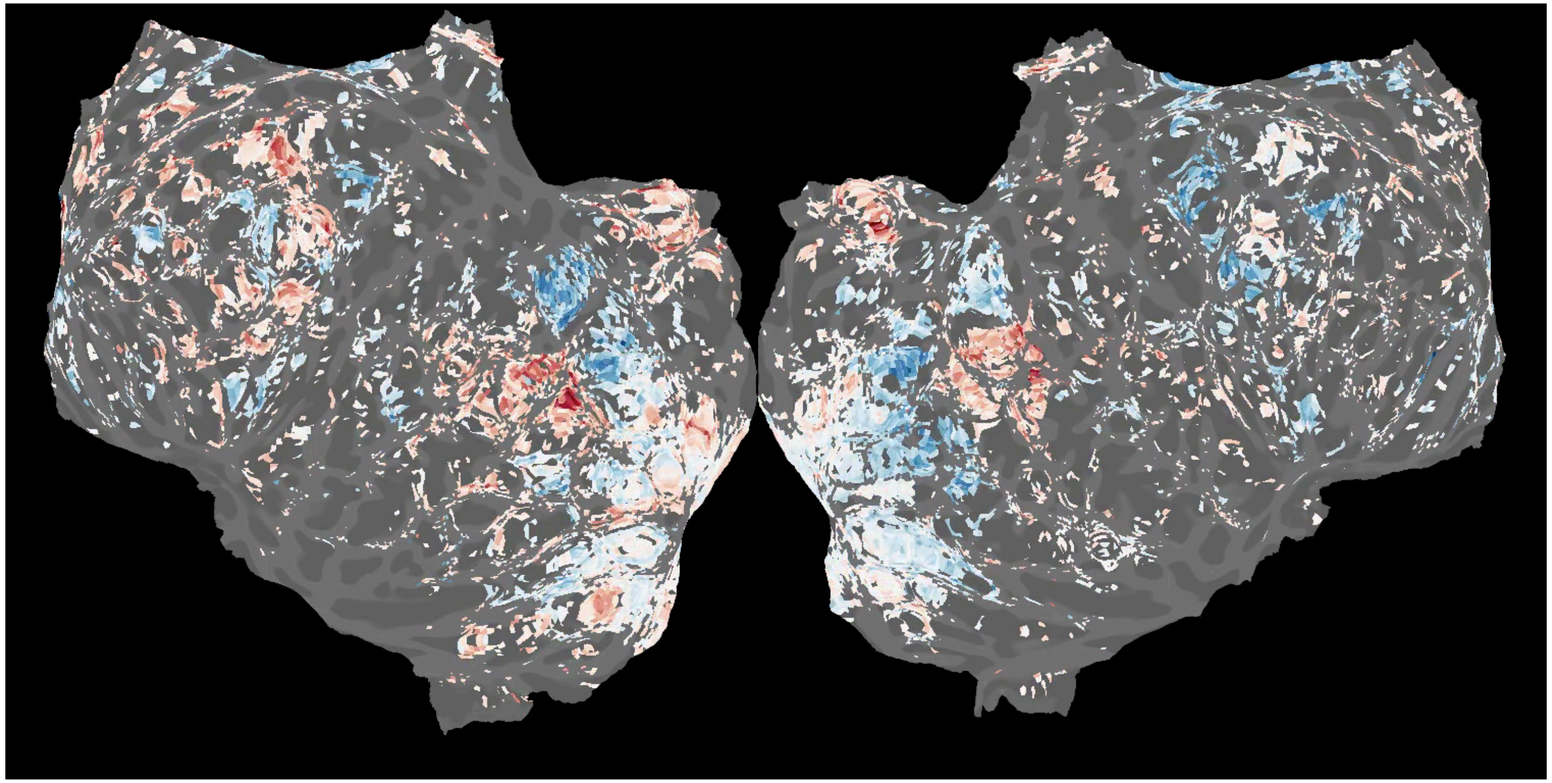
Motion
V1 & MT

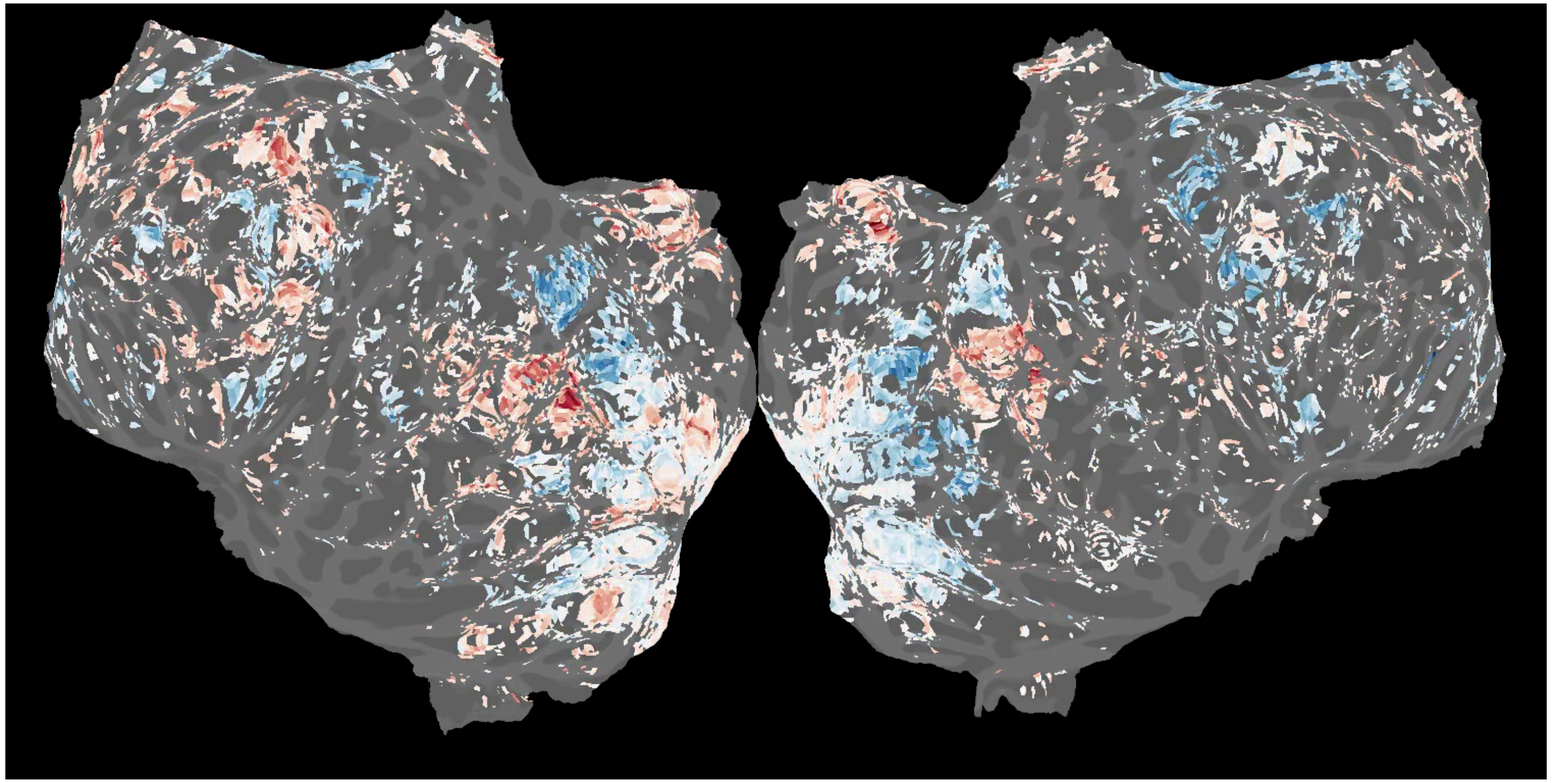


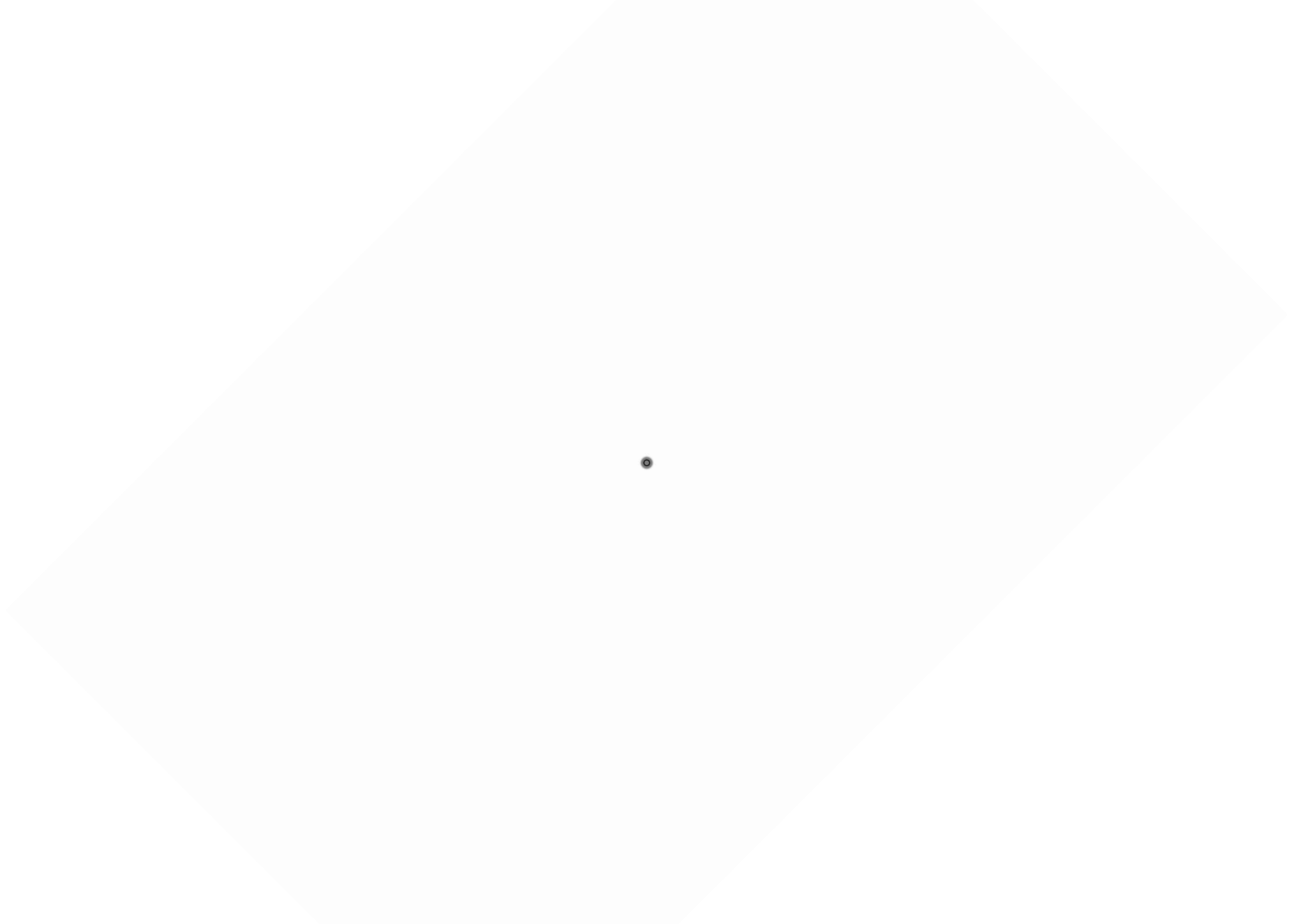





V3d
V2d
V1
V2v
V3v
hV4
VO1
VO2
PCS
IPS4
IPS3
IPS2
IPS1
IPS0
V3A
V3d
V2d
LO1
LO2
TO1
TO2
V3B





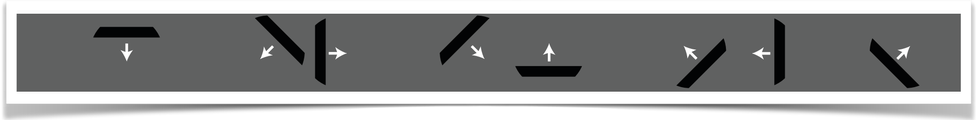


*Structured single-voxel BOLD time course: we can **fit PRF parameters***

Position

$$g(x_0, y_0, \sigma) = exp(-\frac{(x - x_0)^2 + (y - y_0)^2}{2\sigma^2}),$$

Size



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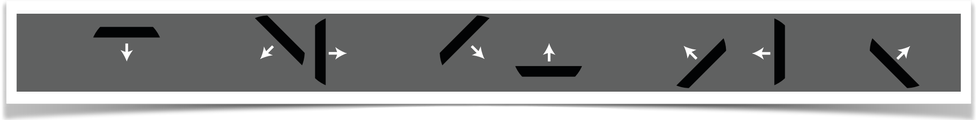

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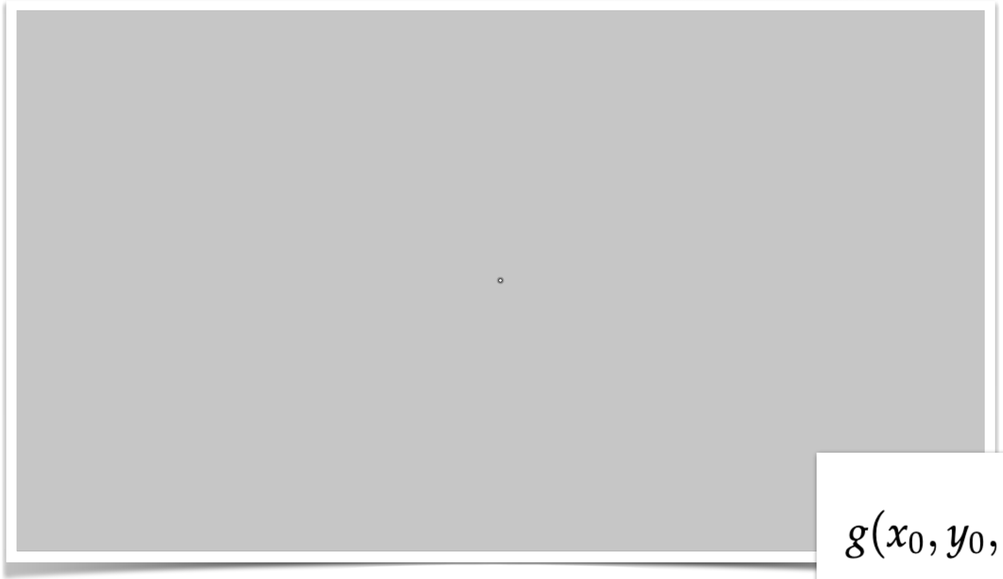

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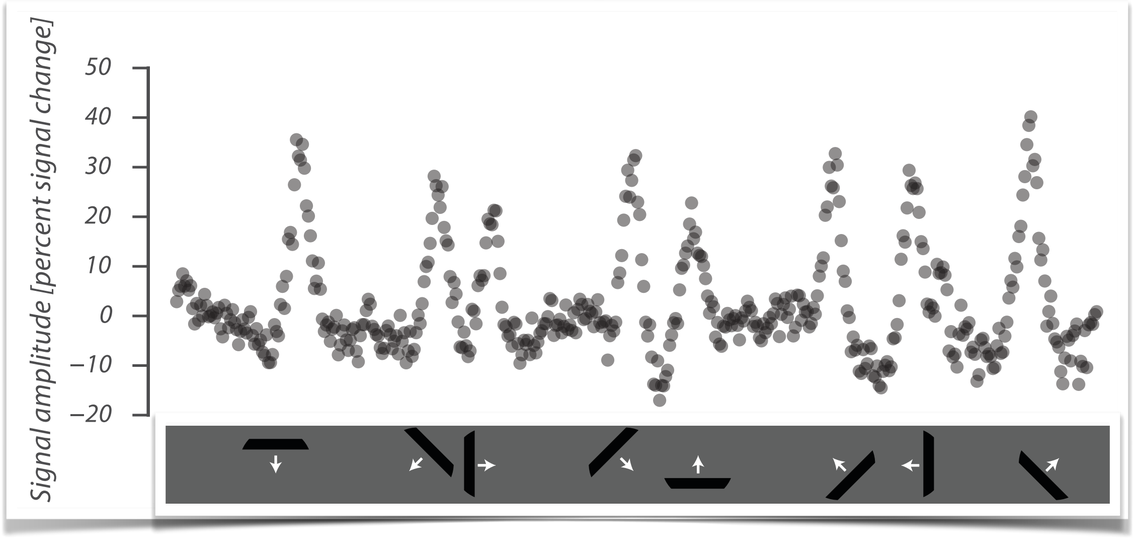

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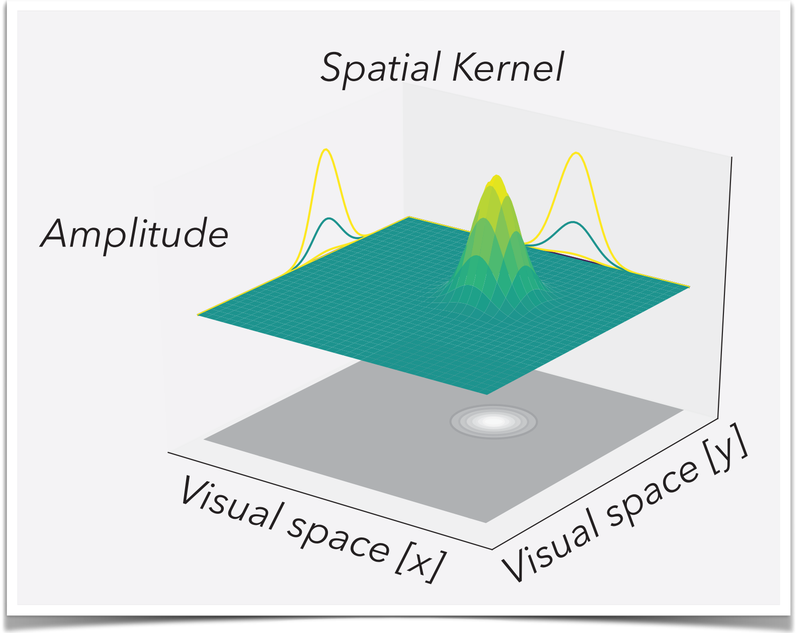

