Pattern-information fMRI and representational similarity analysis

Mathematics in Brain Imaging
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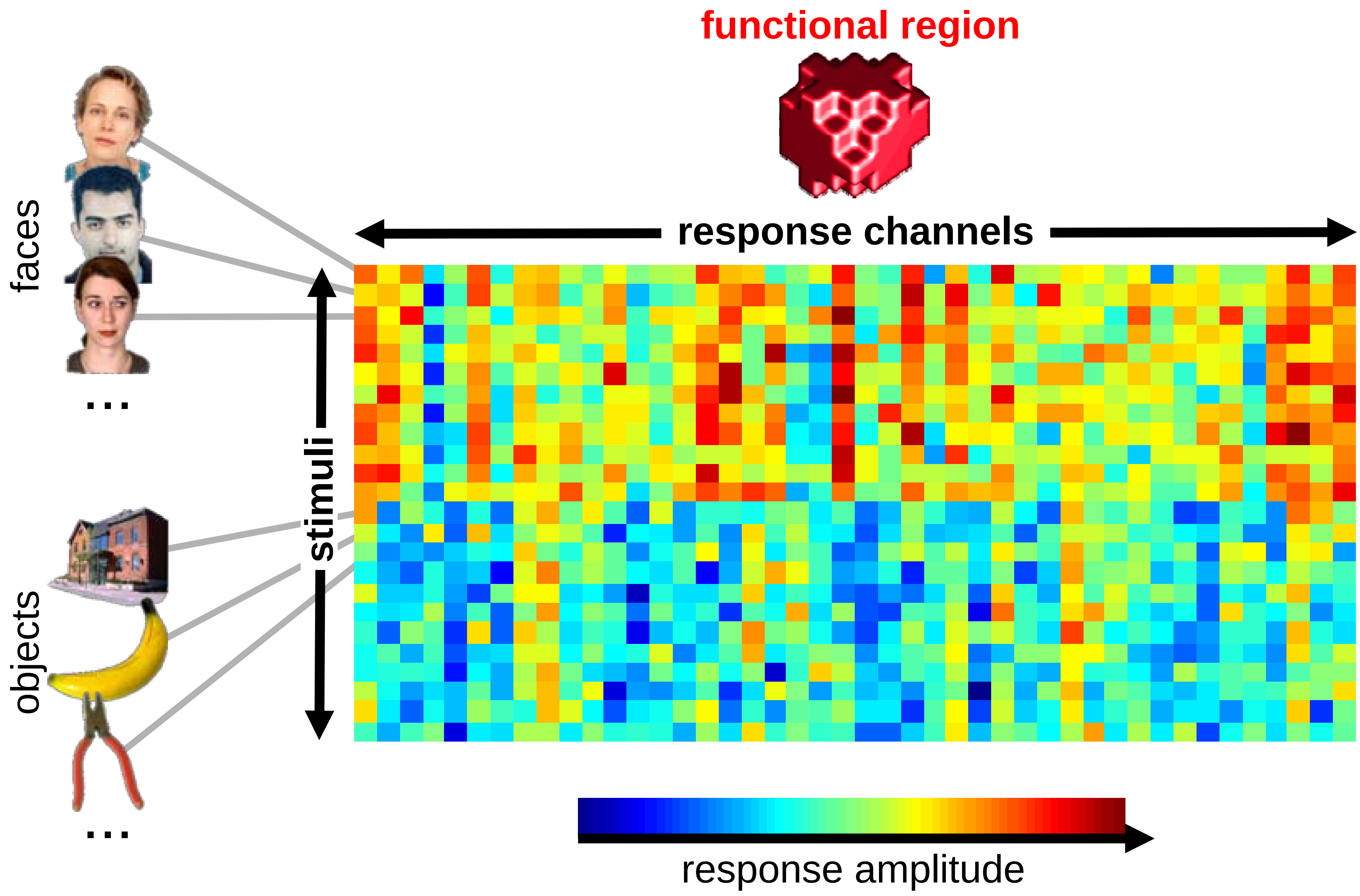
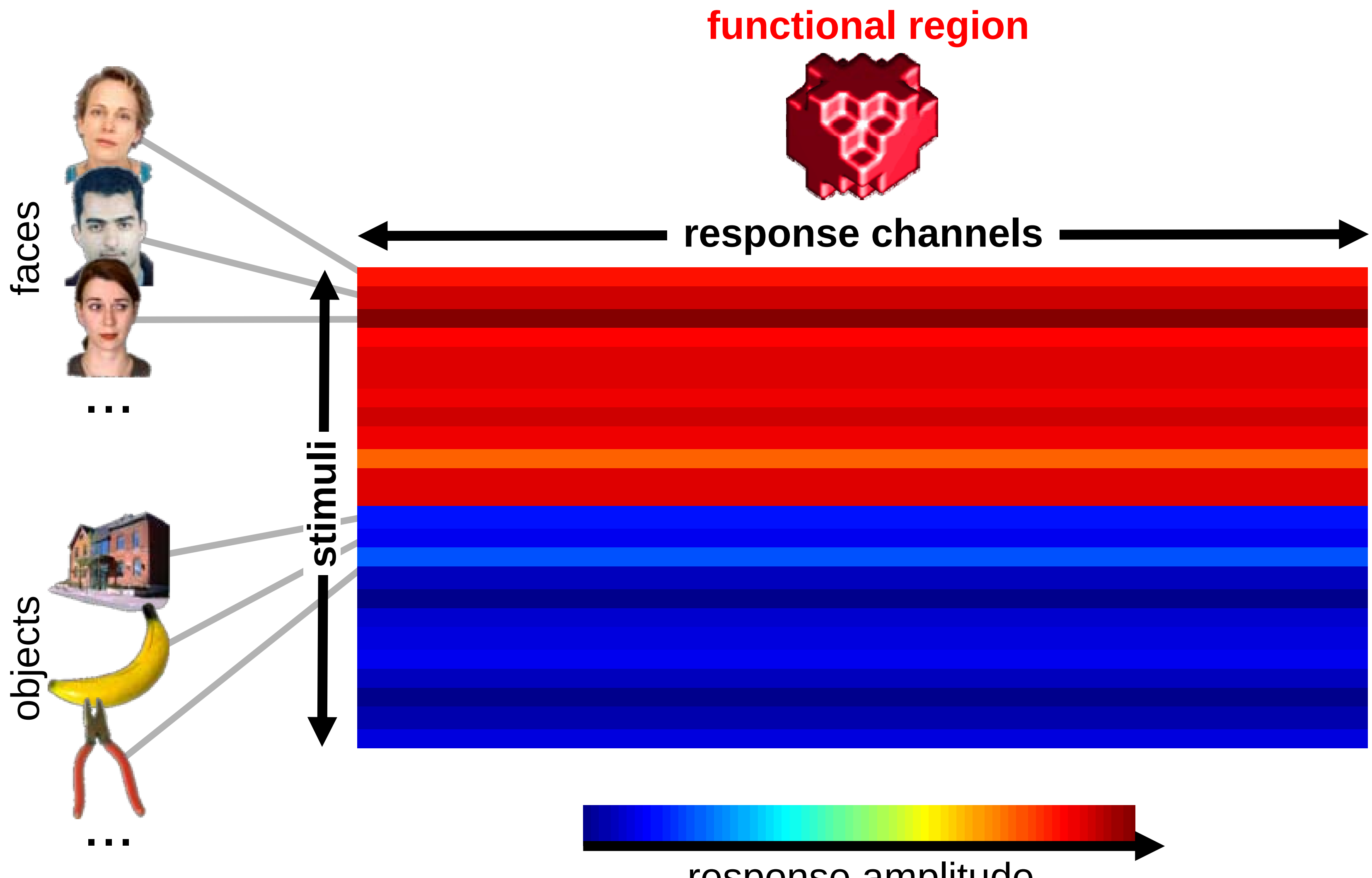
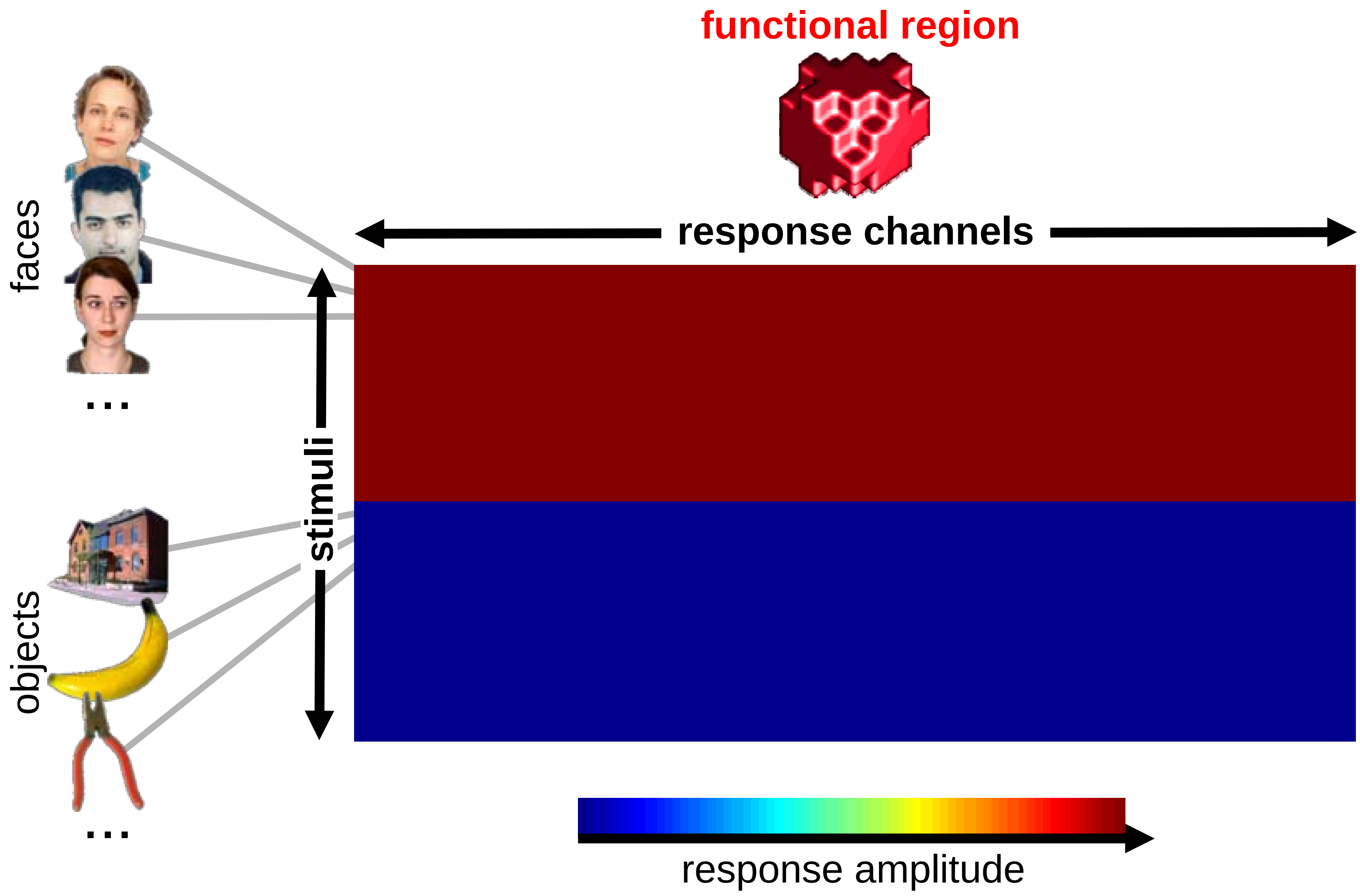
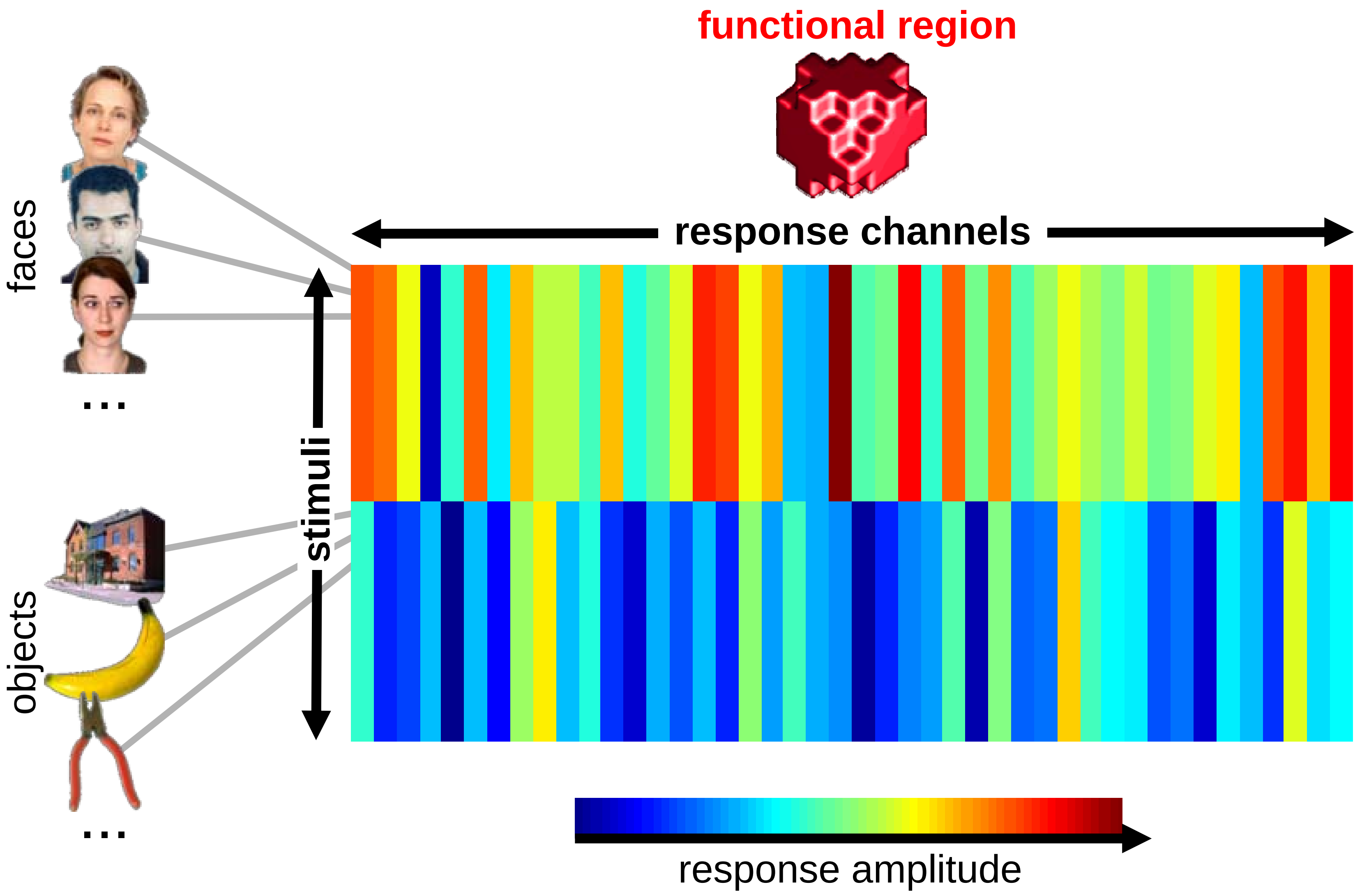

functional region
response channels
faces
...
stimuli
objects
...
response amplitude


functional region
response channels
faces
...
stimuli
objects
...
response amplitude

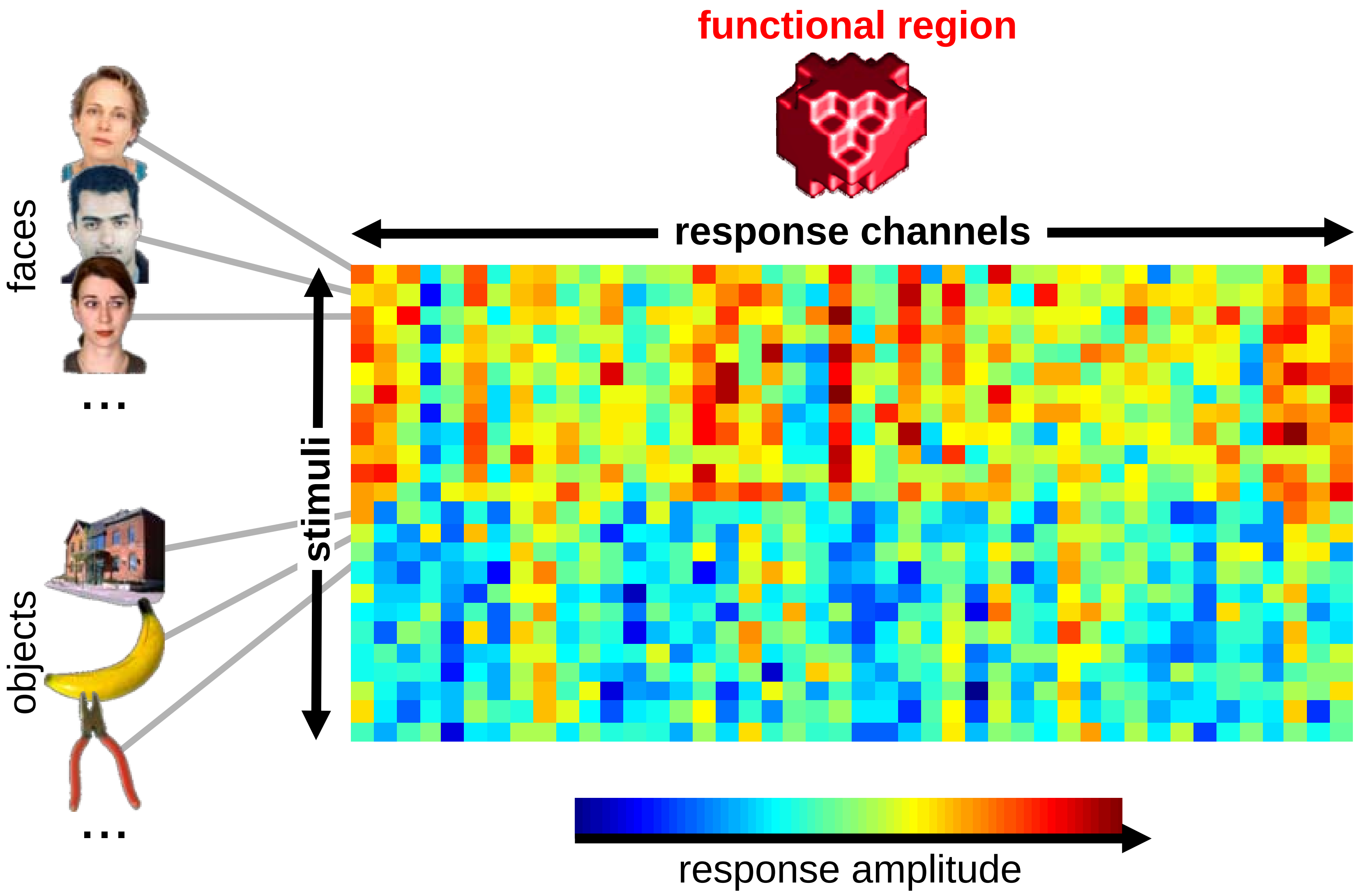
Activation analysis



Pattern-information analysis



Goal: honor all these distinctions



Talk overview

Specific neuroscientific experiments

- inferior temporal object representations in human and monkey

General methodology

- every stimulus is a condition
- condition-rich fMRI design
- representational similarity analysis

Related literature

- **multidimensional scaling**
  Torgerson (1958), Kruskal & Wish (1978), Shepard (1980)

- **second-order isomorphism**
  Shepard & Chipman (1970)

- **first application of multidimensional scaling to fMRI data**
  Edelman et al. (1998)

- **some more recent studies with similarity analyses**
  Laakso and Cottrell (2000) , Op de Beeck et al. (2001), Hanson et al. (2004), O'Toole et al. (2005), Tsao et al. (2006), Sereno & Lehky (2006), Aguirre (2007), Kiani et al. (2007)

Collaborators

Bethesda, MD, USA

- Marieke Mur
- Douglas Ruff
- Jerzy Bodurka
- Peter Bandettini

Seattle, WA, USA

- Roozbeh Kiani

Tehran, Iran

- Hossein Esteky

Wako, Saitama, Japan

- Keiji Tanaka

Overview of experiment and analysis

- **present images of real-world objects to subjects**
  (human, monkey)

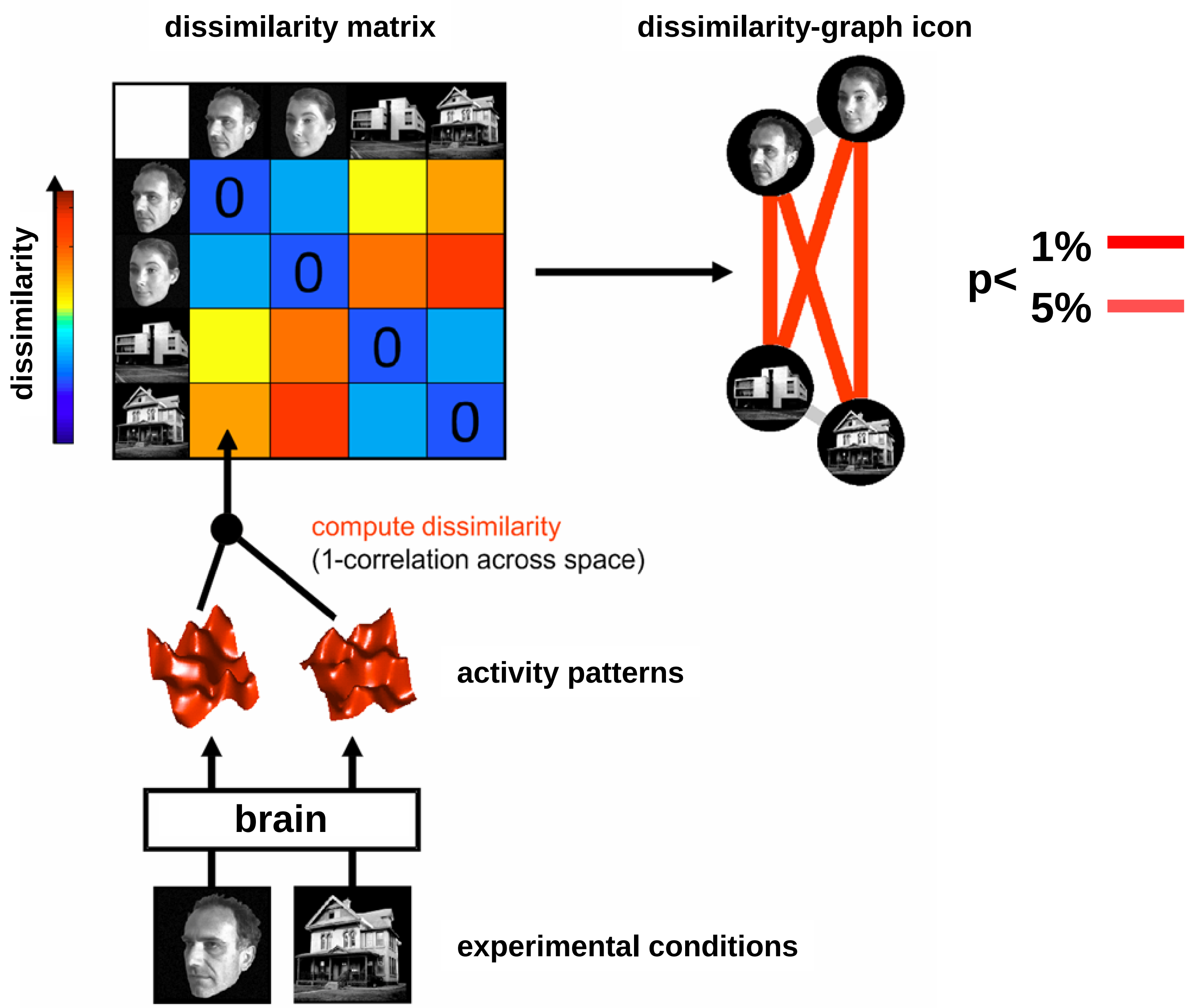
- **measure the brain-activity pattern**
  during perception of each particular image
  (fMRI, cell recording)

- **study similarity structure of object representations**
  focusing on inferior temporal (IT) cortex

- **compare representations in human and monkey IT**
  by relating representational similarity matrices

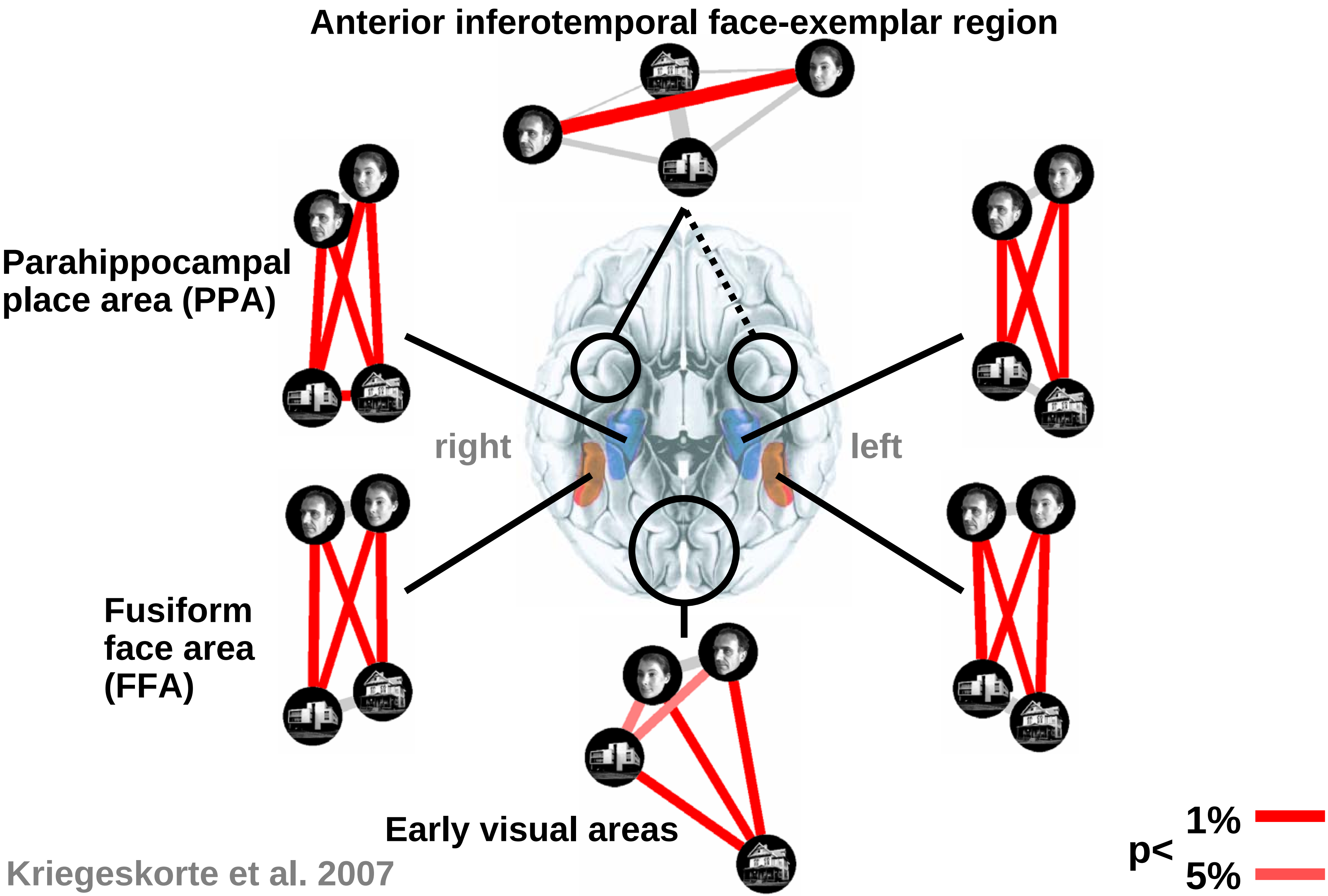
Core concept

representational similarity matrix



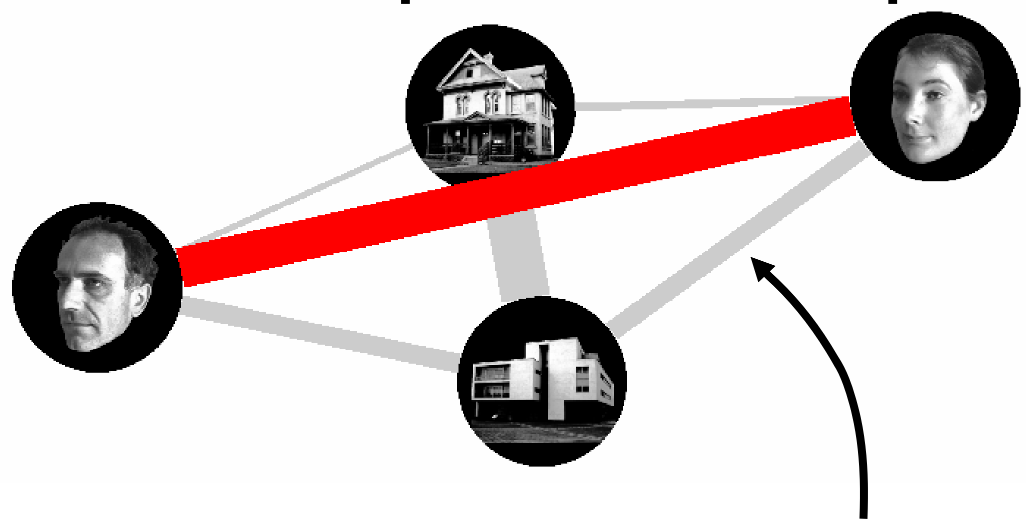
dissimilarity matrix
dissimilarity-graph icon
dissimilarity
0
0
0
0
p<
1%
5%
compute dissimilarity
(1-correlation across space)
activity patterns
brain
experimental conditions

Transformation of representational similarity



Kriegeskorte et al. 2007

Anterior inferotemporal face-exemplar region



rubberband graph

- stretched effects: thin
- compressed effects: thick
- effect [bits] $\propto$ length · tickness

p<0.01

Kriegeskorte et al. 2007

96-stimulus experiment

Brain-activity measurements

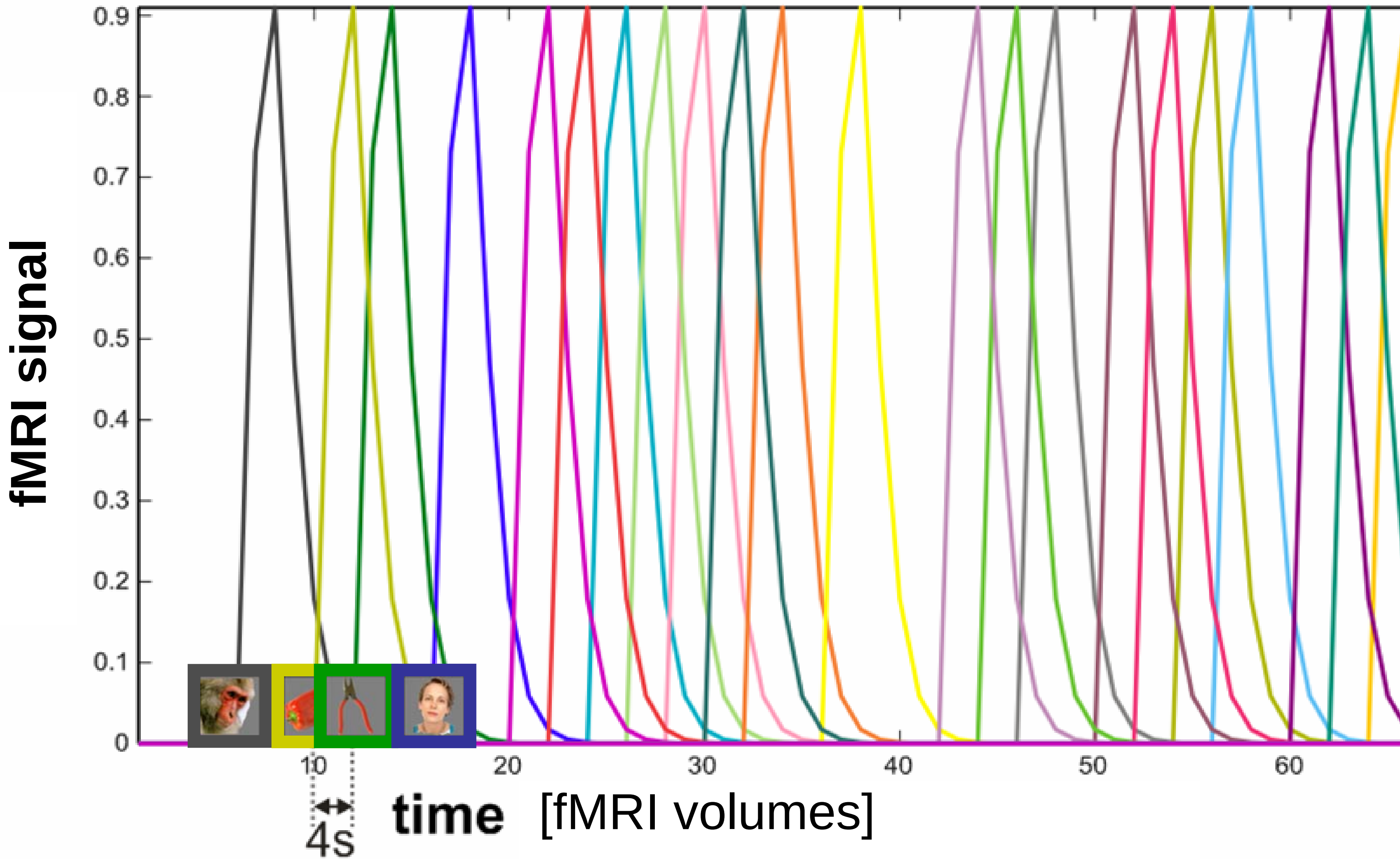
Human

- fMRI in four subjects
  (>12 runs per subject)
- task: fixate, discriminate fixation-point color changes
- occipitotemporal measurement slab
  (5-cm thick)
- voxels: $1.95 \times 1.95 \times 2 mm^3$
- 3T magnet, 16-channel coil
  (SENSE, acc. fac. 2)
- stimulus duration: 300ms
- quick event-related (SOA=4s)

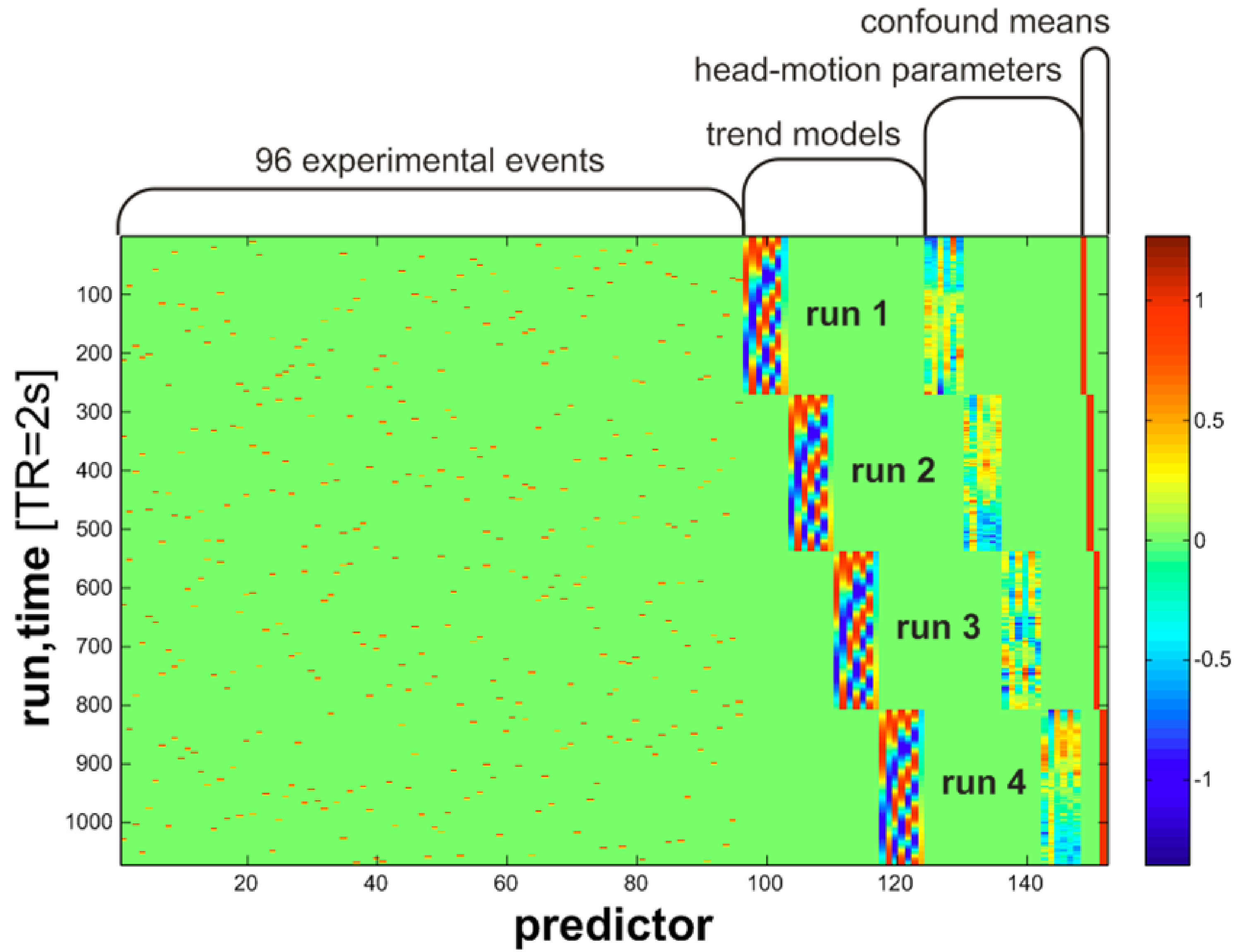
Monkey (**Kiani et al. 2007**)

- single-cell recordings in two monkeys
- task: fixation
- electrodes in anterior IT
  (left in monkey 1, right in monkey 2)
- 674 cells total
- stimulus duration: 105ms
- rapid serial presentation
- 140-ms window spike count starting 71ms after stimulus onset

Single-image hemodynamic response predictors



Design matrix



Stimulus quartets

(multidimensional scaling, metric stress)

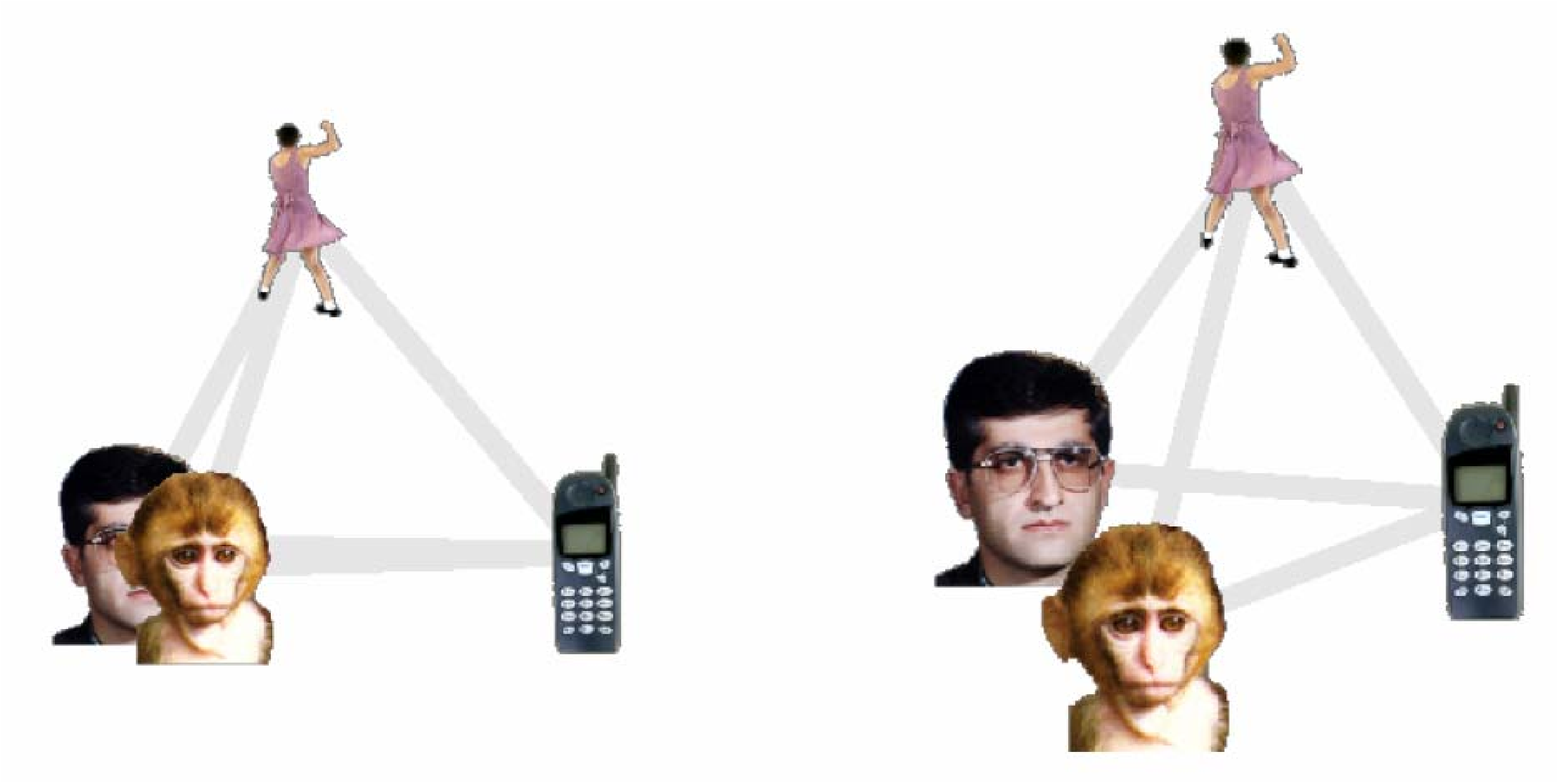
human **monkey**

(1) multidimensional scaling (1-r, metric stress)

(2) rigid alignment for easier comparison (Procrustes alignment)

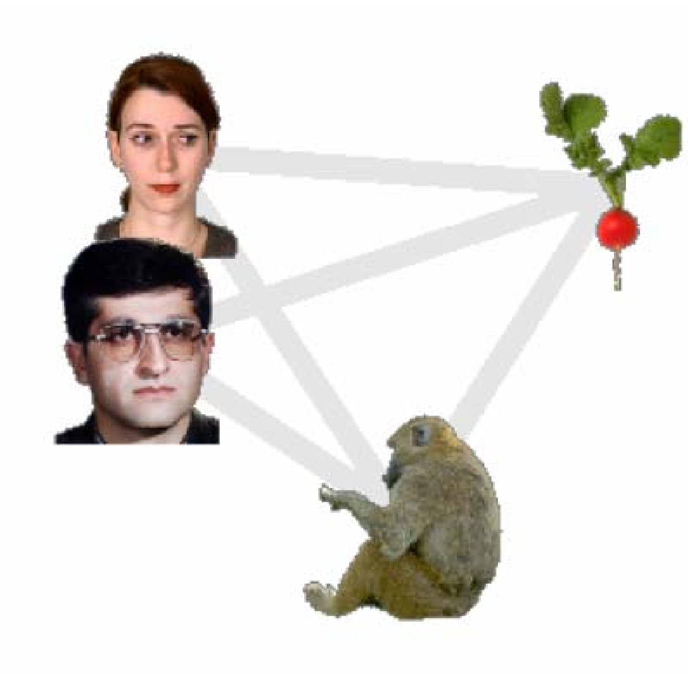
Stimulus quartets

(multidimensional scaling, metric stress)

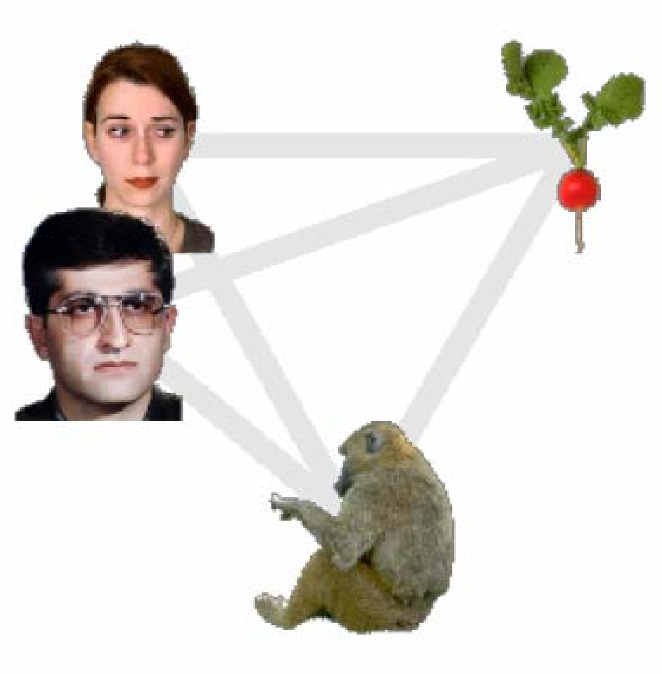


human **monkey**

Stimulus quartets
(multidimensional scaling, metric stress)



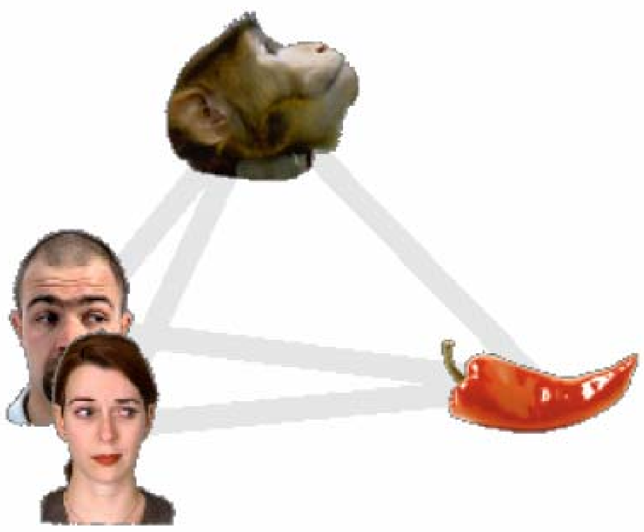
human



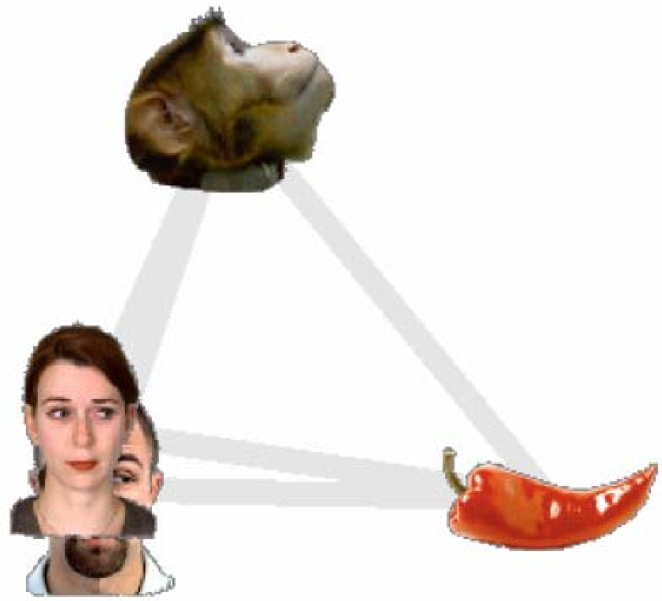
monkey

Stimulus quartets

(multidimensional scaling, metric stress)



human



monkey

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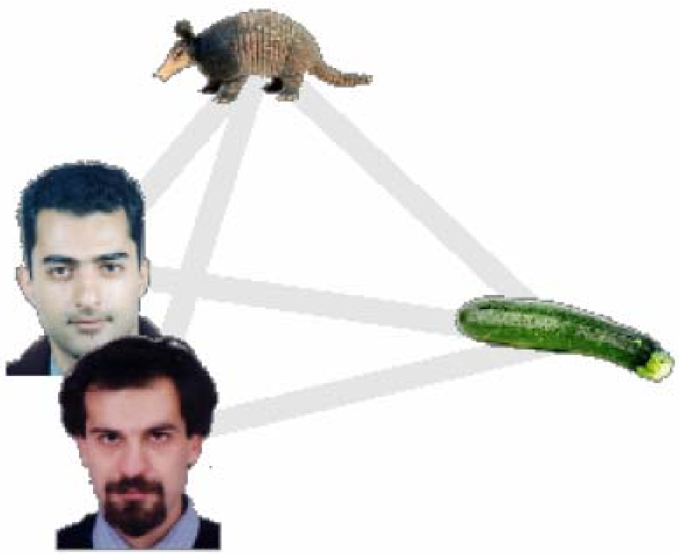

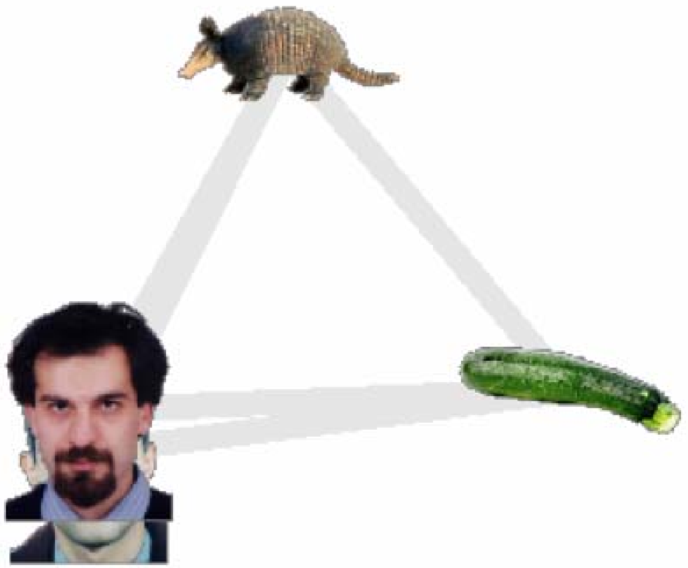

human **monkey**

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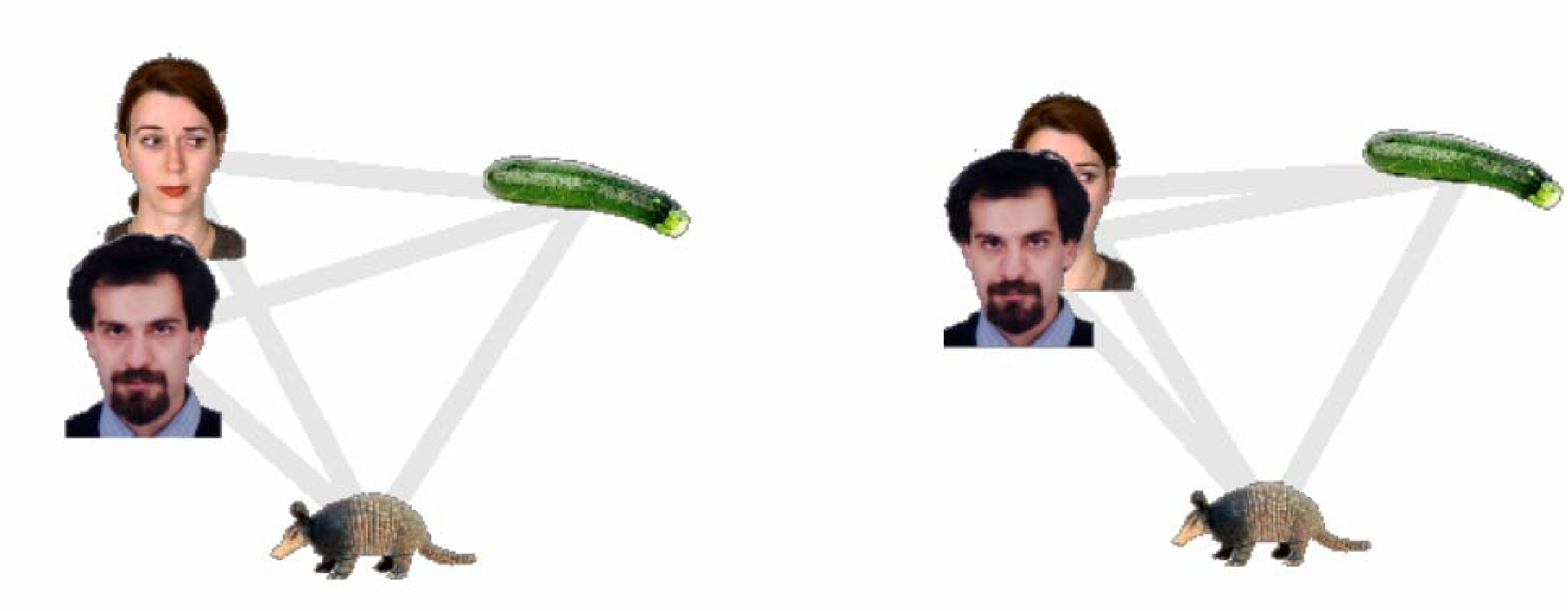

human **monkey**

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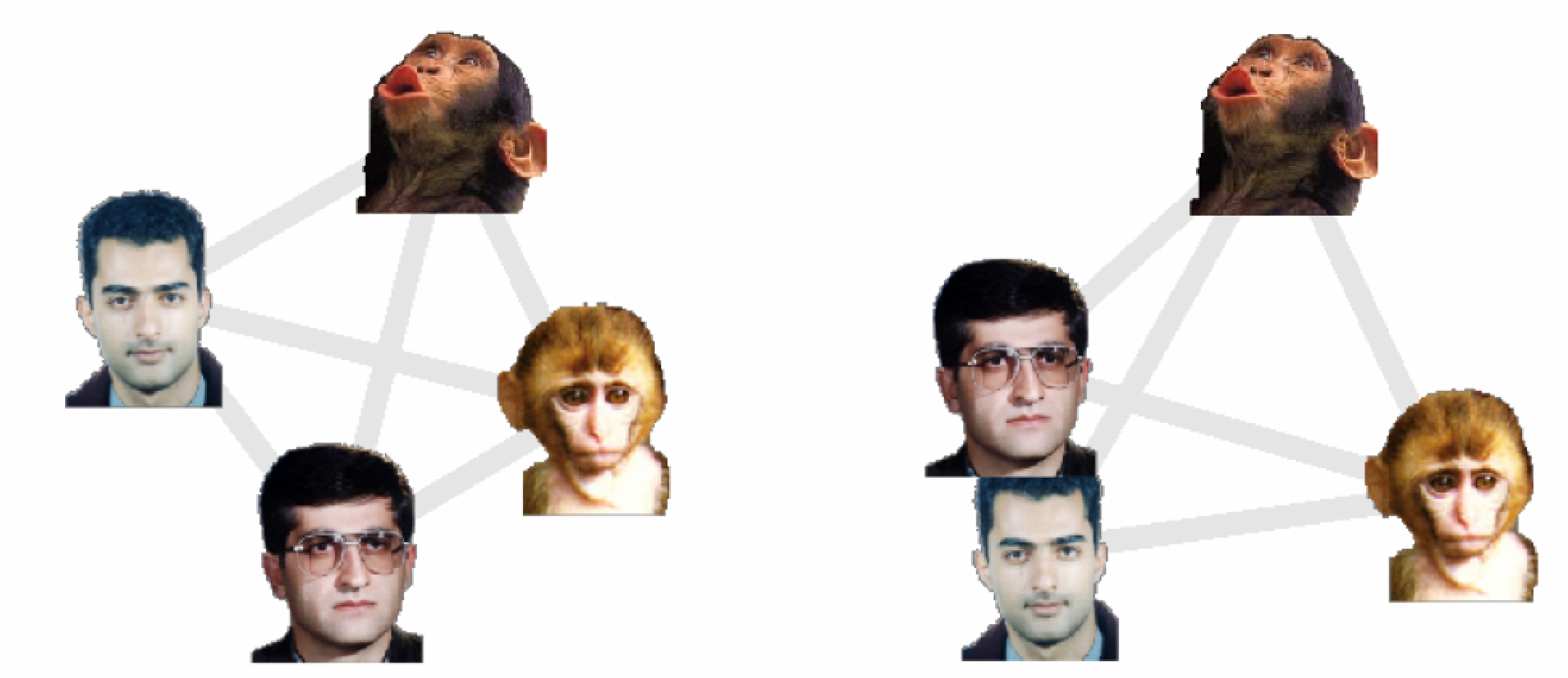