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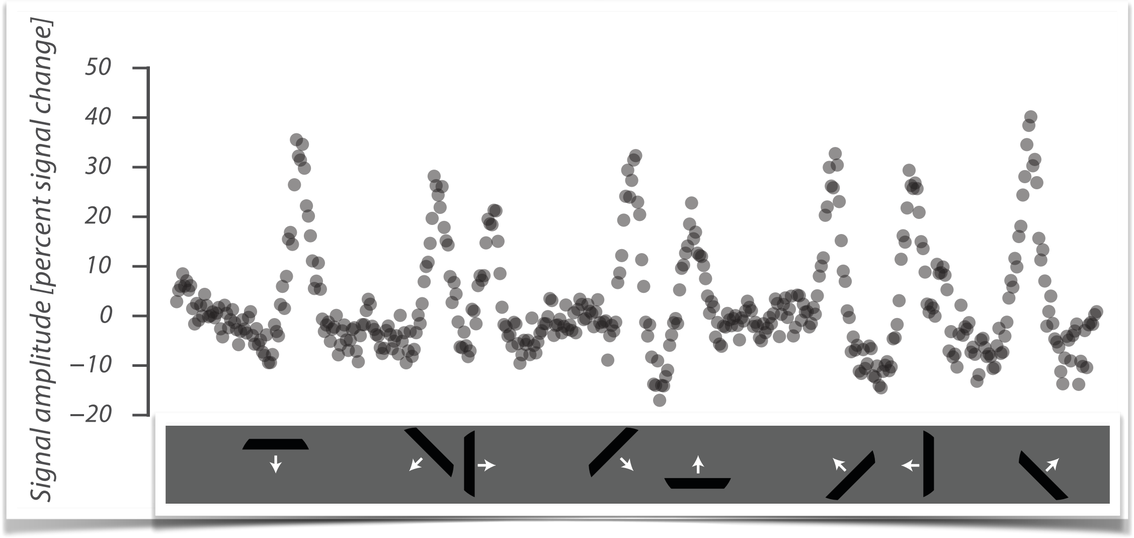

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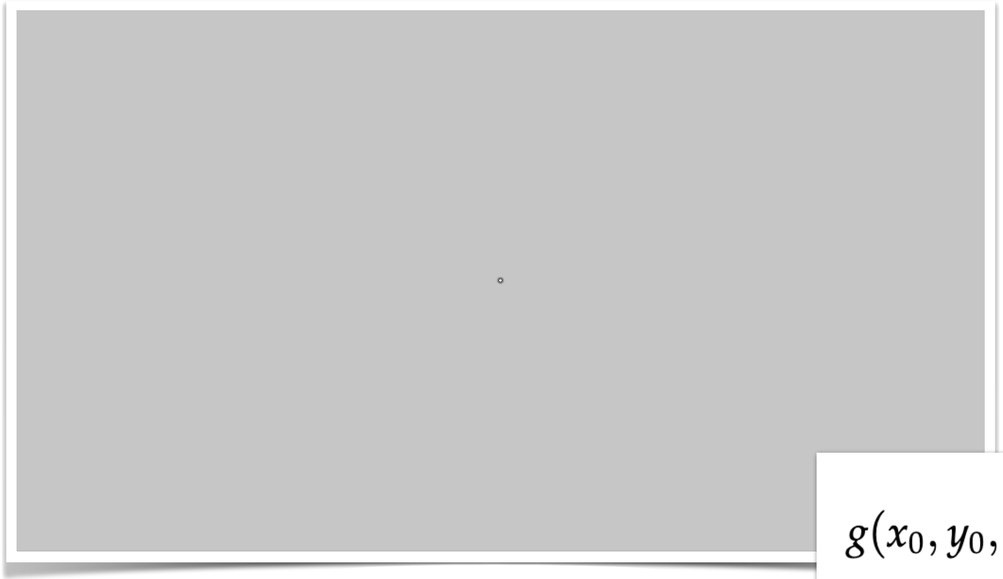

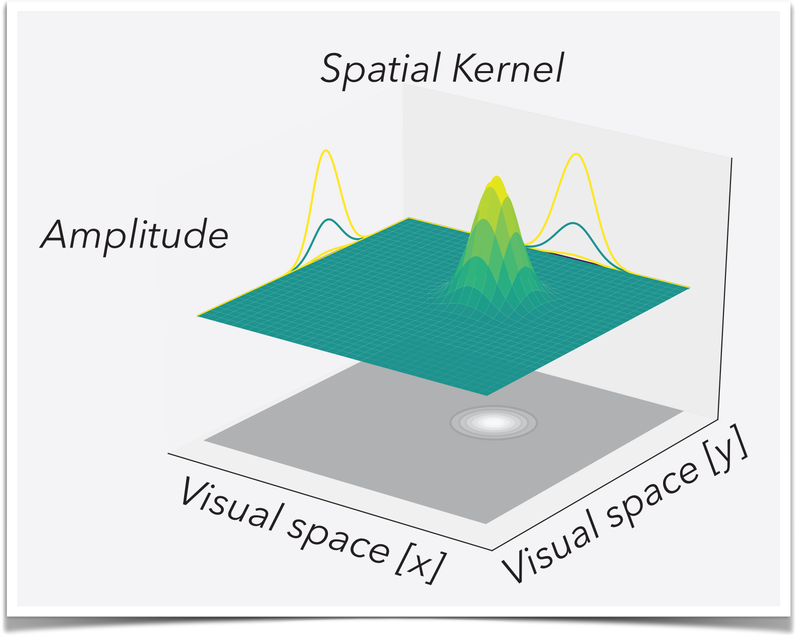

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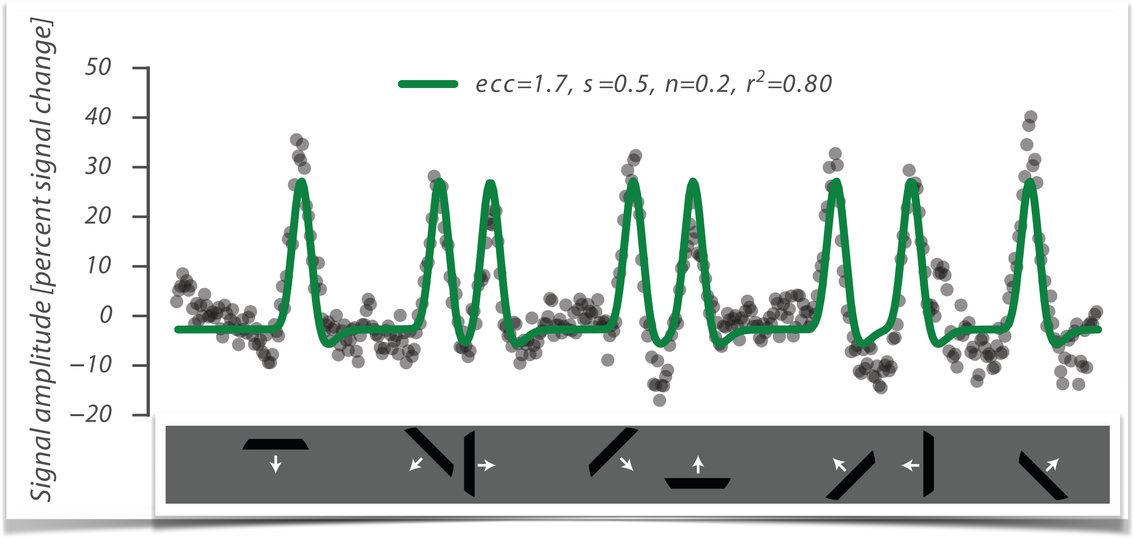
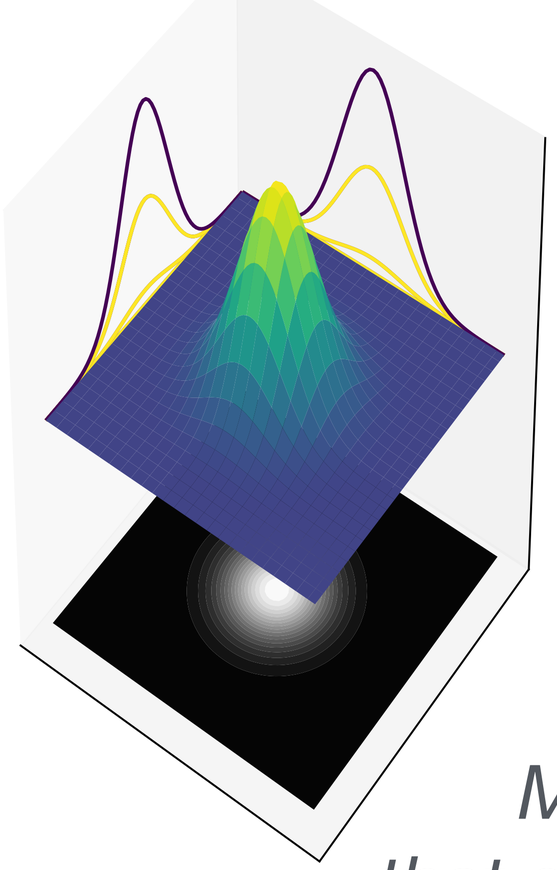
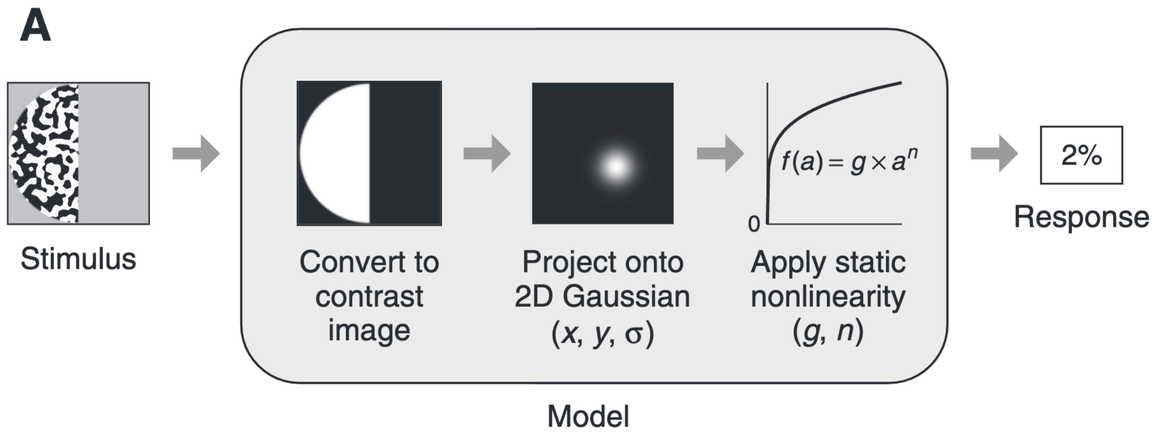
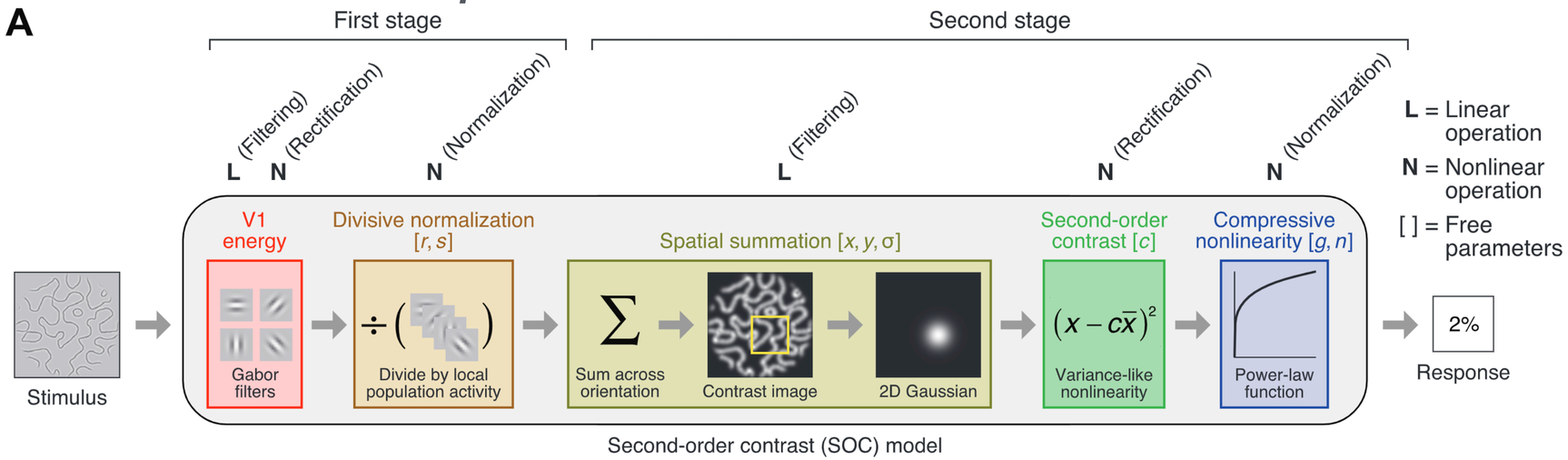






Add "Compressive" Nonlinearity

Make more and more complicated models that explain more and more of the BOLD responses



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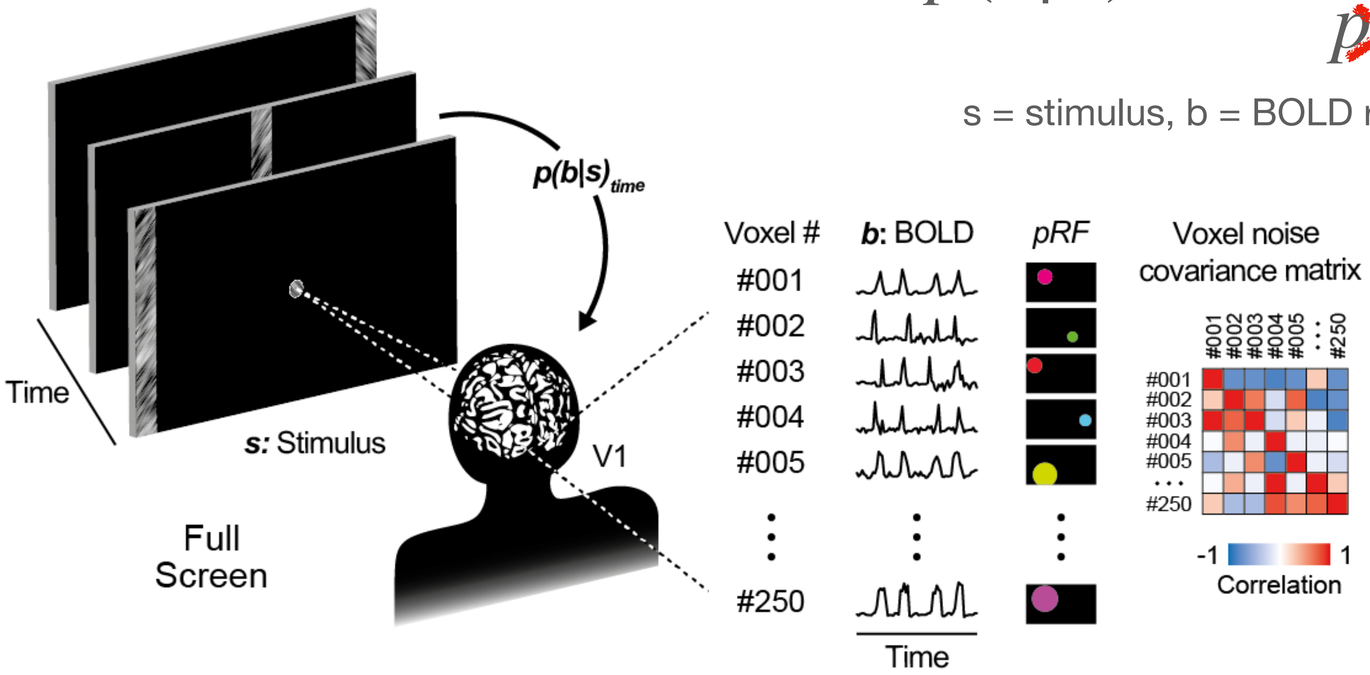

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What we want to know, the probability of a stimulus given a BOLD response pattern