human **monkey**

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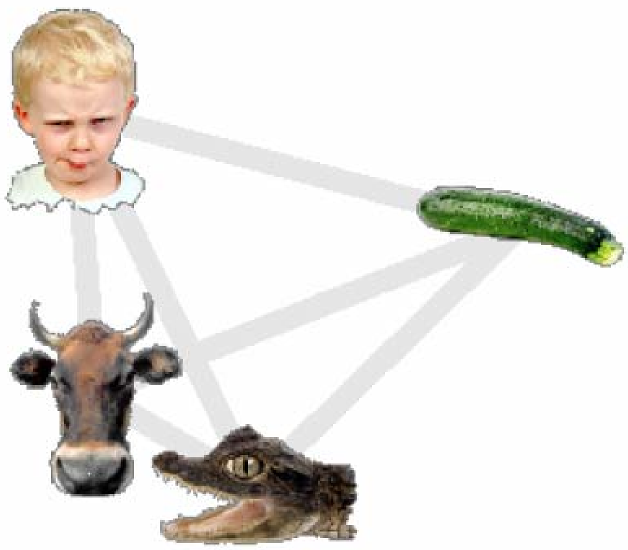
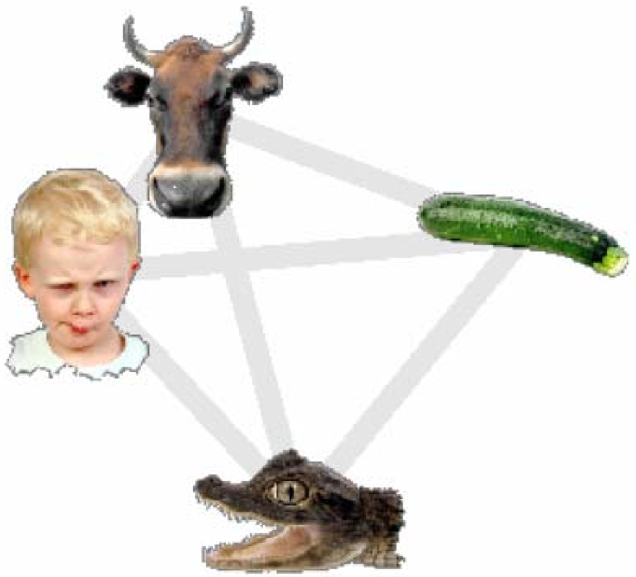
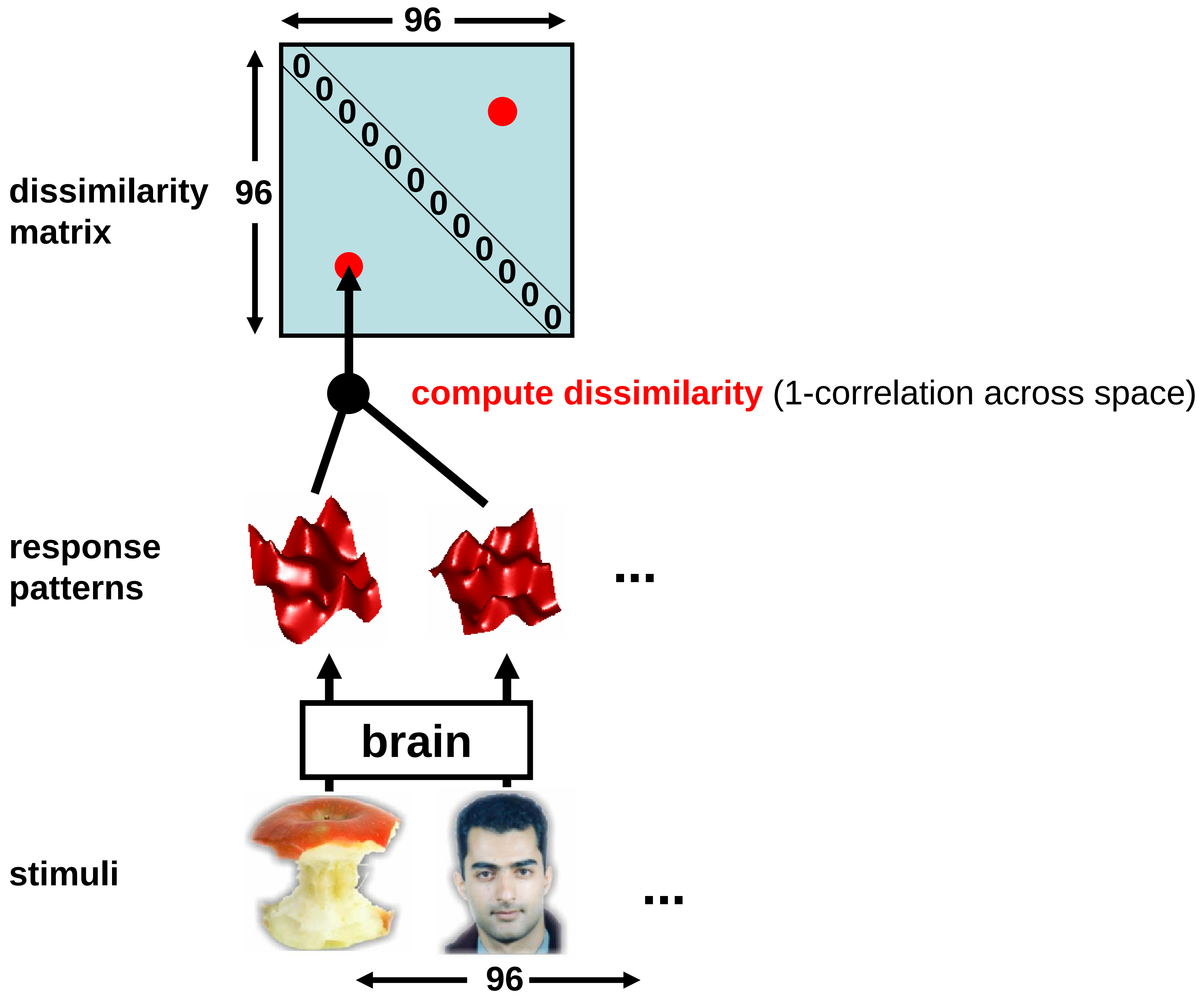


human

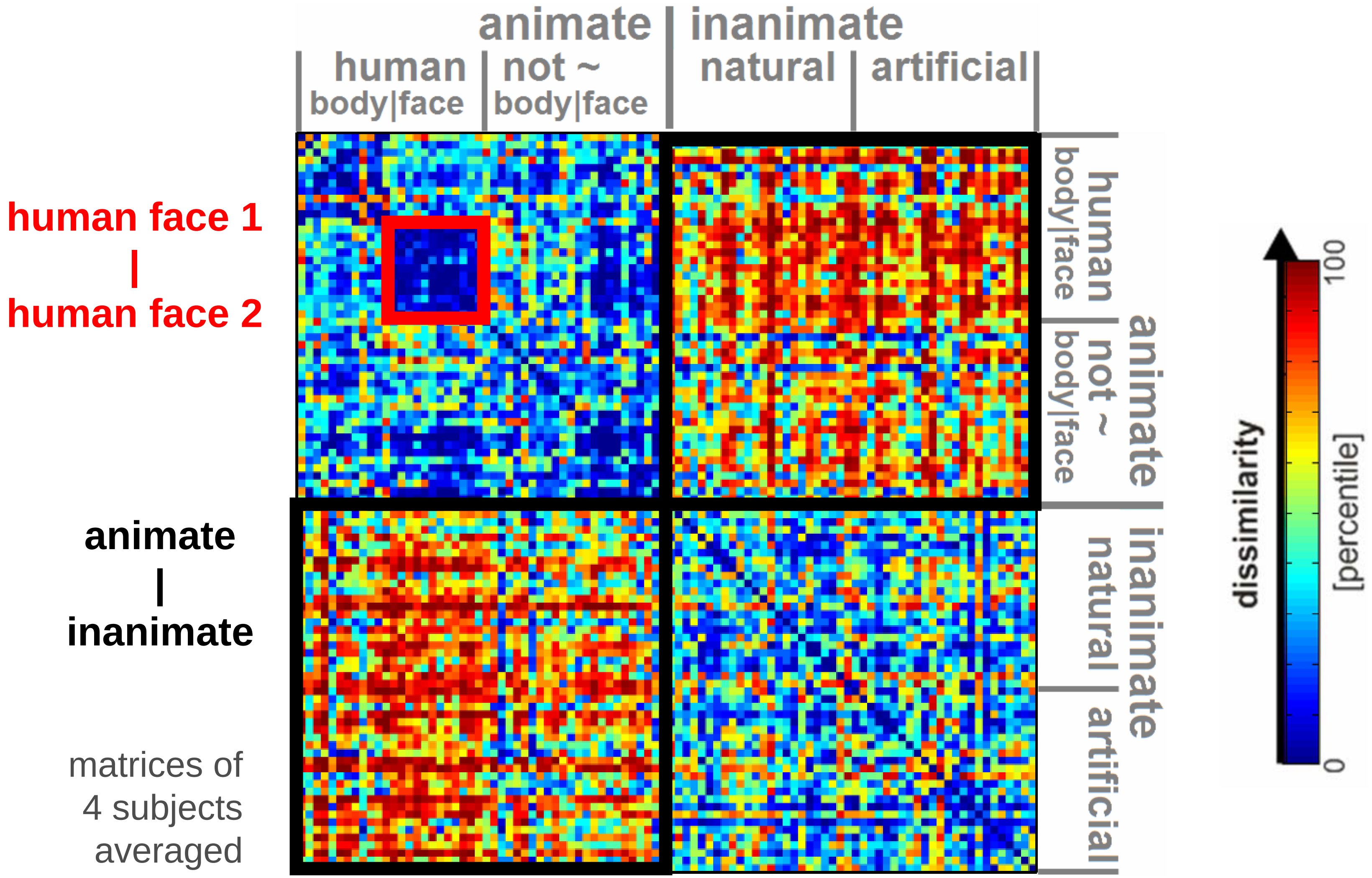


monkey


96
dissimilarity matrix
96
0 0 0 0 0 0 0 0 0 0 0 0
compute dissimilarity (1-correlation across space)
response patterns
...
brain
stimuli
...
96

Human IT

(1000 most visually responsive voxels within anatomical IT mask)



To visualize the representation...

Let's arrange the images in a figure reflecting response-pattern similarity

- images close ➔ similar response patterns
- images far ➔ dissimilar response patterns

Multidimensional scaling

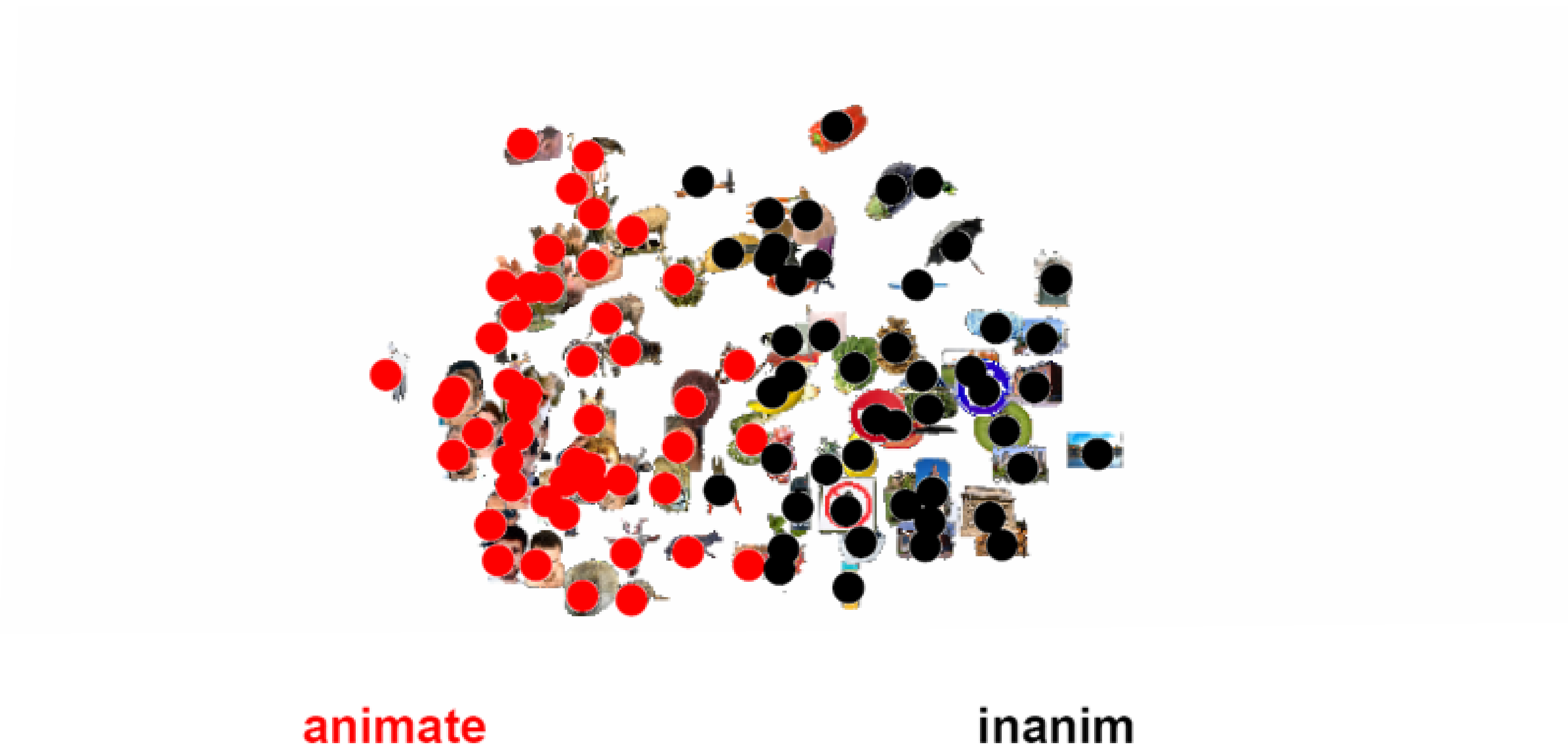
Torgerson (1958), Kruskal & Wish (1978), Shepard (1980)
first application to fMRI: Edelman et al. (1998)

Human IT

(1000 visually most responsive voxels)

Human IT

(1000 visually most responsive voxels)



Human IT

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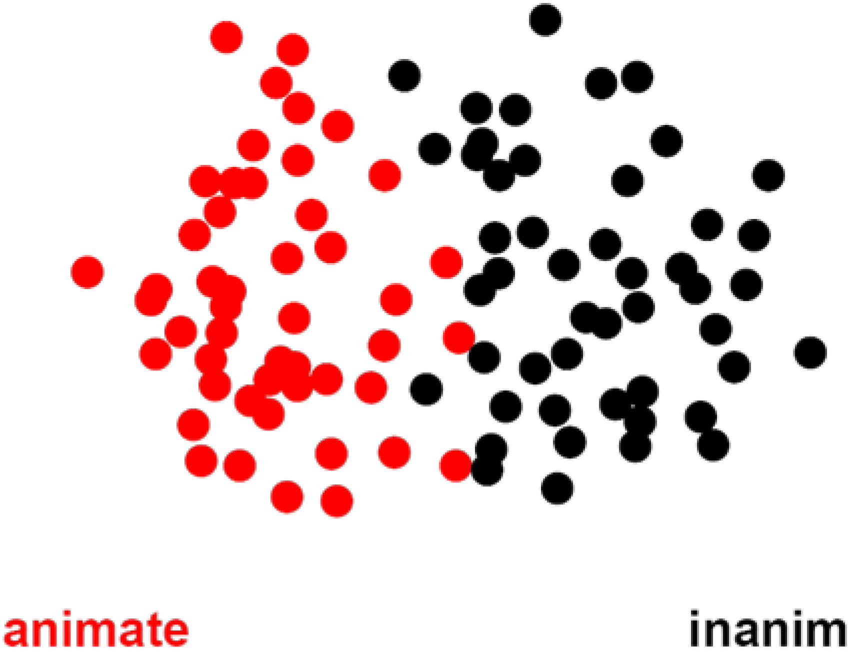

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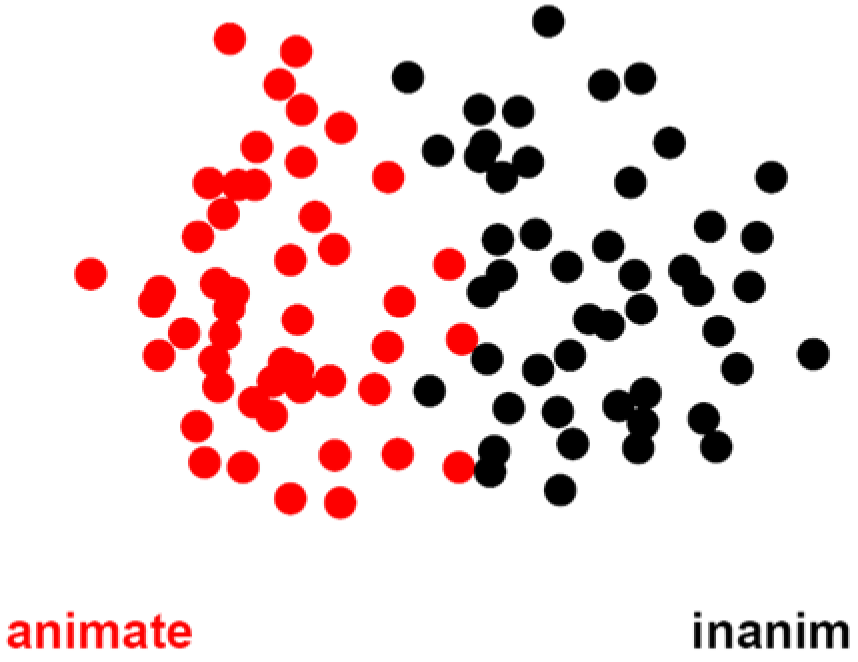
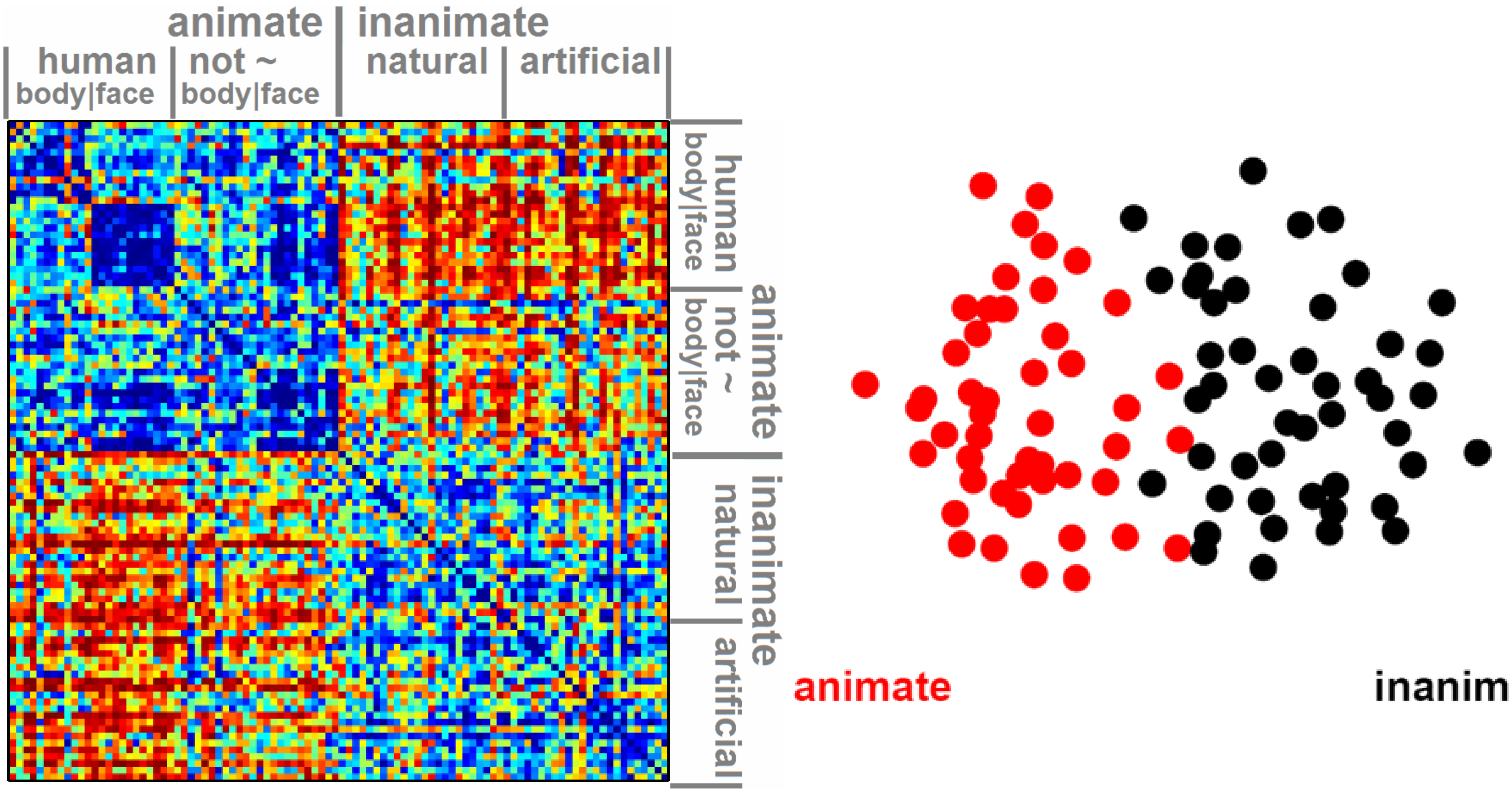


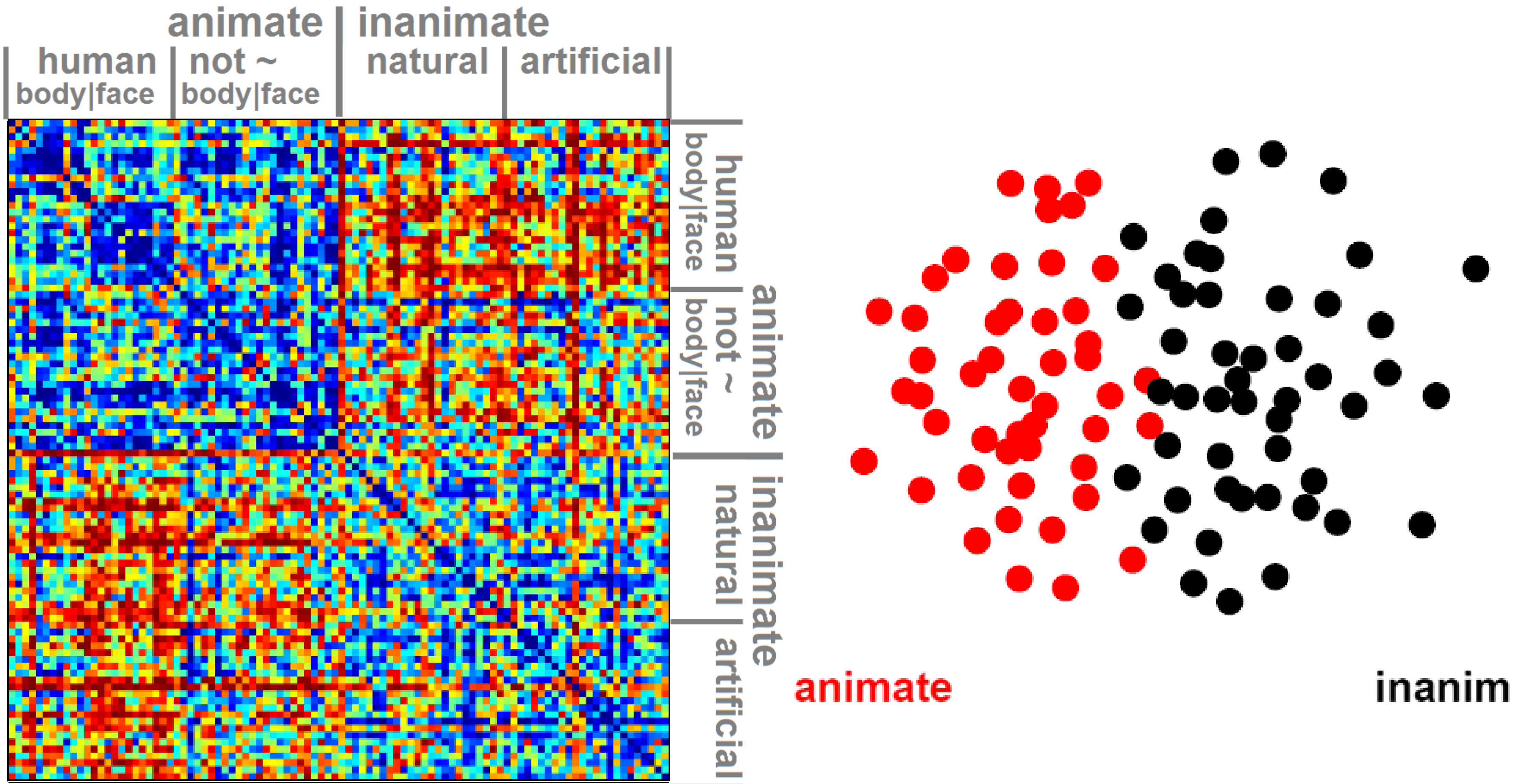
Human IT

(1000 visually most responsive voxels)



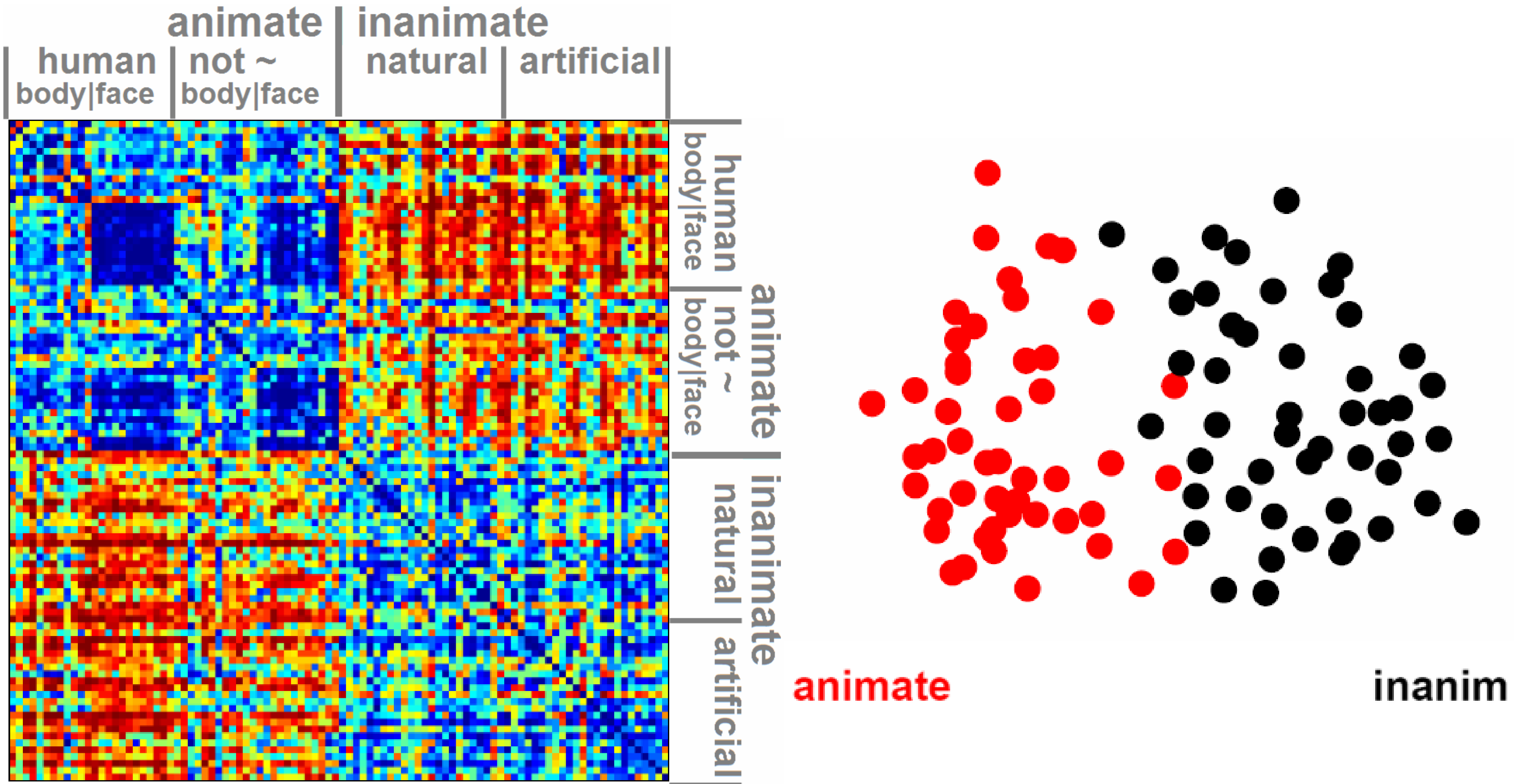
Human IT (larger)