DECODING

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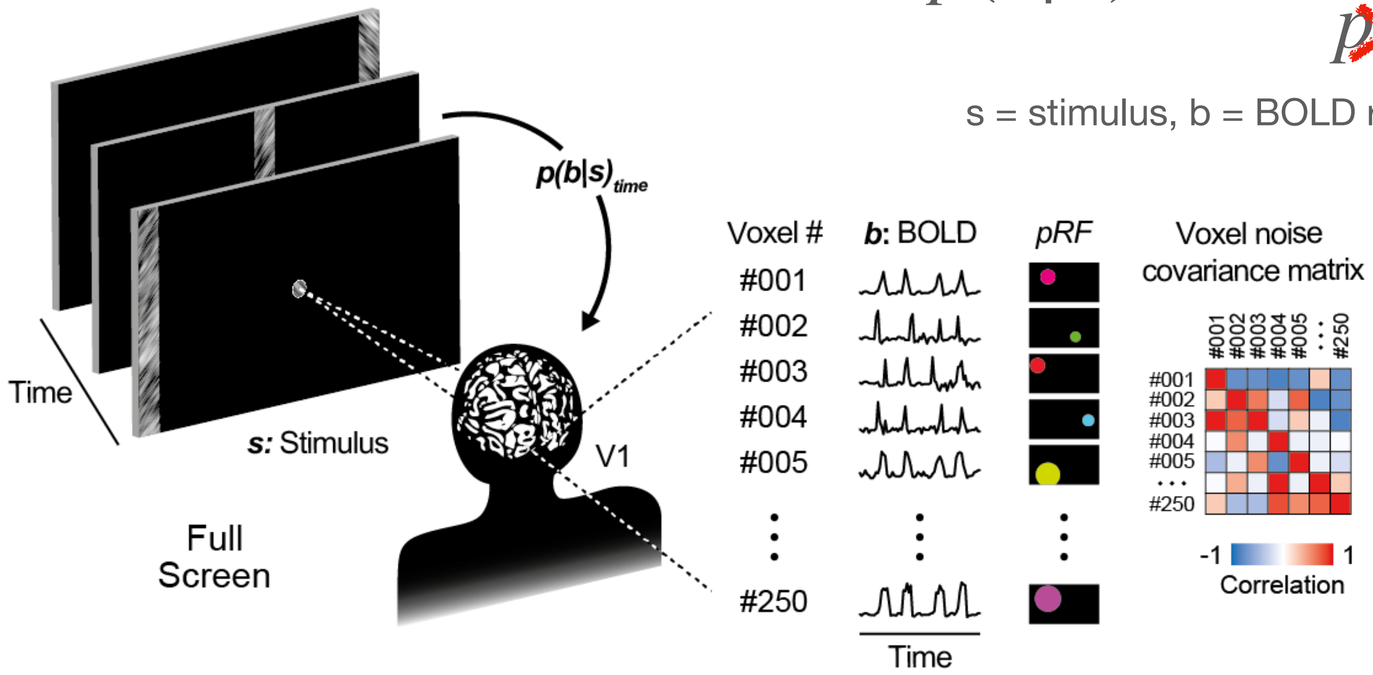

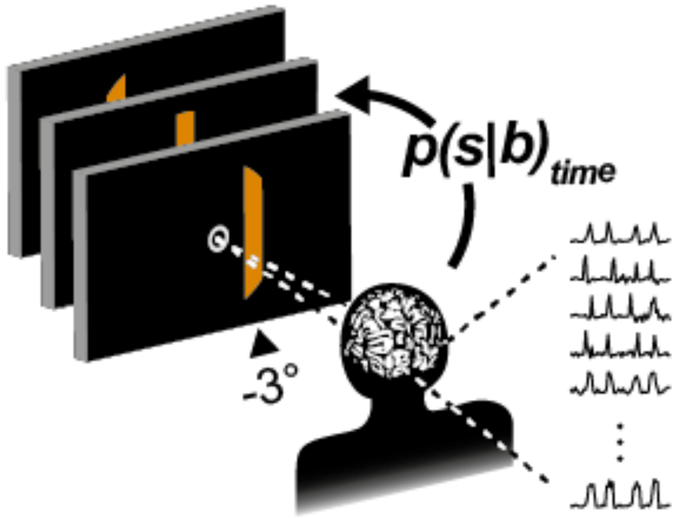

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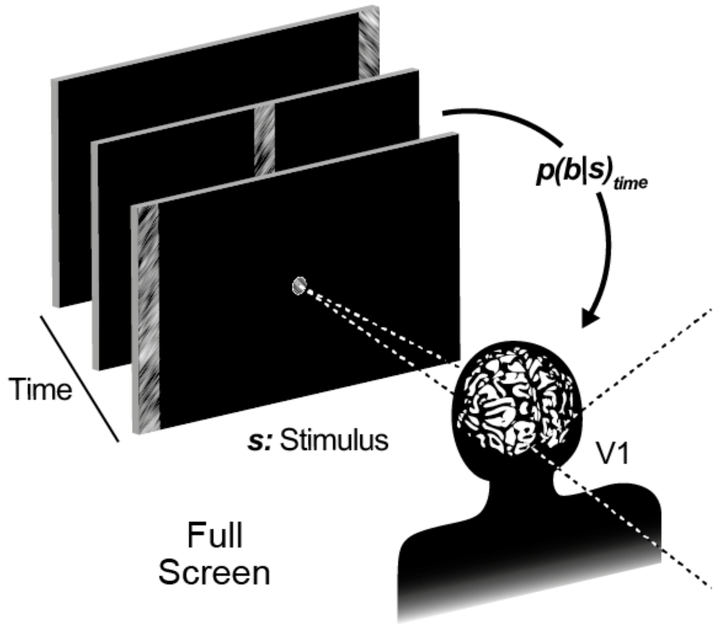

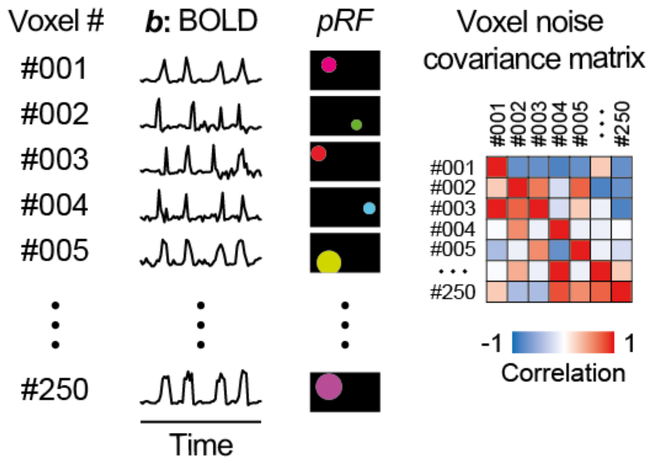

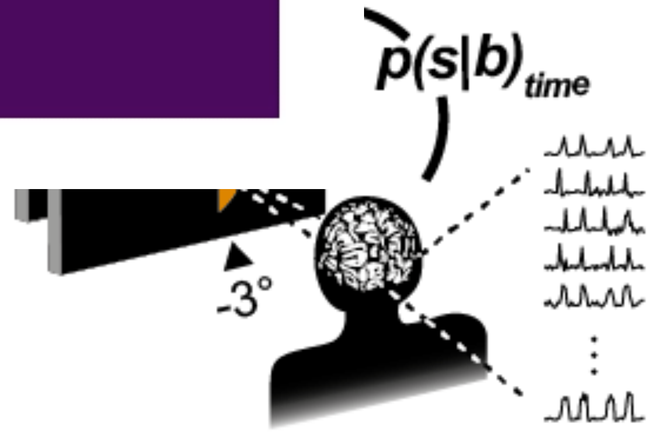

Encoding

Many different models and their predictions

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What is the ‘receptive field’ of a voxel?

More complex receptive fields

Many different models and their predictions

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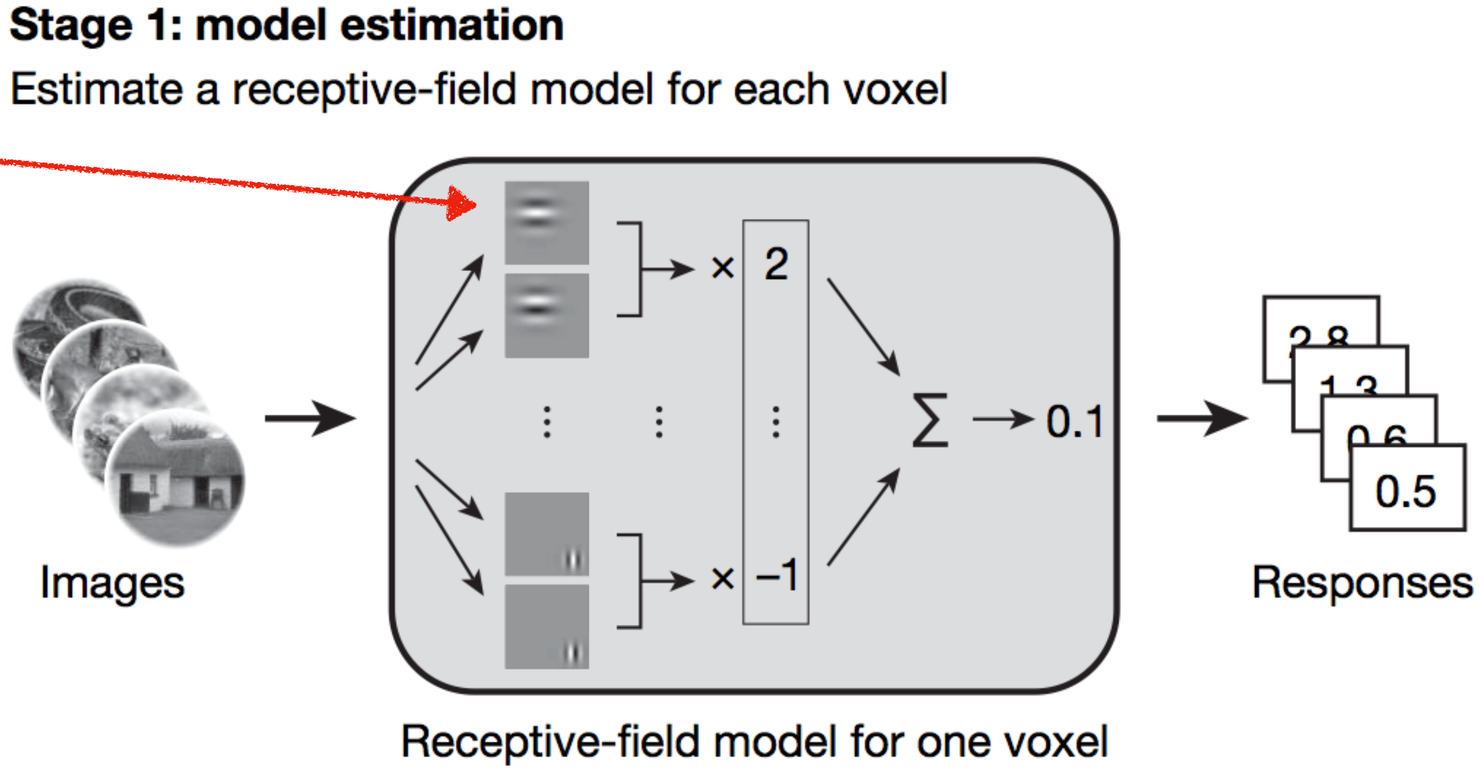

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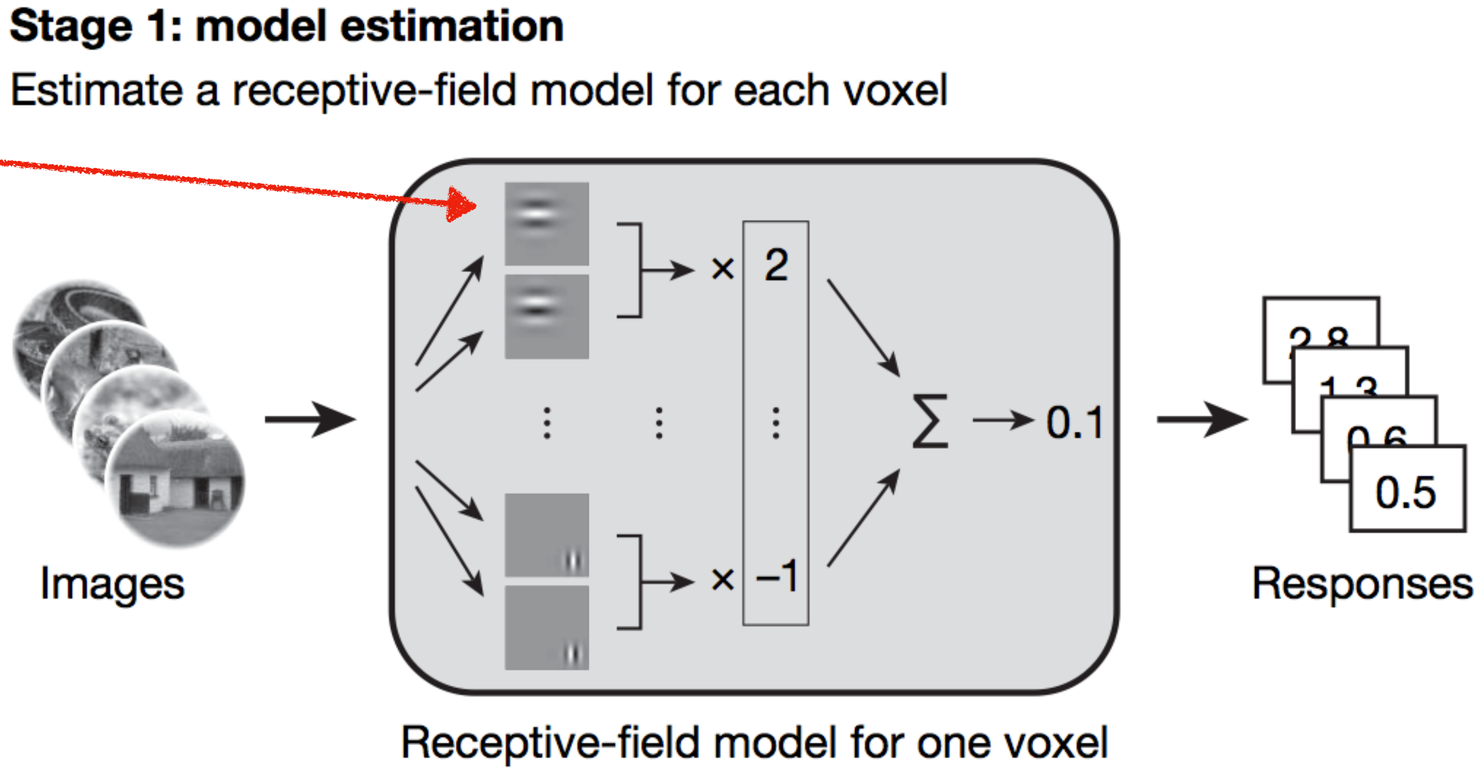

*Estimate a huge amount of parameters, using **penalized regression***

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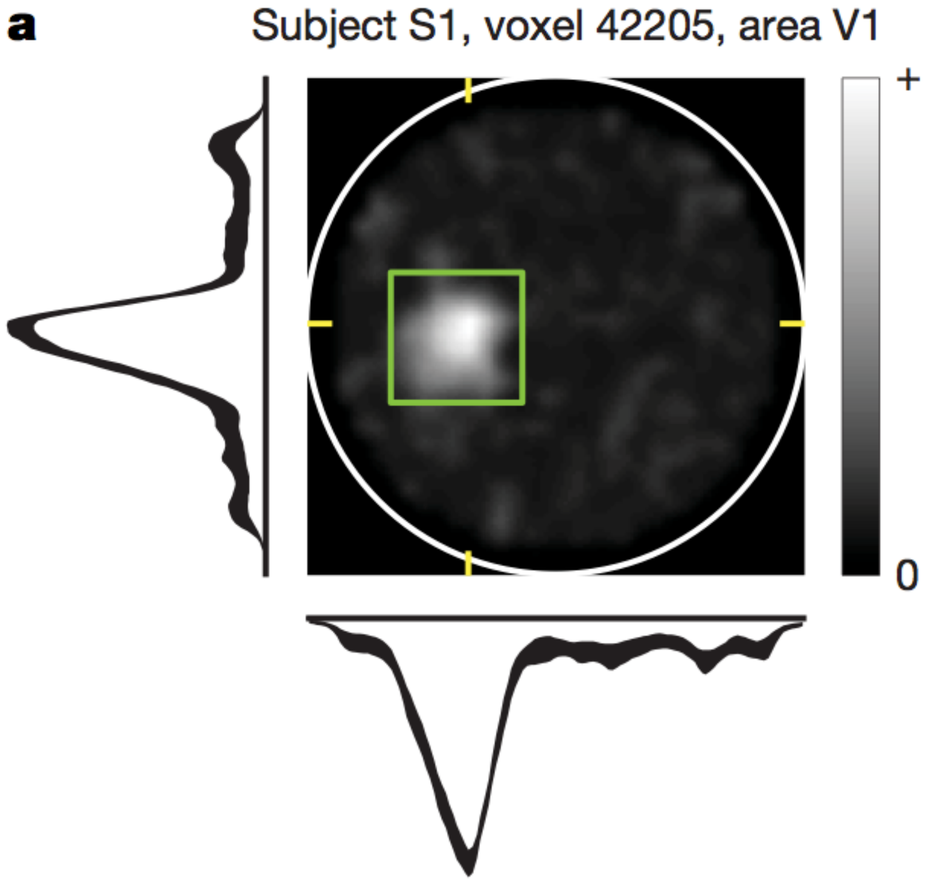