(3162 visually most responsive voxels)



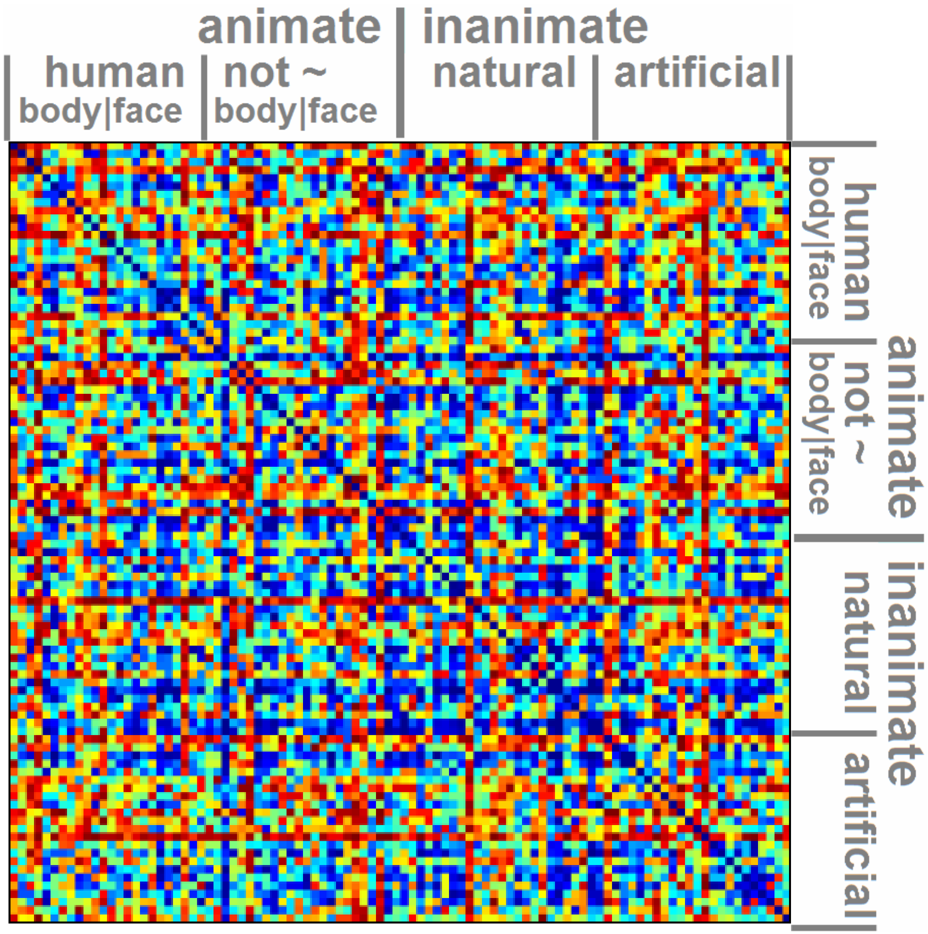
Human IT (smaller)

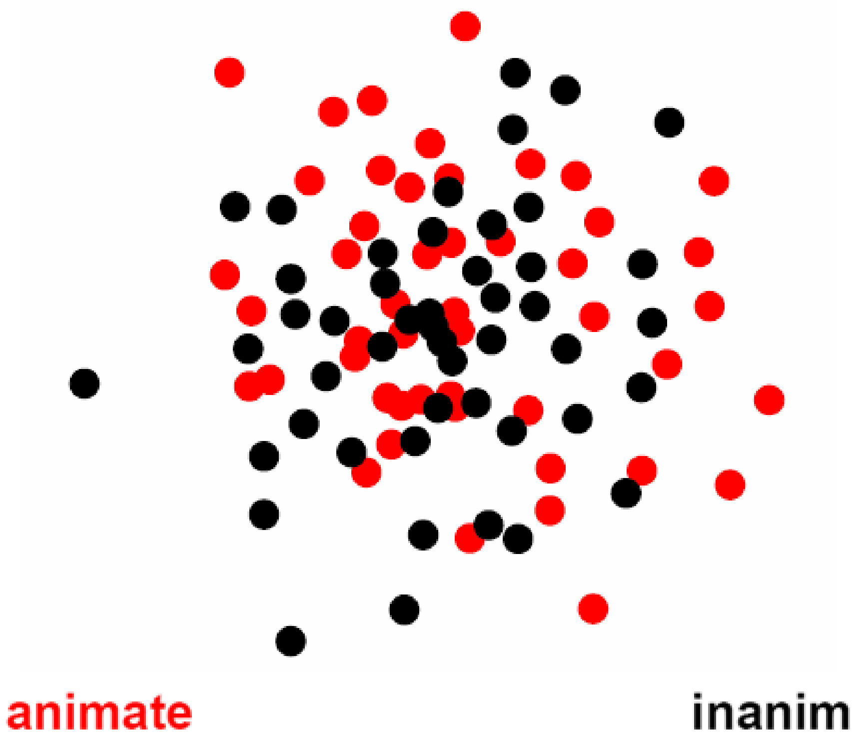
(316 visually most responsive voxels)



Human early visual cortex

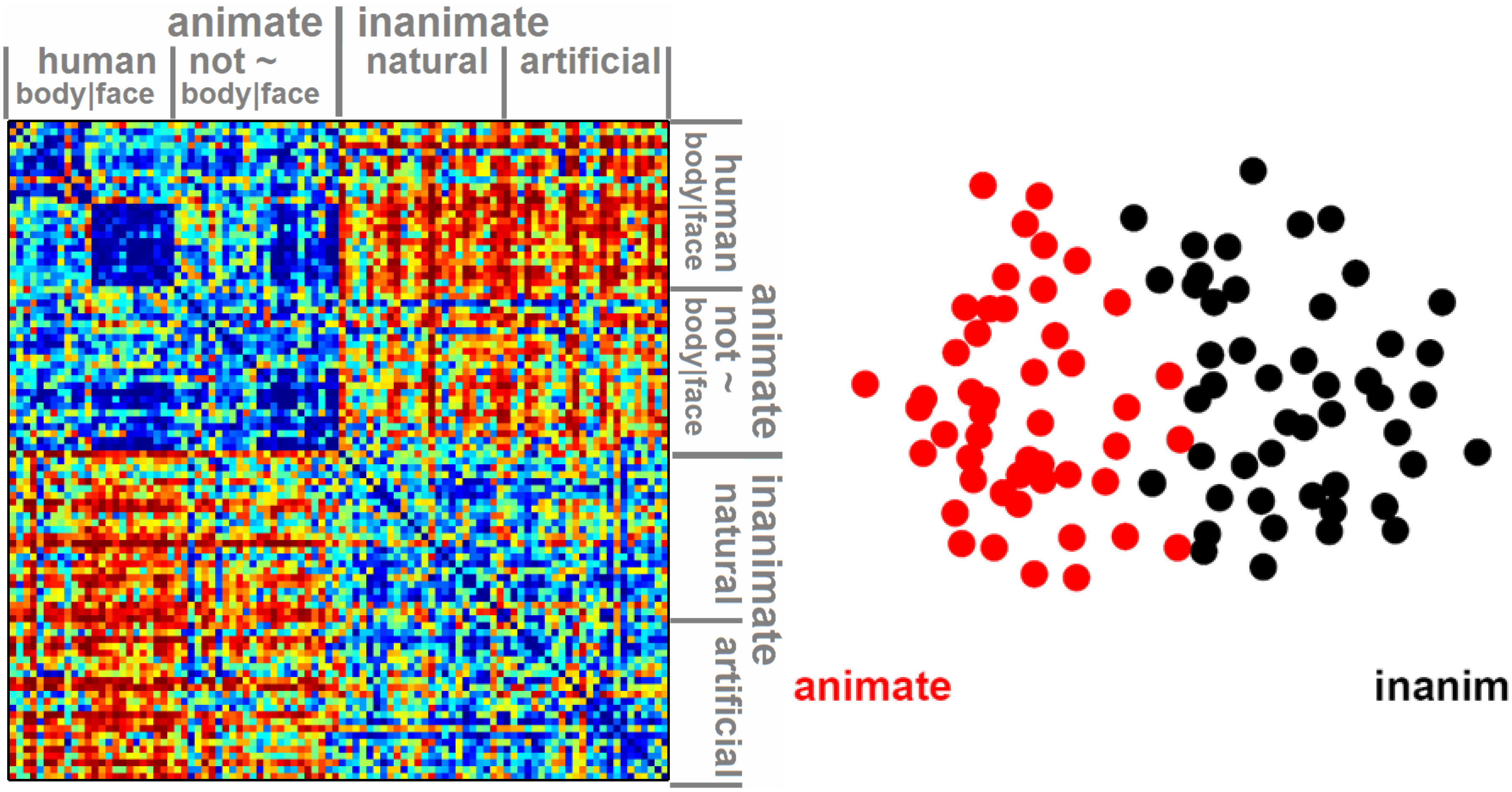
(1057 visually most responsive voxels)

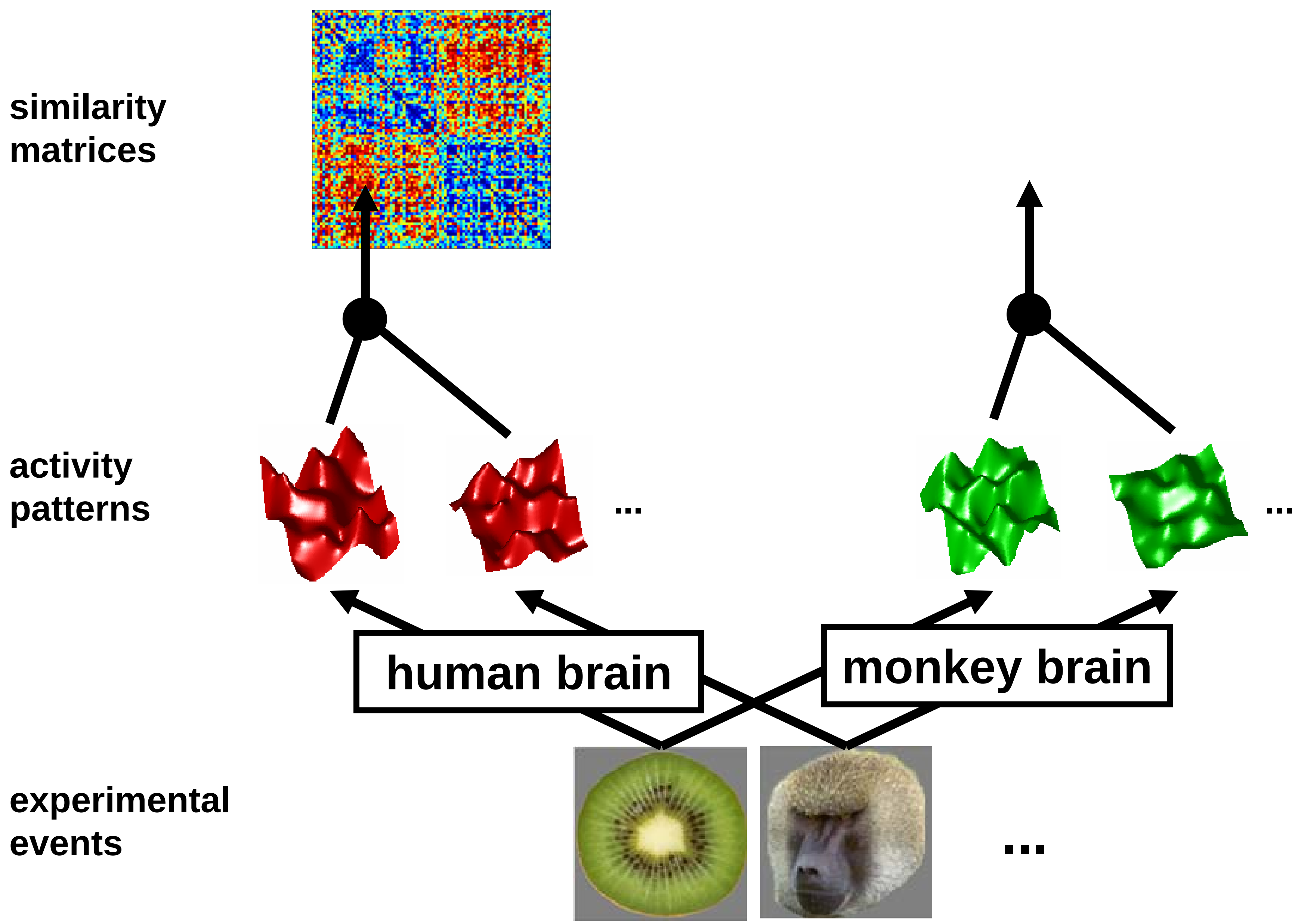




Human IT

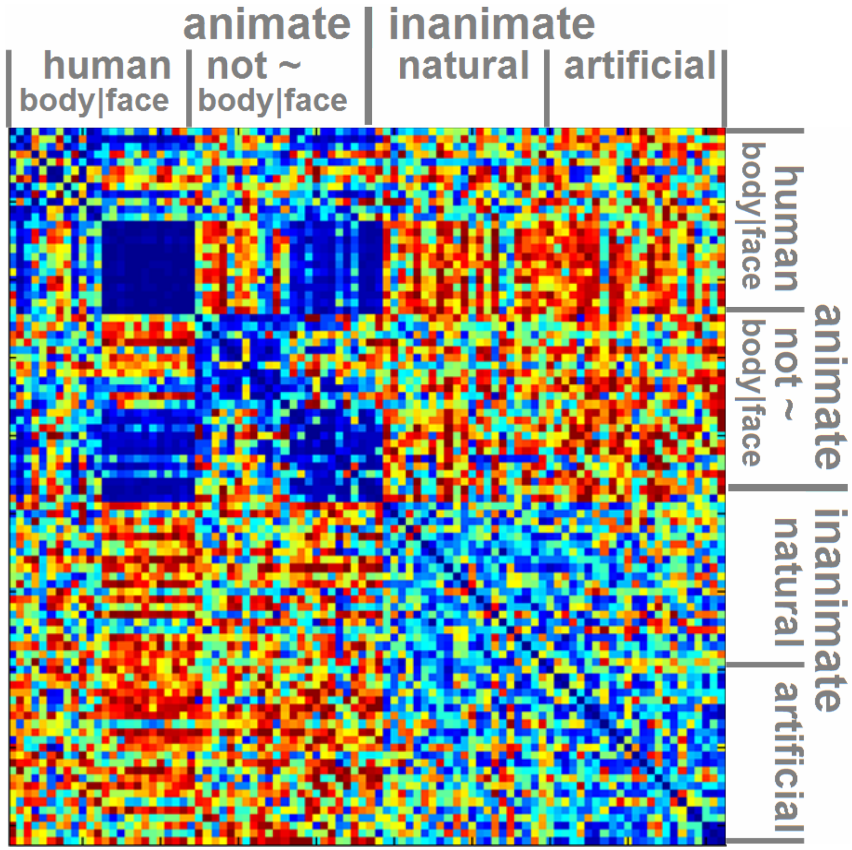
(1000 visually most responsive voxels)



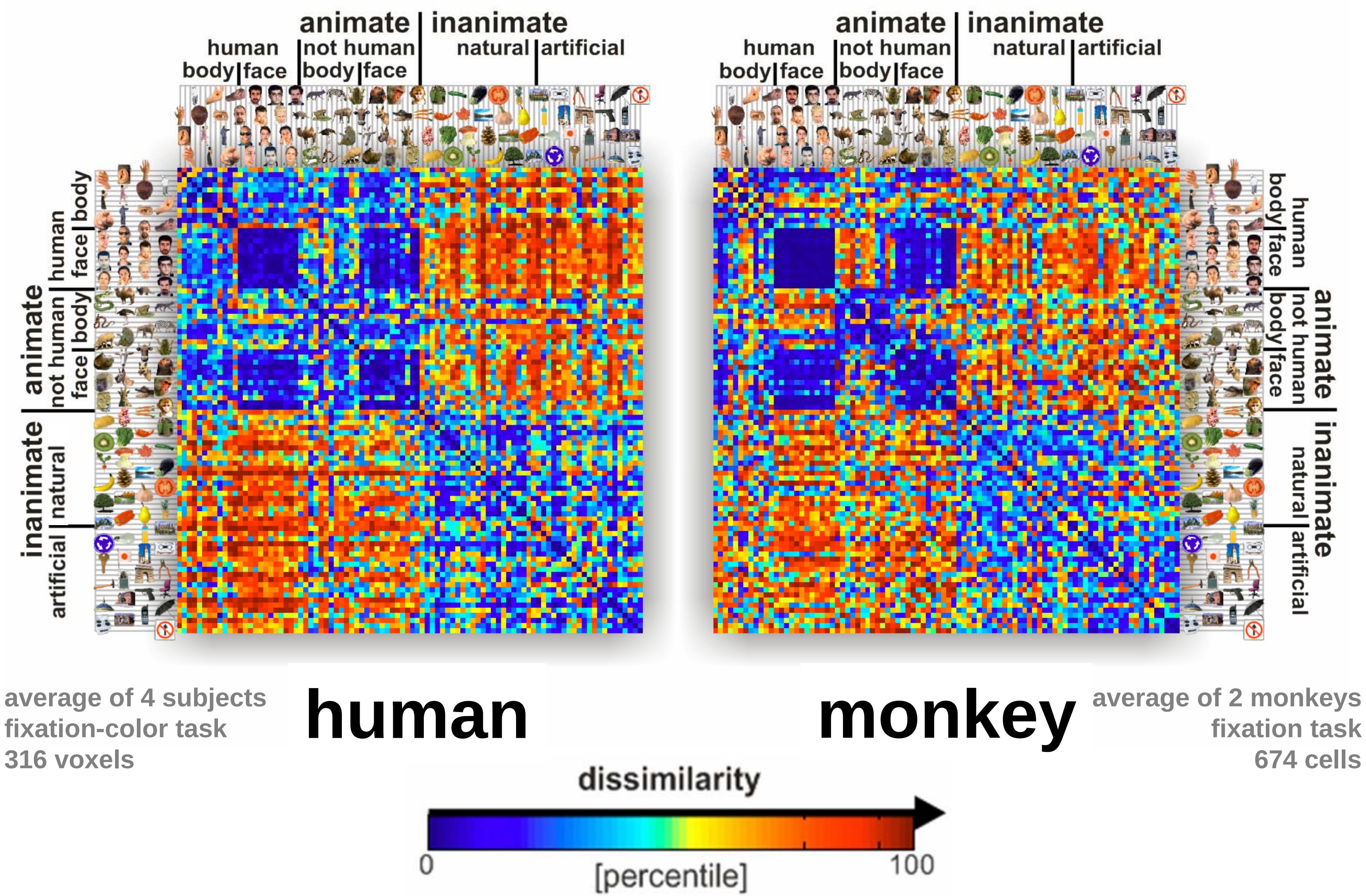

similarity
matrices
activity
patterns
...
...
human brain
monkey brain
experimental
events
...

Monkey IT

(674 cells in left and right aIT, windowed spike count, fixation task, 2 monkeys)

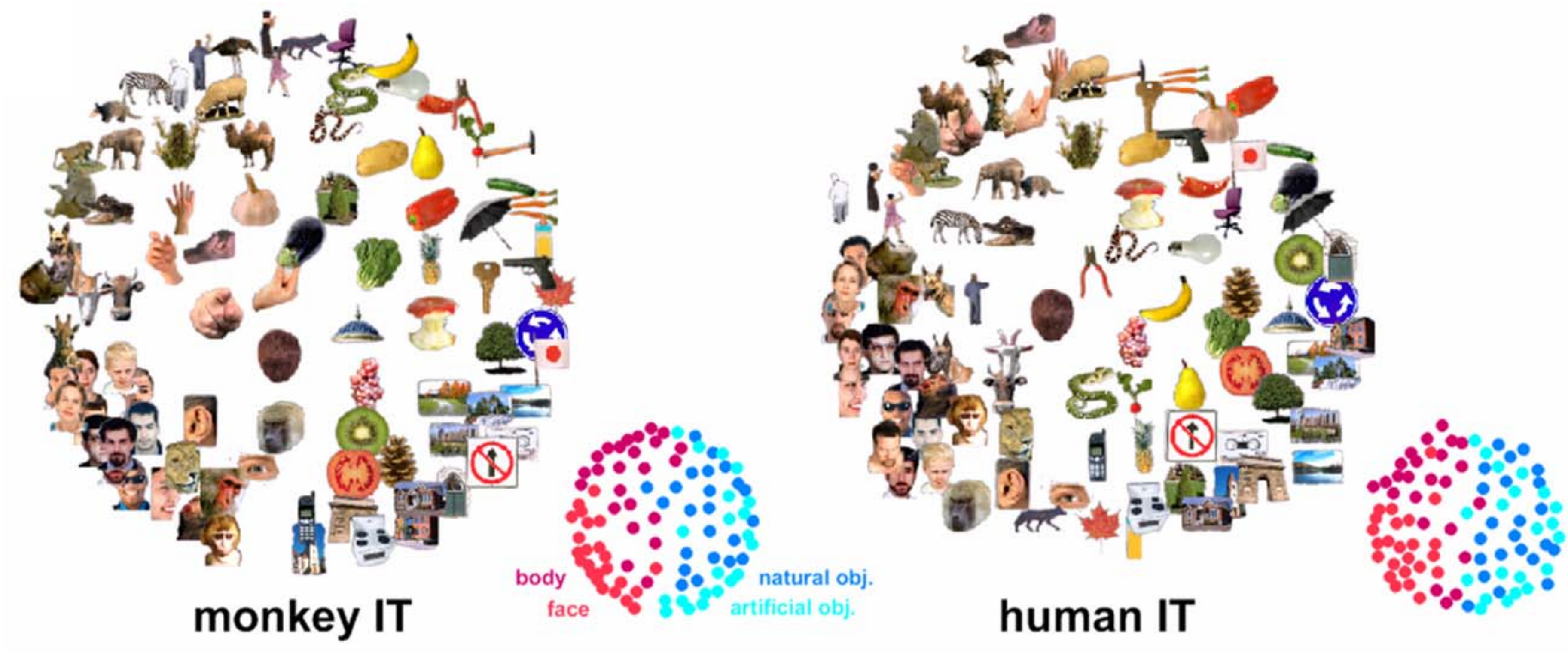


data from Roozbeh Kiani et al. (2007), Journal of Neurophysiology

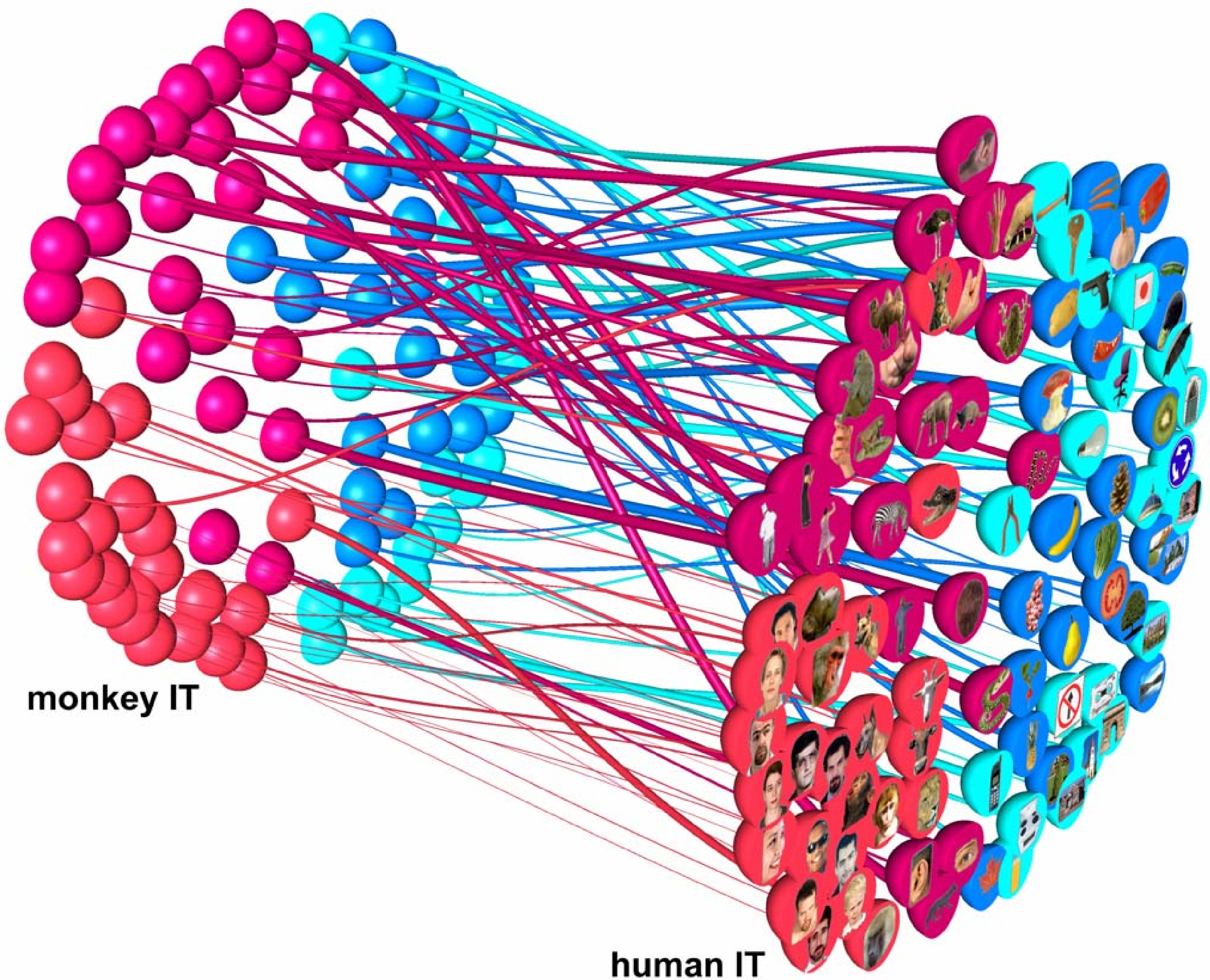


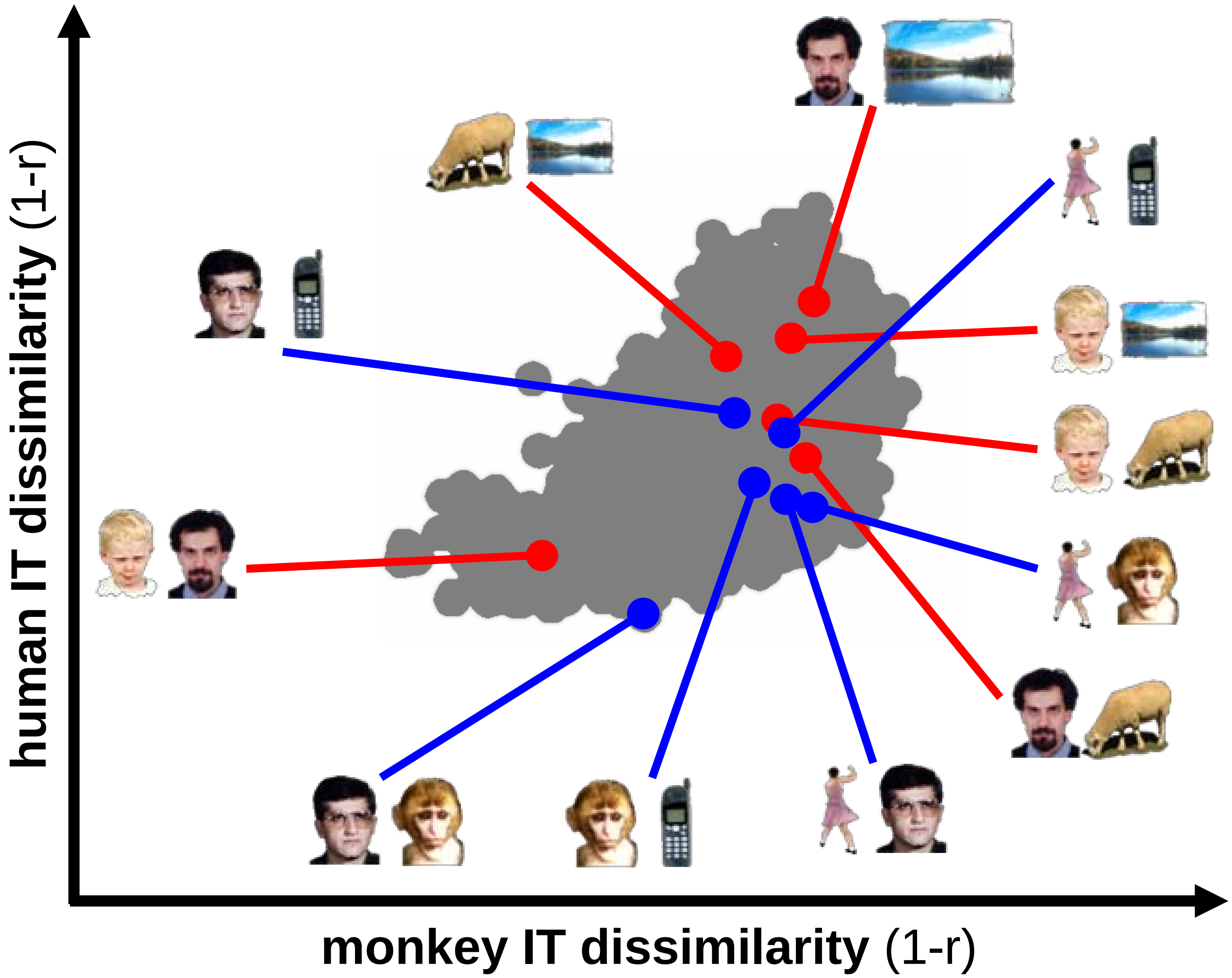
Kriegeskorte et al. (submitted)