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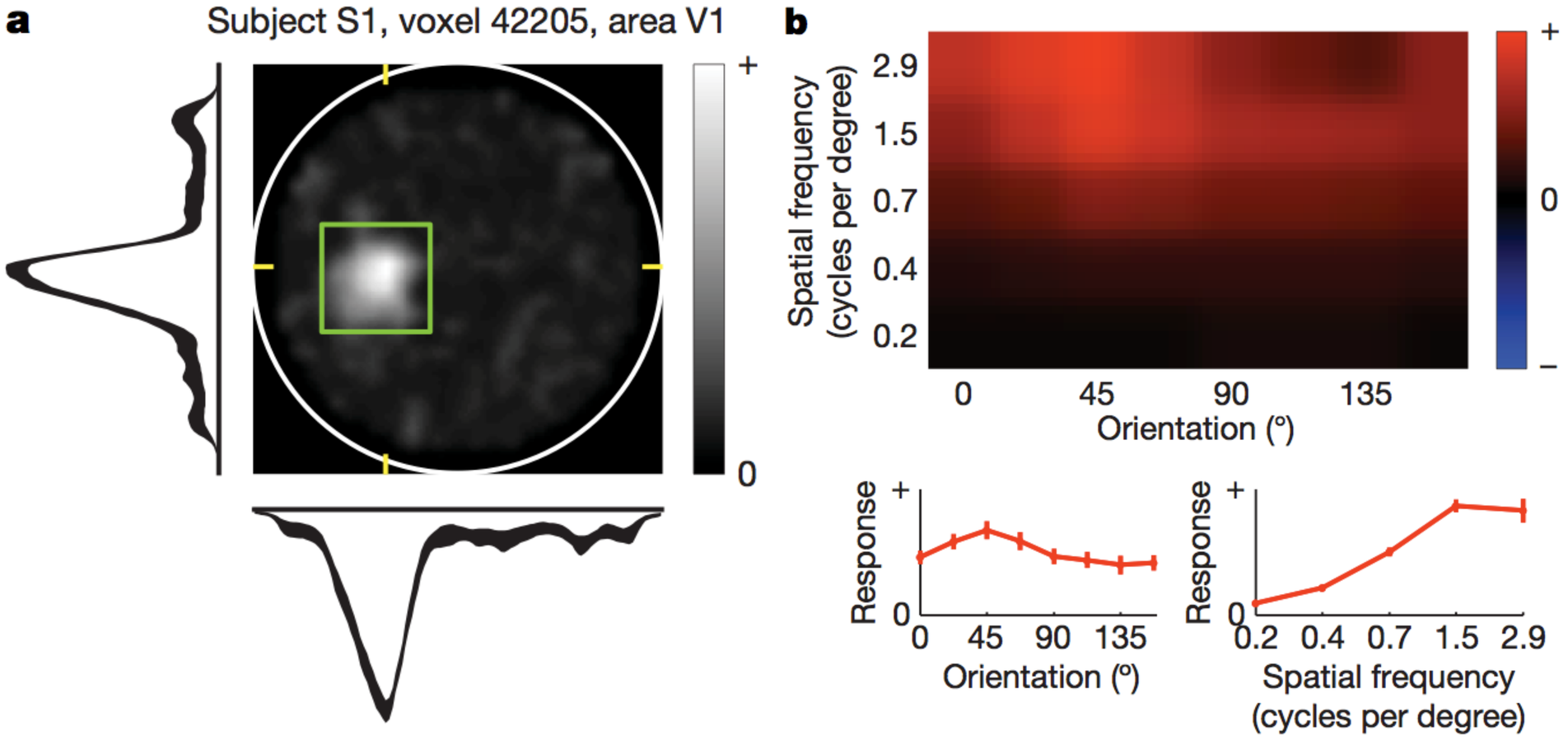
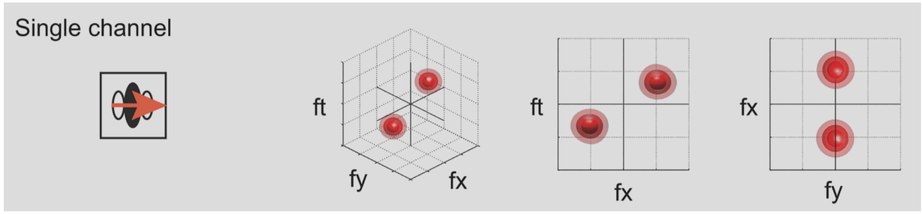


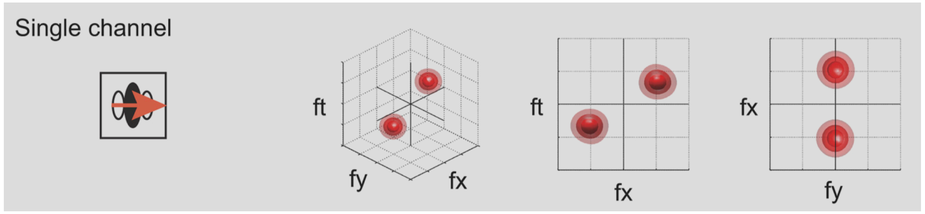
Extend this to movies: Add spatiotemporal receptive field structure



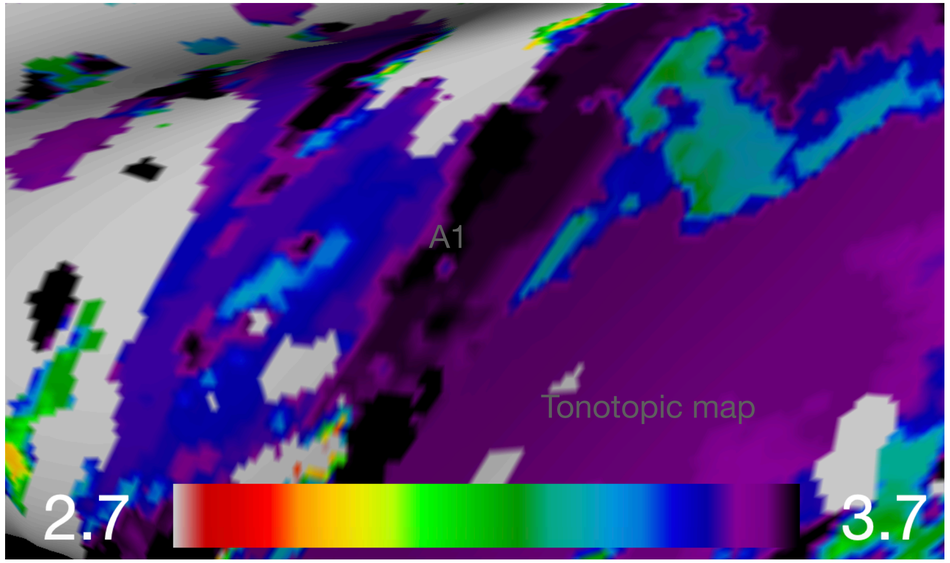
Extend this to movies: Add spatiotemporal receptive field structure

Presented clip

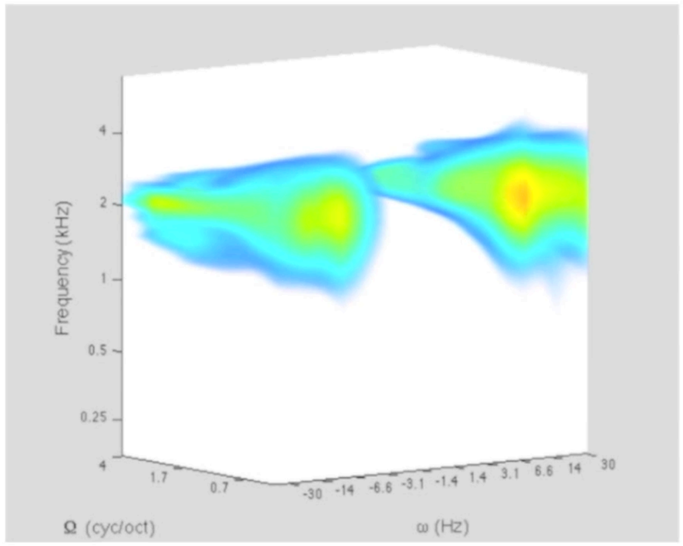
Clip reconstructed from brain activity



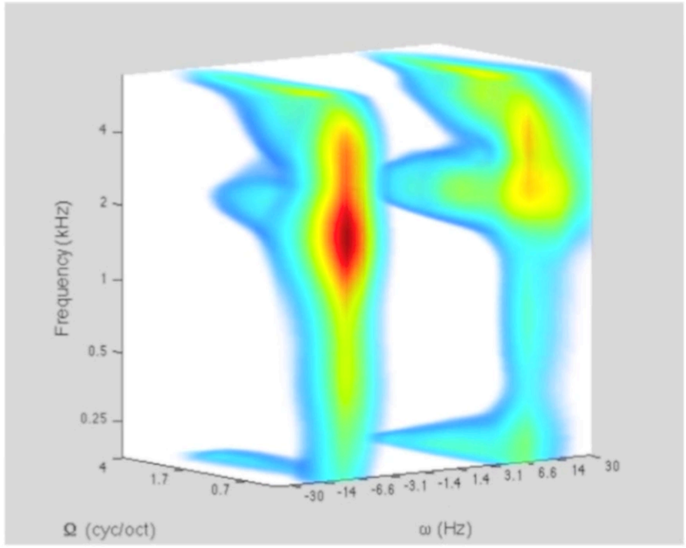
And, this works also for sounds



Original



Reconstructed



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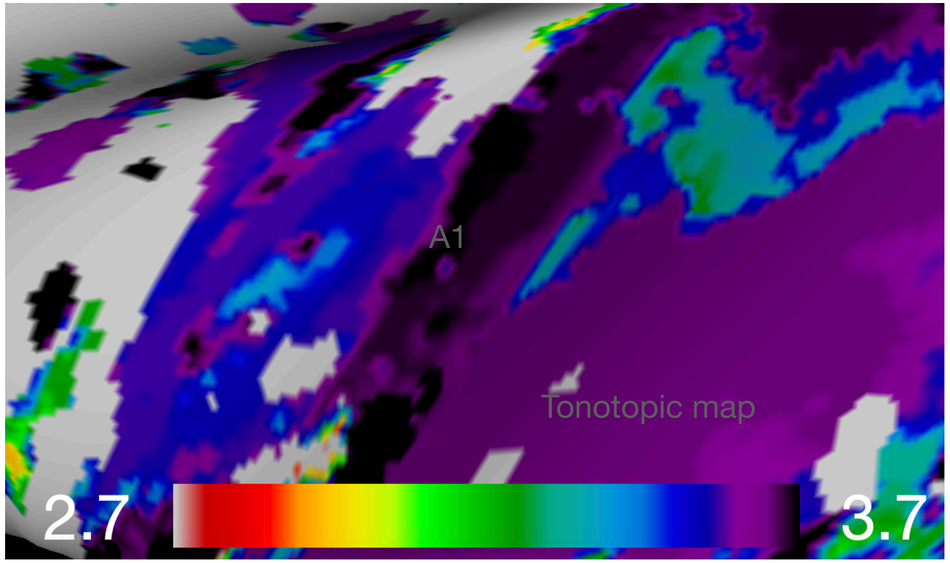
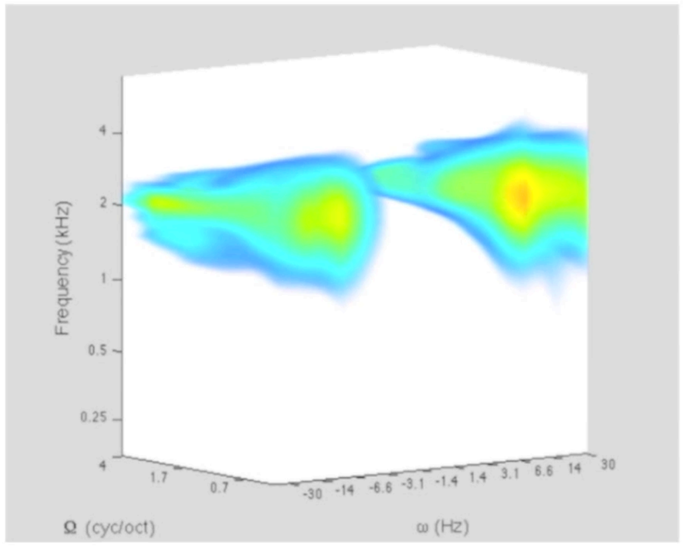
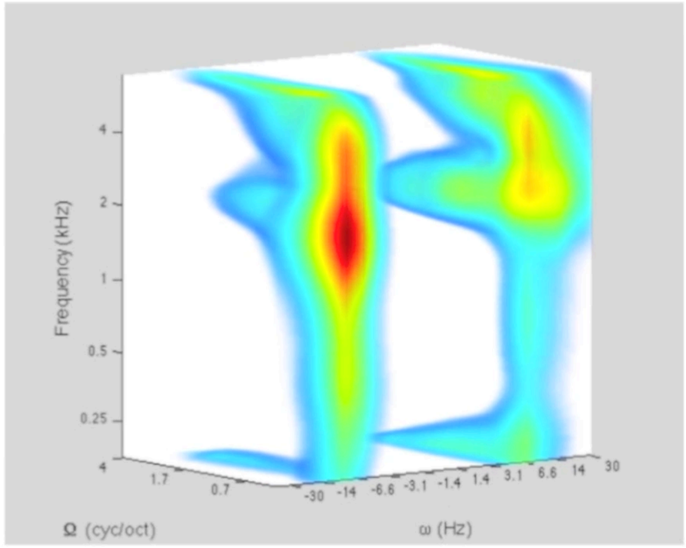


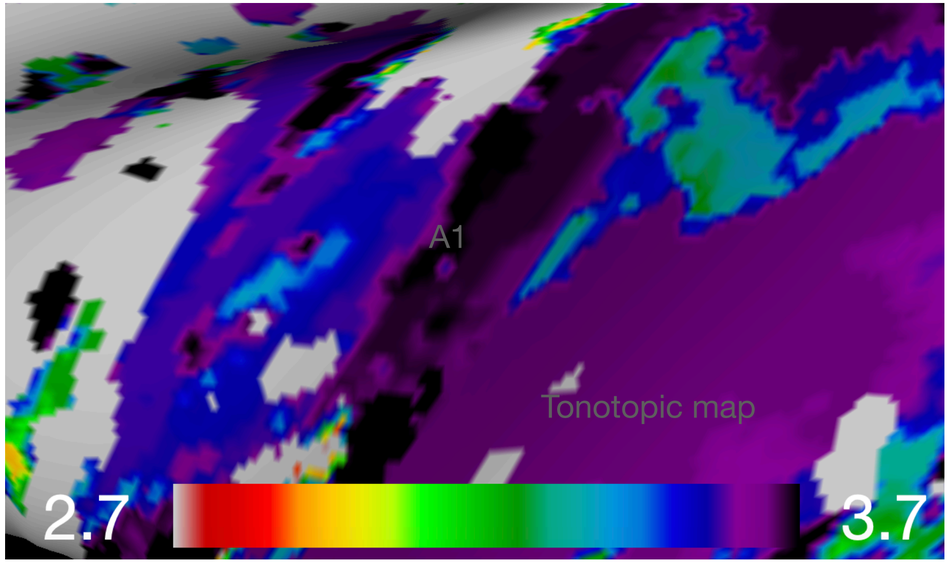
Original



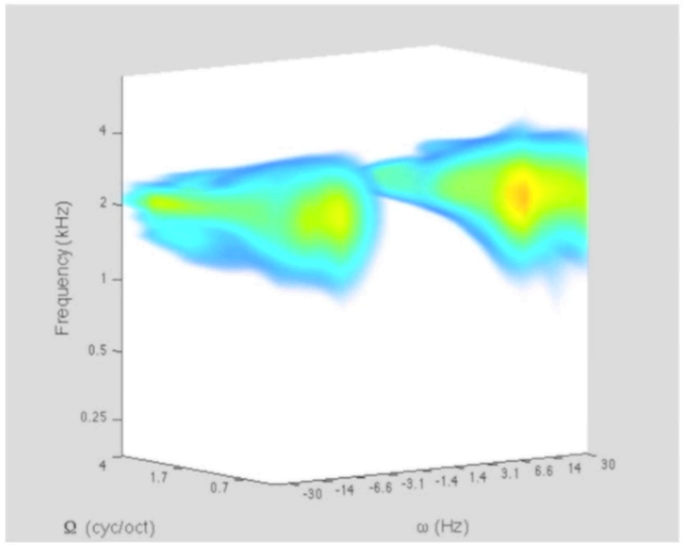
Reconstructed



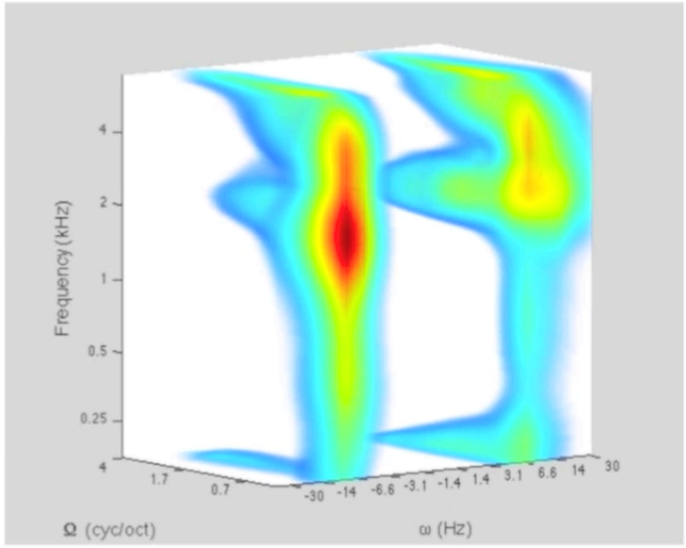
And, this works also for sounds



Original



Reconstructed



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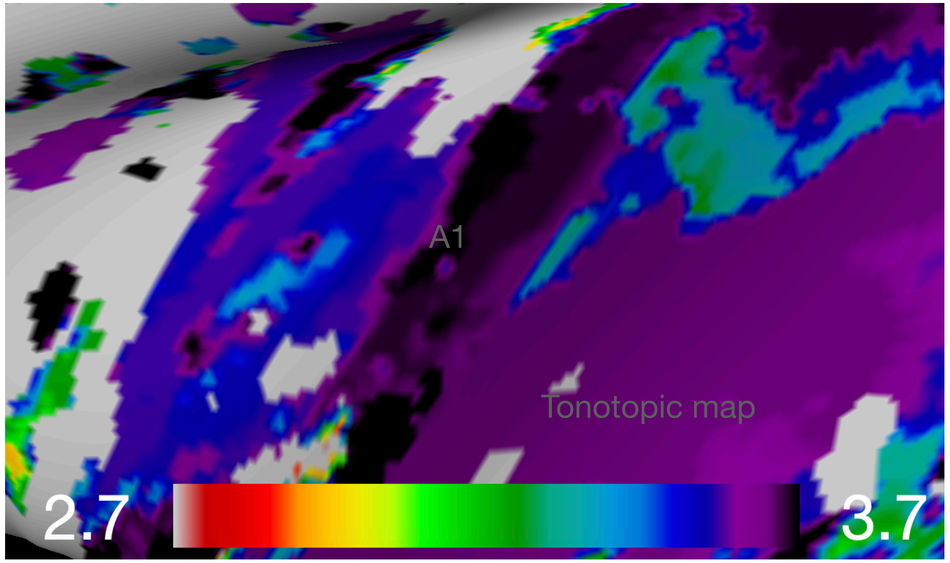