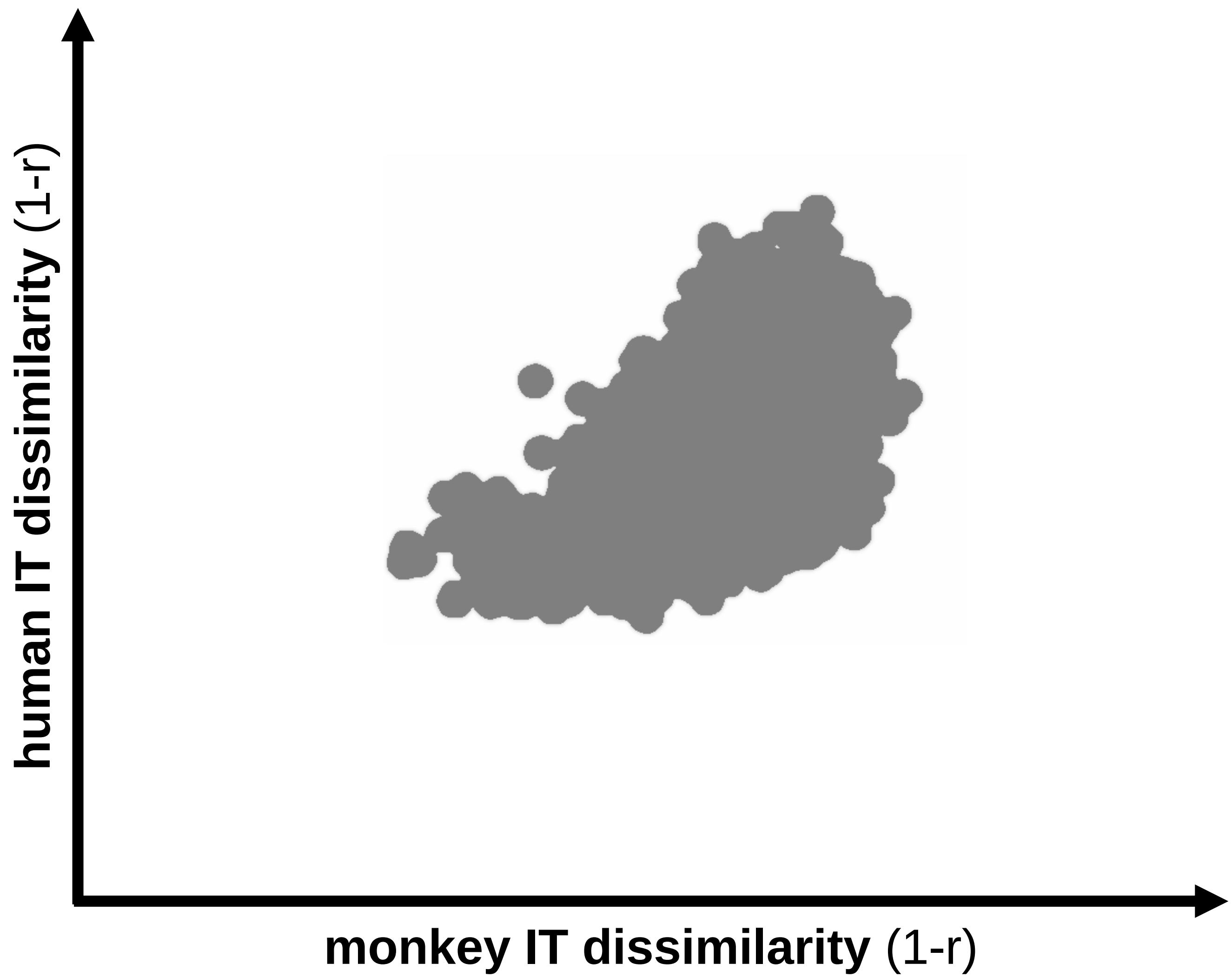
Stimulus arrangements reflecting response-pattern similarity

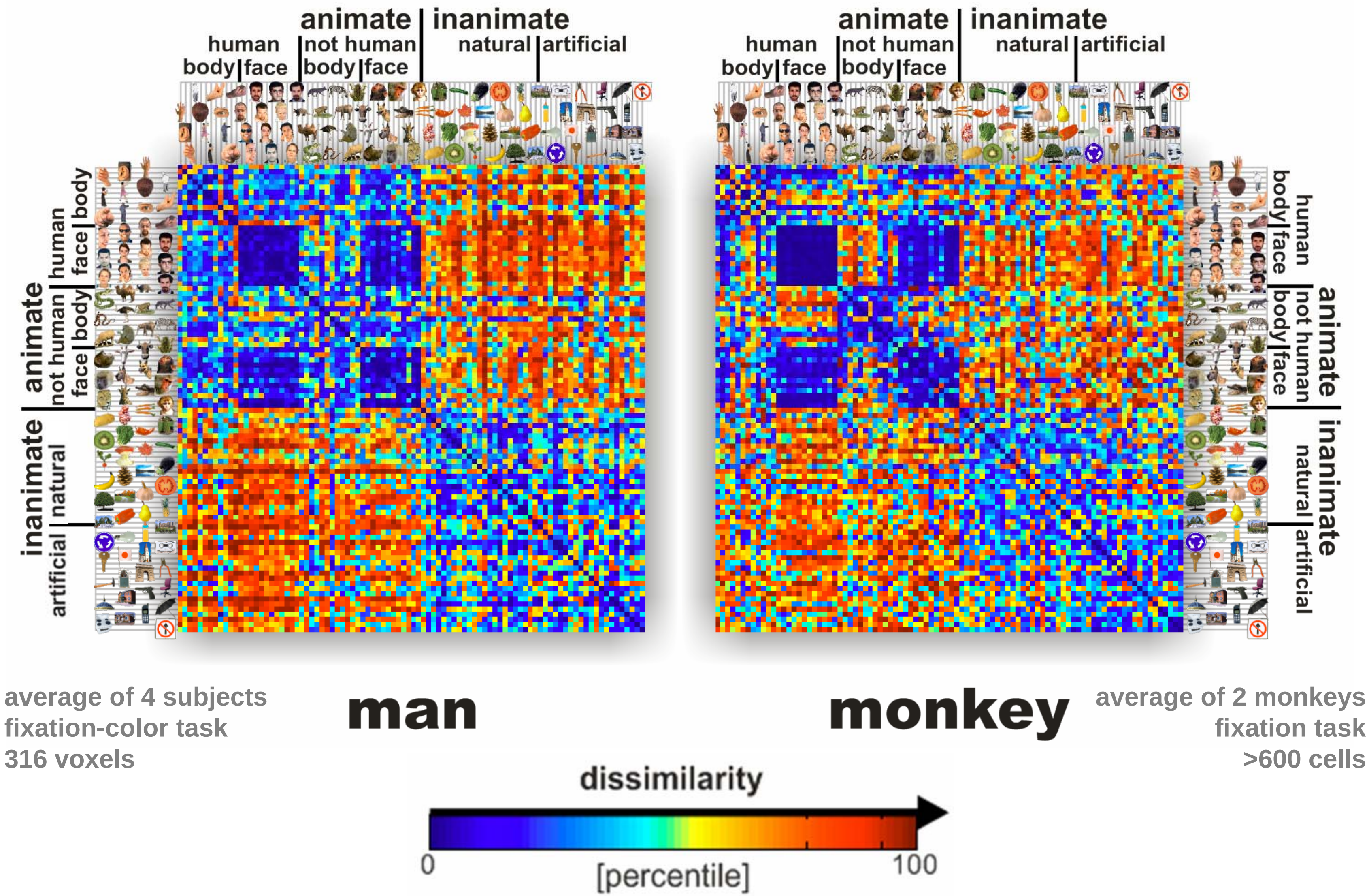


(1) multidimensional scaling (1-r, metric stress)
(2) rigid alignment for easier comparison (Procrustes alignment)


monkey IT
human IT

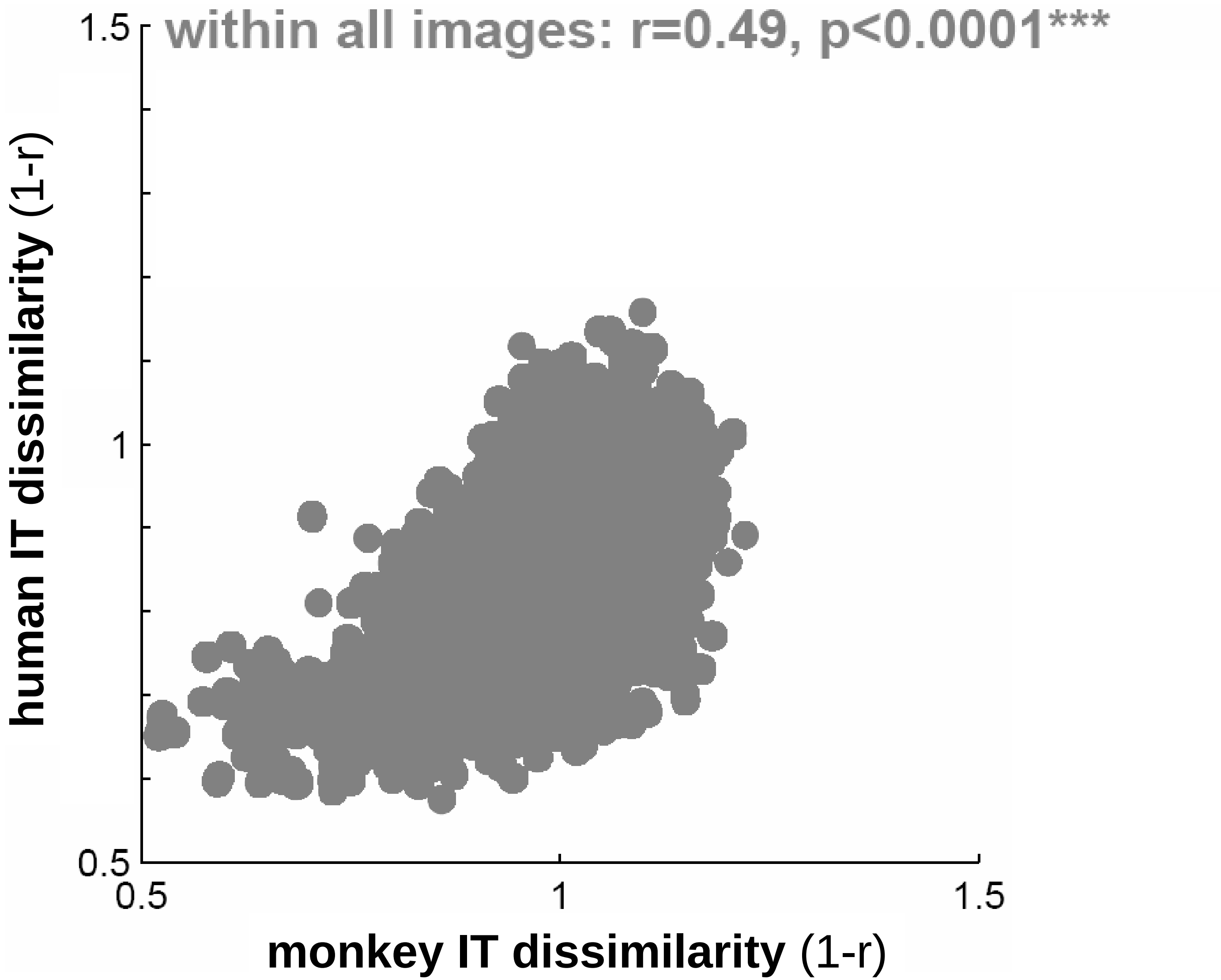

human IT dissimilarity (1-r)
monkey IT dissimilarity (1-r)


human IT dissimilarity (1-r)
monkey IT dissimilarity (1-r)

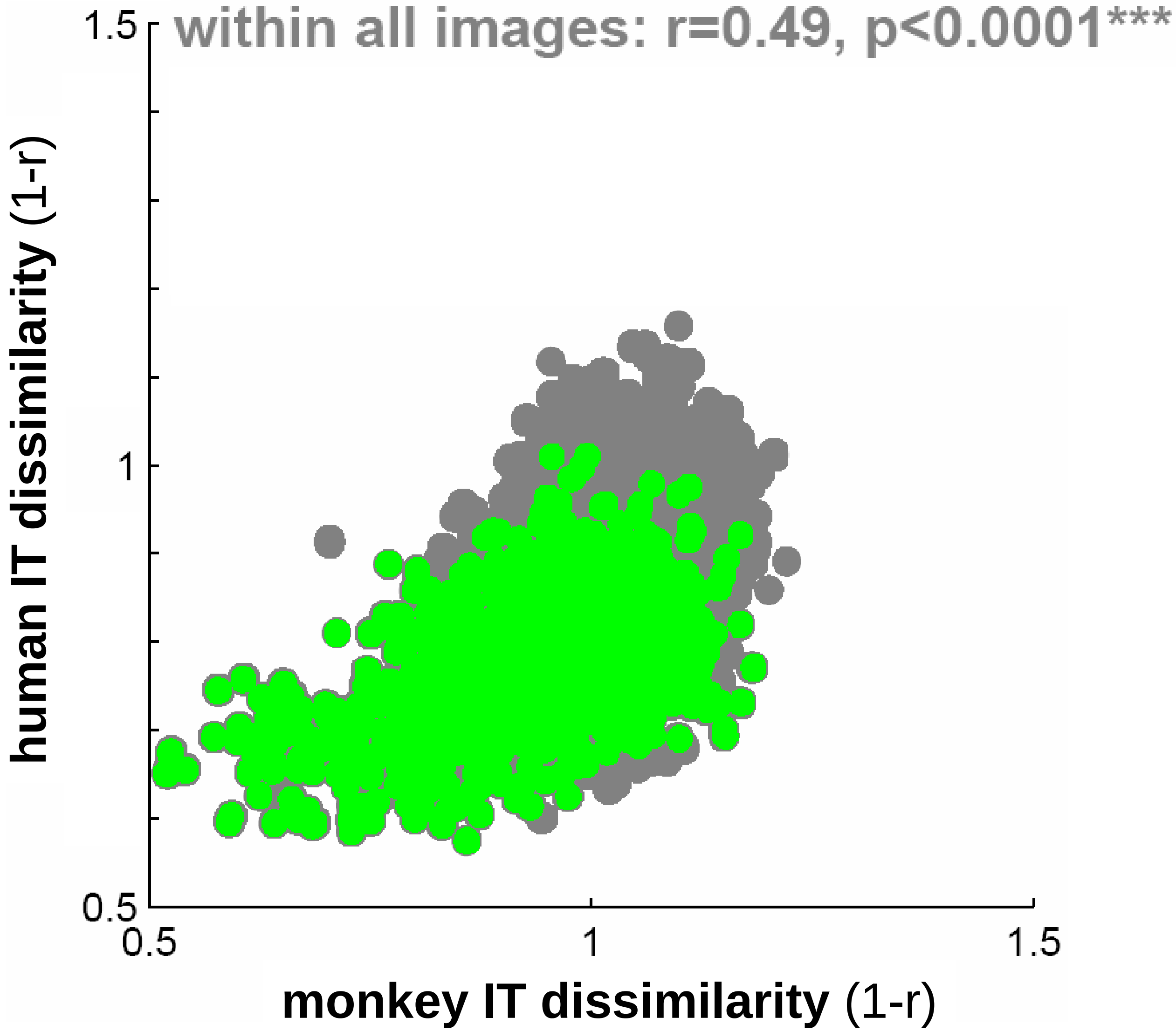


Kriegeskorte et al. (under revision)

Man-to-monkey correlation of dissimilarites



Man-to-monkey correlation of dissimilarities



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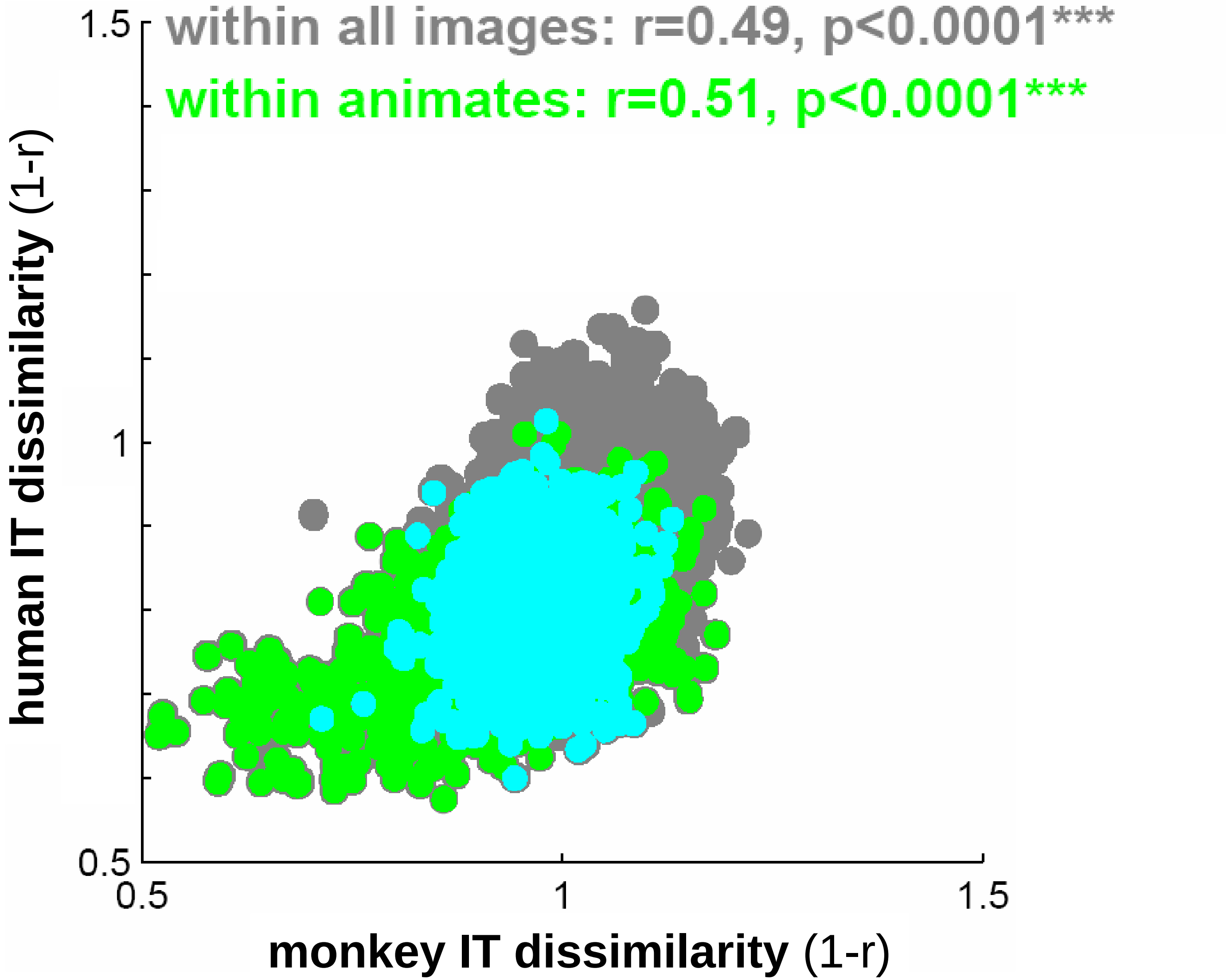

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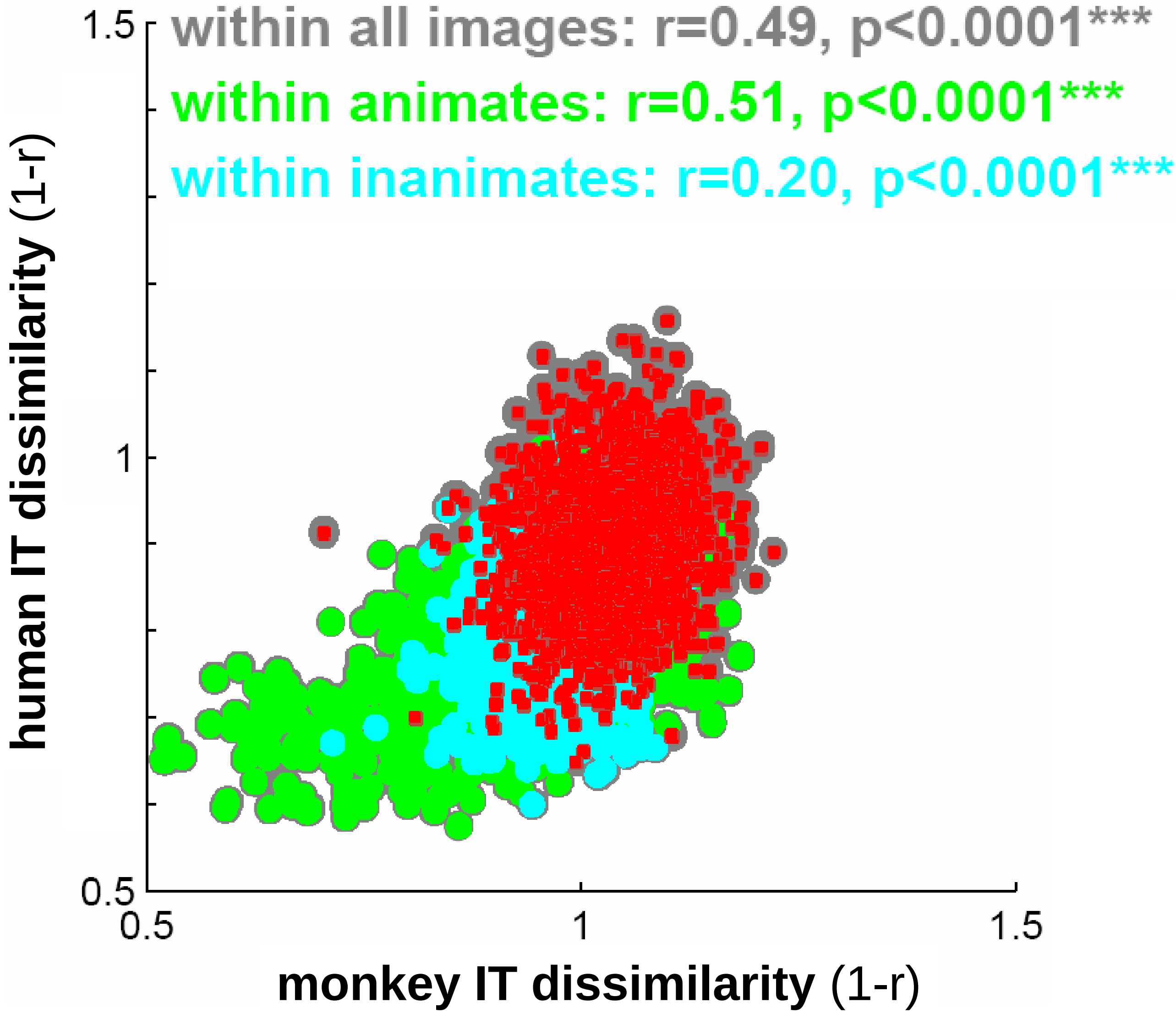


Man-to-monkey correlation of dissimilarites

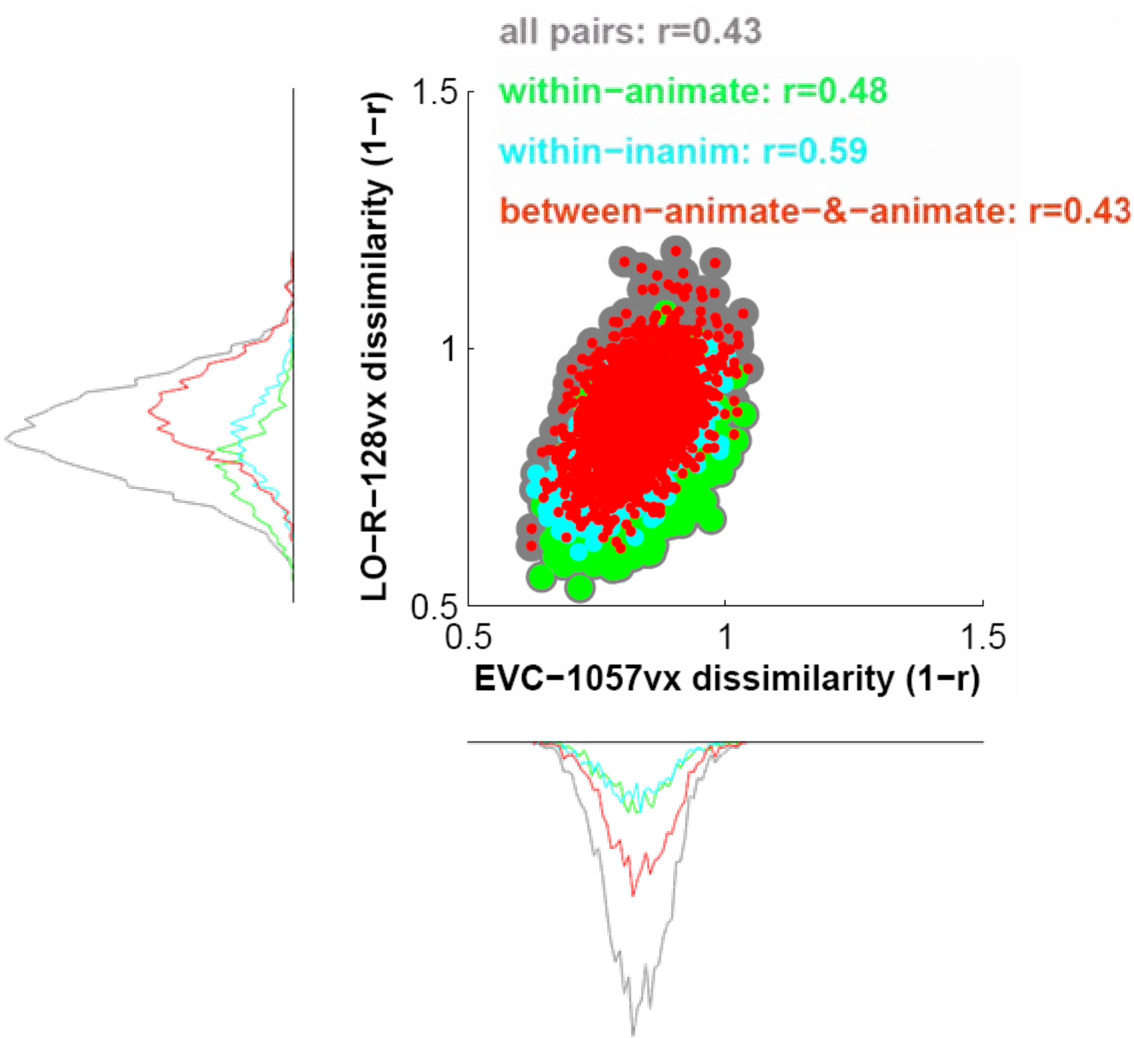
significant also...

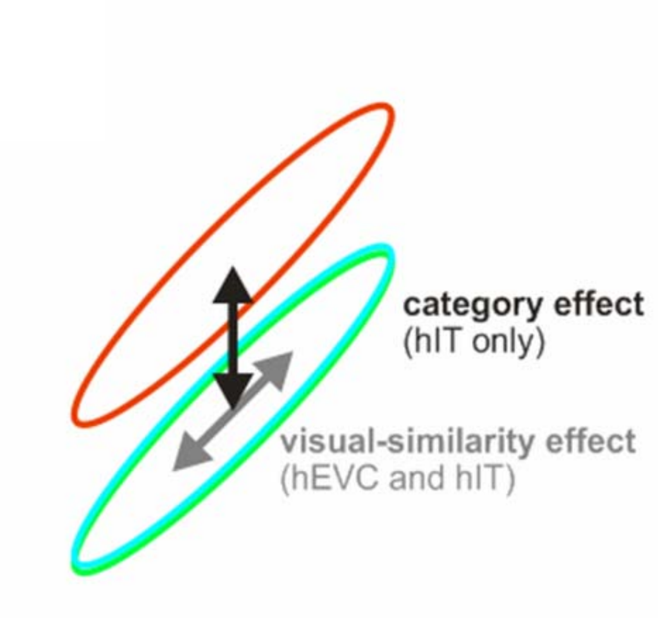
- within faces
- within bodies
- within humans
- within nonhuman animals

not significant...

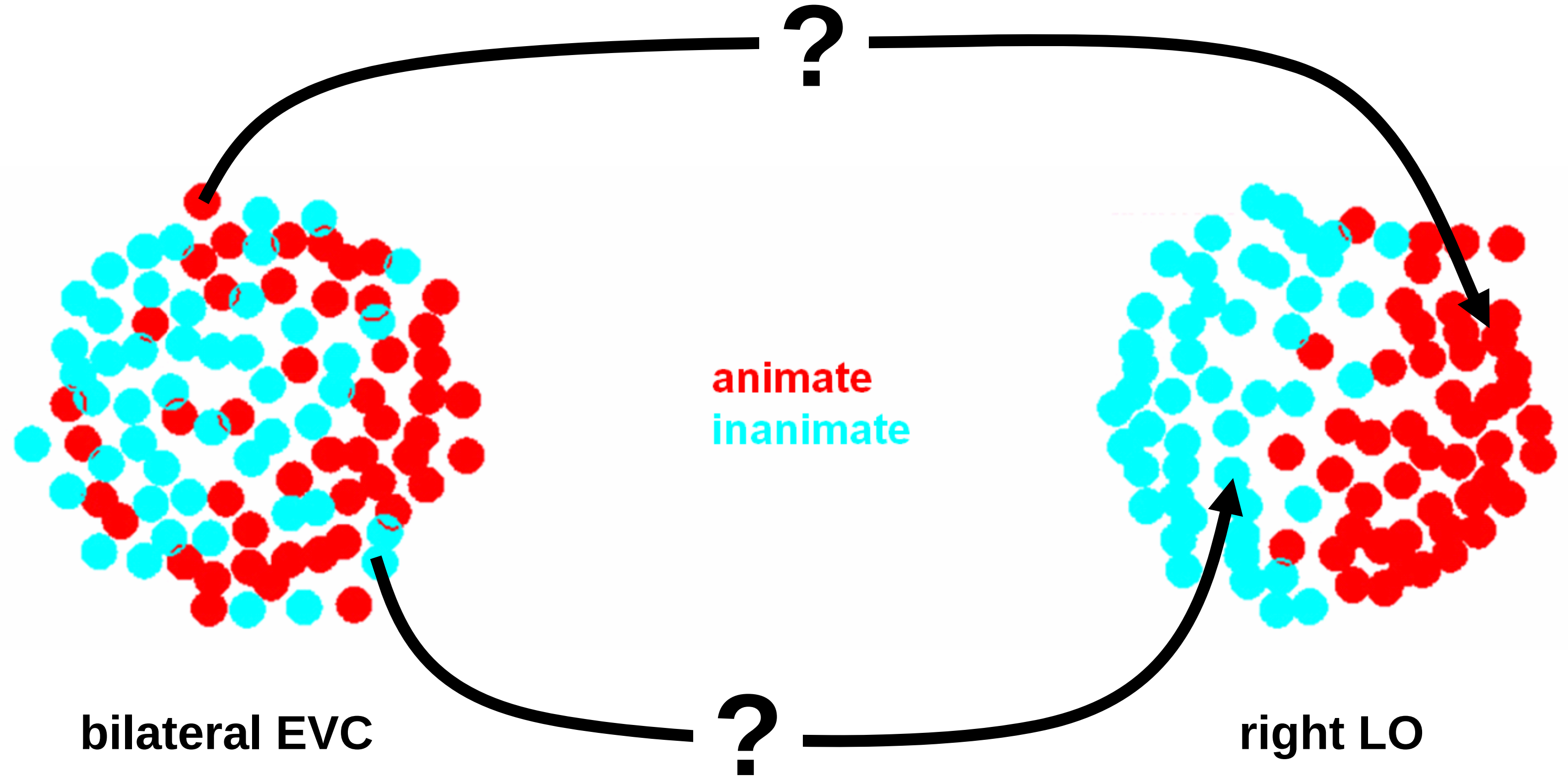
- within human faces
- within animal faces

Representational connectivity
EVC ➔ LO





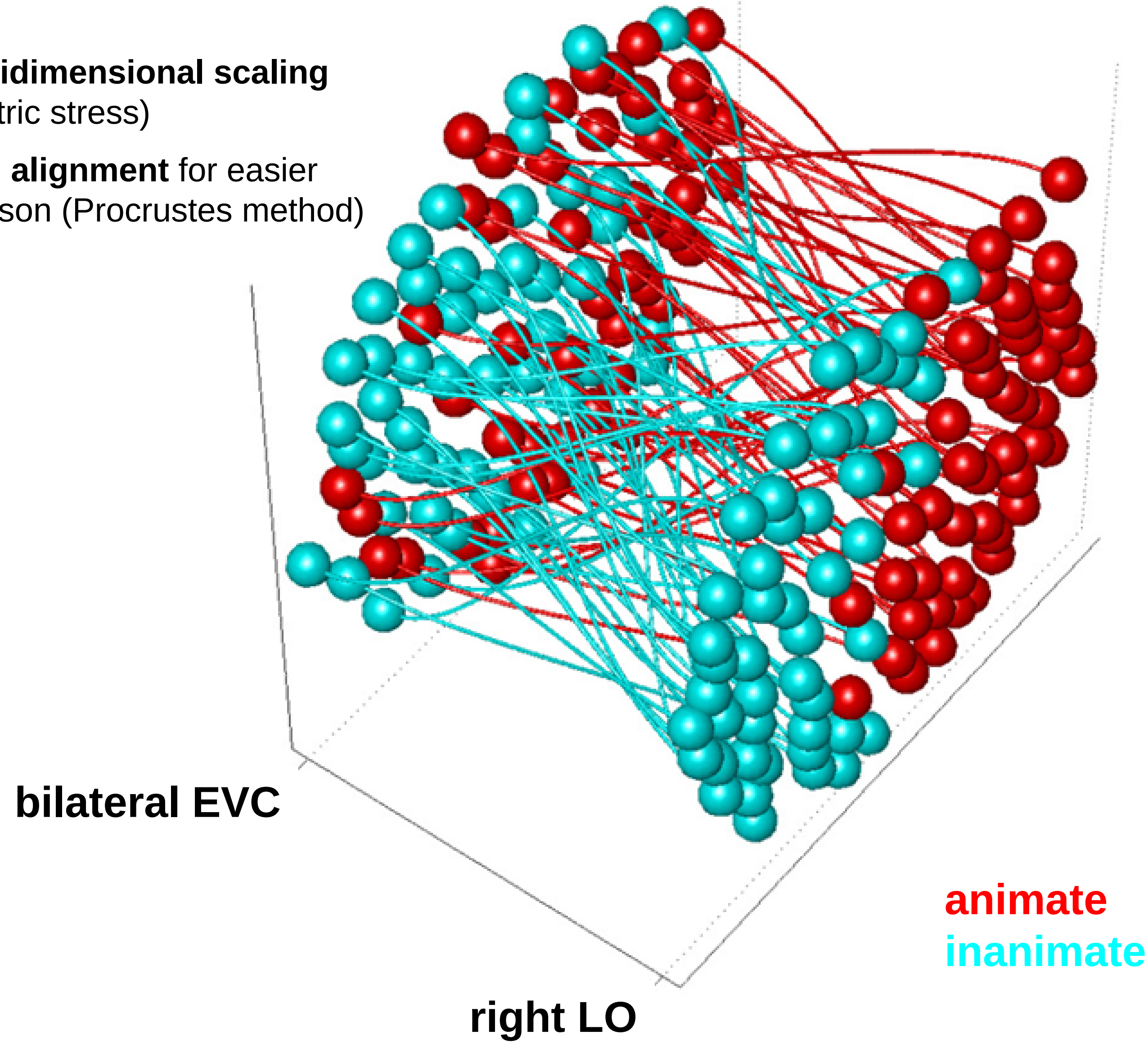
EVC → LO



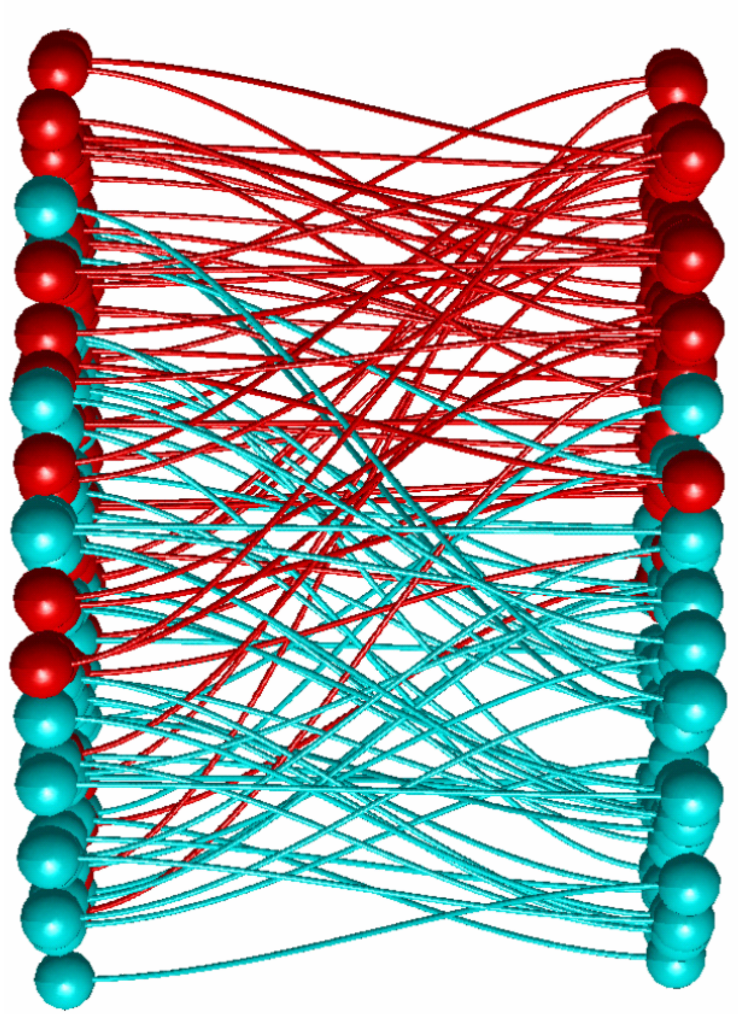
EVC → LO

(1) multidimensional scaling
(1-r, metric stress)

(2) rigid alignment for easier comparison (Procrustes method)



EVC → LO



Summary so far...

- **Natural categorical structure in primate IT**
  - top-level distinction: animate | inanimate
  - faces form a separate tight cluster

- **Man-monkey match of IT representational similarity**
  - matching major categorical clusters
  - matching within-category similarity structure

Interpretation

Human and monkey IT may host a common code for continuous and categorical object information.

But questions remain...

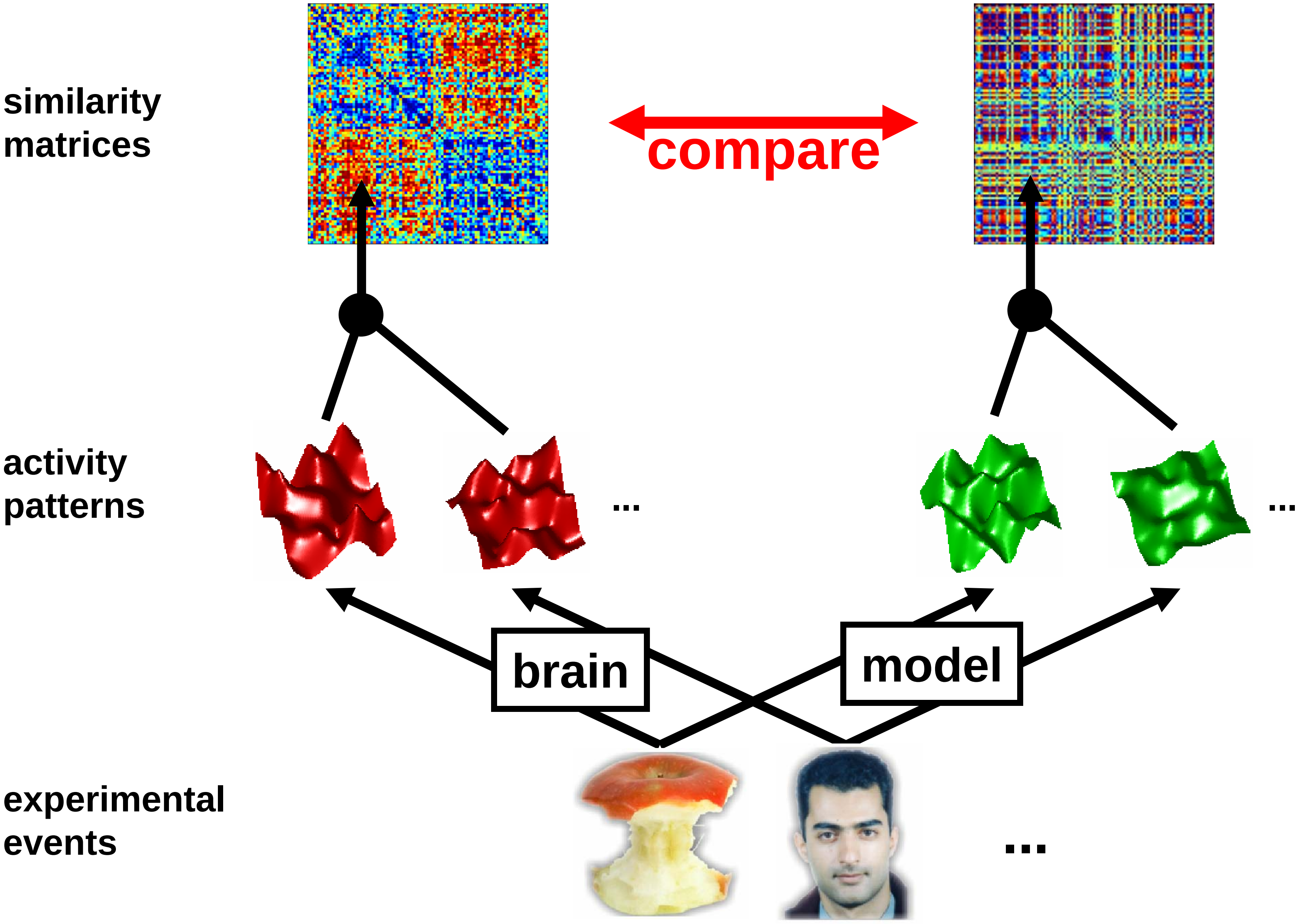
- Can the apparent categorical structure be explained by **low-level features**?

- More generally, what kind of **computational model** can explain our findings?

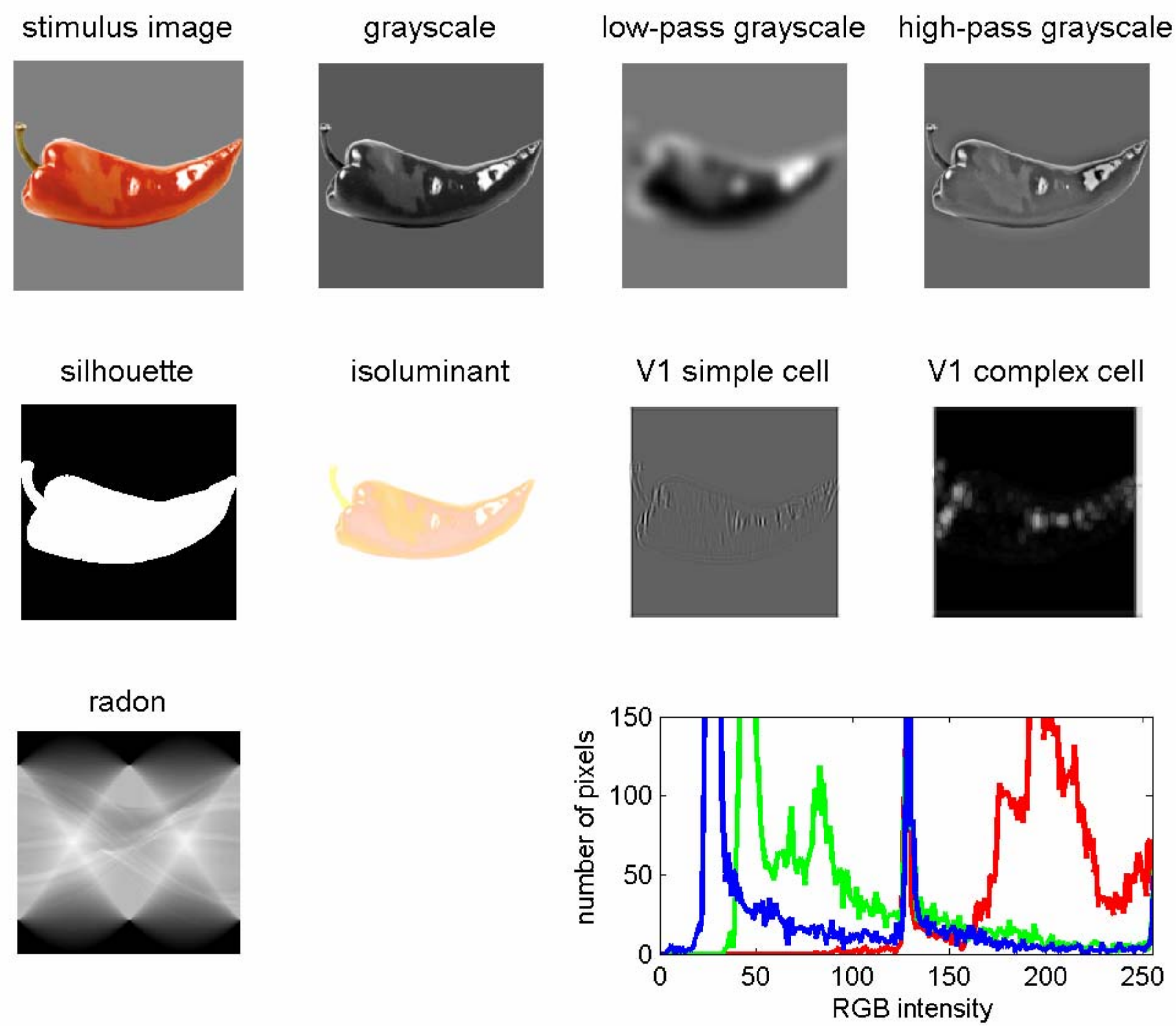
From description to explanation...

- use a range of models to predict representational similarity

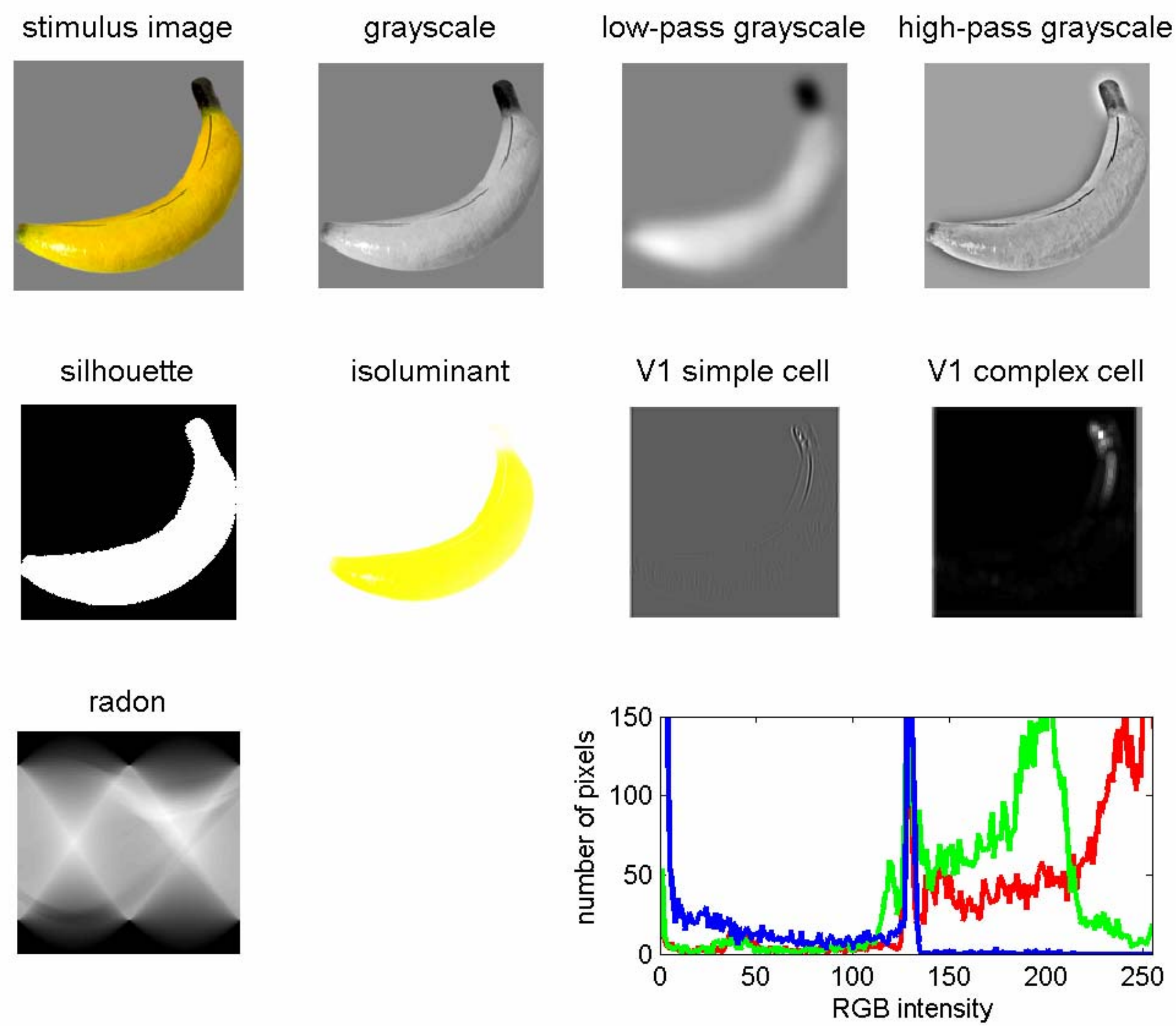
- models can be computational, conceptual, or based on behavioral data



similarity matrices
compare
activity patterns
...
...
brain
model
experimental events
...



stimulus image
grayscale
low-pass grayscale
high-pass grayscale
silhouette
isoluminant
V1 simple cell
V1 complex cell
radon
150
100
50
0
number of pixels
0
50
100
150
200
250
RGB intensity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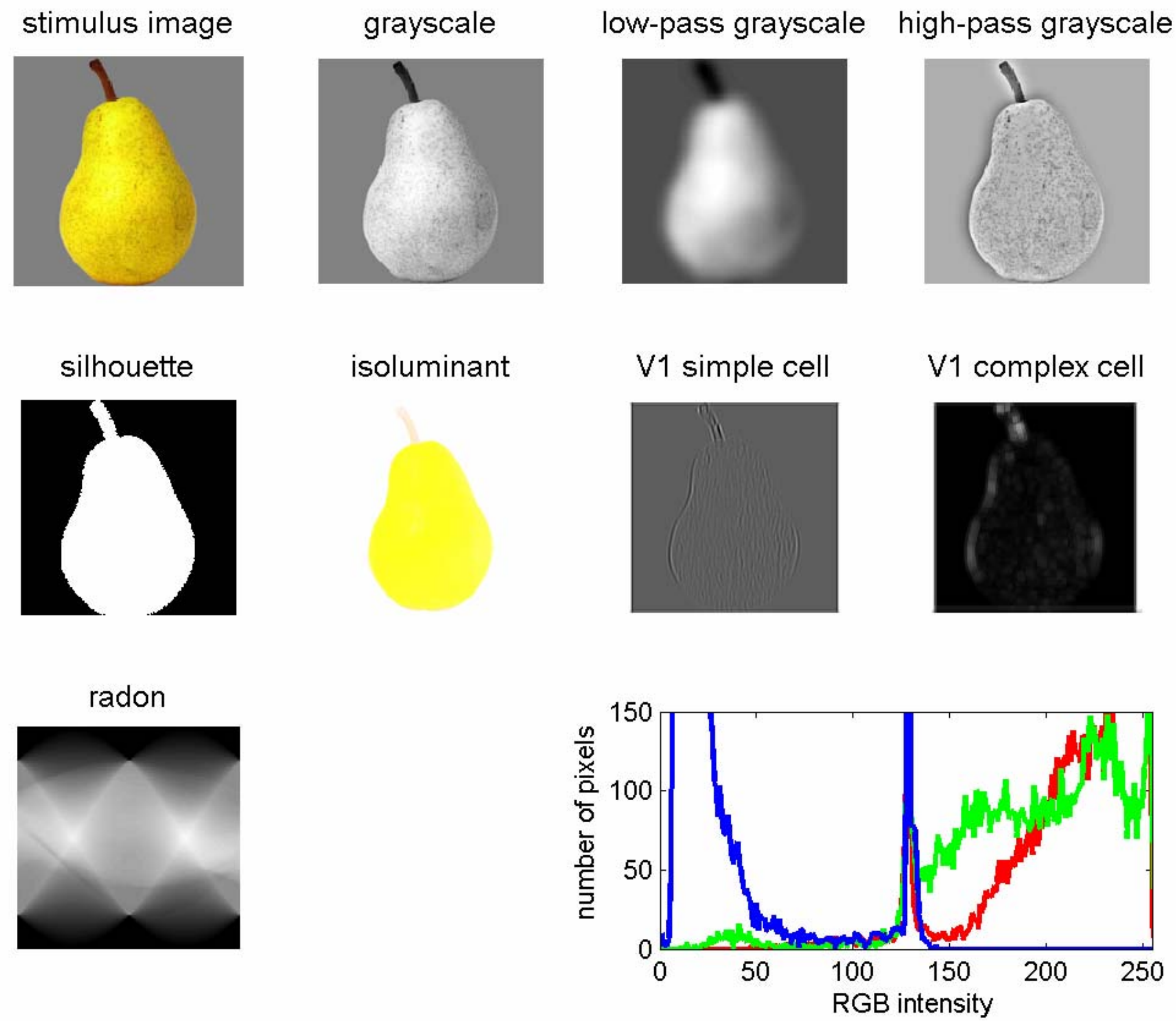