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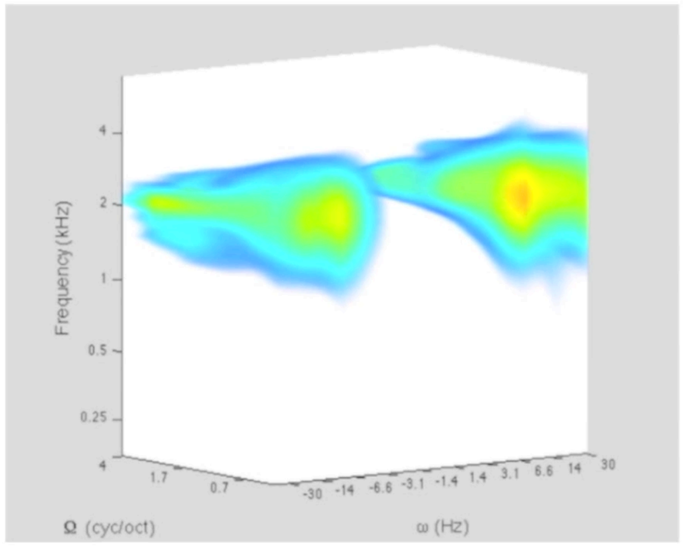

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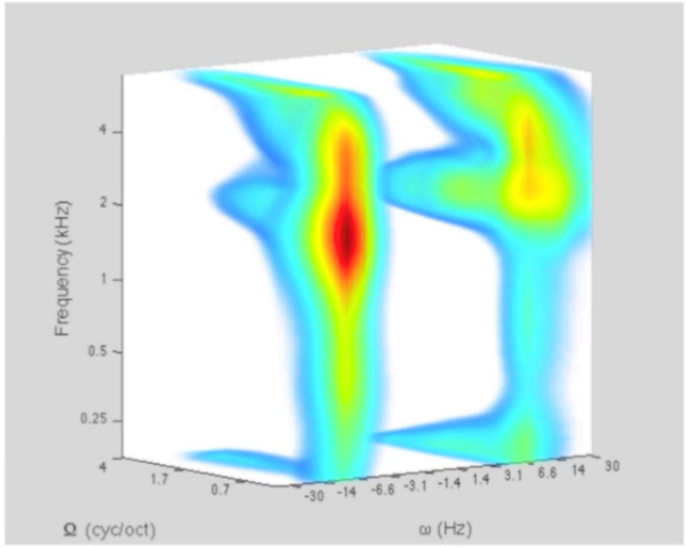
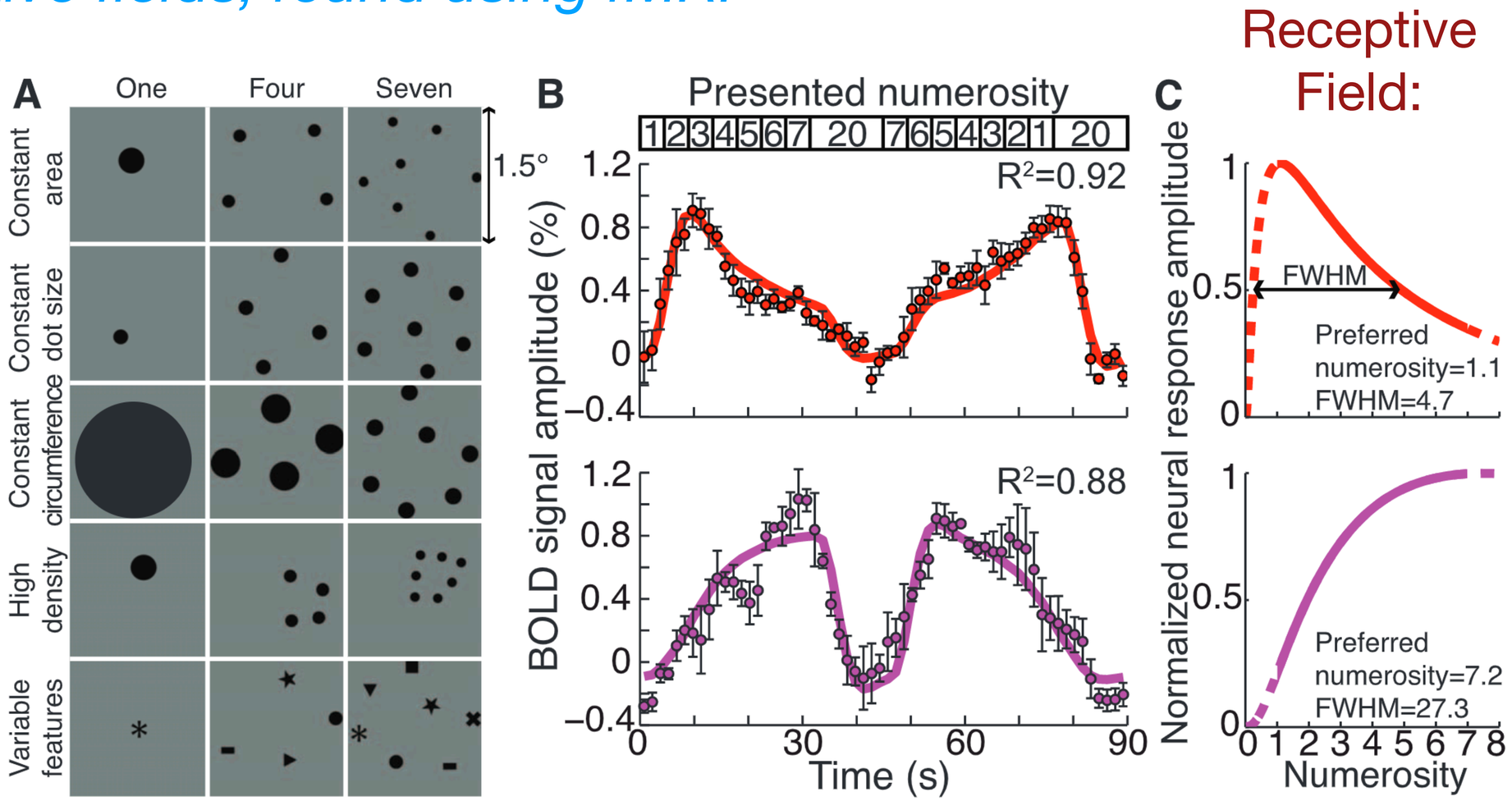
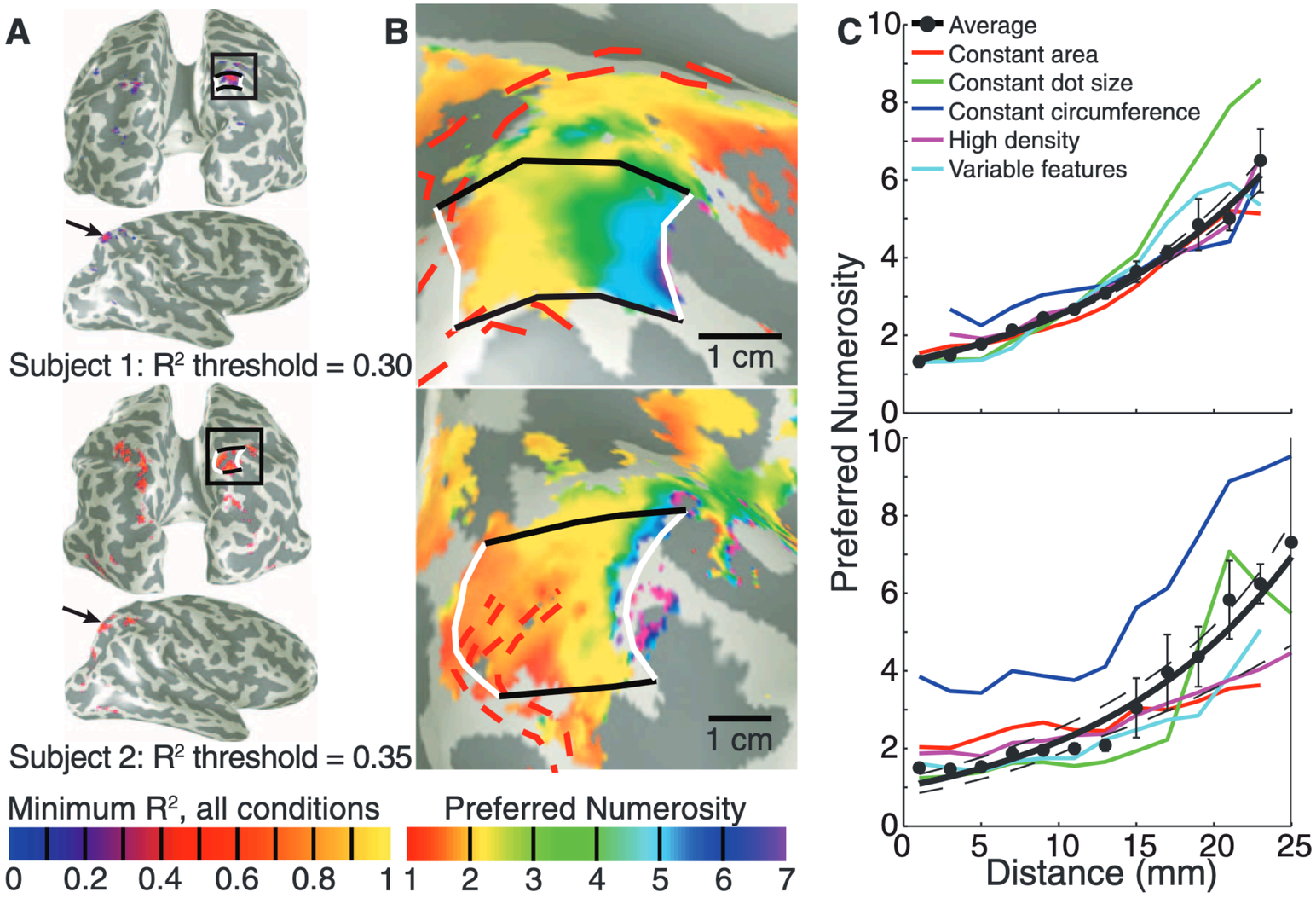


But more…

Also more abstract dimensions are represented using receptive fields, found using fMRI



These receptive fields are layed out on maps…



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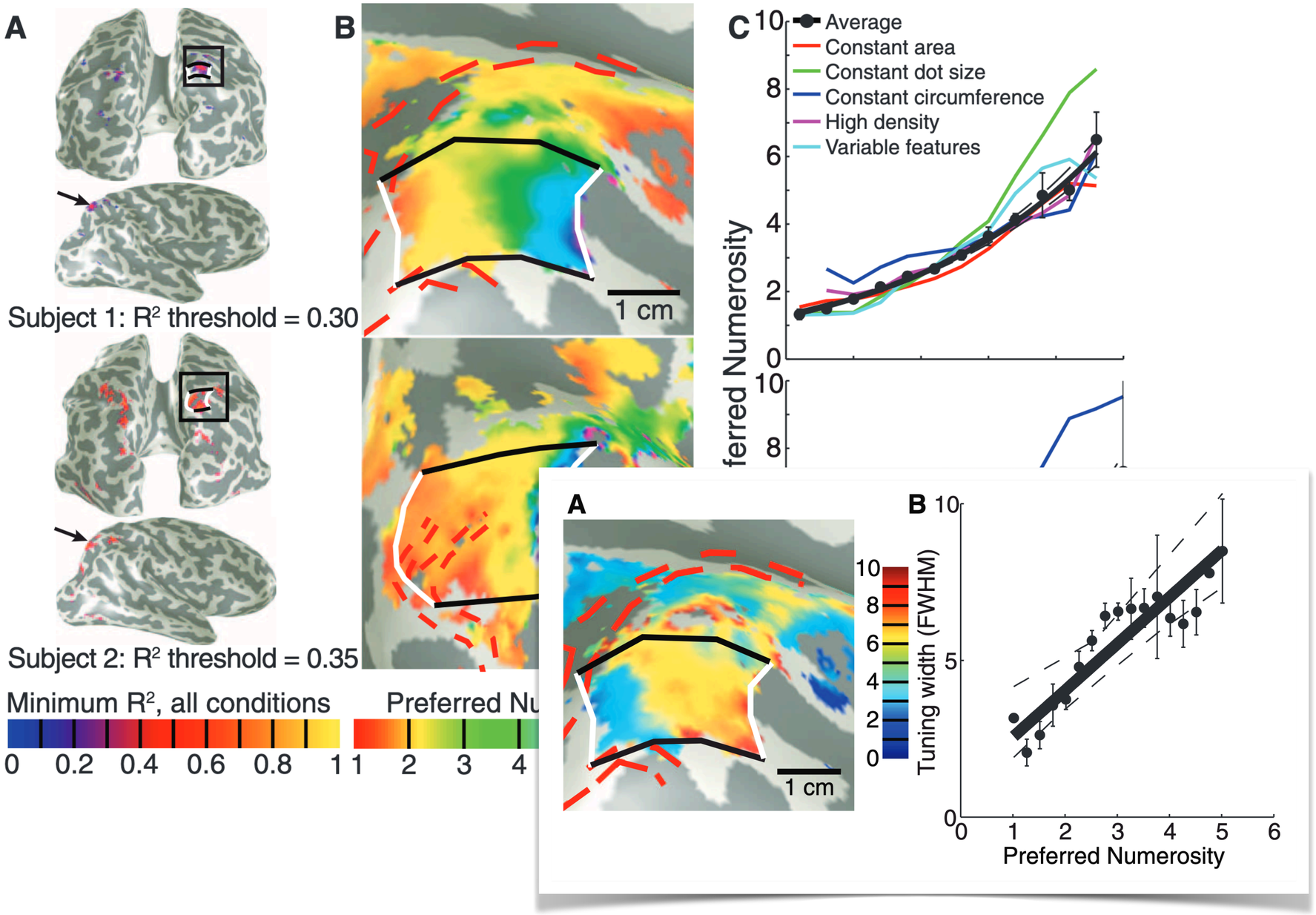

Encoding in higher spaces

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A voxel's receptive field doesn't have to be retinotopic, but can live in a more abstract (semantic) space.