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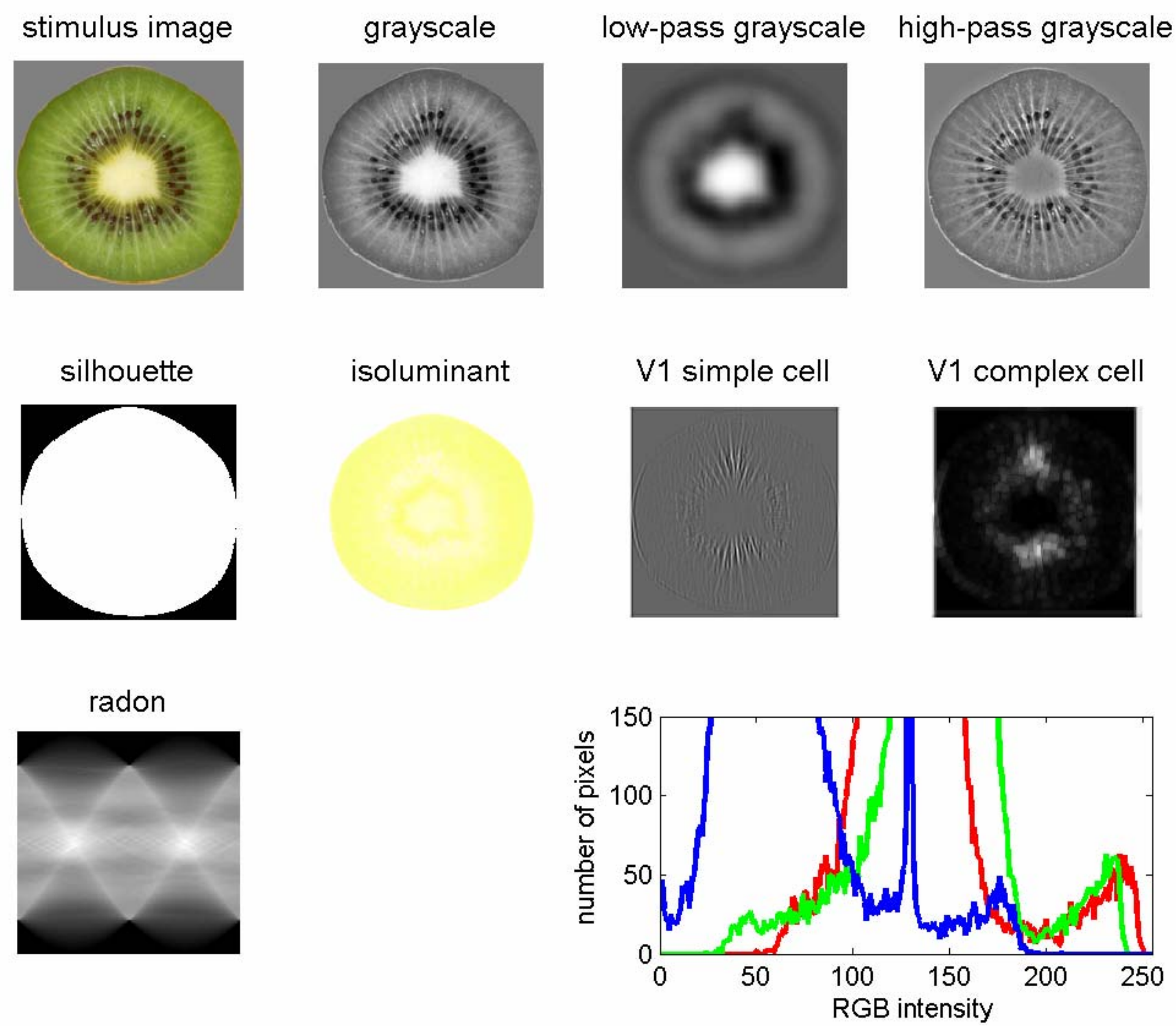
stimulus image
grayscale
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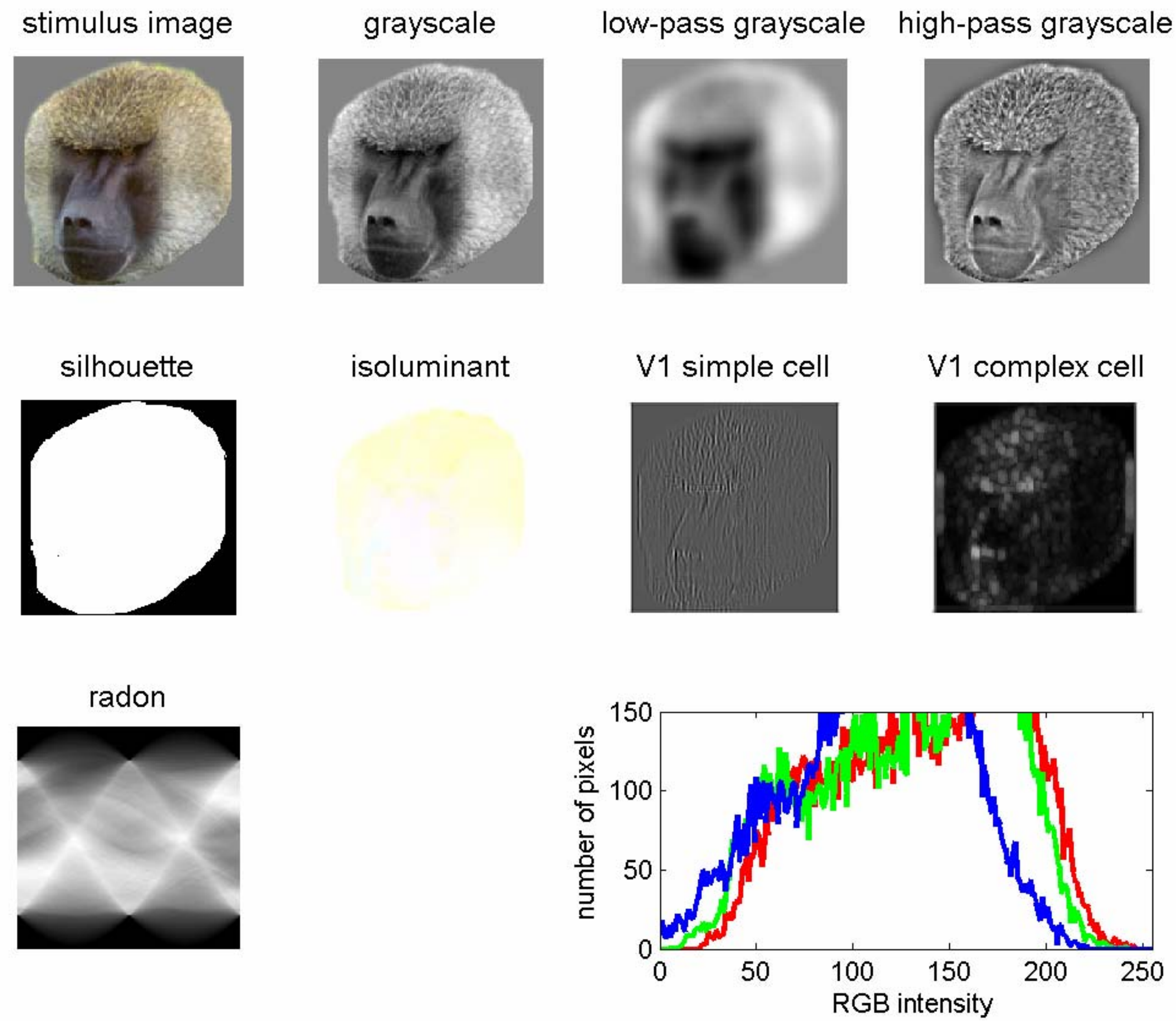
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0
50
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150
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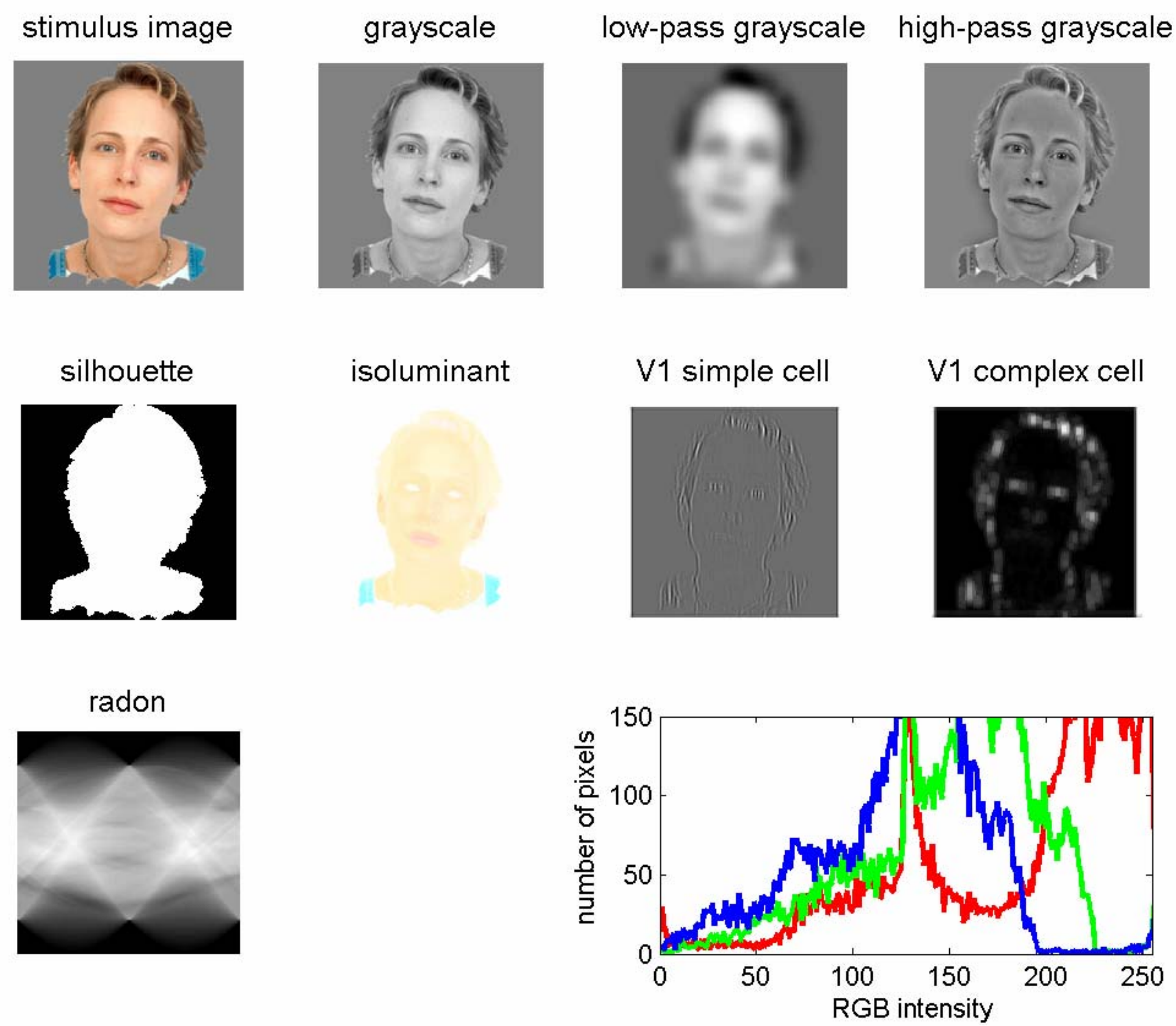
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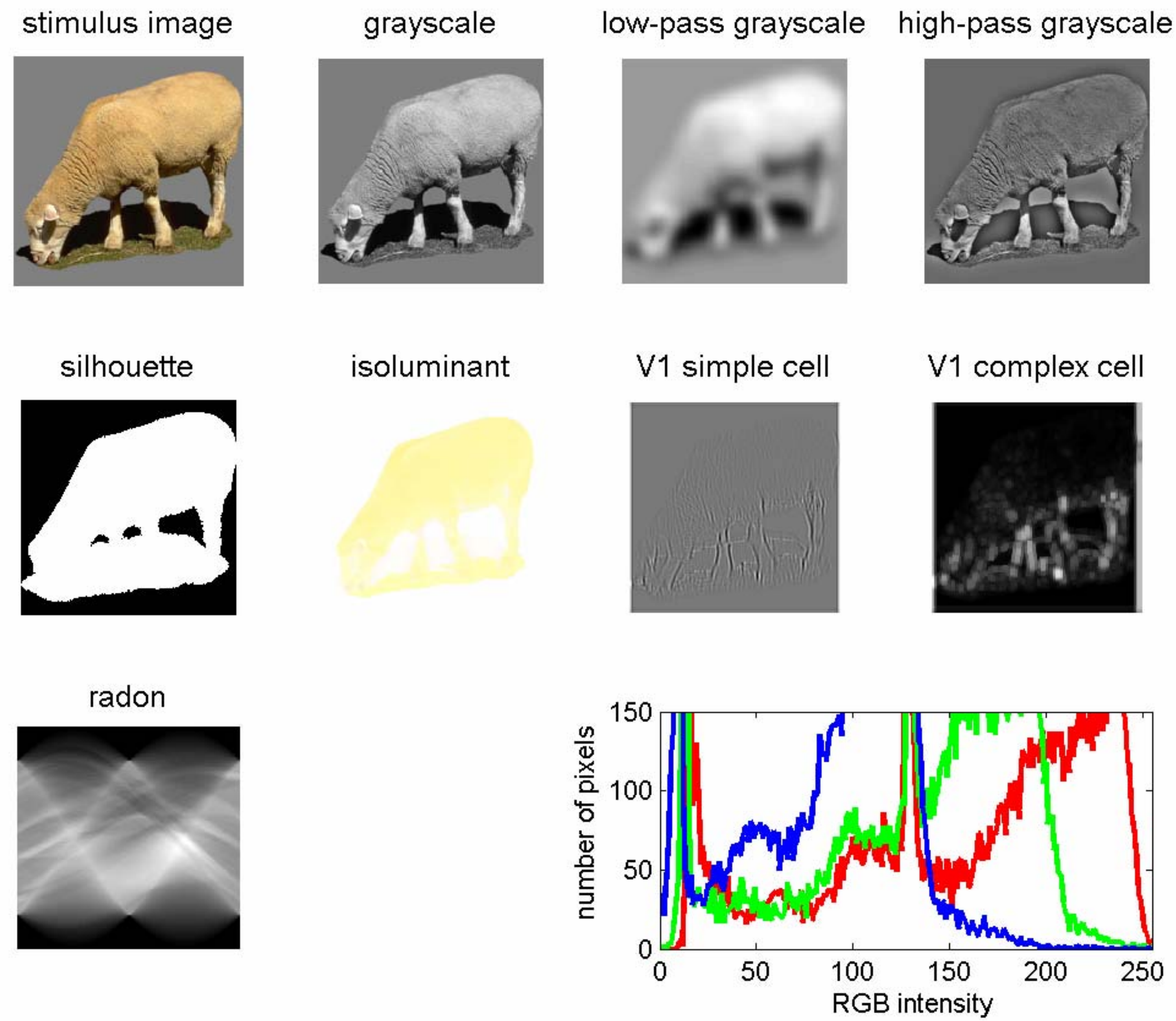
RGB intensity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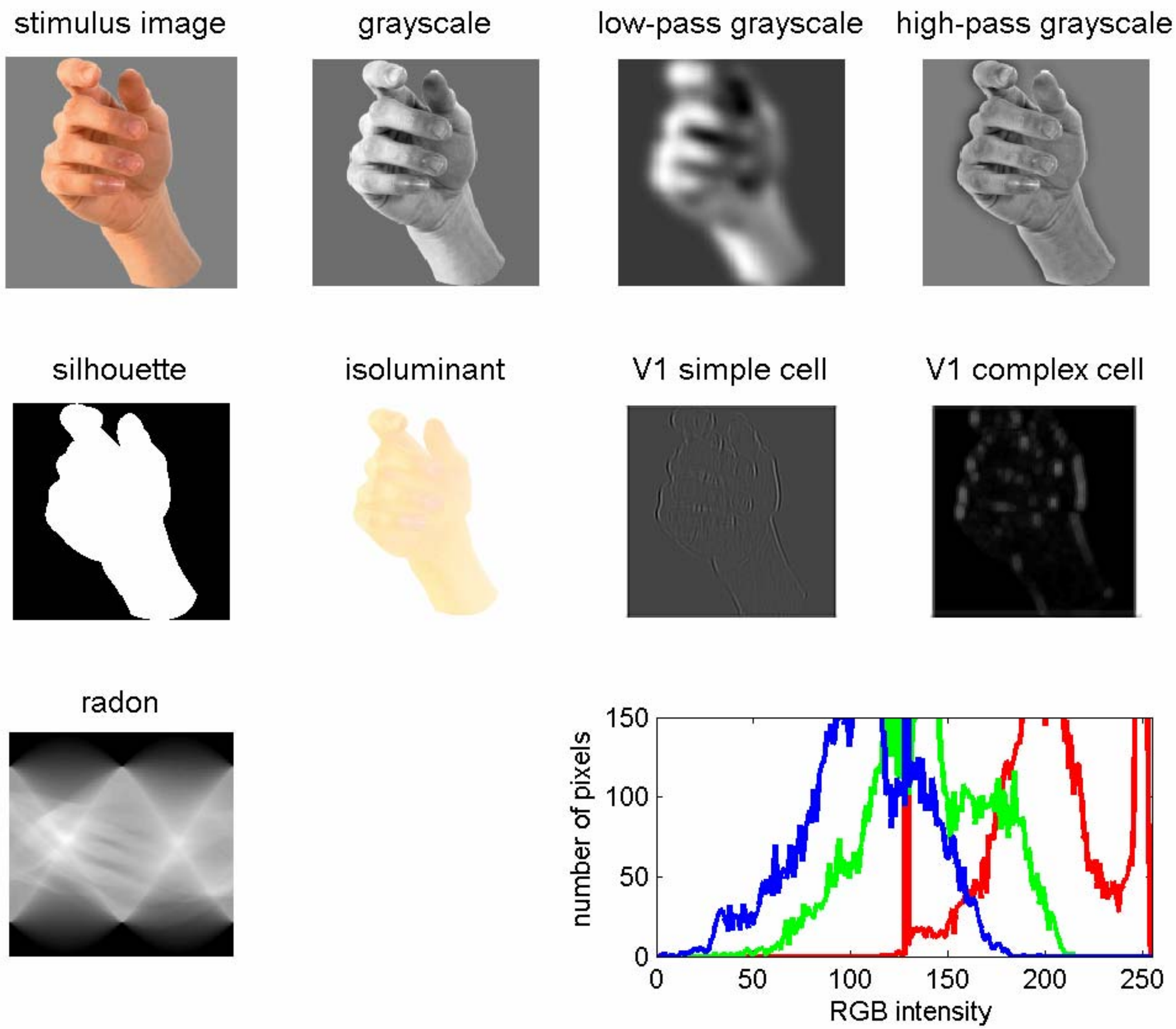

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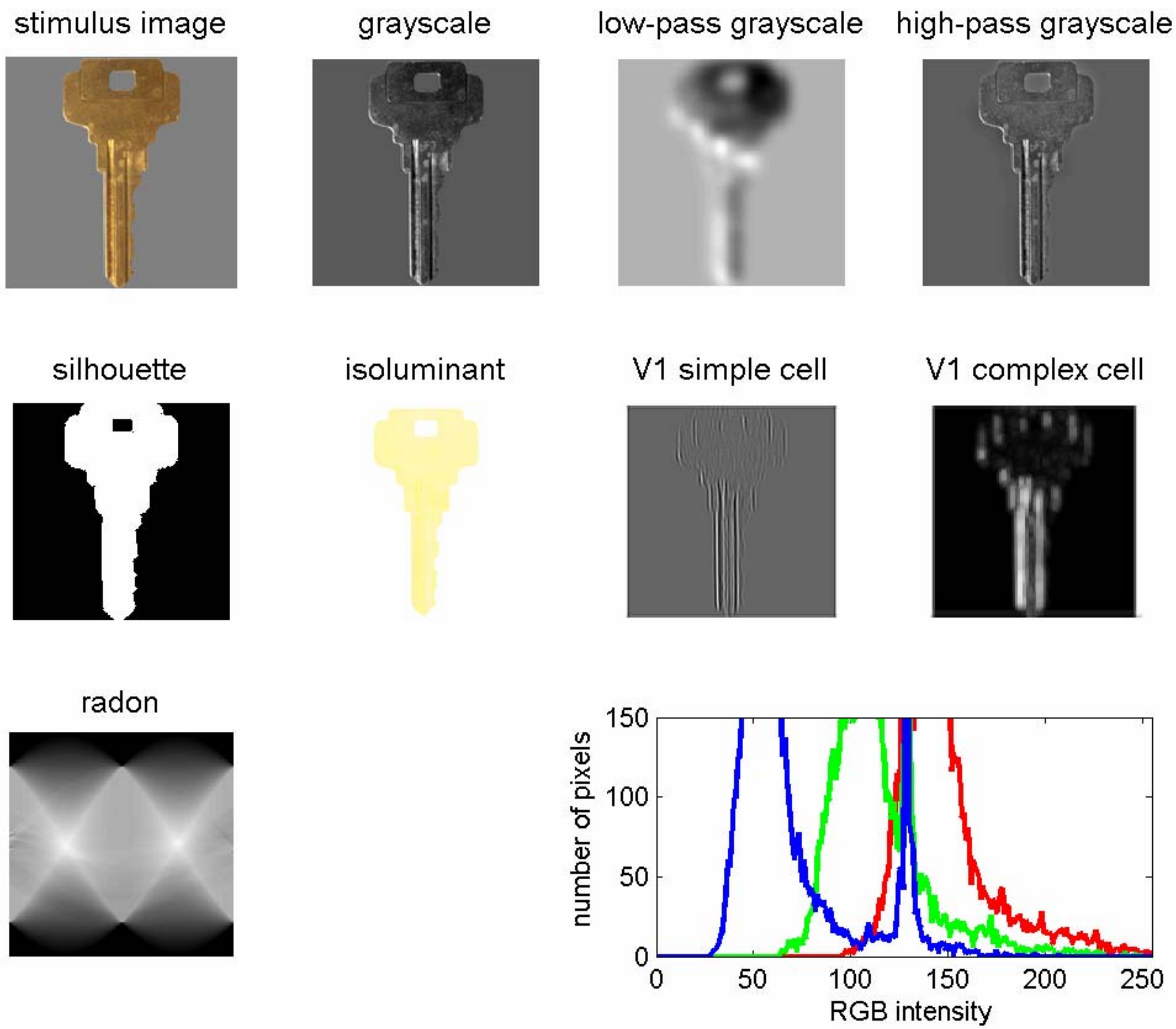
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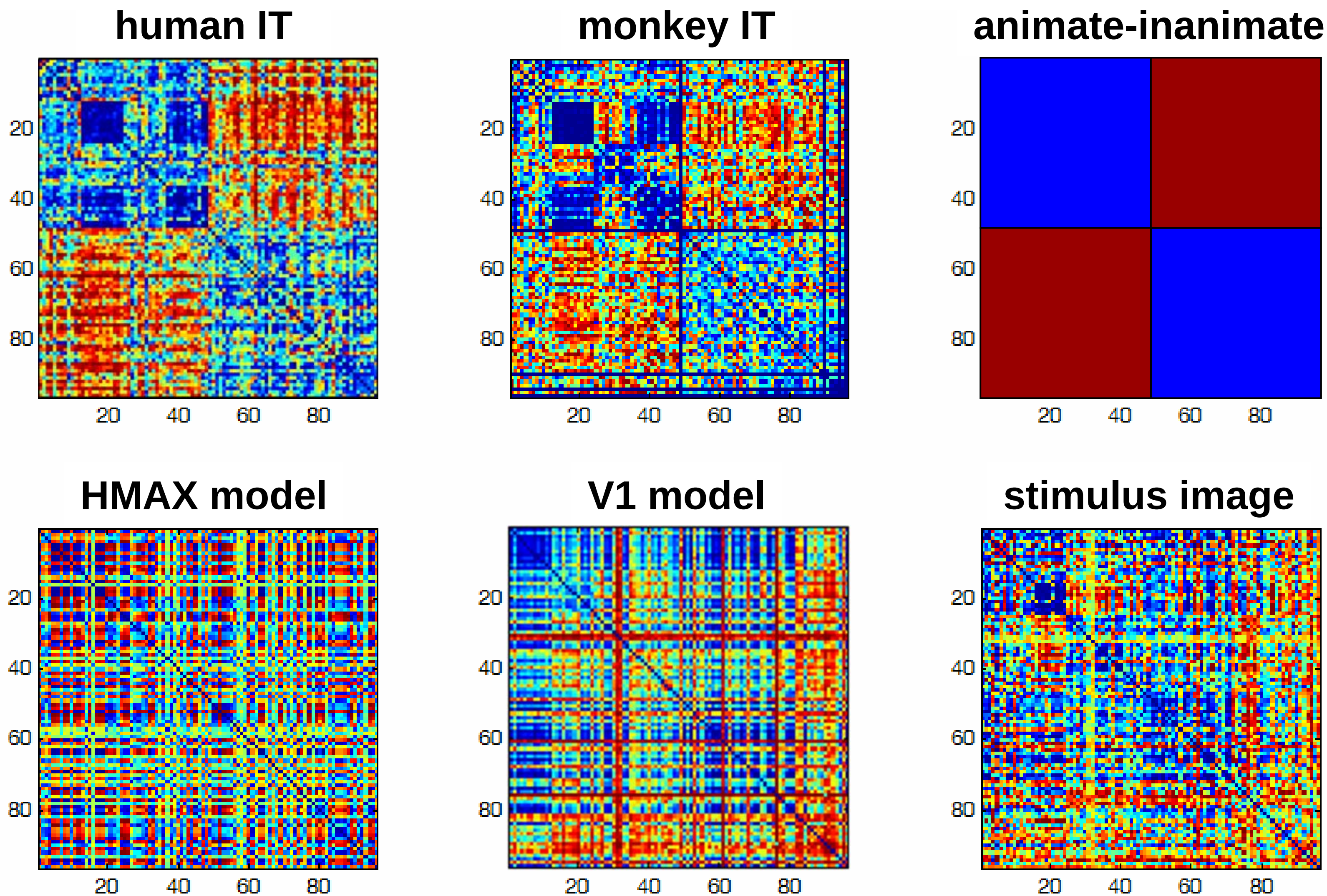
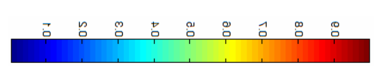
RGB intensity