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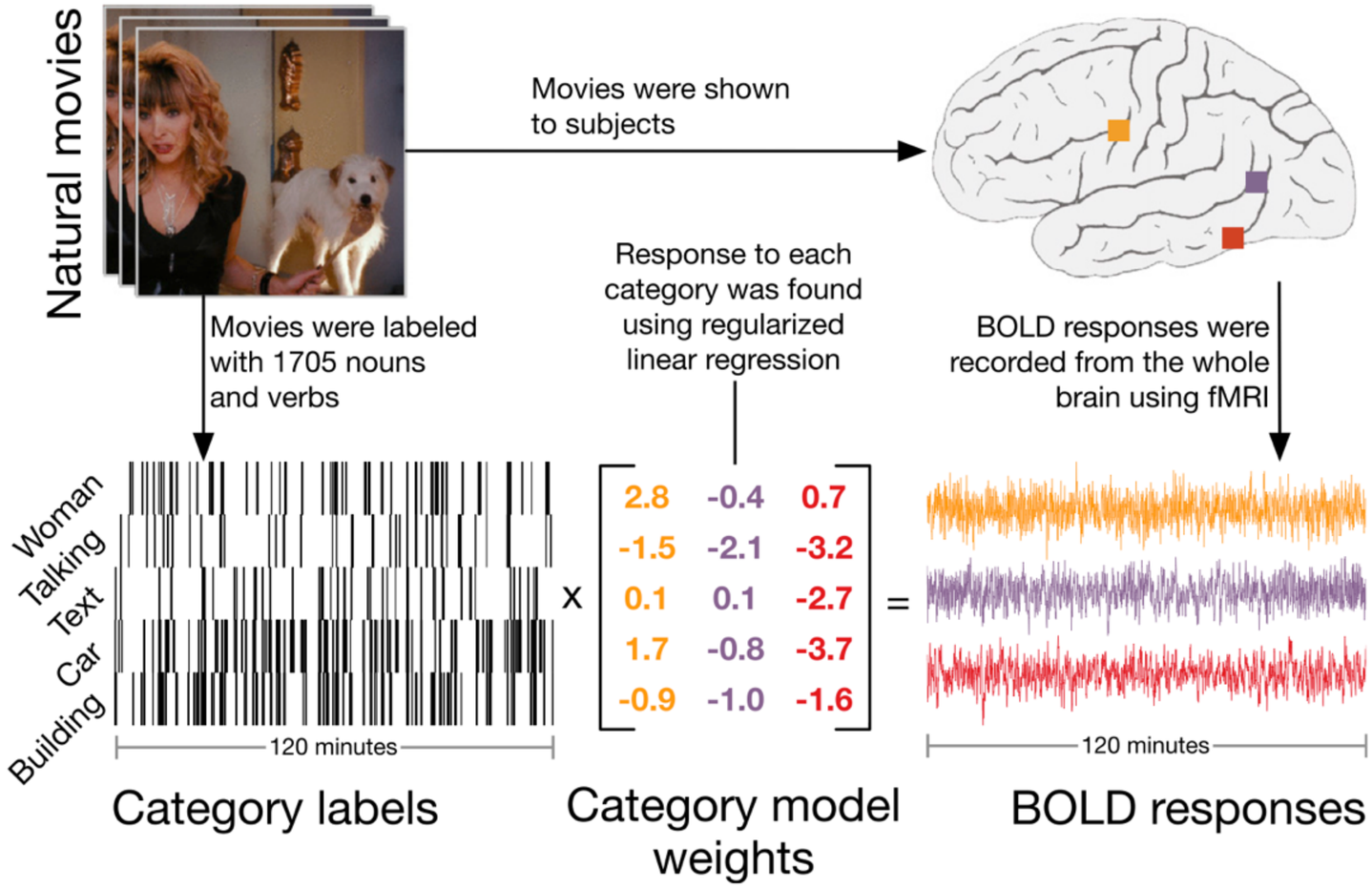

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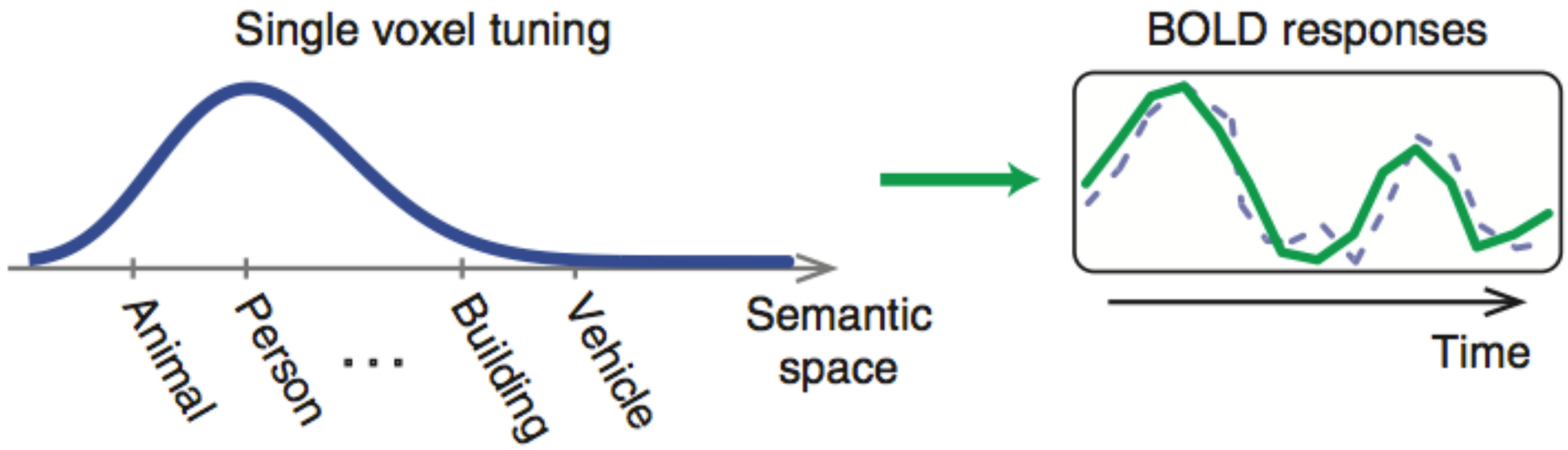
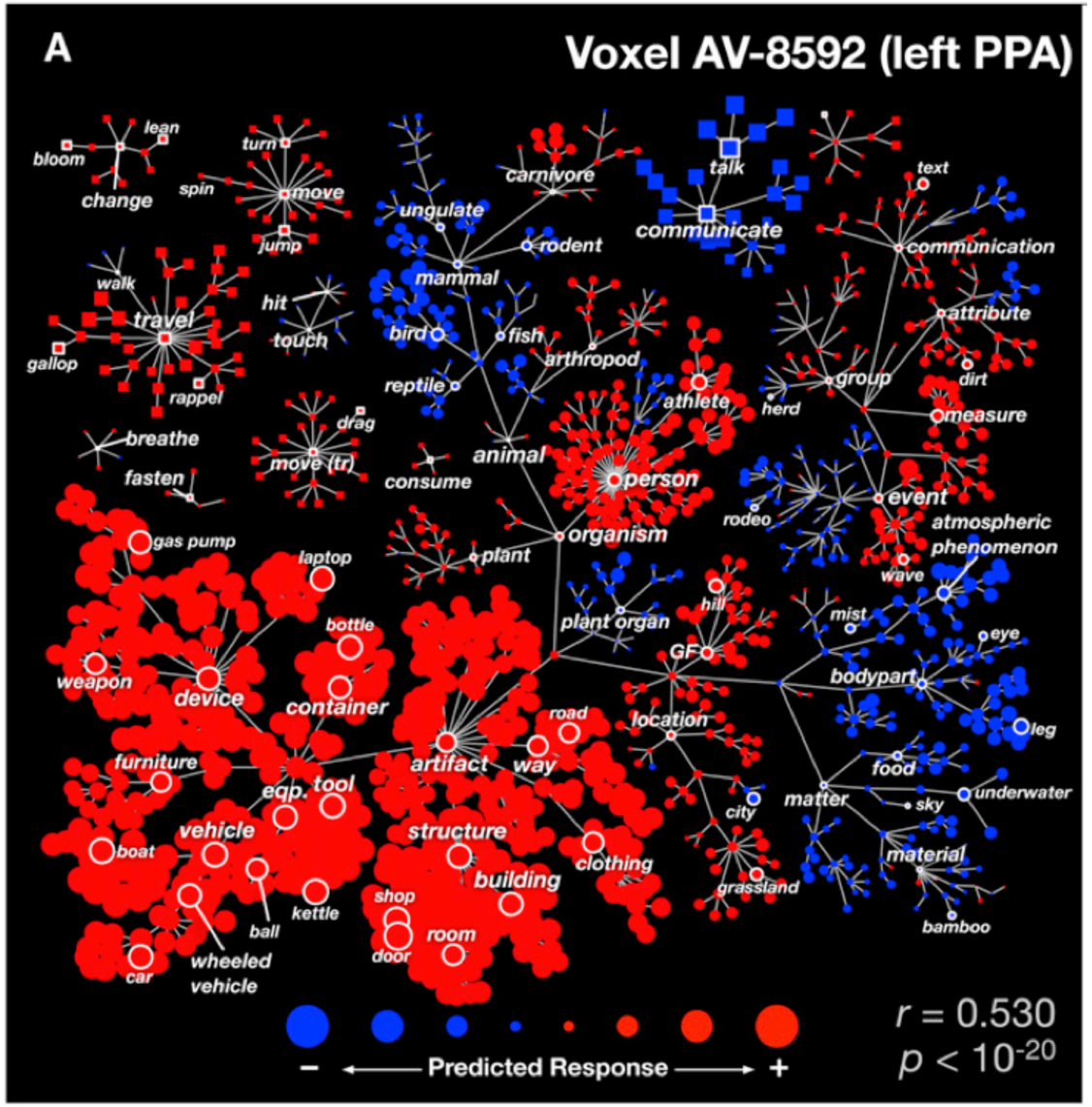


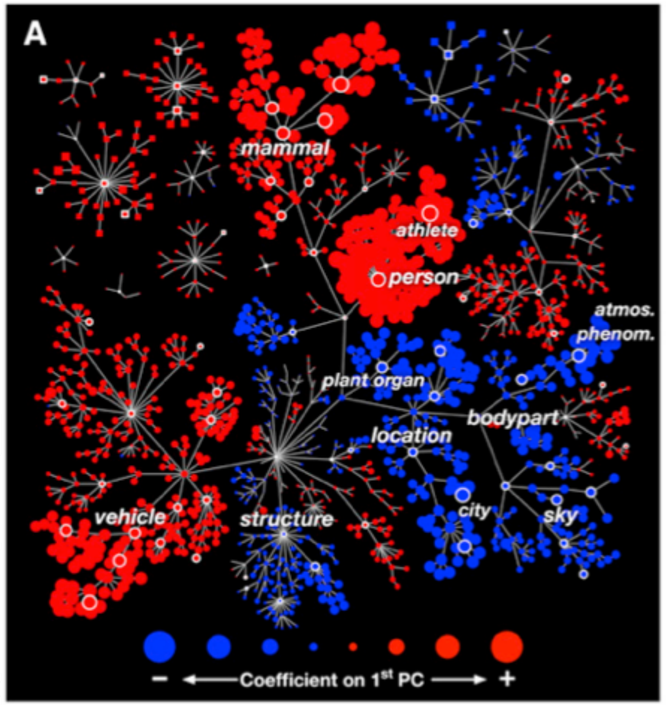
Methods

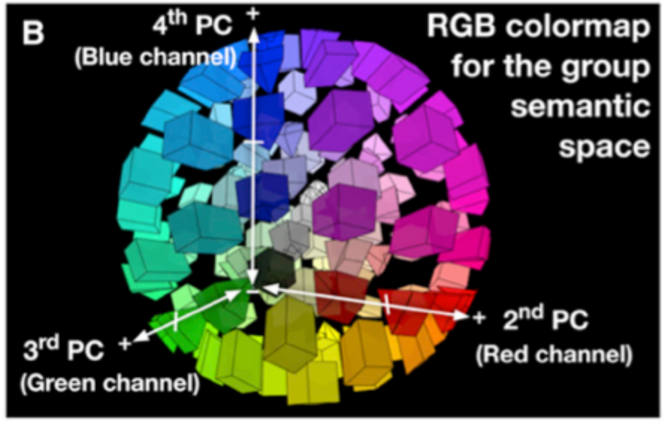
Single-voxel tuning curve in a semantic space

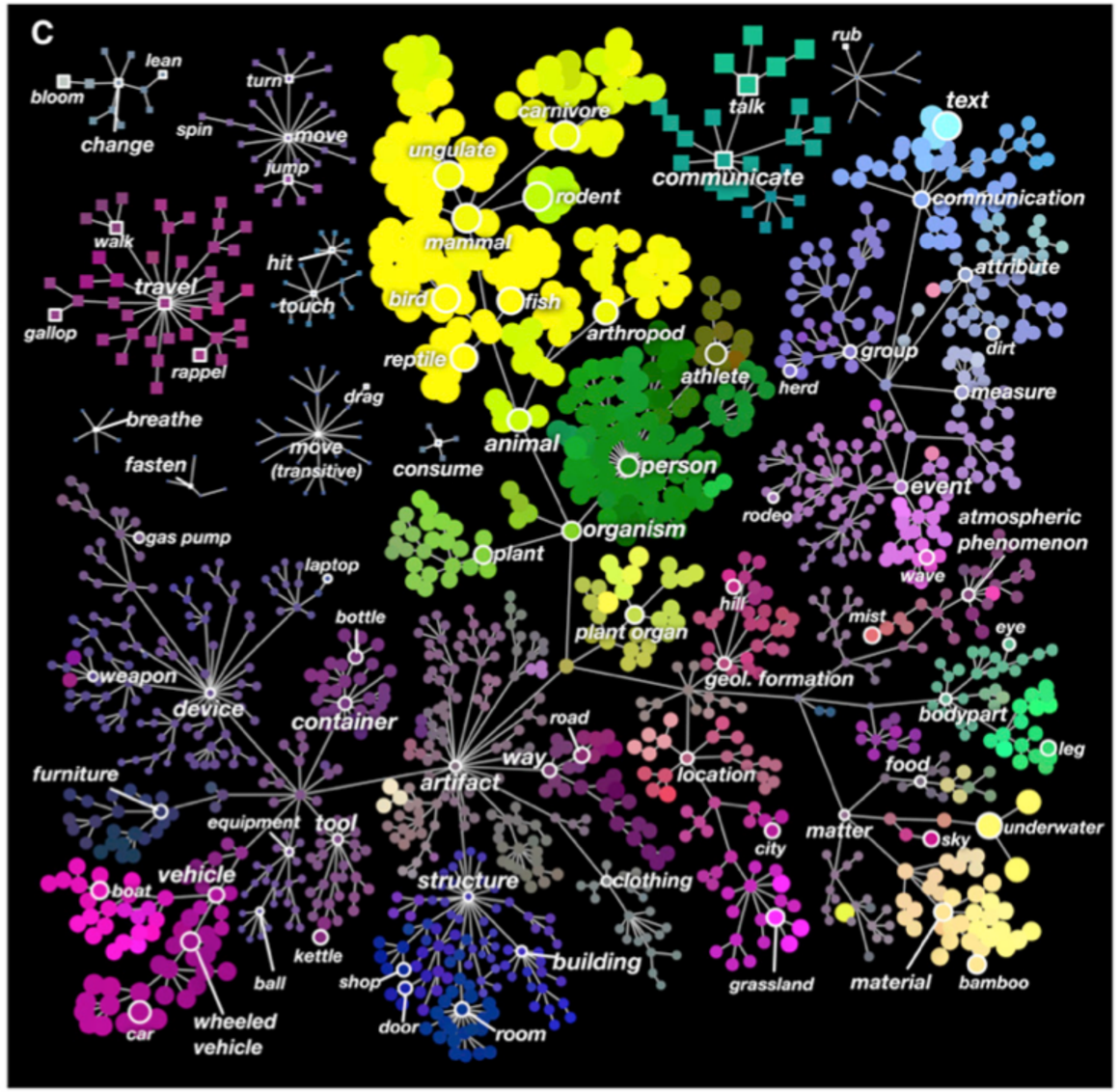


- Doing this for all voxels gives us a very-high multidimensional space of voxels by regressors’ beta weights.
- Dimensionality reduction yields a couple of components
- Projecting onto semantic structure:

- Doing
- Dimer
- Projec

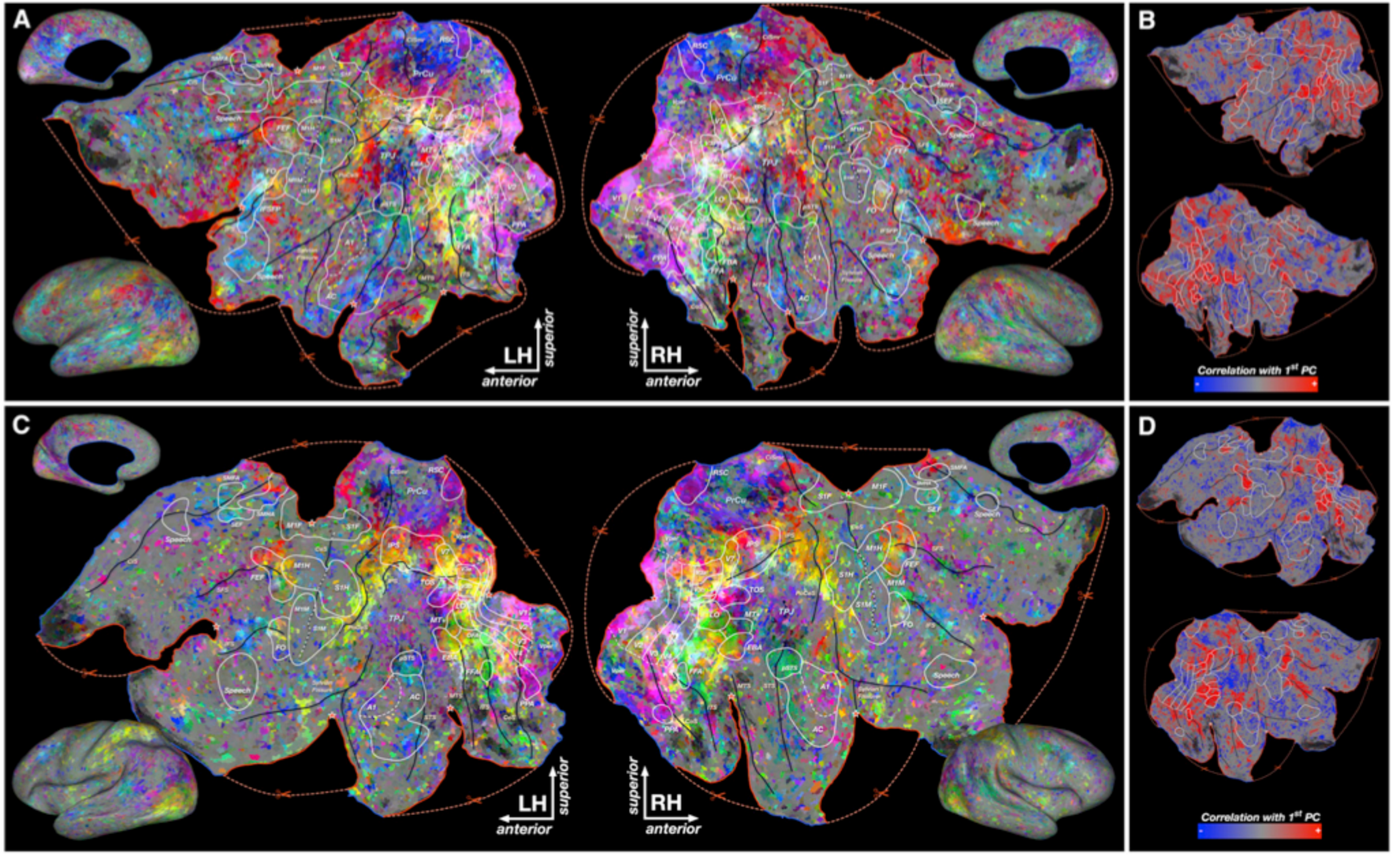




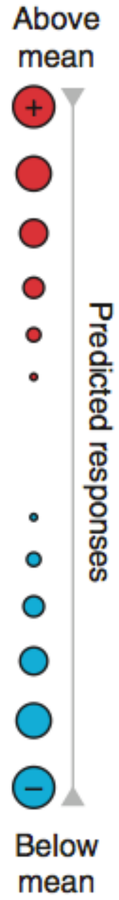


- Projecting semantic components onto voxels

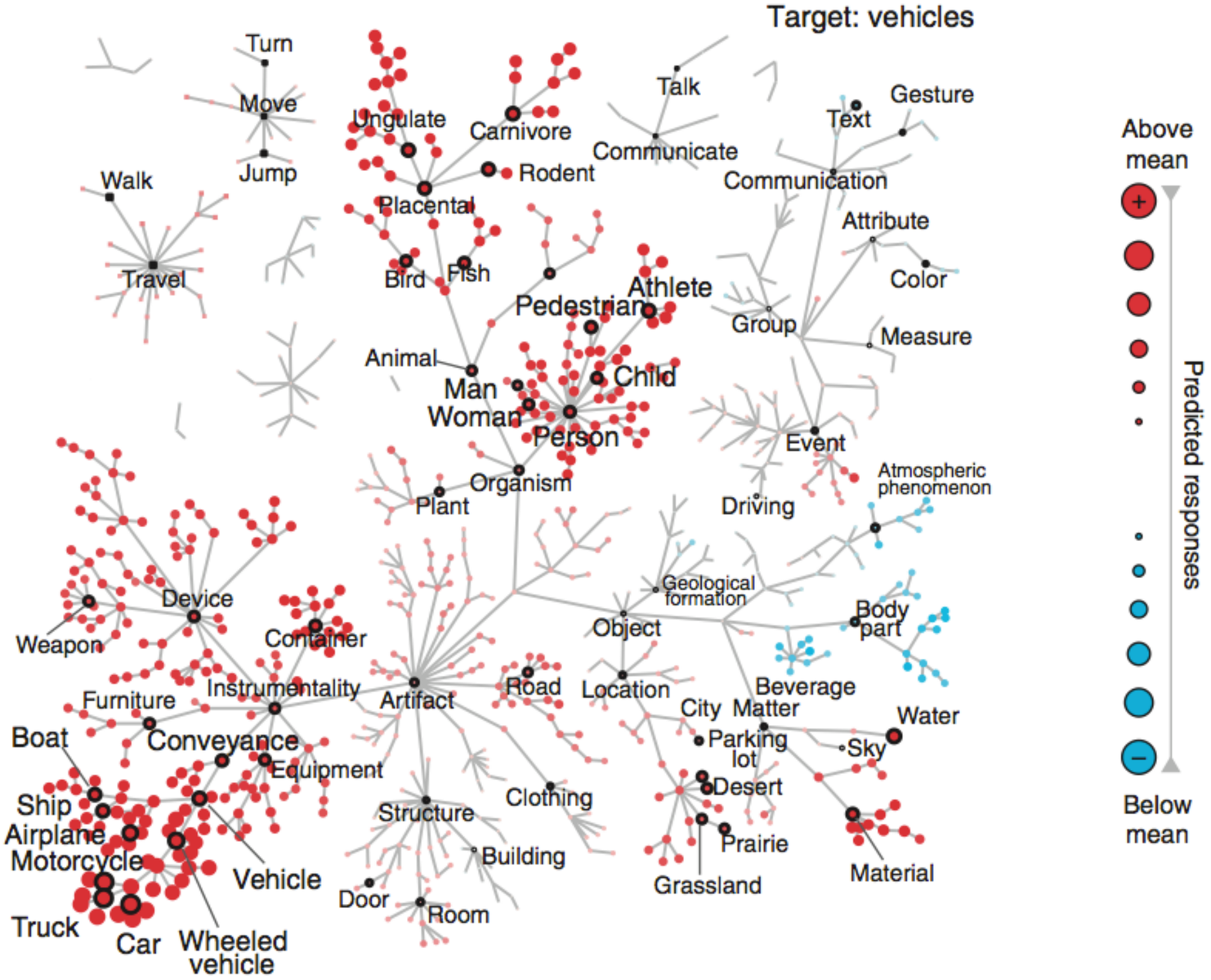
- Project



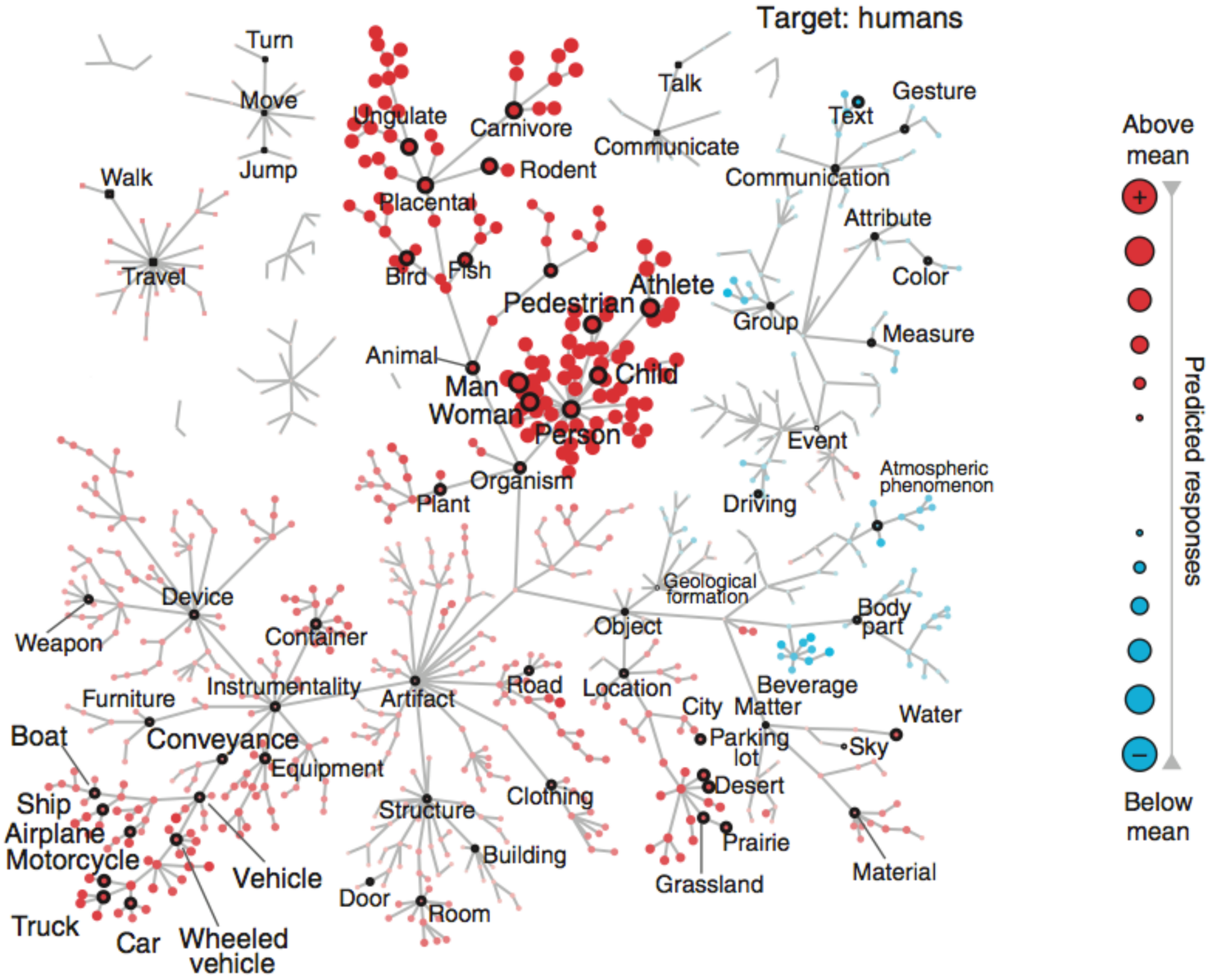
Attention shifts tuning of voxels



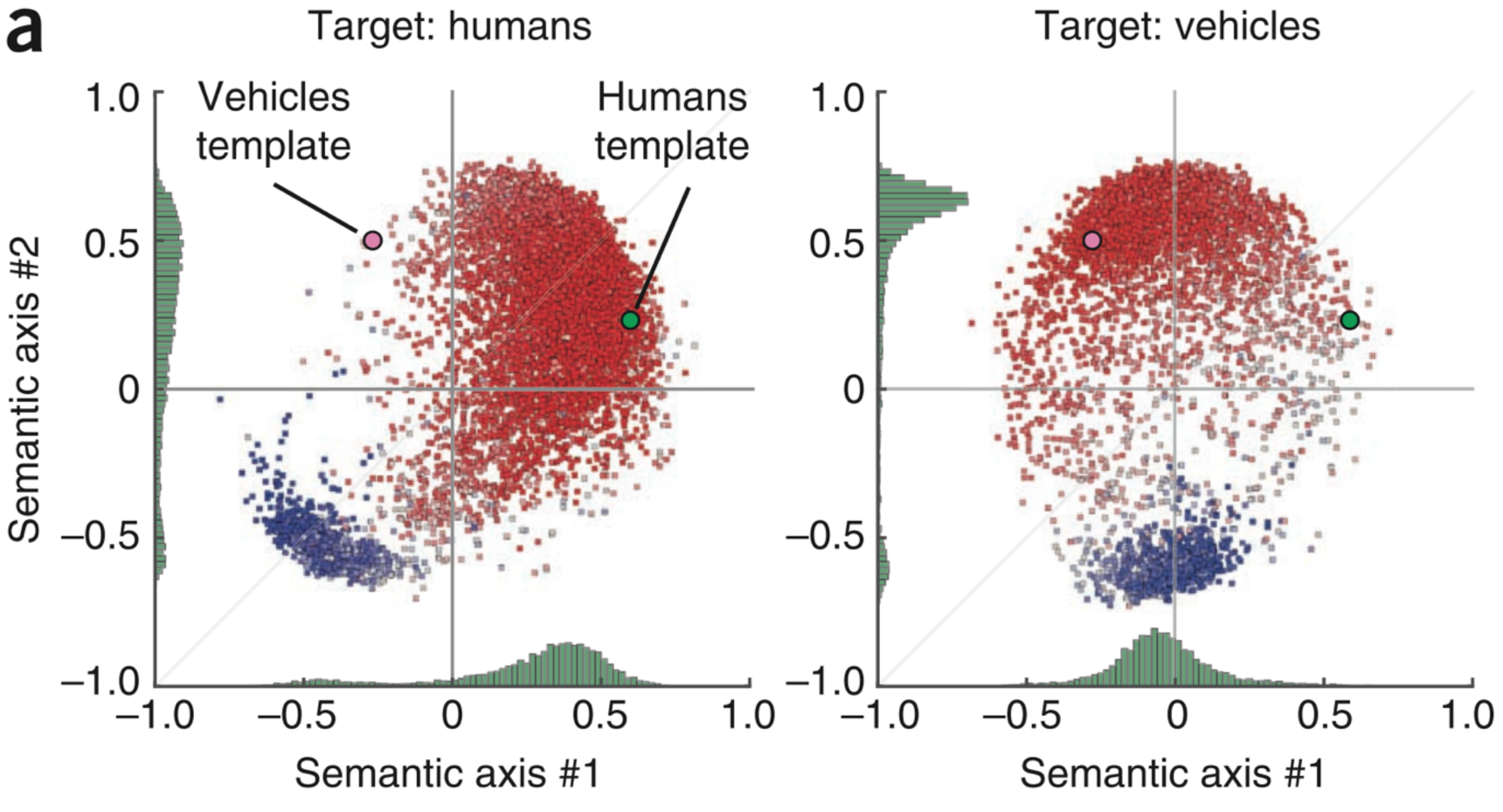
Attention shifts tuning of voxels

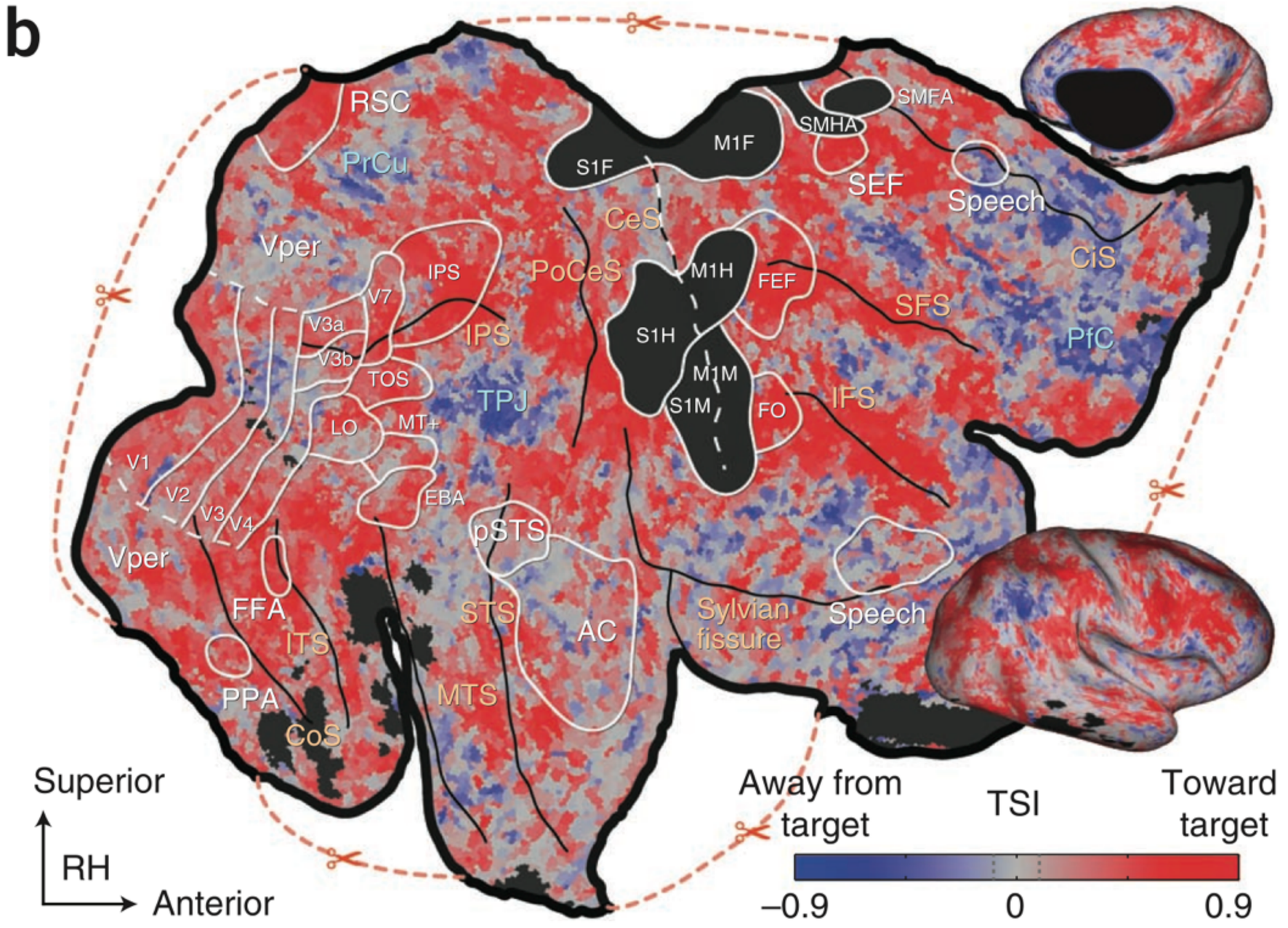


Attention shifts tuning of voxels

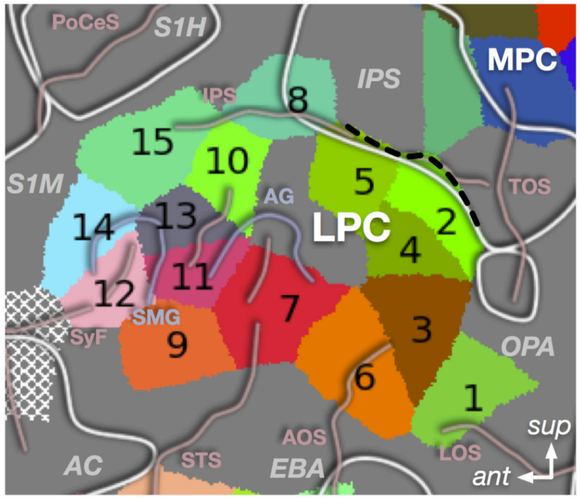


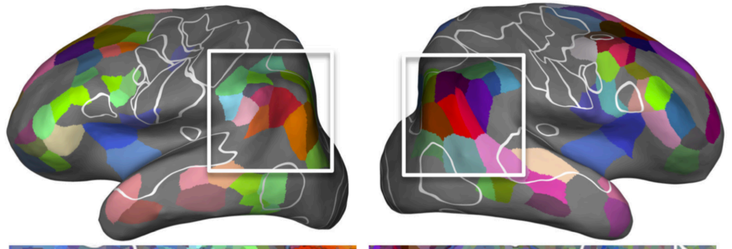
Attention shifts tuning of voxels

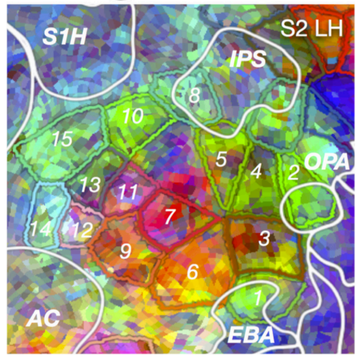


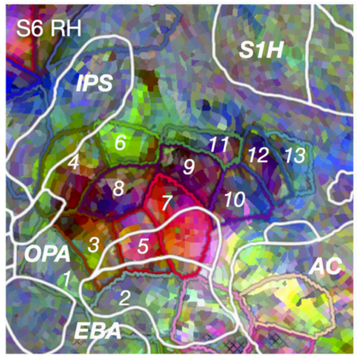

b
RSC
PrCu
S1F
M1F
SMHA
SMFA
SEF
Speech
CeS
Vper
IPS
PoCeS
M1H
FEF
CiS
V7
V3a
V3b
IPS
S1H
SFS
PfC
TOS
M1M
TPJ
S1M
FO
IFS
LO
MT+
V1
V2
V3
V4
EBA
pSTS
Vper
FFA
STS
AC
Sylvian fissure
Speech
ITS
MTS
PPA
CoS
Superior
RH
Anterior
Away from target
TSI
Toward target
–0.9
0
0.9

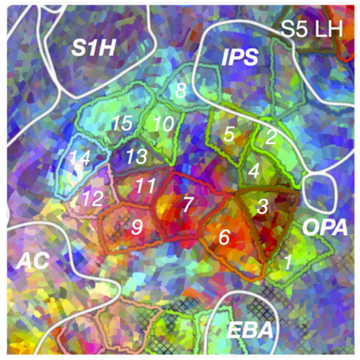
Create atlases based on information-processing preferences.