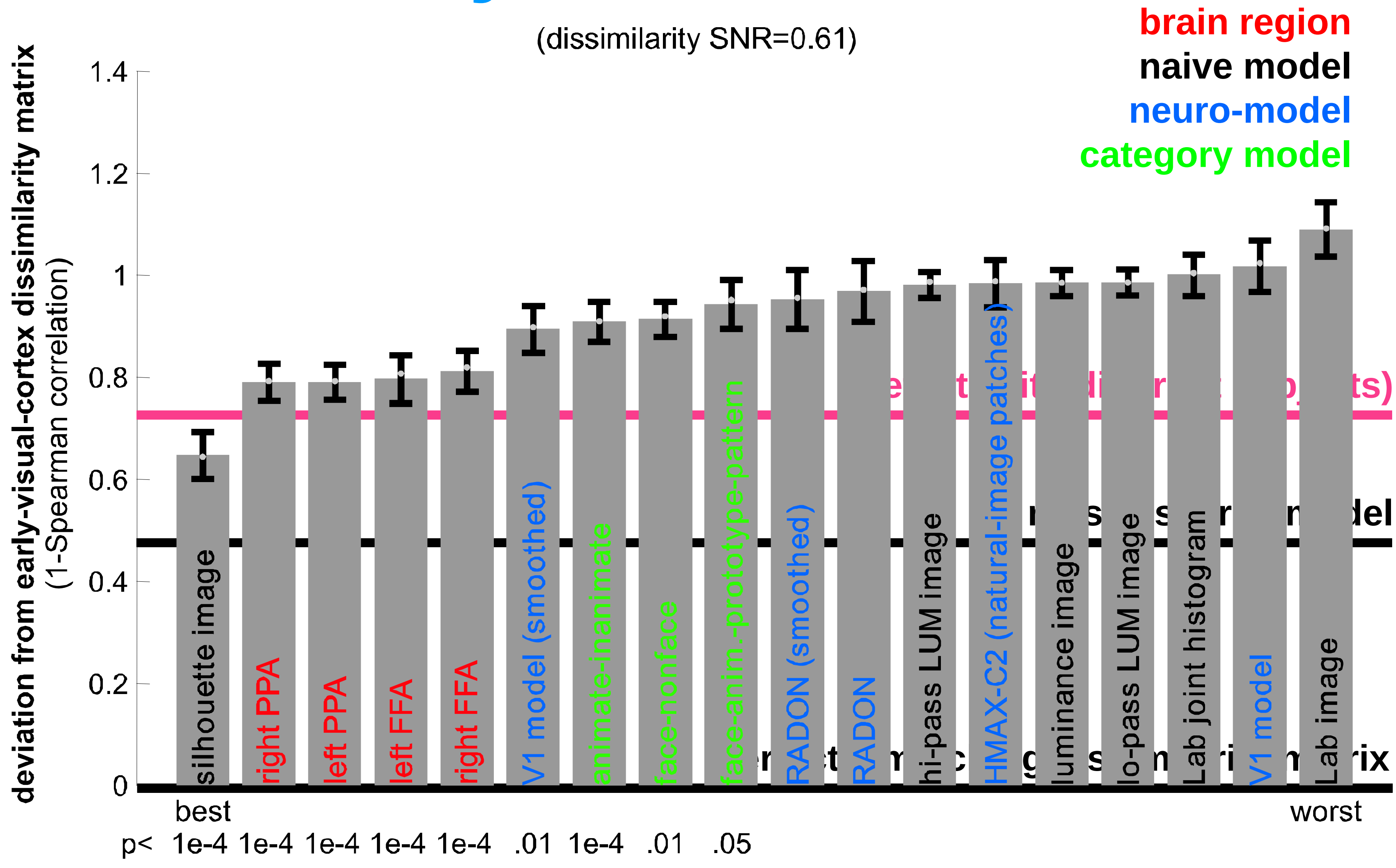
Model dissimilarity matrices



Riesenhuber
& Poggio 2002

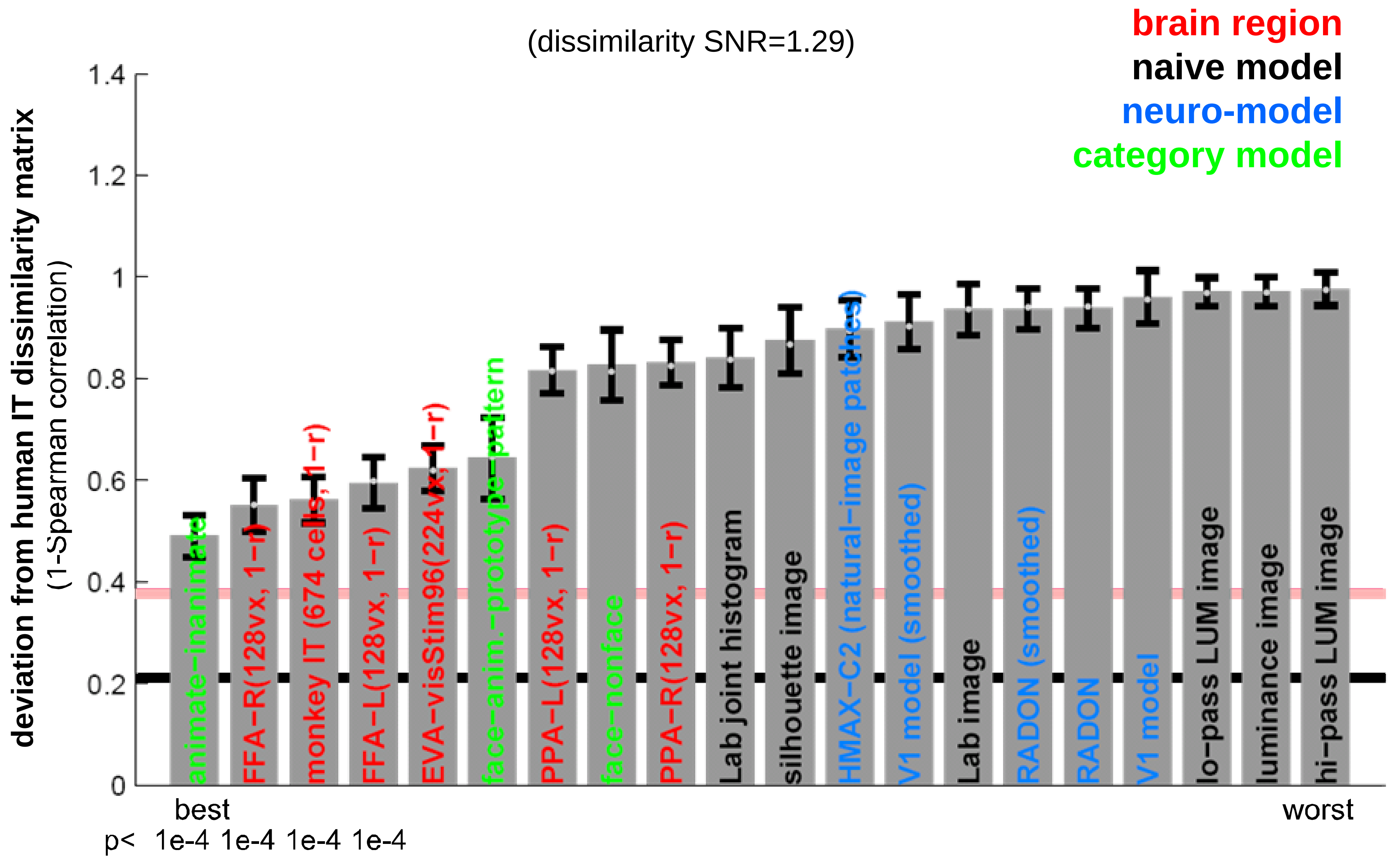


Early visual cortex

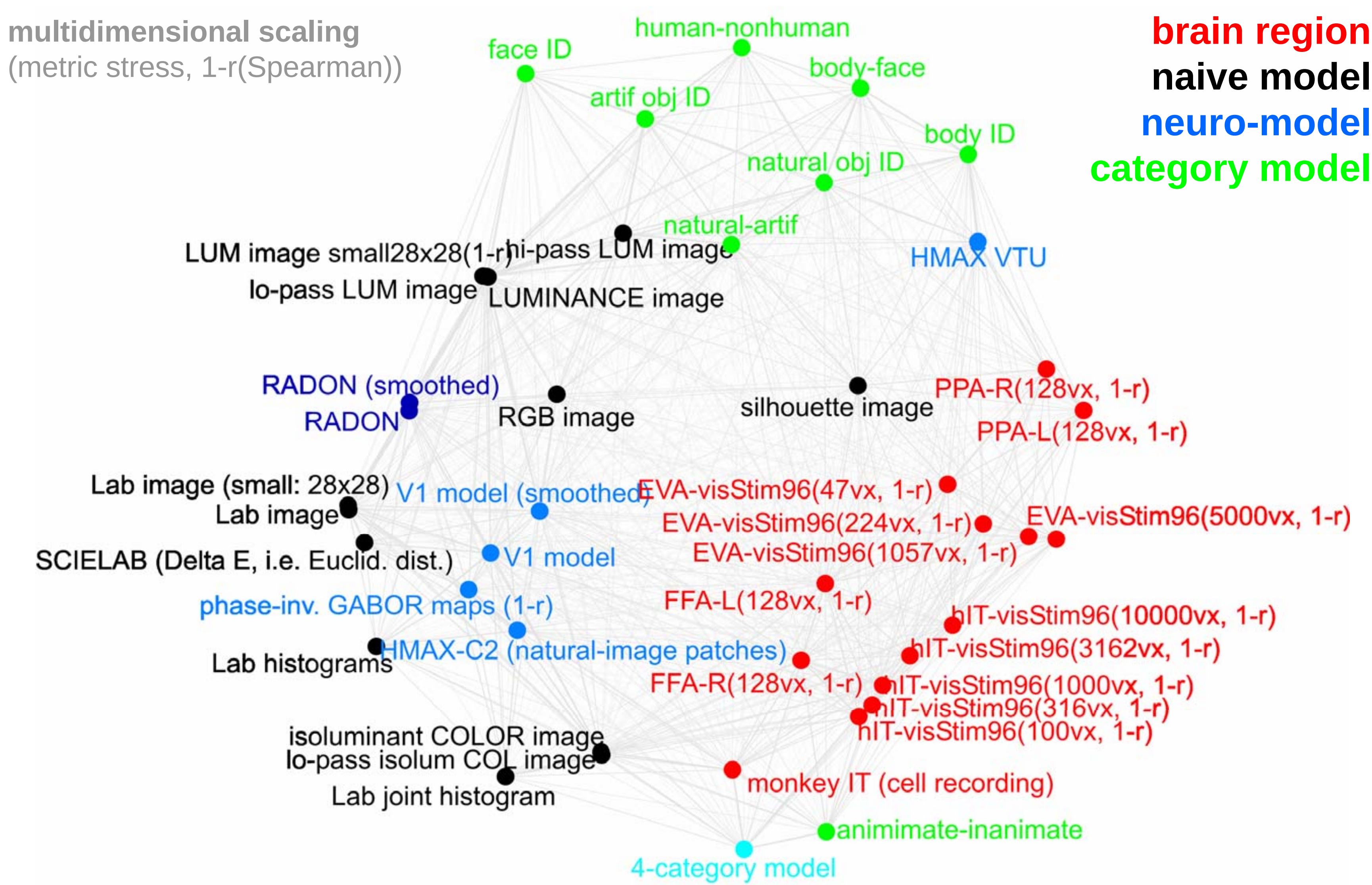


Human IT

(dissimilarity SNR=1.29)



Simultaneously relating multiple representational similarity matrices



Summary of model-based analyses

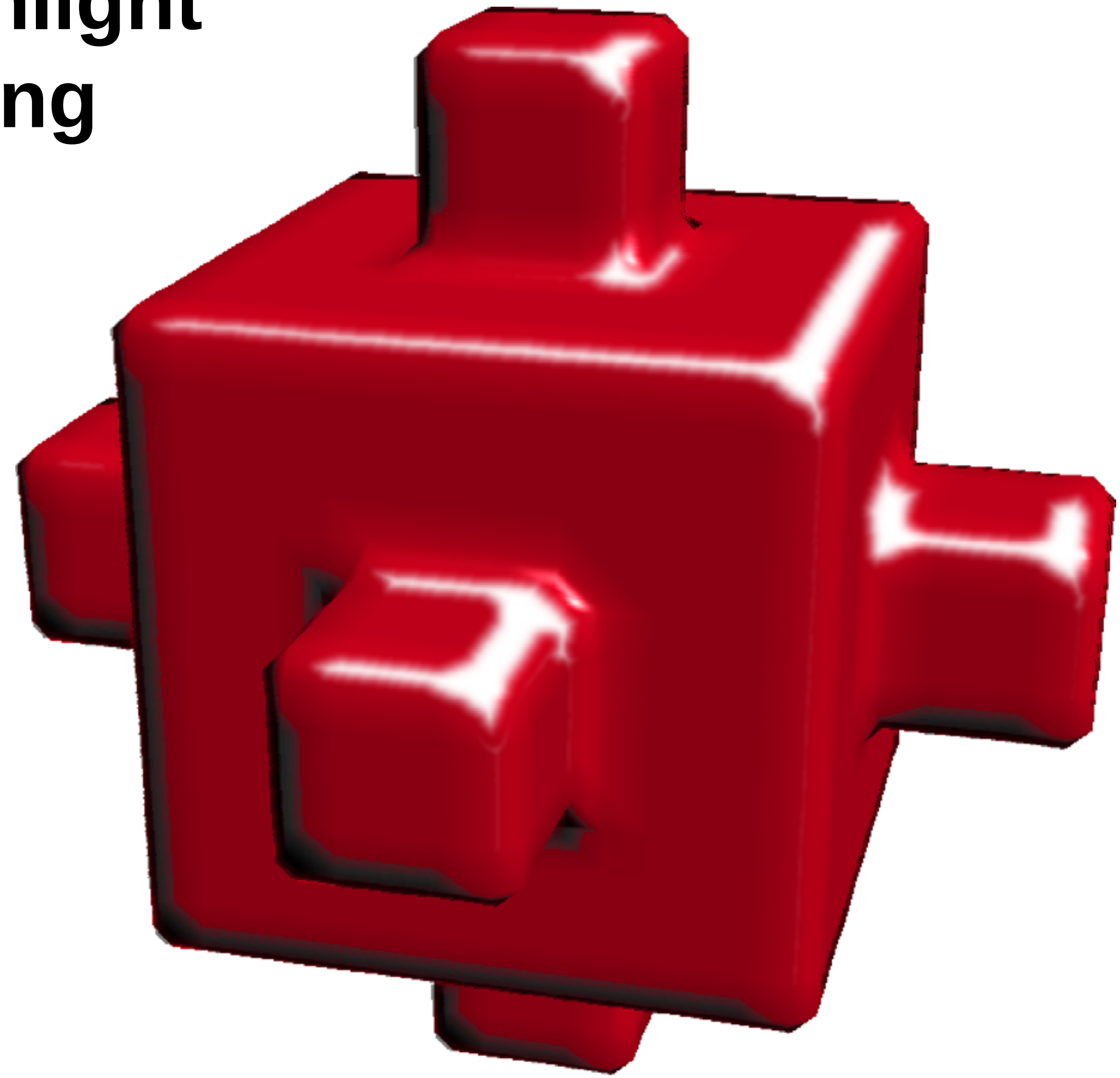
- We compared a range of low- and intermediate-level model representations to the IT representation.
- None of them could explain the categorical clustering we saw in human and monkey IT.

Interpretation

An IT model probably needs to include category-specific visual knowledge – as might be acquired by supervised learning.

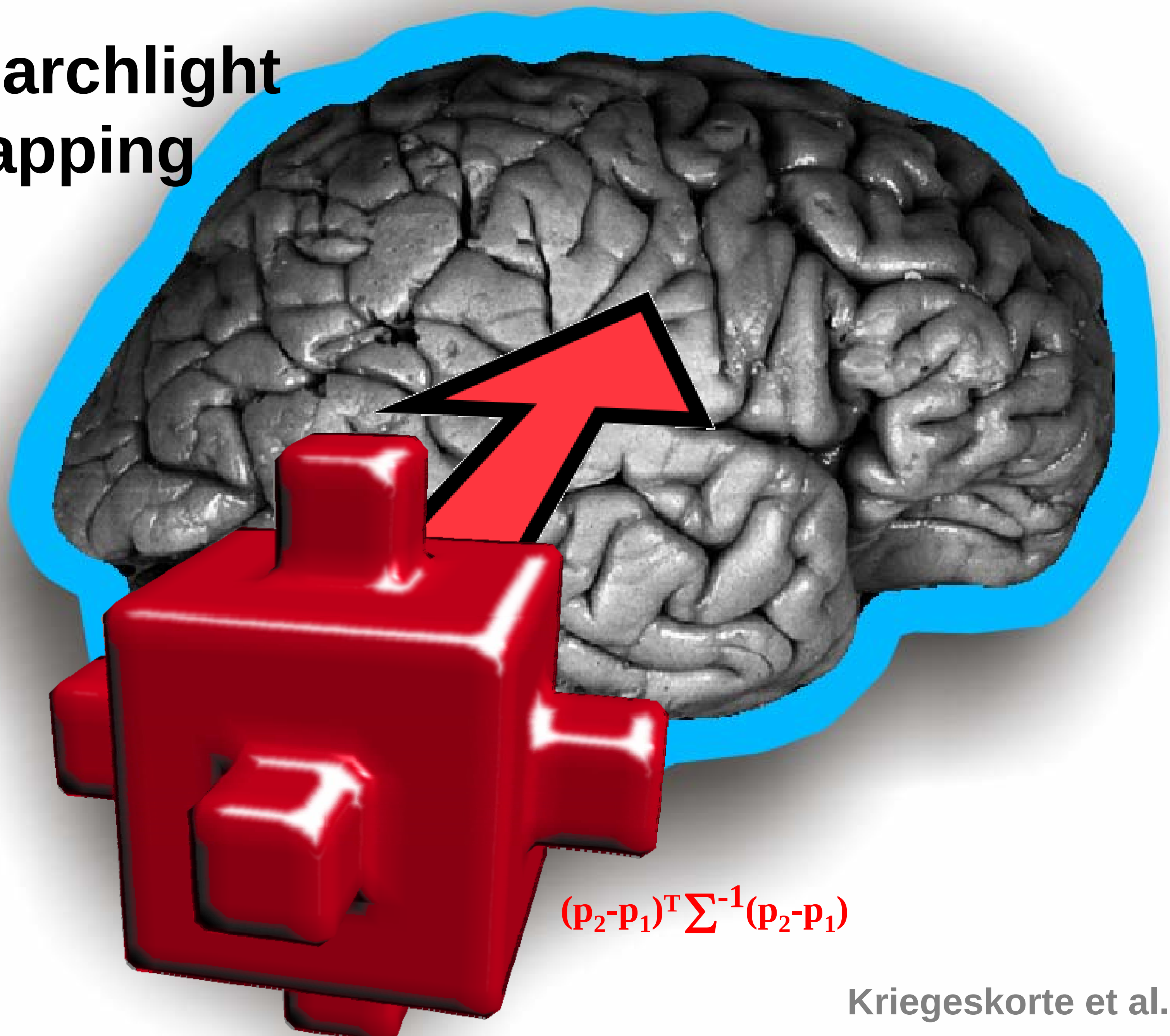
Methodological concepts

Searchlight mapping



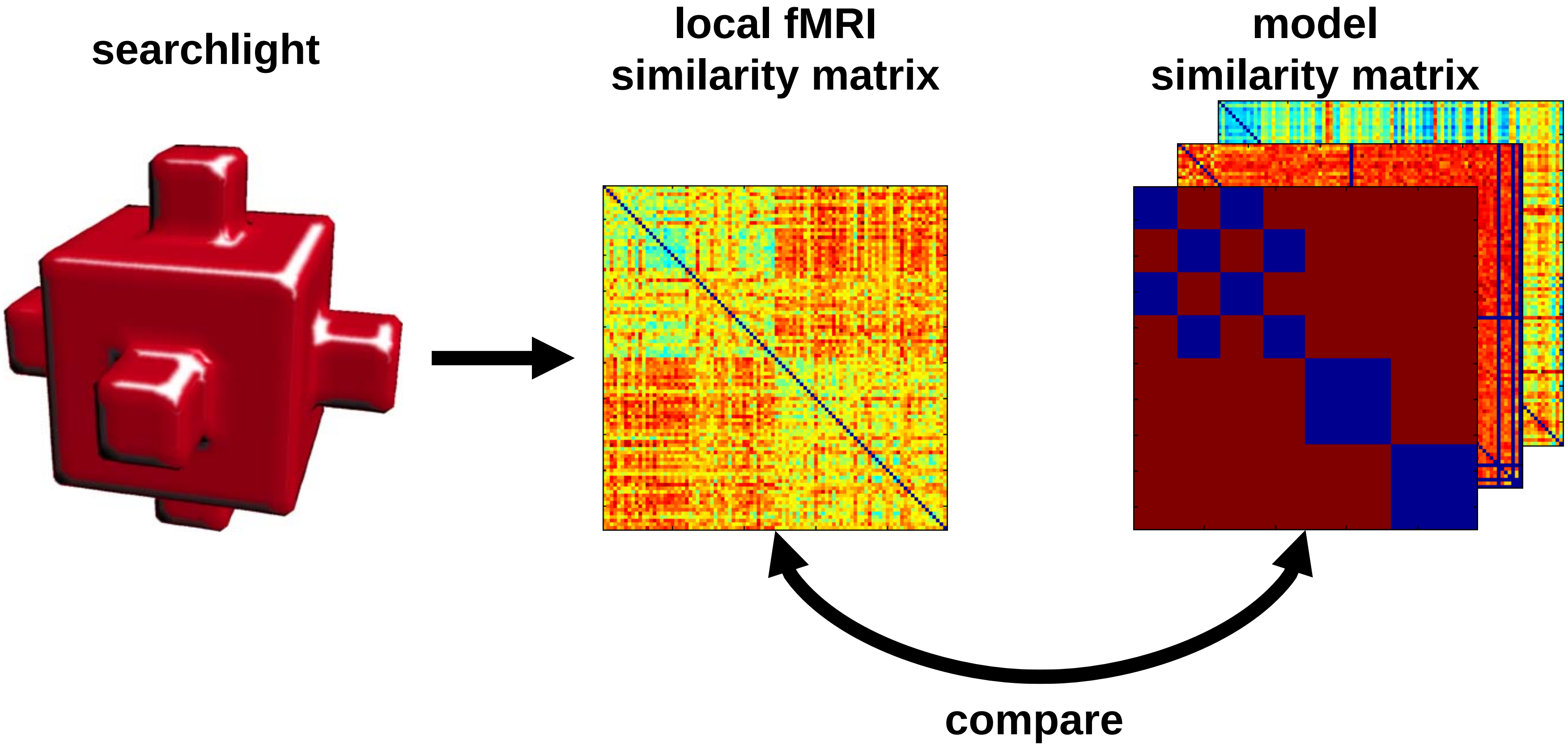
Kriegeskorte et al. 2006

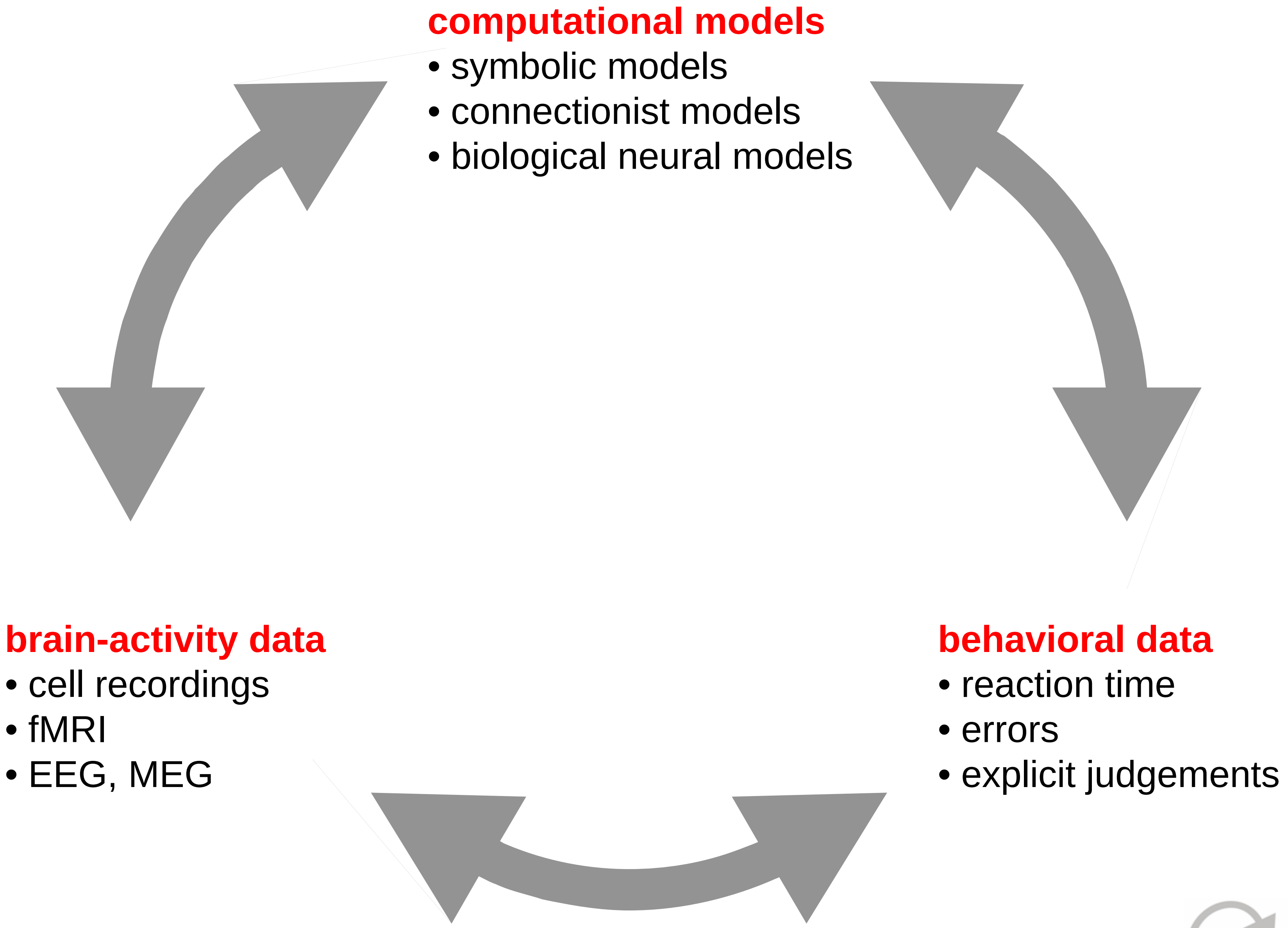
Searchlight mapping



Kriegeskorte et al. 2006

Representational-similarity searchlight mapping




computational models
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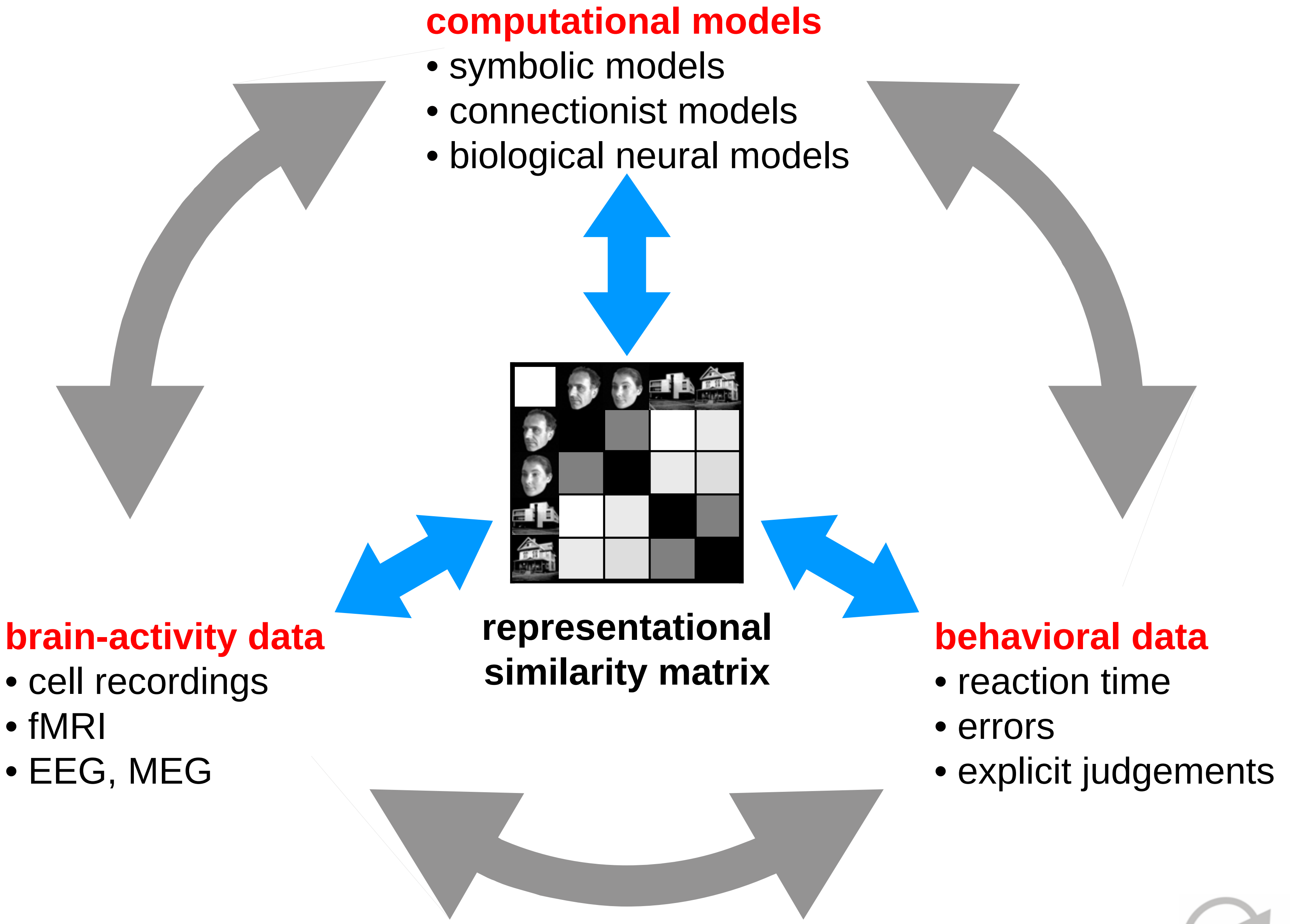
• connectionist models
• biological neural models
brain-activity data
• cell recordings
• fMRI
• EEG, MEG
behavioral data
• reaction time
• errors
• explicit judgements


computational models
• symbolic models
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representational
similarity matrix
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