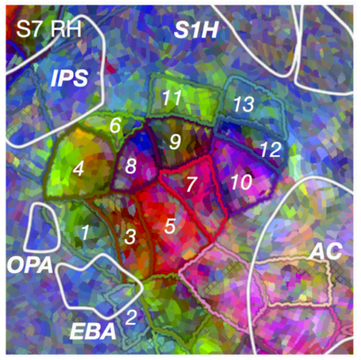


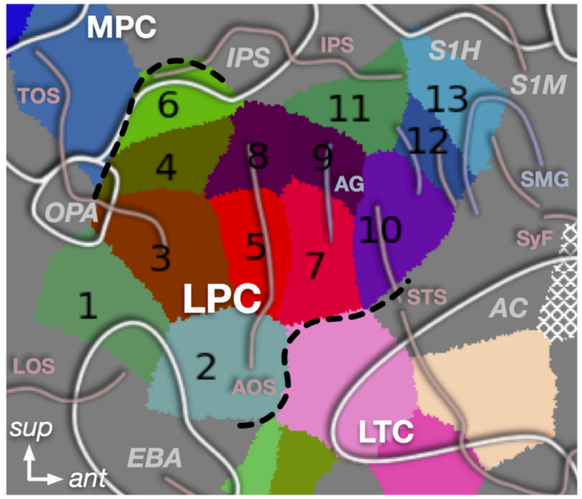


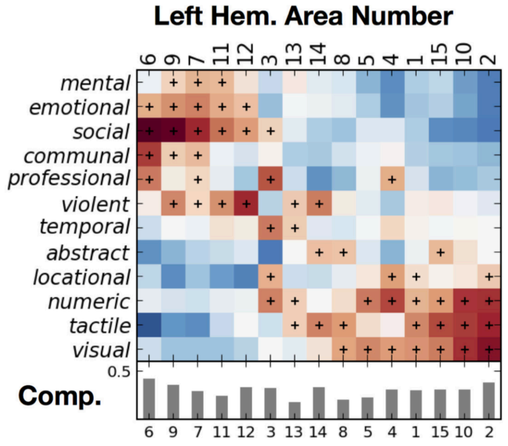


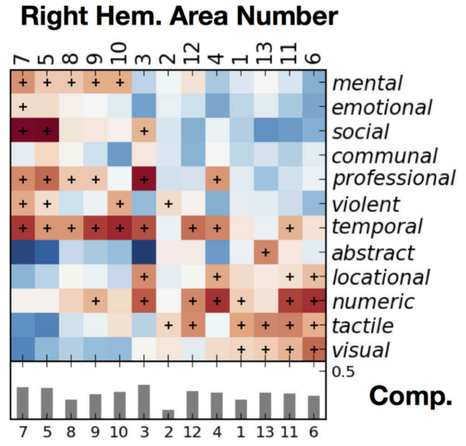




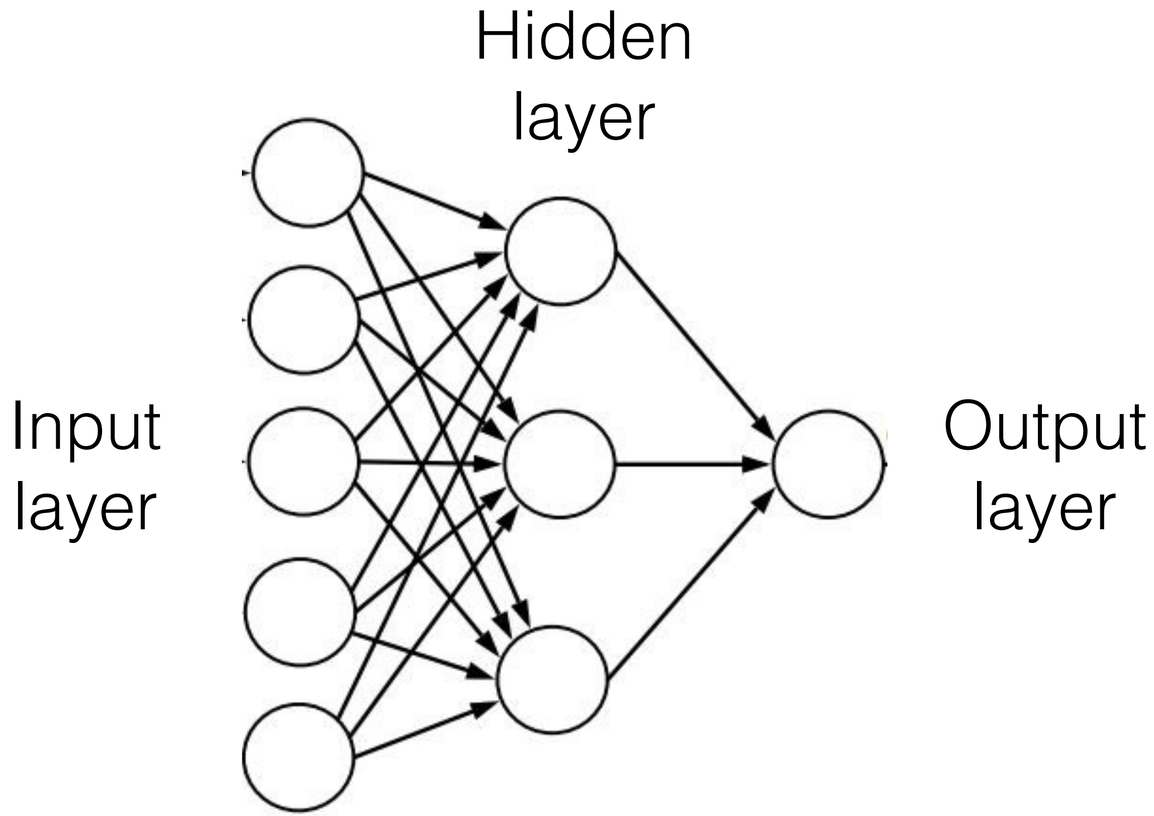




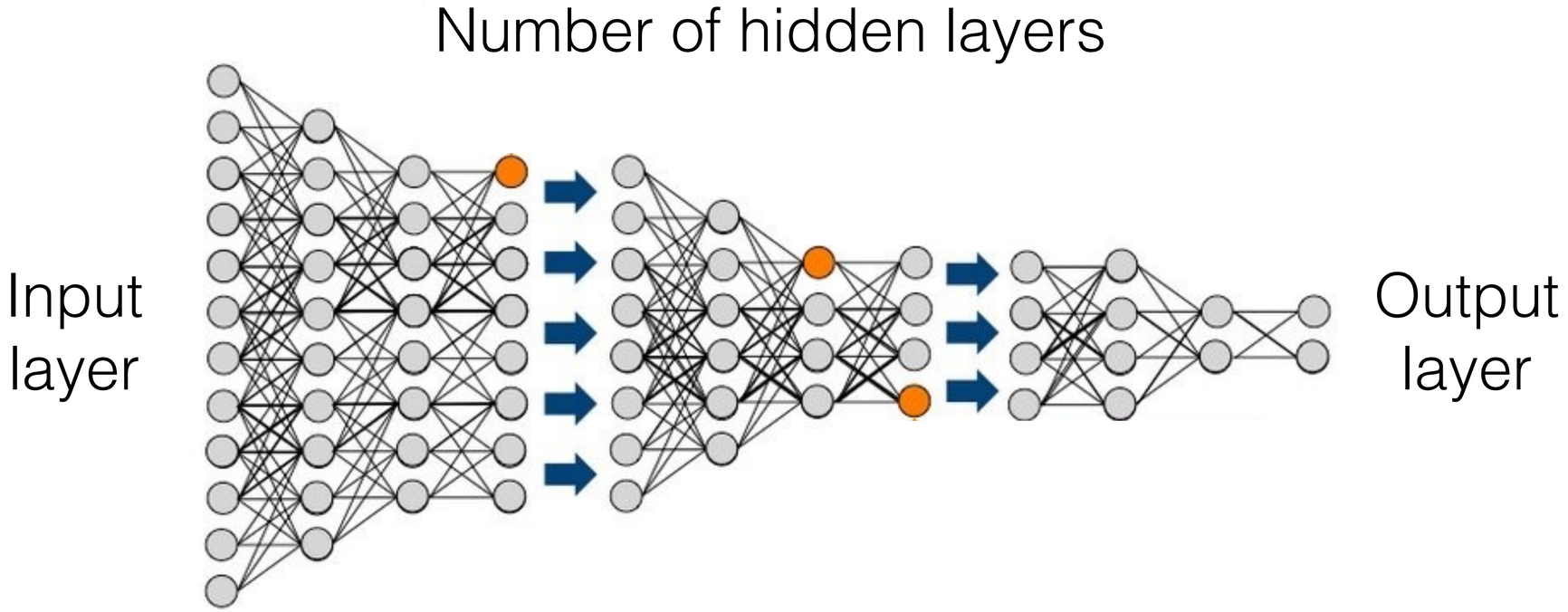




Neural Networks



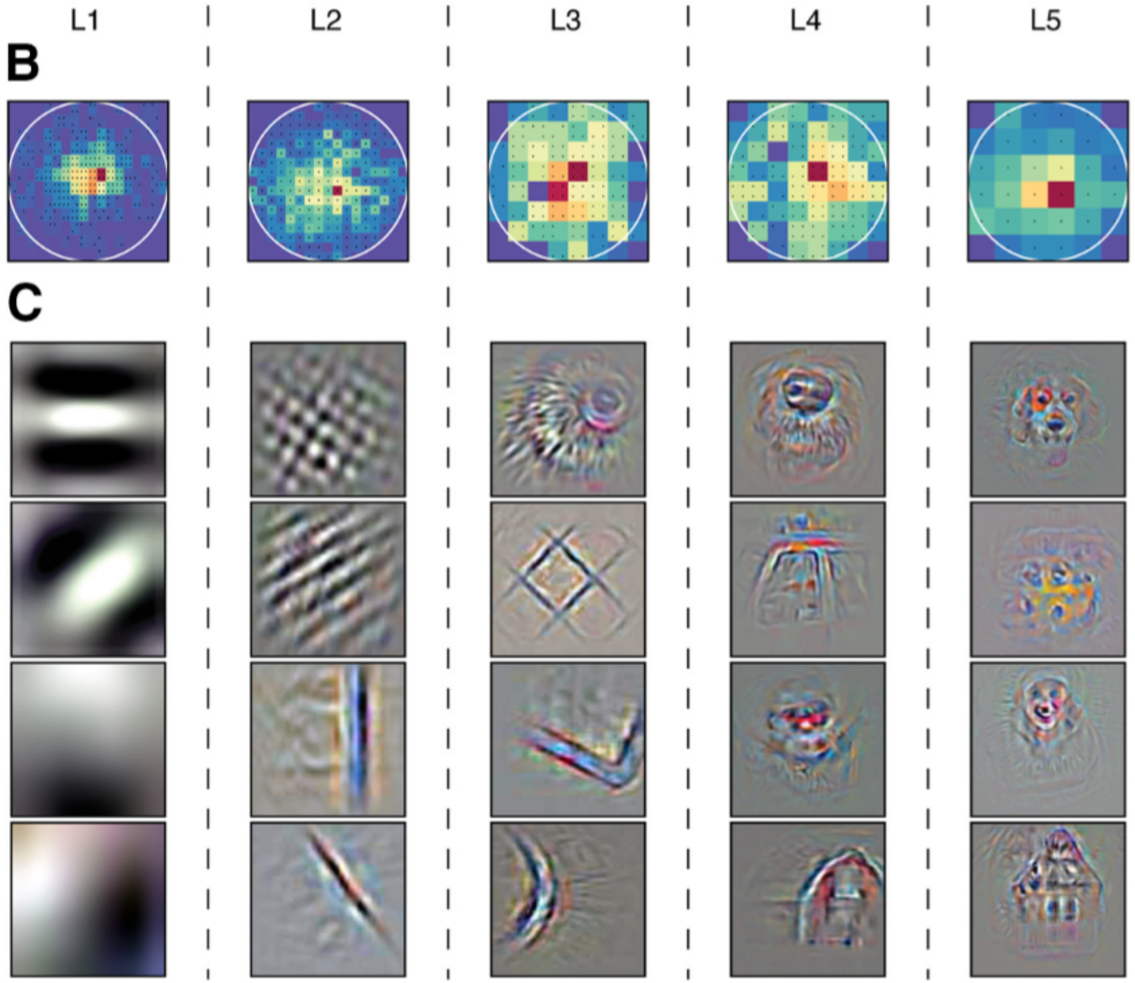
Convolutional Neural Network (CNN)



Object recognition: CNN

- CNNs are trained on millions of images (ImageNet).

CNN as encoding model



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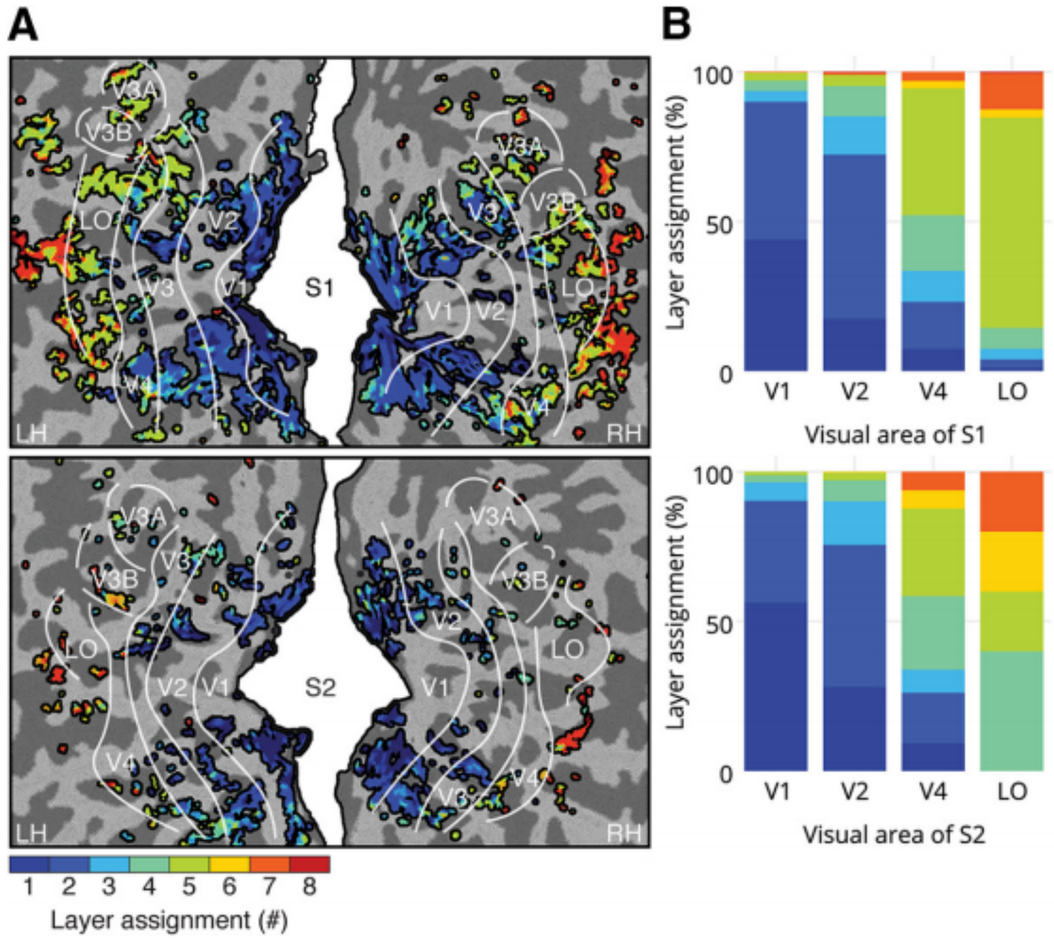
Neural Networks as encoding model



Güçlü U, van Gerven MAJ. 2015

the use of encoding models for neuroscientists

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1. compare different encoding models

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2. explore model behaviour under different conditions

the use of encoding models for neuroscientists

1. compare different encoding models

2. explore model behaviour under different conditions

3. use fMRI voxels as ‘electrodes’,
perform physiology

Encoding models as a basis for decoding

Although principally focused on the single voxel's responses, doing this encoding model estimation for all voxels allows one to investigate the patterns of activation across brain regions.

But now, because we know what single-voxel activations mean, these patterns are informative regarding how the brain as a whole treats information.